Baseline Energy Performance and Opportunities to Improve Energy Efficiency in Family Military Housing

Washington State University Energy Program
and
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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.

Baseline Energy Performance and Opportunities to Improve Energy Efficiency in Family Military Housing

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Definitions

ACH_{50}	Air Changes per Hour at 50 Pascals pressure
BRAC	Base Realignment and Closure
CFA	Conditioned floor area
CFL	Compact fluorescent lamp
CFM	Cubic feet per minute
CFM_{50}	Cubic feet per minute at 50 Pascals pressure
DHW	Domestic hot water
DOD	Department of Defense
EF	Energy factor\
KCHA	Ling County Housing Authority
kWh	Kilowatt hours
JBLM	Joint Base Lewis-McChord
MVL	Minimum ventilation level, 7.0 ACH_{50}
NEEA	Northwest Energy Efficiency Alliance
NREL	National Renewable Energy Laboratory
TMY	Typical Meteorological Year
WSU	Washington State University

Executive Summary

Equity Residential, the owner/manager of military housing units at Joint Base Lewis McChord (JBLM) has taken a number of steps to improve the energy efficiency of new and existing housing at the base. These efforts are part of a 50-year project to replace all of JBLM's non-historic housing. While improving the livability of homes on the base is the primary concern, energy efficiency is also a priority.

Equity Residential owns all 4,901 housing units at JBLM, renting the homes to military families at rates in keeping with military housing allowances (below market rate.) Equity Residential pays for all gas and electric utilities.

The purpose of this research project is to further assist Equity Residential in improving the energy efficiency of housing at JBLM, both in future retrofit efforts as well as new construction. The project involves utility billing analysis, field testing, energy auditing, and energy modeling to assess energy performance and energy efficiency opportunities in six housing communities at JBLM.

The communities described in this report are single and multi-family houses constructed between 1930 and 2008. The newest community within this project consists of modular multifamily homes, meeting ENERGY STAR® and Building America specifications, and built in 2005-08. The billing analysis presented in this report compares the electric, gas and total annual energy use of residences in six communities – the billing histories of 2,276 housing units were examined. The ENERGY STAR homes use less energy than the homes in the other communities. Natural gas use is 30 to 40 percent lower except for a small group of newer homes where the difference is around 13 percent. The impact of the Washington State Energy Code is evident in these results, with housing built since the code went into effect showing lower energy use. Due in large part to restrictions placed on the retrofit of historic buildings, energy use in the historic Broadmoor neighborhood was substantially higher than the other neighborhoods.

A billing analysis of base load gas use in the new Discovery Village community was employed to compare homes with natural gas tank water heaters to a subset of homes in Discovery Village (called Miller Hill) with high efficiency tankless gas water heaters. Even though the number of homes in Miller Hill was small, two different analyses showed the tankless water heaters used less natural gas. Researchers estimated the savings to be approximately 50 therms per year (20 percent). This is in keeping with DOE's estimated savings for this technology (USDOE, 2011).

Researchers collected information from 12 “typical” and 4 “complaint” homes for computer modeling using two programs, BEopt and SIMPLE. BEopt energy usage analysis was conducted to assess cost-effective energy efficiency retrofit measures in each of these communities. SIMPLE provided an additional means of comparing modeled results to the billing data. Cost data was based on a combination of default cost data from the BEopt library, Equity Residential, and local retrofit contractors. “Typical” homes were selected on the basis of condition and availability, while “complaint” homes were selected by Equity Residential through high energy consumption or occupant complaints.

The modeling analysis considered the retrofit opportunities identified in the field visits. The analysis demonstrates three measures repeatedly produce the greatest reduction in energy savings for the lowest price: air sealing, sealing and insulating ductwork, and increasing attic insulation to R-49. By grouping these measures into packages, the cost benefit will be maximized.

Summary of Specific Findings and Recommendations

Finding	Recommendation
High efficiency furnaces have been installed in many units with very leaky, uninsulated duct systems.	Seal and insulate duct systems in all homes but Broadmoor homes with hydronic systems and the ENERGY STAR homes in Discovery Village and Miller Hill.
All tested units besides the ENERGY STAR homes have high air leakage rates.	Apply air sealing using skilled, equipped specialists and quality control.
Ceilings throughout the base are insulated to R-15 that is uneven and not in good condition in most locations.	Seal the ceiling plane, and install insulation to minimum R-38 up to R-49. Evergreen and the newer homes in Broadmoor have aluminum-frame, double pane windows. They are inefficient and leaky.
Guidelines from Washington's State Historic Preservation Office (SPHO) restrict the implementation of energy efficiency upgrades. • **Walls in the Broadmoor homes are uninsulated.** • **Windows in the historic Broadmoor homes are single-pane, double-hung wood with no weather-strip. use three to five times the space heat of any other gas heated homes on the base.**	Work with SPHO to implement guidelines that allow for historic preservation, while addressing necessary energy concerns, including: • As feasible, insulate walls with dense pack insulation the next time interior renovations are done. • In the near term, weather-strip should be installed around the movable sash and at the middle rail. In the long term, double pane low-e glass units can replace single pane glass as has been done at the historic Federal Building in downtown Boise, Idaho.

Finding	Recommendation
Most units have recently installed efficient gas or electric tank water heaters.	Develop a strategic plan for water heater replacement with high-efficiency units during the replacement cycle. If a unit has a natural gas water heater, upgrade to a tankless demand heater if the service allows. If not, upgrade to a condensing tank natural gas water heater. If a unit has an electric water heater—replace with a high-efficient gas heater as stated above if the gas service is feasible. In some cases where the furnace and water heater are separate, it may be most feasible to upgrade to an electric heat pump water heater, although this cannot be recommended without additional unit-specific evaluations.
Most lighting throughout the base is compact fluorescent lamps except at the historic Broadmoor and the Evergreen homes which have incandescent lamps.	Install compact fluorescent in all units in at least 75% of the sockets.
In as much as one-third of the units in most housing groups, the energy use is significantly above the average for the group—sometimes over twice as much.	Research, develop and implement strategies for helping occupants become aware of energy use and of strategies for reducing use.
Testing identified significant variance in exhaust fan flow rates from home to home with the majority being below minimum ventilation code.	Test all exhaust fans to verify that fan flow rate is sufficient (50 CFM is code). Fan duct work should also be inspected at this time to determine if the fan is effectively vented to the outdoors and insulated. Consider replacement of on/off switch controls in bathrooms with timers or motion sensors. At time of replacement install high efficiency, quiet fans with more sophisticated control strategies.

Finding	Recommendation
A radon mitigation system was found in one home randomly selected for audit in nonworking condition. Little information regarding the details and age of this system was found. It is not known if there are other homes on the base with elevated radon levels or radon mitigation systems.	Additional investigation into radon and radon mitigation systems on the base would be useful in identifying and determining what special precautions or prioritization should be placed on homes in terms of weatherization and indoor air quality. Generally, it is recommended that the EPA's Healthy Indoor Environment Protocols for Home Energy Upgrade be followed as part of house tightening. Where systems are already installed, they should be restored to working condition if necessary and operated.
ENERGY STAR homes use significantly less energy than any other homes on the base, and standard has become more stringent since the new homes analyzed in this study.	Equity Residential is commended for implementing the policy of purchasing ENERGY STAR homes, and is encouraged to continue this practice. The efficiency, comfort and safety are important to our service men and women and their families. And the new specification includes features that ensure the long-term durability of the homes that reduces long-term maintenance cost.

Future research is indicated in the following areas:

- Where electric water heater service is already in place, and it is too expensive or unfeasible to expand service for a gas water heater, heat pump water heaters should be explored as an option. The Northwest Energy Efficiency Alliance (NEEA) has developed a set of tiered efficiency and installation standards that is recommended to obtain maximum performance from these units. Performance modeling of heat pump water heaters in the context of natural gas heating could be done using data and models developed for this project together with research done by NEEA on heat pump water heater performance.

- Establish retrofit specifications for re-insulation, air leakage, window retrofit, and other measures and develop a quality assurance protocol to ensure measures are properly installed. All bids specifications for retrofit work would include such specifications and protocol. The newly revised Bonneville Power Administration weatherization specifications would be considered as a starting place.

- Research patterns of energy use and means to educate occupants to reduce energy use. Non-intrusive end use monitors could be placed in representative units to research energy use patterns. Possible means for reducing use include feedback devices, incentive programs, competition, and on-base marketing

- Research pre and post weatherization performance of units to which specific recommended packages are applied. This would provide case study guidance to future retrofits at JBLM, as well as be applicable to other bases located in heating climates.

- Broadmoor uses the most heating energy of any of the developments studied. Further energy auditing investigations in this development are indicated to develop a more accurate analysis of potential savings and how to achieve them. Specialists in retrofitting of historic structures could be consulted.

- Research, plan and conduct a deep energy retrofit pilot to develop and demonstrate the next phase of rehabilitation at JBLM. Over the long term, significantly reduce energy use through retrofit effort. Under the pilot, design, implement and document results.

Introduction

Equity Residential, the owner and manager of the residential housing at Joint Base Lewis McChord (JBLM) has taken a number of steps to improve the energy efficiency of new and existing housing at the base. These efforts are part of a 50-year project to replace all of JBLM's non-historic housing. While improving the livability of homes on the base is the primary concern, energy efficiency is also a priority.

Equity Residential owns all 4,901 housing units at JBLM (in 2002, JBLM participated in one of four pilot projects to transfer military housing to private ownership – since that time, most military housing projects have become privatized.) Equity Residential rents the homes to military families, at rates keeping with military housing allowances (below market rate.) Equity Residential pays for all gas and electric utilities; occupants pay for above average use and receive a credit for below average use as an incentive to energy efficiency (Lubliner M. , Blasnik, Kunkle, & Gordon, 2010).

The purpose of this research is to further assist Equity Residential in improving the energy efficiency of housing at JBLM. Researchers from the Washington State University (WSU) Energy Program worked in partnership with Equity Residential and Minol, the company managing the base's utility billing to conduct the research. Energy use in homes in six JBLM communities was analyzed and compared to assess performance. Field testing was conducted in a sample of homes and energy models were developed to identify opportunities for future energy efficiency improvements.

Community Descriptions

"BRAC" is an acronym that stands for Base Realignment and Closure and is the process the DOD uses to reorganize military installations. BRAC results in closures, expansions, and mergers throughout all branches of the armed forces. The 2005 BRAC saw the merger of Fort Lewis and McChord Air Force Base and the resulting formation of the joint base. JBLM houses approximately 16,300 people, including soldiers on active duty and their families. This number is expected to rise in the future due to the BRAC process. The total daily population for JBLM is approximately 47,160, including nonresidential commuters, a dramatic increase from 27,888 in 2003 and slightly less than the expected population of FY 2016, 48,389 (Rexroad APG, 2010).

Within the Fort Lewis portion of JBLM there are 21 residential communities consisting of more than 1,800 buildings and over 4,901 housing units (Equity Residential, 2011). This study evaluated six of those communities: Broadmoor, New Hillside, Beachwood, Davis Hill, Evergreen, and Discovery Village/Miller Hill.

Broadmoor is predominantly composed of single family residences built between 1929 and 1933 with some residences built as late as 1963. The older, historic residences are anomalous relative to newer housing, because there are restrictions on the type of renovation and retrofitting that can be done. The features of the historic Broadmoor homes include:

- Large footprints, ranging in size from 1,865 ft^2 to 2,650 ft^2
- Two stories and a basement (unique to historic Broadmoor)
- Additions to the original structure (sunrooms – unique to historic Broadmoor)
- Fireplaces (unique to Broadmoor)
- Minimal insulation including uninsulated walls
- Single-pane windows
- Little, if any, weatherization
- Antiquated hydronic heating systems

The remaining housing stock within Broadmoor is composed of multi-unit structures built in 1934, 1939 and 1948, and single family dwellings built between 1959 and 1963. The multi-family buildings present challenges to utility billing analysis due to aggregate gas metering per building, while the newer single-family dwellings have characteristics such as:

- Crawlspace foundations containing ductwork and with a concrete floor ("rat slab")
- Large glazing surfaces
- Fireplaces

Beachwood, New Hillside, and Davis Hill share many characteristics as a result of their age (constructed in the 1960s) and retrofit measures:

- Primarily duplex units with common rooftops above carport space, and, no common walls. Units range from 1,154 ft^2 to 1,262 ft^2
- Slab-on-grade foundations
- Light fixtures are primarily CFL,
- Windows are double-pane with vinyl frames
- Typically have three bedrooms (a few have four bedrooms)
- Almost all (95%) have ductwork located in the unconditioned attic

The water heater and furnace are housed within the mechanical room, which is located within the structure but accessed from the outside. The mechanical room doors include louvers and are accessible only by Equity Residential technicians.

Beachwood differs slightly from the Davis Hill and New Hillside. A portion of the community is made up of homes built in the 1960s, with footprints ranging from 1262 ft^2 up to 1,580 ft^2; the remainder are duplexes constructed in 2003-2005 ranging in size from 1,497 ft^2 to 2,263 ft^2 (Equity Residential, 2011). The mechanical rooms are accessed from the inside, though still locked to the occupant.

Evergreen also experienced two stages of development, the first in 1984 and the second in 1995. The older homes feature:

- Footprints ranging in size from 1,200 ft^2 to 1,560 ft^2 with two to three bedrooms
- Slab-on-grade foundations
- Predominantly incandescent lighting
- Double-pane aluminum windows (dating from the time of construction)

The houses built in 1995:

- Range from 1,600 ft^2 to 1,900 ft^2
- Have two to three bedrooms, and are far fewer in number

The houses built in the initial stage of development were said to feature a "passive solar design." However, due to poor planning and execution, the units do not appear to function as passive solar.

The newest of the communities are Discovery Village and a subdivision, Miller Hill. Constructed between 2005 and 2008, these modular homes are built to Northwest ENERGY STAR Standards. They feature:

- Footprints ranging between 1,711 ft2 and 1,843 ft2 and three or four bedrooms
- Energy efficient envelope design and construction materials
- ENERGY STAR appliances.

An important distinction between the units in Discovery Village and Miller Hill is the installation of efficient tankless water heaters in Miller Hill (.82 Energy Factor (EF) versus .62 EF for tank water heaters at Discovery Village.)

Methodology

Researchers used three approaches to analyze energy use and identify efficiency opportunities at JBLM: utility billing analysis, energy audits, and energy modeling. These approaches are briefly described here. Each section in the report elaborates on the analysis and results for each approach.

Utility Billing Analysis

In 2001, Equity Residential was selected to manage the residential real estate on JBLM. The firm is responsible for the physical buildings and performs or oversees all upkeep, maintenance, and retrofitting. Equity Residential provided structural data, such as floor plans, as well as occupancy data, information on retrofits, and some historical information on the houses. This information was matched with data from Minol USA, the organization responsible for managing the electric and natural gas billing for JBLM. The data was organized and grouped by community and includes:

- Unit number
- Date of metering
- Whether the usage is estimated or verified (meter reading)
- Usage of electricity in kWh and natural gas (gas) in 1000 cubic feet
- Floor plan identification tags (of the metered house)
- Occupancy status of the metered house (vacant or not)

The data arrived in Excel spread sheet format, with one spreadsheet containing energy consumption records per community per month. The data extended 23 months into the past, yielding 23 spreadsheets per community. Before any meaningful analysis could be performed, the data needed to be sorted, filtered and otherwise organized. Once organized, two analyses of the data were conducted:

> An aggregate analysis of the actual utility data was performed by WSU Energy Program staff; Michael Blasnik and Associates completed a regression analysis on the utility billing data.

Energy Auditing

Researchers conducted full energy audits on two unoccupied homes in each of the five non-ENERGY STAR communities. The audits included diagnostic testing along with visual inspections of the envelope and equipment. Four additional audits were conducted in homes with high bill complaints. Three of the bill complaint homes were occupied and one was not. The audit protocol in these homes was the same except that a homeowner's survey was conducted in the three occupied homes (see Appendix D).

Energy Modeling

Energy modeling complemented the billing analysis and energy audits. The programs SIMPLE and BEopt (Building Efficiency optimization) predict the amount of energy usage for a given building based on the building's location and physical features such as construction style and method, orientation of the house, occupancy, and appliances. The audits provide input for the models and the utility bills are a check and basis of comparison.

Performing the energy modeling serves several purposes. By running both programs on each house, the results can be compared against one another and against the utility bills. The results of this comparison provide indications on the accuracy and precision of the programs. More importantly, the results of the models also provide information on energy efficiency opportunities, which will allow JBLM to make better-informed decisions about future building retrofits and new construction.

SIMPLE is a spreadsheet designed by Michael Blasnik to allow the input of qualitative data to generate estimated household energy use. The values given to the qualitative model entries are drawn from extensive analyses of energy consumption from all over the country and represent averaged values of those qualitatively described inputs. For example, wall insulation is entered as "no insulation, partial/semi insulation, standard insulation, good insulation, very good/foam". This is in place of a specific R value. With the structural characteristics entered, SIMPLE generates estimated energy consumption through inter-related equations and computations. It was made available to WSU for this study, because of the involvement of Mr. Blasnik in the analysis. SIMPLE is proprietary and is incorporated into the EPS Auditor software by Earth Advantage Institute (http://www.energy-performance-score.com) and may be available to other users through arrangement with Mr. Blasnik. (Blasnik, 2011).

BEopt is a software program (available at http://beopt.nrel.gov/) developed by the National Renewable Energy Laboratory (NREL) toward the goal of finding "optimal building designs along the path to highly efficient buildings". BEopt provides users with features applicable to both new home construction and retrofitting an existing house, including structural properties and characteristics, market inputs such as utility rates and mortgage information, and fuel types and their respective costs. BEopt possesses a large variety of options with which to customize a representative model and is constructed to simulate energy usage through integrated calculations and formulas. (National Renewable Energy Laboratory, 2011).

Billing Analysis

Equity Residential and Minol provided electric and natural gas utility billing data for 23 monthly periods from January 14, 2009 to December 15, 2010. Researchers received data for 2,276 housing units in 6 communities: Beachwood, Broadmoor, Davis Hill, Discovery Village (including Miller Hill), Evergreen, and New Hillside. Equity also provided information about the characteristics of the housing units, occupancy data, and information about capital improvements. All housing in the sample had natural gas space heat and either natural gas or electric resistance hot water heat. Table 1 provides some basic characteristics for each of these communities.

Community	Units	Typical Square Feet	Typical Vintage	Gas Hot Water Heat (units)	Electric Hot Water Heat (units)
Beachwood	512	1220-1494	1959-1963/ 2003	129	383
Broadmoor	169	1900-2844	Pre-1950	72	97
Davis Hill	433	1154-1262	1959-1963	224	209
Discovery Village	458	1700-2062	2005-2007	458	0
Miller Hill	34	1780-2062	2008	34	0
Evergreen	147	1464-1580	1984/1995	147	0
New Hillside	523	1220-1378	1959-1963		523
Total	2276	-	-	1030	1212

Table 1. JBLM Community Characteristics

Electric service is provided to JBLM by Tacoma City Light, but electric metering and billing is provided by Minol, a contractor to Equity Residential. Minol also handles billing for the natural gas service and metering provided by Puget SoundEnergy. Researchers received the utility billing data from Minol in groups of 23 spreadsheets for each community, entered the data into a database, and then organized the data for further analysis.

Analysis of the billing data had three components:

Actual aggregate monthly energy statistics for 23 monthly billing periods for each community. These periods begin with the monthly billing period ending on February 12, 2009 and end with the monthly billing period ending on December 15, 2010. Monthly usage was calculated from the beginning and ending meter readings for a particular period for each unit in a community, and then statistics were calculated for all the units in the community for the period.

Actual aggregate annual energy statistics for 12 annual periods for each community. These annual periods begin with the annual period from January 14, 2009 to January 14, 2010 and end with the period from December 13, 2009 to December 15, 2010[1]. Annual usage was calculated from the beginning and ending meter readings for an annual period for each unit in a community and then statistics were calculated for all the units in the community for the annual period.

A regression analysis of utility billing data and weather for each housing unit to estimate baseload and total electric and natural gas use under typical weather conditions (using Typical Meteorological Year 3 (TMY3) weather data). Statistics for each community were calculated. Regression models were also developed to analyze electric baseload, tankless gas water heaters, and annual natural gas use by community. There is no separate regression report--all results are incorporated into this report. The regression analysis allowed for:

- Comparison of actual energy use data with estimated use under typical meteorological conditions;
- Separation of the baseload from temperature dependent loads;
- Comparison of natural gas base loads to estimate demand water heater savings; and
- Overall more robust results and confirmation of data quality.

During the analysis, researchers identified data quality issues that created challenges:

- There is a significant amount of turnover in military housing – on the order of 50% in an annual period. For the aggregate statistics researchers only included units that were occupied for an entire month or for an entire annual period (no change in occupancy). The regression analysis only used data for occupied units.

- There were also a significant number of estimated meter readings. In some cases all the meter readings for a particular period were estimates. Energy usage was calculated from beginning and ending meter readings for a monthly or annual period. For the aggregate statistics, researchers excluded usage values where both meter readings were estimates. Researchers included usage values where one or none of the readings was an estimate. This increased the sample sizes and the robustness of the data. The impact of over- or under-estimating the usage of a particular unit washed out in the aggregate values. For the regression analysis estimated readings were excluded.

[1] Several annual periods are a few days longer than a year. Researchers did not adjust the analysis to account for this.

In some cases where meter readings were missing or estimated, researchers used adjacent meter readings to estimate usage when this was possible (e.g., reading 2 in period 1 should be the same as reading 1 in period 2). The regression analysis used the next actual meter reading to calculate energy use.

The regression analysis had screens for standard error, fit (r-squared), baseload, and minimum usage. In the aggregate analysis, cases with excessively high or low use indicating some kind of data error were screened out.

The monthly and annual energy use values are indicators of energy use in each community and allow us to make comparisons between communities. The research questions being addressed include:

- What are the energy usage differences between communities? This requires accounting for differences in water heating fuel.
- Are the Discovery Village/Miller Hill units built to Northwest ENERGY STAR Standards more efficient?
- Are the high efficiency tankless natural gas hot water heaters installed in Miller Hill units using less energy?

Community Energy Use

Community energy use is compared for two different groupings of housing units – units with natural gas hot water heat and units with electric hot water heat. All the housing units have natural gas space heating. In the comparisons of energy use, researchers consider the Broadmoor community separately. The Broadmoor housing units have significantly higher energy use than the other communities and are composed of widely differing housing types and ages.

Housing Units with Natural Gas Hot Water Heat

All the housing units in Discovery Village/Miller Hill and Evergreen have natural gas hot water heat along with some of the housing units in Beachwood and Davis Hill. Researchers compared the natural gas and electricity use for the housing units in these communities with natural gas hot water heat.

Natural Gas Use

The newer communities have the lowest natural gas use (Table 2). The Discovery Village/Miller Hill units were built between 2005 and 2008, and all the Beachwood units with natural gas water heating were built in 2003. For the older communities, the Evergreen units (built more recently than Davis Hill) have lower natural gas use. The monthly data shows that differences in natural gas use between the communities are most significant in the winter, reflecting differences in space heating use. This suggests the energy efficiency of the building envelopes and other factors affecting space heating energy use is better in the newer housing units.

Community	Units	Actual Annual Average (therms)	Actual Annual 3/2009-3/2010 (therms)	Regression Average Annual Use (therms)
Beachwood	129	491	487	484
Davis Hill	224	809	793	846
Discovery Village/ Miller Hill	492	460	450	464
Evergreen	147	667	657	635

Table 2. Total Natural Gas Use for Communities with Natural Gas Water Heat

Figure 1 graphically displays the median value, (the line across the box), average (the diamond), 25th and 75th percentile (the box) and maximum and minimum range (whiskers) in natural gas use. For each of the four communities there is a box plot based on the actual aggregate annual statistics and the regression analysis (all of the figures in this section will follow this format.) The results for the actual natural gas use and regression natural gas use are close. Recall that the regression analysis uses TMY3 weather data. Discovery Village/Miller Hill and Beachwood have similar natural gas use, while the older Evergreen and Davis Hill communities have higher use. There is a fairly wide range in the natural gas use in the housing units within each community, which may reflect changes in occupancy in units due to the nature of military service (even though a unit is occupied) as well as differences in occupant behavior. The shaded boxes are a good reflection of the energy use in each community.

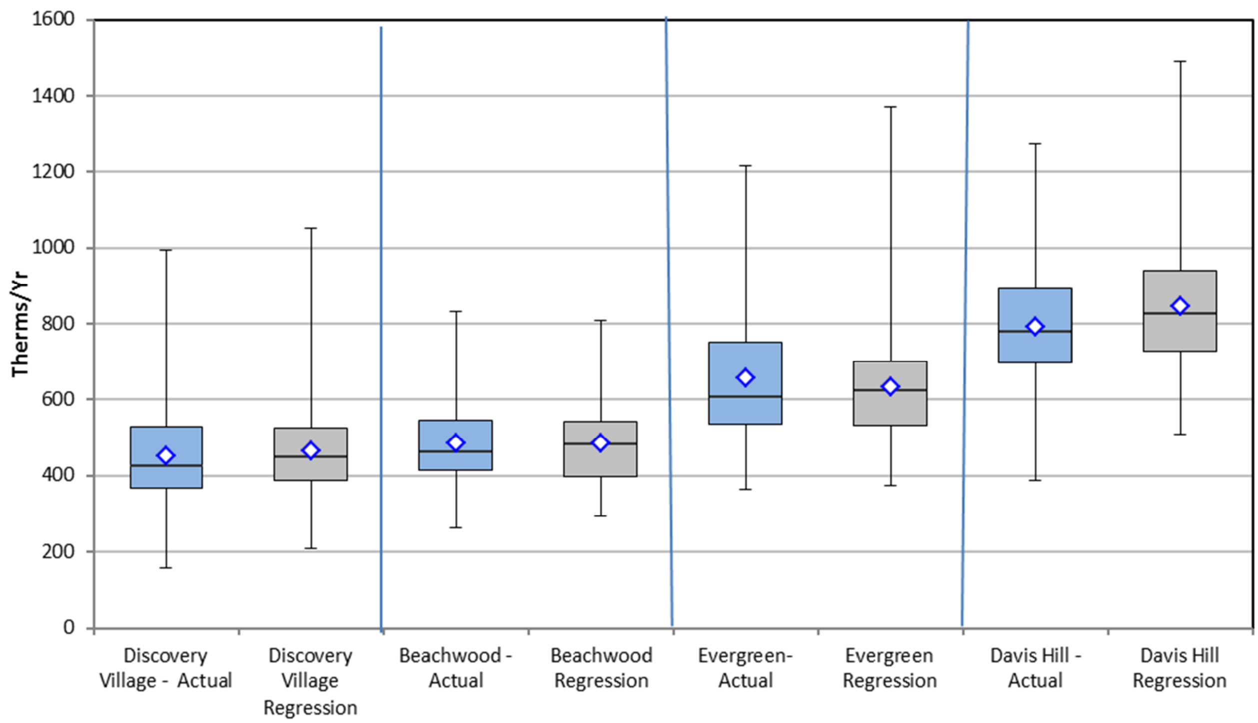

Figure 1. Total Natural Gas Use for Communities with Natural Gas Water Heat

Electricity Use

Annual average electricity use for the communities with natural gas water heat ranges from approximately 7,000 to 9,000 kWh (Table 3). In contrast to its high natural gas use, the oldest community shown (Davis Hill) has lower electricity use, which may be explained by the fact that it has the smallest units. However, Davis Hill has a similar number of bedrooms as the other communities. Monthly electricity use is slightly higher in winter months for all communities and the aggregate monthly usage profiles are similar.

Community	Units	Actual Annual Average (kWh)	Actual Annual 3/2009-3/2010 (kWh)	Regression Average Annual Use (kWh)
Beachwood	129	8561	8526	8757
Davis Hill	224	7332	8450	7249
Discovery Village/ Miller Hill	492	8828	8879	8854
Evergreen	147	8795	8930	8409

Table 3. Total Electricity Use for Communities with Natural Gas Water Heat

The range of electricity use for individual household use in these communities is shown in Figure 2. While the mid-range electricity use is similar, with Davis Hill having lower overall use, some communities have greater variation. In general, the range in annual electricity use of households in each community is fairly wide, suggesting there are significant differences in occupant usage. There are also some outlier usage values that are higher and lower than what would be considered normal electricity use.

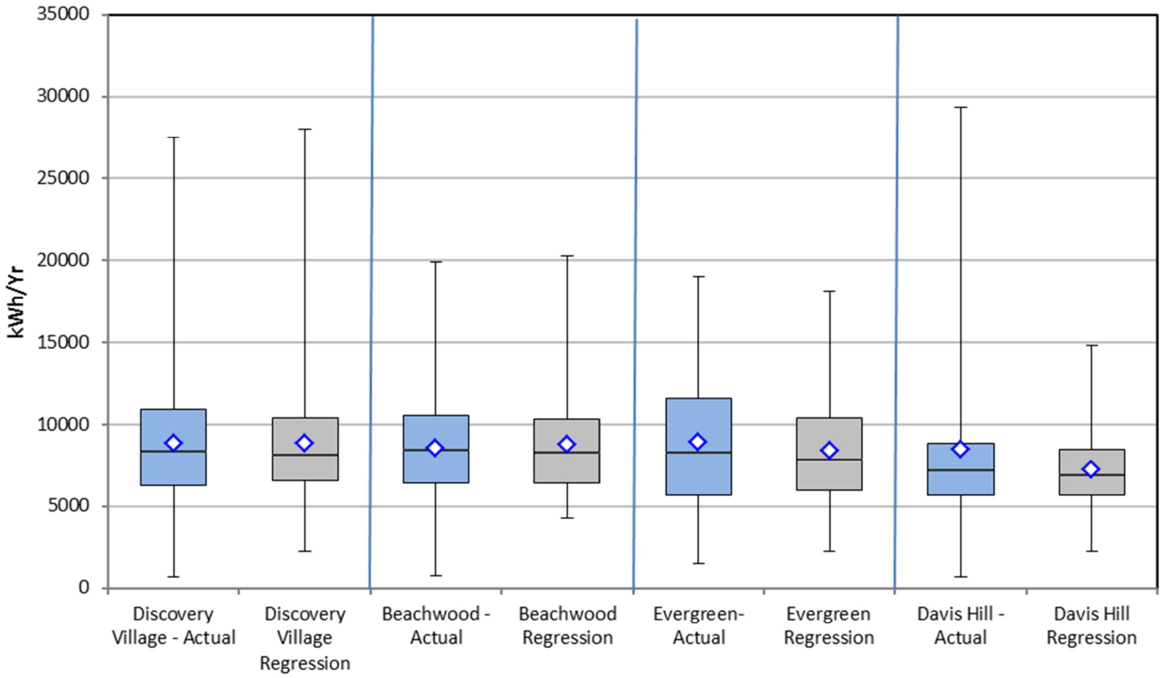

Figure 2. Total Electricity Use for Communities with Natural Gas Water Heat

Housing Units with Electric Water Heat

All the housing units in New Hillside have electric water heaters as do some of the housing units in Beachwood and Davis Hill. Researchers compared the natural gas and electricity use for these communities.

Natural Gas Use

The communities with electric hot water heat have similar average natural gas use (Table 4). The units in these communities were all built around the same time period, are similar in size, and most are duplexes. The Beachwood units show a little lower usage while New Hillside is slightly higher. Monthly natural gas usage data shows that the communities have almost identical usage profiles.

Community	Units	Actual Annual Average (therms)	Actual Annual 3/2009-3/2010 (therms)	Regression Average Annual Use (therms)
Beachwood	383	501	489	482
Davis Hill	209	538	529	555
New Hillside	523	582	607	569

Table 4. Total Natural Gas Use for Communities with Electric Water Heat

The median and range of actual annual and regression analysis natural gas use for these communities is similar (Figure 3). Like the averages in Table 4, Beachwood tends to be lower and New Hillside slightly higher. There is a fairly wide range in natural gas usage with higher users consuming more than twice as much energy as lower users.

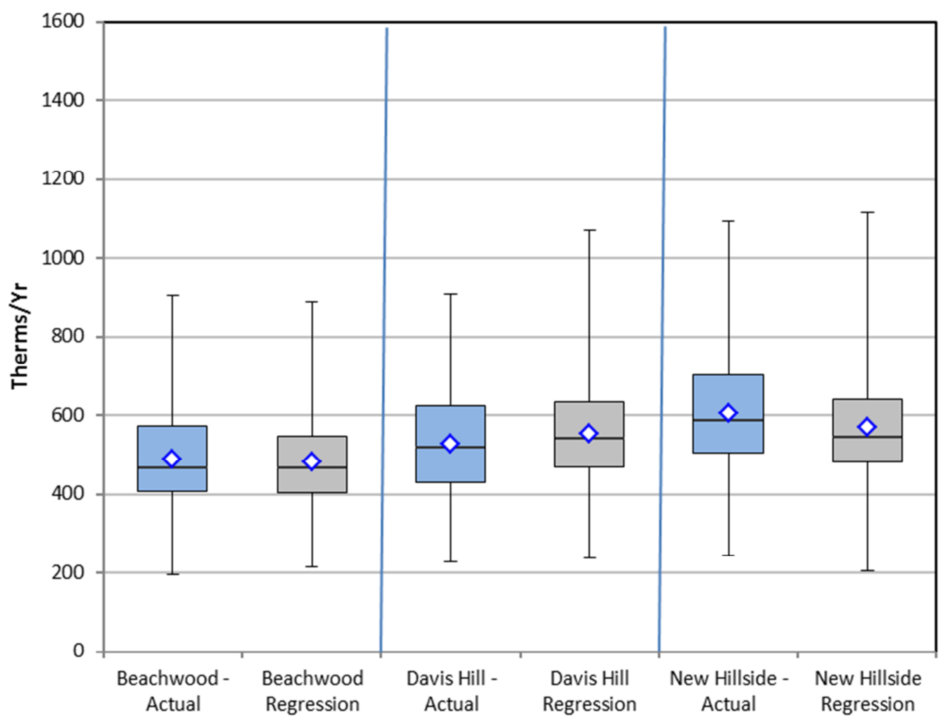

Figure 3. Total Natural Gas Use for Communities with Electric Water Heat

Electricity Use

The communities with electric hot water heat have annual average electricity use that is around 11,000 kWh (Table 5). Differences in electricity use between the communities are modest. The monthly electricity use profiles are also very similar.

Researchers estimated electric hot water heating energy use by comparing the electricity use of units with electric water heat with those with natural gas hot water heat. This comparison is most valid for Davis Hill. Comparing the average annual electricity use, the Davis Hill units with electric water heat use approximately 3,700 kWh per year more electricity than those with natural gas water heat. Researchers developed a model for electric baseload in the regression analysis. The coefficient estimated for electric water heat was 3,245 kWh.

Community	Units	Actual Annual Average (kWh)	Actual Annual 3/2009-3/2010 (kWh)	Regression Average Annual Use (kWh)
Beachwood	383	10761	10908	10604
Davis Hill	209	11046	11185	11248
New Hillside	523	11573	11489	11641

Table 5. Total Electricity Use for Communities with Electric Water Heat

The range in electricity use is also similar in these communities, except for the extreme values (Figure 4). There is a fairly wide range of electricity use across housing units. Future research may be warranted to better understand this range in energy use and to identify opportunities for energy savings for the 25 percent of housing units shown in the upper portion of the box plots for each community.

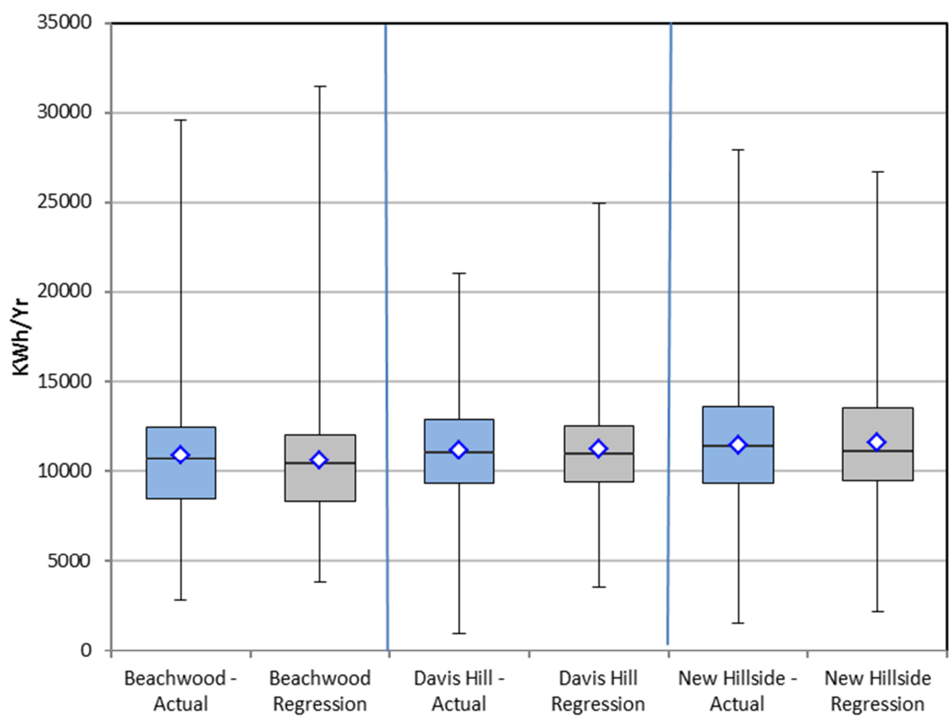

Figure 4 Total Electricity Use for Communities with Electric Water Heat

Energy Use in Broadmoor

The Broadmoor community consists of single-family, duplex, four-plex, and five-plex housing. These are historical homes, many being built between 1929 and 1939. The duplexes were built in 1948 and a few single-family homes were built around 1960. Researchers have electricity use data for 169 units, but natural gas data is only available for 103 single-family units. Seventy-two of the homes have natural gas hot water heaters while 97 have electric hot water heaters. They all have natural gas heat (gas boilers and radiators).

The natural gas use in the Broadmoor homes is three to five times greater than the other communities (Table 6). Because the historical homes have less efficient building envelopes and heating systems and are larger than the homes in other communities, higher energy use is expected. Because of the small sample size for the analysis, it is possible that the high energy use is not representative of Broadmoor as a whole. However, the usage still seems to be excessive and opportunities to reduce natural gas consumption should be explored. [2]

The total electricity usage in the Broadmoor homes is comparable to the other communities. The regression analysis shows higher values, but this may be a data anomaly due to a small sample and some homes with high usage. When accounting for the higher square footage and number of bedrooms, electricity use in Broadmoor tends to be lower than the other communities. This counters one explanation for the high natural gas use – that the occupants of these homes are high energy users.

	Natural Gas Hot Water Heat		Electric Hot Water Heat	
	Natural Gas (therms)	Electricity (kWh)	Natural Gas (therms)	Electricity (kWh)
Annual Average Use	2,390	7,951	2,060	11,517
Annual Use 3/2009-3/2010	2,496	7,960	2,039	9,818
Regression Average Annual Use	2,304	9,014	1,954	13,711

Table 6. Total Energy Use for Broadmoor Single-family Units

Northwest ENERGY STAR Standard and Washington State Energy Code Savings

Discovery Village/Miller Hill homes are built to meet Northwest ENERGY STAR Standards (Northwest Energy Efficiency Alliance, 2005). Analysis was conducted to see how efficient these homes are relative to the other communities. Table 7 shows the results of the analysis of the 12 periods of annual natural gas use for homes with natural gas hot water heating. The Discovery Village/Miller Hills units use significantly less energy than units in Davis Hill and Evergreen.

[2] The sample sizes for the aggregate billing and regression analysis were relatively low in Broadmoor due to the occupancy and data quality screens used in the analysis. This is one reason why box plots are not shown for Broadmoor. Some caution should be used when reviewing these results.

Relative to Davis Hill and Evergreen, energy use for Discovery Village is 200 to 380 therms per year less or 30 to 40 percent lower.

However, the new units in Beachwood have similar energy use to Discovery Village – the difference in energy use is less than 10 percent and is zero in some annual periods. Even though the difference is small, it is statistically different (at 95% confidence) for the three annual periods where the sample of Beachwood homes was more than 60 units. Since these Beachwood homes were built in 2003, the difference in efficiency relative to Discovery Village is less than for the other communities. This difference probably indicates the impact of the Washington State Energy Code (WSEC). Earlier development at JBLM preceded the WSEC which started in 1991 and has been continuously improved since. (Washington State Building Code Council, 1991).

Community	Annual Average (therms)	Percent	Annual Average Range (therms)	Percent	Annual 3/2009-3/2010 (therms)	Percent
Beachwood	31	6%	-10-43	-2-8%	37	8%
Davis Hill	349	43%	329-380	42-44%	343	43%
Evergreen	207	31%	194-233	29-34%	207	31%

Table 7. Community Differences in Natural Gas Use Relative to Discovery Village/Miller Hill

A regression model of natural gas use of three and four bedroom homes relative to Discovery Village (not including Miller Hill) was also developed. The model considered both units with electric and natural gas hot water heat. Annual savings ranged from 192 to 466 therms for all the communities except the newer units in Beachwood. The savings for these Beachwood units was 42 therms with a 95% confidence interval from 14 to 69 therms. These results are similar to what is shown in Table 7.

The units in Discovery Village/Miller Hill are larger than the units in the other communities (except for Broadmoor). Dividing the values in Table 7 by square feet increases the relative difference in energy use for the Discovery Village/Miller Hill Units. Annual natural gas use is around 13 percent lower relative to the new Beachwood units and is significantly lower for the other communities (Table 8).

Community	Annual Average (therms/ft^2)	Percent	Annual Average Range (therms/ft^2)	Percent	Annual 3/2009-3/2010 (therms/ft^2)	Percent
Beachwood	0.037	13%	0.023-0.041	8-14%	0.038	13%
Davis Hill	0.421	62%	0.399-0.454	61-63%	0.412	62%
Evergreen	0.171	40%	0.166-0.185	39-43%	0.166	40%

Table 8. Differences in Annual Natural Gas Use per ft^2 Relative to Discovery Village/Miller Hill

Figure 5 shows the percentage savings per square foot relative to Discovery Village/Miller Hill for the 12 billing periods. Note the consistent differences between Davis Hill, Evergreen and Beachwood. Davis Hill was constructed in the 1960s, prior to any energy code. Evergreen was constructed in two stages; the first stage was constructed in 1984, prior to the WSEC, and part in 1995 after the WSEC went into effect. The Beachwood units with natural gas water heating were built in 2003. The WSEC was the first statewide energy code to implement the Model Conservations Standards of the Northwest Power and Conservation Council. It has been upgraded regularly since its adoption in 1991. It is the key factor in explaining the across-the-board difference in energy use between these non-ENERGY STAR developments.

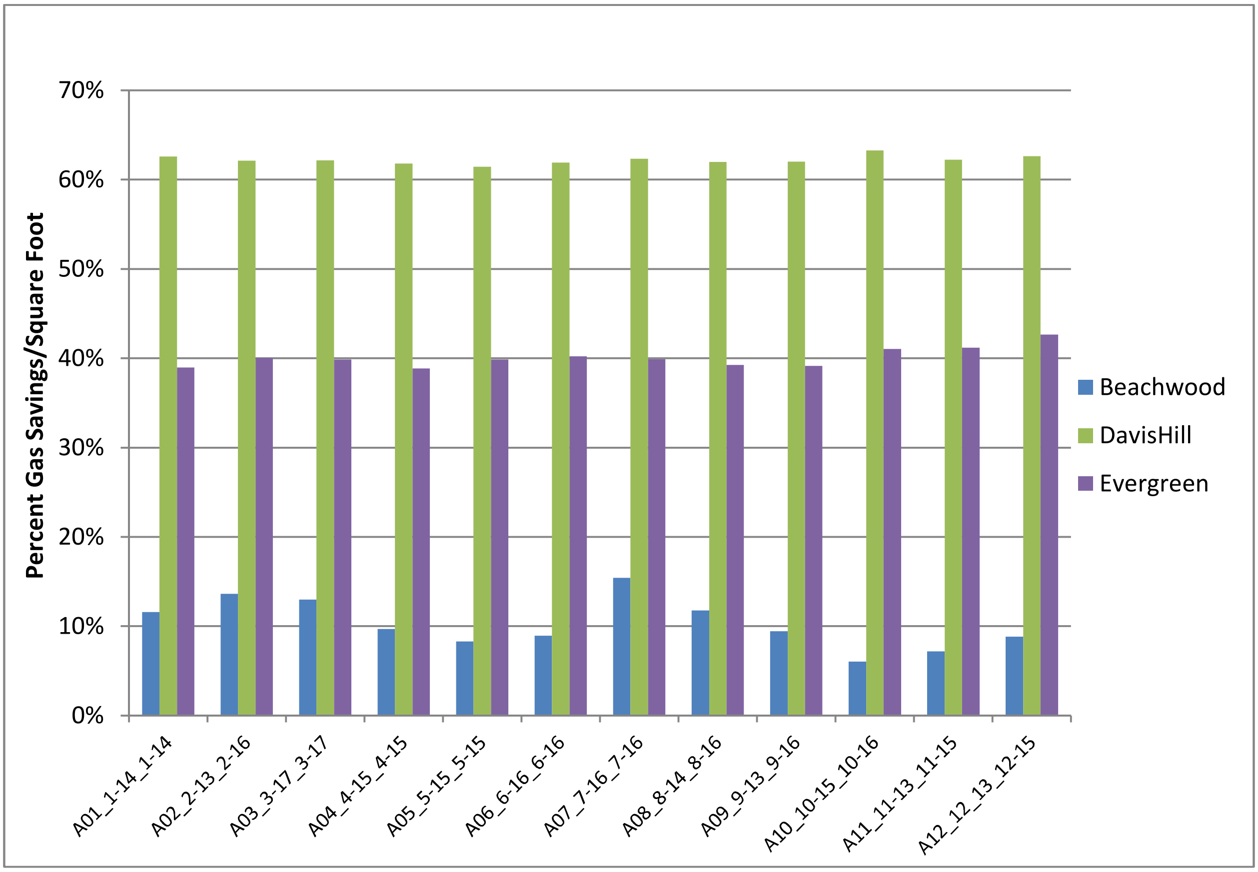

Figure 5. Differences in Annual Natural Gas Use per Square Foot Relative to Discovery Village/Miller Hill ENERGY STAR Homes

Natural Gas Tankless Hot Water Heater Savings

The newest housing units at JBLM were built in 2008 at Miller Hill (part of Discovery Village). These 34 units have high efficiency tankless natural gas hot water heaters (EF=0.82). To identify whether these tankless hot water heaters are generating any natural gas energy savings, researchers compared the natural gas use of Miller Hill units with similar units in Discovery

Village. These Discovery Village units have power vented storage natural gas water heaters (EF=0.62).

Researchers compared the 34 Miller Hill units to two different groups of Discovery Village units – units with similar plans that have four bedrooms (136), and a set of units flagged by JBLM as most similar to Miller Hill (86). Number of occupants is one of the key determinants of hot water use. By comparing similar units with the same number of bedrooms, researchers are more likely to be comparing units with similar numbers of occupants and hot water usage patterns.

Researchers used two methods to estimate the energy savings from the tankless hot water heaters. In one method researchers used a regression model to compare natural gas baseload in four bedroom Discovery Village units with Miller Hill. The result of this analysis was 51 therms lower baseload for Miller Hill, which was 22 percent of natural gas baseload. This reflects the estimated natural gas savings from the tankless water heaters. The 95 percent confidence interval is 20 to 82 therms. This range is relatively large due to the small sample size.

The second analysis method compared the actual natural gas use for summer months when researchers would expect minimal to no space heating. Because many Miller Hills units were not occupied until mid-way through 2009, researchers consider natural gas use for four summer month periods. Table 9 shows the results of this comparison.

	Units	Aug/Sep '09 (therms)	Units	Jun/Jul '10 (therms)	Units	Jul/Aug '10 (therms)	Units	Aug/Sep '10 (therms)	Units
DV-4Bdrm	136	21.2	96	22.8	120	21.2	103	23.7	119
DV-Flagged	86	21.7	57	23.3	71	21.4	64	24.3	76
Miller Hill	34	17.6	25	18.1	29	17.4	22	19.7	30
Savings-4Bdrm		4.1		5.2		4.0		4.6	
Savings-Flagged		3.7		4.8		3.8		4.1	

Table 9. DHW Utility Billing Analysis in DV/MH

The natural gas use for Miller Hill is less than each of the Discovery Village comparison groups, and the difference is statistically significant for all four months at a 95% confidence level. Using the average savings values for the plan units (4 bedrooms) suggests the tankless water heaters are saving about 4.5 therms per month or about 20 percent. On an annual basis the units in Discovery Village are estimated to use 272 therms for hot water heating and tankless hot water heaters would save about 54 therms.

The savings estimates for the two methods are similar at approximately 50 therms per year, slightly less than the 24 percent researchers expect based on the EF values alone. Caution should be used in interpreting these results, since the number of Miller Hill units with tankless water heaters is small. While researchers are confident the tankless water heaters are saving energy further research is warranted to confirm similarities with the Discovery Village units and larger sample sizes would provide more robust savings estimates.

Comparison to Other Use Data

A comparison was made between ENERGY STAR homes at JBLM to results of a NEEA study on Pacific Northwest ENERGY STAR and baseline Washington homes in a paper delivered to ACEEE in 2010. The table and text below are taken directly from the ACEEE paper. (Lubliner, Blasnik, Gordon, & Kunkle, 2010).

	Fort Lewis			New Homes WA 2004-2005	NW ENERGY STAR	
	All Units Discovery Village Billing	3BR Madison Billing	3BR Madison EGUSA Modeled		Study Baseline	Participant
Electric (kWh)	8711	8140	7685-7728	10032	8717	7485
Gas (therms)	484 (285+198)	447 (270+177)	484-533	818	534 (384 +150)	499 (344+155)
Square Feet	2058	2058	2058	2338/2445	2355	2276
EUI Electric (kWh/ft^2)	4.23	3.96	3.73-3.76	4.3 (4.29)	3.70	3.29
EUI Gas ($therms/ft^2$)	0.24	0.22	0.24-0.26	0.3 (0.33)	0.227	0.219

Table 10. Comparison of Fort Lewis Results with other Studies

“While these results show the performance of the Fort Lewis Discovery Village duplexes are comparable to Northwest ENERGY STAR homes, the ability to draw conclusions from these data are limited. The ENERGY STAR® study covers a wide variety of homes throughout the Northwest. The Discovery Village homes are confined to a small area south of Tacoma, WA, are all very similar with similar occupancy patterns, and are duplexes of similar design and construction.” The ENERGY STAR Study referenced in the ACEEE paper was commissioned and published by NEEA. (KEMA, Inc. , 2010).

In addition to the ACEEE paper, NEEA is currently embarking on a massive Residential Building Stock Assessment (RBSA) that will characterize residential building energy use in the Pacific Northwest through audits, billing analysis and direct collection of energy use data through submeters. The contractor is Ecotope, Inc. of Seattle, Washington. A year’s worth of bills from approximately 1,600 homes in the Pacific Northwest will be analyzed. The report of that analysis will be available from NEEA (in the fourth quarter of 2012. The submetered data report will focus on end uses as well as total energy use, and will be available in mid-2013.

Field Testing Results

Energy audits were performed by WSU staff at least two homes in each of the six developments involved in this study. The audits included performance testing using a blower door, duct tester and balometer. Where communities had a mix of older and more recently build homes, audits focused on the older units. Results for each development are summarized in Table 11.

	Blower Door test	ACH_{50}	Duct Leakage-ext.	Housing type	Vintage
Broadmoor					**1929-1963**
Historic unit 2309	4900 CFM_{50} basement door open	12.88	Hydronic Heating	SF detached	1931
	4100 CFM_{50} basement door closed	10.56	Hydronic Heating		
Historic unit 2351	4675 CFM_{50} basement door open	11.57	Hydronic Heating	SF detached	1931
	4225 CFM_{50} basement door closed	10.51	Hydronic Heating		
unit 2651	2850 CFM_{50}	11.15	280 CFM_{50}	SF detached	1959-1963
unit 2652	2800 CFM_{50}	10.95	175 CFM_{50}	SF detached	1959-1963
Evergreen					**1984**
unit 9290	2000 CFM_{50}	10.2	135 CFM_{50}	SF detached	1984
unit 9280	2175 CFM_{50}	10.46	212 CFM_{50}	SF detached	1984
New Hillside					**1960**
unit 6768	2100 CFM_{50}	12.91	85 CFM_{50}	Duplex, shared carport	1960
unit 6759	1800 CFM_{50}	13	390 CFM_{50}	Duplex, shared carport	1960
Davis Hills					**1960-1963**
unit 5428	1890 CFM_{50}	12.28	275 CFM_{50}	Duplex, shared carport	1960-1963
unit 5959	1525 CFM_{50}	9.87	460 CFM_{50}	Duplex, shared carport	1960-1963
Beachwood (Older Units)					**1959-1961**
unit 8450	2260 CFM_{50}, mechanical room open	14.64	160 CFM_{50}	Duplex, shared carport	1959-1961
	2000 CFM_{50}, mechanical room closed	12.95			
unit 8636	950 CFM_{50}	5.36	300 CFM_{50}	SF detached	1959-1961

	Blower Door test	ACH_{50}	Duct Leakage-ext.	Housing type	Vintage
Discovery Village/Miller Hill					**2005-2007**
Average	-	4.14 (18 homes)	4.99% of CFA (total)	Duplex/Triplex over crawlspace	

Table 11. Results of Field Testing

In addition to testing, a comprehensive walk through audit was performed to assess thermal qualities of the envelope, mechanical equipment specifications, lighting, appliances and other miscellaneous loads, as well as other observations relating to energy consumption and moisture migration. All of these audits were performed on unoccupied homes.

Four audits were also performed on homes selected by Equity Residential in response to high bill complaints, or high energy use identified by Equity. Three of these homes were occupied and one was unoccupied. The unoccupied home was located in a development not included as part of the utility bill analysis. All of the homes received the same detailed audit as was performed on the unoccupied homes. A detailed homeowner survey was also performed at the three occupied homes in attempt to identify impacts of occupant behavior on the homes energy consumption.

Detailed case studies for each home are included in this report as Appendix A for the sampled homes and Appendix B for the “complaint” homes. Appendix C, which provides case studies for the new construction Discovery Village and Miller Hill developments, are provided for comparison with the existing home case studies. The survey form is included in Appendix D.

Energy Audits

All homes audited had been retrofitted within the last 5 years with high efficiency (at or about an Annual Fuel Utilization Efficiency (AFUE) of .92) sealed combustion furnaces (see Figure 6a) except for the older Broadmoor development (which are currently phasing in .82 AFUE boilers (see Figure 6b), replacing boilers of unknown efficiency and performance that were in use during the billing periods analyzed in this study.) All of the furnaces were in operation prior to the start of the billing period analyzed in this study.

Figure 6a. Typical sealed combustion natural gas furnace

Figure 6b. Typical boiler found in recently renovated Broadmoor development.

With the exception of Miller Hill, all units in the study have newer natural gas or electric tank type water heaters (Figure 7a); Miller Hill homes have tankless natural gas water heaters (Figure 7b). Evergreen and Beachwood homes have both space heating and DHW equipment located entirely within the conditioned space. All other developments have some portion of this equipment located outside the conditioned space.

Figure 7a. Typical 0.90+ EF electric tank water heater

Figure 7b. Typical 0.60 – 0.62 EF natural gas tank water heater

Figure 7c. Typical 0.82 EF natural gas tankless water heater found in Miller Hill homes

Development of a strategic plan for replacement of domestic hot water (DWH) equipment will ensure maximum cost-to-benefit when DHW equipment needs to be replaced again. Current models were placed into service relatively recently and are of higher than minimum efficiencies. However, higher efficient technologies are available, such as tankless natural gas and heat pump water heaters, and may be more cost effective than the models currently in use. In addition, fuel switching to natural gas may also prove to be an attractive option for homes where the furnace and DHW are installed in the same vicinity, and the service capacity allows the expanded use.

All space heating systems for homes in this study have been recently upgraded to high efficiency natural gas units; there is no recommendation for system replacement at this time. However, it is recommended that analysis of technologies and utility rates be conducted when these heating systems reach the end of their effective life. In the meantime, overall performance of both space heating and DHW systems can be increased by installing them within conditioned space. This could be achieved relatively easily in the New Hillside and Davis Hill developments by replacing the existing exterior mechanical room door with an R-5 insulated door, and assuring that combustion air is plumbed directly to the sealed combustion furnace from the outside (see Figure 8a and 8b.)

Figure 8a. Typical mechanical closet in Davis Hill and New Hillside developments.

Figure 8b. Combustion supply air intake cut at furnace cabinet.

Significant renovation has taken place at all developments in the study except at Evergreen and Discovery Village/Miller Hill. In the homes that have seen significant renovation, the most important energy efficiency improvement measures (other than space and water heater retrofits) were window replacement and lighting efficiency upgrades to 75% –100% compact fluorescent lamps (CFLs). Many of the homes also have upgrades to ENERGY STAR qualified refrigerators and dishwashers, but no consistent pattern of implementation was observed. No homes at JBLM are outfitted with air conditioning, and no homes contained occupant-installed air conditioning at the time of audit.

Upgrading all remaining homes to a minimum of 75% high efficiency lighting is recommended. Additionally, old dishwashers, refrigerators and clothes washers should be replaced by ENERGY STAR certified products (the homes at Discovery Village and Miller Hill were built under version 2 of the Northwest ENERGY STAR Homes program which requires a minimum of 50% high efficiency lighting as well as an ENERGY STAR dishwasher.)

The Beachwood, New Hillside and Davis Hill developments were all very similar in home plan design and specification, with almost identical conditioned floor areas (CFA). Evergreen homes predominately have two bedrooms with greater CFA than the three bedroom Beachwood, New Hillside and Davis Hill homes. Broadmoor and Discovery Village/Miller Hill homes varied the most in size, floor plan and specification from other housing types in their respective developments and from the all other housing types in the study.

In general, most homes had minimal attic insulation, at or about R-15. The insulation that was present was typically in poor condition with large areas of compression and incomplete and uneven coverage (See Figure 9).

Figure 9. Attic insulation in two different plan types showing compressed and inconsistent fill

Ceilings were also found to be have compromised air barriers with poor or no air sealing around penetrations such as bathroom exhaust fans. (See Figure 10 – note light from bathroom below showing gap between sheetrock and fan [see arrow].) The only exceptions are the homes in the Discovery Village/Miller Hill communities which are insulated to R-38 with intact air barriers.

Figure 10. Bathroom exhaust fan installation showing significantly compromised air and thermal barrier

All homes, except for those in the Discovery Village and Miller Hill developments, would see significant improvement in occupant comfort and energy efficiency if ceilings are air sealed and insulated to a minimum of R-38; ideally to R-49. Air sealing must be performed in conjunction with the addition of insulation. This will likely require existing insulation be removed in order to effectively seal at all penetrations of the ceiling and at all framing and sheet rock junctions.

Wall insulation was found to be present in all homes except for those in the Broadmoor development (Equity staff informed researchers that the Broadmoor homes never had insulated walls. Researchers did not physically inspect the wall cavities, or perform infrared scans to confirm this, but the homes' age, along with their higher overall energy use, gave researchers no cause to doubt that assertion.) Wall insulation was installed as a retrofit measure over 20 years ago at the New Hillside, Davis Hill and Beachwood communities. Evergreen received batt insulation (estimated R-11) in the walls at time of construction. Installation quality and effectiveness is unknown for these four developments. The small percentage of homes built in these developments post the 1991 Washington State Energy Code are assumed to have been built to current energy codes, with R-19 to R-21 walls.

It is strongly suggested that the homes in the Broadmoor development receive wall insulation when major interior renovation is done. This will most effectively be achieved by dense packing the walls from the interior in the historic Broadmoor homes. The 1960s vintage homes have a mixture of brick and wood panel siding and would be easier to insulate from the exterior when major repainting or re-siding is planned for those homes.

Figure 11a. Newer (1960s) Broadmoor home

Figure 11b. Historic (1930s) Broadmoor home

All homes in the Evergreen, Beachwood, Davis Hill and New Hillside developments are built on uninsulated slabs. The homes in the historic Broadmoor development have uninsulated floors over unconditioned basements. There are ten homes in the new portion of the Broadmoor development with uninsulated floors over semi-conditioned and unvented crawl spaces. Floor assemblies in the Discovery Village/Miller Hill developments are located over ventilated crawlspaces and are insulated to R-30.

Since it is fairly cost prohibitive to insulate on-grade slabs post construction, there is no recommendation to insulate homes built on slabs at this time. Where floors are built over unconditioned basements or crawl spaces, there are opportunities to add floor insulation. The older Broadmoor homes are built over unconditioned basements and would benefit from floor insulation. However, the floor above the basement is unconventional (joists over concrete) and may prove very difficult to insulate effectively without significant damage to recently refinished hardwood floors. The 10 homes in Broadmoor that were built in the 1960s could be air sealed at the floor and insulated to R-30. If the floor is insulated, the crawlspace would need to be ventilated to code requirements. Another option is to air seal and insulate the rim joist and stem wall to current code specifications. In either case, a vapor barrier should be installed to cover the crawlspace slab.

Figure 12. Foundation of newer (1960s) Broadmoor home

Windows in all developments but Evergreen and Broadmoor were typically multi-paned and vinyl framed. Evergreen and the newer homes in the Broadmoor development had aluminum framed double paned windows; a few had site-built ¼" double paned stopped in insulated glass units as fixed picture windows. The majority of the windows in the historic Broadmoor homes were original wood sash double hung single pane units; during renovation, the windows were repainted, but no additional air sealing was completed; testing found significant air leakage at all sash rails. A few double paned vinyl windows were installed in the non-historic portion of the structures.

Figure 13. Renovated single pane, double hung windows at historic Broadmoor home

At the next major renovation, all windows in homes of this study should be replaced with code compliant units (U-factors of .3 to .34.) Single pane glass in historic structures can be replaced by double-pane low-e glazing in the original sash. In addition, windows in the historic structures at Broadmoor should have effective weather seals installed at vertical and horizontal sash rails in the near term.

Performance testing of these homes showed that they all had very similar envelope infiltration rates, with all homes testing between 9.9 and 13.6 air changes per hour at 50 Pascals of depressurization (ACH_{50}); with average leakage of 11.9 ACH_{50}. Typical areas of leakage included (but were not limited to):

- Door and hatch weather seals
- Plumbing penetrations
- Light fixtures, switches and outlets
- Supply and return boot penetrations through exterior assemblies
- Aluminum and wood frame windows (where present)

Leakage rates for the Discovery Village/Miller Hill development averaged 4.14 ACH_{50} (17 homes tested). These rates are well below the ENERGY STAR target leakage of 7.0 ACH_{50}.

Figure 14a. Blower door testing

Figure 14b. Typical air barrier deficiencies

Air sealing measures should be implemented in all homes with assumed infiltration greater than 7.0 ACH_{50}, which is the MVL used in the Pacific Northwest and in this study. Air sealing should focus on all penetrations to the exterior and junctions of sheetrock and framing. This work should be performed by qualified and properly equipped technicians and include a robust quality control protocol. Ideally the protocol would include visual and diagnostic inspections including infrared thermography, and blower door testing.

Duct testing produced significantly varying results but was not directly attributable to any specific system design or vintage. Duct leakage rates to the exterior at 50 Pascals of pressurization varied from 6.9% to 39.7% of the conditioned floor area (CFA) for all homes in the study except for Discovery Village/Miller Hill. Homes at Discovery Village/Miller Hill were tested as part of their Northwest ENERGY STAR Homes verification process and averaged 5% total system leakage (at 50 Pascals) relative to CFA.

Homes at Evergreen, Beachwood, Davis Hill and New Hillside had supply ducts installed in the unconditioned attic space. Supply plenums were uninsulated and unsealed metal with insulated flex duct attached to supply plenums with varying degrees of sealing and mechanical fastening. Return duct work was typically a through wall plenum or flex jumper type duct into the mechanical closet from a hall way. Returns were uninsulated with varying degrees of air sealing.

Figure 15a. Typical duct system

Figure 15b. Disconnected flex supply duct

All homes except those in the older Broadmoor development (non-ducted heating) and those in Discovery Village and Miller Hill (Northwest ENERGY STAR Homes) should have the duct work sealed and insulated. Sealing of duct work should be performed with mastic at all seams and joints in the system. Mechanical connection of flex duct work and plenum collars should be accomplished with cable ties using proper tensioning devices. All ductwork outside conditioned space should be insulated at a minimum to R-8. All duct sealing and insulation should be performed by qualified technicians with a robust quality control process.

In addition to energy performance observations and testing, ventilation system observations and testing was performed in most units audited. None of the homes contained whole house ventilation but, with few exceptions, were outfitted with source specific ventilation in the bathrooms and kitchens. Testing with a balometer identified significant variance in exhaust fan flow rates from home to home, from totally inoperable to 62 Cubic Feet per Minute (CFM). Typical flow rates were between 35 and 45 CFM for the main bathroom exhaust fans. Some units also contained fan/light combos in the shower enclosures. These fans were found to have flow rates between 21 and 28 CFM. Duct work was found to be R-4 insulated flex duct with variable installation quality. All bath fan system control strategies were accomplished with wall mounted on/off switches. Kitchen range hoods were present and functional in all homes however, flow rates were not tested.

It is recommended that all bathroom and kitchen exhaust fans be tested with a balometer or similar flow hood at time of occupant turnover to verify that fan flow rate is sufficient (50 CFM is code). Duct work should also be inspected at this time noting whether the duct work is mechanically fastened to the fan, sealed, and effectively vented to the outdoors. Presence of duct insulation should also be noted. Replacement of on/off switch controls in bathrooms with timers or motion sensors should also be considered, especially when envelope air sealing measures have been implemented in the home. Any replacement of bathroom exhaust fans should consider investment in higher efficiency, quieter technology with more sophisticated control strategies.

Any home air sealed below the minimum ventilation level (MVL) should have whole house ventilation installed. There are several strategies available to accomplish whole house ventilation. Various strategies should be investigated in order to maximize indoor air quality with minimum impact on energy consumption and occupant comfort. It is recommended that whole ventilation systems install follow ASHRAE 62.2 2010 guidelines.

One of the randomly audited homes in the Beachwood development had a radon mitigation system installed. Little information regarding the details and age of this system was found. It was observed to be installed in the slab and designed to power vent to the outside through the roof. However the mechanical connection at the fan and vent flue in the attic had failed. It is not known if there are other homes on the base with elevated radon levels or radon mitigation systems. Reconnection of the exhaust flue to the inline fan should be performed on this system.

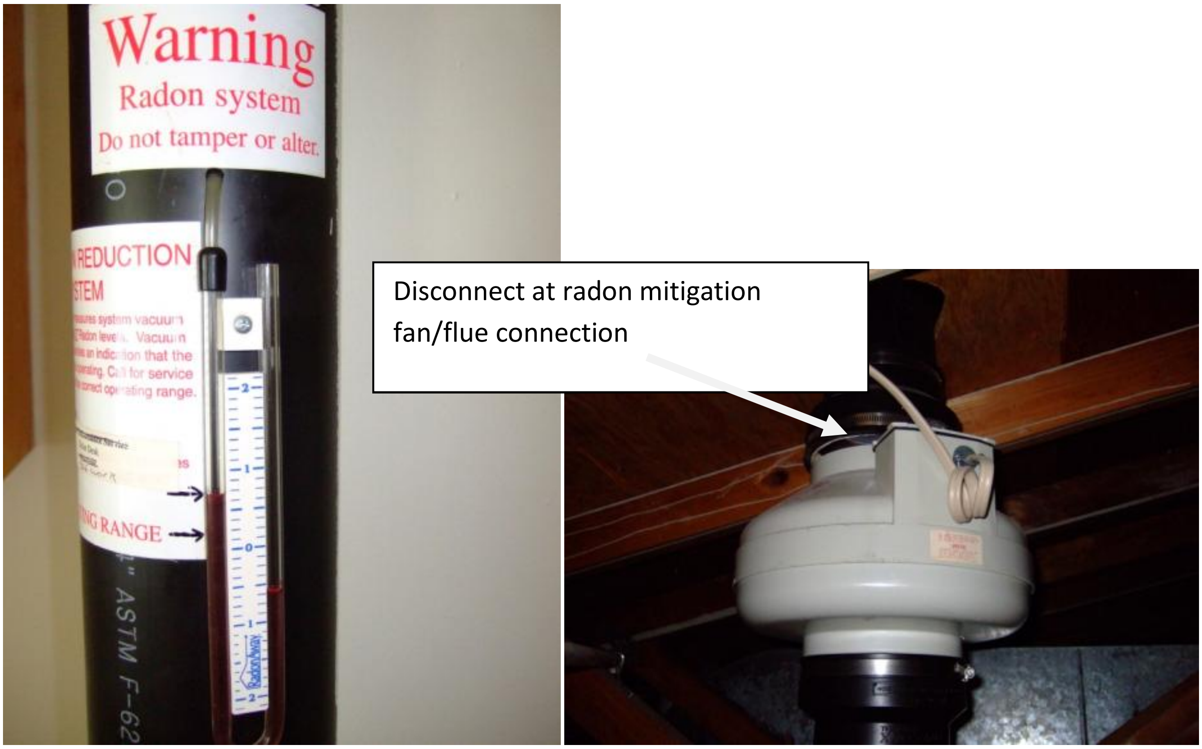

Figure 16. Radon mitigation system, Beachwood development

Additional investigation into radon presence and the number of radon mitigation systems on the base would be useful in identifying and determining what special precautions or prioritization should be placed on homes in terms of weatherization and indoor air quality. Existing radon mitigation systems should be repaired if necessary and placed into operation.

High Bill Complaints

Researchers accompanied Equity Residential maintenance staff on three high bill complaint site visits. These visits included audits of occupied homes and included an occupant survey. Researchers also audited one unoccupied home in the Parkway development prior to window replacement and repeated the blower door test about a month later, post window replacement.

High bill complaint audits were completed in the communities of Beachwood, New Hillside and Discovery Village. These audits were triggered by either occupant inquiry or by Equity Residential's observation of high energy use.

The results of the audits and testing of these homes were very similar to those on the unoccupied homes, with identical insulation levels and window types. Infiltration rates for the homes tested in Beachwood, New Hillside and Discovery Village were within 5% of the average test result. Parkway was the exception. The building design at Parkway was most similar to that of the historic homes in the Broadmoor development; unlike Broadmoor, there has not been significant recent renovation. The blower door result prior to scheduled window replacement was 18.75 ACH_{50}. A post window retrofit test showed a reduction of 18.4%.

Duct testing results for the Discovery Village home was below the Northwest ENERGY STAR Homes specification of 6% of conditioned floor area at 50 Pascals. For the three other homes the leakage rate was higher than the average for all housing types tested within this study. At the Beachwood home researchers found a partially disconnected duct after an initial test had been performed. The duct was reattached by Equity staff and the duct system retested. Results from the retest showed a leakage rate reduction of 70 cfm. The New hillside and Parkway homes showed even more significant duct leakage; however, no obvious disconnects or system deficiencies were identified.

In all but one case (Beachwood), results from the occupant survey showed that occupant behavior was at least partially to blame for perceived and real high energy use concerns. Performance testing supports the conclusion that in all but one case, Discovery Village, duct system leakage is also a significant contributor to higher than average energy use in these homes. In addition, pre and post window retrofit whole house infiltration rates at the Parkway home illustrate the envelope leakage rates are a significant contributor to the home's poor energy performance. The pre and post window retrofit testing also demonstrates the impact modern, weatherized windows have on reducing air whole house infiltration rates.

The results from the audits on these homes support the recommendations based on the unoccupied home audits. Air sealing of both the envelope and the duct system should be the highest priority, and together with increasing insulation in attics.

Additionally, recommendations for the Parkway development go beyond those previously made for homes included in this study. The Parkway homes are built over unconditioned basements containing uninsulated and unsealed metal ducts within an exposed, uninsulated framed floor. Significant effort should be made to air seal and insulate the floor to R-30. Ducts in these homes are much more accessible than homes with ducts in the attics, and should be considered a high priority for renovation.

Modeling Results

Utilizing software programs to model the energy usage of a given building serves a number of functions. It helps identify areas of potentially high energy use and, in some cases, allows identification of cost-effective, energy efficient design and system alternatives. In addition, using modeling programs further refines their accuracy through feedback to the software developers. The utility bills provided the basis to compare actual energy consumption versus predicted energy consumption. Matching the modeling with the billing analysis and the audits provides the means to establish which houses are the most energy efficient and why. With this information in hand, JBLM and Equity Residential will be better situated to make well-informed decisions when tasked with retrofitting buildings as well as when designing new construction.

Using *only* models to predict the energy usage of an existing, occupied house must be approached with some caution. The models calculate what *should* be the gas or electric usage in this house under steady, relatively static conditions. When used alongside other analysis approaches, such as utility bill analysis, the models are a helpful asset.

Overall, the models are useful tools when gauging the behavior of an unoccupied building under a given set of conditions, providing a geometric rendering of the building, specific breakdowns of how the building uses energy and the type of energy being used, adjusted for local climatological factors.

BEOPT and SIMPLE

BEopt

BEopt is a software program developed by the National Renewable Energy Laboratory (NREL) to find "optimal building designs along the path to highly efficient buildings". BEopt provides users with features applicable to both new home construction and retrofitting of existing homes, including structural properties and characteristics, market inputs such as utility rates and mortgage information, and fuel types and their respective costs. BEopt possesses a large variety of options with which to customize a representative model and is constructed to calculate energy usage through integrated calculations and formulas. It is designed to allow analysis of the energy use of various components, in order to optimize the most cost-effective features.

A suggested improvement in BEopt would be to provide a menu of financial indices for each measure, such as levelized cost of units of energy saved and life cycle cost/benefit/ in addition to ROI.

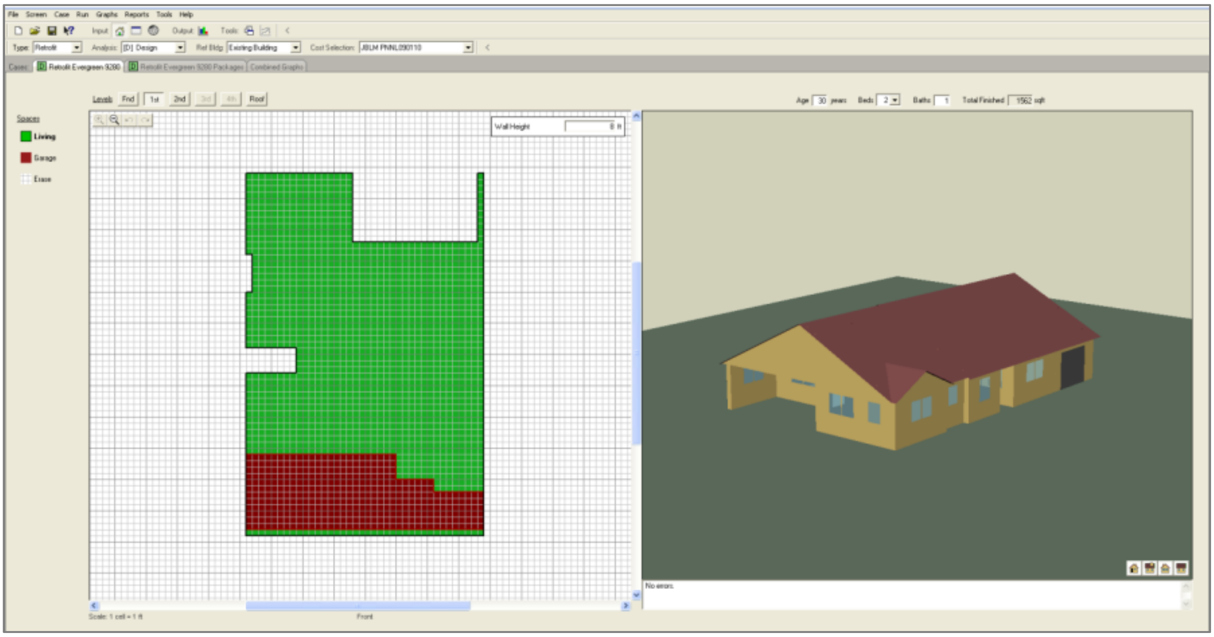

Figure 17. BEopt entry screen, featuring the unit Evergreen 9280

Within BEopt, a base case model was created for each audited house; inputs were determined using results from the field audits, as well as from data sent by Equity Residential. Individual retrofit measures were then developed, to compare predicted energy use for each design. Finally, packages of retrofit measures were developed to compare against the base case. Modeling the retrofit measures in this fashion enables the user to compare the benefits of each measure, both in terms of energy use and in cost savings to the consumer.

SIMPLE

SIMPLE is a spreadsheet designed by Michael Blasnik that allows the input of qualitative data to generate the estimated energy use for the house in question. The values given to the qualitative entries are drawn from extensive analyses of energy consumption from all over the country, and represent averaged values of those described inputs. For example, instead of assigning a specific R-value to wall insulation, walls are described as “no insulation, partial/semi insulation, standard insulation, good insulation, very good/foam”. Should the user desire to enter specific values or parameters for the house, such as air leakage measurements, SIMPLE provides the user with the ability to override the standard values.

SIMPLE analysis is based on pre-calculated results from hourly modeling, using TMY2 weather files, and is designed to quickly compare an existing house with a proposed house. Once all parameters are entered, SIMPLE generates Annual Usage Estimates for both homes, broken into Heating, Water Heating, Cooling, and All Else, for natural gas and electricity.

	A	B	C	D	E	F	G
1	**Simplified Home Energy Usage Estimation Tool**						
2	v 0.9.8 © M. Blasnik 4/6/11 - Olympia WA weather station only						
3			- Data entry in yellow cells only, lower table allows optional overriding of defaults				
4		Current Home		Proposed Home		Estimated Savings	
5	**Annual Usage Estimates**	Gas	Electric	Gas	Electric	Fossil	Electric
6	Heating	697	0	1189	0	-491	0
7	Water Heating	162			6378	162	-6378
8	Cooling		0		0	0	0
9	All Else	22	5586	0	9046	22	-3461
10	Total Usage	882	5586	1189	15424	-307	-9839
11		therms	kWh/yr	therms	kwh/yr		
12	secondary heating use	0		0			
13							
14	Weather Station	WA_OLYMPIA					
15			Copy Current Home				
16	**House Characteristic**	**Current Home**	**Proposed Home**		**Occupancy & Behavior**		
17	Finished floor area (above grd	1560	2424		Occupants, if kn	2	6
18	Stories	1	2		Heating Setpoint	70	68
19	Bedrooms	2	4		Cooling Setpoint	76	76
20	Primary Heating Fuel	Gas	Gas		Lighting hours/d	Average	Average
21	Heating System Type	High Efficiency	Older		Shower Use (tin	Average	Average
22	Heat Distribution Type	Forced Air / Ducts	Boiler / Radiators		Clothes Dryer Us	Avg	Avg
23	Wall Insulation	Std Ins	Std Ins		Laundry Use (H	Average	Average
24	Attic Insulation	Some Ins	Some Ins		Other Hot Water	Average	Average
25	Window Type	Single	Single				
26	Window Area	Typical	High		**Secondary Systems & Components**		
27	Air Tightness	Average	Leaky		Secondary Heat	None	None
28	Foundation Type	Slab	Basement		Secondary heat	0%	0%
29	Foundation Insulation	None	None		Wall Type 2	Std Ins	Std Ins
30	Ducts: % in Attic	95%	0%		Wall Type 2 - %	0%	0%
31	Ducts: % in Slab	0%	0%		Attic Type 2	Some Ins	Some Ins
32	Duct Leakiness	Leaky	Leaky		Attic Type 2 - %	0%	0%
33	Duct Insulation	Std (R-4)	None		Window type 2	Dbl/Sgl&Storm	Dbl/Sgl&Storm
34	**Cooling Info**				Window Type -	0%	0%
35	AC SEER (none=0)	0	0				
36	Window Shading	Typical	Typical				
37	Cool Roof / Rad. Barrier rafter	Std Color	Std Color				
38	**Water Heating Info**						
39	Water Heater Fuel	Gas	Electric				
40	Water Heater Type	Standard	Standard				
41	Hot Water Fixture Efficiency	Average	Average				
42	**All Else Info**						
43	Lighting Efficiency (W/sqft)	Average	Average				
44	Primary refrigerator	Average	Average				
45	Extra Refrigerators / Freezers	None	None				
46	Entertainment (TVs & PCs)	Average	Average				
47	# Other Large Uses (500 kWh	0	0				
48	Other Plug Loads	Average	Average				
49	Clothes Dryer Fuel	Electric	Electric				
50	Cooking Fuel	Gas	Electric				

Figure 18. SIMPLE data entry screen

Models and Actual Energy Consumption Comparisons

Twelve simulations were run in each modeling program, using the physical parameters from the case studies as structural and environmental inputs[3]. The results of the model results for the houses described in the case studies were compared against actual energy usage for individual homes, and aggregate community performance, gathered through utility billing analysis.

This method must be approached with caution, as the modeling software simulates energy use across a variety of circumstances. With that caveat, when comparing actual energy use of the homes in the study, SIMPLE tended to underestimate energy use, while BEopt tended to overestimate. BEopt estimated higher energy use than SIMPLE in a majority of cases.

[3] Occupancy was modeled per Building America default assumptions, not occupancy patterns in the actual homes.

Energy Usage in MMBtus				Percent Difference With Utility Billing	
Community	**Utility Billing**	**SIMPLE**	**BEopt**	**SIMPLE**	**BEopt**
Beachwood					
unit 8450	66.2	80.60	106.5	22%	61%
unit 8636	106.6	99.64	101.7	-7%	-5%
New Hillside					
unit 6759	118.1	87.68	112.7	-26%	-5%
unit 6768	144.3	80.66	103.9	-44%	-28%
Davis Hill					
unit 5428	91.1	85.25	108.4	-6%	19%
unit 5959	119.5	98.65	131.2	-17%	10%
Evergreen I					
unit 9280	78.6	110.76	81.9	41%	4%
unit 9290	90.9	105.92	139.5	17%	53%
Broadmoor					
Historic, 2309	209.4	186.65	238	-11%	14%
Historic, 2351	278.7	198.82	236	-29%	-15%
unit 2651	102.9	96.49	208.2	-6%	102%
unit 2652	90.8	95.79	152.0	5%	67%

Table 12. Results of SIMPLE and BEopt vs. Billing for Field Test Homes

An alternative measure of the modeling program's accuracy is found through comparing a modeled house against the aggregate community energy usage. This helps moderate fluctuations originating from occupant behavior. When compared against the community mean energy use, the percent deviation is considerably reduced. Broadmoor is not included in this comparison, because of the diverse construction and housing types including single and multi-family. These subcategories were too small to analyze separately and the multi-family units had common meters, causing the mean to lack definitive representation of any particular unit's energy use. Thus comparison of the estimated energy use of individual units against this mean is not helpful and was not included in Table 13.

Communities with Electric Water Heat	Mean Energy Use in MMBtus	Unit Number	SIMPLE Projections in MMBtus and %	BEopt Projections in MMBtus and %
Beachwood	86.8	8450	80.6 (-7%)	106.5 (22.7%)
		8636	99.6 (15%)	101.7 (17%)
New Hillside	97.7	6759	87.7 (-10%)	112.7 (15%)
		6768	80.7 (-17%)	103.8 (6%)
Davis Hill	91.5	5428	85.3 (-7%)	108.4 (18%)
Communities with Natural Gas Water Heat	Mean Energy Use in MMBtus	Unit Number	SIMPLE Projections in MMBtus and %	BEopt Projections in MMBtus and %
Davis Hill	105.9	5959	98.7 (-7%)	131.2 (24%)
Evergreen I	96.7	9280	110.8 (15%)	81.9 (-15%)
		9290	105.9 (10%)	139.5 (44%)

Table 13. % Deviation of SIMPLE and BEopt from Community Mean Energy Usage

Energy Retrofit Analysis

To conduct the analysis, individual retrofit measures and packaged measures were analyzed for cost and energy reduction. The individual measures included:

- Improve HVAC ductwork on existing .90 AFUE gas furnaces
- Complete comprehensive building envelope air sealing, to three distinct targets:
- Air sealing to 150% of MVL[4]
- Air sealing to 100% of MVL
- Air sealing to 50% of MVL, with the additional installation of an ASHRAE 62.2 compliant ventilation system
- Increase ceiling insulation from R15 to R49
- Conversion of older electric tank water heaters to tankless gas, and tankless condensing water heaters when electricity rates warrant.

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[4] The MVL or Minimum Ventilation Level is 7 ACH Pa, meaning that if the home's air leakage rate is lower than this, then mechanical whole house ventilation must be added. The only option considered that would trigger this requirement is to reduce leakage to 50% of MVL.

In addition to these individual measures, three packages were created:

A. Improve HVAC ductwork; Air sealing to 150% of MVL; and Ceiling from R15 to R49

B. Improve HVAC ductwork; Air sealing to 100% of MVL; and Ceiling from R15 to R49

C. Improve HVAC ductwork; Air sealing to 50% of MVL; and Ceiling from R15 to R49

The analysis suggests (that) three measures, air sealing, improving ductwork, and increasing attic insulation to R-49 produce the greatest energy savings for the lowest price. In comparing the modeled savings, it is important to note that while the Washington State mean residential retail rates for electricity and natural gas are \$0.08/kWh and \$15.49/1,000 ft^3 of natural gas, JBLM purchases electricity at a \$0.042/kWh and natural gas at \$9.86/1,000 ft^3. The JBLM electric rate is negotiated with the provider and requires consent by JBLM to raise it. The state mean residential rate for electricity was used to provide a more universal picture of the costs and benefits of the efficiency measures related to electricity, while the JBLM price was used for natural gas, because it is a Washington Utility and Trade Commission reviewed and approved rate closer to the mean. Also, the cost of measures 5a and 5b for water heaters are installed prices, but the incremental cost above the cost of standard gas and electric water heaters was used in the analysis. Table 15 shows the results of the BEopt analysis for all three packages in all communities including Broadmoor.

Measure	Cost	Cost Estimate Compiled From[5]:
1) Improve Ductwork	$1.10/sq. ft. of duct surface area	KCHA[6]
2a) Air sealing to 10.5 ACH50	$75 per 100 CFM50 reduction from existing to 150% MVL	KCHA
2b) Air sealing to 7.1 ACH50	$100 per 100 CFM50 reduction from 150% MVL to 100% MVL	KCHA
2c) Air sealing to 3.5 ACH50 with mechanical vent. to 100%/62.2	$125 per 100 CFM50 reduction from 100% MVL to 50% MVL + $300 for mechanical ventilation	KCHA
3) Ceiling insulation R15 to R49	$1.23/ sq. ft.	KCHA
4a) Upgrade from gas standard DHW to Gas Tankless water heater	$1,138 (incremental)	EQR
4b) Upgrade from gas standard DHW to Gas Tankless, condensing water heater	$1,350 (incremental)	EQR
5a) Upgrade from electric standard DHW to Gas Tankless water heater	$1,278 (incremental)	EQR
5b) Upgrade from electric standard DHW to Gas Tankless, condensing water heater	$1,490 (incremental)	EQR
PACKAGE A: measures 1, 2a, 3	$2.33/ sq. ft. +$75 per 100 CFM50 reduction from existing to 150% MVL	KCHA
PACKAGE B: measures 1, 2b, 3	$2.33/ sq. ft. +$100 per 100 CFM50 reduction from existing to 100% MVL	KCHA
PACKAGE C: 2measures 1, 2c, 3	$2.33/ sq. ft. +$125 per 100 CFM50 reduction from existing to 50% MVL + $300 for mechanical ventilation	KCHA

Table 14. Cost Estimates of Each Retrofit Measure

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[5] KCHA – King County Housing Authority. EQR – Equity Residential. Cost data was obtained from these two local entities, rather than the NREL National Measures database, because they were believed to be more relevant to the analysis.

[6] KCHA has pioneered advanced energy retrofits in public housing, and is partnering in a Building America study with WSU through the Florida Solar Energy Center. Results will be available in the second quarter, 2012. The $1.10 value per square foot of duct area is based on KCHA's flat rate of $450 per house.

AVERAGE ESTIMATED	PACKAGE A: 2, 3a, 4	PACKAGE B: 2, 3b, 4	PACKAGE C: 2, 3c, 4
Site Energy Savings in MMbtus/year	17.9	24.8	26.4
Site Energy Savings in $/year (gas + elec.)	$181.02	$250.32	$262.33
Cost per measure	$2,062.29	$2,632.14	$3,890.47
Simple payback in years =	11.4	10.5	14.8
Monthly savings in $ =	$15.09	$20.86	$21.86
Monthly cost at 7% over 30yrs=	$14.44	$18.42	$27.23
Monthly Cash Flow at 7% over 30yrs	$0.65	$2.44	-$5.37
Monthly cost at 4% over 30yrs	$9.84	$12.57	$18.57
Monthly Cash Flow at 4% over 30yrs	$5.25	$8.29	$3.29

Table 15. BEOPT analysis of retrofit measures

These results incorporate default assumptions within BEopt; including a 1% fuel cost escalation rate, and a mortgage tax deduction. The mortgage cost assumption may not apply to Equity Residential's purchasing of retrofit measures. While the fuel cost escalation rate is editable within BEopt, the mortgage tax deduction is apparently not. Researchers decided to present the results from Table 14 as if the packages were being financed by a homeowner on the open market, instead of by Equity Residential, which has a unique situation.

Tables 15, 16a and 16b show the results of researchers' calculated results of retrofit analysis, based on the site energy savings generated by BEopt for all the communities. Table 15 shows all communities averaged together. Table 16a shows results for all communities except Broadmoor. Table 16b shows only Broadmoor. The research team separted the results because of the diversity in construction and air leakage of the Broadmoor sample as these features significantly impact the analysis. Because of them it was difficult to analyze Package A for this community in BEopt, so it is not included in Table 16b.

As Table 16a indicates, packages A and B possess strong potential to provide a good return on investment in the non Broadmoor communities in a reasonable amount of time, given financing at 4% interest rate. While package C provides the highest degree of energy efficiency, it also included the installation of mechanical ventilation to meet the household exhaust requirement of ASHRAE 62.2. The addition of mechanical ventilation and the higher price per square foot of air sealing a house to 3.5 ACH_{50} produces greater costs and requires longer periods for payback with package C.

AVERAGE ESTIMATED	PACKAGE A: 2, 3a, 4	PACKAGE B: 2, 3b, 4	PACKAGE C: 2, 3c, 4
Site Energy Savings in MMbtus/year	17.9	22.7	18.1
Site Energy Savings in $/year (gas + elec.)	$181.02	$229.55	$179.86
Cost per measure	$2,062.29	$2,663.70	$3,682.45
Simple payback in years =	11.4	11.6	20.5
Monthly savings in $ =	$15.09	$19.13	$14.99
Monthly cost at 7% over 30yrs=	$14.44	$18.65	$25.78
Monthly Cash Flow at 7% over 30yrs	$0.65	$0.48	-$10.79
Monthly cost at 4% over 30yrs	$9.85	$12.71	$17.58
Monthly Cash Flow at 4% over 30yrs	$5.24	$6.42	-$2.59

Table 16a. BEopt Analysis of Measures without Broadmoor Community

AVERAGE ESTIMATED	PACKAGE B: 2, 3b, 4	PACKAGE C: 2, 3c, 4
Site Energy Savings in MMbtus/year	32.2	44.5
Site Energy Savings in $/year (gas + elec.)	$322.93	$442.82
Cost per measure	$2,569.03	$4,306.53
Simple payback in years =	8.0	9.7
Monthly savings in $ =	$26.91	$36.90
Monthly cost at 7% over 30yrs=	$17.98	$30.15
Monthly Cash Flow at 7% over 30yrs	-$2.32	$0.69
Monthly cost at 4% over 30yrs	$12.26	$20.56
Monthly Cash Flow at 4% over 30yrs	$14.65	$16.34

Table 16b. BEopt Analysis of Measures for Broadmoor Alone[7]

In Broadmoor, packages B and C are shown by the results in Table 16b to be cost effective. In addition, it is important to note that wall insulation was not included in the Broadmoor

[7] Broadmoor homes are larger than those in the other communities, and include several multi-family buildings. Thus the retrofit costs are higher, and, even though the savings are greater, the payback is not necessarily shorter.

package, because it was not part of the packages analyzed for the rest of the communities, and an apples-to-apples comparison was desired. It is a cost-effective retrofit measure as shown by the robust rate of return in Table 17.

The cost effectiveness of individual measures is widely varied. BEopt provides a modified rate of return (ROI) using the consumer investment return rate as the discount rate. These (ROI) are calculated using the discounted savings value over the life of the measure, and provide a relative ranking of the cost-effectiveness of the investment.

Table 17 shows BEopt's modified ROI for each of the measures in the packages and special measures, such as insulation of the historic Broadmoor walls. In addition the ROI for the packages are listed at the bottom of the table. There is diversity in the ROI for many of the measures between the other communities and Broadmoor. This can only be said to be a function of the different buildings and BEopt. For this reason, it is recommended that these ROI not be seen as actual economic values, but as relative indicators of the value of various measures in comparison to one another for either the aggregated communities or Broadmoor. It is probably not fruitful to compare values from these two categories.

It should be noted that the ceiling insulation upgrade in Broadmoor assumes a higher initial insulation level, providing a reduced ROI. The researchers did find ten homes in Broadmoor built between 1959 and 1963 that probably have little to no ceiling insulation. These are not factored into the values in Table 17, but would undoubtedly see a much higher ROI than the other homes in Broadmoor[8].

[8] The savings calculated by BEopt in these cases was 116 therms per year, compared to 76 therms for the Broadmoor homes listed in the table. The cost would be only slightly higher, but the savings would increase over 50%.

Beachwood, D. Hill, N. Hillside, Evergreen		Broadmoor	
Measure	**Average**	**Measure**	**Average**
1) Improve Ductwork	13.55	1) - Ductwork - tight to 10%	9.75
2a - Air Infiltration to 150% BAS/MVL, 10.5 ACH50	22.88	1b) - Dense-pack wall insulation	12.75
2b - Air Infiltration to 100% BAS/MVL, 7 ACH50	9.55	2b - Air Infiltration to 100% BAS/MVL, 7 ACH50	15.75
2c - Air Infiltration to 50% BAS/MVL, 3.5 ACH50	(3.50)	2c - Air Infiltration to 50% BAS/MVL, 3.5 ACH50	20.05
3) Ceiling insulation R15 to R49	6.05	3) Ceiling insulation R25 to R49	5.38
4a) Upgrade from gas standard DHW to Gas Tankless water heater	4.61	4a) Upgrade from gas standard DHW to Gas Tankless water heater	4.20
4b) Upgrade from gas standard DHW to Gas Tankless, condensing water heater	4.36	4b) Upgrade from gas standard DHW to Gas Tankless, condensing water heater	4.40
5a) Upgrade from electric standard DHW to Gas Tankless water heater	4.18	5a) Upgrade from electric standard DHW to Gas Tankless water heater	2.75
5b) Upgrade from electric standard DHW to Gas Tankless, condensing water heater	4.24	5b) Upgrade from electric standard DHW to Gas Tankless, condensing water heater	3.10
Package A)	12.26	Package A)	N/A
Package B)	8.61	Package B)	9.78
Package C)	6.44	Package C)	10.88

Table 17. BEopt Rates of Return on Investment for Individual Measures

Findings and Recommendations

Finding	Recommendation
High-efficiency furnaces have been installed in many units with very leaky, uninsulated duct systems. The overall leakage to the exterior in the homes tested ranges from 6.9 to 39.7% of conditioned floor area, with most result tending toward the higher end. This indicates that 20 to 30% of the heated air is being wasted. In addition, leaky ducts create risk of differential pressures that can back draft combustion appliances.	Seal and insulate duct systems in all homes but Broadmoor homes with hydronic systems and the ENERGY STAR homes in Discovery Village and Miller Hill. For large developments of similar type homes, the Pacific Northwest has developed programs that seal all ducts in a systematic and cost-effective fashion.
All tested units besides the ENERGY STAR homes have high air leakage rates. This increases energy use, decreases comfort and adds to pressure differentials that can back draft appliances.	Apply air sealing using skilled, equipped specialists and quality control. -Areas to be sealed include attics, floors, rim joists in basements, window frames, chimneys, plumbing and electrical penetrations, hatches, doorways, and lighting fixtures.
Ceilings throughout the base are insulated to R-15 that is uneven and not in good condition in most locations. This is significantly below cost-effective levels, wastes energy and decreases comfort.	Seal the ceiling plane, and install insulation to a nominal (full depth where possible) R-49. Removing the existing insulation prior to sealing should be considered for several reasons: 1) it is not providing much insulation; 2) in places the insulation appears to be filled with material from filtering leaked air; and 3) in some cases the leaks in the ceiling plane can be properly sealed only after removing the insulation.

Finding	Recommendation
Guidelines from Washington's State Historic Preservation Office (SPHO) restrict the implementation of energy efficiency upgrades. • **Walls in the Broadmoor homes are uninsulated.** • **Windows in the historic Broadmoor homes are single-pane, double-hung wood with no weather-strip. use three to five times the space heat of any other gas heated homes on the base.**	Work with SPHO to implement guidelines that allow for historic preservation, while addressing necessary energy concerns, including: • As feasible, insulate walls with dense pack insulation the next time interior renovations are done. • In the near term, weather-strip should be installed around the movable sash and at the middle rail. In the long term, double pane low-e glass units can replace single pane glass.
Most units have recently installed fairly efficient gas and electric water heaters. Unfortunately, there are significantly more energy efficient technologies now available.	Develop a strategic plan for water heater replacement with high efficiency units during the normal replacement cycle. If a unit has a natural gas water heater, upgrade to a tankless demand heater if the service allows. If not, upgrade to a condensing tank natural gas water heater.
Most lighting throughout the base is CFL, except at the historic Broadmoor and the Evergreen homes which have incandescent lamps. Compact fluorescent lamps use two-thirds less electricity than the incandescent they replace.	Install CFLs in at least 75% of the sockets in historic Broadmoor and Evergreen. For classic fixtures with dimming capability, consider LED lamps.

Finding	Recommendation
Testing with a balometer identified significant variance in exhaust fan flow rates from home to home, from totally inoperable to 62 Cubic Feet per Minute (CFM). Typical flow rates were between 35 and 45 CFM for the main bathroom exhaust fans. Some units also contained fan/light combos in the shower enclosures. These fans were found to have flow rates between 21 and 28 CFM.	All bathroom and kitchen exhaust fans be tested with a balometer or similar flow hood at time of occupant turnover to verify that fan flow rate is sufficient (50 CFM is code). Duct work should also be inspected at this time noting whether the duct work is mechanically fastened to the fan, sealed, and effectively vented to the outdoors. Presence of duct insulation should also be noted. Replacement of on/off switch controls in bathrooms with timers or motion sensors should also be considered, especially when envelope air sealing measures have been implemented in the home. Any replacement of bathroom exhaust fans should consider investment in higher efficiency, quieter technology with more sophisticated control strategies.
The radon mitigation system found in one home was not working. Little information regarding the details and age of this system was found. It was observed to be installed in the slab and designed to power vent to the outside through the roof. The mechanical connection at the fan and vent flue in the attic had failed. It is not known if there are other homes on the base with elevated radon levels or radon mitigation systems.	Additional investigation into radon and radon mitigation systems on the base would be useful in identifying and determining what special precautions or prioritization should be placed on homes in terms of weatherization and indoor air quality. Generally, it is recommended that the EPA's Healthy Indoor Environment Protocols for Home Energy Upgrade be followed as part of house tightening. Where systems are already installed, they should be restored to working condition if necessary and operated.

Finding	Recommendation
ENERGY STAR homes use significantly less energy than any other homes on the base, and the standard has become more stringent since the new homes analyzed in this study.	Continue the policy of purchasing ENERGY STAR homes. The efficiency, comfort and safety are important to our service men and women and their families. And the new specification includes features that ensure the long-term durability of the homes that reduces long-term maintenance cost.

Opportunities for Future Research

- Where electric water heater service is already in place, and it is prohibitively expensive or unfeasible to expand service for a gas water heater, heat pump water heaters should be explored as an option. As noted above, NEEA has developed a set of tiered efficiency and installation standards (Northern Climate Specification) that is recommended to obtain maximum performance from these units. Performance modeling of heat pump water heaters in the context of natural gas heating could be easily done given data and models developed for this project together with research done by Bonneville Power Administration and NEEA on heat pump water heater performance.
- Establish retrofit specifications for re-insulation, air leakage, window retrofit, and other measures and develop a quality assurance protocol to ensure measures are properly installed. All bids specifications for retrofit work would include such specifications and protocol. The newly revised Bonneville Power Administration weatherization specifications would be considered as a starting place.
- Research patterns of energy use and means to educate occupants to reduce energy use. Non-intrusive end use monitors could be placed in representative units to research energy use patterns. Possible means for reducing use include feedback devices, incentive programs, competition, and on-base marketing
- Research pre and post weatherization performance of units to which specific recommended packages are applied. This would provide case study guidance to future retrofits at JBLM, as well as be applicable to other bases located in heating climates.
- Broadmoor uses the most heating energy of any of the developments studied. Further energy auditing investigations in this development are indicated to develop a more accurate analysis of potential savings and how to achieve them. Specialists in retrofitting of historic structures could be consulted.
- Research, plan and conduct a deep energy retrofit pilot to develop and demonstrate the next phase of rehabilitation at JBLM. Over the long term, retrofit is taking the direction of significantly reducing energy use. This kind of project would design, implement and document the results of following this opportunity.
- Research the modeled energy savings and cost benefits of implementing all package measures at a community-wide or base-wide level to demonstrate the cost-effectiveness of large-scale retrofit efforts. If the suggested measures were indeed implemented on a large scale at JBLM, a utility billing analysis could be implemented to document achieved energy savings and calibrate the BEopt model.

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Appendix A – Case Studies for “typical” JBLM homes

Historic Broadmoor

- Four bedroom, three bathroom, 2-story single-family home with an unconditioned basement
- Naturally drafted gas boiler (.817 AFUE) supplying hydronic radiators
- Electric tank DHW, 0.91 EF
- 100% Incandescent lighting
- 10.51 and 10.56 ACH_{50} envelope air leakage

Audits were performed at 2309 and 2351 in the historic Broadmoor neighborhood. The homes in this neighborhood are two stories above grade with unconditioned basements and are considered historic structures (circa 1930s). The homes are stick-framed and clad with full brick exteriors. The homes are heated with radiators powered by new natural gas boilers. There are roughly 159 homes in historic Broadmoor of similar construction and specification.

The historic Broadmoor development is currently being renovated as tenant turnover occurs. Most of the renovation is cosmetic/aesthetic, however, significant restoration work is being done to the homes’ original single-pane wood double-hung windows; major appliances and mechanical equipment are also being replaced. Audits were performed in unoccupied homes post renovation.

2309 Broadmoor

This home is typical of Broadmoor’s historic neighborhood - four bedroom, three bath, and 2-story with an unconditioned basement and attached single car garage. The home is heated with free standing hydronic radiators fueled by a .817 AFUE gas boiler located in the basement. Domestic hot water is supplied by an electric tank-style water heater located in the basement. The home has source specific exhaust ventilation in two of the three baths, as well as above the range in the kitchen.

- Street view of typical historic Broadmoor single family home (c. 1931)
- Stick-framed 2X4 construction with full brick facade

- Alley view of typical historic Broadmoor single-family home (c. 1931)

Testing: Blower door test results showed the home's envelope leakage to be 10.5 ACH_{50}. This is roughly 10% lower than the average of all homes tested in this study but the home's specific leakage area is actually 10% higher than the average for the whole study.

Audit: Visual inspection showed the home's air barrier to be typical of most existing homes. The recently renovated wood windows had little or no weather stripping, doors and hatches were missing or had non-functioning weather stripping, and penetrations of the envelope for mechanical ventilation, outlets and lights were not sealed. In addition, this home also had a laundry chute to the basement that, while not operational, was not properly sealed; the home also had a fireplace with an operational flue, but no sealed doors. The laundry chute and fireplace were only present in the Broadmoor development.

Substantial (largely interior) renovations had just been completed, but without any apparent air sealing measures

The home had been recently upgraded with a few energy efficient vinyl-framed windows located in a 350 $ft.^2$ addition, but the majority of the windows were original single-pane with wood frames. The attic had been insulated over the years with a mixture of batts and blown material to R-25-30, grade III (per RESNET standards (RESNET, 2006)). Although the presence of exterior wall insulation was not confirmed, it is unlikely due to the time of construction and exterior brick façade. The floor separating the conditioned space from the unconditioned basement is a dimensional lumber structure (2X6 or 2X4) built on top of a suspended slab. This floor is assumed to be uninsulated.

The home had just received new ENERGY STAR appliances (refrigerator/freezer and dishwasher) and there was also an extra refrigerator/freezer located in the basement. All lighting was 60 Watt incandescent. Bath fans with built-in lights were located in two of the three bathrooms with flow rates of 39 and 36 CFM. The combination fan/light was controlled by an on/off switch. No evidence of excessive moisture was noted.

Analysis: Utility bill analysis showed this model of home to be the highest natural gas consumer in the study. Space conditioning is the primary use of natural gas in this model of home (range is also run on natural gas). This specific home was on the lower end of gas consumption relative to other homes built to the same floor plan and specifications but still had high consumption. Both homes audited in the historic Broadmoor development had new boilers that were not present during the billing analysis period of study. The efficiency of the boiler present during the period of billing analysis is unknown but could have had significant impact to the homes' overall energy performance. Despite the potential inefficiencies related to the previous mechanical equipment, this audit provides plenty of evidence to support an assumption that the home's high space heating costs are partly associated with an insufficient thermal and air barriers.

- Original double-hung, true divide light single-pane, wood framed windows.
- Windows had been restored, but sashes were not effectively sealed from air intrusion.

New vinyl Non-historic addition had been retrofitted with thermally efficient double- glazed vinyl windows in non-historic addition (sun porch)

- View through doorway leading to “sun porch” addition to conditioned space.
- Period appropriate lighting fixtures may inhibit use of high efficiency lamps.

Recommendations: Investment in air sealing of all penetrations in the exterior envelope of this home should help considerably in reducing the home’s space conditioning energy use. Specific attention should be paid to weather stripping all exterior doors/hatches and windows as well as air sealing all penetrations made by light fixtures, outlets/switches and exhaust fans, especially at the second floor ceiling. Rolling back or removing existing insulation in the attic to allow for air sealing should be pursued in order to maximize the thermal benefits of insulation.

Currently the installation quality of the attic insulation is poor and does not cover the bottom chord of the trusses. The existing insulation can be properly reinstalled after air sealing and an additional layer of insulation can be installed over the top, providing additional insulation and a thermal break over the bottom chord of the truss. Additionally, insulation strategies for the floor assembly between the conditioned space and the basement as well as insulating the exterior walls should be investigated. Insulating the walls and floor may prove difficult however and will likely not be as cost effective as attic insulation and air sealing.

Although these homes are of historical significance and alteration of exterior facades may be regulated by federal guidelines, interior alterations are rarely regulated. Therefore, replacement of all incandescent lighting with high efficiency lighting is recommended. The lighting load for this home can be cut by at least half by switching out each lamp with a compact fluorescent lamp (CFL) without the need to change the fixtures or degrade the quality of light. A 2700K “warm white” CFL is recommended to match the light quality emitted by common incandescent lamps.

Attic insulation showing typical mixture of insulation materials and installation deficiencies.

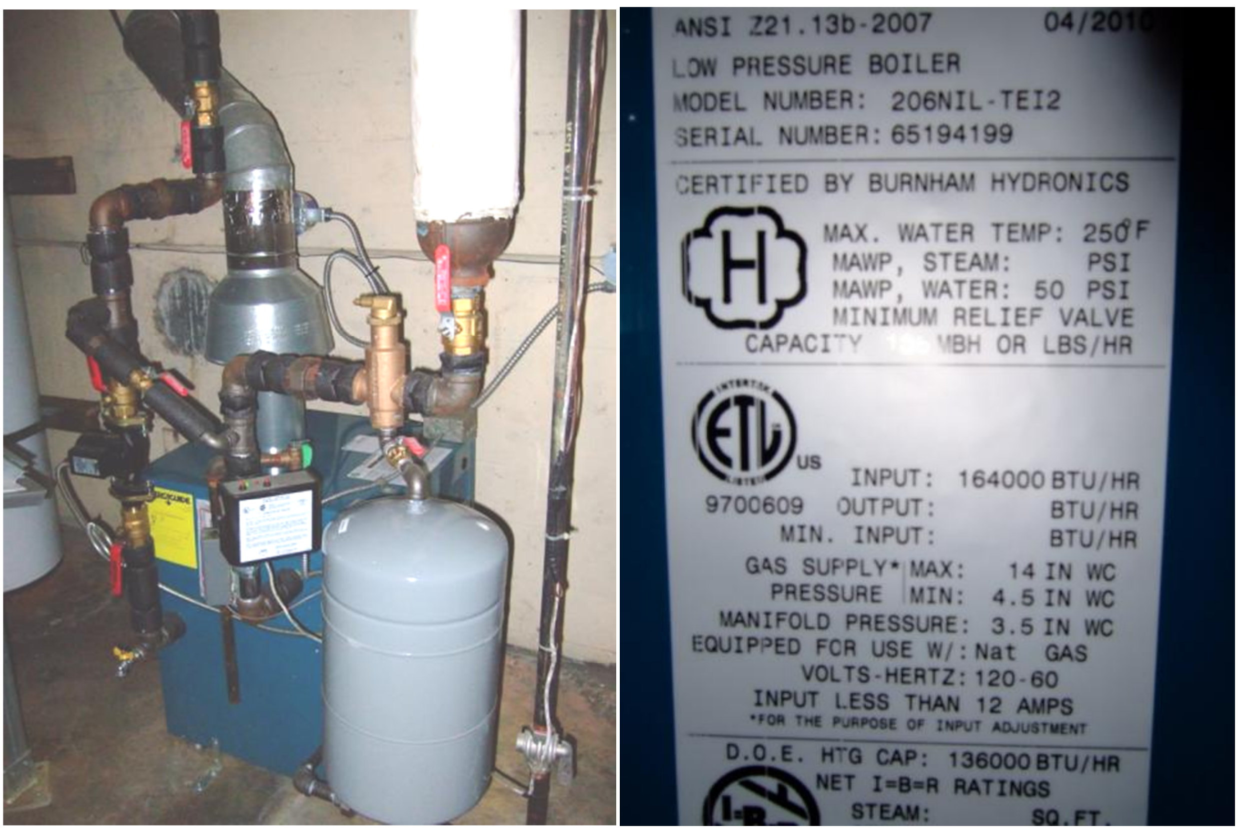
2351 Broadmoor

Audit and Testing: This home is identical in floor plan and specification to 2309. Coincidentally, blower door results were also virtually identical (10.56 ACH_{50}). This home had also been recently renovated in the same manner as 2309. Upstairs bathroom exhaust fan performance varied little relative to those tested in 2309.

Analysis: In theory these two homes should perform similarly under identical occupancy rates and behavior. However, 2351 used 58% more natural gas than 2309 but had only 30% of the electrical consumption of 2309 for the same annual billing period. Both of these homes were unoccupied at the time of audit, making it difficult to relate occupant behavior to these discrepancies. It is known that 2309 had 3 occupants and 2351 had 6 occupants during the billing period analyzed; intuitively, the home with higher occupancy would have higher gas and electric use, but this is not borne out in the energy usage data.

One possible explanation for the discrepancy is occupant behavior; this could be addressed by providing targeted occupant education for high energy use occupants. In addition, the gas boilers observed at the time of the audit were newly installed, and were not the heating systems in place during the utility billing periods used in this study. There may have been significant heating system deficiencies in this home prior to the renovation. More investigation is necessary to get a clearer picture of the reason for the difference in gas usage between 2351and 2309.

Recommendations: There were no substantial differences in thermal or mechanical properties between the two homes at 2309 and 2351 in the Broadmoor development therefore; weatherization and energy efficiency measures recommended are identical to those discussed for 2309.



The boilers in both historic Broadmoor units were replaced with the recent home renovation. The boilers that were replaced were naturally drafted natural gas models of 1970s vintage and unknown efficiency. The performance of these new models is not reflected in this study's billing analysis.

- Typical electric DHW, 0.91 EF
- Tanks sat directly on an unconditioned slab in an unconditioned basement.

- Abandoned laundry chute
- Originates on the second floor and terminates in the unconditioned basement
- Cavity currently used for domestic water piping and filled with fiberglass insulation
- No air seal—is a major leak source

Hydronic radiator typical throughout homes in the historic Broadmoor development

New Broadmoor

2651 and 2652 Broadmoor

- Three bedroom, 1 ½ baths, 1-story single-family home built over an unvented crawl space with a concrete slab over the crawl space floor (rat slab).
- Ducted Condensing natural gas furnace (.912 AFUE)
- Electric tank DHW, 0.90 EF
- 100% CFL lighting
- 13.1 and 12.9 ACH_{50} envelope air leakage
- 280 and 175 CFM_{50} duct leakage to the exterior
- Un-insulated and un-sealed ducts. Supply in crawl, return in attic and crawl
- Wood-burning fireplace

Audit: This neighborhood of the Broadmoor development was built in the 1960s. All 10 units in this neighborhood are of identical design. The homes are 3 bedrooms, 1 ½ bath single story structures built over a semi insulated and unvented crawl space with rat slabs. Approximately 70% of the roof is attic, with the remainder single rafter vault construction.

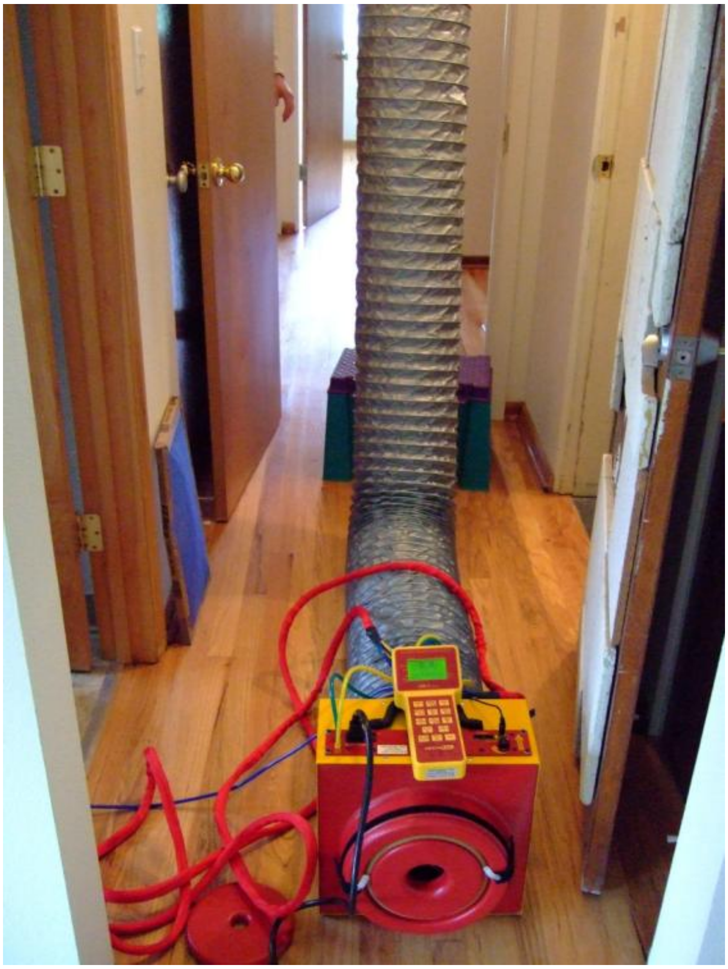
The majority of the glazing in these homes are operable, double paned aluminum framed windows in functional condition. The large fixed windows in the great room are double paned

(1/4” spacer) stopped in (insulated glass (IG) units within the existing rough opening) and without functional seals. The home also contains a large thermal paned, aluminum framed sliding glass door.

The exterior walls are of 2X4 stick frame construction and are assumed to be uninsulated. The single rafter vault roof is uninsulated and sheeted with tongue and groove 2X6 car decking, and shows a history of minor bulk water intrusion from the roof, especially at the chimney penetration. The attic was not readily accessible, so insulation presence and grade was not evaluated on site. Further investigation through interview of Equity Residential determined attics and vaults for this floor plan to be uninsulated. The unvented crawlspace was dry and showed no sign of moisture intrusion. The floor of the crawlspace has been finished with a rat slab and the stem walls were insulated with 1” of fiberglass board. No air sealing of the rim joist or penetrations to the interior or exterior from the crawl space was noted. Most of the homes’ plumbing runs through the crawlspace and is insulated to some degree.

Testing: Duct leakage to the exterior was tested at 280 CFM_{50} and 170 CFM_{50}, or 18.3% and 11.4% of the conditioned floor area (CFA) respectively. Average duct leakage to the exterior is roughly19% of CFA for the region (and for the base.)

It was noted on inspection of the crawlspace that the supply registers were not sealed, and most of the original return ducts had been capped, abandoned and replaced with a single jumper duct style return. It was not determined whether the crawlspace was within the thermal envelope, but is assumed that it is somewhere between the pressure boundary of interior and exterior space. In this case one would expect reduced energy impacts due to duct leakage relative to the same rate of duct loss into a vented crawlspace. Neither crawlspace inspected contained vapor barriers over the slab; no signs of bulk water intrusion or vapor moisture issues were noted. It is unlikely a vapor retarder exists under the slab, since such a feature was not (and still is not) required by code.



Duct tester connected to retrofitted return located in the hall ceiling outside the mechanical closet

The original duct system had been installed with at least one return per room

Original returns have since been capped and abandoned

Blower Door testing results showed fairly significant air infiltration (13.11 and 12.9 ACH_{50}) but this is not unusual for this vintage and style of construction. The average leakage rate for the homes researchers tested was just under 12.0 ACH_{50}. Much of the air leakage in these homes is likely occurring at the floor assembly due to the unsealed rim joist and sill plates, unsealed register boots at floor penetrations, unsealed plumbing and wiring penetrations and capped, unsealed and abandoned return registers. Above the midpoint of the living space where the pressure balances, it is likely that the tongue and groove car decking, chimney and the chimney penetration of the ceiling are the most significant leakage points.

Fireplace flue without doors and penetration are significant air leaks

The condensing natural gas furnace (.90 - .92 AFUE) is typical for single family housing at JBLM. The furnace in 2651 was installed in a mechanical closet located outside the thermal boundary. The furnace at 2652 is located inside the thermal boundary of the home and has had much of the metal duct work in the mechanical closet replaced recently. This likely contributes to the difference in duct leakage rates between the two homes. In both units the electric tank water heaters were located within the conditioned space.

Recommendations: Opportunities for improvement are similar to other homes in this study. Specifically, envelope and duct leakage reduction should be a priority, with special attention given to the tongue and groove vaulted ceiling, chimney penetration of the roof assembly and the chimney flue, and the interstitial space between the subfloor and the supply register boots. After air sealing has been performed, adding insulation to the attic to R-39 to R-49 is advised. Additionally, replacement of the aluminum frame windows and increasing the thermal performance of the floor structure should be prioritized. Replacement of these windows with modern energy efficient models would increase the homes comfort and reduce leakage (if proper attention is given to air sealing between the wall framing and window assembly.) Crawlspace perimeter insulation should be removed and replaced with R-30 floor insulation, taking care to establish code minimum ventilation. Alternately, the rim joist should be sealed, and code approved perimeter insulation should be installed. The walls should be insulated with dense pack material the next time major interior renovation is done. This could be done by filling the walls with dense-pack insulation by temporarily removing the baseboards to access the wall cavities.

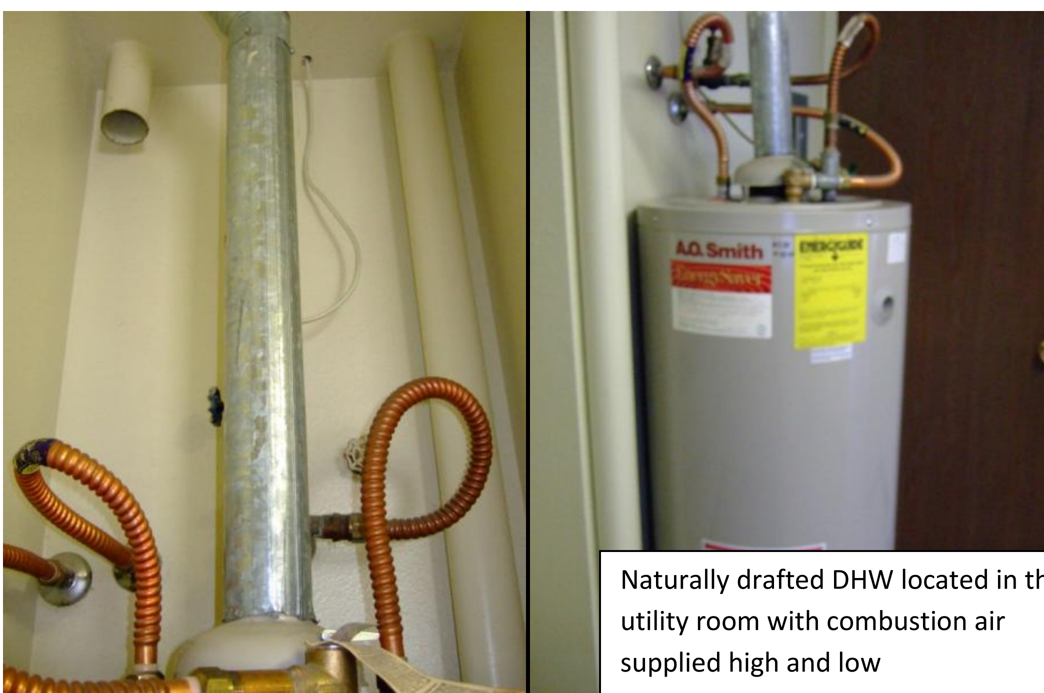
9280 and 9290 Evergreen

- Two bedroom, 1 bath, 1-story single-family home built slab-on-grade
- Ducted condensing natural gas furnace (.92 AFUE) located within the conditioned envelope
- Ceiling supply with central return at utility closet
- Natural Gas DHW (0.59-.061EF) located within the conditioned envelope
- 95% and 100% Incandescent
- 13.6 and 10.2 ACH_{50} envelope air leakage
- 212 and 135 CFM_{50} duct leakage to the exterior
- Supply ducts located in unconditioned attics. Flex branch ducts insulated, supply plenums are uninsulated. and unsealed

Audit: The majority of the homes in the Evergreen development were built in the early 1980s and are unique in design and specification to the other homes within this study. The development's house plans were based on passive solar designs popular at the time in the California market. They are single story 2 bedroom 1 bath homes, built with slab-on-grade. These homes were originally built with a Trombe wall on a portion of one exterior wall. Unfortunately, these Trombe walls were not specifically oriented to face south so most were ineffective in accomplishing the design's intention of passive solar heat gain. In addition, the original furnace was installed in a way that the glazing of the Trombe wall had to be removed in order for it to be serviced or replaced. Consequentially, all Trombe walls have been encapsulated, insulated and finished to match the rest of the exterior (which is stucco.) Space heating, domestic hot water and the range are all fueled with natural gas. These homes also have attached garages which is unique to this development and the homes at historic Broadmoor and New Hillside (there are other isolated cases of homes within the study having attached garages, but this is not typical). Doors to the garage lack effective weatherstripping, leading to potential added heat loss and indoor air quality issues.

Other than furnace upgrades, the homes at Evergreen have not been as significantly renovated as most of the other homes in the study. Attics had R-15 grade III blown fiberglass insulation. Windows were the original double paned aluminum windows; several windows had blown seals. The slab floors in these homes were uninsulated. Although the walls are known to be insulated, it is assumed to be of poor value. Lighting was primarily provided by incandescent lamps (95%+).

Both homes have been updated with sealed combustion furnaces of .92 AFUE. The furnaces are located within the conditioned envelope (bathroom closet.) The return plenum is a ducted opening below the closet door. All supply ducts run through the unconditioned attic space. Supply ducts are uninsulated, unsealed metal, with insulated flex branch runs. DHW is provided by an atmospherically drafted natural gas tank heater, located in the utility room. Although the water heater has combustion air supplied via 4” duct there is potential for back drafting, particularly since the DHW is located in the same room as the dryer.



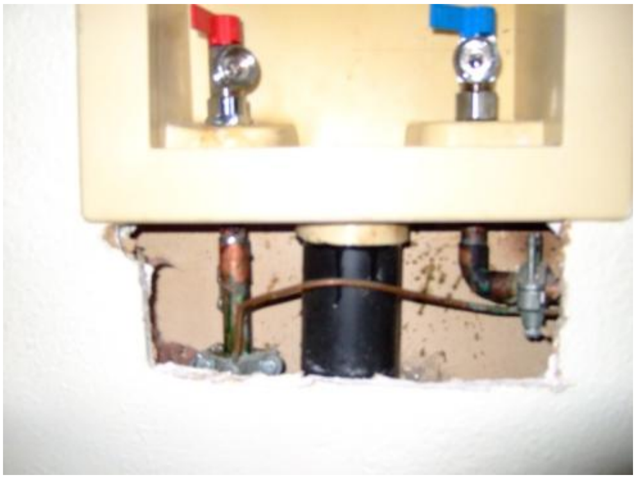
Naturally drafted DHW located in the utility room with combustion air supplied high and low

Testing: Both the kitchen range and the bathroom in these units are equipped with source specific exhaust ventilation. While the bath fan in 9280 did not function, the bath fan in 9290 provided 48 CFM, higher than most ventilation systems tested within this study. No physical evidence of high moisture related issues was observed. It is important to note that these homes were tested during occupancy turnover, and had recently been thoroughly cleaned in preparation of new tenants. This cleaning may have removed any visible indication of mold or mildew.

Performance testing indicated 13.6 ACH_{50} at 9280 and 10.2 ACH_{50} at 9290 (average for the study was 11.9 ACH_{50}.) Duct leakage rates were considerably higher for 9280 than for 9290 - 17.7% CFM_{50} leakage to exterior relative to CFA for 9280 compared to 9.2% for 9290.

Recommendations: It is recommended that improvements be made to Evergreen homes to match what has already been implemented at New Hillside, Davis Hill and Beachwood. In addition, it would be advised to implement the following measures in order to maximize energy savings:

- Air sealing of the envelope with specific attention given to the ceiling assembly
- Air sealing of the duct system
- Increased insulation in the attic (remove existing insulation, air seal, and replace insulation to R-38 to R-49.



Plumbing penetration showing significant degradation to the homes air barrier

Exterior door to attached garage providing significant potential of infiltration of polluted ambient air

8450 and 8636 Beachwood

- Three bedroom, 1 ½ bath, 1-story single-family home with slab-on-grade foundation
- Ducted Condensing natural gas furnace (.92 AFUE) located within the conditioned envelope
- Ceiling supply with central return in interior wall to mechanical closet
- Electric tank DHW (0.89 and .90 EF) located within the conditioned envelope
- 100% and 70% CFL
- 12.95 and 5.36 (11.6) ACH_{50} envelope air leakage
- 160 and 300 CFM_{50} duct leakage to the exterior
- Supply ducts located in unconditioned attics. Flex branch ducts insulated, supply plenums uninsulated

Audit: The Beachwood development has gone through extensive renovation in the past several years, with the homes receiving new vinyl siding, vinyl double pane windows, condensing natural gas furnaces, electric tank type water heaters and up to 100% compact fluorescent lighting. Besides the windows, there were no other apparent envelope upgrades. The attic contained roughly R-15 blown in fiberglass insulation of very poor quality. Exterior walls are assumed to contain minimal and degraded insulation. These homes are built upon uninsulated slabs.

Both homes audited had .92 AFUE natural gas furnaces located within the conditioned envelope. Supply ducting was uninsulated and unsealed metal; branch runs were insulated flex duct, “sealed” with duct tape and cable ties. All supply ducts are located in the unconditioned attic, and the return is a direct connection to the furnace cabinet through an interior wall. Domestic hot water (DHW) is provided to both units via electric tank type heaters (0.89 and

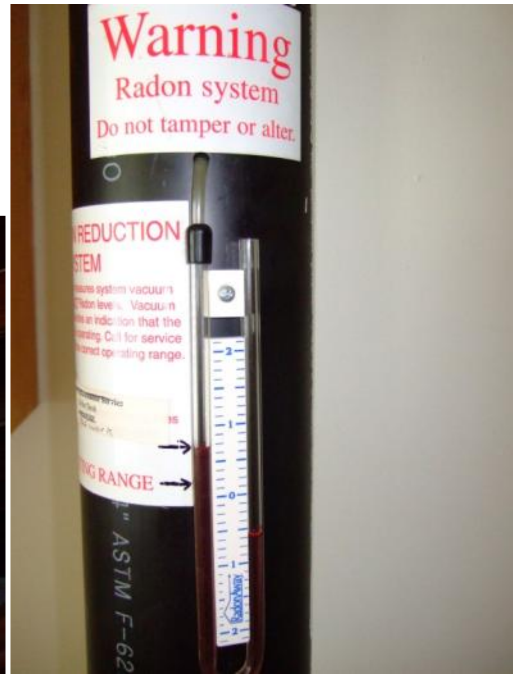
0.90 EF) located inside the conditioned space. Lighting in these two homes was provided by100% and 70% CFLs respectively. Appliances were newer but not ENERGY STAR rated.

92% AFUE natural gas furnace typical of all homes in study except for historic Broadmoor

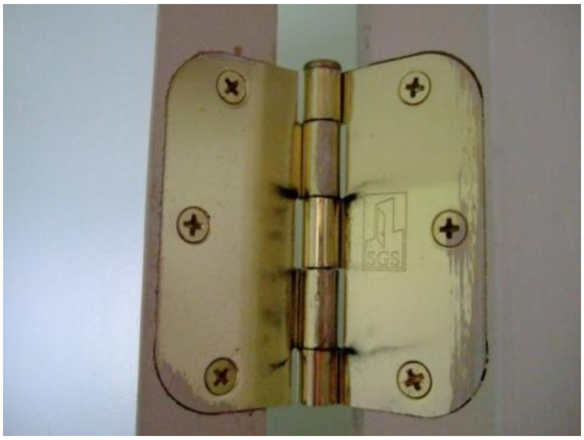
Testing: Performance testing of these two homes resulted in very different leakage rates for both envelope leakage and duct leakage to exterior. The blower door result for 8450 was 12.95 ACH_{50}, about 10% higher than the average for all homes tested in the study. The infiltration rate for 8636 was measured at 5.6 ACH_{50}, more than half the average leakage rate for all homes tested. This anomaly may be explained by the fact that this home also has a radon mitigation system installed; this may have included additional air sealing as part of the work scope. Further investigation in recommended.

Radon mitigation power vented from below slab through conditioned space and terminates through attic.

Note disconnected terminus duct at fan



Duct testing of these homes also varied considerably. In this case, 8636 had the larger leakage rate - 22.6% leakage to the exterior at 50 Pa, relative to CFA, roughly 8% higher than the next highest tested result at the base. Duct leakage for 8450 was only 70% of the average (13.8% CFM_{50} relative to CFA). Soot was visible at the hinge pin at all bedrooms of unit 8636, suggesting the rooms were pressurized relative to the rest of the house when doors were closed. Door undercuts in these rooms was less than ½", likely insufficient for pressure balancing.



Bedroom door showing soot/dust staining

Insufficient return area at door undercut causing pressurization of bedrooms

The Beachwood, Davis Hill and New Hillside developments largely use an identical floor plan and specifications; tested performance is also similar. The only substantial difference between the three developments is that the furnace and DHW at Beachwood are located inside the conditioned space. Both Davis Hill and New Hillside have furnaces and DHW located outside the conditioned space.

Recommendations: Despite low average annual energy consumption at Beachwood (relative to the rest of the developments in the study) there are still several weatherization measures identified through these audits that would be worth pursuing. Lowering infiltration rates to below 7.0 ACH_{50} should be prioritized. Efforts to seal all penetrations to the exterior, such as plumbing, wiring and lighting as well as improving functionality of weather stripping around doors and attic hatches should yield appreciable savings. In addition, attics should be sealed and insulated to R-38 – R-49.

5428 and 5959 Davis Hill

- Three bedroom, 1 ½ bath, 1-story single-family home built slab-on-grade
- Ducted Condensing natural gas furnace (.92 AFUE) located within an unconditioned but adjacent mechanical closet
- Ceiling supply with central return in interior wall to mechanical closet
- Electric tank DHW in 5428, natural gas tank DHW in 5959, both located in exterior mechanical closet
- 75+% CFL
- 12.28 and 9.87 ACH_{50} envelope air leakage
- 275 and 460 CFM_{50} duct leakage to the exterior

Audit: The Davis Hill development is very similar in plan type and specification to the Beachwood and New Hillside developments. The homes are roughly 1200 ft.^{2} single story homes with 3 bedrooms and 1.5 baths. Windows and exterior siding have been upgraded in the last few years to vinyl products. The furnaces have been upgraded to .90+ AFUE natural gas sealed combustion units. Supply ducts are uninsulated and unsealed metal with insulated flex branch runs, located primarily in the attic. Returns are generally no more than a short plenum located in an exterior wall adjacent to the unconditioned mechanical closet. Hot water for 5428 is provided by a 0.90 EF, 50 gallon electric resistance tank; 5959 uses 0.58 EF, 50 gallon natural gas tank. Both units had the DHW unit located in the exterior mechanical closet, accessed from the exterior of the home through a louvered door that provides combustion air. The attics are insulated to R-15 with blown fiberglass of degraded installation quality. Walls have been insulated by the Army approximately 20 years ago when siding was replaced. Slab floors are uninsulated. Lighting is predominately compact fluorescent lamps (75+%) and appliances are not ENERGY STAR rated models. Bath fans were located in the full bath and showed reasonable flow rates (44 CFM).

Testing: The infiltration rate for 5428 was 12.28 ACH_{50}, slightly higher than the tested average of 11.9 ACH $_{50}$; 5959's test result of 9.87 ACH_{50} was roughly 15% lower than the average. Duct leakage rates to the exterior for both units tested were high for this study; 23% of CFA at 50 Pa for 5428, 39.7% for 5959 (compared to the average of 13.8%).

Typical attic insulation and supply duct system for Davis Hill, New Hillside, Beachwood and Evergreen

Recommendations: Since all supply ducts are located in the attic, further degradation of the existing insulation is likely when any duct sealing measures are attempted. With this in mind, it may be best to first remove the existing insulation; seal the attic from the conditioned space seal all ducts; and re-insulate the attic to current code levels, and cover the uninsulated supply plenum. Replacement of the louvered mechanical closet doors with solid R-5 insulated doors will increase the overall thermal efficiency of the building envelope and mechanical equipment. Sealed combustion furnaces must be piped directly from the outdoors if the louvered doors are replaced. Homes with natural draft gas water heaters should not have these doors replaced.

6759 and 6768 New Hillside

- Three bedroom, 1 ½ bath, 1-story single-family home built slab-on-grade
- Ducted Condensing natural gas furnace (.92 AFUE) located within the conditioned envelope
- Ceiling supply with central return in interior wall to mechanical closet
- Electric tank DHW (0.90 and 0.91 EF)
- 75+% CFL
- 12.8 and 12.2 ACH_{50} envelope air leakage
- 390 and 85 CFM_{50} duct leakage to exterior

Audit: The New Hillside development is very similar in design and specification to that of Beachwood and Davis Hill; the renovations have also been similar. The windows and exterior siding have been recently replaced. The new siding is cement fiber planks and the windows have been upgraded to double pane vinyl frame types. Furnaces have been upgraded to .92 AFUE sealed combustion natural gas units; DHW is delivered via 0.90 and 0.91 EF electric tanks. As with Davis Hill, DHW and furnaces are located in an attached, unconditioned mechanical closet with ventilated exterior access doors. Supply ducts are uninsulated, unsealed metal, with insulated flex branch runs. Return ducts run across the top of an interior closet and through the exterior wall to the mechanical closet and furnace. Unlike other homes in this study, no filter was noted in either system (believed to be the result of modifications to the return made at the time of new furnace installation). Attic insulation was similar to what has been observed in other homes in this study: R-15 blown fiberglass with degraded installation quality. As with Beachwood and Davis Hill, it is assumed that all homes in New Hillside had wall insulation blown in when the Army resided the homes over 20 years ago. Slabs are uninsulated.

Testing: Performance testing of envelope infiltration for both of these homes produced very similar results, 12.8 and 12.2 ACH_{50}. These infiltration rates were just slightly higher than the average for the homes tested in this study (11.9 ACH_{50}). Duct leakage to the exterior varied greatly; 6759 tested at 31.7% relative to CFA at 50 Pascals, compared to 6.9 % for 6768.

Recommendations: Suggested weatherization measures are similar to those made for Beachwood and Davis Hill. Attic insulation should be removed, air sealing should take place at all seems joints and penetrations between the attic and the conditioned space below, duct should be sealed with an approved duct sealant and the attic should be insulated to code. A solid insulated (R-5) exterior door should also be installed on the mechanical room of all homes with sealed combustion and/or electric mechanical equipment. Assure sealed combustion furnaces have combustion air piped directly to the furnace from the outside if solid insulated doors are installed.

Exterior access unconditioned mechanical closet typical in Davis Hill and New Hillside developments

Appendix B – Case Studies for "complaint" JBLM homes

8332 Beachwood

- Ducted Condensing natural gas furnace (.92 AFUE) located within the conditioned envelope
- ~0.90 EF Electric DHW located within the conditioned envelope
- 100% fluorescent lighting
- 10.8 ACH_{50} envelope air leakage
- 340 CFM_{50} initial duct leakage to exterior

- Typical Beachwood home (circa 1959-1961)
- 3-bedroom, 1-3/4 bath, slab-on-grade, 2X4 stick frame construction

Audit and Testing: This home had been renovated within the last 10 years, along with most of the housing at JBLM. The home is 1-story, 3 bedrooms and 1-3/4 baths built over an uninsulated slab-on-grade. This model is common in several of the developments at JBLM.

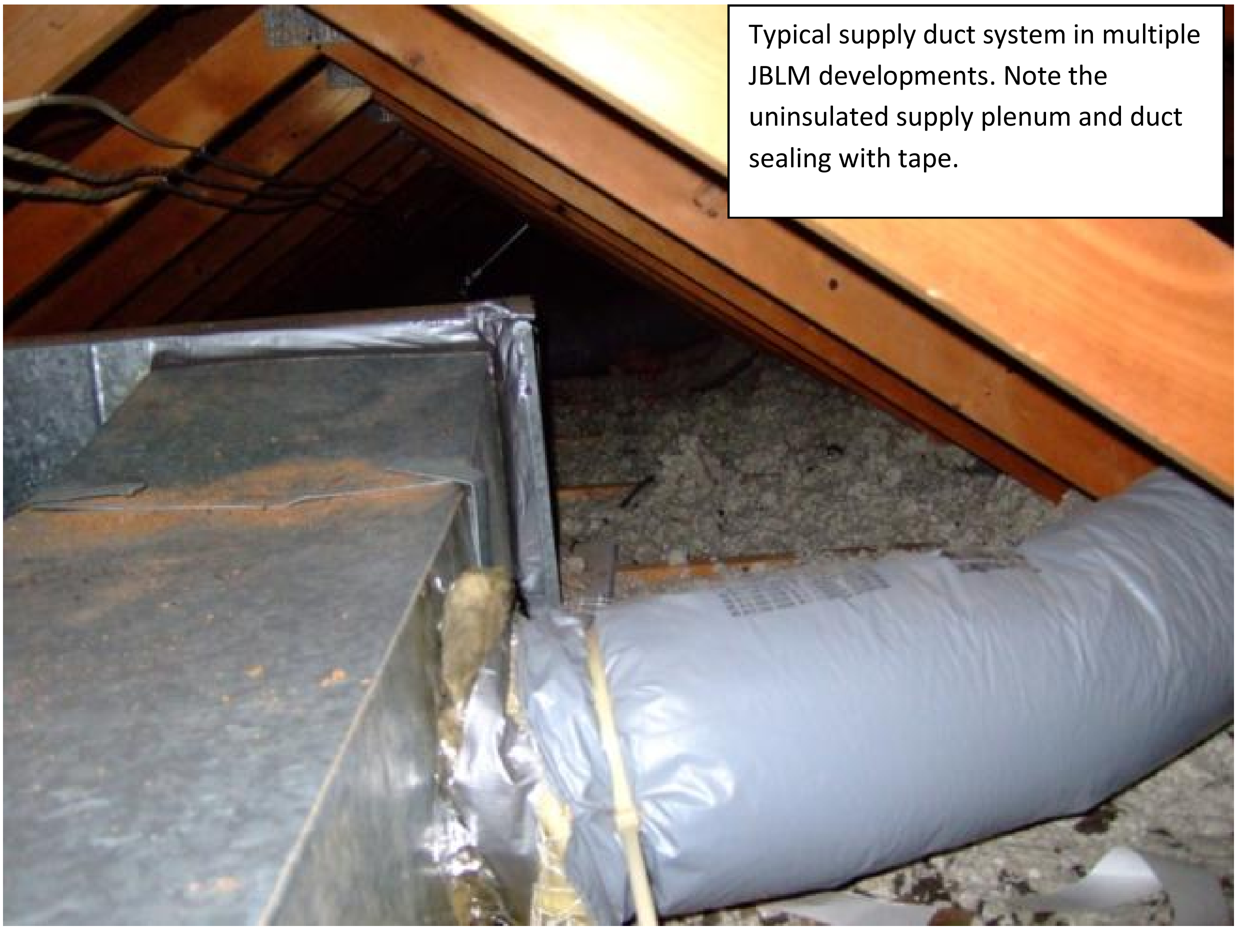
The furnace has been upgraded to a .90+ AFUE sealed combustion unit with a newer electric tank water heater, 100% fluorescent lighting, ENERGY STAR appliances and double-paned vinyl windows and siding. All supply ducts are in the attic and flexible branch runs are insulated, but the metal supply trunk is not. This home's air leakage rate of 10.8 ACH_{50} is roughly average for what researchers have seen for homes of this style and vintage located on the base.

This site visit was triggered by the occupant's inquiry into a high bill. The occupant does not typically get billed for utilities, but was billed for March and April. By the occupant's account there had been no change in occupancy or occupant behavior during the billing period in question. The home is occupied by two adults and one child less than 6 years of age. Occupant survey showed that the home owners were conservative with their use of lights, appliance and miscellaneous electrical loads. However, the thermostat is set at 72°F during the heating season with no set back periods. A 60" LCD television is used roughly 12 hours per day.

The occupants noted in survey that they were generally very satisfied with the comfort level and efficiency of their home, though one occupant noted that hot water will run out when taking long showers. The occupants had no complaints with the 100% fluorescent lighting package in regards to the lighting quality, but found that pin-based lamps at the vanity burned out within 4 months and were expensive to replace.

Equity Residential maintenance staff found a dislocated supply duct at the main supply plenum in the attic. A duct test was performed prior to reconnection of the disconnected duct which resulted in a duct system leakage rate of 340 CFM_{50} to the exterior. The duct was reconnected (with duct tape) and retested to 270 CFM_{50} to the exterior. The particular branch connection that was disconnected originally had its inner helix taped to the plenum collar; the insulation was Panduit strapped to helix a couple of inches beyond the collar. The Equity Residential technician informally stated that flex duct partial or full disconnection is not unusual in JBLM housing. Duct leakage rates to the exterior between 250-300 CFM_{50} are typical results for existing homes at JBLM.

Recommendations: Identification and sealing of disconnected duct with duct tape is only a temporary and partial fix for the high duct leakage in this home. It is recommended that this home receive thorough duct sealing with the appropriate duct sealing materials. In addition, envelope air sealing and increased attic insulation to R-38 to R-49 is recommended.



Typical supply duct system in multiple JBLM developments. Note the uninsulated supply plenum and duct sealing with tape.

20E Parkway

- Condensing natural gas furnace located in the unconditioned basement
- Electric DHW in unconditioned basement
- 70% fluorescent lighting
- 18.75 ACH_{50} pre window retrofit, 15.3 ACH_{50} post window retrofit
- 315 CFM_{50} duct leakage to exterior

- Parkway development (circa 1940s)
- 2 story, 3 bedroom, 1 ½ bath with unconditioned basement

Audit: The Parkway development consists of 299 zero lot line, 1200 square foot, 2 story, 3 bedroom, 1 ½ bathroom, single family residences with unconditioned basements. These buildings have brick facades and were built in the 1940s; no major improvements have been made to the building envelopes since original construction. Floors between the conditioned space and the unconditioned basement are uninsulated, attics contain minimal blown insulation, and walls are assumed to be uninsulated. The original windows were single-pane with metal frames.

Original single-pane, metal-framed casement windows

These multiplex residences are all heated with natural gas furnaces. Supply ducts originate from the unconditioned basement and return ducts are located in exterior wall cavities. Furnaces have been upgraded within the last 10 years to .90+ AFUE sealed combustion units; DHW is provided by electric tank heaters. The furnaces and DHWs are located in the unconditioned basement. Unit 20E contained 70% fluorescent lighting. The dishwasher was noted to be ENERGY STAR rated, the refrigerator was not found in the list of ENERGY STAR qualified refrigerators.

This home was slated for a complete window replacement and general interior renovation, and was singled out by Equity Residential as a high energy use home. Although this home was unoccupied, information received from Equity Residential stated that the home had a relatively high occupancy rate of people and dogs. WSU Energy Program staff conducted a full audit of the home on July 21st, prior to the rehab work. The home was retested prior to occupancy and post window replacement on the 12th of August.

Testing: The initial test out on unit 20E resulted in duct leakage results of 315 CFM_{50} to the exterior or 26% of CFA in CFM_{50}. The blower door test result for envelope leakage was 3000 CFM_{50} or 18.75 ACH_{50}. The home was retested on August 12th, post window retrofit, and was found to have a leakage rate reduction of 555 CFM_{50}, amounting to an improvement of 18.5%. Exhaust fan flow rates were tested with an Alnor balometer. The upstairs ¾ bath exhaust rate was 16 CFM and the ½ bath down stairs exhaust rate was 27 CFM.

Envelope leakage rates for this home were the highest of all the homes audited on base and the duct leakage was just slightly above average. There were no big holes or disconnects identified in the envelope or duct system, so it is assumed that other homes within the development of similar construction would see similar air leakage rates. High energy use for this home relative to other similar models is most likely attributed to occupancy rate and behavior.

Recommendations: The Parkway development is currently one third of the way through its renovation/retrofit project, which is slated to be a 2 year project. There are no other energy efficiency measures planned for this round of work other than window replacement. However, serious consideration should be given to investment in weatherizing these homes due to their poor performance, age and accessibility to significant weatherization opportunities. Some of the opportunities include:

- Air sealing
- Insulation to attic and floor to code levels
- Duct sealing and insulation of all ductwork located in the basement
- Air sealing of the basement
- Weatherization of all exterior doors

7149C Discovery Village

- .92+ AFUE condensing natural gas furnace
- Sealed and insulated ducts
- 0.62 EF natural gas tank DHW
- 100% fluorescent lighting
- 3.9 ACH_{50} envelope air leakage
- 57 CFM_{50} duct leakage to exterior

- Tri-plex. 2-story slab-on-grade
- 2004 NW Energy Star BOP1

Audit: Discovery Village is a newer development of over 450 multi-story duplexes and triplexes built less than 5 years ago. These homes were built under the Northwest ENERGY STAR Homes BOP 1 specifications and are modularly constructed. The specifications require a maximum duct leakage rate of 6% of CFA in CFM_{50} but have no envelope air leakage standard.

This home has been occupied by the same individuals for the last 9 months. They generally keep their monthly energy consumption under the average and therefore do not receive utility bills. However, the occupants received a utility bill for the March-April billing period which is what triggered the high bill complaint and resulting site visit. Researchers accompanied Equity Residential staff on this visit and completed a full audit and occupant survey.

This home is occupied by a married couple in their early to mid-30s with no children or pets. Up until three months ago both occupants worked full time and spent over 40 hours each out of the home every week. As of three months ago, when one occupant stopped working full time, the home is only unoccupied 10-15 hours per week.

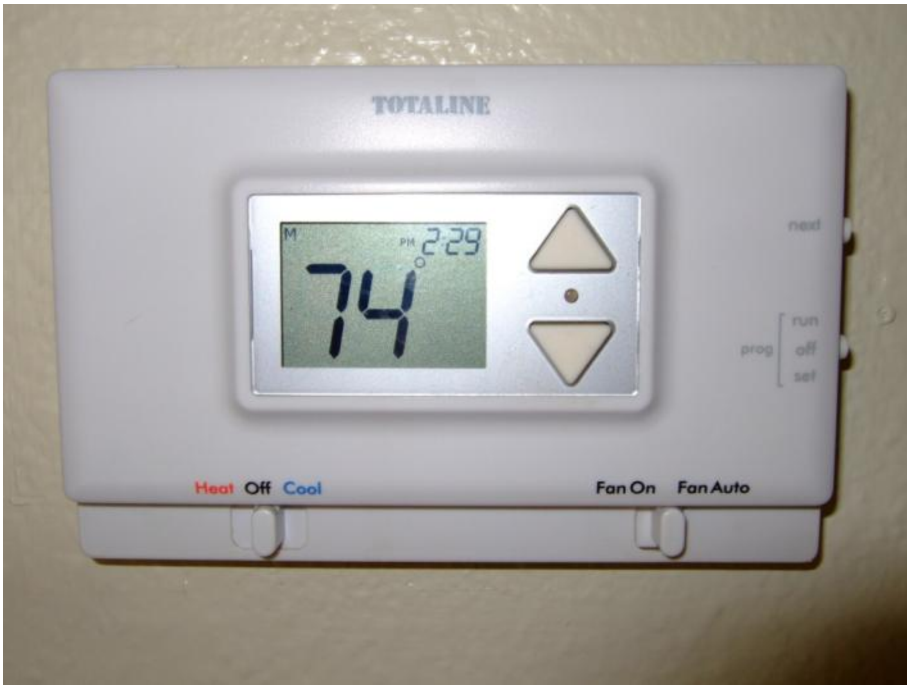
Analysis: According to the occupant survey, the homeowners are fairly conservative in their use of energy, relative to the average occupants at JBLM. Lights and televisions are not left on when not in use, thermostats are setback at nighttime and when the home is unoccupied, and there is no apparent evidence of high hot water usage. Duct leakage rates are within the Northwest ENERGY STAR specs and envelope air leakage is average for new construction in this development.

This high bill complaint was generated at the end of the heating season and testing results have shown no real issues with air leakage of the home or duct leakage. This indicates that the high bill could be attributed to occupant load on the electrical system due to increased time of occupancy due to one of the occupants leaving their job three months ago. This theory could be supported by showing a relationship between the time the home increased its time of occupancy and increased electrical consumption for the same period.

Recommendations: This home appears to be performing as would be expected considering its observed and tested envelope and mechanical specifications. It is recommended that the occupants be mindful of their use of miscellaneous electrical loads in order to reduce consumption.

6855 New Hillside

- Condensing natural gas furnace outside the conditioned space
- Electric DHW
- 100% fluorescent lighting
- 11.5 ACH_{50} envelope air leakage
- >550 CFM duct leakage to exterior (could not reach 50 Pascals)



- Programmable thermostat used in many of the developments on JBLM
- The residents at 6855 New Hillside left thermostat in “Fan On” position most of the year

Audit: The homes in the New Hillside development are very similar in construction and floor plan to those units in the Beachwood development. The home researchers visited at 6855 was a single story rambler with 3 bedrooms and 1½ baths. The home is built over a slab on-grade and has all supply ducts located in the attic. The natural gas furnace has been updated to a high efficiency sealed combustion unit located in an exterior accessed closet. The home’s central return is located on an interior wall adjacent to the furnace closet. The home has also had a window upgrade to vinyl double glazed units.

This high bill visit was stimulated by Equity Residential in order to investigate identified high usage from monthly billing reports. Researchers accompanied Equity Residential and completed a full energy audit and home owner survey.

The home has been occupied since May of 2009 by two adults and two children between the ages of 6 and 18. The home is unoccupied roughly 40 hours per week for the 9 month school year and rarely unoccupied in the summer months when school is not in session.

Some of the high energy usage can be attributed to occupant behavior. The occupants keep the home at 75 deg. F. during the heating season with no set back periods. There are more than 3 televisions in the home and many of them are on whenever the home is occupied, including sleeping hours. The occupants keep several dogs which are frequently coming and going from the home. The homeowners also have a chest freezer year in their garage. Researchers also found that the furnace fan is kept on to re-circulate interior air even when heat is not called for.

Testing and Analysis: Performance testing of the home also identified significant energy loss through air leakage. Blower door testing resulted in an envelope leakage rate of 11.5 ACH_{50}. This envelope infiltration rate is typical for JBLM, but contributes to the high energy use.

Duct leakage to the exterior was recorded at over 550 CFM (the duct testing equipment was only able to pressurize the system to about 19 Pascals, instead of 50). A visual inspection did not identify any major disconnections in the system. This leakage number was considered significant enough to justify pressure pan testing.

Pressure pan testing showed all registers to have pressure reading of 1.8-2.4 Pascals, meeting the criteria for a very leaky system in need of repair. The test is used to identify disconnected ducts or major leaks in the system (The Washington State Department of Commerce's Low Income Weatherization standard for pressure pan results is a maximum of 1.0 Pascals.) There could be significant leakage at the return plenum between the interior wall and the furnace cabinet. There is little doubt that the combination of occupant behavior and duct leakage are the chief culprits in the home's high energy use.

Recommendations: The findings from this audit provide more support for recommendations made for the unoccupied homes audited in this study. Air sealing of the envelope and ducts with additional insulation in the attic should be prioritized to increase the efficiency and comfort of the home. Due to its extremely high leakage rate, the duct system should be sealed immediately.

Typical furnace and DHW closet with exterior access. Note grills in door to provide combustion air to mechanical closet.

Appendix C – Case Study for Discovery Village/Miller Hill

- One and two story duplexes and triplexes Built to the Northwest ENERGY STAR Homes 2004 BOP 1 standard
- Ducted Condensing natural gas furnace (.92 AFUE) located outside the conditioned envelope
- Enclosed and vented crawl space
- .61 EF natural gas tank water heaters located outside conditioned envelope (Discovery Village)
- .82 EF natural gas tankless water heaters located outside the conditioned envelope (Miller Hill)
- 50% CFL
- 3.0 – 7.0 ACH @ -50 Pascals envelope air leakage
- Duct leakage to the exterior average of 5% leakage to exterior relative to CFA

Typical Tri-Plex found in Discovery Village

The homes in Discovery Village and Miller Hill were built between 2005 and 2008 to the 2004 Northwest ENERGY STAR Homes BOP 1 standard. These homes vary from one and two story duplexes to two story triplexes. There were 458 units built in Discovery Village and 34 units built in Miller Hill. All units are heated with .92 + AFUE natural gas furnaces and the majority of the homes are provided domestic hot water (DHW) from 0.62 EF storage tank type natural gas water heaters. All DHW in the Miller Hill Development is provided by tankless natural gas water heaters with an EF of 0.82.

These homes are of standard framing and insulated to R-21 in the walls, R-38 in the ventilated attic and R-30 in the floor over an enclosed but ventilated crawlspace. Window U-factors are 0.35 and skylight U-factors are 0.58. The duct systems for these homes are located primarily in the enclosed and ventilated crawlspace and the ventilated attic. All ducts are sealed and insulated to R-8.

Although these two developments were not field audited for this study, 18 of these homes were tested for infiltration rates through the Northwest ENERGY STAR Homes program prior to occupancy. These homes averaged 4.14 ACH at -50 Pascals of depressurization. Duct testing was performed on all homes at the rough in phase of construction. Tests resulted in an average total leakage rate of 4.99% at 50 Pascals of pressure.

Appendix D: Occupant Survey

JBLM FIELD SURVEY 2011

High Bill Complaint Field Visit

For USDOE – PNNL

Site ID#_________ Date_______________

Occupant Name___________________________Address__________________________________

City, State ______________________________ Zip__________ Phone_________________

Utility (include both gas & electric) _________________________________

Electric Meter ID # ________________ Gas Meter ID # _____________

Other (wood) # cords per year _________________ (what years used) _________________

Propane (propane dealer name and account #) ___________________

Person filling out this report_____________________________________

<u>Basic Information</u>

Home Type: double wide, single wide, other ____________ (circle one)

Floor Area: _____ ft2, Volume = ______ft3 Comments ______________________

Year built: _______

Mfg.: ________, Model ________ Serial # _____ HUD # _________________

Super Good Cents, MAP, ENERGY STAR, other ________________

HVAC system type, make and model #: __________________

Duct leakage results: _____ CFM@50PA to outside, _____CFM@50 total

Blower Door Test: _____ CFM@ 50PA, _____ft3 volume, _____ ACH@50 PA

DHW type, make and model #: ________________

Appliances (ENERGY STAR) yes or no

Dishwasher: Make ______________, Model ________________

Refrigerator: Make ______________, Model ________________

Laundry: Make ______________, Model ________________

Lighting: _____% CFL (estimate)

Describe additional loads that would affect a billing analysis (well pump, welder, outbuildings, etc.):
____

Plans Available: Y or N (circle one). If no: Attach a sketch floor plan with exterior dimensions.

Include Pictures & ID#: ____

Consumer Questionnaire

1. How long have you lived in the home? _______________
2. How many people live in the home (full-time occupants)? ______ Other ___________________________________
3. How many people are home most of the time? _____, Ages ____
4. How many people work or volunteer outside the home at least 20 hours per week? _____________, Ages ____
5. How many people attend school at least 20 hours per week? _____________, Ages ____
6. Are any other people living in the home often not at home? Are there any other people who spend a significant amount of time at the home? Please describe other occupancy factors: ____
7. How many hours a week is nobody in the home? ____
8. How satisfied are you with the energy efficiency of your home?

Energy Efficiency: Very satisfied ______ Somewhat satisfied______ Somewhat dissatisfied_____ Very dissatisfied _______

Why do you say [insert what they picked]:

9. How satisfied are you with the comfort of your home?

Comfort: Very satisfied ______ Somewhat satisfied______ Somewhat dissatisfied_____ Very dissatisfied _______

Why do you say [insert what they picked]:

[we could specifically ask about certain aspect of their comfort – are they warm/cold; adequate lighting; noise, fresh air, healthy, etc.]

10. What one thing would you fix or repair in your home if you had the resources to do so?

11. Are there other things that need to be fixed or repaired? Please describe?

12. Have there been any significant improvements made to your home in the last 5 years? Please describe?

13. Have there been any energy efficiency (weatherization) improvements made to your home? Please describe.

14. Have you made any of the following energy efficiency upgrades (read items in the list that they did not mention in #13) [develop list of measures we want to check]

15. Would you ever consider purchasing a new home to replace your current home?

Yes, enthusiastically___

Yes, with some reservations____

Definitely not_____

Please describe any benefits you think a new home would provide compared to your current home?

What things would make it difficult for you to choose to replace your current home with a new home?

Would you be able to pay any more each month to live in a new home? How much more would you be willing to pay? [we could ask how much they think it would be worth regardless of their ability to pay.]

[We could give examples of the increased monthly payment and the potential energy savings and see if that would make any difference in their interest in a new home. However, their answer to how much they are willing to pay mostly gives us what we need.]

16. Describe Your heating system: ____
17. How often do you change your furnace filter? ________________
18. Do you have any air conditioning? Please describe:

19. What temperature is your thermostat set at when someone is home? winter ____ summer____

20. Do you lower the temperature on your thermostat when no one is at home or at night (when you are sleeping)? ___ yes ___ no Describe:________________
21. Do you have a programmable thermostat? Do you program the temperature settings on your thermostat (for different days and times of days)?

Heat Pump T-stat [do we need to ask this or is programmable good enough?]

Air Quality/Ventilation

Technician's observations of odors or moisture

____None ____Odors ____Moisture _____Mold/Mildew

Location and Description: ____

____

Note any conditions which may significantly affect air quality or ventilation (e.g. smokers, solvents, and aquarium):____

____

Number of full-time _______ adult occupants ______children (under 12)

Exhaust Ventilation Systems

Make and Model	Photo ID#	Location	Flow (cfm)	Daily run time (hrs.)	Noisy?	Control type*
		Kitchen				
		Master bath				
		Bath 2				
		Laundry				
		Whole House				

*manual switch, timer *(note flow measurement device used)*___________________________

Is whole house fan operating as designed? Yes No

Location of whole house fan switch ____________________ Is switch labeled? Yes No

Note any problems (no exhaust stack, suspected disconnect between fan and termination, etc.):

____

____

Classify the **make-up air** or other type ventilation system

None	
Passive duct to HVAC return	
Dampered duct to HVAC return	
Air Inlets vents in windows/walls (circle one)	
Other	

Make-up duct diameter _______inches. Flow Rate _______

Note if the make-up damper is jammed or otherwise inoperable:
____.

Do all bedrooms have pass-through vents or door undercuts? Yes ____   No_____

Room pressures > 3 Pa?   Note deficiencies and comfort issues)? If so, note here:
____

Use of windows for ventilation: ____

Interior/exterior Lighting review

List each fixture type observed in the house. Include exterior lights attached to the house. Describe these fixtures as they appear when developing the lighting power for the house each of these fixtures should be represented in the fixture counts in the next section. If two fixtures are essentially identical but have different lamps then enter them as separate fixtures with separate wattage.

Where fixture descriptions beyond the generic types would be helpful the auditor can add them with the appropriate lamp and ballast information. Use the notes field to expand on the description as needed.

Fixture Schedule:

Fixture Type ID	Fixture/lamp Type[1]	# of Lamps	Ballast Type[2]	Watts/ Fixture	Field Verif	Estimated? Y/N	Notes
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14 **15**							

[1] Use generic fixture descriptions: Incandescent, CFL, Linear fluorescent, Track light, Other

[2] Magnetic or electronic from instrument