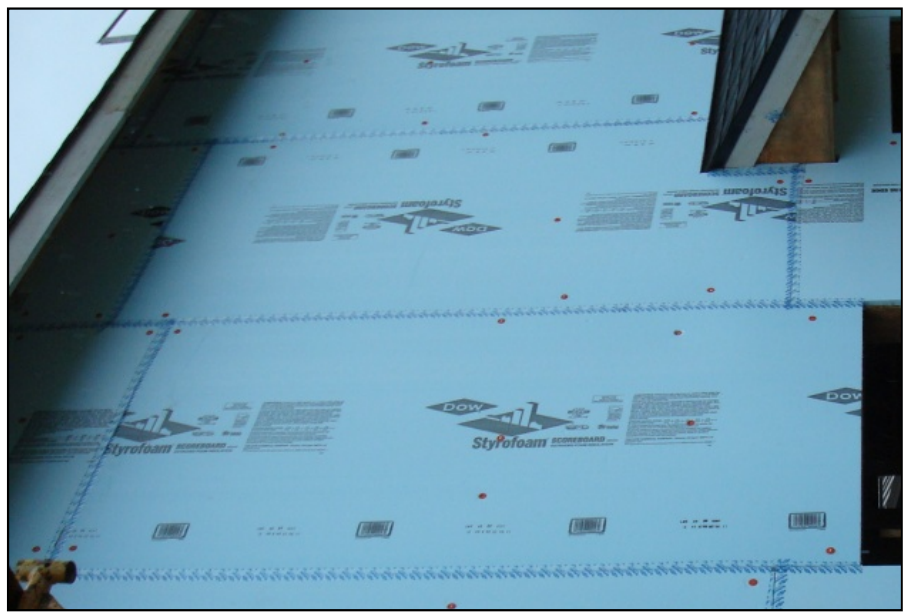
Technical Solutions for High Performance Habitat Homes in Washington State



Washington State University Energy Program
and Habitat for Humanity

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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.

Technical Solutions for High Performance Habitat Homes in Washington State

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Definitions

ACH 50	Air Changes per Hour at 50 Pascals
BOP	Builder Option Packages
EF	Energy Factor
ESDS	Evergreen Sustainable Development Standard
HfHI	Habitat for Humanity International
HfH - Seattle/South King County	Habitat for Humanity-Seattle/South King County Affiliate
HRV	Heat Recovery Ventilator
IECC	International Energy Conservation Code
IRC	International Residential Code
MEL	Miscellaneous Electric Load
NCS	Northern Climate Specification
PNNL	Pacific Northwest National Laboratory
SCL	Seattle City Light
SLA	Specific Leakage Area
SHA	Seattle Housing Authority
TCO	Technical Compliance Options
XPS	Extruded Polystyrene
WSEC	Washington State Energy Code

Executive Summary

As energy costs continue to rise, energy efficiency is becoming an increasingly critical issue in the affordability of housing. Habitat for Humanity-Seattle/South King County is committed to providing affordable housing with its partner families. The affiliate has undertaken a multi-year evaluation of efficiency measures that have been installed in 23 homes in two developments and analysis of measures for possible future installation. Support was provided by Washington State University Energy Program with U.S. Department of Energy funding through Building America, via training and technical assistance in the design, construction, commissioning, and occupancy phases.

Habitat for Humanity-Seattle/South King County builds new homes beyond the efficiency required in the Washington State Energy Code in an attempt to certify the projects through voluntary programs such as Northwest ENERGY STAR® Homes and the BuiltSmart program through the local utility provider. In the process of certifying the homes and increasing the efficiency of their standard building components, Habitat for Humanity-Seattle/South King County has applied lessons learned, and instituted improved design and construction practices.

During this multi-year research project, energy usage data has been obtained and evaluated for seven all electric homes. While the energy consumption data set from these homes is not large enough to draw conclusive results, it has identified issues for further investigation by Habitat for Humanity-Seattle/South King County.

Efficiency measures already implemented by the affiliate were analyzed using modeling software including BEopt and REM/Rate, and indexed to actual usage available for the seven home sample. The efficiency measures currently included in Habitat for Humanity-Seattle/South King County's standard building process were determined to be cost effective and resulted in a positive monthly cash flow when financed at a zero percent interest rate thirty year loan (the loan structure available to all Habitat homeowners).

Measures evaluated for future installation include R-10 rigid foam board insulation on the exterior of fully insulated wall assemblies, ductless heat pumps and heat pump water heaters. The results of the energy modeling indicate that these measures result in a positive monthly cash flow when financed at zero percent. However, the limited capability of the modeling software to address the mechanical upgrades indicates that further analysis will be needed.

Cost effectiveness for Habitat for Humanity-Seattle/South King County differs from standard market rate construction because the affiliate receives donations of various products and completes projects with a large percentage of volunteer labor. These variables created challenges in modeling and determining incremental costs associated with the installation of

the efficiency measures. The research results are particularly valuable to organizations like Habitat that operate in this financial context, but also demonstrate the impact that policies such as zero percent financing may have on implementation of advanced efficiency measures.

1 Introduction

Habitat for Humanity-Seattle/South King County (HfH - Seattle/South King County) is one of more than 1,700 Habitat for Humanity affiliates in the United States. It has been building and renovating houses for 25 years. Like many US affiliates, HfH - Seattle/South King County has been improving the energy efficiency of its homes using various programs such as the Northwest ENERGY STAR Homes Program for guidelines and certifications. This improvement is aided by partnerships with technically expert organizations such as Washington State University (WSU) Energy Program, funders such as Home Depot and product suppliers such as DOW. Other partnerships, including those with the Seattle Housing Authority (SHA), have allowed HfH - Seattle/South King County to continue building new houses in the expensive Seattle area.

1.1 Habitat for Humanity

Habitat for Humanity operates on different levels from international to community level local affiliates all working towards the same mission and goals.

1.1.1 Habitat for Humanity International Overview

Habitat for Humanity International (HfHI, Habitat) is an ecumenical Christian ministry seeking to eliminate poverty housing. Since its founding in 1976, Habitat has built more than 500,000 houses worldwide, providing simple, decent and affordable shelter for more than 2 million people. There are more than 1,700 affiliates in the United States and more than 550 international affiliates that coordinate Habitat house-building projects in over 3,000 communities around the world.

Through volunteer labor and donations of money and materials, Habitat builds and rehabilitates homes in cooperation with the homeowner (partner) families. Habitat is not a giveaway program. In addition to a down payment and monthly mortgage payments, homeowners invest hundreds of hours of their own labor (sweat equity) into building their Habitat house and the houses of others. Habitat houses are sold to partner families at no profit and financed with affordable loans. The homeowners' monthly mortgage payments are used to build yet more Habitat houses.

Families in need of decent shelter apply to local Habitat affiliates. The affiliate's family selection committee chooses homeowners based on their level of need, their willingness to become partners in the program and their ability to repay the loan. Every affiliate follows a nondiscriminatory policy of family selection. Neither race nor religion is a factor in choosing the families who receive Habitat houses.

Affiliates are community-level Habitat for Humanity offices that act in partnership with Habitat for Humanity International. Each affiliate is an independently run, nonprofit organization. Each affiliate coordinates all aspects of Habitat home building in its local area: fundraising, building

site selection, partner family selection and support, house construction and mortgage servicing[1].

1.1.2 Habitat for Humanity-Seattle/South King County Overview

The Seattle Habitat for Humanity affiliate was founded in 1986. The first house, a renovation, was completed in 1987. The Seattle and South King County affiliates merged in 2003. All Habitat affiliates have an area where they construct or renovate homes. The Seattle/South King County affiliate's local area covers all cities within King County to the west of Lake Washington (including Seattle) and all areas within King County to the south of and including the City of Renton. The affiliate has constructed and repaired over 200 houses throughout Seattle and in 8 other cities in King County. The houses are between 900 and 1900 square feet, 2 and 6 bedrooms and 2 to 11 occupants per house. The houses may come in many styles and designs – 1, 2, or 3 story, single family, duplex, and town houses[2].

1.2 Habitat for Humanity-Seattle/South King County Partners

Partnerships have been instrumental in the successful implementation and advancement of HfH - Seattle/South King County goals and objectives. As the affiliate continues to strengthen existing partnerships, cultivation of new partnerships is happening in tandem.

1.2.1 Partnership with WSU Energy Program

Since 2006, WSU Energy Program, with support from Pacific Northwest National Laboratory (PNNL) and other U.S. Department of Energy (DOE) Building America prime contractors, has been working in partnership with HfH - Seattle/South King County. This partnership started with WSU Energy Program providing training materials and onsite instruction for HfH - Seattle/South King County jobsite staff in air sealing and insulation techniques. Over the last few years WSU Energy Program has also provided ventilation and heating system consultation, assistance with understanding and making choices to meet Northwest ENERGY STAR Homes' program requirements, consultation in the purchase of two manufactured homes, energy modeling to assist in the space heating and water heating decisions for new projects, and analysis of energy bills of houses built by HfH - Seattle/South King County and occupied by Habitat families.

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[1] Habitat for Humanity International, http://www.habitat.org/how/factsheet.aspx

[2] Habitat for Humanity Seattle/South King County, 2011, http://www.seattle-habitat.org/about/index.shtml

1.2.2 Partnership with the Seattle Housing Authority

HfH - Seattle/South King County has partnered with the Seattle Housing Authority (SHA) on various projects for the last 12 years. Established in 1939, SHA provides long-term rental housing and rental assistance to more than 26,000 people in the city of Seattle. The agency owns and operates buildings of all shapes and sizes on more than 400 sites throughout the city[3].

1.2.3 Habitat for Humanity International Partnerships

HfHI has developed partnerships with companies who support Habitat's mission to end poverty housing. These partnerships are utilized by affiliates throughout the country. Many are set up to aid in the construction of affiliate houses by providing building materials at no cost. Some of these partnerships include:

- DOW (free weather resistive barrier "house wrap", expanding foam, rigid insulation, window flashing tape, and construction tape)
- Yale (free interior and exterior locksets)
- Valspar (free interior and exterior paints)
- Whirlpool (free ENERGY STAR refrigerators, free stoves, and discounted appliances)
- Hunter Douglas (free blinds for bedrooms and bathrooms).

The partnership with DOW has enabled HfH - Seattle/South King County to afford to put 1" DOW rigid foam on the exterior of each home and fully insulate the slabs with 2" of foam. This material would be cost prohibitive for Habitat to use without the donation. The cost of insulating each unit with rigid foam board insulation varies from $1600-$2600 for both wall and slab insulation.

[3] Seattle Housing Authority, 2011, http://www.seattlehousing.org/housing/

2 Research Background and Questions

In 2005 HfH - Seattle/South King County was strongly encouraged by the City of Seattle, HfHI, agencies that provide funding for projects, as well as HfH - Seattle/South King County staff to meet green or sustainable building standards. Operating with a largely volunteer workforce to construct homes in a cost effective manner, the affiliate began a process to identify products and building strategies to implement in addition to researching best practices for their installation.

2.1 Path to More Energy Efficient Homes

Two of the green and sustainable building programs HfH - Seattle/South King County have embraced in order to meet energy and green building targets are the Northwest ENERGY STAR Homes program and the Seattle City Light BuiltSmart program.

HfH - Seattle/South King County's efforts to voluntarily comply with various "beyond code" programs and certifications has provided the affiliate with the opportunity to implement market ready energy efficiency technologies that were not required by the energy code in effect at that time. HfH - Seattle/South King County developed clear specifications on applying foam sheathing to the exterior of wall assemblies, advanced air sealing techniques to comply with maximum blower door test leakage rates, and Heat Recovery Ventilator (HRV) installation and commissioning.

HfH - Seattle/South King County recently began a partnership with the Heat Pump Store in order to cultivate relationships for future installations of ductless heat pumps. Cost, installation procedures and maintenance considerations are currently being evaluated by HfH - Seattle/South King County and are discussed in Section 4, Evaluation of Measures for Future Implementation. The affiliate is also interested in the results of performance studies that are in process in the northern climates for potential future use; specifically the energy use impact in homes with higher occupancy levels (NEEA, 2009).

2.1.1 Funding Requirements

Habitat is funded primarily by donations. One of the primary supports for enhancing the efficiency of the homes is provided by the Home Depot Foundation (Foundation) and by local utilities. The Foundation encourages green/sustainable building by providing grants for homes that are ENERGY STAR certified and additional money if a second green/sustainable building program certification is also achieved. Those houses achieving Northwest ENERGY STAR certification would receive $5,000 per house with an extra $2,000 if certification was also achieved for another green/sustainable building. Phase 2 of Rainier Vista and phase 3 of High Point were to receive Home Depot Foundation money if Northwest ENERGY STAR certification

was achieved. The Seattle City Light (SCL) BuiltSmart program was the second certification undertaken[4].

SCL has a green/sustainable building program called BuiltSmart[5] that encourages multifamily projects, which are commonly electric zonal heat, to be more energy efficient. Money is given to projects for installing features that improve the energy efficiency beyond what the local building codes require. This is verified by a SCL BuiltSmart inspector.

The Washington State Housing Trust Fund, which is a major source of funding for Habitat, developed a green and sustainable building standard to assure that all of its projects meet minimum standards. This standard, the Evergreen Sustainable Development Standard (ESDS)[6], was developed based on the national Green Communities standard. These units researched were not constructed to ESDS.

2.1.2 Northwest ENERGY STAR Homes

Washington, Oregon, Idaho and Montana have an ENERGY STAR program that differs from the national ENERGY STAR program for new homes. Northwest ENERGY STAR Homes is a program unique to the northwest. It is set up in two prescriptive Builder Option Packages (BOPs) with Technical Compliance Options (TCOs) to modify the BOPs. The main difference between the BOPs is the heating system; BOP 1 is applicable to forced air gas furnaces while BOP 2 is for 100% zonal electric resistance heating. Each BOP standard has prescriptive requirements for insulation, ventilation, water heating, lighting, appliances, and air leakage.

HfH - Seattle/South King County had chosen to use electric resistance heating in the High Point and Rainier Vista homes, specifically baseboard heating with individual thermostats to control each baseboard. Electricity is relatively affordable in Washington compared to the rest of the country (roughly 8 cents per kWh in Western Washington)[7]. Baseboard heaters require little maintenance, have an extremely long service life, and are inexpensive to replace when they do fail. They are simple to use and allow zonal control. By putting emphasis on the envelope of the home, which is there for the life of the structure, the unit's heating load is reduced, allowing for the installation of a smaller system. This is a typical "systems engineering"

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[4] Home Depot Foundation, http://homedepotfoundation.org/

[5] Seattle City Light, BuiltSmart, http://www.ci.seattle.wa.us/light/conserve/resident/cv5_bs.htm

[6]Washington State Department of Commerce, Evergreen Sustainable Development Standard, http://www.commerce.wa.gov/site/1027/default.aspx

[7] Puget Sound Energy, 2011
http://pse.com/aboutpse/Rates/Documents/summ_elec_prices_2011_01_01.pdf

approach promoted by Building America, Northwest ENERGY STAR, and other energy efficiency programs. This heating equipment choice required the use of the BOP 2 standard.

The Northwest ENERGY STAR Homes program BOP 2 standard has several components that are significantly more stringent than those required in the BOP 1 standard. BOP 2 requires lower U-factor windows, increased wall insulation, a much tighter building shell, and a heat recovery ventilator (HRV) to assure proper ventilation. The maximum allowable air leakage with the BOP 2 standard was 2.5 ACH 50. This significantly reduces air leakage, but can be very difficult to achieve, especially in a multi-family or attached housing context.

2.2 Relevance to Building America's Goals

In an effort to reduce operating costs for Habitat homeowners, improve comfort for building occupants, and limit maintenance needed on the structures, HfH - Seattle/South King County's goals align with the DOE's Building America program goal to reduce home energy use by 30%-50%[8].

By researching best practices, sharing lessons learned and evaluating cost effective installation measures in affordable housing in the mild Marine Climate, this project aims to inform decisions made by the 1,700 Habitat affiliates in the US. Measures deemed to be cost effective in the Marine Climate could be readily applied to other more extreme climate zones where the heating load is more substantial and/or mechanical cooling is necessary.

While this research project is focused on new construction, best practices for air sealing strategies and installation of heat recovery ventilators (HRV) can be applied to Habitat's retrofit projects as well.

2.3 Research Questions

The following research questions and *corresponding approaches* were evaluated during the course of this project:

1. What impacts have the efficiency measures already completed had on energy use in Habitat homes?
    - Model 2006 Washington State Energy Code (WSEC) built units prior to implementation of energy upgrades. Compare code model to upgraded model to estimate energy savings and cash flow.

[8] Building America, Program Goals, http://www1.eere.energy.gov/buildings/building_america/program_goals.html

- Obtain utility data from occupied units to evaluate against modeled energy use.

2. What are the key lessons learned from the audit and analysis work?
    - Conduct process evaluation for installed measures to identify what worked and what did not work from an installation/purchasing perspective.
    - Cross check utility data, field data and modeled data to identify any discrepancies or outliers in the analysis process.
3. What best practices can be identified for increasing the efficiency of Habitat Homes in the future?
    - Identify building process key steps for installation of efficiency measures and include these in the Habitat building process work flow.
4. What is the impact of exterior foam sheathing, ductless heat pumps and heat pump water heaters on modeled energy use?
    - *Utilize BEopt software to evaluate impact of additional efficiency measures for future Habitat installation. Also identify modeling software limitations.*
    - *Determine cost effectiveness of additional measures by comparing estimated monthly utility savings against increased monthly mortgage.*

2.4 Cost-Effectiveness

It is critical that measures and practices evaluated for installation in HfH - Seattle/South King County's homes be cost-effective due to financial circumstances of typical Habitat homeowners.

Zero interest mortgages have allowed the affiliate to invest additional money in efficiency measures while not substantially affecting the homeowner's monthly mortgage payment. Habitat homeowners, including those at High Point and Rainier Vista, have access to zero interest, 30 year loans. **Table 1** includes the appraised value, purchase price of the units, and the monthly mortgage payment for 16 of the units (ranging from 1242 to 2106 square feet).

Each unit is appraised before the time of sale. The difference between the appraised value and the purchase price of the unit equals the equity note and in some cases, includes a City of Seattle note. The equity note stays with the unit in future transfer of ownership. If the homeowner were to sell the unit shortly after purchase they are required to pay Habitat back for the entire value of the equity note. Each year they live in the house, a small portion of the equity note is reduced. The equity note is entirely gone after 15-20 years.

Table 1. Purchase Price of Homes and Monthly Mortgage Payment.

Unit Size (sq-ft)	Appraised Value (includes equity note)	Purchase Price	Mortgage Based on Purchase Price
1609	$340,000	$148,000	$411
1458	$315,000	$161,187	$448
1609	$320,000	$166,187	$462
1609	$255,000	$188,000	$522
1458	$250,000	$168,000	$467
1609	$255,000	$228,000	$633
1458	$250,000	$168,000	$467
1458	$215,000	$163,000	$453
1458	$215,000	$163,000	$453
1674	$305,000	$255,000	$708
1355	$275,000	$169,000	$469
1355	$275,000	$169,000	$469
2106	$327,000	$272,000	$756
1587	$285,000	$215,000	$597
1242	$250,000	$155,000	$431
1561	$275,000	$205,000	$569

The base design energy features evaluated include envelope and equipment efficiencies consistent with the 2006 WSEC, with some exceptions. A summary of the base design is included in **Table 2**. Measures exceeding the requirements of the 2006 WSEC are noted in italics.

Table 2. Summary of Base Design Features

Building Component	Efficiency Level
Walls	R-21, 16" OC
Framed floor	R-30
Slab	*R-10 full, R-10 thermal break*
Attic insulation	R-38
Single rafter vault	*R-38*
Windows	*U .30, 12% glazing*
Infiltration	*3.1 ACH_{50}*
All elect. appliances	*Estar DW and clothes washer*
Lighting	*100% fluorescent*
Heating	Electric baseboard
Water heater	*Electric EF .92*

The incremental costs for the upgrade packages evaluated vary from $566 to $8,013.50 and are summarized in **Table 3**. Measures evaluated for installation in Habitat projects have the potential to increase Habitat homeowner's monthly mortgage in the range of 0.13% to 5%, not accounting for cost savings in utility bills.

The upgrade packages were selected by HfH - Seattle/South King County based on building practices that the affiliate is either in the process of considering implementing or has implemented. The mechanical equipment upgrades have not yet been installed in the homes, with the exception of HRVs. HfH - Seattle/South King County is using this research analysis to inform decisions regarding mechanical equipment upgrades in future projects.

Table 3. Summary of Evaluated Improvement Packages

Package number	Measures included	Cost
1	Base Design	NA
2	R5 exterior wall foam	$566.00
3	R10 exterior wall foam	$1,201.00
4	R10 foam and U -.22 windows	$1,945.50
5	R10 foam, U-.22 windows and HRV	$3,783.50
6	R10 foam, U-.22 windows, HRV and .95 EF water heater	$3,873.50
7	Package 6 and ductless heat pump	$6,873.50
8	Package 6 and heat pump water heater	$5,013.50
9	Package 6, heat pump water heater and ductless heat pump	$8,013.50

The costs used in evaluating the improvement packages are for materials only. Estimates from RS Means Construction Cost Data are used when appropriate to back out labor costs (RS Means, 2011). Further discussion of the cost of improvement packages for measures that are not included in BEopt Software, Version 1.1, is included in **Section 4**, Evaluation of Measures for Future Implementation. Evaluating the cost increase of the improvement packages presented difficulty. Habitat affiliates construct houses with a large percentage of volunteer and "sweat equity" labor. The amount of paid labor vs. volunteer labor varies by project. Due to this variation, it has been difficult for HfH - Seattle/South King County to track construction costs with labor costs fluctuating from project to project.

2.5 Utility Rates

The electric utility provider in Seattle, SCL, has a two tiered fee structure for residential electricity based on usage. SLC has a low income rate available for those making less than 40% of area median income in addition to a "market rate". The low income rate is 1.94 cents per kWh for the first 10 kWh used per day; all additional use is charged at 3.55 cents per kWh. By way of comparison, the market rate fee structure is 4.61 cents per kWh for the first 10 kWh used per day; all additional use is charged at 9.56 cents per kWh. Both the low income and market rate fee structures have a daily base service charge of 5.87 cents and 11.55 cents per meter, respectively[9].

Some of the homeowners in the homes evaluated paid the low income rate, while some paid market rate. This variation in utility fee structures based on income in addition to a tiered fee approach, made evaluation using BEopt challenging, as the software did not have the capability of accommodating a tiered fee structure.

[9] Seattle City Light, Rates, 2011, http://www.seattle.gov/light/accounts/rates/

3 Evaluation of Habitat Measures Implemented

The focus of improvement measures prioritized for implementation in the affiliate's projects was air leakage reduction, ventilation, and improving the thermal performance of the building envelope. Field inspection and testing was undertaken to determine if these goals were met.

3.1 Air leakage Reduction

The levels of air leakage reduction undertaken by HfH - Seattle/South King County are lower than the targets in the 2012 International Energy Conservation Code (IECC) and approach those used in high performance house construction. The issues faced by HFH are important to DOE and Building America as they must be solved before national implementation of dramatic air leakage reduction standards.

HfH - Seattle/South King County committed to building to the BOP 2 standard and embarked upon a program to achieve the standard's tight air sealing requirement. WSU Energy Program team members and Habitat for Humanity Washington State Support Organization sustainability consultants were brought in several times to conduct on the job training, review the construction progress, and make recommendations for improvements. An AmeriCorps Vista volunteer was hired to develop a jobsite protocol for the green and sustainable building programs that were being used. A large part of this protocol was developing the air sealing details needed to achieve 2.5 ACH_{50}. HfH - Seattle/South King County staff researched methods other affiliates and home builders had used, as well as attending conferences and building science training to increase the affiliate's knowledge and understanding of air sealing.

The majority of the units being constructed to BOP 2 standards were attached dwelling units including duplexes and townhomes. Therefore, every unit has at least one shared (party) wall with an adjacent unit. Party walls presented many challenges in determining and sealing potential air leakage paths.

3.1.1 Air sealing Techniques and Products Used in Construction

HfH - Seattle/South King County invested time and energy into training both their paid and volunteer workforce in air sealing techniques. Various strategies were employed, including sealing penetrations with caulk and/or spray foam, use of air tight electrical boxes to significantly reduce the air leakage to the house from electrical boxes shown in **Figure 1**, and installing drywall gaskets to seal the drywall to framing members.

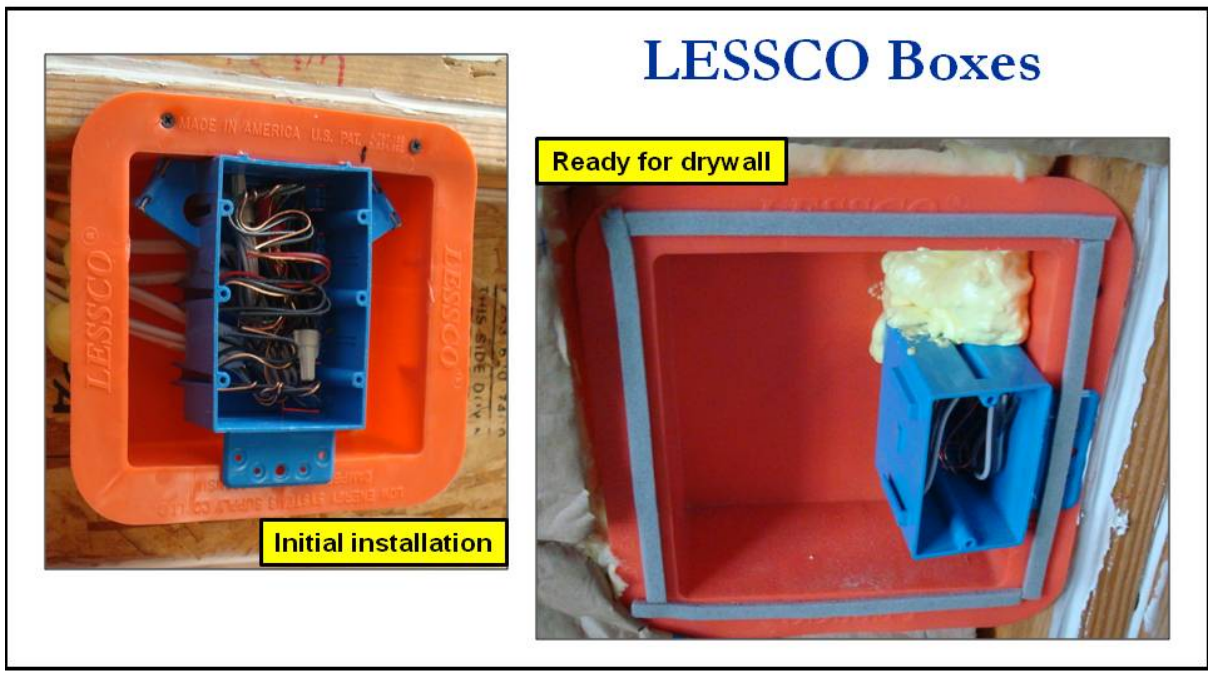

Figure 1. Photo of a Lessco Box Used in Air Sealing Electrical Boxes

Specialty sealing products such as the Owens Corning Energy Complete™ System, shown in **Figure 2**, were applied by licensed contractors. These types of products were only used on 5 homes and were installed after some air sealing with caulk and foam had already been completed, making it difficult to assess the direct impact of these specialty products on the home's air leakage rate. This is an area identified by HfH - Seattle/South King County staff for future research.

Figure 2. Photo of an Owens Corning Energy Complete System Installation

An additional factor impacting air leakage reduction is the installation of rigid foam board insulation on the exterior of the units at both High Point and Rainier Vista with all seams taped and sealed. Extruded polystyrene (XPS) rigid foam sheathing provides an additional insulation value of R-5 per 1 inch used. DOW brand rigid foam board insulation is donated to all Habitat affiliates throughout the country for use on the homes they construct or rehabilitate. The homes in the High Point Phase 2 development used 1 inch of rigid foam on the exterior of the building, as shown in **Figures 3 and 4**. Further discussion of rigid foam insulation is included in **Section 4**, Evaluation of Measures for Future Implementation.

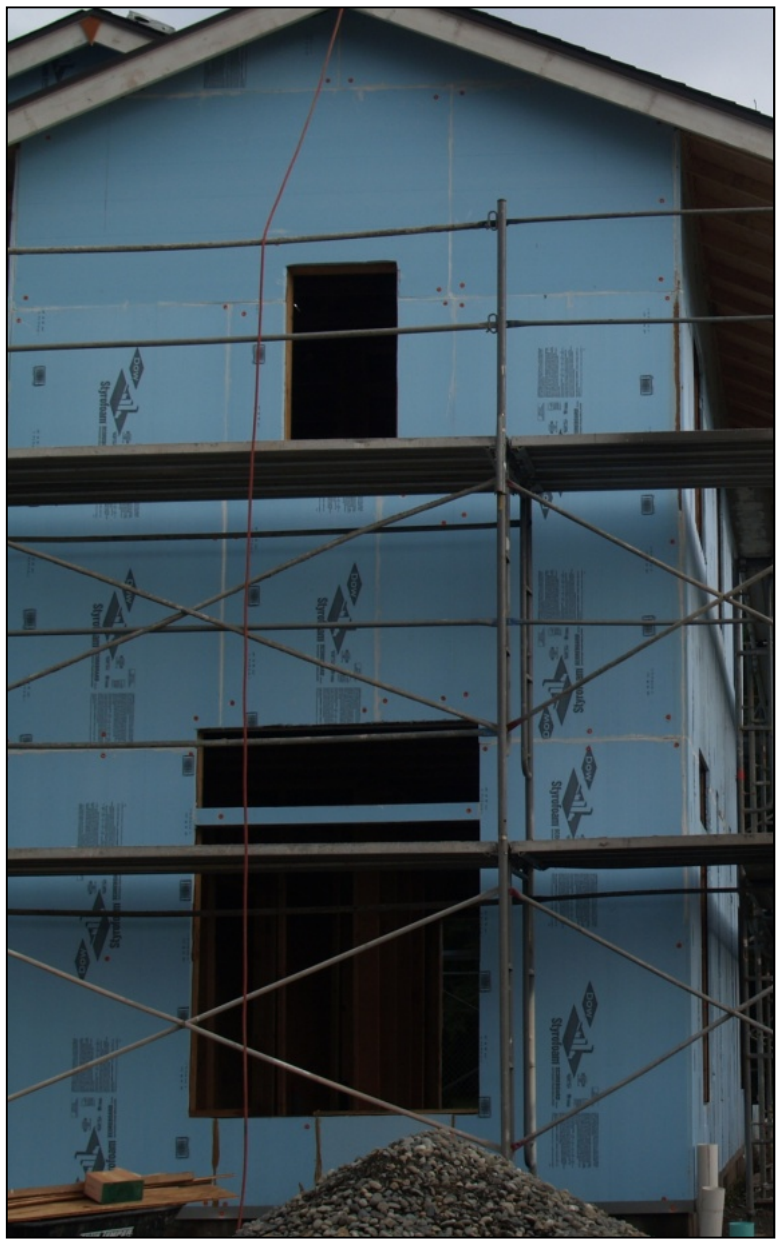

Figure 3. Photo of Rigid Foam Board Installed on the Exterior of the Wall Assembly

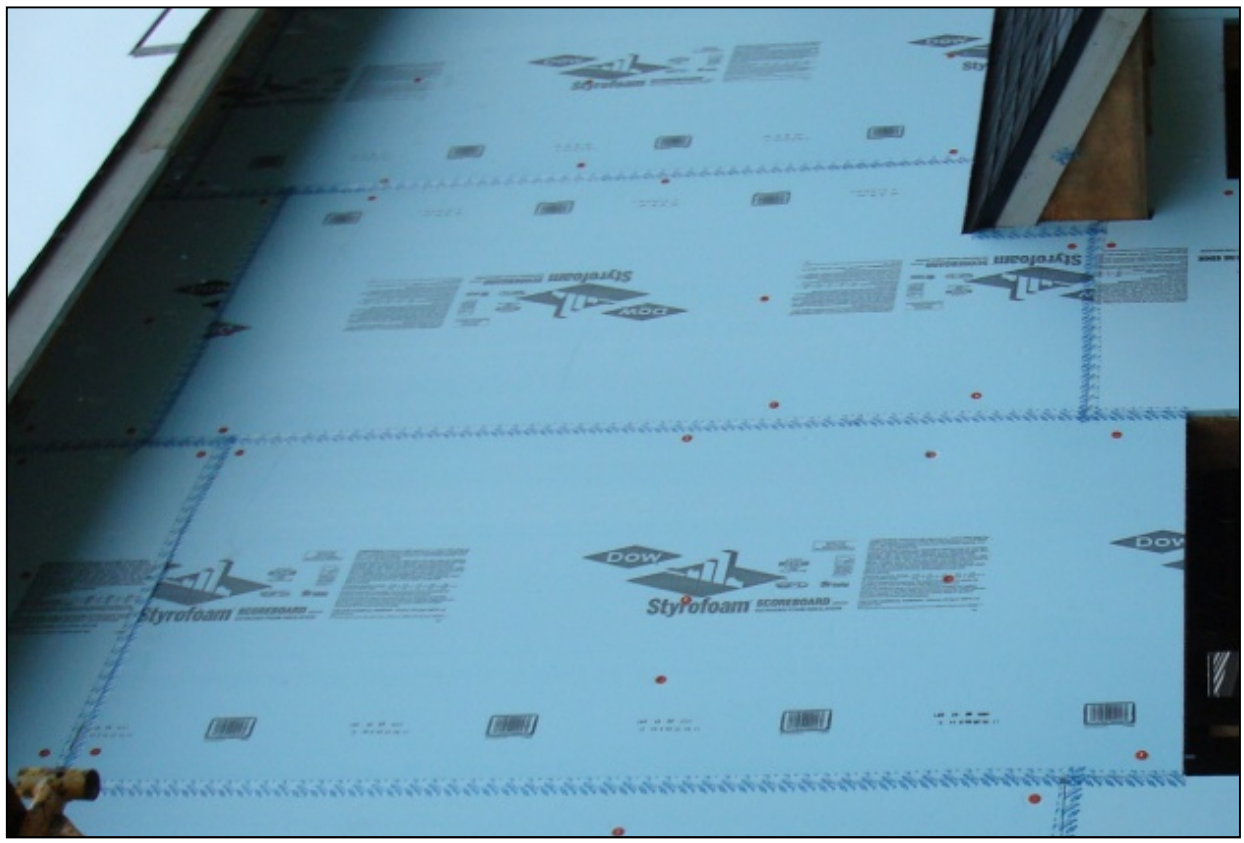

Figure 4. Photo of Taped Seams on Rigid Foam Board

3.1.2 Performance Testing of Building Envelope

Each unit was depressurized to 50 Pascals with relationship to the outside using blower door equipment following industry standards. These tests were conducted without simultaneously depressurizing the adjacent units. As a result, the blower door test results reflect air leakage outside of conditioned space in addition to air leakage to adjacent units. The Northwest ENERGY STAR Homes Program standard does not currently specify how the blower door test is to be conducted for multifamily-townhome style attached units. As such, it is unclear whether the air leakage requirement is intended to apply only to leakage to the exterior or includes leakage to adjacent units as well. The results would likely have been different if multiple blower doors were used to equalize the pressures between neighboring units, and is indicated as an issue for future Building America research in multi-family housing.

Twenty-three units were tested and included in the analysis. Multiple units in multiple developments completed over a three year time period were evaluated. **Table 4** includes the blower door results from the performance testing data in Air Changes per Hour at 50 Pascals (ACH_{50}) and Specific Leakage Area (SLA).

Table 4. Summary of Building Air Leakage Testing Results

Unit No.	Year Completed	Unit Type	Unit SF	CFM_{50}	ACH_{50}	SLA
1	2007	Duplex	1609	1083	4.75	0.00026
2	2008	Duplex	1458	958	4.64	0.00025
3	2008	Duplex	1609	866	3.8	0.00021
4	2009	Duplex	1609	670	2.94	0.00016
5	2009	Duplex	1458	599	2.9	0.00016
6	2009	Duplex	1609	754	3.31	0.00018
7	2009	Duplex	1458	578	2.8	0.00015
8	2010	Single Family	1774	525	2.09	0.00011
9	2010	Duplex	1230	436	2.5	0.00014
10	2010	Duplex	1230	472	2.71	0.00015
11	2010	Duplex	1458	673	3.26	0.00018
12	2010	Duplex	1458	609	2.95	0.00016
13	2010	Duplex	1230	502	2.88	0.00016
14	2010	Duplex	1230	526	3.02	0.00016
15	2010	Single Family	1230	418	2.4	0.00013
16	2010	4-Plex-Outer unit	1674	844	3.56	0.00019
17	2010	4-Plex-Inner unit	1355	561	2.92	0.00016
18	2010	4-Plex-Inner unit	1355	747	3.89	0.00021
19	2010	4-Plex-Outer unit	2106	1355	4.54	0.00025
20	2010	4-Plex-Outer unit	1587	625	2.78	0.00015
21	2010	4-Plex-Inner unit	1168	976	5.9	0.00032
22	2010	4-Plex-Inner unit	1242	915	5.2	0.00028
23	2010	4-Plex-Outer unit	1561	887	4.01	0.00022

Both High Point and Rainier Vista included multiple unit configurations completed at different times. Units completed prior to 2009 had no emphasis on air sealing (beyond the prescriptive air sealing requirements of the 2006 WSEC) during construction.

In an effort to reduce the air leakage rate to comply with the BOP 2 requirements built beginning in 2009, the volunteer work force attempted to identify and seal every possible source of air leakage. Habitat homes are largely constructed by volunteers supervised by paid Habitat site supervisors. Of the 20 homes that were to be constructed to the Northwest ENERGY STAR Homes program BOP 2 standard, 5 had professionally applied interior air sealing products such as Owens Corning Energy Complete or Knauf EcoSeal. The remaining 15 homes were entirely sealed by volunteers trained by Habitat staff. Very few of the volunteers have a construction background. Approximately half of the volunteers work on the jobsite at least monthly, the rest volunteer once and are typically unskilled in construction practices and

processes. The average leakage of the BOP 2 homes entirely sealed by volunteers was 3.63ACH$_{50}$, while the average house sealed by professionals was 2.87ACH$_{50}$.

The results of the blower door tests done at High Point and Rainier Vista are shown in **Figure 5**. The 2.5ACH$_{50}$ requirement for Northwest ENERGY STAR BOP 2 is indicated by the yellow line.

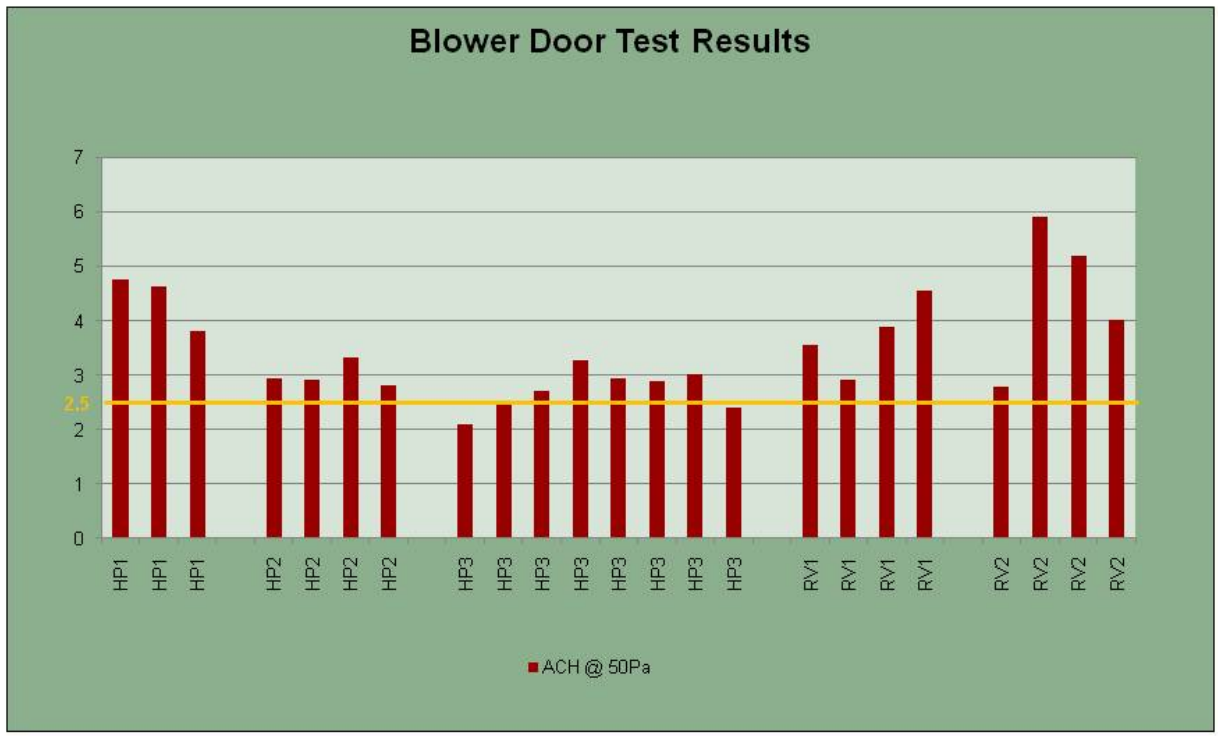

Figure 5. Blower Door Test Results for 23 Units

Photos of blower door tests in progress at High Point are included in **Figure 6**.

Figure 6. Photos of Blower Door Tests in Progress

3.2 Ventilation

As air leakage levels are reduced dramatically, induced ventilation becomes necessary. For this reason, whole house ventilation was provided to each home, providing an opportunity to study the energy impacts of two different ventilation strategies installed at High Point and Rainier Vista. The High Point Phase 1 development used an exhaust fan in the laundry room that was on a timer to run intermittently. Vents in the windows provided make-up air. The remaining developments (High Point Phase 2 and 3 as well as Rainier Vista buildings 1 and 2) used HRVs. **Figure 7** shows an HRV with its heat exchanger exposed. Window vents, when present, were closed during the blower door test, and HRV supply ports were closed and exhaust ports were sealed with tape.

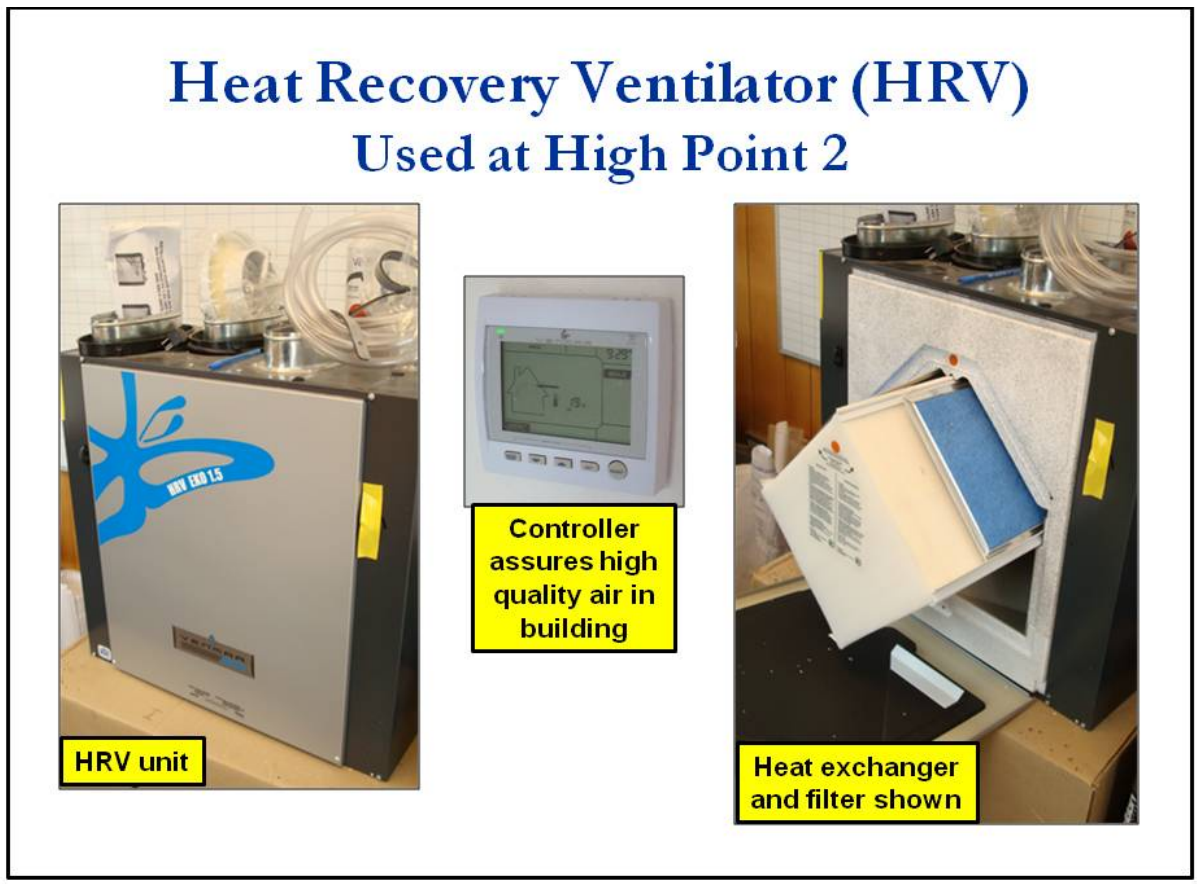

Figure 7. Photo of HRVs Used at High Point

Spot ventilation was provided in the bathrooms using exhaust fans in both developments. Some HRV installations use the HRV to draw moisture out of the bathrooms, but moisture can be a significant issue in the Seattle area therefore bathroom exhaust fans were provided in each of the bathrooms. Range hoods exhausting over the kitchen stoves were provided. The High Point Phase 2 and 3 developments as well as the Rainier Vista buildings 1 and 2 also included an exhaust fan in the laundry room set on a timer to run intermittently.

The Northwest ENERGY STAR BOP 2 specifications require the installation of a heat recovery ventilation system. Because the BOP 2 specifications require reduced air leakage, installing an HRV helps to ensure adequate indoor air quality. In addition, heat recovery ventilation systems provide the most energy efficient ventilation to homes achieving air tightness levels at BOP 2 levels or tighter.

The HRVs installed were Venmar AVS HRV EKO 1.5 with a sensible recovery efficiency of approximately 64-75 percent. Wattage consumed varies from 24 to 40 when operated at a flow range of 49-61 cubic feet per minute (CFM)[10].

3.2.1 HRV Installation

The HfH - Seattle/South King County experience found that the HRVs were simple to install and balance as specified in the manufacturer's instructions. The duct run placement and installation was more challenging. Ideally the ducts should be run, like all exhaust ducts, with as many straight runs and as few bends as possible which can constrict air flow and add static pressure. The ducts should to be properly sealed using mastic rather than duct tape. These best practices for installation proved to be challenging in a compact, complex, multi-family unit. Due to structural requirements, there were certain locations that penetrations for ducting could not be placed or could not fit. Some units had less than ideal duct runs. However, the flows to each zone were not tested, so the effect of the performance of the system is unknown at this time.

The HRV units themselves were installed in the conditioned space; typically hanging over the washer and dryer in the laundry closet. The ducts are mostly in the conditioned space; however, some of the ducting is in the attic and covered by blown-in insulation in the attic. If the ducts had been kept entirely within the conditioned space, associated duct leakage from the HRV would not affect the blower door test results, and the HRV, in general, would typically be more efficient.

3.2.2 HRV Commissioning and Operation

While the Northwest ENERGY STAR BOP 2 standards require installation of an HRV (or ERV), there is no specification or protocol in the standard to assure that the HRV has been commissioned properly or that the correct amount of supply and exhaust air is distributed to each living space.

HfH - Seattle/South King County did test the HRVs after installation; however, the manufacturer did not specify desired supply and exhaust air flow to each room. The system commissioning instructions, as provided by the manufacturer, simply required balancing the supply (fresh air flow) and the exhaust (stale air exhaust flow) using dampers within the unit. The balancing took place within the HRV unit itself. The individual flow rates to each room were not measured or adjusted. There does not appear to be a way to adjust flows, as there are no

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[10] Venmar, EKO 1.5 HRV, http://www.venmar.ca/en/product/root-category/air-exchangers/venmar-avs/products/eko-15-hrv-_124.aspx

adjustable dampers and the vents that are installed into each room do not appear to have the capability to adjust air flow with any precision.

More precise commissioning, including measuring and adjusting both supply and exhaust air flow to each room, can be challenging to accomplish, since it is very difficult to test and measure air flow at such low rates. Measuring supply and exhaust air flow from the exterior of the dwelling can problematic, including accessibility of exhaust air termination and fresh air intake location, often requiring ladders to access. Other factors affecting measurements include that the termination and intake locations are subject to wind variations, and the type and condition of exterior siding can impact accuracy of flow readings. With the products currently available, measuring the flow results from each supply port and adding the flows leads to results that may not be accurate or reliable (it should be noted, that some building performance testing equipment manufacturers are developing or considering developing products that combine a duct testing device with a powered flow hood – these products promise to measure flows down to 5-10cfm).

HfH - Seattle/South King County provided occupants with instruction on how the HRVs work and how to operate them correctly. The importance of cleaning the filter in the system has been stressed. Follow up will be needed in order to determine if the occupants truly understand how to use and maintain the systems properly. HRVs have been in 4 of the High Point units since 2008. There have been no complaints or questions raised to the affiliate about them. However, additional research and follow up may be conducted to further investigate occupant interaction and maintenance of these systems.

3.3 Building Envelope

The building envelope measures studied include:

3.3.1 Slab Insulation

With the exception of one phase at the multi-phase High Point development, all units have R-10 XPS installed under the full slab and have an R-10 thermal break between the slab and foundation stem wall, shown in **Figure 7**. While the WSEC requires full R-10 insulation to be installed only under a heated slab, an unheated slab requires R-10 for 2' either horizontally or vertically around the perimeter.

The donation of XPS foam to Habitat affiliates allows them to fully insulate slabs to R-10 cost effectively. While the cost of labor with HfH - Seattle/South King County has been difficult to track per unit given the amount of volunteer labor that is performed during the completion of a project, the increased cost for Habitat to fully insulate the slabs does not significantly impact the budget per unit.

Based on cost information available from DOW, the incremental cost to purchase 2" R-10 XPS to fully insulate a slab to R-10 vs. insulating the perimeter to R-10 for the High Point and Rainier Vista projects would roughly equate to an increase of $750 for material.

Figure 7. Photo of 2" R-10 XPS Installed Under a Slab at High Point

3.3.2 Rigid Foam Board Exterior Wall Insulation

Initially, HfH - Seattle/South King County staff and volunteers were skeptical about the use of R-5 XPS foam on exterior walls. However, following training and ongoing technical assistance, the use of foam was quickly embraced by Habitat, and has become standard for HfH - Seattle/South King County's building process. HfH - Seattle/South King County also installs R-5 XPS rigid insulation on rehabilitation projects when the siding is replaced. Since DOW donates their product to HfH - Seattle/South King County, the affiliate would like to install more than 1"on the exterior of the wall assemblies. This could be 2" of XPS or 1.5" of polyisocyanurate. However, HardiePlank® lap siding is typically installed on HfH - Seattle/South King County projects; Hardie specifies that in order to maintain the warranty of their product the attaching nail cannot cantilever any longer that 1" from solid wood. Battens would have to be used to install any more that one inch of XPS. A typical wall assembly section from High Point is included in **Section 6**, Appendices.

3.3.3 Windows

One of the greatest sources of heat loss in a home is through the windows. The 2006 WSEC (in effect at the time of initial construction of High Point and Rainier Vista) prescriptively required windows with an area weighted U-factor of .35. Later phases of development at High Point and Rainier Vista implemented the installation of more efficient windows. The first phase used U-.35 windows; successive phases improved to U-.30 and U-.22.

Building durability and low maintenance exteriors are critical issues for Habitat homeowners. The windows are carefully flashed with house wrap over the top of the upper window flange in order to prevent water intrusion problems shown in **Figure 8.**

Figure 8. Photo of High Performance Window Flashing

3.4 Analysis of Measures Implemented

The analysis of measures implemented included obtaining utility data for four High Point duplexes and comparing the usage data to modeled data using REM/Rate and BEopt.

3.4.1 Usage Data

The energy usage of seven all electric homes was evaluated as a component of this research project. At least one year of energy usage data was collected from four identical duplexes (there were only seven units in the analysis pool because HfH - Seattle/South King County was unable to obtain a signed waiver to release the energy usage data from one unit).

Each duplex consists of a 4 bedroom unit and a 5 bedroom unit. They are all 3 stories high. The footprint and the layout of the first two floors are identical; the third floor consists of either one or two bedrooms (the only variation between units). For both floor plans, there is a half bath on the ground floor and a full bath on the second floor.

All of the units were constructed in the Seattle Housing Authority neighborhood of High Point. This neighborhood's microclimate tends to be cooler and windier than many Seattle neighborhoods.

Energy usage in kWh per year is shown for each unit in **Figure 9**. The three units in Phase 1 have been occupied for over 2 years so, 2 year's worth of utility data is available. Despite the fact that Phase 2 incorporated improved air sealing detail and insulation levels, there does not appear to be lower energy usage in Phase 2. Looking at the year 1 and year 2 usage for Phase 1, there does not appear to be an across the board reduction in energy usage. No analysis was done to normalize heating or cooling degree days from year 1 to year 2 or to Typical Meteorological Year (TMY) 3 data used in BEopt.

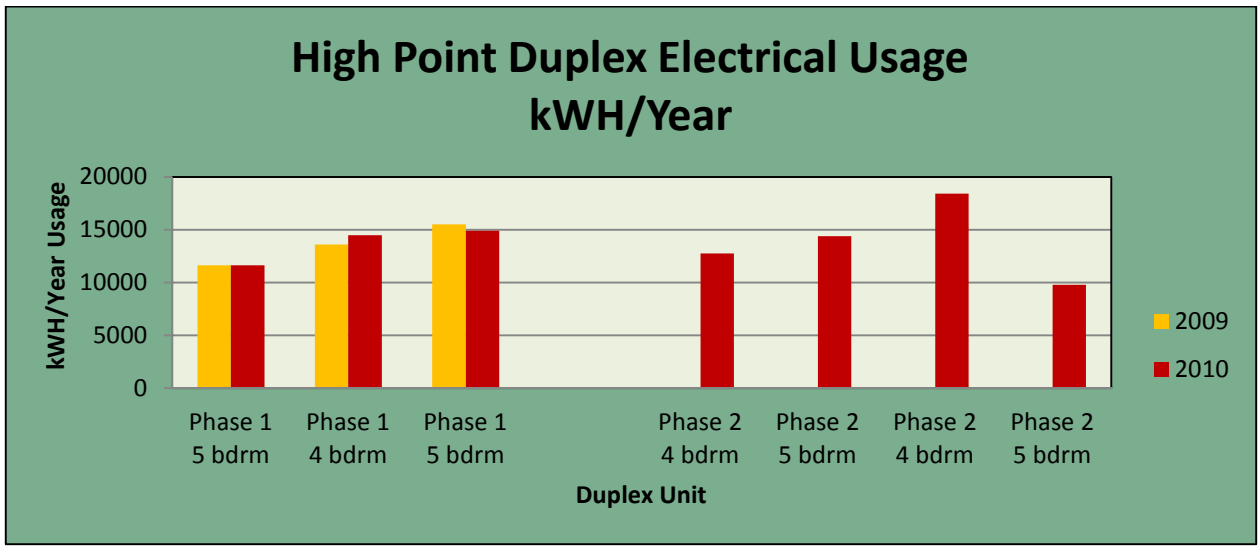


Figure 9. High Point Electrical Usage Data in kWh per Year

One question that the affiliate had posed was whether the low income rate offered through SCL discourages homeowners from energy conservation. **Figure 10** breaks out the annual usage by rate type. The rates have a base service charge per day, and a tiered fee structure based on usage (as described in **Section 2.5**). The difference between the low income and market rates are significant; however, there does not appear to be greater usage by the homes with the lower rates.

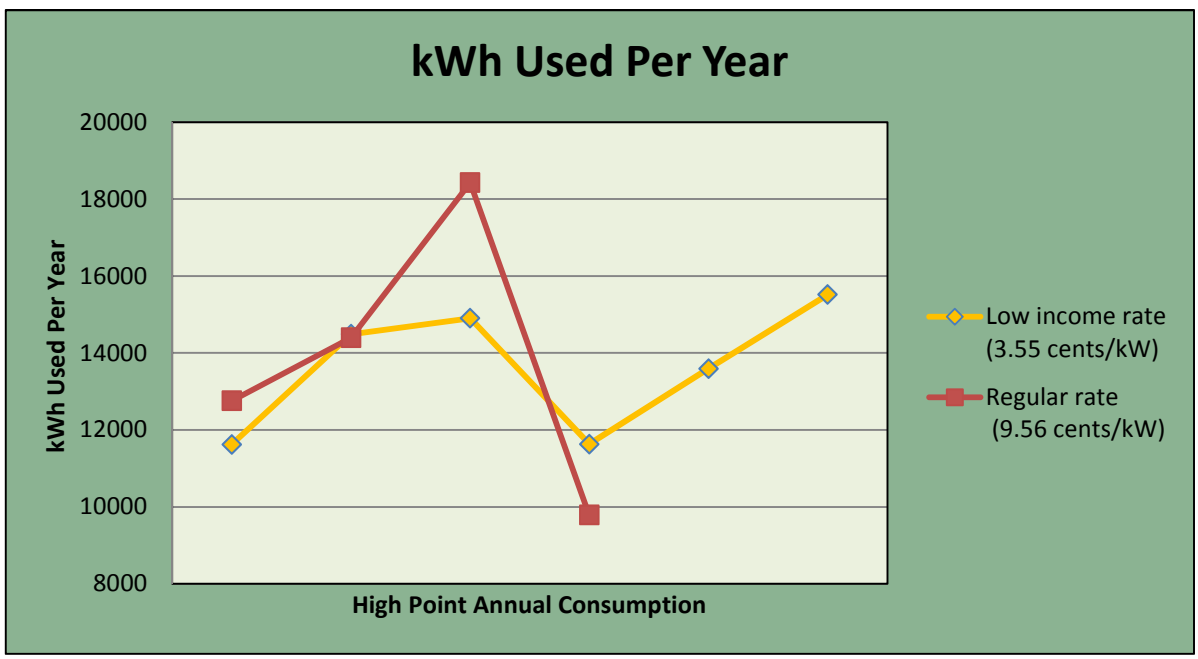


Figure 10. High Point Electrical Usage Data in kWh per Year, Regular vs. Low Income Rate

3.4.2 Modeled Energy Use

The energy modeling portion of the research project took place in two segments. The initial analysis was completed in REM/Rate v. 12.91. The results from REM/Rate allowed comparison of HERS Index results among units, estimated annual kWh usage to actual kWh usage, and estimated annual energy costs to actual annual energy costs.

REM/Rate v. 12.91 includes the ability to model multi-family units including delineation of adiabatic walls, floors and ceilings; a critical component of modeling units for High Point and Rainier Vista. The utility rate inputs for REM/Rate have the capability to specify a multi-tiered fee structure based on usage blocks. Since SCL has a tiered fee structure, the estimated annual energy costs from REM/Rate could be compared to the actual energy costs. **Figure 11** provides a comparison of the estimated annual energy consumption in kWh from REM/Rate to the actual annual energy use in kWh for units where utility bill data was available.

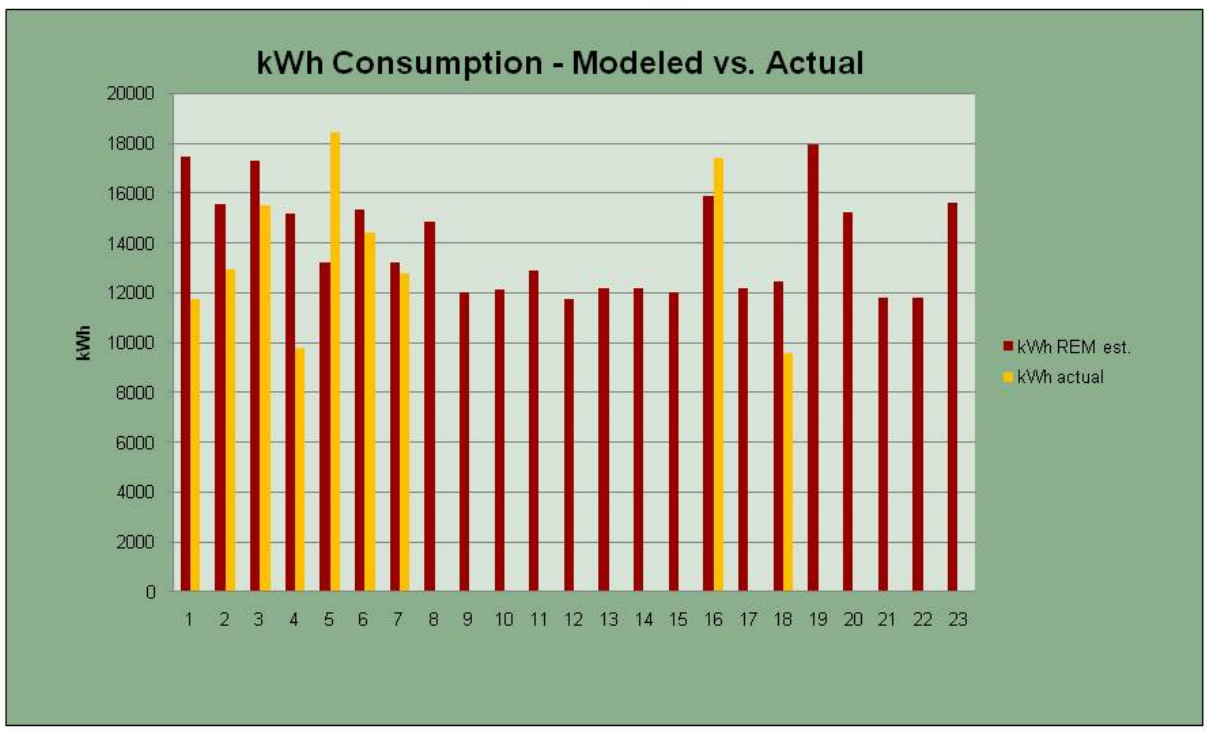


Figure 11. Chart Modeled vs. Actual kWh usage

Figure 12 allows comparison of the Home Energy Rating System (HERS) Index for the 23 units at High Point and Rainier Vista. The HERS index scoring system is a scale from 100 to 0, with 100 being a HERS Reference Home (essentially a home compliant with the 2004 IECC), 0 being a zero energy home. Each point corresponds to a percentage point of energy consumption

compared to the HERS Reference Home[11]. The HERS Index range for the Habitat units included in the research project is 68-90.

Phase 1 of High Point corresponds to units 1-3 in **Figure 12**. High Point Phase 2 is captured in units 4-15. There does seem to be a correlation between the phase of development for High Point and a reduction in HERS Index numbers. Units 16-23 are from Rainier Vista.

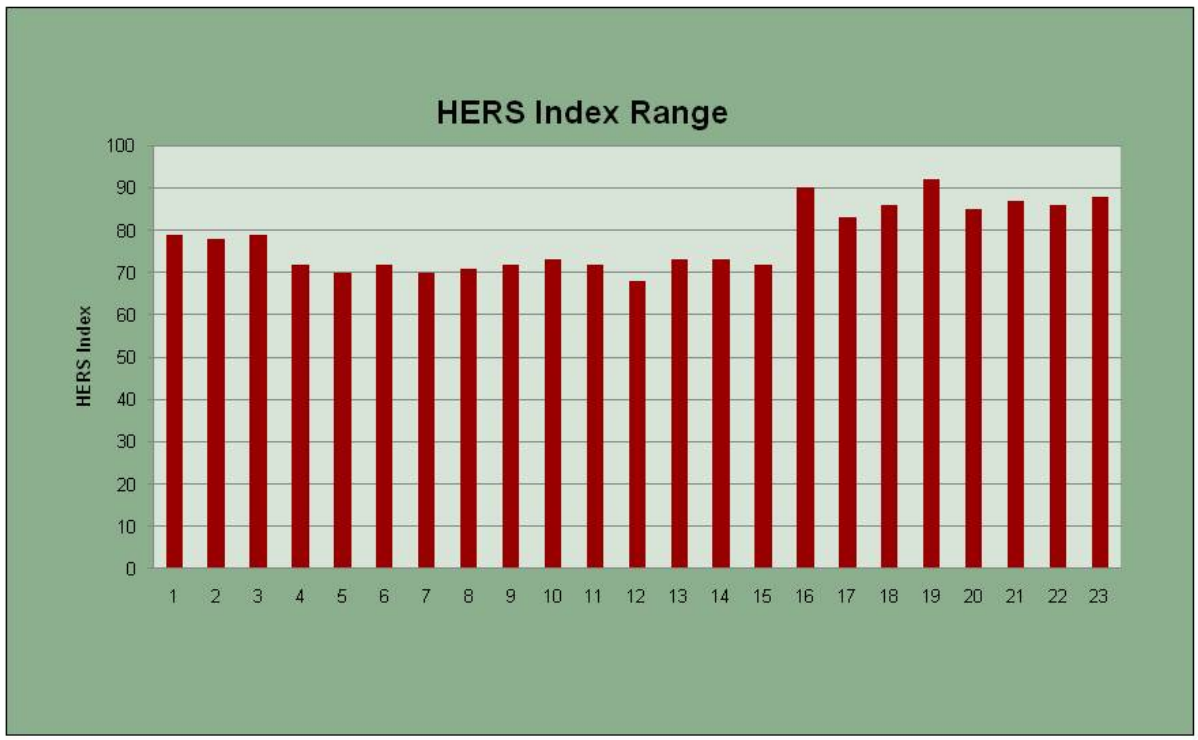


Figure 12. Chart HERS Index

A follow up analysis was then completed in BEopt v. 1.1. The BEopt analysis included several challenges based on the capability of software in its current state. A methodology to address these limitations was developed and discussed with BEopt software developers at NREL.

BEopt v. 1.1 does not have the capability to model multi-family or attached units. Because the majority of the attached units included in the study have a three story floor plan, there was not an easy way to account for adiabatic walls between units. As such, it was determined that the duplex buildings should be modeled as whole buildings; related outputs would be divided by two, with the exception of mechanical equipment that was adjusted externally, using BEopt output data, to account for the fact that there were two mechanical systems per building.

[11] Residential Energy Services Network, http://www.resnet.us/home-energy-ratings

Occupancy patterns also created challenges. BEopt includes a maximum of 5 bedrooms per building modeled, which is then used to calculate occupancy. Occupancy is based on the following equations from the Building America Simulation Protocols:

> The number of occupants in single-family and multi-family dwellings during non-vacation periods shall be estimated based on the number of bedrooms using Equations 28 and 29, respectively.
>
> ***Equation 28: Number of occupants = 0.59 × N_{br} + 0.87***
> ***Equation 29: Number of occupants = 0.92 × Nbr + 0.63***
>
> (Hendron, Engebrecht 2010)

Based on the occupancy assumptions in BEopt, the modeled buildings assumed occupancy of 3.82 and 5.23 respectively, for the whole building. Being that the 4 and 5 bedroom duplex units could not be modeled separately, occupancy has been dramatically underestimated. The sum total of bedrooms for whole buildings is 9. Occupancy in each unit varies for High Point and Rainier Vista between 5 and 11, meaning that a whole building could be occupied by 20+ individuals. As a result, internal gains have also been underestimated.

In discussions with BEopt developers, it was determined that while occupancy could be adjusted in the BEopt source files, using this approach can result in energy usage categories not scaling appropriately. Being that there was going to be post-processing of BEopt output data for modeling heat pump water heater and ductless heat pumps, it was determined that occupancy should not be adjusted[12].

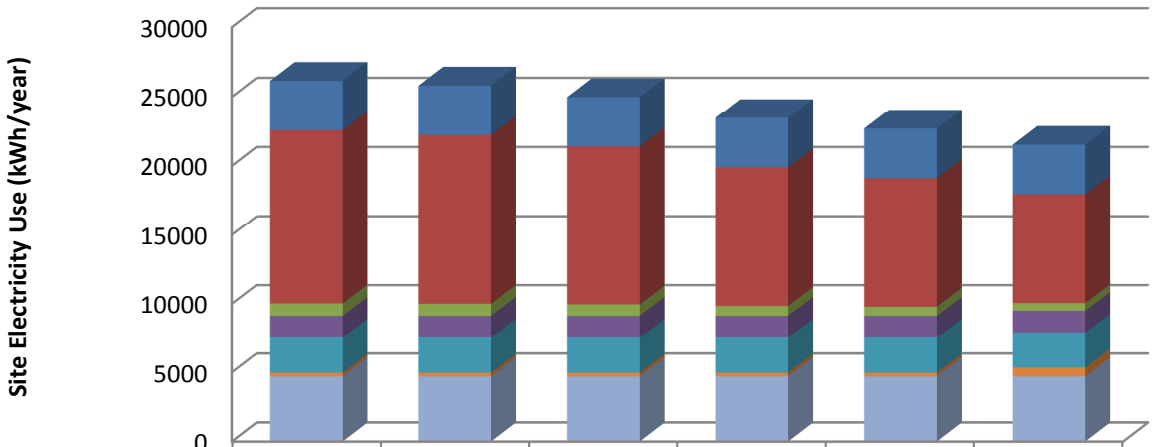
Further discussions of BEopt limitations are included in **Section 4**, Evaluation of Measures for Future Implementation.

Figure 14 includes the BEopt modeled site electricity use in kWh per year for the whole building, containing two duplex units, for the above baseline efficiency measures that the affiliate has implemented to date. On the left is a base building, built to the 2006 WSEC. To the right, the following improvement measures are added in succession:

- U-0.30 windows
- R-10 insulation under the full slab
- R-5 rigid insulation on the exterior wall assemblies
- U-0.22 windows

[12] Conversations with NREL, August 2011.

- Installation of an HRV (note that as modeled, this scenario only includes one HRV; in reality, it would include two – one for each unit).



	1 - 2006 Base	2 - 2006 + .30 windows	3 - Design	4 - Design +R5 Ext.	5 - Design +R5 ext. + .22 wind	6 - Design +5 ext. + .22 wind +HRV
Hot Water	3567	3567	3567	3567	3567	3567
Heating	12558	12235	11466	10056	9338	7902
HVAC Fan/Pump	897	873	820	716	664	560
Lights	1592	1592	1592	1592	1592	1592
Lg. Appl.	2566	2566	2566	2566	2566	2566
Vent Fan	258	258	258	258	258	624
Misc.	4707	4707	4707	4707	4707	4707
Totals	**26145**	**25798**	**24976**	**23642**	**22692**	**21518**

Figure 14. Chart of BEopt Modeled Energy Use for Whole Building

Table 5 includes the BEopt modeled energy usage by improvement package; each category from the whole building was cut in half to illustrate modeled estimates for each duplex unit. The improvement packages are listed in order of cost effectiveness, shown in **Table 3**. Plug loads and loads not included under major appliances are captured as Miscellaneous Electric Loads (MELs) abbreviated 'Misc.' in **Table 5**.

Table 5. Modeled Energy Use in kWh per Year for Duplex Unit.

	2006 WSEC	.30 wind	R-10 Full Slab	R-5 ext	.22 wind	HRV
Misc. kWh/yr	2353.5	2353.5	2353.5	2353.5	2353.5	2353.5
Vent Fan kWh/yr	129.0	129.0	129.0	129.0	129.0	312.0
Lg. Appl. kWh/yr	1282.9	1282.9	1282.9	1282.9	1282.9	1282.9
Lights kWh/yr	796.0	796.0	796.0	796.0	796.0	796.0
HVAC Fan/Pump kWh/yr	448.5	436.5	410.0	358.0	332.0	280.0
Heating kWh/yr	6279.0	6117.5	5733.0	5028.0	4669.0	3951.0
Hot Water kWh/yr	1783.5	1783.5	1783.5	1783.5	1783.5	1783.5
Total kWh per year	13072.4	12898.9	12487.9	11730.9	11345.9	10758.9

Energy use savings over the WSEC 2006 base unit were then calculated in kWh per year and in dollars per year; assuming a cost of 8.7 cents per kWh show in **Table 6**. Each measure was modeled in succession resulting in cumulative savings for the package.

Table 6. Modeled Energy Savings for Incremental Measure Install per Duplex Unit

	Savings in kWh/yr over 2006 Base Unit	1st year Savings in utility cost; 8.7 cents/kWh
2006 WSEC Base	NA	NA
.30 windows	173	$15.09
R-10 Full Slab	585	$50.85
R-5 ext. foam	1342	$116.71
.22 windows	1727	$150.21
HRV	2314	$201.27

For reference, BEopt modeled energy use estimates for each improvement package was divided by the average square footage for the High Point duplex units (1551 square feet) and average occupancy, see Table 7. These include the Miscellaneous or plug load in Table 5.

Table 7. Modeled Energy Use per Square Foot and Per Occupant.

	Annual Energy Use (kWh) per Square Foot	Annual Energy Use (kWh) per Occupant, Average Occupancy = 7
2006 WSEC Base	8.43	1867.49
.30 windows	8.32	1842.70
R-10 Full Slab	8.05	1783.99
R-5 ext. foam	7.56	1675.84
.22 wind	7.32	1620.84
HRV	6.94	1536.99

In an effort to index the two software products to each other in addition to actual energy use, for the nine units that utility usage data is available, the kWh per year, both modeled estimates and actual usage, were compared. **Table 8** summarizes these results. The additional 2 units in the sample are from Rainier Vista building 1, and are listed as units 8 and 9.

Table 8. Comparison of Actual to Modeled Estimate, kWh/year

Unit	REM kWh est.	kWh actual	BEopt kWh est.
1	17463	11741	13072
2	15558	12935	13072
3	17287	15520	13072
4	15177	9790	11730
5	13214	18429	11730
6	15324	14397	11730
7	13214	12758	11730
8	15881	17388	11730
9	12453	9592	11730

To further compare the software against actual energy use, the percentage of deviation for each software's energy use estimates were calculated against the actual energy use. Additionally, the percentage of deviation between REM/Rate and BEopt was calculated. The results are summarized in **Table 9**.

Table 9. Percent Deviation of Estimated Energy Use from Actual

Unit	% REM/Rate deviates from actual	% BEopt deviates from actual	% of deviation between BEopt and REM/Rate
1	48.73	11.34	25.14
2	20.28	1.06	15.98
3	11.39	-15.77	24.38
4	55.03	19.82	22.71
5	-28.30	-36.35	11.23
6	6.44	-18.52	23.45
7	3.58	-8.06	11.23
8	-8.67	-32.54	26.14
9	29.82	22.29	5.80

The mean deviation of the software estimates and actual use based on the 9 home sample set is included in **Table 10.**

Table 10. Mean Percent Deviation of REM/Rate and BEopt Estimated Energy Use from Actual

Mean % REM/Rate deviates from actual	Mean % BEopt deviates from actual	Mean % of deviation between BEopt and REM/Rate
15.37	-6.3	18.45

4 Evaluation of Measures for Future Implementation

With the affiliate becoming increasingly comfortable implementing efficiency measures above energy code required efficiencies and primarily focused on the building envelope, HfH - Seattle/South King County is ready to evaluate measures for future implementation in their building process. The measures that the affiliate has prioritized for evaluation are increasing exterior rigid foam insulation to R-10, installing ductless heat pumps and heat pump water heaters. Additionally, U-0.22 windows and EF .95 water heaters will be evaluated.

Hardie lap siding is the typical product used on the exterior wall assemblies for the affiliate's projects. As previously stated, Hardie specifies that attaching nails cannot exceed 1" cantilever for the product warranty to be valid. The use of R-10 rigid foam board insulation on the exterior of the wall assemblies includes product warranty challenges, but was not eliminated as a measure worthy of evaluation.

Ductless heat pumps are another measure that the affiliate would like to install in future projects. HfH - Seattle/South King County's heating system product selection is guided by the philosophy of being simple to operate, low maintenance, durable, and low cost. Electric resistance baseboard heaters with individual thermostats are often provided as the heating system. Baseboard heaters are durable, easy to use and control, require little to no maintenance, are inexpensive to replace, and do not circulate dust around the living space (which can exacerbate asthma concerns for many of the families). A picture of a typical heater and simple thermostat used in Habitat developments is shown in **Figure 15**. The heaters vary in Wattage from750-1500W depending on the size of the space being heated. The total heating load per unit in High Point and Rainier Vista varies from 5.00-7.75 kW/unit, with the number of heaters per unit between 5 and 8. The total baseboard wattage provide per unit ranges from 6.25 to 7.0 kW. Seattle has a heating outdoor design temperature of 24 degrees. Seattle does not have a large cooling load. As such, no cooling is currently provided.

Figure 15. Photo of Typical Baseboard Heaters Used at High Point and Rainier Vista

Ductless heat pumps (DHP) would appear to be a good fit for install in the main living spaces of the Habitat units, with electric resistance back up heaters in the bedrooms. As such, the cost effectiveness of installing DHPs was evaluated.

Heat pump water heaters (HPWH) are also a measure that has been identified as a priority for evaluation. Habitat homes typically have high occupancy and the amount of energy used for water heating is often a larger percentage of the total energy use for the unit than would be expected. Efficiency improvements in the water heating equipment could potentially pay back more quickly than would otherwise be expected.

Currently, 60 gallon electric tank water heaters are provided for each unit. The water heaters are located in the conditioned space. The efficiency for the units provided at High Point and Rainier Vista ranges from EF 0.90 to EF 0.92. The units have a small overall footprint, so the plumbing runs are short. **Figure 16** shows a typical water heater installation in an interior closet. The affiliate has not received any negative feedback from the homeowners about the water heaters or any complaints that they run out of hot water even in high occupancy homes.

Figure 16. Photo of Typical Water Heater Installed in Conditioned Space

4.1 Challenges of Modeling Mechanical Upgrades

BEopt v. 1.1 does not currently have the capability of modeling ductless heat pumps or heat pump water heaters. Given that these two technologies were prioritized for evaluation in Habitat projects, a post-processing strategy of adjusting the end-use output data from BEopt was developed in consultation with NREL and Ecotope based on operating efficiencies of these technologies in the mild marine climate.

Zoning of the heating system, in addition to the variable-speed compressor performance, where a DHP serves the main living space and electric resistance serves the secondary zones creates a challenge for BEopt energy modeling. It was determined that the heating energy use category from the BEopt model outputs with 100% electric resistance would be divided by 1.6 to reflect the efficiency of a DHP with a COP of 1.6 taking into account the zonal considerations of electric resistance backup[13] and the internal gains in the conditioned space. The impact of cooling energy use was not evaluated because Seattle has little to no cooling load.

HPWHs located in conditioned space use room air for supply and return that air at a substantially cooler temperature. To address this limitation, the Miscellaneous Electrical Loads (MELs) in BEopt were adjusted by subtracting the equivalent of 600 Btu/h to account for the increase in heating load. The annual water heating energy from the BEopt output would then be divided by a COP of 1.7 to account for the efficiency of the HPWH. The Pacific Northwest is working on a technical fix called the Northern Climate Specification (NCS). In addition to requiring certain performance factors, it also specifies installation practices. One of the key requirements is that the discharge air be vented outside the conditioned space rather than cooling conditioned space.

4.2 BEopt Estimated Energy Savings

The estimated energy savings from BEopt software was calculated annually and monthly. Monthly savings estimates were then derived in kWh per month over the base design and monetary savings over the base design using an 8.7 cent kWh cost estimate. The results are summarized in **Table 11**.

[13] Conversations with Ben Larson, Ecotope, August 2011.

Table 11. Estimated Annual Energy Use, Monthly Energy Use and Savings by Package

Package number	Measures included	Annual Total kWh/yr	Monthly Total kWh/month	Monthly Savings over base kWh	Monthly Savings over base $$$
1	Base Design	12487.9	1040.7	NA	NA
2	R5 exterior wall foam	11730.9	977.6	63.1	$5.49
3	R10 exterior wall foam	11328.4	944.0	96.6	$8.41
4	R10 foam and U -.22 windows	10943.9	912.0	128.7	$11.19
5	R10 foam, U-.22 windows and HRV	10758.9	896.6	144.1	$12.54
6	R10 foam, U-.22 windows, HRV and .95 EF water heater	10695.6	891.3	149.4	$12.99
7	Package 6 and ductless heat pump	9213.8	767.8	272.8	$23.74
8	Package 6 and heat pump water heater	9624.7	802.1	238.6	$20.76
9	Package 6, heat pump water heater and ductless heat pump	7997.3	666.4	374.2	$32.56

4.3 Incremental Costs for Measure Packages and Monthly Cash Flow

The incremental costs represent the material cost without labor for the energy improvement packages and were calculated using RS Means Construction Data adjusted where appropriate to take into account HfH - Seattle/South King County specific costs. The affiliate has had difficulty tracking and estimating labor costs due to the variation in volunteer vs. paid labor on projects. Cost data involving mechanical systems was derived by contacting local HVAC suppliers in the Northwest Region, and adjusted for bulk purchasing discounts for the affiliate[14].

Because Habitat is able to offer 30 year loans with a 0% interest rate to the homeowners, cost effectiveness is more readily justified than it would be in a typical 30 year loan with a 7% interest rate. All measure packages evaluated resulted in a positive monthly cash flow when comparing the monthly energy savings to the increased monthly mortgage cost (due to the cost of the energy efficiency package) at 0% interest. This is not the case if comparing to the increased monthly mortgage at a 7% interest rate.

Table 12 summarizes the monthly mortgage payment increase at both 0% and 7% and calculates the monthly cash flow.

[14] Conversations with Gensco and Johnstone Supply, September 2011.

Table 12. Increased Monthly Payments and Monthly Cash Flow

Package number	Measures included	Cost for Package	Monthly Increase at 0% Interest	Monthly Increase at 7% Interest	Monthly Cash Flow: Savings - at 0% Interest
1	Base Design	NA	NA	NA	NA
2	R5 exterior wall foam	$566.00	$1.57	$3.77	$3.92
3	R10 exterior wall foam	$1,201.00	$3.34	$7.99	$5.07
4	R10 foam and U -.22 windows	$1,945.50	$5.40	$12.94	$5.79
5	R10 foam, U-.22 windows and HRV	$3,783.50	$10.51	$25.17	$2.03
6	R10 foam, U-.22 windows, HRV and .95 EF water heater	$3,873.50	$10.76	$25.77	$2.23
7	Package 6 and ductless heat pump	$6,873.50	$19.09	$45.73	$4.64
8	Package 6 and heat pump water heater	$5,013.50	$13.93	$33.35	$6.83
9	Package 6, heat pump water heater and ductless heat pump	$8,013.50	$22.26	$53.31	$10.30

4.4 Analysis of Measures Recommended for Future Install

The modeled energy usage estimates for all improvement packages seem to indicate that the cost savings in utility bills would exceed the increased mortgage payment to finance the improvement when applied to a zero percent loan. Given the limitations of the modeling the proposed mechanical upgrades in the modeling software, further analysis will need to be completed before the affiliate is likely to implement upgraded mechanical equipment as standard practice. Possible installation of equipment upgrades will likely be accompanied by extensive monitoring of usage data and homeowner feedback in order for the affiliate to truly evaluate the cost effectiveness and suitability of such measures.

5 Conclusions

The results of this research project thus indicate that the efficiency measures that the affiliate is currently including in their construction processes are cost effective and feasible to install with a volunteer labor force. Measures evaluated for future use indicate that further analysis needs to be completed. Software with improved capability to model attached units and proposed mechanical upgrades, in addition to monitoring of installed measures in test homes, would assist in this evaluation.

5.1 Utility Data

The energy usage of seven all electric homes were studied as a component of this project. At least one year of energy usage data was collected. Looking at this very small sample size of 7 units with 10 data points, it is difficult to draw any specific conclusions. There are, however, several homes that warrant additional study and exploration due to extremely high or low energy usage compared to the others. Additional data from these and other units need to be added to the data set in order to draw firm conclusions.

5.1.1 Utility Data Acquisition

HfH - Seattle/South King County builds homes throughout the greater King County region. There are multiple utility providers in the region; each with varied forms and/or processes in place for a third party to obtain usage data.

In the affiliate's experience, it has been difficult to streamline the process of the utilities releasing the usage data to Habitat. A waiver is often signed by the homeowner at time of sale, but has not historically always been completed. Changes in staff and points of contact at both the utilities and with the affiliate add additional potential for complication. A unified waiver form- signing process at time of sale and unified release policies for usage data in coordination with Habitat and other low income programs and their research partners would appear to address this problem.

The data is not presented in a consistent manner from the multiple utility providers. The data has been presented to the affiliate in yearly, bi-monthly, monthly, or daily totals. It can be time intensive to process the data when it becomes available to make comparisons among projects with different utility providers. A data managing tool would assist the affiliate in the data tracking and analysis.

5.1.2 Homeowner feedback

The family services representative may hear feedback from Habitat homeowners regarding issues or concerns about their home; but not always. Specific complaints about the operation or maintenance of the homes motivates the homeowners to express their opinions, however, more subtle issues around operating their homes for optimum energy reduction is not typically

addressed. Follow up homeowner surveys done on an annual basis would assist the affiliate in identifying these issues in addition to providing feedback on high/low energy use.

5.2 Cost Data

Precise cost data has been difficult to obtain, due to the products that are discounted, or donated to Habitat. The cost of labor is another variable that can fluctuate with the affiliate's projects based on the amount of volunteer labor that is available during the build process.

Careful tracking of cost data by building component, equipment and installation costs (including both material and labor) would assist the affiliate in more accurately determining the cost effectiveness of various energy improvements. In absence of consistent cost data for the affiliate, an evaluation of cost effectiveness is an approximation.

5.3 Capability of Modeling Software

Modeling buildings to accurately estimate energy usage is an issue that is increasingly discussed in the building community as additional modeling tools become available and refined for the market. As the technology and systems that we install in homes becomes increasingly more complex, software tools require revision to take into account these components and their interaction.

The next version of BEopt will likely include the capability of modeling attached units, ductless heat pumps and heat pump water heaters. When it is released, follow up modeling and comparison of the new BEopt output results against the results of this study should be conducted. This comparison will serve to better inform the recommendations of measures for future installation in Habitat projects.

5.4 Air Leakage Testing Protocol for Multi-Family and Attached Units

The data sample included in this study for blower door results is not large enough to draw detailed conclusions, however there are a number of observations to be made and research questions that may be investigated in the future.

Twenty-three units were blower door tested in two different developments built over a total of 5 different phases. The more complex Rainier Vista 4-plexes showed higher air leakage numbers. These numbers may have been lower if multiple blower doors were used to depressurize the adjacent units so only exterior leakage was evaluated. Both phases of the Rainier Vista development also had multiple site supervisors; this made it difficult to ensure that air sealing specifications were consistently met. It is unknown at this time if the lack of continuity in site supervision impacted blower door results.

The High Point units showed a drop in air leakage rates once air leakage became a focus in the construction process. Having a consistent site supervisor for all of the phases, along with the identical design for many of the units likely aided in the lower leakage numbers.

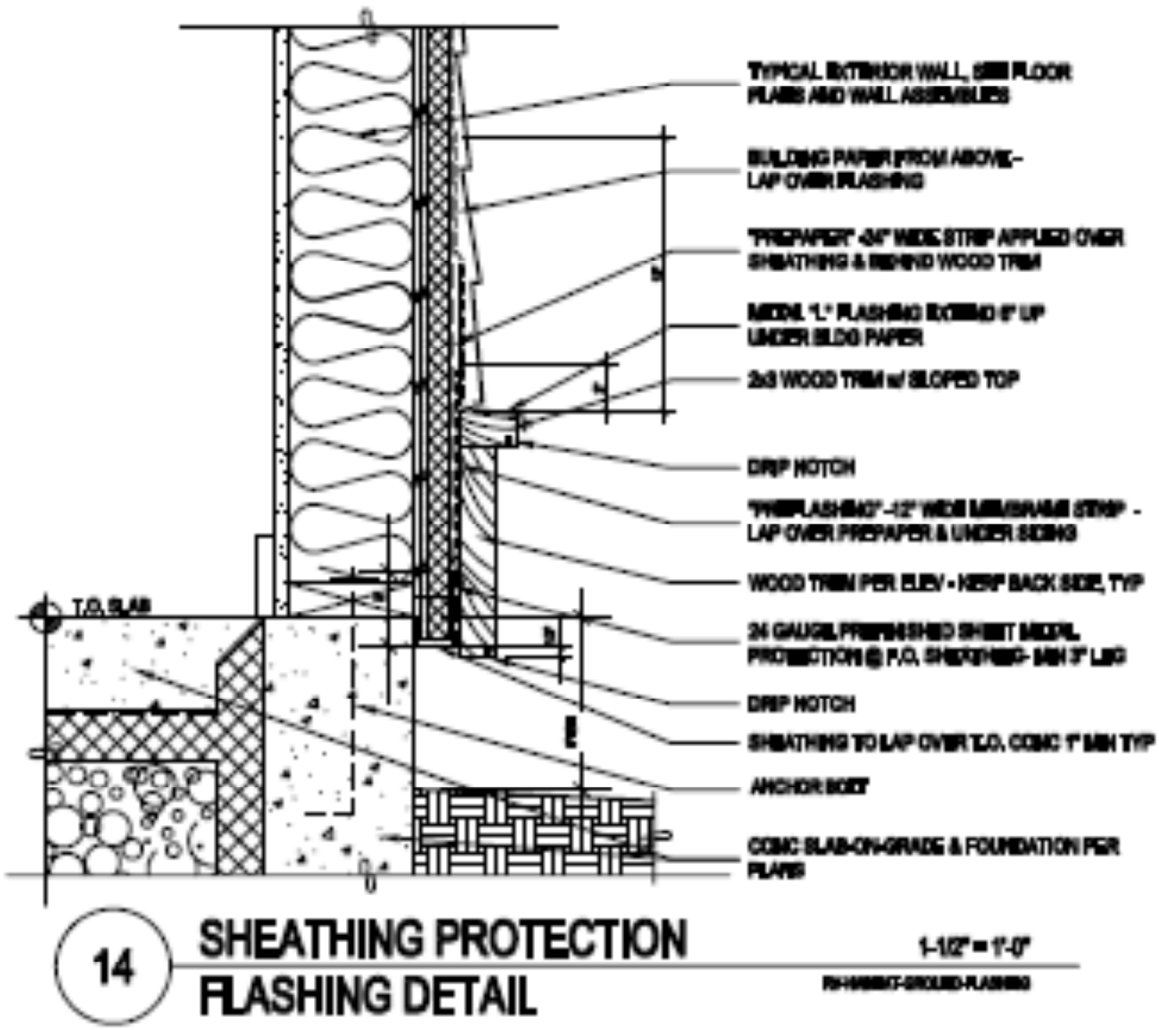
While the data set was limited, the units that were air sealed using standard foam and caulk did not seem to have increased air leakage compared to blower door results from the units that had Energy Complete and EcoSeal installed. This seems to indicate that a well trained staff can be just as effective at air sealing as specialty products used for this purpose.

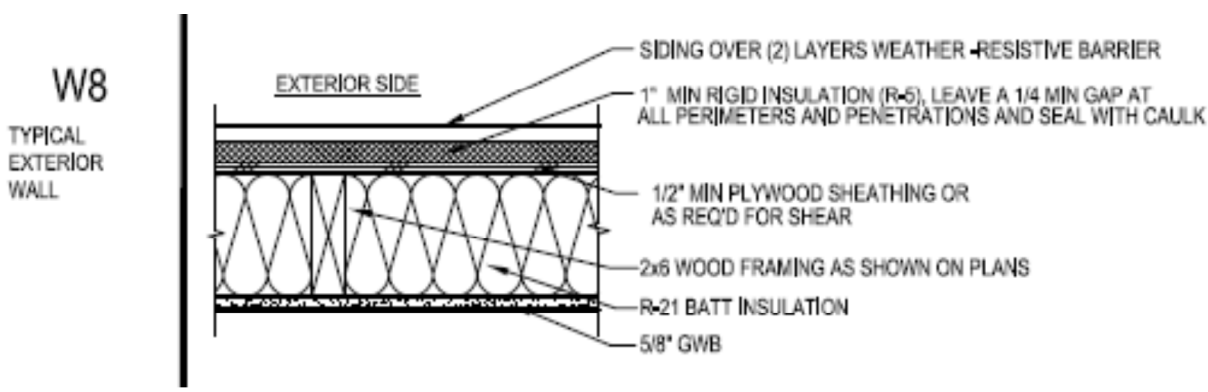
It would be informative to retest these units while simultaneously depressurizing the adjacent units to have a clearer understanding of the amount of air leakage to adjacent units and the amount of air leakage to ambient conditions. Access to additional blower door equipment and trained operators would be key to executing this comparison and testing future projects in this manner. The result of a systematic approach would be to develop a protocol for accurately testing adjacent units.

Performing the blower door tests on attached units while not depressurizing the adjacent units likely impacted the affiliate's ability to meet the air leakage targets for the Northwest ENERGY STAR, BOP 2 threshold of 2.5 ACH_{50}. As the WSEC now includes a blower door requirement and maximum leakage rate for all IRC defined single family residential structures, a clear protocol for testing attached dwelling units will be critical for these units to meet specifications of both the energy code and voluntary certification programs in future projects.

6 Appendices

6.1 High Point Wall Assembly Section; Sheathing Protection Flashing Detail and Typical Exterior Wall





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