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Evaluation of Modeled and Measured Energy Savings in Existing All Electric Public Housing in the Pacific Northwest

Andrew Gordon, Michael Lubliner, Luke Howard, Rick Kunkle, and Emily Salzberg
BA-PIRC

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Evaluation of Modeled and Measured Energy Savings in Existing All Electric Public Housing in the Pacific Northwest

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Definitions

ACH_{50}	Air changes per hour at 50 Pascals
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEopt™	Building Energy Optimization software
CFM_{50}	Cubic feet per minute at 50 Pascals
DHP	Ductless heat pump
ELA	Effective leakage area
EqLA	Equivalent leakage area
ERV	Energy recovery ventilation
HPWH	Heat pump water heater
KCHA	King County Housing Authority
LEED	Leadership in Energy and Environmental Design
MEL	Miscellaneous electric load
RH	Relative humidity
THA	Tacoma Housing Authority
TPU	Tacoma Public Utilities
VIAQ	Washington State Ventilation and Indoor Air Quality Code
WSEC	Washington State Energy Code
WSU	Washington State University Energy Program

Acknowledgments

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Executive Summary

This project evaluates market-ready energy solutions to improve the efficiency of affordable housing for new and existing (built since 2001) affordable housing in the marine climate of Washington State.

The project analyzes the cost effectiveness of energy savings measures installed by a large public housing authority in Salishan, a community in Tacoma, Washington.

The previous, first year report focused on the last of seven phases of construction (referred to as Salishan 7 in this report), which integrated energy efficiency technologies including a "hybrid" heating system, with a ductless heat pump (DHP) providing heat to the first floor, electric resistance heaters providing heat to the bedrooms, and increased envelope insulation (Gordon, Lubliner, Howard, & Kunkle, 2013).

This report focuses on the modeled and measured energy usage of the first six phases of construction (referred to as Salishan 1–6 in this report), and compares the energy usage of those phases to phase 7.

Building America researchers conducted detailed audits of eight dwelling units in the Salishan community, representative of each of the first six phases of construction. The goal of the audits was to conduct visual inspections of the homes, perform envelope leakage and ventilation system flow testing, and conduct occupant surveys.

A typical Salishan duplex (975 ft^2) was modeled to the 2006 Washington State Energy Code (WSEC—the code in place at the time of construction) using BEopt version 1.4, to predict the energy usage for Salishan Phases 1–6 (to be compared to the billing analysis).

Researchers conducted a billing analysis of all 631 housing units in Salishan, phases 1–7. The purpose of the billing analysis was to compare Salishan phases 1–6 built to WSEC with electric baseboard heat to the more efficient units in Salishan phase 7.

This report focuses on the following primary Building America research questions:

1. How does the modeled energy use (using Building Energy Optimization Software [BEopt]™) for Salishan phases 1–6 compare to the actual use derived from billing data?

   Total modeled energy usage for Salishan phases 1–6 was 11,922 kWh/year, with 3,544 kWh/year for heating, or 29% of total energy usage.

   The billing analysis suggests annual energy use of the two-bedroom duplex (comparable to the unit modeled with BEopt) to be 12,088 kWh, with 5,091 kWh from heating. While the BEopt model and utility billing analysis yielded good alignment overall (a difference of 166 kWh or 1.37% for total energy use), the heating load estimates were not well aligned, with a difference of 1,469 kWh or 21%, suggesting that this BEopt analysis may be overpredicting base load and underpredicting heating load.

2. How does the annual energy usage of phases 1–6 compare to phase 7?

A comparison of annual energy usage (from billing analysis) between Salishan phases 1–6 and Salishan 7 indicates savings of 1,400 to 4,300 kWh/year, a strong indicator of the benefits from the Salishan 7 energy efficiency improvements.

3. What are the opportunities for energy efficiency retrofit improvements in Salishan phases 1–6?

   The energy efficiency and economic impact of mechanical upgrades were evaluated for Phases 1–6 (these phases were energy code compliant at the time of construction) as possible retrofit options. Given the fairly efficient building envelopes required under WSEC at the time of construction, evaluations focused on mechanical upgrades—specifically DHPs and heat pump water heaters (HPWHs).

   If 100% of the existing electric resistance heating is assumed to be provided by the DHP, energy savings is predicted to be 2,602 kWh annually; this amounts to $193 in cost savings, and a 15-year payback (well within the expected life of the equipment). If the displacement level of the electric resistance heating is less than 100%, the savings and payback are reduced. Based on DHP retrofit research conducted in the Pacific Northwest (used in previous Building America projects), these savings may be reduced by as much as 60%.

   Researchers believe that displacement assumptions need additional investigation. Regardless of the displacement assumption, the installation of DHPs may be justified for units with a high heating load, where tenants have expressed strong dissatisfaction with comfort, or where there is a need for cooling (elderly tenants, or those with medical problems.)

   The analysis of HPWHs suggests annual savings of 778 kWh, or $58. Using current incremental cost assumptions, payback for the HPWH does not fall within the useful life of the system. However, the installation of HPWHs may be justified for homes with high base load use and high occupancy (a surrogate for high domestic water heating usage). Combining the installation of HPWHs and DHP retrofits may improve cost effectiveness and installation logistics in occupied dwellings.

4. How do the mechanical ventilation systems perform compared with Washington State-mandated requirements and ASHRAE 62.2-2010, and how did field assessments and occupant surveys reflect the operation of the systems?

   Researchers determined that all eight dwelling units that received audits had ventilation systems capable of meeting Washington State Ventilation and Indoor Air Quality Code or ASHRAE 62.2-2010 requirements (in terms of fan flow), though runtimes varied. None of the tenants seemed to have a working knowledge of their ventilation systems.

5. What are the measured temperature and relative humidity (RH) levels in the homes during the heating season, and what impact did they have on occupant comfort?

   Researchers installed HOBO temperature and RH data loggers at the time of the field audits; monitoring took place during the heating season 2012–2013 (November 2012 through March 2013.) Average hourly indoor temperatures were 73°F for the monitoring period. The monitoring data do suggest high temperature swings in each home (as much as 31°F difference between minimum and maximum monitored temperatures). Occupant surveys indicated a high degree of variability of satisfaction with the comfort levels in their homes; the high degree of variability in the monitored temperatures further reflects this.

Average hourly RH levels were 40% for the monitoring period, reflecting good humidity control with well operating whole-house fans and with air change rates typical for new construction (5–7 ACH_{50}).

Building America researchers believe that additional research is warranted in the proper modeling of "hybrid" DHP/electric resistance heating systems, and displacement assumptions for DHP load in such a system.

1 Introduction and Background

Salishan is a mixed-income neighborhood of Tacoma, Washington, originally built by the federal government in 1942 to provide worker housing to support the war effort. The Tacoma Housing Authority (THA) managed Salishan for the federal government until the war's end, and afterward, when the federal government gave most of Salishan, with about 880 apartments on 188 acres, to THA to own and manage as a public housing community. Since construction, Salishan has been an important part of the City's stock of affordable housing; in addition, it has served as a gateway—a first home for new immigrants.

By the end of the 1990s, the condition of the housing in Salishan was very poor. At the time of construction, long-term durability was not a high priority. In addition, the buildings were not well maintained and were falling apart.

Figure 1. Salishan housing, prior to reconstruction

From 2001 to 2011, THA undertook a $225 million effort, to demolish and reconstruct Salishan in seven phases. New Salishan is a mixed-use neighborhood of affordable and market-rate rental units, single-family homes for sale, commercial buildings, and parks, all on new infrastructure (Tacoma Housing Authority, 2009).

In late 2009, Washington State University Energy Program (WSU) began working with THA, Walsh Construction, Tacoma Public Utilities (TPU), and consultant O'Brien and Company on the design, construction, and commissioning of phase 7 of the Salishan development.

Phase 7, which began construction in late 2009, and was completed in late 2010, is composed of 91 low-income housing units built to ENERGY STAR® standards, and is the first federal Hope VI project to achieve Leadership in Energy and Environmental Design (LEED) Platinum.

Whereas previous phases were heated by electric baseboard units (one in each bedroom, two in the living room), Salishan 7 homes included ductless heat pumps (DHPs) (first floor, with baseboards in the bedrooms). In addition, the phase 7 units included improved insulation in the slab perimeter, walls, and ceiling. The previous, first year report focused on phase 7 (referred to as Salishan 7 in this report) (Gordon, Lubliner, Howard, & Kunkle, 2013).

2 Scope and Purpose

This report focuses on the modeled and measured energy usage of the first six phases of construction (referred to as Salishan 1–6 in this report), and compares the energy usage of those phases to phase 7.

The benefit of this research is to provide low-income housing organizations with analysis of market-ready energy efficiency solutions that can improve the efficiency of new housing stock, and identify cost-effective opportunities for retrofits of existing homes when appropriate.

Building America researchers conducted detailed audits of eight dwelling units in the Salishan community, representative of each of the first six phases of construction. The goal of the audits was to conduct visual inspections of the homes, perform envelope leakage and ventilation system flow testing, and conduct occupant surveys.

A typical Salishan duplex (975 ft^2) was modeled to the 2006 Washington State Energy Code (WSEC—the code in place at the time of construction) using Building Energy Optimization software (BEopt) version 1.4, to predict the energy usage for Salishan Phases 1–6 (to be compared to the billing analysis).

Researchers conducted a billing analysis of all 631 housing units in Salishan, phases 1–7. The purpose of the billing analysis was to compare Salishan phases 1–6 built to WSEC with electric baseboard heat to the more efficient units in Salishan phase 7.

This report focuses on the following primary Building America research questions:

1. How does the modeled energy use (using BEopt) for Salishan phases 1–6 compare to the actual use derived from billing data?
2. How do phases 1–6 compare to phase 7?
3. What are the opportunities for energy efficiency retrofit improvements in Salishan phases 1–6?
4. How do the mechanical ventilation systems perform compared with Washington State-mandated requirements and ASHRAE 62.2-2010, and how did field assessments and occupant surveys reflect the operation of the systems?
5. What are the measured temperature and relative humidity (RH) levels in the homes during the heating season, and what impact did they have on occupant comfort?

3 House Description

The duplexes are mirrored floor plan, 1,109-ft^2 and 975-ft^2, two-story, two-bedroom, 1.5-bath units with a common wall separation. The homes are frame construction with trussed attics and perimeter insulated slab-on-grade floors. These homes were all built under the prescriptive requirements of the 2003 or 2006 WSEC (Table 1). Bedrooms are located on the second floor.

Figure 2. Salishan 975-ft^2 duplex (left), and 1,109-ft^2 duplex (right)

Table 1. Salishan Phase 1–6 Envelope Specifications

Code	Vertical Glazing	Door U-Factor	Ceiling	Wall Above Grade	Slab on Grade
2003 WSEC	0.40	0.2	R-38	R-21	R-10
2006 WSEC	0.35				

All units are heated with individual thermostatically controlled baseboard heaters, located in both bedrooms and the first-floor living room. Domestic hot water is provided by electric tank water heaters (50 gal) located within the conditioned space.

Whole-house ventilation is provided by a continuously operating exhaust fan located in the first-floor laundry closets of all units. All duplexes have eight or nine dedicated fresh air intakes per dwelling unit. These intakes are operable trickle vents integrated into the frames of windows located in the kitchen, living room, bedrooms and upstairs bathroom. All whole-house ventilation systems are controlled by 24-h pin timers capable of running automatically or manually with a manual override function.

4 Energy Audits

In October of 2012, WSU conducted detailed audits of eight dwelling units in the Salishan development, in order to provide inputs for the modeling effort.

At least one dwelling unit was audited in phases 1–6 of the development. The dwelling units audited were nearly identical in floor plan to each other and those previously audited and reported on in Salishan 7 (Gordon, Lubliner, Howard, & Kunkle, 2013).

The audit protocol was consistent with the Residential Energy Services Network's Quality Assurance Standard (RESNET, 2013). Each audit included:

- Blower door testing, utilizing The Energy Conservatory's TECTITE software (The Energy Conservatory, 2012)
- Flow rate measurement of whole-house and spot ventilation
- Confirmation of basic home features, including area takeoffs and appliance, heating, ventilation, and air conditioning, and lighting information.

Above and beyond the standard quality assurance protocols, researchers conducted assessments of window trickle vents (fresh air intakes) and conducted worst-case depressurization tests of all exhausting fans and appliances (not typically indicated as there are no combustion appliances present in these homes.)

A blank audit form is included in Appendix A.

In addition, researchers administered a survey to the occupants of four of the homes (Phases 2, 3 [two homes] and 6), to assess the occupancy patterns and other factors that might affect electricity use. A copy of the survey is included as Appendix B.

During the audits, Onset HOBO data loggers were installed in each of the eight units. The data loggers recorded temperature and RH levels at hourly intervals beginning on November 1, 2012 through March 27, 2013.

5 Modeling Methods

The purpose of the energy simulation modeling is to compare the predicted energy use to the utility usage for Salishan Phases 1–6 built to the WSEC and Salishan Phase 7 built with improved thermal performance and DHPs. Additionally, the energy efficiency and economic impact of mechanical upgrades were evaluated for Phases 1–6 as possible retrofit options. Researchers used BEopt version 1.4 for estimation of energy performance of all Phases (National Renewable Energy Laboratory, 2013). Modeling evaluated the predicted performance of:

- Homes built in phases 1–6 to the 2003 and 2006 WSEC
- Homes built in phase 7 with improved envelope and mechanical equipment performance
- Homes built in phases 1–6, with additional energy efficiency mechanical upgrades.

The Salishan housing units modeled are the duplex floor plans, with square footage of either 975 or 1,109 ft^2 of conditioned floor area. The homes' envelope and performance parameters in all seven phases for modeling purposes are specified in Table 2.

Table 2. Salishan House Characterization

Phase	1, 2, 3	4, 5, 6	7
Code	2003 WSEC	2006 WSEC	2009 WSEC
Square Footage	1,109/975	1,109/975	1,109/975
Number of Bedrooms	2	2	2
Vertical Glazing	0.40	0.35	0.30
Door U-Factor	0.20	0.20	0.20
Ceiling Insulation	R-38	R-38	R-49 Advanced*
Wall Above Grade	R-21	R-21	R-23
Slab on Grade	R-10	R-10	R-15
Space Heating	Electric baseboards	Electric baseboards	DHP
Thermostat Set Points	71°F Heating	71°F Heating	71°F Heating 76°F Cooling
Water Heating	0.95 Energy factor	0.95 Energy factor	0.95 Energy factor
Lighting	50% Compact fluorescent lamps	50% Compact fluorescent lamps	100% Compact fluorescent lamps
Dishwasher	ENERGY STAR	ENERGY STAR	ENERGY STAR
Exhaust Fan	ENERGY STAR	ENERGY STAR	ENERGY STAR

* Full insulation depth at heel

Envelope leakage rates used for modeling Salishan units from phases 1–6 are based on field air leakage testing with the fresh air window inlet vents in the position that the homeowners typically maintain and were found during the field audits. The average envelope leakage rate found through field audits was 953 CFM_{50} for the eight units audited from Salishan 1–6. The lowest tested leakage rate was 792 CFM_{50} and the highest was 1,144 CFM_{50}. The 1,144 CFM_{50} unit had two windows that could not be closed securely due to data cables that passed through the windows and could not be disconnected according to requirements by the data provider. As such, an adjusted average was calculated taking the 1,144 CFM_{50} leakage rate unit out of the envelope leakage range; 926 CFM_{50} is the adjusted average used in the energy simulation modeling for Salishan 1–6. Table 3 lists leakage rates expressed as air changes per hour (ACH) at 50 Pascals and specific leakage area (SLA) for both the larger and smaller units.

Table 3. Salishan 1–6 Average Leakage Converted to ACH_{50} and SLA

Conditioned Floor Area	1,109 ft^2	975 ft^2
CFM_{50}	926	926
ACH_{50}	5.9	6.7
SLA	0.00032	0.00036

There is little difference in the efficiency of building components required under the WSEC in the two energy code versions that Salishan 1–6 was built under (2003 and 2006), and likewise little difference in the efficiency of building components in each phase of construction as built prior to phase 7. As shown in Table 2, Vertical glazing U-factor is the differentiating factor among the first six phases of construction. As such, no discussion will take place in this paper regarding the incremental cost to meet the efficiency of the 2003 WSEC and the 2006 WSEC. The incremental costs for all energy efficiency improvements in Salishan 7 (noted in the first year report) were $6,064 (Gordon, Lubliner, Howard, & Kunkle, 2013).

6 Billing Analysis Methods

The purpose of the utility bill analysis is to compare the housing units in Salishan phases 1–6 built to WSEC with electric baseboard heat to the units in Salishan phase 7. TPU provided monthly utility data[1] for all 631 housing units in Salishan 1–7. The Salishan housing units are single-family, duplexes, triplexes, and fourplexes (Table 4). Two- and three-bedroom duplexes and triplexes are most common. There is a common set of floor plans and square footage is similar for units with the same number of bedrooms. For example, most two-bedroom units are between 970 and 1,145 ft^2 and most three-bedroom units are between 1,224 and 1,373 ft^2.

Table 4. Characteristics of Salishan Housing Units

Type	Single		Duplex				Triplex		Fourplex	Total
Bedrooms	3	5	1	2	3	4	2	3	2	–
Salishan 1–6	14	8	22	113	161	36	59	79	48	540
Salishan 7	2	1	4	18	14	4	12	24	12	91

The duplexes are side-by-side with one common wall. The triplexes are also side-by-side (row houses) with two end units (with one common wall) and an interior unit (with two common walls). The fourplexes are stacked units with two upper units and two lower units. These units have one shared wall and a shared floor/ceiling.

For the purposes of the utility billing analysis, comparisons between Salishan 1–6 and Salishan 7 are based on the housing unit location and number of bedrooms. Researchers compared end units for duplexes and triplexes with two and three bedrooms, interior units (triplexes) with three bedrooms, and stacked units (fourplexes) with two bedrooms. The majority of units are two- and three-bedroom end units (Table 2), so the analysis focuses on those units. Researchers did not consider the single-family and one-, four-, and five-bedroom units and interior two-bedroom units because there are so few of those units.

Table 5. Utility Billing Analysis Comparison Groups

Position	Single		End				Interior		Stacked	Total
Bedrooms	3	5	1	2	3	4	2	3	2	–
Salishan 1–6	14	8	22	153	213	36	19	27	48	540
Salishan 7	2	1	4	28	28	4	2	10	12	91

The monthly utility data provided by Tacoma Public Utilities go back until the end of 2008, but some of the Salishan 7 units were not occupied until the end of 2010 or early 2011 (Gordon, Lubliner, Howard, & Kunkle, 2013). To allow for stable occupancy, this analysis focuses on the most recent 12-month period of utility data, which covers December 2011 to November 2012 (referred to here as 2012). Researchers used two approaches to analyze the data:

- Monthly Aggregate Analysis: For each comparison group, the average electricity use for each month is calculated. Very low use is screened from the averages to attempt to

[1] The actual billing periods do not correspond to calendar months, but the TPU data system allocates billing data to calendar months, which greatly simplifies the analysis.

remove cases where a unit may not have been occupied. This analysis essentially creates a “prototype” for each comparison group of typical monthly energy use. The monthly electricity use profiles are compared and a linear regression of electricity use and degree days is conducted to estimate base load and space heat electricity use for each prototype comparison group.

- Annual Analysis: The annual electricity use for each housing unit from December 2011 to November 2012 is calculated. Housing units that have very low use in any particular month are screened out to remove cases where the unit may not have been occupied for the year. The difference in electricity use between the comparison groups is analyzed and the statistical significance is determined.

7 Results

7.1 Audits

As noted above, the duplexes are equipped with dedicated fresh air intakes integrated into the frames of windows located in the kitchen, living room, bedrooms, and upstairs bathroom. During the audits, the position of these vents varied. Two homes were found with all the trickle vents closed, three homes had eight of nine closed, one home had seven of eight closed, one home had six of nine closed, and one home had four of nine vents in the closed position. The homeowner survey showed that occupants were not adjusting the position of these vents. In many of the units, opening of windows was used as a strategy for providing fresh air exchange when the weather was conducive to do so.

Per the Washington State Ventilation and Indoor Air Quality (VIAQ) code, homes using exhaust whole-house ventilation systems that do not have ducted space conditioning systems, must provide dedicated fresh air inlets to each habitable space. These fresh air inlets must provide no less than 4 in.^{2} of net free area per habitable space (Washington State Building Code Council, 2009) . As defined by code, the duplexes had four habitable spaces (living and dining rooms, and two bedrooms).

Ventilation system controls were located high on the wall in the laundry closet. These controls were readily accessible but were not labeled as whole-house ventilation controls. Most controls were programmed to run for 8 h/day, which is the VIAQ code minimum daily runtime. These run cycles were predominately dispersed in 2-h blocks and 4 h apart. However, one fan was programmed to run for 23 h/day while two others were programmed to run for 4.5 h/day and 5 h/day.

Figure 3. Exhaust ventilation system controls

Whole-house exhaust fan flow rates in all units were measured for flow with a commercially available flow capture hood (Balometer Junior, manufactured by Alnor), for an average of 72 CFM; flow rates ranged from 54 to 90 CFM (see Table 6 for individual fan flow rates and runtimes). This is more than their listed rate of 57 CFM (at 0.25 in. water column), and well exceeding the VIAQ code minimum requirement of 45 CFM systems running a minimum of 8 h/day.

Table 6. Salishan Fan Flow Rates

Dwelling Unit	Salishan 1	Salishan 2	Salishan 3a	Salishan 3b	Salishan 4	Salishan 5a	Salishan 5b	Salishan 6
Whole-House Fan Flow (CFM)	54	90	87	87	60	62	62	69
Runtime	5 h	5 h	8 h	8 h	40 min	8 h	8 h	8 h
VIAQ Code-Compliant Flow Rate	55 min 82 max	60 min 90 max	55 min 82 max	55 min 82 max	60 min 90 max	55 min 82 max	55 min 82 max	55 min 82 max
62.2-2007-Compliant Flow Rate	45	45	45	45	45	45	45	45
Downstairs Bath	33	48	78	71	Not functional	No data	78	56
Upstairs Bath	49	9	45	60	No data	No data	60	60
Kitchen Fan	Functional	Functional	Functional	Functional	Functional	Functional	Functional	Functional

Air leakage testing was performed on all eight homes audited using The Energy Conservatory blower door test equipment and software (TECTITE). Blower door tests were conducted in three configurations—with window vents open, closed and as found. Results of these tests are shown in Table 7. Estimates of the homes' trickle vent net free areas were derived from these tests and are also shown in Table 7. This estimate roughly equates to the VIAQ codes minimum requirement (16 in.^{2}) for fresh air intakes in the majority of these homes.

Table 7. Envelope Leakage Testing Results

Dwelling Unit	CFM_{50} Vents as Found	CFM_{50} Vents Open	CFM_{50} Vents Closed	CFM_{50} Vents*	ACH_{50} Vents Closed	Est. Vent Net Free Area (in.^{2})	# of Vents
Salishan 1	792	887	729	158	5.28	15.8	9
Salishan 2	862	1,011	862	149	5.5	14.9	9
Salishan 3a	986	1,006	919	87	6.6	8.7	9
Salishan 3b	926	1,074	899	175	6.4	17.5	9
Salishan 4	1,144	1,282	1,098	184	7.0	18.4	9
Salishan 5a	957	1,063	957	106	6.9	10.6	8
Salishan 5b	980	1,070	980	90	7.1	9.0	8
Salishan 6	976	unknown	960	unknown	7.0	unknown	8

*Difference between vents open and vents closed.

Although none of the homes at Salishan 1–6 were built with combustion appliances, they were all tested to determine the effect exhaust fans had on house pressure with reference to the outdoors when activated. Table 8 represents the average house depressurization with reference to outside with the introduction of each exhaust ventilation system starting with the whole-house fan.

The ambient conditions during the times of testing were windy (gusts > 20 mph); therefore, data were recorded for only four of the homes tested. Of these homes, the low end of depressurization with all exhaust appliances on was –9.2 Pascals. The greatest depressurization under these conditions was –13.3 Pascals. With only the whole-house fan on, maximum depressurization was –2. However, the whole-house fan depressurization data were well below the normal fluctuation induced by exterior wind conditions. All pressures were taken over a 30-s average.

Table 8. Combined House Depressurization

House Depressurization With Reference to Outside			
	Fresh Air Intake Closed (Pascals)		
	Average	High	Low
Baseline	–1.2	–1.8	1.7
Whole-House Fan	–1.8	–2	–0.8
+ Dryer	–3.1	–3.4	–2.7
+ Kitchen Range Fan on HIGH	–7.5	–8.6	–5.9
+ First-Floor Bath Fan	–9.2	–11	–7.3
+ Second-Floor Bath Fan	–11.2	–13.3	–9.2

7.2 Temperature and Relative Humidity Monitoring

The average indoor temperature for the eight units monitored was 73°F for the monitoring period. Temperature and RH distributions for all eight units are shown in Figure 4 and Figure 5.

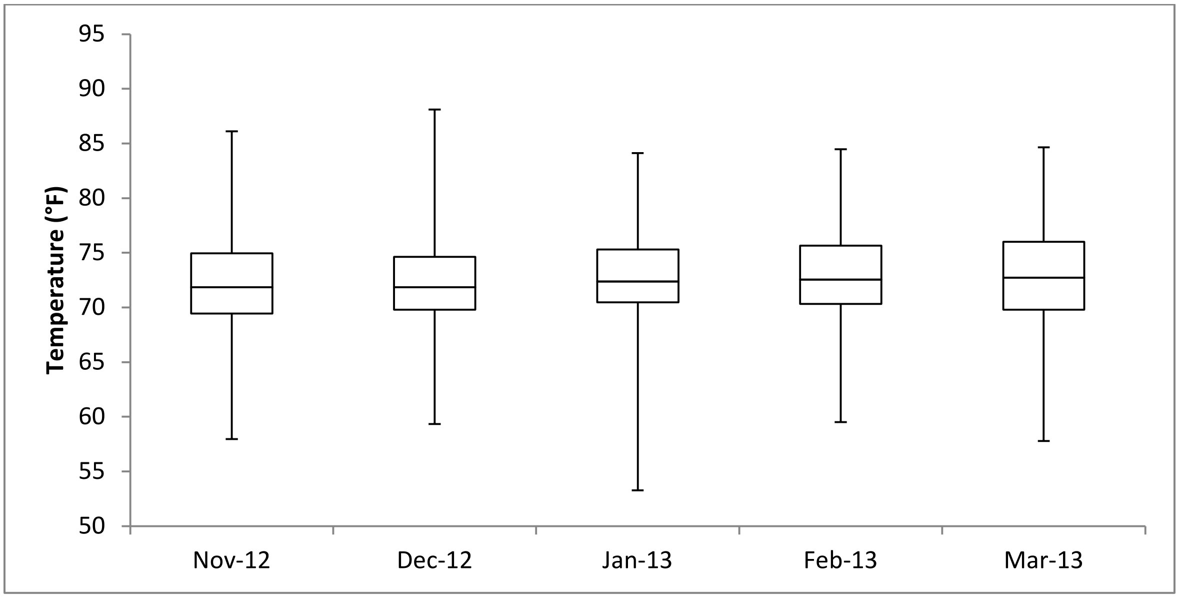


Figure 4. Monitored temperature, Salishan phases 1–6

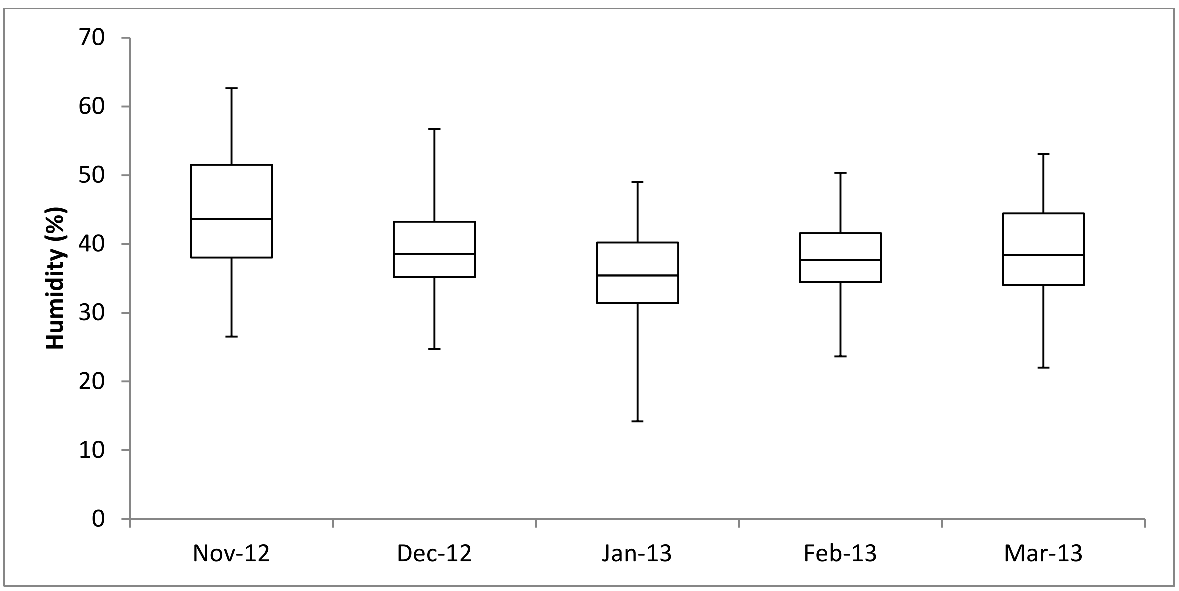
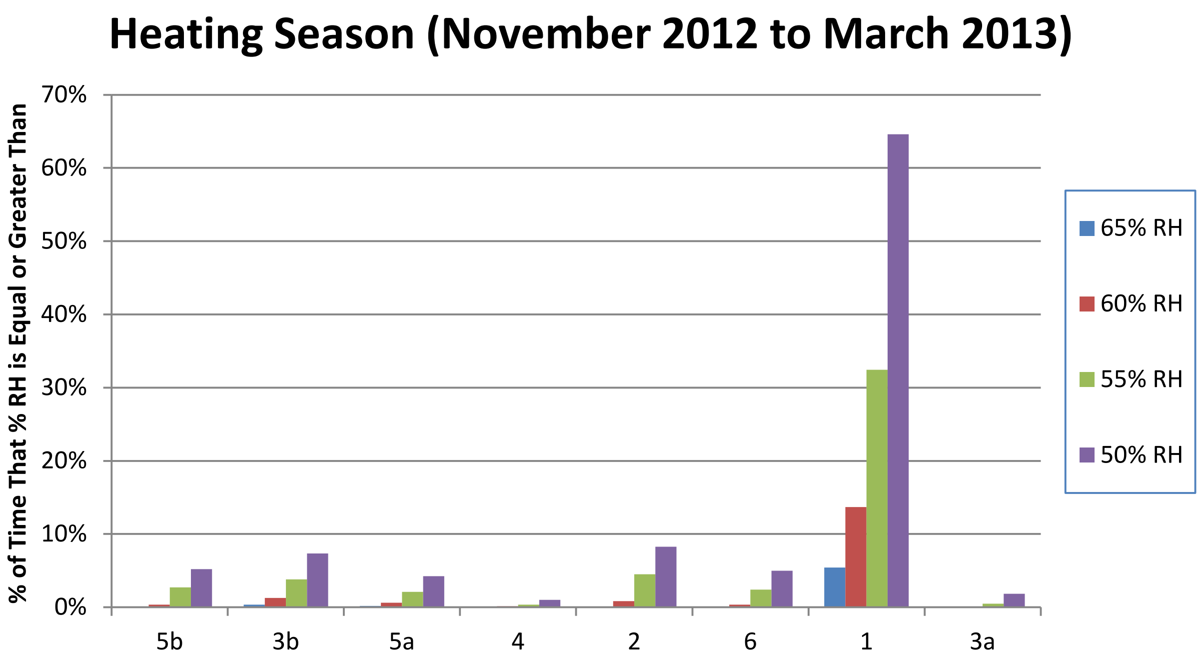


Figure 5. Monitored RH, Salishan phases 1–6

RH monitoring results are also shown in Figure 6, along with minimum, maximum, and average temperatures in each unit. The RH data require some explanation—the colored lines represent the frequency of RH values at or above specific bin values. For example, the purple line represents the frequency of RH values at or above 50%; the y-axis indicates the percentage of the monitoring period that the hourly average RH monitoring data meet or exceed that number.



Temp. Min	53°F	63°F	61°F	63°F	61°F	59°F	63°F	65°F
Temp. Max	84°F	83°F	85°F	88°F	83°F	79°F	74°F	83°F
Temp. Avg	69°F	73°F	75°F	76°F	71°F	71°F	69°F	75°F

Figure 6. RH and temperature for monitored units in Salishan, November 2012 to March 2013

As shown in Figure 6, the monitoring data do suggest high temperature swings in each home (as much as 31°F difference between minimum and maximum monitored temperatures). Occupant surveys indicated that all tenants were dissatisfied with the uneven distribution of heat in their home; the high degree of variability in the monitored temperatures further reflects this. It should be pointed out that researchers had no means of associating low temperature readings with periods of no occupancy, but the homeowner surveys (see Section 7.3, below) indicate that the units were occupied much of the time.

Average RH levels were 40% for the monitoring period, suggesting good humidity control with well operating whole house fans and envelope leakage rates between 5 and 7 ACH_{50} (typical for new construction). As shown in Figure 6, one home (Salishan 1) experienced high humidity during the monitoring period. This home had no working dryer, and the tenants were drying clothes inside the home.

7.3 Homeowner Surveys

The results of the homeowner surveys are summarized below.

- With the exception of one home (Salishan 6) containing a chest freezer, there were no unusual electrical loads in any of the homes.
- All homes were occupied by two full-time adult occupants except for one of the phase 3 homes, which had one adult full-time occupant. All homes were occupied by at least one

occupant for 96% of the hours of the week and none of the homes were occupied by anyone spending more than 20 h outside the home for work or school. The phase 2 home rarely had visitors, whereas the other three homes frequently had daytime and evening guests.

- Homeowners had limited knowledge of the presence and operation of the ventilation system. All but one air inlet vent was found to be in the closed position in all but the phase 3 homes, which had four and nine vents open. None of the homes' whole-house ventilation controls were labeled as required by code.
- None of the occupants surveyed commented that they noticed any negative or positive effects of the ventilation system. Operable windows were used in all homes during favorable weather in order to allow intake of fresh air. Window trickle vents were never adjusted by occupants of any surveyed homes. Moisture-related issues were not observed.
- There was no use of air conditioners in any of these homes.
- Occupant control of the thermostat varied. Two of the homes' occupants (phase 3 [one home] and phase 6) set the thermostat and left it there for the duration of the heating season. The phase 2 home's occupants left the downstairs thermostat in one position for the entire heating season but varied the upstairs thermostats upon demand. The other phase 3 home's occupants adjusted thermostats often and dramatically.

The homeowners were either very satisfied or very dissatisfied the energy efficiency and comfort of their homes. However, there was commonality in that they were all dissatisfied with the uneven distribution of heat throughout the home. This may be due to the occupant control issues noted above; the occupant may have to make continual adjustments to the thermostat to achieve comfort.

7.4 Modeling

The results of the energy simulation modeling for Salishan 1–6 are detailed in Table 9 and include units built to the 2003 and 2006 WSEC for the two different floor plans based on square footage. The highest usage model is the larger of the two floor plans built to the earlier 2003 energy code. Predictably, the lowest usage model is the smaller of the two floor plans built to the subsequent 2006 energy code. The difference in estimated usage between these two models is 1,360 kWh annually.

Table 9. Salishan 1–6 BEopt Estimated Site Energy Consumption in kWh Annually

	975-ft^2 Model		1,109-ft^2 Model	
	2003 Code	2006 Code	2003 Code	2006 Code
Miscellaneous Electric Loads (MELs)	5,518	5,518	6,185	5,643
Heating	3,631	3,544	3,695	3,869
Hot Water	2,860	2,861	3,402	2,862
Total	12,009	11,922	13,282	12,374

All homes visited during the field auditing portion of the study were two-bedroom homes. Comparative energy models and associated upgrades were performed on a two-bedroom model as a result. The occupancy assumptions based on the Building America House Simulation Protocols Equations 28 and 29 are listed in Table 10 for the Salishan BEopt models (Hendron & Engebrecht, 2010). Based on the findings of the field audits and homeowner surveys, the average actual occupancy is two to three full-time occupants. As such, occupant dependent usage assumptions in BEopt seem appropriate. A three-bedroom unit comparative model was also run to test the impact of increased occupancy, as seen in Table 11.

Table 10. Calculated Occupancy for Two- and Three-Bedroom Units

Equation	Two-Bedroom Number of Occupants	Three-Bedroom Number of Occupants
0.59 × Nbr + 0.87	2.05	2.64
0.92 × Nbr + 0.63	2.47	3.39

where Nbr = number of bedrooms

Table 11. BEopt Estimated Consumption Comparison, Two- and Three-Bedroom Units

	2006 Code 975-ft^2 Two-Bedroom	2006 Code 975-ft^2 Three-Bedroom
MELs	5518	6079
Heating	3544	3353
Hot Water	2861	3401
Total	11922	12834

During the field audits of Salishan phases 1–6, researchers determined that there were few cost-effective improvements that could be made to the building shell. The state of Washington has had fairly stringent energy codes in place since 1991. Based on the energy code versions that phases 1–6 were built under, the slab floor is insulated to R-10 at 2 ft horizontal (interior perimeter) and cannot be cost-effectively fully insulated, the walls are fully insulated 2 × 6 framing cavities and the attics are insulated to R-38. Building air leakage was found to be average for the Northwest region—not classified as "tight" construction, but tight enough that additional air sealing would not be cost effective.

Having identified the lack of retrofit opportunities for the existing homes, there are several lost opportunities for maximizing building envelope efficiency at time of construction. For subsequent phases of construction, careful attention to air sealing details at time of new construction can yield a reduction 2.4–3.2 ACH_{50}, as seen in Salishan 7 for little to no increase in cost (Gordon, Lubliner, Howard, & Kunkle, 2013).

Given the fairly efficient building envelope required under the 2003 and 2006 WSEC, the measures evaluated for retrofit in Salishan 1–6 are focused on mechanical upgrades, including the installation of DHPs and heat pump water heaters (HPWHs).

The incremental cost for DHPs used in the study was $3000 (Lindsay, 2013); this is slightly less than the $3,315 observed in the first year report for new construction at Salishan 7 (Gordon, Lubliner, Howard, & Kunkle, 2013). The cost-benefit analysis used an incremental cost of $1,800 for the HPWHs (based on BEopt cost data).

Cost effectiveness is difficult to evaluate for Salishan given that the investment in improvements would be at THA's cost and the benefit of reduced monthly and annual utility costs would be experienced by the occupant. The monthly and annual cost savings of improvement measures were calculated using $0.7.4/kWh, based on current costs from the electric utility provider, TPU (Tacoma Public Utilities). There is a fixed service charge of $4.50 for all separately metered apartments. Additionally, TPU offers a 30% low income discount to qualifying households. This discount brings the cost per kWh to $0.0518. For purposes of this project, the market rate cost per kWh of $0.074 is used.

Table 12 provides the energy usage and cost benefit analysis of retrofit measures in Salishan 1–6. The scenarios are modeled with and without ventilation systems. The initial runs were performed with exhaust only systems operating constantly at ASHRAE 62.2-2010 levels. The actual homes observed in the field had operational times far shorter than this. Some whole-house ventilation systems were not run at all on a consistent or regular basis. That being the case, a second set of runs was performed with no ventilation system running to show the impact on savings.

Table 12. Energy Usage and Cost Benefit of Retrofit Measures in Salishan 1–6

	2006 925-ft^2 Base (Electric Resistance Heat)	HPWH	DHP
Assumes ASHRAE 62.2-2010 Ventilation System			
MELs	5518	5518	5518
Cooling	0	0	63
Heating	3544	4177	874
Hot Water	2861	1449	2865
Total	11922	11144	9320
Reduction in kWh		778	2602
Reduction in %		7%	22%
Incremental Cost		$1,800	$3,000
Annual Cost Savings		$57.61	$192.58
Monthly Cost Savings		$4.80	$16.05
Simple Payback, Years		31.25	15.58
Assumes No Ventilation System Operating			
MELs	5437	5413	5437
Cooling	0	0	69
Heating	2933	3489	718
Hot Water	2859	1574	2864
Total	11229	10476	9087
Reduction in kWh		753	2142
Reduction in %		7%	19%

Given that the units in Salishan are fairly low load units to begin with, savings as a result of potential upgrades are not dramatic. The reduction in space heating load by installing a DHP is the most substantial of the mechanical measures evaluated for retrofit. This brought the heating load from 29% of the total energy use annually to 9% (see Figure 7 and Figure 8).

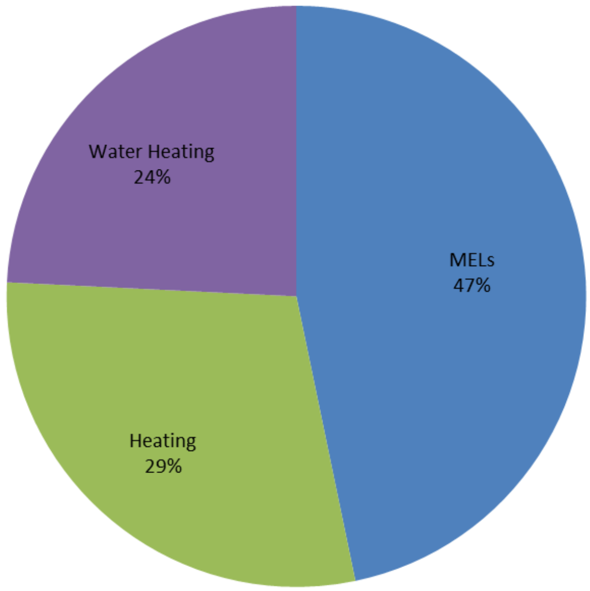


Figure 7. Breakdown by load type; 100% electric

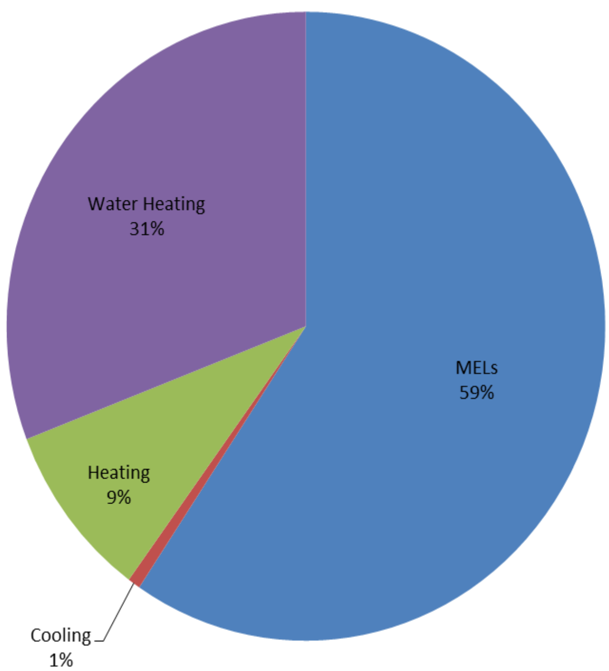


Figure 8. Breakdown by load type; 100% DHP

If DHPs were to be installed as a retrofit measure at Salishan, the electric resistance heaters in the upstairs bedrooms and bathroom would need to remain in place and operating, per requirements of the International Residential Code (International Code Council, 2012). Under this hybrid scenario, field research conducted in the Pacific Northwest suggests a reduction in energy use of approximately 48%, considerably less than suggested by the 100% DHP scenario within the BEopt analysis (Ecotope, Inc., 2013).

Ongoing research may explore whether the use of whole house mechanical ventilation fans or other strategies can improve the distribution of heat from the DHP to the upstairs bedrooms.

7.5 Utility Billing Analysis

Figure 9 and Figure 10 show the monthly electricity use profiles for two- and three-bedroom end units.

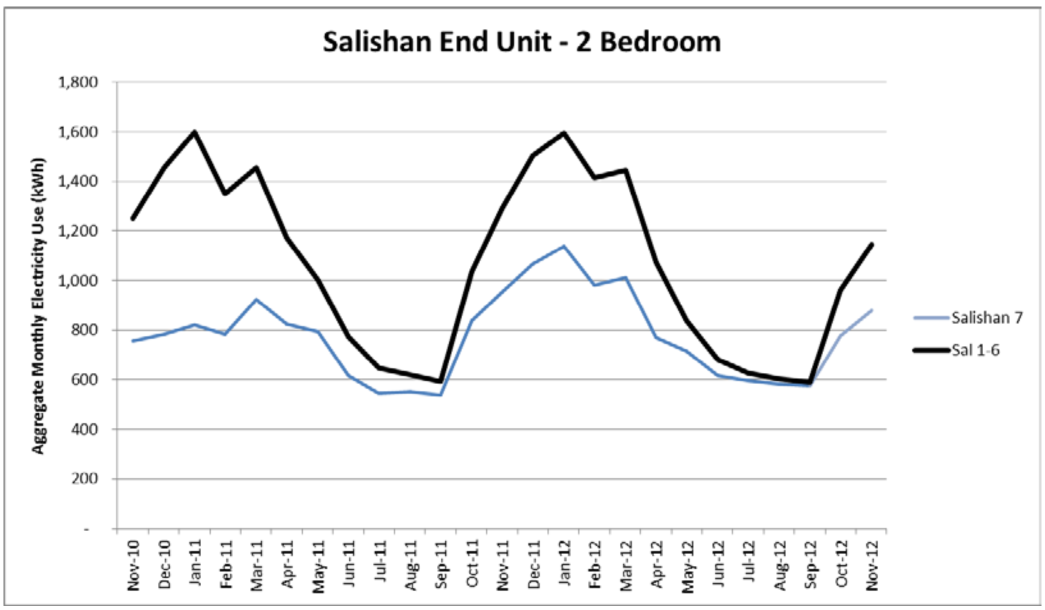


Figure 9. Monthly aggregate electricity use for two-bedroom end units

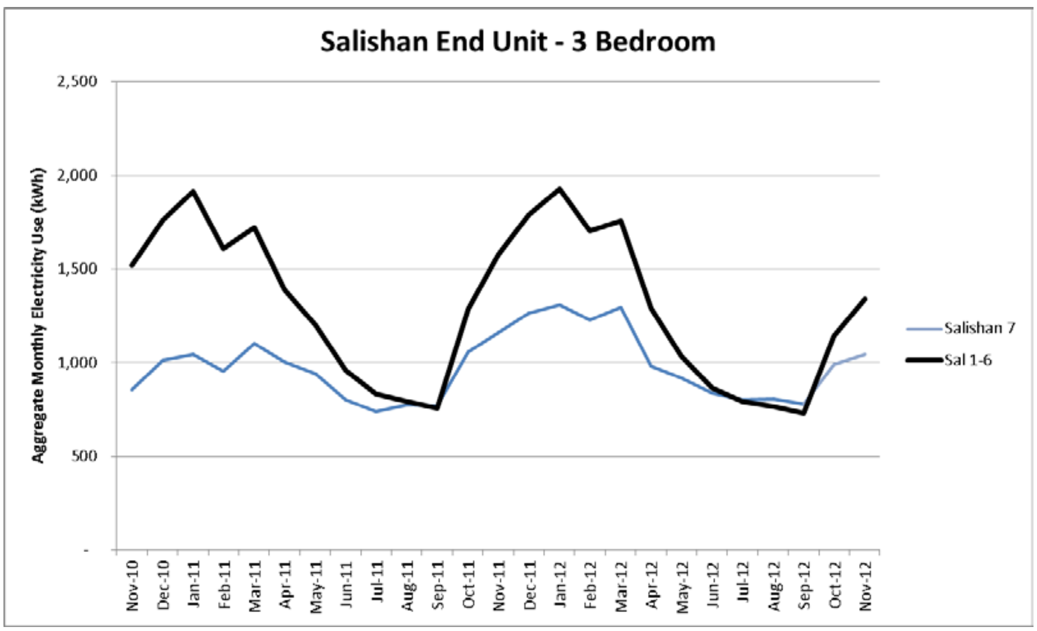


Figure 10. Monthly aggregate electricity use for three-bedroom end units

Several observations from the figures can be made:

- Electricity use for Salishan 7 is lower in the winter months, indicating electricity savings is due to lower energy use for heating.
- Electricity use in the summer is similar, suggesting that we are not seeing an increase in electricity use from the cooling capability of the DHPs. Some of the variation in the electricity use of individual units may be due to cooling, but this is not significant enough to show up in the aggregate data.
- Electricity use in the winter of 2012 is higher than 2011 for Salishan 7, but is similar for Salishan 1–6 (Gordon, Lubliner, Howard, & Kunkle, 2013). Degree day data indicate 2012 was slightly warmer than 2011. So the increase in heating electricity use for Salishan 7 is counter to what would be expected. This might be an anomaly due to homes just being occupied at the end of 2010. It also could indicate that as residents get used to operating the DHPs in the main living space and baseboard heaters in the bedrooms, they increase heating system use (thermostat settings). This observation needs to be tested with additional research.

These observations also apply to the monthly electricity use for the other comparison groups (stacked and interior units).

To identify the space heat and base load for each comparison group, regression models of electricity use and degree days were developed for each of the comparison groups. The aggregate monthly electricity use was normalized to Typical Meteorological Year 3 temperature data. The degree day temperature base was varied for each case to obtain the best model.[2] The results of the weather normalization are shown in Table 13.

[2] Researchers used a spreadsheet regression analysis tool developed by Michael Blasnik. It uses a Bayesian approach to select the best balance point based on R-squared and a prior estimate of balance point. The tool uses daily average temperature data (in this case from Sea-Tac Airport) to estimate degree days at different base temperatures.

Table 13. Regression Model Results for Each Comparison Group

Regression Model	# of Data Points	Base Load (kWh)	Heating (kWh)	Total (kWh)	Balance Point Temp. (F)	R-Squared	Number of Units[3]
End Two-Bedroom Salishan 1–6	12	6,998	5,091	12,088	61	0.980	144–152
End Two-Bedroom Salishan 7	12	6,892	2,594	9,486	60	0.983	24–27
Savings (kWh)		**106**	**2,497**	**2,603**			
Savings (%)		**2%**	**49%**	**22%**			
End Three-Bedroom Salishan 1–6	12	9,048	5,638	14,686	60	0.975	200–213
End Three-Bedroom Salishan 7	12	9,454	2,594	12,048	60	0.955	27–28
Savings (kWh)		**(406)**	**3,044**	**2,638**			
Savings (%)		**–4%**	**54%**	**18%**			
Interior Three-Bedroom Salishan 1–6	12	9,271	4,558	13,829	59	0.968	25–27
Interior Three-Bedroom Salishan 7	12	9,312	2,192	11,504	59	0.932	9–10
Savings (kWh)		**(41)**	**2,366**	**2,325**			
Savings (%)		**0%**	**52%**	**17%**			
Stacked Two-Bedroom Salishan 1–6	12	7,372	3,951	11,323	60	0.978	48
Stacked Two-Bedroom Salishan 7	12	7,410	2,531	9,942	61	0.976	11–12
Savings (kWh)		**(38)**	**1,420**	**1,382**			
Savings (%)		**–1%**	**36%**	**12%**			

[3] The number of units included in the calculation of the monthly average electricity use varies from month to month.

The results for the regression analysis are consistent with the observations for Figure 9 and Figure 10. All the electricity savings is for space heating. The estimated space heat savings is around 50% for the end and interior units and ranges from 2,366 kWh/year for the interior three-bedroom units to 3,044 kWh/year for the end three-bedroom units. The stacked two-bedroom units have the lowest space heat savings (1,420 kWh/year, 36%). We might expect this because these are smaller units with fewer exterior surfaces.

There is little difference in the base loads of comparable units in Salishan 1–6 and Salishan 7. There does not appear to be an increase in electricity use in Salishan 7 from cooling by the DHPs. The three-bedroom units have higher base loads (~9,000+ kWh/year) than the two-bedroom units (~7,000+ kWh/year) as we would expect. The base loads are greater than the space heat loads in all cases, and are significantly greater for the Salishan 7 units.

While the space heat electricity savings is large, is the difference in annual electricity use between Salishan 7 and Salishan 1–6 significant? There is a fair amount of variation in the annual electricity use of the housing units in Salishan 1–7 (Figure 11). Most units use between 10,000 and 17,000 kWh/year. The highest users consume more than 20,000 kWh/year while the lowest use around 5,000/6,000 kWh/year. The average use is 13,976 kWh/year. There are some units that did not have enough data to calculate annual use that appear as white spots in the data.

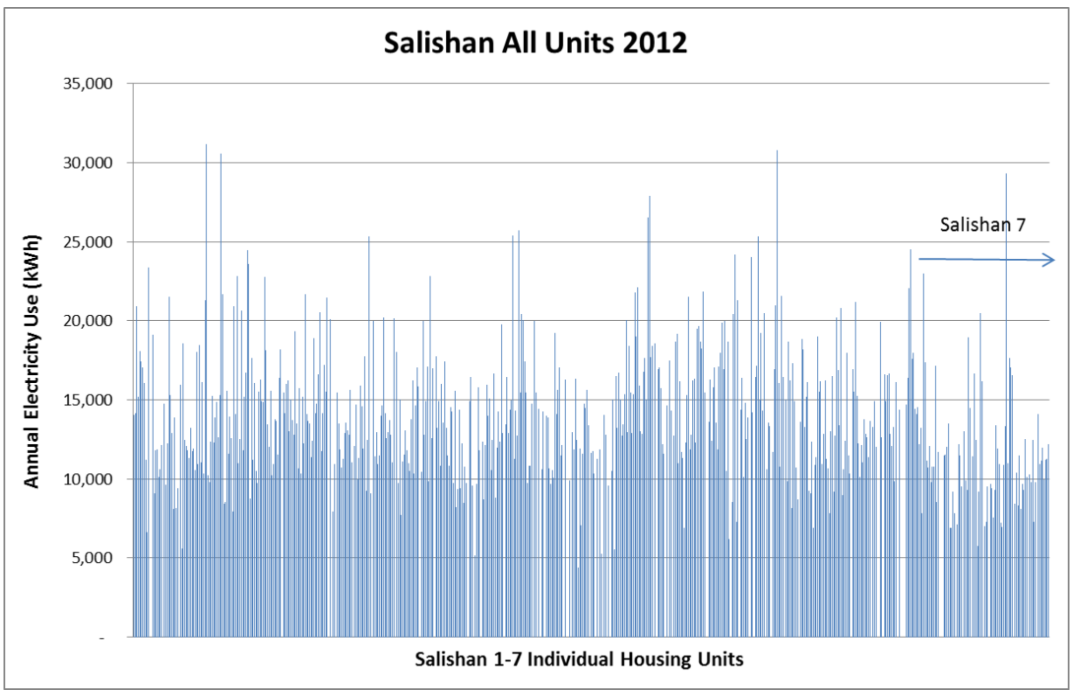


Figure 11. Annual electricity use of each Salishan 1–7 housing units

The Salishan 7 units (on the far right of Figure 11**)** appear to have lower electricity use than the other housing units. To test whether this difference is significant, we conducted a statistical analysis of the annual electricity use for each housing unit for the comparison groups. The results of this t-test analysis are shown for each comparison group in Table 14.

Table 14. T-Test Results for Each Comparison Group

Comparison Group	Data Points (Salishan 1–6/7)	Savings Mean (kWh)	Savings (%)	Savings 95% Confidence Interval (kWh)
End Three-Bedroom	132/22	2,869	22.5	1,428–4,309
End Three-Bedroom	192/27	2,818	18.5	1,398–4,238
Interior Three-Bedroom	24/8	2,400	17.0	391–4,408
Stacked Two-Bedroom	46/10	1,622	13.6	–343–3,586

The t-test analysis indicates annual electricity use for the two- and three-bedroom end units in Salishan 7 is clearly lower than Salishan 1–6 and there are energy savings. The savings are estimated to be 1,400 to 4,300 kWh/year at 95% confidence. These results are a strong indicator of the benefits from the Salishan 7 energy efficiency improvements.

The electricity use for the interior three-bedroom units for Salishan 7 is also statistically less than Salishan 1–6 at 95% confidence, although the confidence interval is wider and nears zero at the lower end. For the stacked two-bedroom units, the 95% confidence interval is slightly negative. For this particular comparison group, statistical significance is a little less than 95% confidence. Because the samples for these last two comparison groups are small, the results are more prone to be skewed by other factors besides the Salishan 7 energy efficiency improvements.

The annual savings results in Table 14 are very similar to the results from the regression analysis shown in Table 13. The regression analysis results for the two- and three-bedroom end units are 22% and 18% savings, the interior three-bedroom 17%, and the stacked two-bedroom 12%. The magnitude of the electricity use and savings is a little less for the regression analysis, which uses Typical Meteorological Year 3 weather data (typical year). This is the expected result since the actual 2012 weather was a little cooler than a typical year.

The fact that the different utility bill analyses produce comparable results adds confidence to the conclusion from the Year one report that the LEED Platinum Salishan 7 units use significantly less electricity than the units built to the WSEC in Salishan phases 1–6 (Gordon, Lubliner, Howard, & Kunkle, 2013). This savings is from a reduction in space heating electricity use on the order of 50%. There is no evidence that the cooling capability of the DHPs is adding to the average summer electricity use of the Salishan 7 units. The base load (non-space heating) electricity use is generally greater than the space heating use in all cases. This is particularly true for Salishan 7, where space heat loads are around 20%–25% of total electricity use.

7.6 Utility Model and Energy Simulation Model Comparison

Comparison of utility regression models to the energy simulation models yielded fairly good alignment for estimated whole-house electricity use. The difference between the regression model and simulation model for Salishan 1–6 was 166kWh, or 1.37%. As shown in Table 15, the difference between the regression model and simulation for Salishan 7 was 460 kWh, or 4.48% indicating that the energy simulation modeling is representative of whole-house electricity usage at the Salishan development.

Table 15. BEopt Model Compared to Utility Regression Model

	Utility Regression Model	Energy Simulation Model	Difference (kWh)	Difference of Model From Utility (%)
Salishan 1–6	12,088	11,922	166	1.37%
Salishan 7	9,486	9,026	460	4.84%

However, comparing the breakdown of base load and heating load estimates between the BEopt energy simulation model and the regression model, alignment by category is not as favorable. These results, shown in Table 16, indicate that for Salishan phases 1–7, the BEopt model is overpredicting the base load and underpredicting heating load.

Table 16. BEopt Model Compared to Utility Regression Model, Base Load, and Heating Load

	Base Load	Heating	Total
Salishan 1–6 BEopt	8,467	3,455	11,922
Salishan 1–6 Regression	6,998	5,091	12,088
Difference of BEopt From Regression	**–1,469**	**1,636**	**166**
Salishan 7 BEopt	8,531	495	9,026
Salishan 7 Regression	6,892	2,594	9,486
Difference of BEopt From Regression	**–1,639**	**2,099**	**460**

8 Conclusions

1. How does the modeled energy use (using BEopt) for Salishan phases 1–6 compare to the actual use derived from billing data?

   Total modeled energy usage for Salishan phases 1–6 was 11,922 kWh/year, with 3,544 kWh/year for heating, or 29% of total energy usage.

   The billing analysis suggests annual energy use of the two-bedroom duplex (comparable to the unit modeled with BEopt) to be 12,088 kWh, with 5,091 kWh from heating. While the BEopt model and utility billing analysis yielded good alignment overall (a difference of 166 kWh or 1.37% for total energy use), the heating load estimates were not well aligned, with a difference of 1,469 kWh or 21%, suggesting that the BEopt analysis may be overpredicting base load and underpredicting heating load.

2. How do phases 1–6 compare to phase 7?

   A comparison of annual energy usage (from billing analysis) between Salishan phases 1–6 and Salishan 7 indicates savings of 1,400 to 4,300 kWh/year, a strong indicator of the benefits from the Salishan 7 energy efficiency improvements.

3. What are the opportunities for energy efficiency retrofit improvements in Salishan phases 1–6?

   If 100% of the existing electric resistance heating is assumed by the DHP, energy savings is predicted to be 2,602 kWh annually; this amounts to $193 in cost savings, and a 15-year payback (well within the expected life of the equipment). If the displacement level of the electric resistance heating is less than 100%, the savings and payback are reduced. Based on DHP retrofit research conducted in the Pacific Northwest (used in previous Building America projects), these savings may be reduced by as much as 60%.

   The analysis of HPWHs suggests annual savings of 778 kWh, or $58. Using current incremental cost assumptions, payback for the HPWH does not fall within the useful life of the system. However, the installation of HPWHs may be justified for homes with high base load use and high occupancy (a surrogate for high domestic water heating usage). Combining the installation of HPWHs and DHP retrofits may improve cost effectiveness and installation logistics in occupied dwellings.

4. How do the mechanical ventilation systems perform compared with Washington State-mandated requirements and ASHRAE 62.2-2010, and how did field assessments and occupant surveys reflect the operation of the systems?

   All audited units have ventilation systems capable of meeting VIAQ or ASHRAE 62.2-2010 requirements (in terms of fan flow), though runtimes varied. None of the tenants seemed to have a working knowledge of their ventilation systems.

5. What are the measured temperature and RH levels in the homes during the heating season, and what impact did they have on occupant comfort?

   Average hourly indoor temperatures were 73°F for the monitoring period November 2012 to March 2013. The monitoring data do suggest high temperature swings in each home (as much as 31°F difference between minimum and maximum monitored temperatures). Occupant surveys indicated a high degree of variability of satisfaction with the comfort level in their homes; the high degree of variability in the monitored temperatures further reflects this.

   Average hourly RH levels were 40% for the monitoring period, suggesting good humidity control with well operating whole-house fans and with air change rates typical for new construction (5–7 ACH_{50}).

9 Recommendations

- If the DHPs can be acquired by King County Housing Authority (KCHA) at the price assumed in the analysis, they should be considered for future retrofit efforts, particularly for homeowners with high space heat use, or who express concerns about comfort with the use of the resistance heat. Additional benefit may be seen by tenants with a need for air conditioning (for example, seniors, or tenants with special health needs). At the assumed cost, the DHP could pay back within its expected life (15–20 years).

- The use of the HPWH in retrofit efforts is more questionable. At the assumed cost, the HPWH does not pay back within its expected life. TPU billing data can identify units with high base load use as candidates for HPWH retrofits.

- In the course of routine maintenance, KCHA staff can verify that the whole-house ventilation systems are set up correctly, to either VIAQ or ASHRAE specifications, and neither under- nor overventilating. KCHA staff can also use the opportunity to educate tenants on the purpose and correct operation of their ventilation systems.

10 Potential Research Opportunities

- Additional research is needed to confirm whether the electric resistance displacement assumptions used in Pacific Northwest DHP studies is consistent with low-load, high efficiency housing such as Salishan phases 1–6. A pilot project by THA and TPU could identify dwellings that would be good candidates for retrofits (homes with high space heating use, determined through billing analysis).The pilot project can also investigate changes in RH and temperature pre- and post- DHP retrofit.

- Further research is warranted into the proper modeling in BEopt and other single-zone hourly simulation models of multizone hybrid space heating systems, utilizing DHPs and electric resistance heat.

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Appendix A: Audit Forms

Salishan Audit Form

Date:	10/31/2012	Technicians:	Emily S., Luke M. & Luke H.
Address:	SALISHAN 1		

Envelope Inspection

CONDITIONED SPACE

Ceiling height:	8.5	Area:	975	Room Volume:	8288	Total Glazed Area:	147
Ceiling height:		Area:		Room Volume:	0	Glazing % of CFA:	15%
		Total Conditioned Floor Area:	975	Total House Volume:	8288		
# of Bedrooms:	2	Floors above grade:	2	Foundation type(s):	Slab on Grade		
Crawl space vented?	N/A	Slab insulation: Perimeter-	R-10 to 2'	Full-	N/A	Grade-	unknown

INSULATION	Depth	Type/Notes	Nominal R
☼Attic	~16"	Blown in fiberglass	38
☼Above grade wall	5.5"	Fiberglass	21
☼Framed Floors	N/A	N/A	N/A
☼Slab	2"	R-10 rigid on the interior of slab fromtop of slab to top of footer (18" min)	10

	Location	Type	Area
Floor coverings over thermal mass:	Kitchen and Entry	Vinyl	~300 sf
	Living Room	Carpet	~187 sf

GLAZING	Orientation	U-Factor	Quantity	Width	Height	AREA	Notes
Vnl frmd dbl glzd low E w/ Argon	W	0.40	1	22.7	46.3	1051	Per code
Vnl frmd dbl glzd low E w/ Argon	W	0.40	1	20.8	35.3	734	Per code
Vnl frmd dbl glzd low E w/ Argon	S	0.40	2	34.6	70	4844	Per code
Vnl frmd dbl glzd low E w/ Argon	E	0.40	1	68.3	70	4781	Per code
Vnl frmd dbl glzd low E w/ Argon	W	0.40	2	34.8	58	4037	Per code
Vnl frmd dbl glzd low E w/ Argon	S	0.40	1	23	40	920	Per code
Vnl frmd dbl glzd low E w/ Argon	W	0.40	2	35	58	4060	Per code
Total Window Area (square inches)	20427.05						

Skylights	Orientation	U-Factor	Quantity	Width	Height	AREA	Notes
None						0	none
						0	
						0	
Total Skylight Area (square inches)	0						

DOORS	Orientation	U-Factor	Quantity	Width	Height	% Glazed	Notes
Insulated steel front door	W	0.2	1	36	80	0%	none
Insulated steel back door w/1/4 glz	E	0.2	1	36	80	25%	none
Total Glazed Area (square inches)	720						

Equipment & Performance Testing

Lighting	Incandescents Lamps	Total	Estar Qualified Lamps	Total	% EStar
	IIIIII	7	IIIIIIIIIIIII	14	67%

☼Domestic Hot H_2O Fixture flow rates	Shower(gpm)	1.50	Kitchen sink (gpm)	1.50	Bathrooms (gpm)	half: 1	full: 1
Fuel/Type/Brand:	Electric		Storage		A.O. Smith		
Model #:	PXHT 52P200			Size:	50	EF:	0.95
☼Dishwasher							
Manufacturer:	GE		Model #	unknown		EF:	EStar
☼Heating							
Fuel/Type/Brand:	Electric		Baseboard		unknown		
Model #:	unknown			Size:	?	Efficiency:	100%
☼Cooling:							
Fuel/Type/Brand:	n/a		n/a		n/a		
Model #	n/a			Size:	n/a	Efficiency:	n/a
☼Whole House Ventilation:							
Type/Brand/Model #:	Exhaust w/ trickle vents		Panasonic		FV-08VQ3		
Tested Flow Rate:	54	MERV: no filter	Control Strategy:	intermitent		Hours/day:	5.00

Note location and position of inlet vents

Living Room	3 trickle vents ocated in window frams, all found in closed position
Kitchen	1 trickle vent located in window frame, found in closed position
Bedroom 1	2 trickle vents located in window frames, both found in open position
Bedroom 2	2 trickle vents located in window frames, one found in closed position and one found open

☼Local Exhaust Fans:

Range:	*Brand*	**GE**	*Model #*	**JV347H1WW**	CFM	***unknown***
Utility/Whole House:	*Brand*	**see wh ventilation**	*Model #*	**see wh ventilation**	CFM	***wh ventila***
Full Bath:	*Brand*	**Panasonic**	*Model #*	**unknown**	CFM	***49***
Half Bath:	*Brand*	**Panasonic**	*Model #*	**unknown**	CFM	***33***

☼Infiltration

	50 pascals		*25 pascals*		ACH_{50}
Test #1 (vents in found position)					
Ring Size	***see TecTite File***		***see TecTite File***		
Fan Pressure	***see TecTite***	pa	***see TecTite***	pa	**5.73**
Fan Flow	***792***	CFM_{50}	***see TecTite***	CFM_{25}	
Test #2 (vents in open position)	*50 pascals*		*25 pascals*		ACH_{50}
Ring Size	***see TecTite File***		***see TecTite File***		
Fan Pressure	***see TecTite***	pa	***see TecTite***	pa	**5.28**
Fan Flow	***729***	CFM_{50}	***see TecTite***	CFM_{25}	
Test #3 (vents in closed position)	*50 pascals*		*25 pascals*		ACH_{50}
Ring Size	***see TecTite File***		***see TecTite File***		
Fan Pressure	***see TecTite***	pa	***see TecTite***	pa	**6.42**
Fan Flow	***887***	CFM_{50}	***see TecTite***	CFM_{25}	

☼House pressure with reference to exterior

Baseline	***-0.9***	pascals
Whole house fan	***-1.4***	pascals
Whole House fan and dryer	***no dryer***	pascals
Whole house fan, dryer and range hood	***-5.3***	pascals
Whole house fan, dryer, range hood and full bath exhaust	***-8.3***	pascals
Whole house fan, dryer, range hood, full bath exhaust and half bath	***-8.5***	pascals

Notes: The home felt moist and there was evidence of high humidity. The weather was warm and breezy with rain and high humidity. There was no dryer in the home and clean laundry was hung up inside the home to dry. Beyond typical household appliances, this home had a small chest freezer (Electro Lux WFC05K0DWO)

Appendix B: Occupant Survey

SHALISHAN FIELD SURVEY 2012
Shalishan 1
For USDOE – PNNL

Address ______________________ Date __________
Electric Utility ______________ Electric Meter ID # ______________
Person filling out this report ______________

Basic Information

Home Type: __________ Floor Area: ______ Year built: ______ Model: ______
Energy Star, other: ______________
Describe additional loads that would affect a billing analysis (well pump, welder, outbuildings, etc.):
____
____

Plans Available?: ______ If no: Attach a sketch floor plan with exterior dimensions.
Include Pictures & ID#: See Audit Form
Describe position and location of each of the fresh air intake trickle vents in:
Open: ______________________________________
Closed: ______________________________________

Consumer Questionnaire

1. How long have you lived in the home?
2. How many people live in the home (full-time occupants)? ______ Part time ______
3. How many people are home most of the time? ______ Ages ______
4. How many people work or volunteer outside the home ≥20 hours per week? ______ Ages ______
5. How many people attend school ≥20 hours per week? ______ Ages ______
6. Are any other people living in the home often not at home? ______
7. Are there any other people who spend a significant amount of time at the home? ______

Please describe other occupancy factors:

8. How many hours a week is nobody in the home? ______
9. How satisfied are you with the energy efficiency of your home?

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐
Why do you say:

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

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐
Why do you say:

10. How satisfied are you with the temperature throughout your home?

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐
Why do you say:

10. How satisfied are you with the temperature distribution throughout your home?

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐
Why do you say:

11. How satisfied are you with the light in your home?

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐
Why do you say:

12. How satisfied are you with the quality of the air in your home?

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐
Why do you say:

13. How satisfied are you with how quiet your house is?

Very satisfied ☐ Somewhat satisfied ☐ Somewhat dissatisfied ☐ Very dissatisfied ☐

Why do you say:

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

____

15. Are there other things that need to be fixed or repaired (or improved?)? Please describe?

____

17. How do you use your thermostats to control the temperature in your home?

____

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

Living Area: winter ________ Summer ________

Bedroom 1: Living Area: winter ________ Summer ________

Bedroom 2: winter ________ Summer ________

Bedroom 3: winter ________ Summer ________

____

20. Do you lower the temperature on your thermostat when no one is at home or at night (when you are sleeping)?

Living Area: ________

Bedroom 1: ________

Bedroom 2: ________

Bedroom 3: ________

____

21. How are the electric resistance heaters operated? Do you:

- ☐ Leave the thermostat on a low setting so the heaters are mostly off
- ☐ Leave the thermostat on a setting that causes the heaters to come on
- ☐ Frequently change the temperature on the thermostat so that the heaters come on when someone is using the room, but are mostly off when the room is vacant
- ☐ Other:

22. Did you know you have a ventilation system? ______________________________

Did anyone explain to you why your house has a ventilation system and how to use it?

____

What do you like about the ventilation system?

____

What don't you like about the ventilation system?

____

What is the general perception of the ventilation system and does this affect the way it is operated ?

____

23. Do you change the window vent positions frequently, occasionally, or do they mostly stay in one position? What causes you to change the position?

- ☐ Stay the same
- ☐ Occasionally change
- ☐ Frequently change
- ☐ Other

24. What is the operation strategy used with the ventilation system?

____

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, aquarium):

____

Number of full-time adult occupants ________ Number of full-time child occupants (under 12) ________

____

Is whole house fan operating as designed? ______________________________

Location of whole house fan switch ________ Is switch labeled? ________

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

____

____

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

☐ None

☐ Air Inlets vents in windows/walls (circle one)

☐ Other

Make-up duct diameter ________________ Flow Rate ________

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

____

Do all bedrooms have pass-through vents or door undercuts? ________

Note deficiencies and comfort issues? ______________________________

____

Use of windows for ventilation: ______________________________

Use of Air Conditioner? ______________________________

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