Measured vs. Predicted Analysis of Energy Star Modular Permanent Military Housing: Fort Lewis Case Study

Michael Lubliner, Rick Kunkle, and Andrew Gordon,
Washington State University Energy Program
Michael Blasnik, Blasnik and Associates

ABSTRACT

This paper presents the first phase of a multi-year billing analysis of Discovery Village homes, a multifamily home development in Fort Lewis, Washington. Discovery Village is the first project in the United States to use modular construction for permanent military family housing. The homes are built to Northwest ENERGY STAR® standards by Fort Lewis Communities LLC, a partnership between the developer, the Department of Defense (DOD), and a large modular home builder. The US Department of Energy's (DOE) Building America program provided technical assistance, including design guidance, field tests and factory inspections.

The paper provides measured gas and electric use compared to predicted energy use from a DOE2 simulation. Results are also compared to previous billing analyses of ENERGY STAR® and code level homes in the region.

Four units at Discovery Village incorporate additional HVAC, DHW and lighting efficiency improvements. These new technologies were evaluated as part of a four-home demonstration effort and subsequently adopted on future phases of permanent military housing projects.

The paper provides lessons learned and recommendations to the DOE and the DOD for future procurements and specifications, and opportunities associated with additional monitoring, as well as expanded billing analysis policies based on design consultation, factory inspection support, field technical assistance and monitoring.

Introduction

Since 2005, almost 500 energy efficient modular homes have been constructed at Fort Lewis Army Base, located approximately five miles south of Tacoma, Washington State. These factory-built homes are constructed to Northwest ENERGY STAR® Home standards, featuring 90% AFUE furnaces, efficient windows, and ENERGY STAR® appliances and lighting (NEEA 2010). Homes are built to Northwest ENERGY STAR® standards, as shown in **Table 1.**

Table 1. Fort Lewis Energy Efficiency Measures

Measure	Description
Ceiling	R-38 Attic
Wall	R-21, 16" on center
Floor over crawlspace	R-30
Windows	U-.35, maximum glazing 21% of conditioned floor area
Doors	R-5
Duct Insulation	R-8
Duct Sealing	Mastic, tape not allowed
Maximum Duct Leakage	.06 CFM_{50} per ft^2 or 75 CFM_{50}
Ventilation	Exhaust ventilation per state code (SBCC)
Maximum Envelope Leakage	7 ACH_{50}
Gas Furnace	90% AFUE
Gas Water Heater	.61 EF storage (Discovery Village) .85 EF tankless (Miller Hill and demonstration duplex at Discovery Village)

The Building America Industrialized Housing Partnership (BAIHP) has worked with Building America partners at the Oregon Department of Energy (ODOE), Idaho Energy Division, and several modular home builders, in coordination with the Fort Lewis developer, in an effort to build and monitor these and other energy efficient modular homes at Fort Lewis. The developer is responsible for the construction, operation and maintenance of these homes over a 50-year period; such arrangements are common in new military family housing throughout the US. As a result, the developer has a greater stake in ensuring energy efficiency and durability over the home's useful life.

In 2005, a local builder was awarded the contract to construct 458 homes at the Discovery Village development. In 2008, a second builder was awarded the contract to construct an additional 34 units at Miller Hill, (another Fort Lewis development) using identical floor plans as Discovery Village. Most homes in Discovery Village and Miller Hills are two-story modular duplexes, 3 and 4 bedroom configurations with an average of 2058 square feet of conditioned floor area. BAIHP staff provided technical assistance (TA) on design, training, and in-field testing, and coordinated with factory and on-site third-party inspectors.

Featured Energy Efficiency Technologies

In addition to the standard ENERGY STAR® Homes, BAIHP worked with the builders to construct a single demonstration duplex with a 94% AFUE furnace with variable speed blower motor, extremely tight ducts, whole house exhaust fans as well as ENERGY STAR® lighting, gas tankless hot water system (.85 EF), and active crawlspace ventilation. Preliminary cost data and modeled energy savings estimates suggest that monthly energy savings from these improvements exceeded the increased monthly mortgage payments (Lubliner 2009).

The Miller Hill homes used tankless water heaters, as a result of the demonstration at the Discovery Village development. It should be noted that the developer's decision to switch to tankless water heaters at Miller Hill was primarily due to significant maintenance issues with the control boards of the power vented storage water heaters, rather than a desire to improve the energy efficiency of the systems.

More detailed utility billing analysis is underway to evaluate implementing some of these technologies in future projects. For example, BAIHP staff are providing technical assistance to the design of Fort Lewis' Town Center, a 290 multi-family unit project slated to start in 2010, which will include improved whole house ventilation, tankless water heaters, all ducts within conditioned space and a higher percentage of ENERGY STAR® lighting.

Findings

Duct Leakage

The most important early lessons learned in the quality assurance (QA) construction process for the builders were reducing duct and envelope leakage, while achieving adequate and consistent attic insulation levels. Prior to Building America technical assistance (TA), the builder's HVAC contractor was not able to meet Northwest ENERGY STAR criteria for total duct leakage (Maximum CFM_{50} of 6% of conditioned floor area).[1] This was apparent after BAIHP staff tested and trained the HVAC contractor on the first two homes. Total duct leakage was found to be 216-288 CFM_{50} before repairs, and 128 CFM_{50} after the ducts were sealed with mastic and retested. With onsite technical assistance, provided by BAIHP staff, the HVAC contractors were able to reduce duct leakage rate significantly, to less than 5% of conditioned floor area (see **Table 2**).

Table 2. Fort Lewis Duct Leakage Test Data 2005-2007

Year	# of homes tested	Average duct leakage - CFM_{50}	Average duct leakage - % of floor area (CFM_{50})
2005	74	96.3	5.2%
2006	164	91.0	5.1%
2007	218	86.1	4.8%
Total	456	89.5	4.9%

While all the homes met the minimum housing tightness requirements in Northwest ENERGY STAR® specifications of 7.0 air changes per hour at 50 Pascals (ACH_{50}), there was significant anecdotal evidence of steady improvement in building envelope tightness from the first homes to the last homes. When field assessments began in 2005, air leakage testing typically indicated envelope leakage around 6.0 ACH_{50}. By 2007, BAIHP staff were finding envelopes as tight as 3.2 $ACH_{50.}$ This improvement is believed to be largely due to quality assurance feedback from house pressurization and thermographic (infrared) inspections that led

[1] CFM_{50} is defined as the duct leakage flow rate in cubic feet per minute (CFM) at duct pressure of 50 Pascals (Pa) with respect to ambient pressure. The Northwest Energy star program uses CFM_{50} for duct leakage measurement, whereas most of the rest of the country uses CFM_{25} (6% CFM_{50} is roughly equal to 4% CFM_{25}).

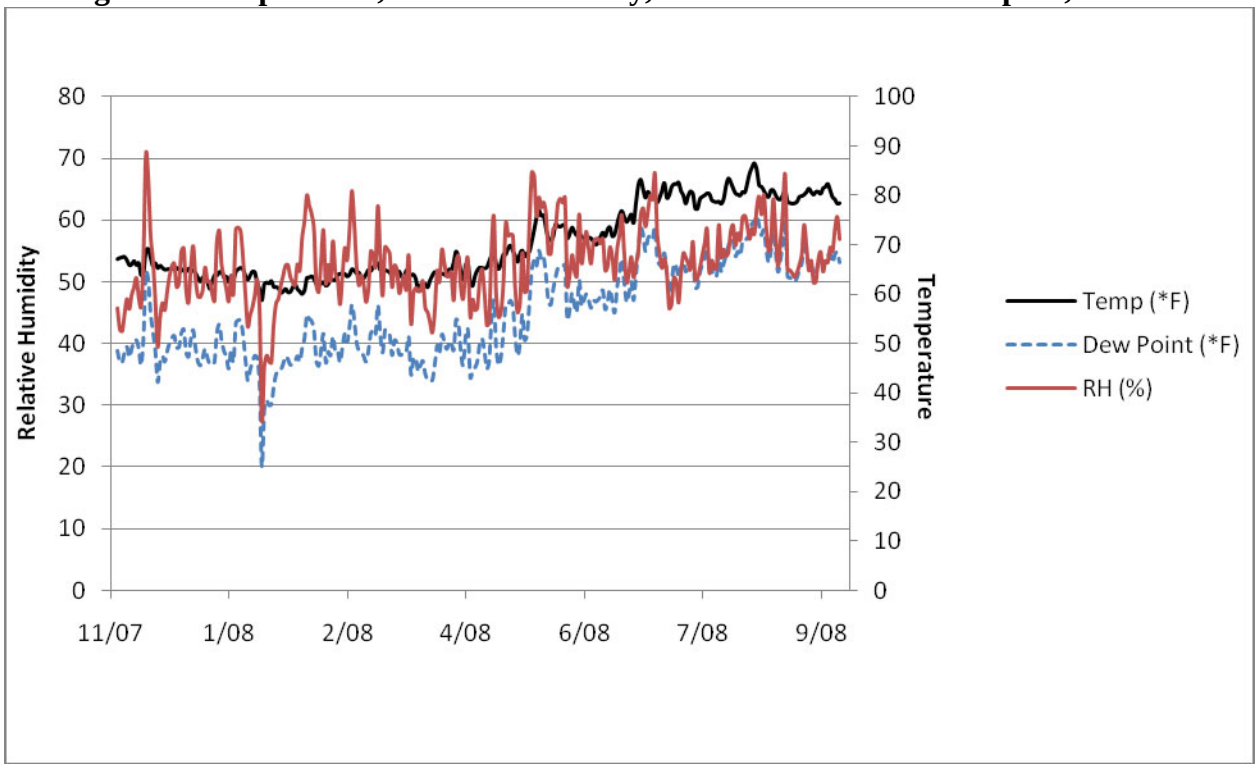
to improvements in sealing the marriage line,[2] the attic hatch, ductsystems, and the chase used for running second floor supply air ducts from the mechanical room to the attic.

Transport of the modular units and compression caused by other trades for the first few homes at Discovery Village reduced the nominal R-38 insulation by 12.5 percent to R-33; less than the ENERGY STAR® specification. With some coaching from BAIHP staff, these problems were addressed, and the insulation was brought up to ENERGY STAR® requirements.

Crawlspace Venting

All Fort Lewis duplex crawlspaces are mechanically ventilated, controlled by humidity sensors (humidistats) when the relative humidity (rh) exceeds 60%. **Figure 1** shows the temperature, relative humidity and dew point of one unit with the crawlspace fan turned off for a one year period. Though the rh was frequently at or above 60%, the crawlspace temperature exceeded the dew point throughout the one year monitoring period.

Figure 1. Temperature, Relative Humidity, and Dew Point of Crawlspace, Fan Off



These findings suggest that the crawlspace fans can be turned off, saving thousands of dollars in electric bills over the life of the home (fan run-time data for units with fans turned on was lost during the monitoring period, making a more specific estimate difficult). The developer is not interested in this approach, due to concerns with building code compliance requirements. As a result, BAIHP staff are working with the developer to investigate adjusting the humidistat settings to maintain acceptable crawlspace humidity levels. This adjustment would have the added benefit of increasing crawlspace temperatures, thereby reducing floor heat/duct heat loss.

[2] In factory built housing, a marriage line is the seam where sections of the home are joined together.

BAIHP staff are also concerned about the use of mechanical crawlspaces where there is high surface and subsurface water (typical at many Fort Lewis building sites, and throughout marine climates generally). BAIHP staff are working with state and national code organizations to explore the possibility of eliminating mechanical crawlspace ventilation under such circumstances.

Water Heating

The benchmark and utility data presented are for the gas storage water heaters used at Discovery Village (.61 EF), not the tankless water heaters used in the Miller Hill development (.85 EF). Tankless water heaters are expected to increase benchmarked savings by 8%, based on Energy Gauge USA 2.8 (EGUSA) analysis (FSEC 2008).[3] One additional benefit of the tankless water heater was the ability to use concentric vents for combustion air and flue gases. This venting configuration eliminated the requirement for passive high and low venting of the mechanical room, which in turn led to reduced standby losses from the furnace and water heater. After a year of data has been collected from Miller Hill, additional analysis will be conducted to compare the hot water use from the tankless water heaters at Miller Creek with that of the storage units at Discovery Village.

100% Energy Star Lighting

The demonstration home used 100% ENERGY STAR® lighting fixtures and lamps, as compared to the 50% requirement in Northwest ENERGY STAR® specifications. A variety of lamps and fixtures were required for this demonstration. The developer was concerned about the increased first cost of this lighting package and the potential confusion associated with the long term requirement to stock multiple type lamps and fixtures. While the demonstration home used U30 universal pin based CFL lamps, future homes at Miller Creek and Town Center employ screw-in CFL lamps on nearly all fixtures This is important since many of the CFLs installed at Discovery Village were located in low usage areas such as closets as opposed to kitchens, bathrooms and main living areas, thereby reducing actual savings compared to EGUSA and BA benchmark assumptions (Hendron 2004).

Modeling Analysis

Using the USDOE benchmarking procedure[4] with Energy Gauge 2.8 for the most typically built floor plan (a 2 story, 3 bedroom duplex) indicated whole house benchmarked savings from meeting Northwest ENERGY STAR® specifications of between 30 to 40 percent, depending on tightness of the envelope and HVAC system efficiency. Based on typical testing results, envelope leakage was assumed to be 900 to 1600 CFM_{50}; total duct leakage was assumed to be of 90 CFM_{50} (57 CFM_{25}) based on what is believed to be most typical of homes tested. The overall energy usage was found to be 7685 to 7728 kWh per year electric use, and 484 to

[3] Energy Gauge USA is a DOE2 driven energy analysis software tool.

[4] The benchmarking procedure compares the site and source energy use of a home to a USDOE defined reference, or benchmark home. USDOE developed the benchmark "to track and manage progress toward multi-year, average whole-building energy reduction research goals for new construction, using a fixed reference point." (Hendron 2004)

533 therms per year for natural gas (low end of range for 900 CFM_{50} envelope leakage, high end of range for 1600 CFM_{50}). For the estimated gas use, 262 to 311 therms were from space heating and 222 therms per year from domestic water heating.

Utility Billing Analysis

The research team developed a preliminary billing analysis for Fort Lewis. For the 458 units in Discovery Village, the team was able to obtain "good" gas utility data for 265 units and "good" electric data for 89 units. The data attrition was due to missing or estimated meter readings and failure to meet the minimum requirements for the weather normalization analysis. The analysis shown here compares the Madison 3 bedroom duplex (a 51 home subset) electric and gas utility bills to Energy Gauge modeling. Preliminary results show reasonable agreement (**Table 3**). Mean electric usage for 51 homes with complete data is a Normalized Annual Consumption (NAC) of 8140 kWh/year as compared to the EGUSA prediction of 7685 to 7728 kWh per year. The modeling of electric base load usage in new homes (prior to occupancy) is not expected to be particularly precise although it would be worthwhile to investigate reasons for higher use than predicted. Table 3 indicates mean gas usage of 447 therms per year for 185 homes with data. This is slightly less than the 484 to 533 therms from the EGUSA prediction. The billing data space heating usage was 270 therms per year – essentially the same as the 262 to 311 therms per year from the EGUSA model. However, the hot water estimate from the EGUSA model of 222 therms was higher than the 177 therms from the billing analysis. The actual weather data used for billing data normalization had 3.8% fewer heating degree days (base 60° F) than the TMY weather data used for the EGUSA model estimates, resulting in an expected discrepancy of about 4%. In addition, the seasonality of hot water use tends to cause an over-estimate in heating energy use and under-estimate hot water use in the billing analysis. This explains some of the differences in the results.

Table 3. Fort Lewis Billing Analysis (2008-09)

Electric Usage – kWh (08-09)				
Variable	**# Homes**	**Mean (kWh/yr)**	**Std Dev (kWh/yr)**	EGUSA
Total Use (NAC)	51	8,140	2,670	7,685-7,728*
Baseload	51	6,913	2,523	
"Heating" Use	51	932	957	
"Cooling" Use	51	295	404	
Gas Usage – Therms (08-09)				
Variable	**# Homes**	**Mean**	**Std Dev**	EGUSA
Total Use (NAC)	185	**447**	106	484-533
Heating Use	185	**270**	86	262-311
Baseload	185	**177**	72	222
T-ref (bal point)	185	**57.0**	3.9	
R-squared	185	**0.91**	0.07	
CV(NAC)%	185	**4.9%**	2.4%	

*EGUSA values vary due to envelope leakage

Comparisons with Other New Homes

Another way to evaluate the performance of the Fort Lewis ENERGY STAR® homes is to compare them with other new homes in the region. This type of analysis is an important way to assess the actual performance of homes. However, there is a limited amount of available energy use data for conducting comparative analysis of residential energy use. We draw on two studies supported by the Northwest Energy Efficiency Alliance to make some simple comparisons with the Fort Lewis billing data.

The first study is based on a sample of 604 single family homes and 200 multi-family homes built in the Northwest in 2004 and 2005 (RLW Analytics 2007)[5]. Useable utility bill data was acquired from 458 homes and normalized annual consumption was calculated using a PRISM type billing analysis. The authors note that the relatively high data attrition mean the results are not necessarily representative of the region. For the purposes of our comparison, we used the results for homes in Washington with natural gas space heat.

The second study draws from the population of 4,458 Northwest ENERGY STAR® homes certified from 1/2006 through 9/2007 (KEMA 2009). A sample of 345 participant homes was drawn from this population. Electricity billing records were obtained for 225 sample homes and gas billing records for 141 homes. A baseline sample representing standard new homes use the 604 single family homes in the RLW report noted above. Billing records were obtained for 310 baseline homes for electricity and from 272 homes for gas. Regression models were developed to estimate heating, cooling, and baseload energy use. The models used a pooled time series, cross-section analysis approach, intended to account for weather and other factors influencing energy use besides program participation. For the purposes of our comparison, we used the results for homes with natural gas heating and water heating and no air conditioning. We compared the results from these studies with the Fort Lewis billing analysis for all the Discovery Village houses with useable data and with the Madison duplex billing data and EGUSA estimates (**Table 4**).

The Fort Lewis billing results are similar to the Northwest ENERGY STAR® evaluation. Electric use is between the Northwest ENERGY STAR® baseline and participants. Since the Fort Lewis homes are smaller, adjusting for square footage increases their energy use relative to the Energy Star Study homes. Gas use is close to participants. The energy use for the new homes in Washington (2004-2005) is quite a bit higher than the other results, suggesting these results are not representative of new, ENERGY STAR® homes in Washington.

[5] Homes in this study were built to Washington State Energy Code (SBCC 2007). Primary differences between these homes and ENERGY STAR® specifications relate to space and water heating efficiencies, and duct sealing requirements.

Table 4. Comparison of Fort Lewis Results with other Studies

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

While these results show the performance of the Fort Lewis Discovery Village duplexes are comparable to Northwest Energy Star homes, the ability to draw conclusions from these data are limited. The ENERGY STAR® study covers a wide variety of homes throughout the Northwest. The Discovery Village homes are confined to a small area south of Tacoma, WA, are all very similar with similar occupancy patterns, and they are duplexes of similar design and construction.

Utility Billing Conservation Program

There is a behavior element contributing to the energy performance of the Discovery Village Duplexes. The Department of Defense has established a Utility Billing Conservation Program for on-base housing, including Fort Lewis (USDOD 2005), (USDOD 2008). The developer establishes a utility allowance for similar groups of housing units using a rolling average baseline. After a "mock" billing period, residents receive a bill that credits or penalizes them if their use deviates +/- 5% from the baseline. Initial results from the Fort Lewis developer (Greer 2009) suggest that natural gas energy use for the most recent heating season is less than previous years. BAIHP staff are planning to work with the developer to look more closely at the Fort Lewis data to see if there is evidence of reductions in energy use that might be attributed to the information and billing credit/payment incentives of the Utility Billing Conservation Program. BAIHP is also interested in looking at how utility usage varies at Fort Lewis by house type, vintage and other parameters, since the developer collects utility data on over 3700 residences in 13 developments.

Lessons Learned

A number of issues were identified during the project that can be applied to similar projects in the future:

- The DOD minimum specification (in this case ENERGY STAR®) defines what will be built. There is no motivation for the developer to exceed this minimum. There are opportunities to demonstrate or incorporate "beyond ENERGY STAR®" measures by obtaining additional funding or identifying other incentives for the developer.
- Opportunities to improve lighting, HVAC and appliances need to address operation and maintenance needs, and the developer's desire to stock one brand in order to meet a "one size fits all" mentality.

- Engineers, modular builders and developers need to improve their understanding of basic building science principles, tools, commissioning and utility monitoring. Upfront quality assurance and technical assistance support is critical to address construction issues that ultimately degrade building performance.
- The use of billing analysis to track individual and aggregate home energy performance provides an ideal opportunity for feedback on energy saving technologies and behavioral issues. However, it is important to set up procedures for data collection, begin collecting billing data soon after the projects are completed, and verify the quality of data being collected. Otherwise there may be problems with missing or poor data that limit the ability to draw conclusions.
- Caution should be used when employing models especially without the utility billing analysis feedback from the field. Utility bill analysis provides a reality check on the modeling analysis. Submetering of end uses (heating, cooling, water heating, major appliances, miscellaneous, etc) would be beneficial in better understanding discrepancies between modeled and actual energy use.
- Implementing beyond-code construction in military housing requires coordinating with a broad range of stakeholders, and constant engagement with both the developer and partners, including utilities and suppliers.

Recommendations

Study findings support the following recommendations:

- Significant up-front 3rd party training, quality assurance and technical assistance needs to be provided to ensure performance standards are met for projects like Discovery Village.
- The utility bill analysis needs to be expanded to assess the long-term performance of these homes, to provide comparative data for future developments, and to evaluate the impact of behavioral efforts like the utility bill conservation program.
- It appears that baseload energy use in households is growing, and energy models need to be refined to predict this use. It would be valuable to investigate baseload electricity use in Fort Lewis housing to better understand what components are increasing most rapidly and how best to educate and influence the homeowners.
- The performance of new developments at Fort Lewis should be compared with the initial development phases.
- Additional monitoring should be completed to assess individual technologies for field performance and cost-effectiveness.

Conclusions

Large, robust data sets of new home energy use need to be collected to support comparative analyses of new home performance. This effort is necessary to improve our understanding of the energy use in new homes, and the factors that influence energy use (construction methods, technologies and behaviors) so that we can meet aggressive regional and national energy savings goals.

Military housing provides an ideal opportunity to conduct research and demonstration efforts in the residential sector. Energy efficiency, indoor air quality and durability can be evaluated as a longer term and more controlled experiment than is typically the case with private (owner-occupied) large scale housing projects. As new developments are planned at Fort Lewis and other military bases, the results of this research can provide valuable input into the design process.

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References

FSEC. 2008. **Energy Gauge USA**, Version 2.8. . Florida Solar Energy Center. Cocoa Beach, Fla.

Greer, Michael. 2009. **Fort Lewis/McChord Communities**. Presented at RCI Asset Manager and Partner Utilities Implementation Workshop. Equity Residential

Hendron, R., R. Anderson, R. Judkoff, C. Christensen, M. Eastment, P. Norton, P. Reeves and E. Hancock. 2004. **Building America Perfomance Analysis Procedures**, Revision 1. National Renewable Energy Laboratory. Golden, CO.

KEMA. 2009. **Evaluation of the Northwest ENERGY STAR® Homes Program: 2006 – 2007**. For the Northwest Energy Efficiency Alliance

Lubliner, Michael. 2009. **Stagegate Report for Building America Industrialized Housing Project**. Washington State University Extension Energy Program for USDOE.

NEEA. 2010. **Northwest Energy Star Homes Program Builder Option Package 1.** http://www.northwestenergystar.com/downloads/NWBOP1_GasFiredFurnace-HeatPump.pdf

RLW Analytics. 2007. **Residential New Construction (Single and Multi-Family) Billing Analysis**, Report # E08-185. For the Northwest Energy Efficiency Alliance.

SBCC. 2006. **Washington State Ventilation and Indoor Air Quality Code** (2006 Edition), section 502.1.2. Washington State Building Code Council.

SBCC. 2007. **Washington State Energy Code (2006 Edition)**. Washington State Building Code Council.

USDOD. 2005. **Letter to Requirements and Billing Info to Fort Lewis Residents Regarding Army's Residential Communities (RCI) Residential Utility Policy**. United States Department of Defense.

USDOD. 2008. **Memo and Attachment: Army's Residential Communities (RCI) Residential Utility Policy Update**. United States Department of Defense.