PUGET SOUND ENERGY
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2011 Multi-Family Weatherization Study Documents

Contents:

- **2011 Multi-Family Weatherization Study**
- **Evaluation Report Response**

This document contains both the final **2011 Multi-Family Weatherization Study** and the Puget Sound Energy (PSE) **Evaluation Report Response** (ERR). PSE program managers are required to complete an ERR upon completion of an evaluation of their program. The ERR addresses and documents pertinent adjustments in program metrics or processes subsequent to the evaluation.

Report by **SBW CONSULTING, INC.**

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FINAL REPORT

IMPACT EVALUATION OF MULTIFAMILY WEATHERIZATION PROGRAM

PROGRAM YEARS 2007-2009

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ENERGY + WATER + EFFICIENCY

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EXECUTIVE SUMMARY

Introduction

The Puget Sound Energy Multifamily Weatherization program provides financial incentives to encourage owners of existing multifamily buildings to upgrade the efficiency of their buildings, including the thermal envelope. Measures include ones affecting the building shell, such as attic, floor, and wall insulation as well as high efficiency windows. They also include efficient equipment measures, such as ductless heat pumps, in-unit water heaters, refrigerators, and in-unit furnaces. For program years 2007 through 2009, the multifamily program implemented a wide variety of measures in over a thousand participant buildings at 266 sites.

PSE's current program energy savings estimates for the shell measures were prepared by a third-party vendor using SEEM simulation software. Savings for electric non-shell measures used the Regional Technical Forum (RTF) deemed values and deemed savings values for gas non-shell measures were developed internally.

This study was an impact evaluation of selected shell and non-shell measures that were implemented during the 2007-09 program years. It produced estimates of the electric and gas energy savings actually realized by a representative sample of 2007-09 participants. This information can inform program planners about the likely savings from future program participants who install selected measures.

Objectives

The three objectives of this study were as follows:

1. <u>Determine Program Participant Characteristics</u>. Prepare calibrated participant prototypes using energy simulation software. Use these prototypes to determine the as-built energy consumption characteristics of existing multifamily buildings that represent the population of 2007-09 program participants.
2. <u>Establish Baseline Characteristics</u>. Determine the baseline energy consumption characteristics of participants, excluding the implemented program measures. Modify the calibrated participant prototype simulation by removing the program measures.
3. <u>Estimate Energy Savings</u>. For each prototype, determine the energy savings associated with the selected program measures, computed as the difference between participant and baseline models under typical meteorological conditions and post-retrofit occupancy levels. Provide estimates of realized savings for four measure groups (attic, floor, and insulation, and also high-efficiency windows). As appropriate, adjust the savings to reflect the characteristics of expected future program participants. In addition review the deemed savings values used by the program for five non-shell measures.

Methodology

The evaluation team first analyzed the program tracking database, and developed an evaluation sample of 20 representative projects. For these, they collected building characteristics information--as well as billing, load, and weather data--necessary to support the analyses. They then analyzed and processed these data sources in advance of model calibration. Building simulation analyses were conducted using eQUEST® Version 3.64 software, powered by DOE-2, the standard energy simulation tool in the U.S.

The evaluation team developed two fully calibrated participant prototype models. One prototype represented the sampled sites with electric space heat and the other represented sites with gas space heat. The prototypes reflected the as-built characteristics and conditions of the respective groups of sampled sites. The corresponding baseline model for each prototype reflected the baseline conditions that existed prior to the implementation of the program measures (without program influence).

Combined shell measures annual energy savings for each prototype were computed as the difference between the as-built and combined shell measure baseline models, under post-retrofit occupancy and typical meteorological conditions. This savings result represents the package of all shell measures, as they occurred during the 2007-2009 program years. These results were then normalized by dividing the annual savings by the respective gross floor area used in the models. Individual shell measure savings were also calculated as the difference between the as-built and the shell measure specific baseline models, under the post retrofit occupancy and typical meteorological conditions, and then divided by the measure installed area.

Once the preliminary savings analysis had been conducted, the evaluation team met to discuss the results and assess how characteristics of future participants would be different from the 2007-09 participants. To quantify future measure savings, additional sensitivity runs on the eQUEST models were performed. These measures for future programmatic efforts included a variety of scenarios for attic, floor, and wall insulation, as well as efficient windows.

The evaluation also assessed savings from non-shell measures—namely, ductless heat pumps, in-unit gas furnaces, refrigerators, and electric/gas storage water heaters. Because of the minimal program savings to date associated with these measures, the evaluation focus was to compare present PSE deemed measure savings with other regional and national standards and research. For the two heating measures, savings estimates were developed using this study's eQUEST models. Recommendations were made for each non-shell measure to help inform future program planning efforts.

Findings

After examining the characteristics of projects that had implemented shell measures, separate models to represent electrically-and gas-heated buildings were created. The evaluation sample of 20 sites consisted of 12 electric buildings and eight gas buildings, with a proportional allocation of projects across four measure strata (attics, floors, walls, and windows). Though recruiting customers and obtaining adequate documentation proved very challenging, the evaluation team was able to obtain adequate information and a sufficiently diverse project sample.

The average sizes of electric and gas dwelling units were 799 and 773 sq. ft., respectively, based on an assessment of 569 electric units and 102 gas units. For the electric prototype building, the exterior floor and ceiling areas are 177,525 sq. ft and 203,540 sq. ft respectively, versus 454,435 sq. ft. of gross floor area, while the gas building has 20,110 sq. ft of exterior floor area and 32,860 sq. ft of attic to the 78,805 sq. ft. of gross floor area are much smaller than the total building floor area, indicating the presence of a parking garage and multiple floor buildings. The electric model was dominated by attic roof construction and slab floor type, while the gas model had a majority vault roof construction and nearly even portions of slab, frame and post-tension slab floors.

Aggregated and summarized October 2009-September 2010 billing data from tenants of electric and gas sampled buildings provided EUI targets for both prototypes. For electric customers, the average EUI was 14.7 kWh/sq.ft./year. For gas customers, it was 3.59 kWh/sq.ft./year and 0.51 therms/sq.ft./year. Both models were successfully calibrated within the target values of ±10% of each month and ±5% overall, suggesting these fully calibrated models represented an accurate depiction of predicted end use consumption under full occupancy, and with the weather conditions that existed during the calibration year.

The final savings results for the 2007-2009 program shell measures in electric- and gas-heated buildings are shown, respectively, in Tables 1 and 2 below. The projected savings from expected future measures are shown in Tables 3 and 4. Table 5 summarizes the findings and recommendations for the analyzed non-shell measures.

Table 1: Electric Model Unit Savings Breakdown by Component

		Treated Area				
Retrofit component	kWh/year/sq.ft.*	Baseline U-value	Installed U-value	Baseline R-value	Installed R-value	% improvement
Windows	9.346	0.750	0.300	1	3	60%
Roof Insulation (Attic)	1.167	0.066	0.028	15	36	58%
Floor Insulation (Framed)	1.225	0.083	0.032	12	31	61%
Wall Insulation	1.353	0.105	0.061	10	16	42%

* Savings expressed as kWh per year per square foot of measure treated component.

Table 2: Gas Model Unit Savings Breakdown by Component

		Treated Area				
Retrofit component	Therms/year/sq.ft.*	Baseline U-value	Installed U-value	Baseline R-value	Installed R-value	% improvement
Windows	0.553	0.750	0.359	1	3	52%
Roof Insul. (Attic)	0.114	0.069	0.026	15	39	63%
Roof Insul. (Vaulted)		0.089	0.027	11	37	70%
Floor Insul. (Framed)	0.216	0.155	0.035	6	29	78%
Floor Insul. (PT Slab)		0.196	0.029	5	35	85%
Floor Insul. (Slab Perimeter)		0.224	0.224	4	4	0%

* Savings expressed as therms per year per square foot of measure treated component.

Table 3: Electric Model Future Measures Savings

Retrofit Component	Baseline (U or R)	Installed (U or R)	Energy Savings* (kWh/sq.ft./year)
Windows	U=1.2	U=.3	14.92
	U=1.2	U=.25	16.03
	U=.6	U=.3	5.98
	U=.6	U=.25	7.09
Roof Insul. (Attic)	R-0	R-38	4.89
	R-0	R-49	5.02
	R-6	R-38	2.21
	R-6	R-49	2.35
	R-14.5	R-38	0.99
	R14.5	R-49	1.12
Floor Insul. (Framed)	R-0	R-30	3.46
	R-11	R-30	0.85
Wall Insulation	R-0	R-11	3.85

* Savings expressed as kWh per year per square foot of measure treated component.

Table 4: Gas Model Future Measures Savings

Retrofit Component	Baseline (U or R)	Installed (U or R)	Energy Savings* (Therms/sq.ft./year)
Windows	U=1.2	U=.3	1.12
	U=1.2	U=.25	1.21
	U=.6	U=.3	0.46
	U=.6	U=.25	0.55
Roof Insul. (Attic)	R-0	R-38	0.32
	R-0	R-49	0.32
	R-6	R-38	0.14
	R-6	R-49	0.15
	R-14.5	R-38	0.07
	R14.5	R-49	0.08
Roof Insul. (Vault)	R-0	R-38	0.40
	R-0	R-49	0.41
	R-6	R-38	0.16
	R-6	R-49	0.17
	R-14.5	R-38	0.07
	R14.5	R-49	0.08
Floor Insul. (Frame)	R-0	R-30	0.27
	R-11	R-30	0.06
Floor Insul. (PT Slab)	R-0	R-30	0.39
	R-11	R-30	0.07

Table 5: Non-Shell Measures Savings

	PSE Multifamily Program			SBW Multifamily Study	
Measure Name	PSE Deemed Annual Savings/Unit	PSE Deemed Savings Source	2011 MF Program Offering?	Recommended Annual Savings/Unit	Findings/Recommendations
Ductless Heat Pumps	3500 kWh	RTF 2009	No	1873 kWh	1) Until a definitive DHP regional multifamily sector study is completed, the uncertainty of the savings will be high. 2) A provisional savings value from the eQUEST weatherized prototype model with annual savings at 1873 kWh is recommended.
In-Unit Gas Furnaces	66 Therms	PSE Deemed 2008	Yes	26 therms	1) The current savings value based on the KEMA billing analysis study - derated for multifamily from 89 Therms to 66 Therms. 2) DEER deemed savings for single family with an AFUE of 90% is 83 Therms, adjusted for HDDs is 87 Therms. 3) The Energy Star Calculator is about 30 Therms, depending on housing stock vintage assumptions. 4) SBW eQUEST modeling for the measure estimates annual savings at 26 Therms for the weatherized prototype unit and 34 Therms for the baseline prototype unit. 5) The eQUEST model for a weatherized prototype with annual savings of 26 Therms is recommended.
Refrigerators	97 kWh	RTF 2010	No	44 kWh	1) The current (2011-2012) RTF deemed values are: - Energy Star (+22% Fed standard): 44 kWh - CEE Tier 1 (+20% Fed): 37 kWh - CEE Tier 2 (+25% Fed): 65 kWh - CEE Tier 3 (+30% Fed) 86 kWh 2) The Energy Star savings of 44 kWh is recommended.
Electric Water Heaters	62 kWh	RTF 2009	Yes	131 kWh	Recommend using the (2010-2015) RTF savings for a 95% efficient standard for tanks between 45-55 gal are 131 kWh annual savings.
Gas Water Heaters	18 Therms	PSE Deemed 2008	No	8 therms	The KEMA analysis is somewhat equivocal, with the engineering analysis suggesting up to 15 therms, with 10 therms being the maximum "reasonable" value. The billing analysis, though, suggests 0 therms, but with a big confidence bound. A value somewhere in the middle may be the best value until further research is available.

Conclusions and Recommendations

The impact evaluation of the 2007-2009 Multifamily Weatherization Program yielded the following conclusions and recommendations:

1. **Building characteristics varied significantly depending on heating fuel**. Electrically-heated buildings among the program participants were built in the 1970s and contained, on average, 90 units with a total floor area of around 70,000 sq.ft. By contrast, participant gas-heated buildings were much older (built in the 1930s) and smaller, with an average of 19 units and total floor area of approximately 12,500 sq.ft.

1. **The program reduced electric use by 10% in electrically-heated buildings.** For program participants with electrically-heated buildings, the cumulative effect of the various implemented shell measures was to reduce electrical usage in residence spaces from 16.07 to 14.67 kWh/year per square foot of floor area, in a typical weather year. This difference of 1.40 kWh/year/sq.ft. represents a reduction of nearly 10%.

2. **The program reduced gas use by 19% in natural-gas-heated buildings.** For program participants with gas-heated buildings, the cumulative effect of the various implemented shell measures was to reduce gas usage in residence spaces from 0.619 to 0.523 therms/year per square foot of floor area, in a typical weather year. This difference of 0.096 therms/year/sq.ft. represents a reduction of nearly 19%.

3. **Deemed savings values for non-shell measures should be updated**. Over the last several years, customer interest in the non-shell measures—namely, ductless heat pumps, in-unit gas furnaces, refrigerators, and efficient water heaters—has been slight. As a result, the corresponding savings claims for these measures have also been modest. Nonetheless, the deemed savings values assigned to these measures should be revised based on the evaluated findings, the latest research, and industry guidelines. Specific recommendations for each measure are detailed in Table 7 in the previous section. For all measures named previously, with the exception of electric water heaters, these revisions will reduce the deemed savings.

4. **Program documentation should be improved**. The evaluation revealed deficiencies in the program documents that not only complicated the work, but also would in general make it difficult to verify program accomplishments. The paperwork often lacked basic information about which buildings were treated, where in a building program measures were installed, what was installed, and what the baseline conditions were.

5. **Detailed, accurate building information is difficult to obtain**. For future evaluations of existing multi-family buildings, it should be noted that as-built construction documents and drawings can be very hard to get. Local building departments often do not retain plan sets. Likewise, many building owners also are lacking these, and if they have them, may be reluctant to go through the trouble of assisting evaluators. Available documentation was frequently inadequate for the evaluation modeling effort, and thus could not be used.

1. INTRODUCTION

The Puget Sound Energy (PSE) Multifamily Weatherization program provides financial incentives to encourage owners of existing multifamily buildings to upgrade the efficiency of their buildings, including the thermal envelope. The Multifamily Weatherization program began in 2007 as an addition to the PSE residential portfolio. In 2009, PSE expanded the program to include custom measures for common spaces. Measures include ones affecting the building shell, such as attic, floor, and wall insulation as well as high efficiency windows. They also include efficient equipment measures (referred to as "non-shell" measures), such as ductless heat pumps, in-unit water heaters, refrigerators, and in-unit furnaces. For program years 2007 through 2009, the multifamily program implemented a wide variety of measures at over 1,000 participant[1] buildings (266 sites), as documented in PSE's program tracking database.

PSE's current program energy savings estimates for the shell measures were prepared by a third-party vendor using SEEM simulation software. Savings for electric non-shell measures used the Regional Technical Forum (RTF) deemed values and deemed savings values for gas non-shell measures were developed internally.

This study was an impact evaluation of selected shell and non-shell measures that were implemented during the 2007-09 program years. It produced estimates of the electric and gas energy savings actually realized by a representative sample of 2007-09 participants. This information can inform program planners about the likely savings from future program participants who install selected measures.

The evaluation team used typical energy program evaluation methods, including the review of data from utility program records, analysis of energy consumption histories, collection of characteristics data, analysis of load data collected from previous research, preparation of weather data, selection of representative participant buildings, prototype development and calibration to billing data, and prototype modeling of energy impacts from the program.

1.1. Objectives

The three objectives of this study were as follows:

1. Determine Program Participant Characteristics. Prepare calibrated participant prototypes using energy simulation software. Use these prototypes to determine the as-built energy consumption characteristics of existing multifamily buildings that represent the population of 2007-09 program participants.
2. Establish Baseline Characteristics. Determine the baseline energy consumption characteristics of participants, excluding the implemented program measures. Modify the calibrated participant prototype simulation by removing the program measures.

[1] *Participants* are defined as multifamily buildings in the Puget Sound Energy service area that implemented qualified efficiency improvements during the 2007-09 program years.

3. Estimate Energy Savings. For each prototype, determine the energy savings associated with the selected program measures, computed as the difference between participant and baseline models under typical meteorological conditions and post-retrofit occupancy levels. Provide estimates of realized savings for four measure groups (attic, floor, and insulation, and also high-efficiency windows). As appropriate, adjust the savings to reflect the characteristics of expected future program participants. In addition review the deemed savings values used by the program for five non-shell measures.

2. METHODOLOGY

This section describes the methodology that was used by the evaluation team to accomplish the three objectives described previously. The six main stages of this methodology were data collection, data analysis, participant model development, baseline model development, energy savings analysis of implemented measures, and energy savings analysis for future measures.

2.1. Data Collection

The evaluation team collected building characteristics information--as well as billing, load, and weather data--necessary to support the analyses.

Building Characteristics

At the onset of the study, PSE provided a program database, which provided information on the customers who participated in the program, as well as the measures they implemented. The information provided covered activity from October 2006 through April 2010, with 1,294 discrete entries over this period. Consolidating the program database, and then excluding the smallest savers accounting for less than 5% cumulatively of the savings for each fuel, yielded a sample frame of 149 sites where one or more measures were implemented. PSE and the evaluation team then augmented this sample frame using search engine visualization tools (such as Google™ Earth) and publicly available county assessor's data. This effort yielded additional insights into high-level building characteristics, such as the size of the complexes, number of stories, and number of buildings.

This characterization effort confirmed the appropriateness of designating two prototypes, one an aggregate of all sites that implemented electric measures, the other an aggregate of all sites with gas measures. Based on preliminary data, the average building areas, number of units, and vintages of the electric and gas savers differed substantially. Consequently, PSE and the evaluation team agreed to allocate the sample of 20 total sites to 12 electric savers (representing 106 sites) and 8 gas savers (representing 43 sites). The random sample occurred within seven domains, with each domain consisting of a combination of saved fuel and envelope measure class, such as Electric–Wall or Gas–Floor. The sampled projects are listed in Table 1. The sampling process also included randomly selecting replacement projects, which were activated when initially sampled projects proved unsuitable as the data collection process proceeded. A significant number of replacements proved necessary because of difficulties encountered recruiting sites and finding adequate site plans.

The evaluation team collected participant characteristics data from PSE project files, design documents available from municipal planning and building departments, and owners. These data include (1) building-level details, such as number of floors; types of wall, floor, and roof construction; window and door types; presence of fireplaces; water heating; and heating type, as well as (2) zone-level details, such as floor, roof, window, door, and exterior wall areas. This information was used to develop inputs to the participant models. The specifications of the installed measures were taken from the project files and program tracking system.

Table 6: Final Study Sample

E/G count	ID#	Measure stratum	City	Building characteristics*: # of Buildings	# of Floors	# of Units	Avg. unit area (sq. ft.)	Year built	Effective year	Total floor area (sq. ft.)	Measures: Attic insulation	Floor insulation	Wall insulation	Windows, efficient	Non-envelope
ELECTRIC SAVINGS PROTOTYPE															
1	117	Attic	Kirkland	5	2	32	1,512	1979	1979	48,409	1				
2	56		Sumner	6	2	72	724	1970's		50,904	1			1	
3	106		Bremerton	5	2	64	732	1975		46,838	1			1	
6	185	Floor	Bellevue	22	2 & 3	598	974	1972	1979	582,416	1	1		1	
7	21	Wall	Kent	38	2	262	967	1970	1986	327,129			1	1	
8	10		Kent	9	3	150	926	1979	2000	138,870			1		
4	184	Window	Woodinville	2	3	20	906	1986	1991	18,129				1	
5	82		Bellevue	1	4	32	1,193	1967	2003	38,176				1	
9	162		Olympia	1	3	28	745	1961		20,883				1	
10	41		Bellevue	3	3	152	453	1969	1993	68,798				1	
11	96		Olympia	8	3	64	803	1973		51,441				1	
12	79		Bellevue	10	2	102	823	1980		83,968				1	
				9.2	**2.6**	**131**	**897**	**1974**	**1990**	**122,997**	**% of sample with measure =**				
				6.8	**2.4**	**90**	**851**	**1976**	**1991**	**68,867**	**33%**	**8%**	**17%**	**83%**	**0%**
GAS SAVINGS PROTOTYPE															
1	124	Attic	Seattle	1	4	13	654	1926	1983	8,504	1	1		1	
4	125	Floor	Seattle	1	2	7	690	1954	1984	4,832	1	1		1	
5	152		Seattle	1	4	20	687	1958	1984	13,754		1		1	
6	35	Window	Seattle	1	2	11	695	1957	1986	7,649				1	
7	37		Seattle	1	3	10	698	1907	1970	6,986				1	
8	161		Seattle	1	3	10	715	1962	1982	7,145				1	
2	123		Kirkland	1	2	12	1,706	1991	1991	20,472				1	
3	107		Seattle	1	4	20	612	1947	1978	12,251				1	
				1.0	**2.9**	**13**	**807**	**1950**	**1982**	**10,199**	**% of sample with measure =**				
				1.2	**2.8**	**19**	**808**	**1935**	**1981**	**12,475**	**25%**	**38%**	**0%**	**100%**	**0%**

* Information shown here was derived from KIng County Assessor's data when available and has been supplanted with firmer information for all sites through the data collection process.

Electric Loads

Relevant electric load data came from the previously completed Bonneville Power Administration Multifamily Metering Study [2]. It was used to construct typical infiltration, internal load (lighting and equipment) and thermostat set-point schedules.

Billing

PSE provided monthly or bimonthly electric and gas billing records for all housing units in the participant sample. These records were in electronic form and spanned the post-retrofit calibration period with some exceptions. The calibration period was chosen to be October 2009 through September 2010.

The exceptions were as follows. For the sampled electric sites, 14% of the total sampled building areas had no billing data for September 2010, so 2009 was applied instead. Additionally, 9% of total sampled building square footage was completed in March 2010, so for these sites, billing data may include some pre-retrofit consumption.[3] For the sampled gas sites, 19% of total sampled building areas had no billing data for all of 2010, so billing data from 2009 was applied for those buildings but adjusted using heating degree days from 2010. Some of the billing data for these two buildings could include some pre-retrofit consumption.

Weather

For the calibration model, the TMY3 (typical meteorological year) file for the SeaTac, Washington weather station was updated with actual weather data from WeatherBank® over the calibration period.

2.2. Data Analysis

SBW analyzed and processed the four data sources listed above in advance of model calibration. Building simulation analyses were conducted using eQUEST® Version 3.64 software, powered by DOE-2, the standard energy simulation tool in the U.S. More detailed information on this software tool is provided in Appendix C.

These analyses are described in more detail below:

2.2.1. Building Characteristics

The envelope components collected from the plans were used to compute U-values for each type of exterior wall, floor, and ceiling for each participant building (U-values before and after program intervention). These were used to analyze unit-level UA data (where UA is the coefficient of heat transmission for a given area), to determine appropriate housing unit types for use in the prototypes. The specifications of the program shell improvements were taken from the project file and program tracking system.

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[2] SBW Consulting, Inc. 1994. *Multifamily Metering Study: Impact Evaluation of the Model Conservation Standards*. Portland, Oregon: Bonneville Power Administration.

[3] Completion dates were determined based on inspection date; however, the buildings may have been occupied in the post-retrofit period prior to their completion dates. There was no certain indication of when the post-retrofit period began.

Electric Loads

The evaluation team analyzed and applied hourly load data collected by the Bonneville Power Administration Multifamily Metering Study to construct typical infiltration, internal load (lighting and equipment) and thermostat set point schedules for the eQUEST® models.

Billing

To prepare for model calibration, analysis of billing records for housing units at each sampled building occurred. This analysis included "calendarizing" the billing records, so usage corresponded to calendar months and totaling usage per building per month. This process also involved examining outliers and periods of high or low usage and determining their disposition. The evaluation team calculated Energy Use Indices (EUIs), defined as energy consumption per unit of gross floor area, for all buildings considered in the prototype development for each month in the calibration period. PSE automated meter read (AMR) data were used to prepare load profiles and other useful data summaries.

Weather

To enter actual weather conditions into the eQUEST® simulations required adjusting the SeaTac TMY3 weather data file using actual hourly outdoor air dry bulb temperatures, wind speeds, and wind directions for the calibration period of October 2009 through September 2010. This modified weather file was converted into the binary file format required by eQUEST® for model calibration. The prototypes were calibrated to billed consumption during the same timeframe as the calibration period. The weather files were then changed back to the unmodified TMY3 data in the models and all savings were calculated based on the difference between the pre-retrofit and post-retrofit models using typical year data.

2.3. Participant Model Development

The evaluation team developed two fully calibrated participant prototype models using eQUEST®. One prototype represented the sampled sites with electric space heat, and the other those with gas space heat. The prototypes reflected the as-built characteristics and conditions of the respective groups of sampled sites.

Inputs to the eQUEST® simulation were prepared for each prototype using the characteristics data, measure performance data, and load data collected and prepared in the previous steps. The eQUEST® models for the prototypes were run and the monthly post-retrofit EUIs predicted by the model were compared to the monthly EUI targets prepared from the billing data. Adjustments were made to the simulations until the predicted post-retrofit EUIs were within 10 percent of the target value on a monthly basis for each prototype. The final as-built model was then prepared for each prototype by rerunning the fully calibrated model under typical weather conditions.

2.4. Baseline Model Development

The evaluation team then developed a baseline model for each prototype and each specific shell measure, using eQUEST®, e.g. the electric calibrated model with baseline windows. Each model reflected the shell-specific baseline conditions that existed prior to the implementation of the program measures (without program influence). Shell-specific baseline model development included reverting specific implemented measures to their baseline condition in the calibrated as-built eQUEST® models. Also, a combined shell measure baseline model was created for both prototypes with all of the shell components set to their baseline conditions. To the extent possible, baseline conditions were determined by examining construction plans and documentation of baseline conditions in the project files. These conditions were entered into the models and the models run to estimate monthly energy consumption. TMY shell-specific and combined shell measures baseline models were then prepared for each prototype by rerunning the model under typical weather conditions.

2.5. Energy Savings Analysis for Implemented Measures

2.5.1. Shell Measures

Annual whole building energy savings for each prototype were computed as the difference between the as-built and combined shell measure baseline models, under post-retrofit occupancy and typical meteorological conditions. These savings represented the package of all shell measures, as they occurred during the 2007-2009 program years. As these results represent savings from multiple measures and shell types, they were simply normalized by dividing the annual savings by the respective gross floor area used in the models. This produced savings expressed as annual energy saved (kWh or therms) per square foot of gross floor area.

Annual shell-specific measure energy savings were also calculated for each prototype as the difference between the as-built model and the shell-specific baseline model, under post retrofit occupancy and typical meteorological conditions. These savings represented the individual shell measure savings that occurred during the 2007-2009 program years. Since these results were measure specific, they were normalized by dividing the annual savings by the measure affected area. This resulted in shell measure specific annual energy saved per square foot of measure installed.

2.5.2. Non-Shell Measures

The original work plan called for estimating the energy savings impact for five non-shell measures:

- Ductless Heat Pumps (DHP)
- In-Unit Gas Furnaces
- Refrigerators
- Electric Storage Water Heaters
- Gas Storage Water Heaters

Review of the PSE program installation data for the measures revealed the non-shell measures did not provide significant savings for the program. Savings associated with these measures constituted less than 50,000 kWh and 700 therms of annual savings, which was minimal relative to the program savings as a whole. Consequently, the focus of the review was changed from program impact savings to comparison and review of the present PSE deemed measure savings with the current Regional Technical Forum's (RTF) deemed values, other standards such as California's Database for Energy Efficient Resources

(DEER) and Energy Star, previous analyses done for PSE, and modeling done for this study. For two of the measures, ductless heat pumps and in-unit gas furnaces, savings estimates were developed using this study's eQUEST models. Recommendations were made for each measure to help inform future program planning efforts.

2.6. Energy Savings Analysis for Future Measures

An important objective of this evaluation was to estimate annual savings that future program participants might realize from these measures. Additional analysis was performed to estimate the impact of these measures on future participants. The evaluation team summarized for PSE important information regarding the prototype characteristics and the performance of the selected measures within each prototype. PSE examined this information and compared it to the anticipated characteristics of future participants. These included both participants who might be specifically targeted by PSE in future years (2011 and beyond), as well as those not specifically targeted.

Once the preliminary savings analysis had been conducted, SBW and PSE met to discuss the results, and assess how characteristics of future participants would be different from the 2007-09 participants. PSE provided the list of future measures shown below. Quantifying measure savings required performing additional sensitivity runs on the eQUEST models. These measures for future programmatic efforts included the following, expressed as a baseline value (such as R-0 insulation) and an efficient value (such as R-38 insulation):

- **Attic Insulation**
  - R-0 to R-38
  - R-0 to R-49
  - R-2/R-10 to R38
  - R-2/R-10 to R49
  - R-11/R-18 to R-38
  - R-11/R-18 to R-49
- **Floor Insulation**
  - R-0 to R-30
  - R-11 to R-30
- **Wall Insulation**, R-0 to R-11
- **Windows**
  - Double-paned (U=0.60) to double-paned (U=0.30)
  - Single-paned (U=1.20) to double-paned (U=0.30)
  - Double-paned (U=0.60) to triple-paned (U=0.25)
  - Single-paned (U=1.20) to triple-paned (U=0.25)

3. FINDINGS

This section discusses the results obtained after applying the methodology described above. It begins with a discussion of the results from the sample selection process. This is followed by a summary of salient characteristics of the selected electrically- and gas-heated buildings. Lastly, the section includes a detailed discussion of the results of the energy savings analyses performed on the two prototypes.

3.1. Sample Characteristics

After examining the characteristics of projects that had implemented shell measures, the evaluation team and PSE agreed to establish separate models to represent electrically-and gas-heated buildings. The budgeted evaluation sample of 20 sites was divided into 12 electric buildings and eight gas buildings. Analysis of the characteristics of the shell measure projects additionally led to sample quotas for each of the four measure strata (attics, floors, walls, and windows). These quotas corresponded to the relative frequency at which these types of measures occurred in the program.

A challenging recruiting process, however, ensued when four of the original twelve electric sites and five of the original eight gas sample sites had to be replaced due to difficulties summarized below.

- Not all building departments or building owners archive building plans.
- Once plans were located and copies obtained, some did not have sufficient detail to provide the inputs required for eQUEST modeling.
- The gas sample sites in particular were problematic due to the older vintage of gas-heated multifamily buildings. Seven of the eight gas buildings in the sample were constructed between 1907 and 1962. Generally, the older the building, the more difficult it is to obtain building plan sets suitable for modeling take-offs.

These resulted in slight modifications to the sample quotas to still maintain the overall goal of 12 electric and eight gas buildings. The final stratification is shown below in Table 7.

Table 7: Achieved Sample Stratification

Measure Strata	Electric Model	Gas Model
Attic	3	1
Floor	1	2
Wall	2	0
Window	6	5
Total	**12**	**8**

Several of the electric sites were large complexes with many buildings. It was not practical to model every building at such sites, so instead representative sample of building types for modeling was selected in those instances. In the end, with the generous assistance of building owners and building department officials, enough plans suitable for take-off work were obtained for the study.

3.2. As-Built Characteristics

Building envelope component data was gathered from the as-built plans and application files in order to calculate the as-built U-value for each type of wall, floor, and ceiling for both the electric and gas prototype models. These data were then aggregated and summarized to develop unit-level UA per square foot estimates (where UA is the coefficient of heat transmission for a given area). Based on these UA/sq.ft. values, the units were grouped into three classifications for each model as follows:

Electric Model	Gas Model
≤ 0.13	≤ 0.12
> 0.13 and ≤ 0.195	> 0.12 and ≤ 0.19
> 0.195	> 0.19

The units were further aggregated into "in unit laundry" and "common laundry" unit types, because of the different infiltration that each type of unit experiences. Table 8 summarizes the aggregate as-built building envelope characteristics for the electric and gas models.

The average sizes of electric and gas dwelling units were 799 and 773 sq. ft., respectively, based on the evaluation's assessment of 569 electric units and 102 gas units. Other key points from this table include:

1. The average "in unit laundry" unit types are larger than the "common laundry" units for both the electric and gas prototypes.
2. The electric model sampled buildings did not include any units with a program-affected slab floor, pt slab floor, or program affected vault ceiling.
3. The gas model sampled buildings did not include any units with a program-affected slab floor or program affected walls.
4. U-values for the program affected floors, roofs, walls and windows were uniformly lower than for the non-program-affected corresponding areas.

Table 8: As-Built Envelope Characteristics for Sampled Buildings

		Apartment Floor		Floor Framed		PT Slab		Slab	
	No. Apt Units	Zone Total (sqft)	Unit Avg (sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)
Option I - Electric Heat									
Apartments									
In Unit Laundry									
A UA/sf <= 0.13095	74	71,667	968		-	-	-	0.153	-
B UA/sf <= 0.195	102	106,712	1,046		-	-	-	0.207	-
C UA/sf > 0.195	57	49,446	867	0.135	-	-	-	0.207	-
Total Area / Average U Value	233	227,825	978	0.135		-	-	0.188	-
Common Laundry									
A UA/sf <= 0.13095	54	39,534	732	-	-	-	-	0.207	-
B UA/sf <= 0.195	225	135,296	601	0.062	0.032	-	-	0.207	-
C UA/sf > 0.195	57	51,781	908	0.069	0.032	-	-	-	-
Total Area / Average U Value	336	226,611	674	0.063	0.032	-	-	0.207	-
Option II - Gas Heat									
Apartments									
In Unit Laundry									
A UA/sf <= 0.12	4	7,177	1,794	-	-	-	-	-	-
B UA/sf <= 0.19	6	10,528	1,755	0.041	-	-	-	-	-
C UA/sf > 0.19									
Total Area / Average U Value	10	17,705	1,770	0.041		-	-	-	-
Common Laundry									
A UA/sf <= 0.12	38	26,336	693	0.042	0.028	-	0.029	0.24	0.21
B UA/sf <= 0.19	30	20,098	670	-	0.039	-	0.029	0.21	0.24
C UA/sf > 0.19	24	14,667	611	0.099	-	-	-	0.31	-
Total Area / Average U Value	92	61,100	664	0.086	0.035	-	0.029	0.253	0.224

Ceiling								
Attic		Vault		Wall		Window		Door
non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)
0.030	-	0.038	-	0.101	0.060	0.350	0.313	0.40
-	0.025	0.038	-	0.093	0.067	0.350	0.294	0.50
-	-	0.065	-	0.113	-	-	0.314	0.50
0.030	0.025	0.056	-	0.100	0.061	0.35	0.304	0.472
0.030	-	0.085	-	0.086	-	-	0.306	0.50
0.048	0.025	0.085	-	0.096	-	-	0.308	0.50
-	0.033	0.085	-	0.119	-	-	0.325	0.50
0.040	0.031	0.085	-	0.102	-		0.313	0.500
-	-	0.024	-	0.058	-	-	0.522	0.50
-	-	0.024	-	0.058	-	-	0.522	0.50
-	-	0.024	-	0.058	-		0.522	0.500
0.035	0.026	0.042	-	0.077	-	-	0.324	0.47
0.035	0.026	0.048	0.027	0.094	-	-	0.323	0.59
-	-	0.057	-	0.149	-	-	0.293	0.61
0.035	0.026	0.052	0.027	0.100	-		0.315	0.576

3.3. Baseline Characteristics

For the combined shell measure baseline model, all of the building components and dimensions remained the same as the as-built model and the U-values for the measure affected areas were returned to their pre-retrofit value. For the shell-specific measure baseline models, all of the components and dimensioned remained the same as the as-built model, but only the specific shell measure affected area was returned to it's pre-retrofit U-value. Although there was a slight difference in the floor areas between the pre and post retrofit sample, due to a remodel, the as-built dimensions were used in the baseline model in order to keep the models consistent and ensure that any change in energy usage was only due to the measure being analyzed. The baseline U-values came from the sampled window's pre-retrofit U-value indicated in the program documentation and by subtracting out the insulation that was added to the floors, attics, and walls as part of the program. The baseline envelope component characteristics are shown in Table 9 below.

Table 9: Baseline Envelope Characteristics for Sampled Buildings

				Floor					
		Apartment Floor		**Framed**		**PT Slab**		**Slab**	
	No. Apt Units	Zone Total (sqft)*	Unit Avg (sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)
Option I - Electric Heat									
Apartments									
In Unit Laundry									
A UA/sf <= 0.13095	76	72,076	948		-	-	-	0.152	-
B UA/sf <= 0.195	102	106,712	1,046		-	-	-	0.207	-
C UA/sf > 0.195	57	49,446	867	0.135	-	-	-	0.207	-
Total Area / Average U Value	235	228,233	971	0.135		-	-	0.188	-
Common Laundry									
A UA/sf <= 0.13095	54	39,534	732	-	-	-	-	0.207	-
B UA/sf <= 0.195	225	135,296	601	0.062	0.083	-	-	0.207	-
C UA/sf > 0.195	57	51,781	908	0.069	0.083	-	-	-	-
Total Area / Average U Value	336	226,611	674	0.063	0.083	-	-	0.207	-
Option II - Gas Heat									
Apartments									
In Unit Laundry									
A UA/sf <= 0.12	4	7,177	1,794	-	-	-	-	-	-
B UA/sf <= 0.19	6	10,528	1,755	0.041	-	-	-	-	-
C UA/sf > 0.19									
Total Area / Average U Value	10	17,705	1,770	0.041		-	-	-	-
Common Laundry									
A UA/sf <= 0.12	38	26,336	693	0.042	0.172	-	0.191	0.24	0.21
B UA/sf <= 0.19	30	20,098	670	-	0.143	-	0.208	0.21	0.24
C UA/sf > 0.19	24	14,667	611	0.099	-	-	-	0.31	-
Total Area / Average U Value	92	61,100	664	0.086	0.155	-	0.196	0.253	0.224

*Some discrepancy exists between the pre and post retrofit floor square footage because one sampled site eliminated units between the pre and post retrofit period.

Ceiling								
Attic		Vault		Wall		Window		Door
non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)	treated (UA/sqft)	non-treated (UA/sqft)
0.031	-	0.038	-	0.103	0.107	0.350	1.000	0.44
-	0.062	0.038	-	0.094	0.081	0.350	1.114	0.50
-	-	0.065	-	0.113	-	-	1.000	0.50
0.031	0.062	0.056	-	0.101	0.105	0.35	1.054	0.483
0.030	-	0.085	-	0.084	-	-	0.975	0.50
0.048	0.073	0.085	-	0.091	-	-	0.984	0.50
-	0.069	0.085	-	0.118	-	-	0.983	0.50
0.040	0.070	0.085	-	0.098	-		0.982	0.500
-	-	0.024	-	0.058	-	-	0.810	0.50
-	-	0.024	-	0.058	-	-	0.810	0.50
-	-	0.024	-	0.058	-		0.810	0.500
0.035	0.069	0.042	-	0.077	-	-	1.000	0.47
0.035	0.069	0.048	0.089	0.094	-	-	1.009	0.59
-	-	0.057	-	0.146	-	-	1.076	1.18
0.035	0.069	0.052	0.089	0.101	-		1.024	0.678

3.4. Model Descriptions

The evaluation team developed electric and gas building simulation models using eQUEST software. Both the electric and gas models were separated into "in unit laundry" and "common laundry" unit types, with each model contained zones representing dwelling units with different ranges of calculated UA/sq. ft. The quantity UA/sq. ft. represents the magnitude of heat transmission through the dwelling unit's exterior surfaces. Consequently, interior units had relatively low values, while corner apartments had higher values.

Although common-area information was gathered during the data collection process, these areas were not built into the models. The billing records for these areas were excluded as well in order to keep the data consistent during the calibration process. These were excluded because the common areas often contained commercial spaces and garages, making it difficult to match billing data to them. In some cases, common/commercial area usage was very high, and would have dwarfed programmatic measure effects.

For both prototype buildings, the exterior floor and ceiling areas are much smaller than the total building floor area, indicating the presence of a parking garage and multiple floor buildings. The electric model is dominated by attic roof construction and slab floor type, while the gas model has a majority vault roof construction and nearly even portions of slab, frame and post-tension slab floors.

Building level infiltration and thermostat set point profiles were developed from previous work the evaluation team had done on modeling Seattle-area multifamily buildings. These in turn were based on measurements made in the BPA Multifamily Metering Study. The BPA data were also used to develop building-level average seasonal consumption profiles by day type (weekday and weekend) for the hot water, lighting and equipment end uses. This particular study looked at buildings between Seattle and Tacoma so they are a fair representation of those in the PSE service area. The study measured indoor air temperatures at every thermostat in all the units (which all had baseboard type electric heat) to determine heating setpoints. In many of the buildings, infiltration was measured using a tracer gas (PFT) technique.

Once the model components and set points were defined, each model was run to determine the monthly and yearly energy consumption. These values were compared with the respective electric and gas monthly billing data and the model inputs were adjusted until the annual usage was within 5% and the monthly usage was within 10% of the billing data. The tuning variables in the model were the installed electric load and usage schedule, DHW load and usage schedule, thermostat set points and schedule, and building air infiltration. The model end use profiles were examined to verify that the energy usage was in accordance with typical residential building end use proportions, e.g. 50% lighting/plug load, 30% heating, and 20% domestic hot water.

Table 18 in Appendix C shows building envelope dimensions, U-values, equipment set points, and schedules for the electric and gas models, respectively.

Billed and Modeled Energy Use

Aggregated October 2009-September 2010 billing data from tenants of electric and gas sampled buildings provided EUI targets for both prototypes. For electric customers, the average EUI was 14.7 kWh/sq.ft./year. For gas customers, it was 3.59 kWh/sq.ft./year and 0.51 therms/sq.ft./year (this converts to 14.9 kWh/sq.ft./year, which is 1.3% greater on average than the electric customers over the same time period, unadjusted for any mitigating factors).

Both models were successfully calibrated within the target values of ±10% of each month and ±5% overall. A separate calibration of monthly and total annual consumption was successfully performed for each of the prototypes. Several iterations of the model were required for each prototype to produce a set of simulation inputs that accurately reflected actual consumption characteristics. Figure 1, Figure 2, and Figure 3 provide a comparison of simulated monthly consumption to the billed monthly targets for both models. For the electric prototype, simulated annual consumption was within ±0.1% of the annual kWh target, a reasonable calibration result, with summer and winter[4] usage predictions both within ±4.8% of actual usage. For the gas prototype, simulated annual consumption was within .17% of the kWh target and 1.6% of the therms target. The monthly kWh usage predictions were within 3.7% of the actual usage, while the summer and winter therms predictions were within 8.4% and 10%, respectively. One possible reason for the greater percent difference from the target therms values in the gas model are the presence of fewer buildings in the sample to lessen the impact of any anomalies in the billing data. Also, the low heat usage, and thus gas consumption, in the summer means that any deviation from the target value is a larger percentage of the total value. These results led to the conclusion that these fully calibrated models represented an accurate depiction of predicted end use consumption under full occupancy, and with the weather conditions that existed during the calibration year.

The fully calibrated as-built model was run under typical weather conditions to remove the effect of unusual weather conditions during the calibration year. Running the as-built model with TMY3 weather instead of 2010 weather resulted in a difference of 2.3% kWh for the electric model, and 0.1% kWh and 5.1% therms for the gas model, suggesting that the 2010 calibration year was relatively similar to a typical weather year.

[4] Defining summer as the months May through October and winter as November through April.

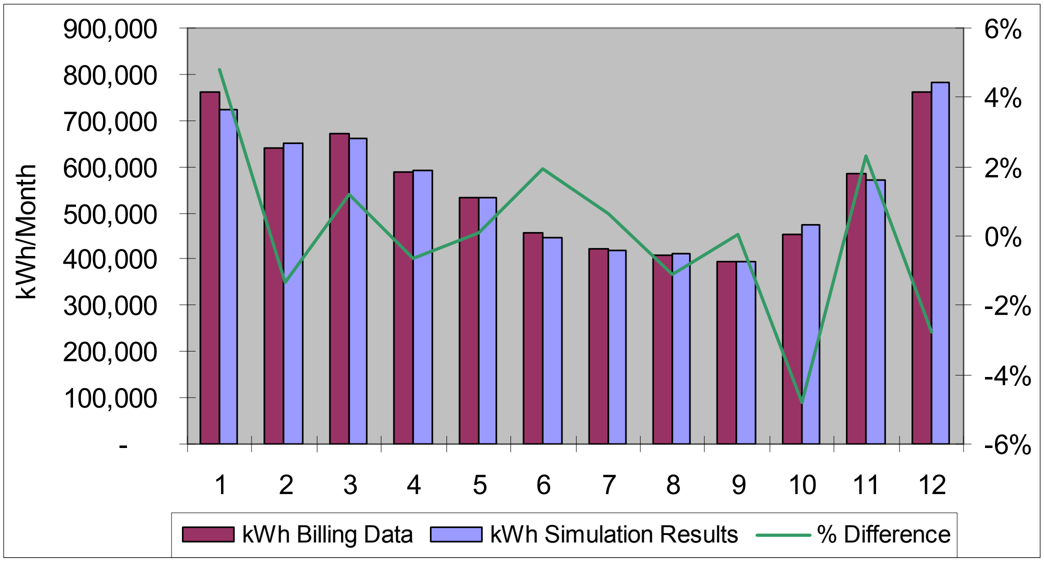


Figure 1: Electric Model Simulated vs. Actual Electric Use

Figure 2: Gas Model Simulated vs. Actual Electric Use

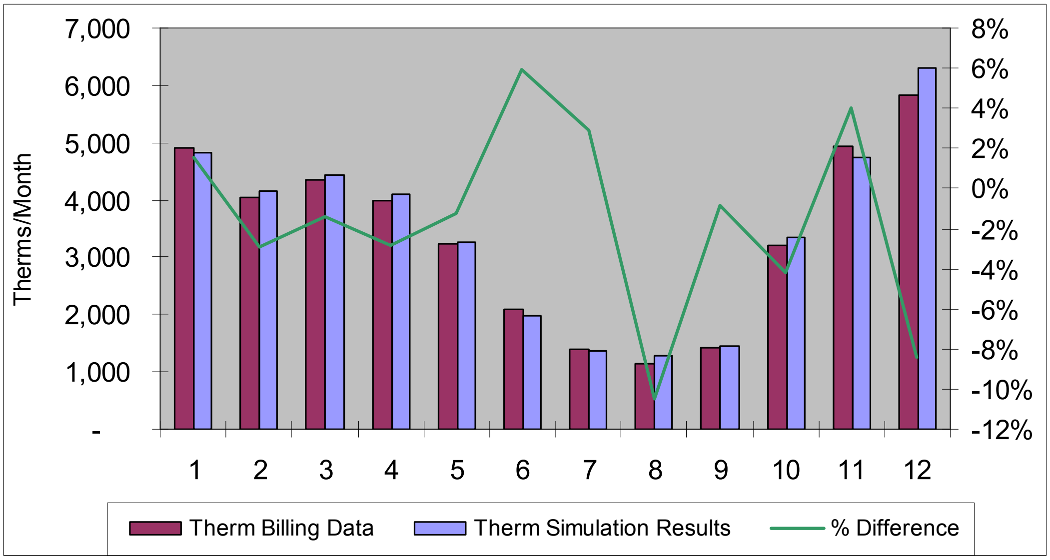


Figure 3: Gas Model Simulated vs. Actual Therm Use

3.5. Energy Savings

3.5.1. Shell Measures

3.5.1.1 Past Unit Savings

Combined Shell Measure Savings

After estimating typical energy usage for the as-built and combined shell baseline models, the difference constituted the savings, as shown in Table 10 and Table 11. As expected, estimated annual usage is greater in the baseline case than it is for the as-built case. Overall, the gross reduction in EUI for the electric model was 1.4 kWh/sq.ft./year, or 9.5% of typical baseline usage and for the electric model and 0.09 Therms/sq.ft./year and 0 kWh/sq.ft./year, or 18.5% and 0% respectively, for the gas model. As one can see, there was no difference in the electric usage in the gas model between the baseline and as-built model. This is because all of the retrofit measures affected heat usage, not lighting or plug load usage

Table 10: Electric Model Evaluated Energy Savings

	Billed kWh	Modeled As-Built kWh	Percent Difference	Modeled Baseline kWh	Percent Difference
January	760,093	723,597	4.8%	805,552	-11.3%
February	641,256	649,881	-1.3%	720,489	-10.9%
March	670,466	662,492	1.2%	741,584	-11.9%
April	589,291	593,215	-0.7%	654,172	-10.3%
May	533,735	533,347	0.1%	582,665	-9.2%
June	457,096	448,172	2.0%	481,186	-7.4%
July	421,047	418,346	0.6%	442,161	-5.7%

	Billed kWh	Modeled As-Built kWh	Percent Difference	Modeled Baseline kWh	Percent Difference
August	407,729	412,315	-1.1%	435,498	-5.6%
September	395,692	395,518	0.0%	401,205	-1.4%
October	454,046	475,925	-4.8%	504,300	-6.0%
November	585,289	571,875	2.3%	644,214	-12.6%
December	762,744	783,941	-2.8%	891,919	-13.8%
Total	**6,678,484**	**6,668,624**	**0.1%**	**7,304,944**	**-9.5%**
kWh/year/sq.ft.	**14.70**	**14.67**		**16.07**	**1.40**

Table 11: Gas Model Evaluated Energy Savings

	Billed Therms	Modeled As-Built Therms	Percent Difference	Modeled Baseline Therms	Percent Difference
January	4,896	4,821	1.5%	5,678	-17.8%
February	4,031	4,149	-2.9%	4,913	-18.4%
March	4,360	4,423	-1.4%	5,264	-19.0%
April	3,980	4,094	-2.9%	4,946	-20.8%
May	3,227	3,267	-1.2%	3,951	-21.0%
June	2,093	1,970	5.9%	2,273	-15.4%
July	1,397	1,356	2.9%	1,536	-13.3%
August	1,153	1,274	-10.5%	1,404	-10.2%
September	1,436	1,448	-0.9%	1,643	-13.5%
October	3,214	3,348	-4.2%	4,045	-20.8%
November	4,939	4,741	4.0%	5,640	-19.0%
December	5,821	6,311	-8.4%	7,512	-19.0%
Total	**40,548**	**41,202**	**-1.6%**	**48,804**	**-18.5%**
Therms/year/sq.ft.	**0.515**	**0.523**		**0.619**	**0.096**

	Billed kWh	Modeled kWh	Percent Difference	Modeled Baseline kWh	Percent Difference
January	25,968	25,279	2.7%	25,279	0.0%
February	22,688	22,784	-0.4%	22,784	0.0%
March	23,927	23,166	3.2%	23,166	0.0%
April	22,507	22,426	0.4%	22,426	0.0%
May	22,650	23,105	-2.0%	23,105	0.0%
June	22,136	22,057	0.4%	22,057	0.0%
July	22,513	22,391	0.5%	22,391	0.0%
August	22,249	22,278	-0.1%	22,278	0.0%
September	22,109	22,017	0.4%	22,017	0.0%
October	24,515	25,217	-2.9%	25,217	0.0%

	Billed Therms	Modeled As-Built Therms	Percent Difference	Modeled Baseline Therms	Percent Difference
November	24,776	24,427	1.4%	24,427	0.0%
December	26,490	27,476	-3.7%	27,476	0.0%
Total	**282,528**	**282,623**	**0.0%**	**282,623**	**0.0%**
kWh/year/sq.ft.	**3.59**	**3.59**		**3.59**	**0.00**

Individual Shell Measure Savings

When examining the individual shell measures savings, it is more appropriate to compare them based on energy savings per measure treated area. This negates the effects of a difference in square footage of measure treated area. Table 12 and Table 13 show energy reductions attributable to each measure. For each trial, the components not being analyzed were kept at their as-built, or fully insulated, condition. This does not make a difference in the results because the shell measures savings are completely additive, so the sum of the individual shell measure savings is almost exactly equal to the savings between the as-built and the combined shell baseline model. As there was no kWh difference between the as-built and baseline in the gas model, there are no shell measure kWh savings results.

For each prototype, the individual retrofit components did no have the same baseline and installed insulation values and therefore it is not possible to directly compare the effectiveness of each measure, but it is possible to see the relative effective savings of each shell measure. For example, by increasing the wall insulation in the electric model by only R6 the kWh savings per treated area are greater than by increasing the attic and floor insulation by R16 and R19 respectively. It is also difficult to compare the savings for the same retrofit shell component between the two models, as the savings are reported in different units. Also, the two models have different as-built and baseline U-values and different occupant behavior, making a direct comparison impossible. However, general trends can be observed between the two models for the retrofit shell components. For instance, for both models the greatest savings were found for the windows measure and the least savings were found for the roof measure.

Table 12: Electric Model Unit Savings Breakdown by Component

		Treated Area				
Retrofit component	kWh/year/sq.ft.*	Baseline U-value	Installed U-value	Baseline R-value	Installed R-value	% improvement
Windows	9.346	0.750	0.300	1	3	60%
Roof Insulation (Attic)	1.167	0.066	0.028	15	36	58%
Floor Insulation (Framed)	1.225	0.083	0.032	12	31	61%
Wall Insulation	1.353	0.105	0.061	10	16	42%

* Savings expressed as kWh per year per square foot of measure treated component.

Table 13: Gas Model Unit Savings Breakdown by Component

		Treated Area				
Retrofit component	Therms/year/sq.ft. *	Baseline U-value	Installed U-value	Baseline R-value	Installed R-value	% improvement
Windows	0.553	0.750	0.359	1	3	52%
Roof Insul. (Attic)	0.114	0.069	0.026	15	39	63%
Roof Insul. (Vaulted)		0.089	0.027	11	37	70%
Floor Insul. (Framed)	0.216	0.155	0.035	6	29	78%
Floor Insul. (PT Slab)		0.196	0.029	5	35	85%
Floor Insul. (Slab Perimeter)		0.224	0.224	4	4	0%

* Savings expressed as therms per year per square foot of measure treated component.

Next was a comparison of PSE shell measure deemed savings to evaluation results. From the PSE Multi-Family Retrofit Document Master Workbook, total claimed measure specific energy savings were divided by the treated area to determine the average PSE deemed savings per year, which is shown below in Table 14. However, the workbook does not specify the baseline and as-built insulation levels or the delta R or U value assumed for each measure type, so a direct comparison to evaluation results could not be made. However, it does provide a reasonable basis for comparison. For the electric model, attic savings were slightly larger than the PSE deemed value, while the floor savings were almost half the deemed value and the wall savings were nearly the same as the 2010 deemed value. The window savings were more difficult to compare as PSE had three ranges of savings, while the evaluation assumed a percentage of single and double paned baseline windows were upgraded to more efficient double paned windows. Evaluation results showed lower savings than all three scenarios. For the gas model, the PSE deemed attic and floor savings were 60% and 70% of evaluated savings results respectively, and the PSE deemed window savings are almost double evaluated window savings results.

Table 14: PSE Deemed Savings per Square Footage of Treated Area

Heating Type	Year	Attic (kWh/qty)	Floor (kWh/qty)	Wall (kWh/qty)	window pre-'10 (kWh/qty)	window sgl-dbl (kWh/qty)	Window dbl-dbl (kWh/qty)
Electric	2006						
	2007	1.09	2.44		18		
	2008	1.09	2.41		18		
	2009	1.09	2.44	2.1	18		
	2010	0.94	2.23	1.3	18	23.74	10.82
Gas	2006						
	2007	0.07	0.15		1.08		
	2008	0.07	0.15		1.08		
	2009	0.07			1.08		
	2010	0.07	0.15		1.08		

3.5.1.2 Future Measure Savings

Further analyses were performed to estimate future savings for shell measures specified by PSE, as listed in Section 2.6). Table 15 and Table 16 show the results of this effort. The normalized savings in these tables represent expected values for building stock similar to that in the electric and gas buildings in the evaluation sample. The reported results were produced and normalized to the areas that had been affected by the particular measure. So, for example, no buildings in the gas sample had wall insulation retrofits, so this measure was not calculated for the gas model and likewise the electric building sample had no vault ceiling or PT slab upgrades, so these measures were not analyzed for the electric model.

As these tables illustrate, measure savings are proportional to the delta R or delta U values, so the greater the change in R or U, the greater the savings. Window measures observed the greatest unit savings, even though other measures had larger increases in insulation. This is because the window areas only have the insulation of the glass, while the other components have building material in addition to the insulation, lessening the impact of the installed insulation in these areas.

Table 15: Electric Model Future Measures Savings

Retrofit Component	Baseline (U or R)	Installed (U or R)	Energy Savings* (kWh/sq.ft./year)
Windows	U=1.20	U=0.30	14.92
	U=1.20	U=0.25	16.03
	U=0.60	U=0.30	5.98
	U=0.60	U=0.25	7.09
Roof Insulation (Attic)	R-0	R-38	4.89
	R-0	R-49	5.02
	R-2/-10	R-38	2.21
	R-2/-10	R-49	2.35
	R-11/-18	R-38	0.99
	R-11/-18	R-49	1.12
Floor Insulation (Framed)	R-0	R-30	3.46
	R-11	R-30	0.85
Wall Insulation	R-0	R-11	3.85

* Savings expressed as kWh per year per square foot of measure treated component.

Table 16: Gas Model Future Measures Savings

Retrofit Component	Baseline (U or R)	Installed (U or R)	Energy Savings* (Therms/sq.ft./year)
Windows	U=1.20	U=0.30	1.12
	U=1.20	U=0.25	1.21
	U=0.60	U=0.30	0.46
	U=0.60	U=0.25	0.55
Roof Insulation. (Attic)	R-0	R-38	0.32

Retrofit Component	Baseline (U or R)	Installed (U or R)	Energy Savings* (Therms/sq.ft./year)
	R-0	R-49	0.32
	R-2/-10	R-38	0.14
	R-2/-10	R-49	0.15
	R-11/-18	R-38	0.07
	R-11/-18	R-49	0.08
Roof Insulation (Vaulted)	R-0	R-38	0.40
	R-0	R-49	0.41
	R-6	R-38	0.16
	R-6	R-49	0.17
	R-14.5	R-38	0.07
	R14.5	R-49	0.08
Floor Insulation (Frame)	R-0	R-30	0.27
	R-11	R-30	0.06
Floor Insulation (PT Slab)	R-0	R-30	0.39
	R-11	R-30	0.07

* Savings expressed as therms per year per square foot of measure treated component.

3.5.2. Non-Shell Measures

A summary of the results from the review of the five non-shell measures is provided in Table 17 below. The objective was to review the deemed savings, and compare those values with the current Regional Technical Forum (RTF) analysis and other sources and standards, as available. This effort yielded recommendations for each category for future program consideration. The analysis of savings for each measure is described in more detail later in this section.

Table 17: Non-Shell Measures Savings

	PSE Multifamily Program			SBW Multifamily Study	
Measure Name	**PSE Deemed Annual Savings/Unit**	**PSE Deemed Savings Source**	**2011 MF Program Offering?**	**Recommended Annual Savings/Unit**	**Findings/Recommendations**
Ductless Heat Pumps	3500 kWh	RTF 2009	No	1873 kWh	1) Until a definitive DHP regional multifamily sector study is completed, the uncertainty of the savings will be high. 2) A provisional savings value from the eQUEST weatherized prototype model with annual savings at 1873 kWh is recommended.
In-Unit Gas Furnaces	66 Therms	PSE Deemed 2008	Yes	26 therms	1) The current savings value based on the KEMA billing analysis study - derated for multifamily from 89 Therms to 66 Therms. 2) DEER deemed savings for single family with an AFUE of 90% is 83 Therms, adjusted for HDDs is 87 Therms. 3) The Energy Star Calculator is about 30 Therms, depending on housing stock vintage assumptions. 4) SBW eQUEST modeling for the measure estimates annual savings at 26 Therms for the weatherized prototype unit and 34 Therms for the baseline prototype unit. 5) The eQUEST model for a weatherized prototype with annual savings of 26 Therms is recommended.
Refrigerators	97 kWh	RTF 2010	No	44 kWh	1) The current (2011-2012) RTF deemed values are: - Energy Star (+22% Fed standard): 44 kWh - CEE Tier 1 (+20% Fed): 37 kWh - CEE Tier 2 (+25% Fed): 65 kWh - CEE Tier 3 (+30% Fed) 86 kWh 2) The Energy Star savings of 44 kWh is recommended.
Electric Water Heaters	62 kWh	RTF 2009	Yes	131 kWh	Recommend using the (2010-2015) RTF savings for a 95% efficient standard for tanks between 45-55 gal are 131 kWh annual savings.
Gas Water Heaters	18 Therms	PSE Deemed 2008	No	8 therms	The KEMA analysis is somewhat equivocal, with the engineering analysis suggesting up to 15 therms, with 10 therms being the maximum "reasonable" value. The billing analysis, though, suggests 0 therms, but with a big confidence bound. A value somewhere in the middle may be the best value until further research is available.

Ductless Heat Pumps

In 2009, PSE adopted the Regional Technical Forum deemed value of 3,500 kWh/year, which at the time, was understood to include multifamily buildings. In 2010, the RTF issued a clarification that the deemed value applied only to single family buildings. In early 2011, the Bonneville Power Administration (BPA) announced it will discontinue funding for multifamily DHPs for the regional pilot in October of 2011 due to the uncertainty surrounding the multifamily savings and the absence of research on DHP performance in the multifamily buildings.

In December 2010, in the RTF's Deemed Measure Review Project, Final Report, SBW made the following recommendation that a regional study be undertaken to develop DHP deemed savings for multifamily residences:

> *It should be possible to deem savings for this measure category. A proposal for deeming this measure should be prepared for RTF consideration. However, the development of deemed savings will require reliable data on baseline and efficient-case heating and cooling energy use for relevant groups of multifamily buildings. Baseline data development may be possible from existing studies. Efficient-case data will be gathered by the BPA study currently underway. These studies need further review to determine whether they can provide sufficiently reliable data for calibrating SEEM models that will be needed to estimate the deemed savings.*

The existing regional study alluded to above is funded through a consortium comprised of BPA, NEEA, EPRI, private and public utilities. The study is based on data monitoring and power metering of residences with DHPs. There are two multifamily sites in the sample, with 10 units total, too small of a sample to be representative of the multifamily sector. The results will be available September 2012. As of the writing of this report, there has been no movement toward the initiation of a regional multifamily DHP study.

An alternative approach to approximate DHP savings in multifamily residences could be to take a prorated share of the single family estimate of 3,500 kWh based on the RTF's single family housing stock assumptions for the Northwest region and apply that to the square footage of electrically heated multifamily units in the PSE customer sample used for modeling in this study.

1. The weighted average used for RTF regional single family housing in SEEM models:
   (1344 x .75) + (2200 x .16) + (2688 x .09) = 1602 sq. ft.

2. Savings per square foot per year for DHPs in single family residences:
   3500 kWh/1602 sq. ft. = 2.18 kWh/sq. ft. savings/year

3. Applying the per-square-foot savings value for single family housing to this study's electrically-heated average unit area of 800 square feet yields an estimated unit savings:
   2.18 kWh/year x 800 sq. ft. = 1,744 kWh/year/unit

There are two noticeable weaknesses in this approach. First, the RTF's provisional deemed value inherently has significant uncertainty. Secondly, this estimate does not account for the prevalence of adiabatic walls, floors, and ceilings in multifamily residences.

SBW eQUEST modeling for DHPs estimated savings for multifamily units with DHPs meeting the minimum efficiency standard for the regional DHP pilot. This introduces some conservatism into the estimate because many DHPs substantially exceed the pilot's minimum efficiency standard. The estimated annual savings for the model prototype for a weatherized unit is 1,873 kWh/year and 2,590 kWh/year for a non-weatherized unit. This analysis presumes the entire unit is converted to DHP heating.

In future programs, to account for partial unit DHP installations or to provide weighting based on unit area, savings and funding could be established by treated unit square footage or on savings and incentives based on the installed tonnage. The latter would probably be preferable from a program operations standpoint.

It should be noted that ductless heat pumps are not currently offered in the 2011 Multifamily Program due to low participation and uncertainty surrounding the savings.

> Recommendation: As a provisional savings measure, use the eQUEST modeled savings for weatherized units of 1,873 kWh/year. Similar to the regional pilot, and keeping program requirements uncomplicated, use a fixed savings and incentive per unit, provided the primary living space is conditioned by the DHP. The hope is that interest and support for a regional multifamily DHP study will develop and result in a RTF deemed savings value in the future.

In-unit Furnaces

This measure is currently part of the 2011 multifamily program. The current deemed annual savings value is 66 therms/year for a furnace with a minimum efficiency of 90% AFUE. This is derived from the single-family residential savings value of 89 therms/year, and de-rated by 25% for the smaller area of a typical multifamily unit. The 89 therms/year savings is based on a recent single family billing analysis study[5].

In addition, three other sources for savings estimates were considered:

- The Energy Star furnace savings calculator, using inputs for Seattle weather, a 78% AFUE baseline (code minimum) and an installed unit with a 90% AFUE, using various permutations of older housing stock, resulting in a savings estimate of 30 therms/year.
- California's Database for Energy Efficient Resources (DEER) in California Climate Zone 1 (CZ1), has 95% of Heating Degree Days (HDDs) of SeaTac weather data, and with 78% AFUE baseline, shows the following results for three AFUE ratings in single family residences:

Efficiency	Therms/year savings
90% AFUE average	82.9
94% AFUE average	117.6
96% AFUE average	133.7

[5] KEMA. 2008. *PSE's Residential Energy Efficient Furnace Program Impact Evaluation*. Bellevue, Washington: Puget Sound Energy.

- eQUEST modeling from the shell measure portion of this evaluation, using 90% furnace efficiency against a 78% efficient furnace, shows annual savings per unit for the weatherized model of 26 therms/year and 34 therms/year for the non-weatherized model.

To summarize, the results fall into two general groups. The single family studies by KEMA and the DEER results have savings of 89 and 83 therms/year respectively. The single family Energy Star calculator and SBW multifamily modeling results are respectively 30 and 26 therms/year.

Recommendation: Because three of the four estimates are based on, or derived from, single family energy savings, use the results of the eQUEST weatherized multifamily model of 26 therms/year.

Efficient Refrigerators

In 2009 when refrigerators were an active multifamily program measure, the deemed savings were 97 kWh/year, based on the previous RTF deemed value. For the 2011 program, refrigerators did not pass the PSE cost effectiveness test.

The current RTF deemed values for 2010 through 2012 are in the table below. For the Consortium for Energy Efficiency (CEE) standards, Tier 1 is 20% greater than the federal standard, Tier 2 is +25%, Tier 3 is +30%. The Energy Star standard falls between CEE tiers 1 and 2 and is 22% more efficient than the federal standard.

RTF category				kWh Savings/year
Energy Star Refrigerator - Any	All Dwelling Types	New and Existing Construction	Any Style	44
CEE Tier 1 Refrigerator - Any	All Dwelling Types	New and Existing Construction	Any Style	37
CEE Tier 2 Refrigerator - Any	All Dwelling Types	New and Existing Construction	Any Style	65
CEE Tier 3 Refrigerator - Any	All Dwelling Types	New and Existing Construction	Any Style	86

The current DEER standard for code baseline for all refrigerators is 54 kWh/year annual savings for Climate Zone 1.

Recommendation: The RTF deemed savings workbook cites 2009 product availability and sales data which could be useful in making a decision on which efficiency level to choose for future programs. Use the high-profile Energy Star standard and the corresponding RTF deemed savings of 44 kWh/year.

Electric Storage Water Heaters

This measure is offered in the 2011 multifamily program with the minimum efficiency standard of 0.95 and using the RTF's 2010 annual deemed savings of 97 kWh/year. In the PSE program workbook (*Res_PSE Deemed SoS reconciliation.xls*, issued August 2010), a water heater with a 0.94 efficiency factor and 50-gallon capacity has a deemed savings of 125 kWh/year.

Below is the RTF summary of savings from the current workbook implemented in 2011, which will remain in force into 2015.

Water Heater Capacity	Efficiency Factor	kWh Savings/Year
Residential-type Water Heater (>= 25 gallons, <35 gallons)	≥0.94	39
Residential-type Water Heater (>= 35 gallons, <45 gallons)	≥0.94	99
Residential-type Water Heater (>= 45 gallons, <55 gallons)	≥0.94	131
Residential-type Water Heater (>= 45 gallons, <55 gallons)	≥0.94	111
Residential-type Water Heater (>= 55 gallons, <75 gallons)	≥0.94	175
Residential-type Water Heater (>= 75 gallons, <100 gallons)	≥0.94	165
Residential-type Water Heater (>= 100 gallons, <120 gallons)	≥0.94	135

Recommendation: Use the current RTF deemed annual savings value of 131 kWh for a 0.95 EF storage tank between 45 gallons and 54 gallons. To simplify program operations, limit incentives to tanks between 45 and 54 gallons.

Gas Storage Water Heaters

This measure is not offered as part of the 2011 Multifamily Program. The deemed annual savings for the 2008-2009 program years, when incentives were last paid, was 18 therms/year, based on a minimum efficiency of 0.62.

A recent impact evaluation of the hot water heater program for single-family residences[6] concluded that with a 76% confidence factor, the annual savings from a gas water heater using the older 0.62 efficiency rating standard is less than 10 therms/year. This analysis is somewhat equivocal, with the engineering analysis suggesting up to 15 therms, with 10 therms being the maximum "reasonable" value. The billing analysis, though, suggests 0 therms, but with a big confidence bound. A value somewhere in the middle may be the best value until further research is available.

In September 2010, Energy Star changed the minimum efficiency rating from 0.62 to 0.67. Tank capacity is not stated.

DEER estimates for a 50 gallon gas water heater in a single family residence in Climate Zone 1 with a minimum efficiency of 0.67 EF will save 37 therms/ year.

Recommendation: Use an 8 therms/year value from the 2010 KEMA study for any gas storage water heaters with a minimum 0.67 EF. This value should be considered provisional until more definitive research becomes available.

[6] KEMA. 2010. *Impact Evaluation of the PSE Efficient Hot Water Heater Program – Program Years 2005-2007, Draft Report*. Bellevue, Washington: Puget Sound Energy.

4. Conclusions and Recommendations

The impact evaluation of the 2007-2009 Multifamily Weatherization Program yielded the following conclusions and recommendations:

1. **Building characteristics varied significantly depending on heating fuel**. Electrically-heated buildings among the program participants were built in the 1970s and contained, on average, 90 units with a total floor area of around 70,000 sq.ft. By contrast, participant gas-heated buildings were much older (built in the 1930s) and smaller, with an average of 19 units and total floor area of approximately 12,500 sq.ft.
2. **The program reduced electric use by 10% in electrically-heated buildings.** For program participants with electrically-heated buildings, the cumulative effect of the various implemented shell measures was to reduce electrical usage in residence spaces from 16.07 to 14.67 kWh/year per square foot of floor area, in a typical weather year. This difference of 1.40 kWh/year/sq.ft. represents a reduction of nearly 10%.
3. **The program reduced gas use by 19% in natural-gas-heated buildings.** For program participants with gas-heated buildings, the cumulative effect of the various implemented shell measures was to reduce gas usage in residence spaces from 0.619 to 0.523 therms/year per square foot of floor area, in a typical weather year. This difference of 0.096 therms/year/sq.ft. represents a reduction of nearly 19%.
4. **Deemed savings values for non-shell measures should be updated**. Over the last several years, customer interest in the non-shell measures—namely, ductless heat pumps, in-unit gas furnaces, refrigerators, and efficient water heaters—has been slight. As a result, the corresponding savings claims for these measures have also been modest. Nonetheless, the deemed savings values assigned to these measures should be revised based on the evaluated findings, the latest research, and industry guidelines. Specific recommendations for each measure are detailed in Table 7 in the previous section. For all measures named previously, with the exception of electric water heaters, these revisions will reduce the deemed savings.
5. **Program documentation should be improved**. The evaluation revealed deficiencies in the program documents that not only complicated the work, but also would in general make it difficult to verify program accomplishments. The paperwork often lacked basic information about which buildings were treated, where in a building program measures were installed, what was installed, and what the baseline conditions were.
6. .**Detailed, accurate building information is difficult to obtain**. For future evaluations of existing multi-family buildings, it should be noted that as-built construction documents and drawings can be very hard to get. Local building departments often do not retain plan sets. Likewise, many building owners also are lacking these, and if they have them, may be reluctant to go through the trouble of assisting evaluators. Available documentation was frequently inadequate for the evaluation modeling effort, and thus could not be used.

5. APPENDIX A – SITE DATA COLLECTION

The data collection forms for this study reside in an Excel Workbook with multiple sheets and tables. Examples of these forms are provided below. The building summary section was used to collect building-level information, such as number of floors, type of wall construction, and heat sources. The zone summary section was used to collect details by space type, such as average conditioned floor and wall area. In addition, the data collection workbook contains schedules for cataloguing and categorizing dwelling units, windows, and doors.

MULTIFAMILY ZONES SUMMARY FORM - *enter data in blue cells only*
Building Number
Building Name **PSE15**
Evaluator Initials **WC**

			R1	R2	R3
	Apartment # or common space		R1	R2	R3
	Space Multiplier		2	6	2
	Space type description		2 BDR 4 ext	2 BDR 3 ext	2 BDR 4 ext
1	General	Conditioned space (yes/no)	yes	yes	yes
2		Number of bedrooms	2	2	2
3		Floor Area (sq.ft.)	648	648	672
		U-A Value For Zone	113.438	80.719	132.879
4		# of exterior surfaces (1/1+/2/.../4+)	4	3	4
5		Washer/dryer present (yes/no)	no	no	no
6	Net Framed Wall	Area (ft2) - *exterior insulated opaque wall area for the spac e*	684	396	720
		Net Area (ft2)	576	288	
		Average Wall Height (ft)	7	7	7
		U-Value Calculated	0.078	0.078	0.078
		U-A Value	53.7	31.1	56.5
10	Underground Wall	Area (ft2) - *exterior, below-grade*	0	-	-
11		U-Value Calculated			
		U-A Values			
12	Windows	Area (ft2)	87	87	81
13		Window U-value	0.29	0.29	0.29
		U-A Value	25.2	25.2	23.5
14	Doors	Area (ft2), *exterior only*	21	21	21
15		Door U-value	0.5	0.5	0.5
		U-A Value	10.5	10.5	10.5
16	Ceiling	Type: A=insulated attic; V=insulated vaulted or flat roof ceiling above; N=conditioned space above	N	N	N
17		Area (ft2), *insulated and exposed to the exterior for the space.*	-	-	-
		U-Value Calculated	0.025	0.025	0.025
		U-A Value	0.000	0.000	0.000
19	Floor	Type: S=slab-on-grade; PT=post-tension concrete slab with space below; F=wood-framed; N=conditioned space below, i.e., another apartment)	S	S	F
20		Insulated floor area (Type F/PT: ft2. Type S: exterior perimeter floor length in feet. Type N: 0)	76	44	672
		U-Value Calculated	0.316	0.316	0.063
		U-A Value	24.1	13.9	42.4
22	Fireplace	Yes/No	No	No	No
23		Fuel Type *(Imp. for non-participants, OK if not available for participants)*			
24	Lighting Interior	Total watts			
25		Total # of fixtures			
28	Lighting Exterior	Total watts			
29		Total # of fixtures			

Comments:

Building Number		**P11**
Building Name		
Date		
Initials		
Number of apartments in building		
Compliance Method (Option I / II / Calculated)		
Total # of floors		
Total Non-residental # of floors		
Wall Construction 1	Wood / steel / other	
	U-value	0.078
	Gross Area	20,736
	Description of component layers	Wood Siding, 1/2" Asphalt Impregnated sheathing, Insulation, 2x4 wood stud at 16" OC, 5/8th GYP BD
	Nominal Insulation R-value	R11
Wall Construction 2 *(only if exists)*	Wood / steel / other	n/a
	U-value	
	Gross Area	
	Description of component layers	
	Nominal Insulation R-value	
Exterior Wall Below Grade *(only if conditioned common/residential area is below*	U-value	n/a
	Gross Area	
	Description of component layers	
	Nominal Insulation R-value	
Windows	Average U-value	1.270
	% glazing	17.5%
	Total glazing area (window sqft)	3,624
Skylights	Average U-value	
	Total glazing area (skylight sqft)	
Doors	Average U-value	0.50
	Total building door area	925
Ceiling (attic)	U-value	0.073
	Gross Area	14,496
	Description of component layers	shingles, 1/2" plywood CDX, 2x10" joists at 24" OC, originally R19, reduced to R11 insulation, 1/2" sheetrock or 5/8" Gypsum
	Nominal Insulation R-value	R11
Ceiling (vaulted/flat)	U-value	n/a
	Gross Area *(calculated horizontal area only)*	
	Description of component layers	
	Nominal Insulation R-value	
Slab Type S=slab-on-grade PT=post tension concrete slab w/space below F = wood framed floor *(relevant to common/residential areas only)*	Type	
	S>> F-value	0.316
	Description of component layers *(e.g. slab+insulation)*	slab with carpet & pad
	PT>> Nominal R-value	
	Description of insulation location *- horizontal underneath slab*	
	F>> U-value	0.06
	Description of component layers	carpet & pad, 1 1/8" plywood, 2x10" joists at 24" OC, 3" insulation
Primary Heat Source - Residential	Type: baseboard heat pump >> through the wall heat pump >> split system heat pump >> ducted hydroninc radiators hydronic wall fan coils forced air wall units forced air furnace other	Hot Water
	Heat source efficiency *(heat pumps only)*	Unknown

PUGET SOUND ENERGY

REBATE APPLICATION FOR MULTIFAMILY BUILDINGS

TRACKING NO. -	OWNER NAME xxx	SITE NAME	
OWNER ADDRESS	CITY	STATE WA	ZIP CODE
SITE ADDRESS xxx	CITY Bothell	STATE WA	ZIP CODE 98011
OWNER PHONE NO. xxx	APPROXIMATE YEAR BUILDING WAS BUILT	NUMBER OF UNITS 4	NUMBER OF FLOORS 2

OWNER REPRESENTATIVE same	MANAGEMENT FIRM	PHONE NO.	EMAIL

WINDOWS

	SQUARE FEET	EXISTING WINDOWS	PROPOSED WINDOWS	U-VALUE	TOTAL BID	TOTAL ESTIMATED REBATE
WINDOW 1		SINGLE PANE ☐ DOUBLE PANE	MANUFACTURER MODEL			

CONTRACTOR NAME	CONTACT NAME	CONTRACTOR PHONE NO.

ATTICS

	SQUARE FEET	EXISTING R-VALUE	PROPOSED R-VALUE	INSULATION ONLY BID	VENTILATION BID	BID TO VENT FANS	OTHER	TOTAL BID	TOTAL ESTIMATED REBATE
ATTIC AREA 1	2334	11	38	NA	NA	NA	-	2107.95	$1167

CONTRACTOR NAME	CONTACT NAME	CONTRACTOR PHONE NO.

FLOORS

	SQUARE FEET	EXISTING R-VALUE	PROPOSED R-VALUE	INSULATION ONLY BID	VENTILATION BID	WRAP WATER PIPES	GROUND COVER	TOTAL BID	TOTAL ESTIMATED REBATE
FLOOR AREA 1		-			-	-			

CONTRACTOR NAME	CONTACT NAME	CONTRACTOR PHONE NO.

DOORS

	QUANTITY	MANUFACTURER	MODEL	TOTAL BID	TOTAL ESTIMATED BID
DOOR 1				$	$
DOOR 2				$	$

CONTRACTOR NAME	CONTACT NAME	CONTRACTOR PHONE NO.

LIGHTING

IN-UNIT LIGHTING

Will there be in-unit lighting installed? ☐ YES ☐ NO If Yes, please provide information below.

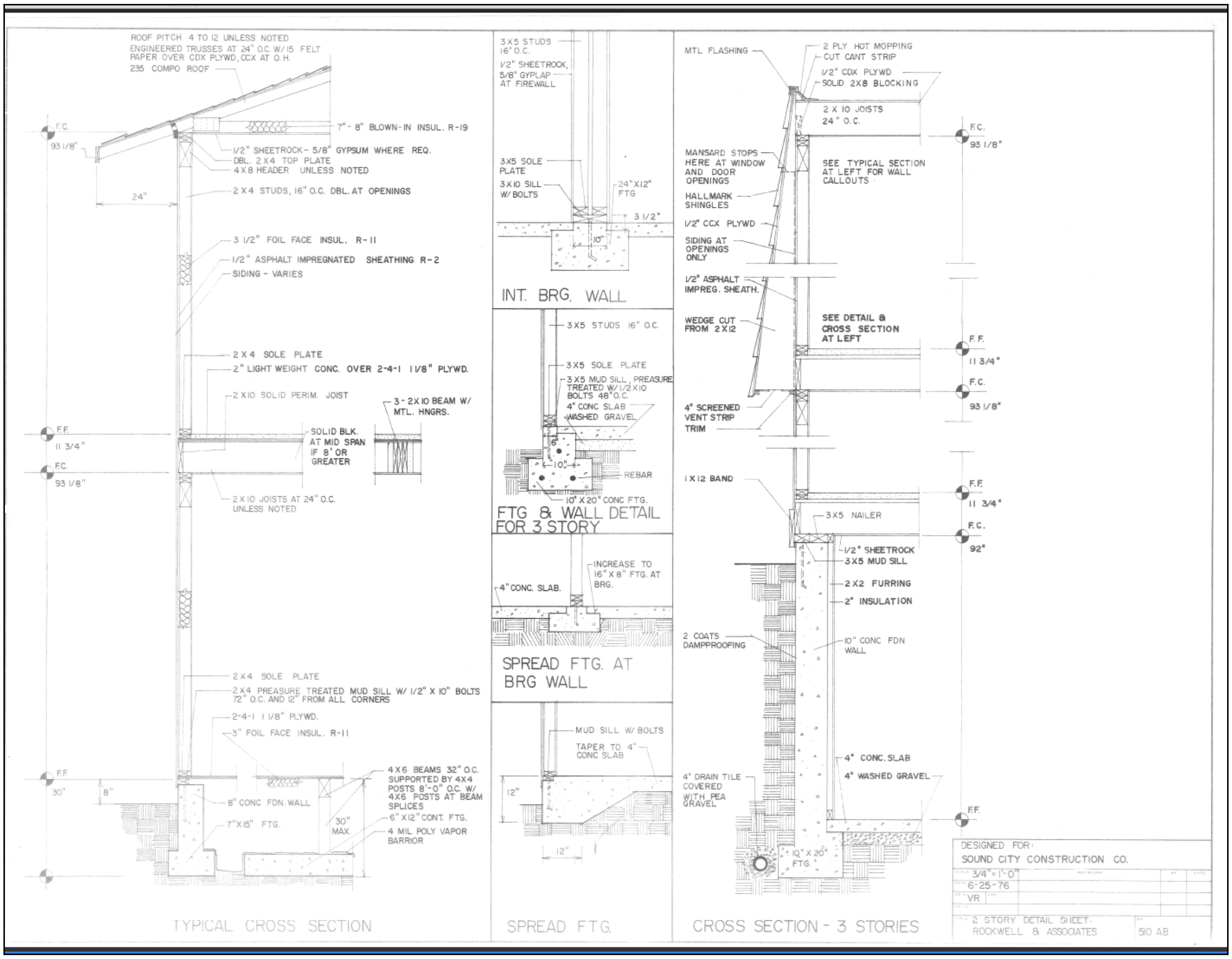
	ENERGY STAR® MANUFACTURER	TO BE PURCHASED AT	FIXTURES	EXISTING WATTAGE	PROPOSED NEW FIXTURE WATTAGE	NUMBER OF FIXTURES
LIGHTING 1			FIXTURE MODEL			
LIGHTING 2			FIXTURE MODEL			

COMMON AREA LIGHTING

Will there be common area lighting installed? ☐ YES ☐ NO If Yes, number of fixtures:

REBATE SUMMARY			
	COST	REBATE	CUSTOMER COST
WINDOWS			
INSULATION	$2107.95	$1167	940.95
TOTAL	$2107.95	$1167	**$**940.95

To schedule the work, contact your contractor.
If you have questions for Puget Sound Energy, call 1-866-997-9797


ROOF PITCH 4 TO 12 UNLESS NOTED
ENGINEERED TRUSSES AT 24" O.C. W/15 FELT PAPER OVER CDX PLYWD, CCX AT O.H.
235 COMPO ROOF
7" - 8" BLOWN-IN INSUL. R-19
1/2" SHEETROCK - 5/8" GYPSUM WHERE REQ.
DBL. 2 X 4 TOP PLATE
4 X 8 HEADER UNLESS NOTED
2 X 4 STUDS, 16" O.C. DBL. AT OPENINGS
3 1/2" FOIL FACE INSUL. R-11
1/2" ASPHALT IMPREGNATED SHEATHING R-2
SIDING - VARIES
2 X 4 SOLE PLATE
2" LIGHT WEIGHT CONC. OVER 2-4-1 1 1/8" PLYWD.
2 X 10 SOLID PERIM. JOIST
3 - 2 X 10 BEAM W/ MTL. HNGRS.
SOLID BLK. AT MID SPAN IF 8' OR GREATER
2 X 10 JOISTS AT 24" O.C. UNLESS NOTED
2 X 4 SOLE PLATE
2 X 4 PREASURE TREATED MUD SILL W/ 1/2" X 10" BOLTS 72" O.C. AND 12" FROM ALL CORNERS
2-4-1 1 1/8" PLYWD.
3" FOIL FACE INSUL. R-11
4 X 6 BEAMS 32" O.C. SUPPORTED BY 4 X 4 POSTS 8'-0" O.C. W/ 4 X 6 POSTS AT BEAM SPLICES
8" CONC FDN WALL
6" X 12" CONT. FTG.
7" X 15" FTG.
4 MIL POLY VAPOR BARRIER
TYPICAL CROSS SECTION
3 X 5 STUDS 16" O.C.
1/2" SHEETROCK, 5/8" GYPLAP AT FIREWALL
3 X 5 SOLE PLATE
3 X 10 SILL W/ BOLTS
24" X 12" FTG
INT. BRG. WALL
3 X 5 STUDS 16" O.C.
3 X 5 SOLE PLATE
3 X 5 MUD SILL, PREASURE TREATED W/ 1/2 X 10 BOLTS 48" O.C.
4" CONC SLAB
WASHED GRAVEL
REBAR
10" X 20" CONC FTG.
FTG & WALL DETAIL FOR 3 STORY
INCREASE TO 16" X 8" FTG. AT BRG.
4" CONC. SLAB.
SPREAD FTG. AT BRG WALL
MUD SILL W/ BOLTS
TAPER TO 4" CONC SLAB
SPREAD FTG.
MTL FLASHING
2 PLY HOT MOPPING
CUT CANT STRIP
1/2" CDX PLYWD
SOLID 2 X 8 BLOCKING
2 X 10 JOISTS 24" O.C.
MANSARD STOPS HERE AT WINDOW AND DOOR OPENINGS
SEE TYPICAL SECTION AT LEFT FOR WALL CALLOUTS
HALLMARK SHINGLES
1/2" CCX PLYWD
SIDING AT OPENINGS ONLY
1/2" ASPHALT IMPREG. SHEATH.
WEDGE CUT FROM 2 X 12
SEE DETAIL & CROSS SECTION AT LEFT
4" SCREENED VENT STRIP TRIM
1 X 12 BAND
3 X 5 NAILER
1/2" SHEETROCK
3 X 5 MUD SILL
2 X 2 FURRING
2" INSULATION
2 COATS DAMPPROOFING
10" CONC FDN WALL
4" CONC. SLAB
4" WASHED GRAVEL
4" DRAIN TILE COVERED WITH PEA GRAVEL
10" X 20" FTG.
CROSS SECTION - 3 STORIES
DESIGNED FOR:
SOUND CITY CONSTRUCTION CO.
3/4" = 1'-0"
6-25-76
2 STORY DETAIL SHEET
ROCKWELL & ASSOCIATES

6. APPENDIX B – MODELING FLOWCHART

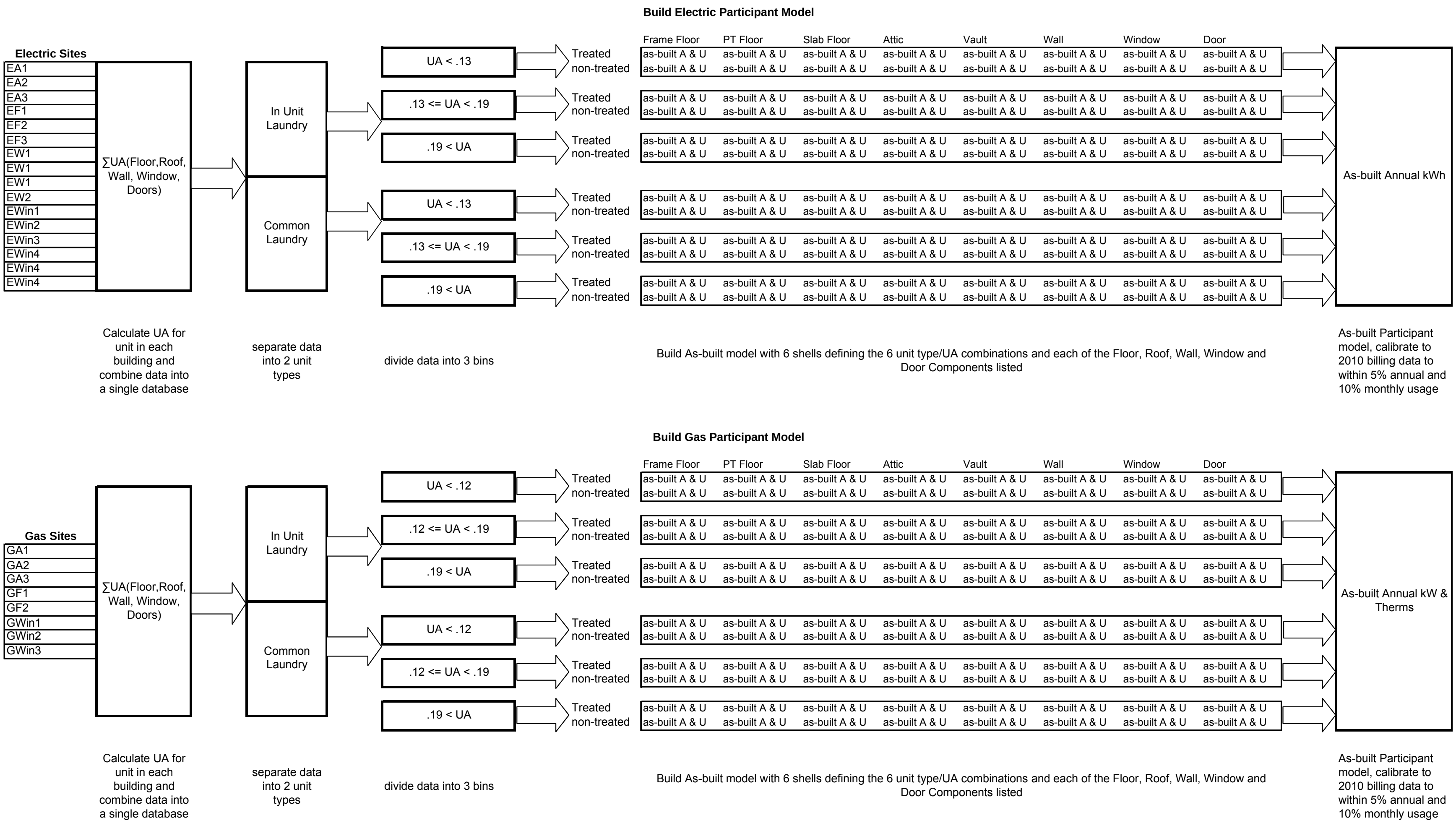


Figure 4: Combine Sample Data into Single Database and Distribute Units into Categories

Electric Model Floor Measure Savings Analysis

			Frame Floor	PT Floor	Slab Floor	Attic	Vault	Wall	Window	Door
In Unit Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
Common Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U

→ Baseline Floor Annual kWh → (Baseline Floor Annual kWh - As-built Annual kWh) = Floor Upgrade kWH Savings

Replace As-built model treated components with Baseline Floor values

Annual Usage for Participant model with baseline floors

Calculate Savings from Floor Upgrade

Gas Model Floor Measure Savings Analysis

			Frame Floor	PT Floor	Slab Floor	Attic	Vault	Wall	Window	Door
In Unit Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
Common Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U

→ Baseline Floor Annual kW & Therms → (Baseline Floor Annual kW - As-built Annual kW) = Floor Upgrade Savings

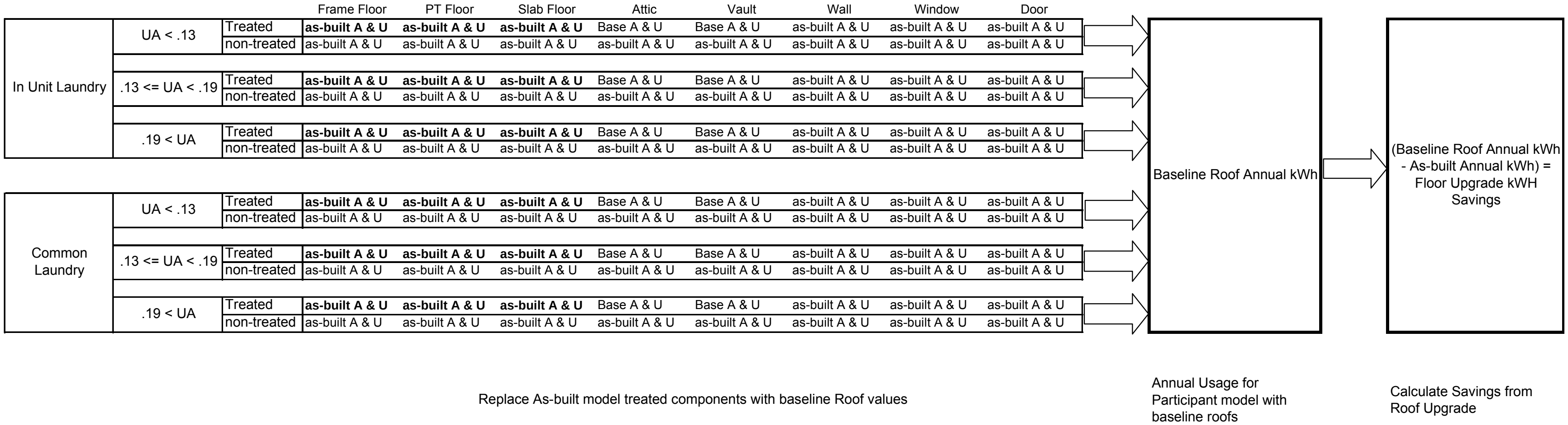
Replace As-built model treated components with Baseline Floor values

Annual Usage for Participant model with baseline floors

Calculate Savings from Floor Upgrade

Figure 5: Calculate Floor Measure Savings

Electric Model Roof Measure Savings Analysis



Gas Model Roof Measure Savings Analysis

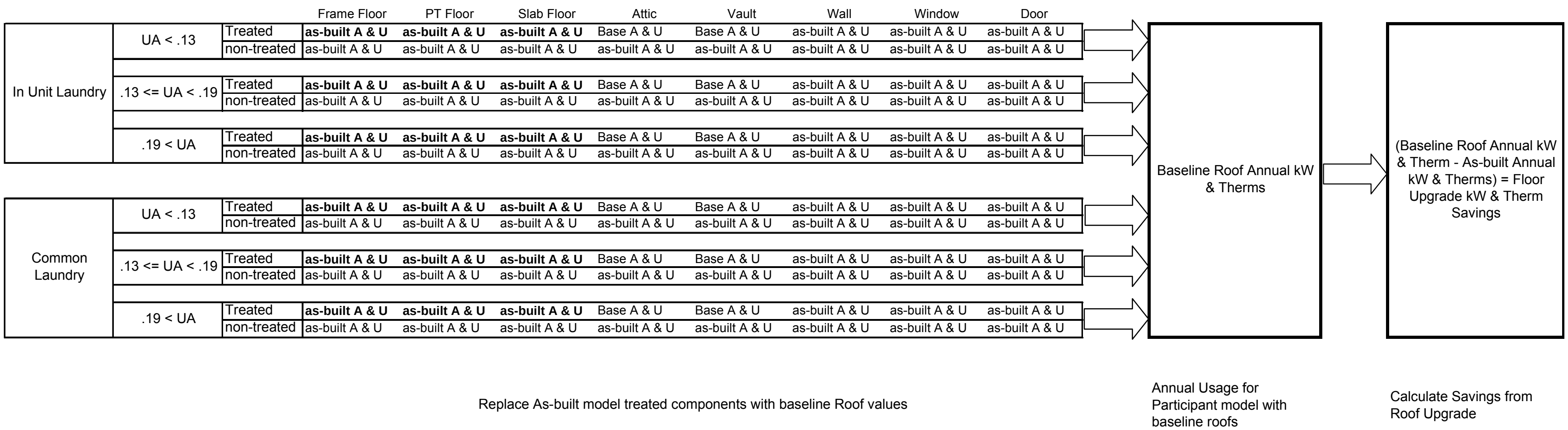


Figure 6: Calculate Roof Measure Savings

Electric Model Wall Measure Savings Analysis

			Frame Floor	PT Floor	Slab Floor	Attic	Vault	Wall	Window	Door
In Unit Laundry	UA < .13	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
Common Laundry	UA < .13	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U

Baseline Wall Annual kWh

(Baseline Wall Annual kWh As-built Annual kWh) = Wall Upgrade kWh Savings

Replace As-built model treated components with baseline Wall values

Annual Usage for Participant model with baseline walls

Calculate Savings from Wall Upgrade

Gas Model Wall Measure Savings Analysis

			Frame Floor	PT Floor	Slab Floor	Attic	Vault	Wall	Window	Door
In Unit Laundry	UA < .13	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
Common Laundry	UA < .13	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**as-built A & U**	**as-built A & U**	**as-built A & U**	as-built A & U	as-built A & U	Base A & U	as-built A & U	as-built A & U
		non-treate	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U

Baseline Wall Annual kWh & Therm

(Baseline Wall Annual kW & Therm - As-built Annual kW & Therm) = Wall Upgrade kWh & Therm Savings

Replace As-built model treated components with baseline Wall values

Annual Usage for Participant model with baseline walls

Calculate Savings from Wall Upgrade

Figure 7: Calculate Wall Measure Savings

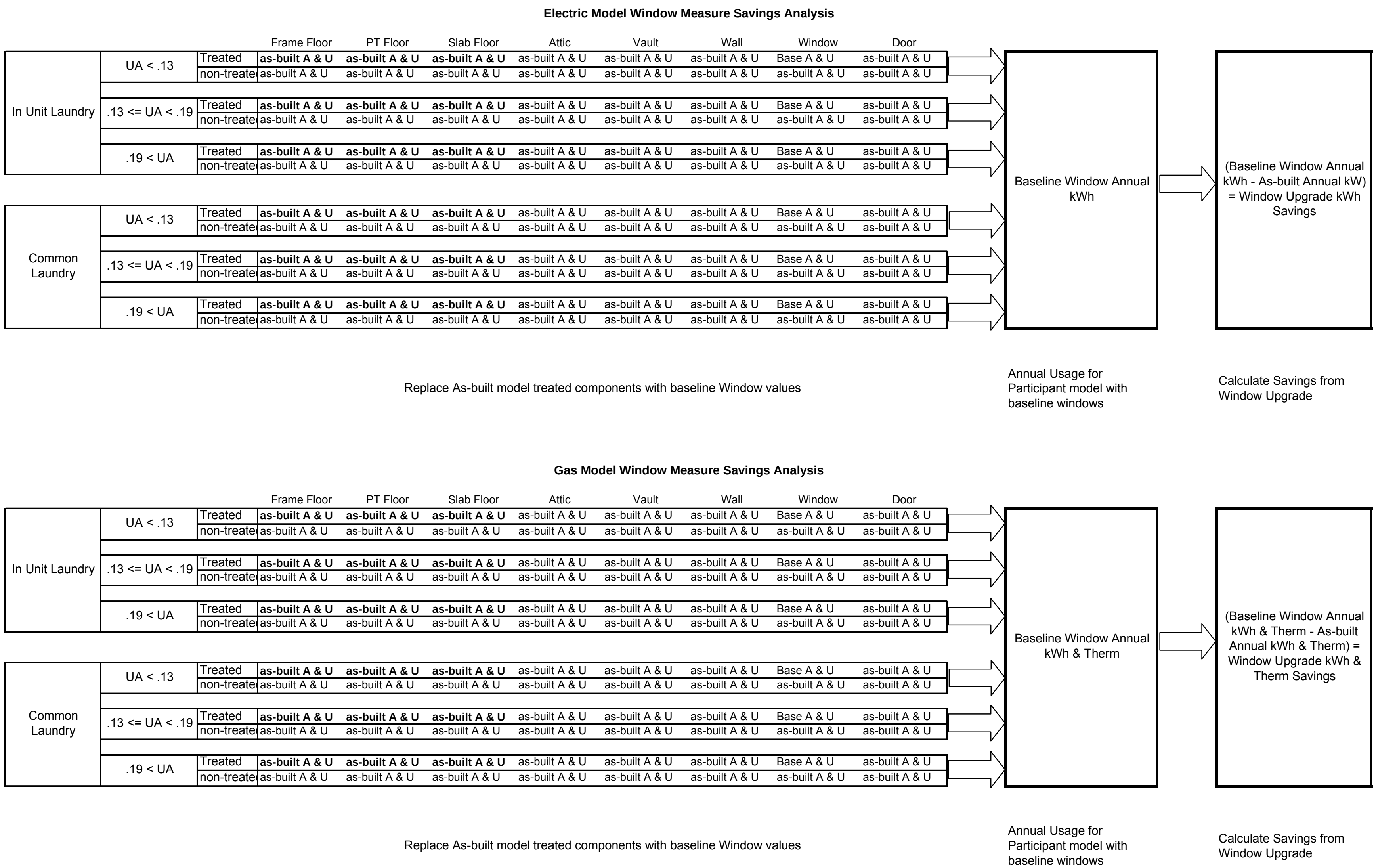


Figure 8: Calculate Window Measure Savings

Electric Model All Measure Savings Analysis

			Frame Floor	PT Floor	Slab Floor	Attic	Vault	Wall	Window	Door
In Unit Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
Common Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U

Baseline Annual kWh

(Baseline Annual kWh - As-built Annual kWh) = Combined Measure Upgrade kWh Savings

Replace all treated components with Baseline values

Annual Usage for Participant model with all baseline components

Calculate Savings from Upgrade: Combined Measure Upgrade Savings = ∑individual component savings

Gas Model All Measure Savings Analysis

			Frame Floor	PT Floor	Slab Floor	Attic	Vault	Wall	Window	Door
In Unit Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
Common Laundry	UA < .13	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.13 <= UA < .19	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U
	.19 < UA	Treated	**base A & U**	**base A & U**	**base A & U**	base A & U	base A & U	base A & U	base A & U	asbuilt A & U
		non-treated	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U	as-built A & U

Baseline Annual kWh & Therm

(Baseline Annual kWh & Therm - As-built Annual kWh & Therm) = Complete Upgrade kWh & Therm Savings

Replace all treated components with Baseline values

Annual Usage for Participant model with all baseline components

Calculate Savings from Upgrade: Combined Measure Upgrade Savings = ∑individual component savings

Figure 9: Calculate All Measure Savings

7. Appendix C – EQUEST Information

[Excerpted and adapted from the *eQUEST Introductory Tutorial, version 3.64*, issued by James J. Hirsch & Associates, December 2010.]

DOE-2-derived engine in eQUEST

DOE-2 is the most widely recognized and respected building energy analysis program in use today. Although DOE-2 was first released in the late 1970's, it used as starting points earlier simulation tools and methods developed and funded by ASHRAE, NASA, the U.S. Postal Service, and the electric and gas utility industries. During the first half of the 1980's, it continued under DOE support, but decreasing national concern about energy created the need for industry support, which became its principal source of support through much of the 1990's. Through this long and collaborative history, DOE-2 has been widely reviewed and validated in the public domain. The simulation "engine" within eQUEST is derived from the latest official version of DOE-2, however, eQUEST's engine extends and expands DOE-2's capabilities in several important ways, including: interactive operation, dynamic/intelligent defaults, and improvements to numerous long-standing shortcomings in DOE-2 that have limited its use by mainstream designers and buildings professionals.

eQUEST and Integrated Energy Design

While DOE-2 has long been available for designers to "test drive" the energy performance of their building designs, it has been too difficult and expensive to use for most projects. Imagine instead, a building energy simulation tool so comprehensive that it would be useful to ALL design team members, yet so intuitive ANY design team member could use it, in ANY or ALL design phases, including schematic design. *eQUEST* is well named because it provides something the buildings industry has been looking for, but until now has been unable to find ... a sophisticated, yet easy-to-use building energy analysis tool ... powerful enough to address every design team member's domain (e.g., architectural, lighting, mechanical) but simple enough to permit a collaborative effort by ALL design team members in ALL design phases.

eQUEST was designed to allow you to perform detailed analysis of today's state-of-the-art building technologies using today's most sophisticated building energy use simulation techniques ... without requiring extensive experience in the "art" of building performance modeling. This is possible because eQUEST's DOE-2-derived engine is combined with a building creation wizard, an energy efficiency measure wizard, industry standard input defaults, and a graphical results display module. eQUEST will step you through the creation of a detailed building model, allow you to automatically perform parametric simulations of your design alternatives and provide you with intuitive graphics that compare the performance of your design alternatives.

Overview of the Process

eQUEST calculates hour-by-hour building energy consumption over an entire year (8760 hours) using hourly weather data for the location under consideration. Input to the program consists of a detailed description of the building being analyzed, including hourly scheduling of occupants, lighting, equipment, and thermostat settings. eQUEST provides very accurate simulation of such building features as shading, fenestration, interior building mass, envelope building mass, and the dynamic response of differing heating and air conditioning system types and controls. eQUEST also contains a dynamic daylighting model to assess the effect of natural lighting on thermal and lighting demands.

The simulation process begins by developing a "model" of the building based on building plans and specifications. A base line building model that assumes a minimum level of efficiency (e.g., minimally compliant with California Title24 or ASHRAE 90.1) is then developed to provide the base from which energy savings are estimated. Alternative analyses are made by making changes to the model that correspond to efficiency measures that could be implemented in the building. These alternative analyses result in annual utility consumption and cost savings for the efficiency measure that can then be used to determine simple payback, life-cycle cost, etc. for the measure and, ultimately, to determine the best combination of alternatives.

HVAC Zoning

HVAC zoning recognizes that load profiles seen by different spaces in a building differ. Identifying those areas with similar load profiles and grouping them under the same thermostat control improves comfort and may reduce energy. For example, imagine measuring indoor air temperatures at many locations throughout a building during hours when the HVAC fans are temporarily turned off. Internal gains, solar gains, and envelope gains/losses would cause the temperatures to vary with time. If, after some number of hours or days, you carefully examined the temperature histories, grouping together those that shared similar profiles over time, you would have effectively grouped together those areas of the building that share similar load characteristics. Each such area or "zone" could, therefore, be adequately controlled by a single thermostat. In other words, HVAC thermal zoning seeks to group together those areas (rooms) in a building that share similar load and usage characteristics, for purposes of control. Of course, this imagined procedure is not how HVAC engineers actually zone any building. Rather, rules such as those listed below are employed. The same rules apply when zoning a simulation model.

- when modeling existing buildings, refer to the actual zoning indicated by the HVAC plans, if available
- for new buildings and when simplifying the zoning of an existing building consider:
  - magnitude and schedule of internal loads
  - magnitude and schedule of solar gains
  - schedule of fan system operations
  - outside air requirements
  - intended efficiency measures (ECM's)
  - location of thermostats called out on the HVAC plans

In general, provide:

- one exterior zone per major orientation (12 to 18 feet deep)
- one internal zone per use schedule
- one plenum zone (if plenum returns) for each air handler to be modeled separately
- one zone each for special uses (e.g., conference rooms, cafeterias, etc.)
- separate ground and top floor' zones

Table 18: eQUEST Model Input Summary

	Item	Source (Electric & Gas Models)	Electric Model Values	Gas Model Values
Architectural	Building & Zone Areas	as-built drawings	454435 sq.ft.	78805 sq.ft.
	Envelope Const. Materials	as-built drawings - wall sections* or Ecos application files		
	attic		U = .028 -.039	U = .026-.035
	vault		U = 0.06	U = .027-.042
	frame floor		U = .032 -.109	U = .035-.056
	pt slab floor		n/a	U =0.029
	slab floor		U = 0.191	U =0.242-0.253
	walls		U = .061 -.101	U = .093
	Surface Area (by orientation)	as-built drawings - building elevations		
	attic		159338 sq.ft.	2298 sq.ft.
	vault		44211 sq.ft.	29492 sq.ft.
	frame floor		23699 sq.ft.	8871 sq.ft.
	pt slab floor		n/a	4173 sq.ft.
	slab floor		153826 sq.ft.	7067 sq.ft.
	walls		248885 sq.ft.	38512 sq.ft.
	fenestration areas (by orientation)	as-built drawings - building elevations	60603 sq.ft.	10491 sq.ft.
	fenestration u-value & SC	as-built drawings - window schedule or Ecos application files	U = 0.31	U = 0.359
Mechanical	HVAC zoning	Previous MF & Metering Model, calibrated to billing data		
	design flow rates	Previous MF & Metering Model	.5 cfm/sq.ft.	.5 cfm/sq.ft.
	equipment description	utility data (electric or gas heat building)	electric heat & DHW	gas heat & DHW
	control sequence	Previous MF & Metering Model		

	Item	Source (Electric & Gas Models)	Electric Model Values	Gas Model Values
Electrical	lighting equipment	Previous MF & Metering Model		
Internal Loads	peak occupancy (by zone)	Previous MF & Metering Model, calibrated to billing data	381 sq.ft./person	381 sq.ft./person
	peak lighting/laundry/plug (by zone)	Previous MF & Metering Model, calibrated to billing data	45 W/sq.ft.	20 W/sq.ft.
	peak DHW (by zone)	Previous MF & Metering Model, calibrated to billing data	4.5 W/sq.ft.	2.358 Btu/hr, 6.5 gpm
Operations	Schedules	Previous MF & Metering Model, calibrated to billing data		
	occupancy		40%-80% occupancy	40%-80% occupancy
	lights/laundry/plug		1%-3.6% usage	1%-3.6% usage
	DHW		7%-12% usage	6%-9.5% usage
	thermostat schedules	Previous MF & Metering Model, calibrated to billing data	69°F, 72°F, 63°F, 67°F	66°F, 69°F, 60°F, 67°F
	outside air operations	n/a - baseboard heat		
	hot & cold deck temp	n/a - baseboard heat		
	fan schedule	n/a - baseboard heat		
	fan kW	n/a - baseboard heat		

*when as-built construction information lacking, default "common practice" data used

Table 19: eQUEST Model Electric and Gas Building Envelope Dimensions and As-Built U-Values

	Apartment Floor			Floor: Framed				Floor: PT Slab				Floor: Slab			
	No. Apt Units	Zone Total (sqft)	Unit Avg (sqft)	non-treated area (sqft)	non-treated (UA/sqft)	treated area (sqft)	treated (UA/sqft)	non-treated area (sqft)	non-treated (UA/sqft)	treated area (sqft)	treated (UA/sqft)	non-treated area (sqft)	non-treated (UA/sqft)	treated area (sqft)	treated (UA/sqft)
Option I - Electric Heat															
Apartments															
In Unit Laundry															
A UA/sf <= 0.13095	74	71,667	968	-		-	-	-	-	-	-	43,723	0.153	-	-
B UA/sf <= 0.195	102	106,712	1,046	-		-	-	-	-	-	-	70,071	0.207	-	-
C UA/sf > 0.195	57	49,446	867	12,390	0.135	-	-	-	-	-	-	12,021	0.207	-	-
Total Area / Average U Value	233	227,825	978	12,390	0.135	-		-	-	-	-	125,814	0.188	-	-
Common Laundry															
A UA/sf <= 0.13095	54	39,534	732	-	-	-	-	-	-	-	-	13,816	0.207	-	-
B UA/sf <= 0.195	225	135,296	601	5,698	0.062	1,166	0.032	-	-	-	-	14,195	0.207	-	-
C UA/sf > 0.195	57	51,781	908	1,642	0.069	2,803	0.032	-	-	-	-	-	-	-	-
Total Area / Average U Value	336	226,611	674	7,341	0.063	3,969	0.032	-	-	-	-	28,011	0.207	-	-
Option II - Gas Heat															
Apartments															
In Unit Laundry															
A UA/sf <= 0.12	4	7,177	1,794	-	-	-	-	-	-	-	-		-		-
B UA/sf <= 0.19	6	10,528	1,755	5,264	0.041	-	-	-	-	-	-		-		-
C UA/sf > 0.19															
Total Area / Average U Value	10	17,705	1,770	5,264	0.041	-		-	-	-	-		-		-
Common Laundry															
A UA/sf <= 0.12	38	26,336	693	568	0.042	458	0.028	-	-	2,909	0.029	508	0.24	748	0.21
B UA/sf <= 0.19	30	20,098	670	-	-	646	0.039	-	-	1,264	0.029	2,730	0.21	824	0.24
C UA/sf > 0.19	24	14,667	611	1,934	0.099	-	-	-	-	-	-	2,257	0.31	-	-
Total Area / Average U Value	92	61,100	664	2,502	0.086	1,105	0.035	-	0.00	4,173	0.029	5,495	0.253	1,572	0.224

Ceiling																	
Attic				**Vault**				**Above Grade Wall**				**Window**				**Door**	
non-treated area (sqft)	non-treated (UA/sqft)	treated area (sqft)	treated (UA/sqft)	non-treated area (sqft)	non-treated (UA/sqft)	treated area (sqft)	treated (UA/sqft)	non-treated area (net sqft)	non-treated (UA/sqft)	treated area (net sqft)	treated (UA/sqft)	non-treated area (sqft)	non-treated (UA/sqft)	treated area (sqft)	treated (UA/sqft)	non-treated area (sqft)	non-treated (UA/sqft)
9,883	0.030	-	-	1,209	0.038	-	-	12,843	0.101	21,332	0.060	1,732	0.350	7,337	0.313	1,752	0.40
-	-	49,800	0.025	11,672	0.038	-	-	72,168	0.093	1,677	0.067	329	0.350	13,549	0.294	3,859	0.50
-	-	-	-	25,035	0.065	-	-	36,920	0.113	-	-	-	-	7,728	0.314	1,170	0.50
9,883	0.030	49,800	0.025	37,916	0.056	-	-	121,931	0.100	23,008	0.061	2,061	0.35	28,614	0.304	6,781	0.472
9,028	0.030	-	-	619	0.085	-	-	14,876	0.086	-	-	-	-	4,994	0.306	991	0.50
44,957	0.048	14,496	0.025	3,182	0.085	-	-	53,487	0.096	-	-	-	-	16,783	0.308	4,196	0.50
-	-	31,166	0.033	2,494	0.085	-	-	35,584	0.119	-	-	-	-	8,151	0.325	942	0.50
53,985	0.040	45,662	0.031	6,295	0.085	-	-	103,947	0.102	-	-	-		29,928	0.313	6,129	0.500
-	-	-	-	7,177	0.024	-	-	2,123	0.058	-	-	-	-	864	0.522	136	0.50
-	-	-	-	1,675	0.024	-	-	4,375	0.058	-	-	-	-	1,341	0.522	204	0.50
-	-	-	-	8,852	0.024	-	-	6,499	0.058	-	-	-		2,204	0.522	340	0.500
728	0.035	793	0.026	2,697	0.042	-	-	12,512	0.077	-	-	-	-	3,138	0.324	435	0.47
460	0.035	1,387	0.026	5,909	0.048	3,878	0.027	12,097	0.094	-	-	-	-	2,950	0.323	223	0.59
-	-	-	-	8,155	0.057	-	-	7,405	0.149	-	-	-	-	2,199	0.293	1,392	0.61
1,188	0.035	2,180	0.026	16,761	0.052	3,878	0.027	32,014	0.100	-	-	-		8,287	0.315	2,050	0.576

Evaluation Report Response

Program: Multifamily Weatherization for Multifamily and Low-Income Programs

Program Manager: John Forde and Sandy Sieg

Study Report Name: Multifamily Weatherization

Report Date: May 11, 2011

Evaluation Analyst: Bobette Wilhelm

Date ERR Provided to Program Manager: May 25, 2011

Date of Program Manger Response: June 13, 2011

Date of Program Action: The Multifamily Weatherization Program Team (John Forde, Sandy Sieg, Clint Stewart, and Bobette Wilhelm) has reviewed the evaluation results from the SBW report and feel it is in PSE's best interest to follow the directive of the RTF; not the directive of the report from SBW.

For the majority of offerings, the SBW evaluation estimates a value of savings which is much higher than current RTF estimates for the same measures. Windows is the only exception to this rule. For Windows, the SBW study estimates a value of savings which is much lower than the current RTF estimates. Additionally, it appears that some non-measure savings are not more than a guess.

SBW's savings estimates are derived from a prototype model building- a building which is unlike any building in PSE service area. PSE program management and evaluation staff repeatedly asked SBW for a description of the prototype building and they were unable to provide us with a satisfactory answer to our questions. Because the savings are drastically different from the RTF estimates, the prototype building is in dimensions which cannot be described, and the difficulty in estimating a reliable savings estimates for multifamily shell measures, it seems the best route (most conservative) is to use RTF estimates for savings.

PSE has contacted Tom Eckman and we will have the ability to obtain RTF values for the incremental R values which have previously not appeared on the RTF site. We will continue to work closely with the RTF for future weatherization savings.