U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Newporter Apartments: Deep Energy Retrofit Short-Term Results

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BA-PIRC

December 2012

Building America
U.S. Department of Energy

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Newporter Apartments: Deep Energy Multifamily Retrofit Short-Term Results

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

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NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40339-00

December 2012

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Definitions

ACH	Air changes per hour
BA	Building America
CAZ	Combustion appliance zone
cfm	Cubic foot per minute
CO	Carbon monoxide
DER	Deep energy retrofit
DOE	U.S. Department of Energy
EEBA	Energy and Environmental Building Association
gpm	Gallons per minute
h	Hour
kBtu	Thousand British thermal units
KCHA	King County Housing Authority
kWh	Kilowatt-hour
LED	Light-emitting diode
MBtu	Million British thermal units
MBtu	???
Pa	Pascal
ppm	Parts per million
SIR	Savings-to-investment ratio
TREAT	Targeted Retrofit Energy Analysis Tool
W	Watt
WSU	Washington State University

Executive Summary

This project was designed to demonstrate a possible path to meet the goal of the U.S. Department of Energy's (DOE) Building America Program to reduce home energy use by 30% (U.S. Department of Energy, 2012) in multifamily buildings. The research develops and documents market-ready energy solutions that improve efficiency, comfort, safety, and durability of existing, individually metered multifamily apartments in the marine climate zone of Washington State.

The project demonstrates cost-effective energy savings targets as well as improved comfort and indoor environmental quality associated with deep energy retrofits (DERs) by a large public housing authority as part of a larger rehabilitation effort. The project focuses on a typical 1960s vintage low-rise multifamily apartment community (120 units in 3 buildings).

The DER effort at Newporter Apartments in Bellevue, Washington, is a good example of a nonprofit housing authority leveraging a variety of federal, state, and utility funding resources to implement a community-scale, system-based retrofit of envelope and mechanical systems in occupied units. The major retrofit measures, which were implemented in 2010, included the following:

- High efficiency combination boilers, providing integrated space and water heating in each apartment
- Increased wall insulation, including dense-pack cellulose, and 1 in. of Roxul exterior sheathing under newly renovated siding
- New efficient windows (U-0.29)
- Efficient lighting (predominately compact fluorescent GU24 lamps, with some light-emitting diodes)
- Continuous whole-house mechanical exhaust ventilation (per ASHRAE 62.2 [ASHRAE 2010]) to replace ineffective fans in the bathroom
- ENERGY STAR efficient refrigerators and dishwashers (as needed for replacement)
- Low-flow sink and shower fixtures.

The housing authority identified Newporter Apartments as a good DER candidate given the need to replace siding, windows, space and water heating equipment, ventilation systems, lighting, and appliances.

This report presents the results of a post-retrofit energy analysis for the apartments using Targeted Retrofit Energy Analysis Tool (TREAT) analysis software (Performance Systems Development Consulting, 2012). The TREAT modeling results were "trued up" to pre-retrofit gas and electric usage. Annual whole-building measured site energy savings were 30% or 477 MBtu. Source energy savings were estimated at 551 MBtu, based on national source energy

factors[1] (Deru & Torcellini, 2007). Measured annual energy savings for gas and electricity were $197.54 per apartment at current utility rates. Energy retrofit measure cost data were collected to determine the cost effectiveness of individual measures and the retrofit packages as a whole. Finally, stakeholder feedback was collected and documented to identify lessons learned and help assess gaps and barriers.

Acknowledgments

This work is sponsored in large part by the DOE Office of Building Technology's Building America Industrialized Housing Program under cooperative agreement DE-FC36-99GO10478. The authors thank the following persons and organizations for their contributions to this project and report: Mark Withrow (architect); Charlie Rogers (mechanical engineer); Jonathan Heller, Ecotope Inc.; Michael Stuart, Fluke Thermography; Colin Olson, The Energy Conservatory; Don Stevens, Panasonic USA; and Eric Martin, DOE Building America Program.

[1] A national source energy factor for electricity of 3.365 was used for consistency with other BA research (note that the source energy factor in the western United States is 2.894 because of the different electricity generation mix).

1 Introduction and Background

The Washington State University (WSU) Energy Program has been providing technical assistance to King County Housing Authority (KCHA) staff for more than 20 years.

In 2009, the WSU Energy Program began coordinating technical assistance efforts with KCHA staff involved with implementation and quality assurance of HVAC and envelope retrofit efforts at the Newporter Apartments in Bellevue, Washington (see Figure 1). Most of the retrofit work has been completed; the project is now in the post-retrofit analysis phase as part of the U.S. Department of Energy Building America (BA) Program's deep energy retrofits (DERs) in marine climates.

Figure 1. Newporter Apartments during retrofit

The 120-unit Newporter Apartments community is composed of one-, two-, and three-bedroom apartments. The complex was constructed in 1968 (King County Housing Authority, 2012).

Before the retrofits began, WSU Energy Program staff conducted several meetings and site visits to review the condition of the building envelopes and systems and to discuss retrofit options. The design process included coordination with KCHA personnel and other key stakeholders to assist in the assessment of measures based on available funding and rehabilitation needs.

In 2010 and 2011, energy efficiency retrofits were implemented at Newporter Apartments. KCHA asset managers were first interested in replacing the leaky, unattractive, and outdated windows. The energy efficient retrofit measures completed to date are as follows:

- Replacement of existing gas furnace and tank water heater systems with a combination ENERGY STAR® condensing boiler
- Replacement of aluminum double-pane windows with U-0.29 vinyl windows

- Walls (2 × 4, estimated R-9) retrofitted with dense pack cellulose insulation (with thermography guided quality assurance), 1-in. Roxul mineral board sheathing and rain screen
- Replacement of incandescent lighting with ENERGY STAR compliant fluorescent and light-emitting diode (LED) lighting, reducing total installed wattage per unit by approximately 80%
- Replacement of ineffective bathroom fans (fan flows measured below 10 cfm) with ASHRAE 62.2-compliant whole-house exhaust fans (ASHRAE 2010)
- ENERGY STAR dishwasher and refrigerator (replaced as needed)
- Low-flow sink and shower fixtures.

The modeling analysis and utility data true-up discussed in this study will capture only the impacts of these measures. To complete this DER, KCHA is pursuing two additional improvements in 2013-14, which might be the subject of future BA research:

- Roof replacement, incorporating additional insulation and air sealing measures
- Retrofitting slab on grade to include trenched perimeter R-10 board insulation.

KCHA funding for the Newporter energy and overall rehabilitation retrofits came from a variety of federal, state, and utility sources, including the following:

- Washington State Department of Commerce Low-Income Weatherization Program
- Puget Sound Energy, the local gas and electric utility provider
- Building owner investments.

The following research questions were identified in the test plan for the post-retrofit analysis for this phase of the project:

1. What is the annual aggregate pre- and post-retrofit modeled energy savings of gas and electric usage of all units in a typical Newporter building?
2. What is the modeled savings-to-investment ratio (SIR) for packages of improvements with and without incentives and leveraging of resources?
3. How do the modeled and measured energy savings compare for packages of retrofit measures?
4. What are the gaps, barriers, and lessons learned in this project, based on field testing, data analysis, and stakeholder feedback?
5. What is an appropriate heat plant design given the physical constraints?

2 Modeling Methods

2.1 Targeted Retrofit Energy Analysis Tool Analysis

In the design phase, the project collected energy efficiency measure cost information to assess energy savings using an energy simulation software called Targeted Retrofit Energy Analysis Tool) (TREAT) (Performance Systems Development Consulting, 2012). The core energy analysis in TREAT is performed by SUNREL, a version of SER-RES, a multinodal simulation tool that was originally designed by Larry Palmiter of Ecotope of Seattle. Ecotope marketed a PC version of the tool as Suncode.

DOE requires low-income weatherization providers to conduct computerized energy audits with approved software that incorporates interactive savings with a body of measures, and (for multifamily projects) allows for a model true-up with billing history. After a lengthy investigation, the low-income weatherization providers selected TREAT several years ago.

TREAT is also required by Washington State Department of Commerce, the state funding source for low-income weatherization projects (Washington State Department of Commerce, 2009).

TREAT was selected as the research analysis tool because at the time the current version of the Building Energy Optimization tool (BEOPT)could not be used to assess complex multifamily structures such as Newporter (National Energy Renewable Laboratory, 2012), (Kruis, Christensen, & Wilson, 2011). TREAT also offers the opportunity to true up the predicted energy use from the model to actual energy use. This is accomplished by adjusting assumptions for certain model inputs until predicted and actual energy use match.

Pre- and post-retrofit electric and gas utility data were collected from Puget Sound Energy from January 2007 to January 2012 for Building A (one of three buildings). The apartments are individually metered. Puget Sound Energy aggregated all the individual apartment data. Only data for the apartments (not common areas) were used in the analysis. TREAT used weather data from Seattle-Tacoma International Airport[2] to adjust actual energy use to typical weather conditions.

True-up of the TREAT model was performed using the billing data and typical meteorological year 3 weather data for the period analyzed (2007–2011). The purpose of true-up is to match model predictions with actual building energy use. For this model, true-up included reducing the thermostat set points and reducing the estimated infiltration rate of Building A.

In an effort to more accurately align heating energy consumption in the model with the utility billing analysis, reductions in the loads were necessary. It was determined that the envelope inputs assumed were reasonable, so the thermostat setting was reduced from 66°F to 65.3°F. Researchers determined that this was a reasonable adjustment because although the units are not

[2] The design-phase TREAT model used Boeing Field weather data, which is closer to the location of the apartments. An analysis of Seattle-Tacoma International Airport weather data, however, showed that they were a closer match to weather conditions in Bellevue where the apartments are located.

equipped with programmable thermostats, investigators assumed that occupants used some degree of manual setback for nighttime and periods when the units were unoccupied.

Air infiltration rates are commonly used as a true-up measure for buildings with no leakage rate test data. No available air leakage rate test data were available for the Newporter Apartments, so researchers used TREAT's default leakage rate of 0.40 ACH.[3] This assumption helped to true up the model.

Predicted water heating consumption was adjusted to within 1% of utility measured analysis results. This true-up was accomplished using fixture flow rate data and equipment efficiency rating information from KCHA. The resulting usage was roughly 13.0 gal per occupant per day. This consumption rate is considered to be on the low end for multifamily housing but within bounds for high occupancy housing (Goldner & Price, 1994) (United States Environmental Protection Agency, 2011).

Lighting fixture count and wattage per fixture data used in the model were obtained from a lighting audit performed by KCHA. Burn times were determined using assumptions used by the local electric utility, Seattle City Light (undated). Additionally, consumption data known from major appliances, such as refrigerators, dishwashers, and exhaust fans, were programmed into the model independently. Remaining loads were lumped together as a single miscellaneous load to true up the model with the measured billing data.

The monthly natural gas and electricity use of 36 individually metered apartment units in one building were analyzed. Table 1 shows the pre-retrofit model before true-up for both gas and electric utility use. Table 2 shows the pre-retrofit model after true-up.

Table 1. Modeled Energy Usage Compared to Billing Data, Pre-Retrofit (Before True-Up)

Annual Consumption	Model Predicted	Billing Data[a]	Variance (%)
Electric Base Load (kWh)	122,714	122,714	0
Heating (Therms)	7,410	7,016	<6
Natural Gas Baseload (Therms)	5,039	4,944	<2
Total MBtu	1,616	1,664	<4

[a] Note that TREAT was used to conduct the billing analysis. Gas usage for space and water heating are disaggregated by the program. As input assumptions change for space and water heating, the program's estimates of consumption will also change.

Table 2. Modeled Energy Usage Compared to Billing Data, Pre-Retrofit (After True-Up)

[3] Because multifamily construction is multizone, conducting blower door tests on buildings like the Newporter Apartments is extremely challenging. A single blower door is insufficient to accurately determine the leakage of any one dwelling unit, because a portion of the tested leakage might be to adjacent apartments or common spaces, and the rest might leak to the outside. When this report was written, there was no clearly defined protocol for conducting these tests. These issues are the subject of ongoing discussions in the building science community, and were the subject of a BA multifamily expert meeting at the Affordable Comfort Conference in March 2012.

	Model Predicted	Billing Data	Variance (%)
Electric Base Load (kWh)	122,714	122,714	0
Heating (Therms)	6,935	6,917	<1
Natural Gas Baseload (Therms)	5,039	5,048	<1
Total MBtu	1,616	1,615	<1

2.2 Savings-to-Investment Ratio Analysis

Cost data were collected from the contractors performing the retrofit work at Newporter. These data were then integrated into an SIR calculation, using post-true-up numbers determined from the TREAT analysis. In TREAT, SIRs of greater than 1 are indicative of an economically cost-effective weatherization measure or package of measures relative to investing in a market-rate bank CD. In this model, SIR calculations were based on state Department of Commerce requirements for calculating SIRs (Washington State Department of Commerce, 2009). Basic assumptions for this calculation include an inflation rate of 3%, a loan interest rate of 8%, a loan term of 30 years, and a bank rate of 6%.

To obtain funding for weatherization measures, KCHA was required to show an SIR of greater than 1 for the entire package based on actual costs, including buydown from rebates and incentives from other sources. In addition, an SIR of greater than 1 also needed to be shown for individual measures within the contracted package to receive the requested funding. All cost data are based on gross installed costs and not incremental or pro-rated costs.

The SIR analysis does not account for the fact that in this major building renovation, some of the improvements were made for reasons other than energy savings and were not funded through weatherization grants or incentives. From the housing authority perspective, it might be inappropriate to assign the full cost of these measures to the energy package. In these cases, the researchers assume that the energy cost of these measures is zero.

3 Description of Retrofit Package

Pre-retrofit meetings between WSU Energy Program personnel and KCHA staff focused on energy efficiency in the design of the retrofit effort, while considering the following:

- Occupant comfort
- Health and safety
- Risk identification
- Risk mitigation
- Building and equipment durability
- System reliability
- Building code compliance issues.

KCHA hired a private energy auditor to conduct combustion appliance zone (CAZ) testing of the Newporter Apartments pre-retrofit. This testing identified the potential for back-drafting associated with the use of atmospherically vented domestic hot water (DHW) and furnaces, which would be exacerbated by reduced air leakage associated with window and wall retrofit efforts. The assessment showed that a sizable number of units failed to meet the combustion safety guidelines established by the Building Performance Institute (Building Performance Institute, 2012). The failures included the following:

- Nine percent of DHW systems and 10% of furnaces continued to spill after 1 min.
- Eight percent of DHW systems and 6% of furnaces had worst-case CAZ test depressurization below –5 Pa (see Figure 2).
- Eleven percent of DHW systems and 17% of furnaces had unacceptable flue drafts (above –1.0 Pa).
- Seventeen percent of DHW and 29% of furnaces had carbon monoxide (CO) levels in flue gases greater than 50 ppm (see Figure 3).
- Gas leaks were observed in 10% of units, typically located near the gas meter/piping.

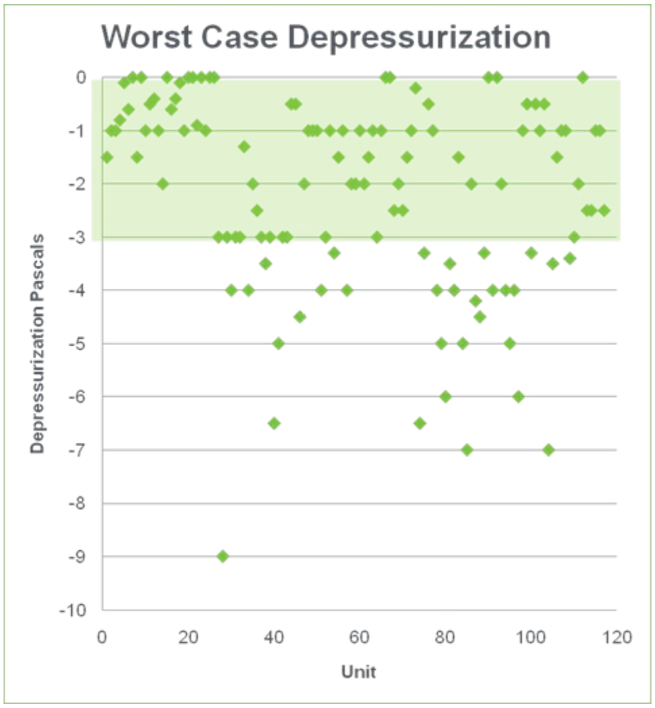

Figure 2. CAZ results

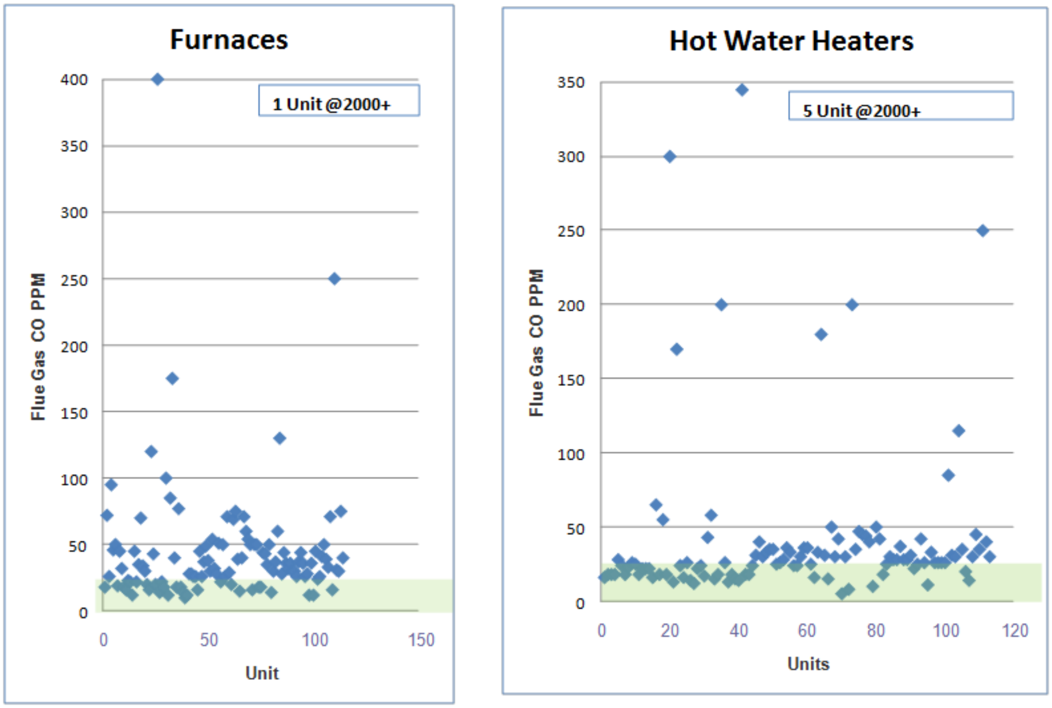

Figure 3. Tested CO levels for Newporter furnaces and water heaters

As a result of this assessment, KCHA specified a direct vent condensing boiler for each unit; space heating is provided by a hydronic fan coil in a new air handler with 200-W blower set at low speed, using the existing duct system (see Figure 4).

Figure 4. Space and water heating systems pre- and post-retrofit

The boiler also supplies DHW. Additionally, plumbing fixtures were replaced or augmented to reduce flow rates to 2.0 gpm for showerheads and 1.0 gpm for faucets. Programmable thermostats were installed for all heating systems.

KCHA was able to secure funding to assist in replacing all of the existing aluminum framed windows. These windows were outdated and in various states of repair but more importantly created comfort, indoor environmental quality, and maintenance issues resulting from air leakage, high conductivity, and condensation. The windows were replaced with new vinyl framed windows with low-e insulated glass units. Installation also included air sealing measures now required by energy codes, which also contributed to a reduction in the building's overall infiltration rate. The modeled infiltration rate for the building after window replacement was 0.26 ACH.[4] Replacement of these windows was partially supported by a utility provider rebate of $\$6/ft^2$ of window area.

The existing wall insulation at Newporter consisted of rockwool batts that only partially filled the wall cavity, and was estimated at R-9. KCHA implemented the measure of leaving the rockwool insulation in place, densely packing the wall cavity with cellulose insulation, and installing 1 in. of continuous mineral wool boards to the exterior or the sheathing before an apartment was occupied. The estimated nominal R-value of the wall assembly after the retrofit was R-18. It was assumed in the TREAT model that this measure also decreased the infiltration rate for the building to 0.23 ACH.

Lighting upgrades implemented at Newporter included reducing the total installed lamp wattage per unit by an average of 955 W. This was done by replacing existing fixtures with GU24 and T8

[4] This is only an estimate. It is very challenging to separate out the air leakage impacts from the retrofit of any given component of the building (e.g., windows and walls).

fixtures and 1 LED (LR6) lamp and fixture per unit. Total installed fixtures were also reduced from an average of 11 fixtures per unit to an average of 8 fixtures per unit. Lighting upgrade costs were partially paid for by utility provider incentives of $72.50/fixture.

Appliances were not replaced as a matter of course during the retrofit process, but are being replaced with ENERGY STAR qualified models as existing appliances reach the end of their service lives.

Washington State low-income weatherization guidelines require whole-house ventilation if the infiltration rate drops below 0.35 ACH. Because KCHA estimated that the air sealing measures would lead to infiltration rates below 0.35 ACH, whole-house ventilation was added. In response, each unit received low-wattage (modeled at 12 W) whole-house exhaust ventilation systems running continuously at 59 cfm. The systems also serve as local exhaust ventilation for the unit's bathroom.

4 Results

4.1 Measured and Modeled Results

Table 3 summarizes the electric and natural gas usage before and after the retrofit. The envelope and DHW heating measures had the most significant impact on reducing total energy consumption in the building analyzed; the lighting retrofit measure had the least.

Table 3. Summary of Energy Usage, Pre- and Post-Retrofit

Annual Consumption	Modeled				Billing Analysis				Variance From Predicted Savings (%)
	Pre-Retrofit	Post-Retrofit	Model Predicted Savings		Pre-Retrofit	Post-Retrofit	Total Savings		
			$	%			$	%	
Electric Base Load (kWh)	122,714	84,914	37,800	31	122,714	118,698	4,016	3	–841
Heating (Therms)	6,935	5,317	1,618	23	6,917	4,489	2,428	35	33
Natural Gas Baseload (Therms)	5,039	2,858	2,181	43	5,048	2,844	2,205	44	1
Total MBtu (Site)	1,616	1,107	509	31	1,615	1,138	477	30	–7
Total MBtu (Source)	2,716	1,868	849	31	2,715	2,163	552	20	–54

The majority of the savings in Building A were attributed to reductions in natural gas usage. Both DHW and heating loads were reduced significantly by improvements in the building envelope's thermal and air barriers as well as replacement of conventional heating and DHW systems with a high efficiency combination space and water heating system. Natural gas consumption was further reduced by including water-saving, low-flow plumbing fixtures. These savings were accomplished despite the addition of continuous whole-house ventilation (per Washington State low-income weatherization specifications), which in itself contributed 296.3 MBtu in increased energy consumption from heat loss.

The model predicted overall natural gas savings at 3,799 therms, a reduction of 32%. The measured reduction in natural gas consumption after 1 full year of operation was 4,633 therms or 39%. This suggests that the predicted natural gas savings are being achieved and they are significant. A longer period of analysis would be needed to confirm whether actual savings are exceeding predicted savings.

TREAT predicted savings attributed to baseload electrical consumption from all implemented measures at 37,800 kWh (130 MBtu). The measured savings for 1 full year after implementation, though, was only 4,016 kWh (13.7 MBtu). This is a reduction in consumption of only 3% versus the model-predicted reduction in total electrical consumption of 31%. No clear explanation has been found for this modeled versus measured discrepancy, but researchers have identified several potential contributing factors:

1. Occupancy rate and behavior: Given the variability of these factors, their influence on the discrepancy is likely high.
2. Utility data: Because the data provided are in aggregate, it is possible that the data might include or exclude areas not included in the model. Determining the validity of this theory would require aligning meter numbers with utility data, and is beyond the ability of the researchers (the utility data are provided in aggregate in part to preserve confidentiality).
3. Fan energy: Before the retrofit, the heating and DHW systems were naturally drafted, and vented independently from each other. The only measurable electrical input to either of them was the furnace fan, but the fan energy was not measured before the retrofit.

   Post-retrofit, the combined space/DHW system uses a 200-W furnace blower, and has additional loads of a coil pump and power draft fan. Run time and total electrical loads for these additional loads are not clear. The model produced by WSU staff assumed identical pre- and post-retrofit electrical loads associated with the space and water heating systems. A more accurate determination of the new, combined system's input wattage and run times might help to shed light on the discrepancy between predicted and measured energy usage.
4. Characterization of lighting use: In the model, a lighting burn time of 3.3 h per fixture was used pre- and post-retrofit. This was based on studies referenced in the TREAT help menu for single-family residences. These referenced burn times varied from 2.0 to 2.47 h/day per fixture at 1.47 and 1.25 W/ft^2, respectively (the implication is that the lower wattage levels result in less light, requiring the use of more fixtures). The lighting audit obtained from KCHA referenced an installed 1.12 W/ft^2 pre-retrofit. No reference data for lighting burn times in multifamily housing were discovered during the writing of this report. It is highly likely that burn time is a significant variable. Using TREAT-recommended, single-family reference data for lighting burn times would have decreased the electrical baseload savings discrepancy by roughly 30%.

Although the overall energy savings realized at Newporter were significant, the overall savings in costs were not as significant in scale because 96% of the overall total MBtus of savings for the building were associated with natural gas consumption. Natural gas prices are only 43% of those for electricity (when compared Btu for Btu of energy). As a result, much lower cost savings are realized at current natural gas and electrical rates. For example,

1 MBtu = $10.46 at current natural gas rate of 1.046/therm

1 MBtu = $24.33 at current electrical rate of $0.083/kWh.

Figure 5 graphically represents Building A monthly energy consumption under pre- and post-retrofit conditions. Natural gas savings of 39% are made evident by the reduction in peak monthly consumption during the heating season as well as base load during the summer of 2011 (illustrated by the red line in the graph). The 3% savings in electrical baseloads are less evident as illustrated by the insignificant drop to the blue line of the graph.

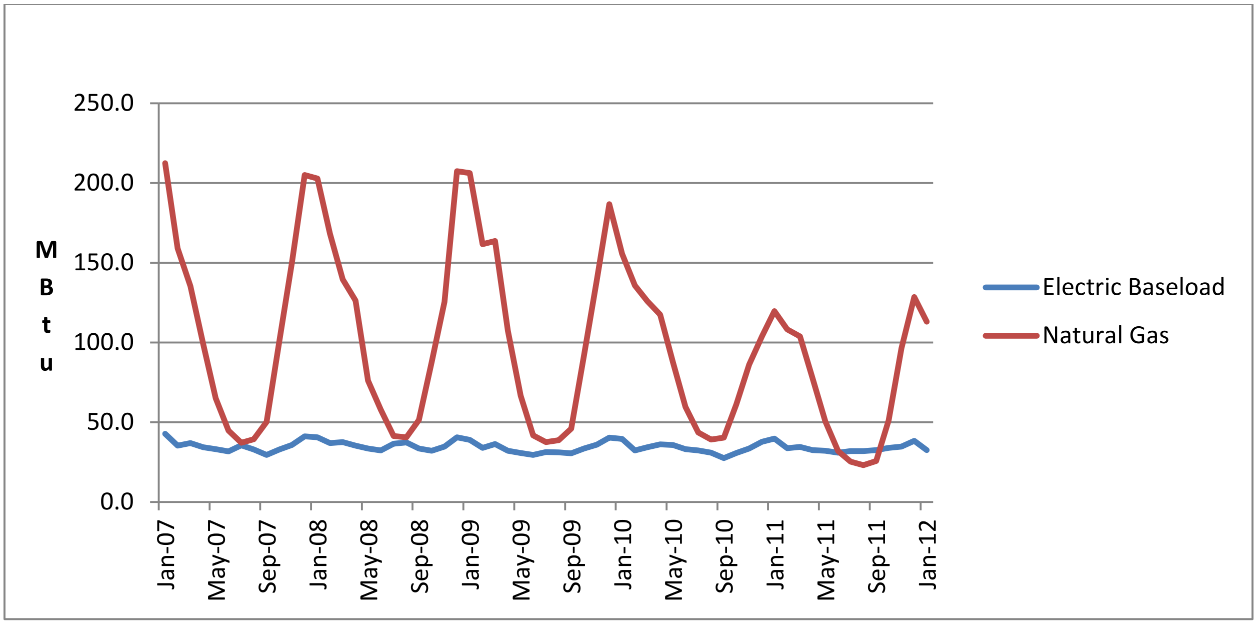

Figure 5. Pre- and post-retrofit energy consumption (Building A)

4.2 Savings-to-Investment Ratio Analysis

Tables 4 and 5 list measure costs and savings for energy efficiency measures implemented at Newporter, and show the SIRs for the package of measures. SIRs for the implemented measures are shown at current utility rates and at utility rates during the period of time in which KCHA originally applied for funding (2009). Table 4 illustrates SIRs for gross energy measure costs without consideration of any rebates or incentives (gross installed costs). See the table notes for details.

Table 4. Package SIR, Calculated With Gross Energy Measure Costs

Model-Predicted Contracted Package SIR (Gross Costs)

Measure	Cost	Savings		Payback	Implementation Life	SIR of Package[a]	SIR of Package[b]
	$	MBtu	$	Years	Years		
DHW	64,084	86.8	908	70.6	15	0.54	0.60
Heating System	64,084	103.9	1,087	58.9	15		
Wall Insulation	43,613	98.8	1,034	42.2	40		
Air Sealing[c]	0	172	1,799	N/A	20		
Lighting	27,075	50.6	2,490	10.9	15		
Window Replacement[d]	113,835	259.2	2,712	42	30		
Total for Package	312,691	771.3	10,029	31.2	N/A		

[a] SIR was calculated at 2012 utility rates of $1.046/therm and $0.083/kWh.
[b] SIR was calculated at 2009 utility rates of $1.22/therm and $0.076/kWh.
[c] This cost is representative of the measure being an incidental benefit of other measures. The modeled total infiltration rate dropped from an estimated 0.40 ACH to 0.16 ACH (Auer, Watkinson, & Doran, 2012).
[d] This cost reflects a $6/ft^2 gas and electric utility incentive.

The SIR calculation is based on a 3% inflation rate, an 8% interest rate, a 30-year loan term, and a 6% bank rate. As seen in Table 4, the weatherization measures installed at Newporter would not be considered cost effective, using the above financial factors and gross installed costs of measures.

There is a compelling argument, however, for reducing installed costs of measures, considering contributions from other funding sources (in this case the gas and electric utility).

In addition, there is a way to consider avoided costs associated with health and safety improvements. In Newporter, the replacement of naturally drafted heating and DHW systems is clearly justified from a health and safety standpoint, and costs related to this replacement should be backed out from the SIR calculation.

Table 5 presents TREAT's SIR calculation with these installed costs modified by these considerations, and shows a package SIR greater than 1.0.

Table 5. Package SIR, Calculated With Net Energy Measure Costs

Model-Predicted Contracted Package SIR (Net Costs)

Measure	Cost	Savings		Payback	Implementation Life	SIR of Package[a]	SIR of Package[b]
	$	MBtu	$	Years	Years		
DHW[c]	0	86.8	908	N/A	15	1.29	1.43
Heating System[c]	0	103.9	1,087	N/A	15		
Wall Insulation	43,613	98.8	1,034	42.2	40		
Air Sealing[d]	0	172	1,799	N/A	20		
Lighting[e]	8,950	50.6	2,490	3.6	15		
Window Replacement[f]	79,265	259.2	2,712	29.2	30		
Total for Package	131,828	771.3	10,029	14.1	N/A		

[a] SIR was calculated at 2012 utility rates of $1.046/therm and $0.083/kWh.
[b] SIR was calculated at 2009 utility rates of $1.22/therm and $0.076/kWh.
[c] This measure was deemed a health and safety concern because of combustion gas spillage and was not required to meet an SIR of 1.0 or greater.
[d] This cost is representative of the measure being an incidental benefit of other measures. The modeled total infiltration rate dropped from an estimated 0.40 ACH to 0.16 ACH (Auer, Watkinson, & Doran, 2012).
[e] This cost reflects a gas and electric utility incentive of $72.50/fixture.
[f] This cost reflects a $6/ft^2 gas and electric utility incentive.

Table 6 shows the SIR calculations for each measure run independently, without the interactive effects of other measures in the package.

Table 6. Measure SIRs, Calculated With Net Energy Measure Costs

Model-Predicted Contracted Individual Measure SIR (Net Costs)

Measure	Cost	Savings		Payback	Implementation Life	SIR of Measure[a]	SIR of Measure[b]
	$	MBtu	$	Years	Years		
DHW[c]	0	78.1	817	N/A	15	N/A[d]	N/A[d]
Heating System[c]	0	115.6	1,209	N/A	15	N/A[d]	N/A[d]
Wall Insulation[e]	43,613	213.2	2,230	19.6	40	1.0	1.17
Air Sealing[f]	0	190.9	1,997	N/A	20	N/A[g]	N/A[g]
Lighting[h]	8,950	40.4	2,384	3.8	15	3.2	2.57
Window Replacement[i]	79,265	370.2	3,872	20.5	30	0.98	1.15

[a] The SIR was calculated at 2012 utility rates of $1.046/therm and $0.083/kWh.
[b] The SIR was calculated at 2009 utility rates of $1.22/therm and $0.076/kWh.
[c] This measure was deemed a health and safety concern because of combustion gas spillage and was not required to meet an SIR of 1.0 or greater.
[d] The SIR calculation was not computed for this measure because the funding source did not require it (because it was a health and safety measure).
[e] These values include energy savings related to incidental air sealing. The values are based on WSU's pre-retrofit estimated infiltration rate of 0.40 ACH and KCHA's post-retrofit estimated infiltration rate of 0.268 ACH.
[f] This cost is representative of measure being an incidental benefit of other measures. The modeled total infiltration rate dropped from an estimated 0.40 ACH to 0.16 ACH (Auer, Watkinson, & Doran, 2012)
[g] The SIR calculation was not computed for this measure because there was no cost. The measure was an incidental benefit of insulation and window replacement measures.
[h] This cost reflects an incentive from the gas and electric utility of $72.50/fixture.
[i] This cost reflects a $6/ft^2 gas and electric utility incentive and includes energy savings related to incidental air sealing. These values are based on WSU's pre-retrofit estimated infiltration rate of 0.40 ACH and KCHA's post-retrofit estimated infiltration rate of 0.292 ACH.

As the results indicate, high-cost measures are challenged to meet the SIR criteria. The measure SIR analysis does not take into account the "lost opportunity" costs of not completing these retrofits. A prime example is the insulation added to the walls. When KCHA retrofitted the windows, the planners could have chosen not to add the cellulose insulation to the cavity or add the Roxul to the exterior. They chose to do so at a time when the siding had been removed for the window replacement, providing maximum value for the retrofit. If they had not done so then, adding insulation at another time would have been significantly more costly.

Several other issues in determining costs for retrofits in projects like Newporter remain:

- Leaving aside the fact that health and safety measures do not require calculation of an SIR, how do we best determine avoided health impacts and their associated costs for replacement of atmospherically vented space and water heating systems?
- What is the appropriate measure cost for windows that are not functioning well and need to be replaced?
- What is the measure cost for replacing appliances at the end of their useful lives?
- What is the measure cost of replacing lighting fixtures that have faulty wiring?
- How did the overall retrofit effort increase the useful life of the project and what level of savings was achieved by not having to build new housing?

4.3 Stakeholder Feedback

Post-retrofit, WSU Energy Program personnel interviewed KCHA staff that managed the project and the Newporter apartments on site (Auer, Watkinson, & Doran, 2012). KCHA staff identified the following lessons learned from the Newporter DER:

- The apartments were built in 1968 and KCHA recognized the need for renovation work. The original impetus for the retrofit, to replace the existing, leaky, and unattractive windows, led to concerns about using existing atmospherically vented space and water heating equipment. KCHA staff are trained and experienced with issues of combustion safety. Working with WSU Energy Program staff, combustion safety issues were identified and it was quickly determined that the retrofit effort would have to include considerations of space and water heating systems as well as envelope improvements.
- Replacement of the space and water heating systems created challenges:
    - The combustion safety assessment led KCHA to pursue direct vent equipment to replace the existing furnace and water heater.
    - No water heater storage tanks could be found to fit in the utility closet (7 ft × 3 ft) and leave room for a separate space heating system, leading to the choice of a boiler, combining space and water heat.
    - Deciding to use the condensing boiler for space and water heat also had challenges. Initially, the smallest unit KCHA staff found was listed with a capacity of 200 kBtu/h. Not only was this twice as much as was needed, but the gas piping at Newporter was sized for a much smaller load (existing furnace

capacity of 60 kBtu/h). The solution selected had its capacity adjusted (by the manufacturer) from 200 to 100 kBtu/h.

- The use of the boilers (on demand) also limited hot water flow to 3–4 gpm. Even with the addition of low-flow water appliances, Newporter residents have had to adjust their lifestyle habits accordingly: "They don't shower and run the dishwasher at the same time." If KCHA chooses to retrofit the gas piping in the future, the system capacity can be readjusted, which could allow for more hot water flow.
- The use of a direct vented boiler meant that the combustion air needed to be supplied from and vented to the outside. KCHA staff decided to use the existing 8-in. metal sleeves to run the combustion supply and exhaust.

- The window retrofit was quick and easy, and coordinated well with the installation of the Roxul sheathing.
  - The Roxul did not provide structural integrity as backer for the window flange and fastening. A strip of extruded polystyrene was installed around the window, and the Roxul was butted up to that.
  - Doing the windows with the wall retrofit saved costs and resulted in a better thermal package.
- The wall retrofit was considered very successful by KCHA staff, though it required a fair amount of supervision and explanation to contractors.
  - Infrared thermography proved to be very useful in identifying insulation anomalies (see Figure 6).
  - KCHA had a lot of experience with the use of dense pack cellulose, though this was the first time that one of its projects used an exterior sheathing. Because the re-siding was part of the window replacement, it was an ideal time to install the sheathing. The integrated package created synergies. In addition, the Newporter project was a good candidate for this approach because it did not have a lot of angles or alcoves.
  - The sheathing eliminates thermal bridging. This eliminates cold spots where water can condense and lead to mold growth.
  - KCHA staff highlighted the need to coordinate among multiple subcontractors, some of which do not consider weatherization a priority.
  - In the end, the major question for KCHA staff is not whether to use the exterior sheathing in future projects, but how much: "The biggest question is whether we do 1 in., 1½ in., or 2 in."
- The existing exhaust fans did not meet the low-income weatherization program specifications, so they needed to be replaced.
  - The existing fans were chain-switch operated; additional wiring was necessary to convert them to wall-switch control.

- Because the existing fan duct runs were long, there was some concern that the new fans would be challenged to meet the flow requirements, but under testing, they met requirements.

- All lighting was retrofitted to an ENERGY STAR alternative, primarily GU24 compact fluorescents, though some LED lighting was also installed.
    - The existing incandescent fixtures were rated for 75-W lamps, but in many cases, residents had installed 100-W lamps, burning the insulation off the wiring. In addition to fixture replacement, contractors spent a fair amount of time re-insulating the wires. This work was included in the lighting contractor's unit costs.

Before the retrofit, KCHA staff estimated that more than 50% of the occupants had complaints about comfort and drafts. Following the retrofits, KCHA staff said that the feedback was overwhelmingly positive (no more cold and draft complaints), with a few complaints about inadequate hot water supply.

KCHA staff are also very satisfied with the project. Highlights include the use of the boiler combination water and space heating, and the use of Roxul fiber board.

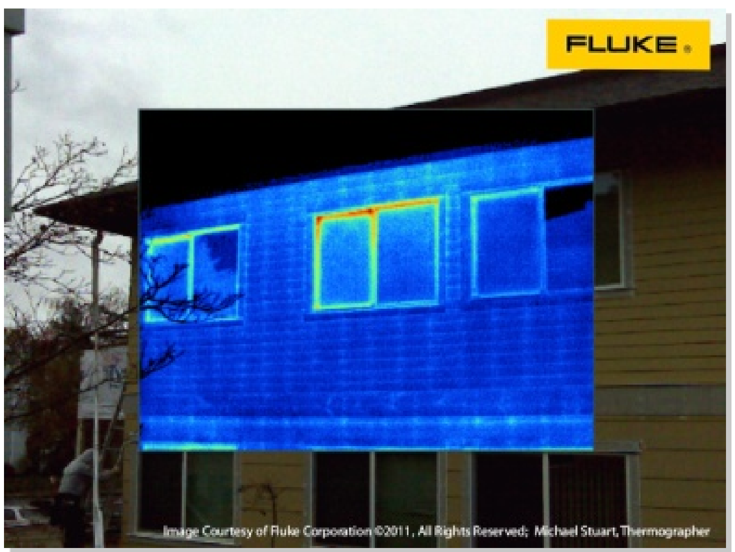

Figure 6. Infrared scan of wall assembly post-retrofit

5 Conclusions

This project raised confidence in energy savings model predictions via utility data true-up. Anticipated gas savings, modeled and trued up with utility data, met expectations; savings associated with electric usage did not.

The model predicted electrical baseload energy savings of 37,800 kWh/yr for the building analyzed. The measured electricity savings were 4,016 kWh/yr; only 10.6% of the model's prediction. This discrepancy cannot be explained without further investigation into such factors as the quality of usage data received from the utility, and whether the billing includes shared areas, occupancy behavior, and baseline assumptions. The model predicted natural gas savings of 3,799 therms/yr. This compared to the measured energy savings of 4,633 therms/yr, or $4,846 at $1.046/therm.

Overall, the total measured savings for Building A post-retrofit is 477 MBtu/yr or $5,179 (approximately $143.86 per apartment annual savings) at current gas and electric utility rates. Source energy savings were 552 MBtu/yr. Feedback from KCHA quality assurance staff suggests that the use of infrared thermography was especially useful for assessing dense pack wall insulation.

The research effort seeks to maximize the cost effectiveness of each measure and strategy by employing a systems engineering approach to DERs, implemented during substantial rehabilitation of typically low-income occupied rental units. At the same time, the research has identified low SIRs (less than 1) for the package, if all of the costs associated with the measures are to be subsidized by energy savings. For the project to have achieved an SIR of 1, the incremental cost of the project would need to be reduced from $312,928 for the building analyzed here, to approximately $132,065. When incentives are included, however, the SIR increases to greater than 1 in most cases.

Note that other, nonenergy savings benefits, although not included in an SIR calculation, are associated with these retrofits, including the following:

- Health and safety, including combustion safety, and indoor air quality
- Deferred maintenance associated with appropriately retired space and water heating equipment, appliances, and lighting, as well as the outdated windows
- Occupant comfort; complaints were significantly reduced
- Durability improvement; Roxul sheathing and rain screen reduced condensation in the wall and protected against bulk-driven moisture. Adding a whole-house ventilation system and improved windows will also reduce condensation.

The successful demonstration of this effort is scalable to other communities owned by KCHA and other public housing authorities in Washington State in need of retrofits to the envelope and systems.

The research can help inform efforts in improving BA and state weatherization guidelines in multifamily projects throughout the Northwest region.

6 Recommendations

The timing of a DER is crucial. In this project, KCHA was able to integrate the energy efficiency measures as part of a substantial renovation process. Coordination of these retrofit efforts, involving occupied units, was successful, though more challenging. This project also demonstrated the value of combining housing authority renovation and energy improvement funding.

For combined low-income weatherization and renovation projects, SIR should not be the only consideration. Other considerations must be factored in, including comfort, health, and safety. In addition, this approach helps to avoid future maintenance crises and extends the useful life of the project by avoiding the high cost of new construction.

An upfront investment in the project design phase, incorporating a systems approach, produces synergies that improve performance and reduce lost opportunities typical of one-at-a-time measure approaches.

Investing time and effort into on-site project management, quality assurance, and training of contractors significantly improved installation of energy efficiency measures. Specific areas include the following:

- Pre-retrofit characterization, including combustion safety testing, exhaust fan flow rates, and occupant and other stakeholder feedback associated with comfort and indoor environmental quality
- Technical support and training of staff to assist in the verification of dense-pack wall insulation, using thermography during the installation process
- Measurement and commissioning of HVAC equipment after installation.

Verification of modeled energy use with actual pre- and post-retrofit billing data is critical to assessing the value of the overall package and individual measures. This can yield valuable feedback for future DERs.

7 Future Research Opportunities

Additional slab and roof insulation retrofits are scheduled for 2013–2014. Evaluation and implementation of these retrofits are additional opportunities for continued BA research.

Further investigations into the discrepancy between the modeled and measured electrical baseload savings are warranted. Identifying the contribution of HVAC fan and pump energy, lighting use characterization, and how the utility billing data were provided to researchers may reduce this discrepancy.

Occupied units complicate the logistics for implementing DERs. KCHA has other unoccupied communities slated for gut rehab, where the potential for additional BA support for even deeper energy retrofits could exist.

BA research into the development of climate-specific DER packages might provide prescriptive alternatives where resources for the implementation of modeling and billing analysis are limited.

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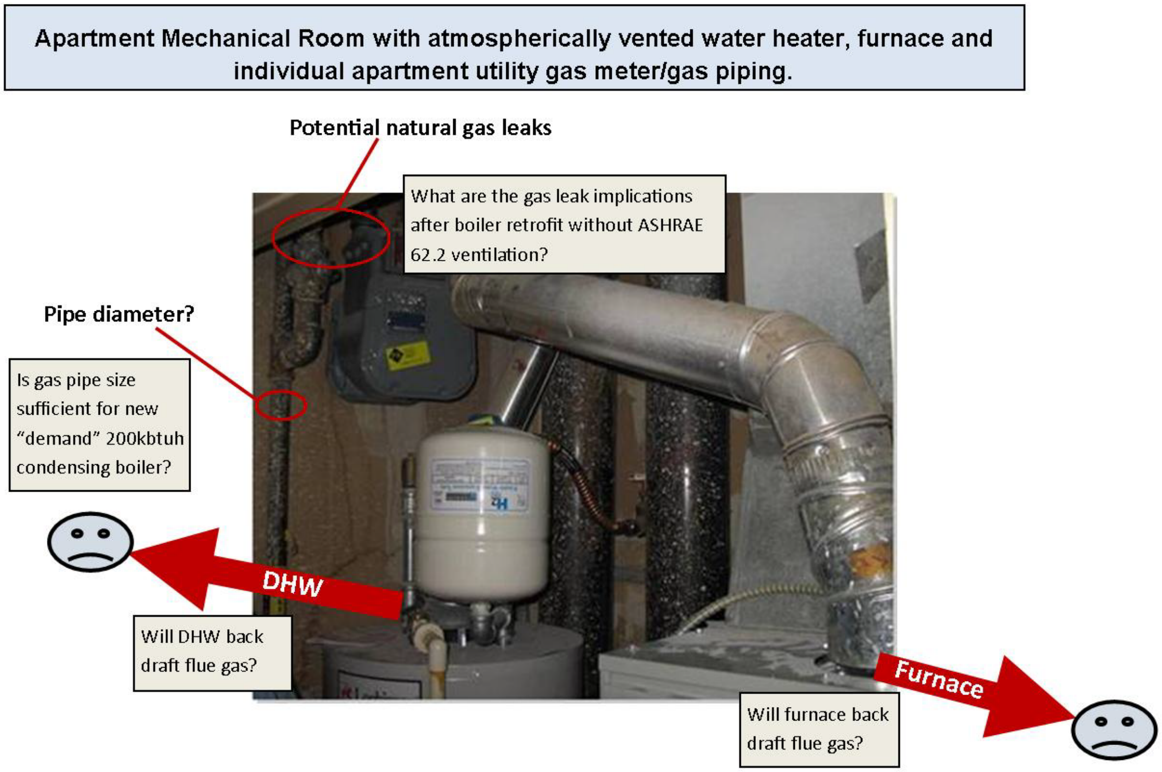
Appendix: Newporter Combustion Safety Testing Report



Description of Issues and Resolutions:

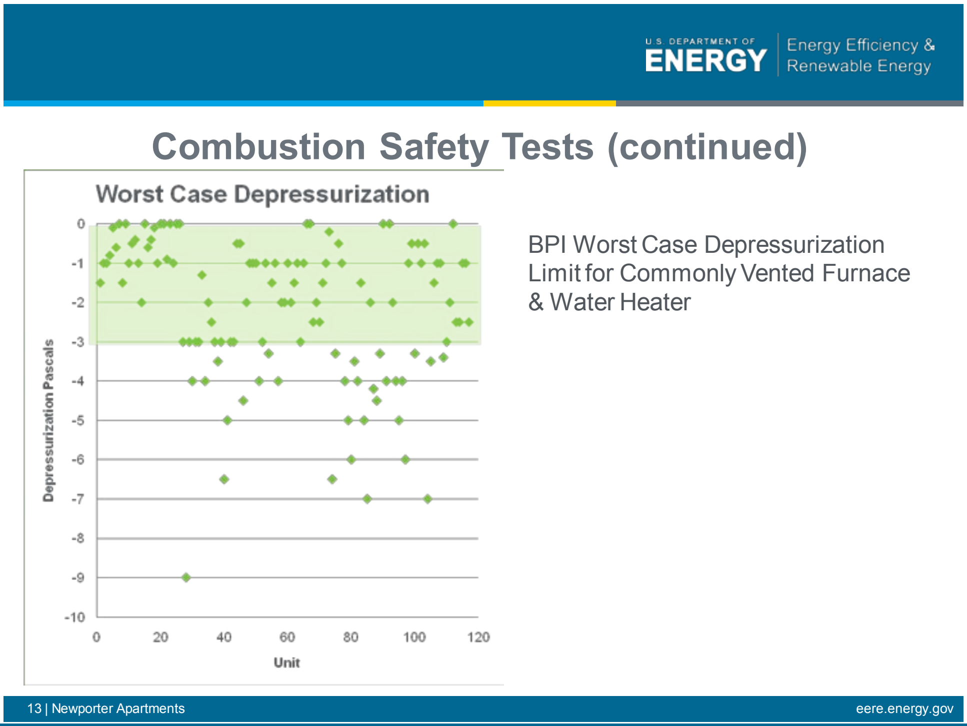
Combustion Appliance Zone (CAZ) tests in graphs below suggest: 1) appliance flue back drafting potential, 2) high carbon monoxide concentrations in flue gas, and 3) natural gas leaks associated with the individual apartment mechanical room gas piping and gas meters. Proposed deep energy retrofit of building envelope, including; dense pack foam walls, exterior house wrap and 1" insulated sheathing, are likely to increase the tightness of the apartments, and further increase flue back drafting potential, and higher concentrations of indoor air pollutants. To avoid back drafting problems and to further reduce space and water heating energy usage, a new sealed combustion combination space heater and demand DHW boiler was installed in each apartment. The smallest available condensing boiler for this product line available was 200KBTU, which is twice as large as required for the apartment hot water fixture demand and space heat demand at design temperature, and there were concerns that the existing gas piping may not be large enough. To address these concerns the boiler manufacturer de-rating the equipment to 100kbtu and re-listing it for code approval. The de-rated boiler was able to operate using the existing gas pipe diameter, originally sized for a 60kbtu furnace and standard DHW storage water heater.

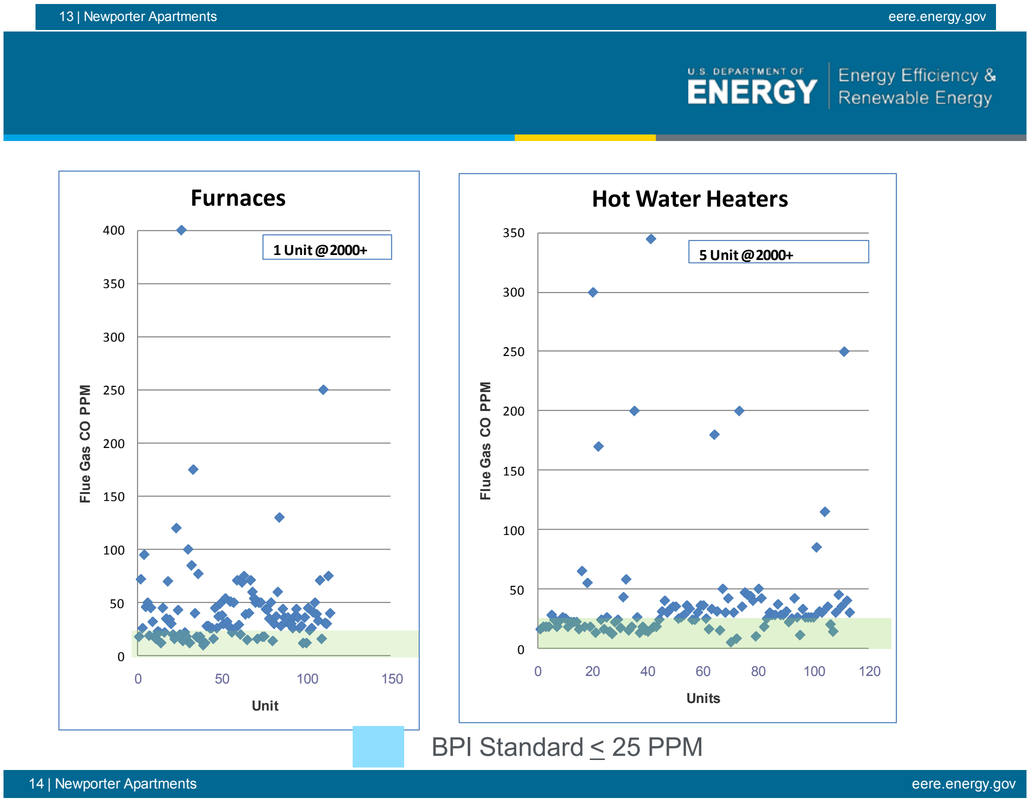
Another concern was the minor gas leaks found in 10% of mechanical rooms during the pre-retrofit CAZ testing of the mechanical room. Envelope tightening measures and retrofitting of sealed combustion equipment reduce infiltration rates, leading to potentially higher incidents of gas leaks. To address these IAQ issues, ASHRAE 62.2 compliant low-sone, whole house exhaust only ventilation systems were designed and installed to provide acceptable ventilation rates in each apartment. The ventilation system runs continuously on low speed without occupant control, and controls allow occupant to increase flow rates for bathroom spot ventilation.

Example Description of Potential Error(s):

Each apartment had a mechanical room as shown in the photo, with atmospherically vented natural gas water heaters and furnaces, individual utility gas meters and 1" supply gas lines. The contractor proposed to install a variety of retrofit wall measures that will tighten up the building envelope, including energy efficient "tighter" windows, and a combination of the following wall measures: 1) dense pack walls 2) continuous weather resistant membrane (WRP) 3) RoxUL insulated sheathing 4) new siding 5) wall penetrations sealed and 6) installation of continuously operated whole house/bathroom exhaust fans. Prior to retrofit, a contractor conducted a series of combustion safety tests of gas piping, furnace flue and DHW flue, in each of the 118 apartment units. The results were as follows:

- 9% of DHW and 10% of furnaces had combustion flue spillage
- 8% of DHW and 6% of furnaces had worse case CAZ test depressurization below -5 PA
- 11% of DHW and 17% of furnaces had flue drafts above -1.0 PA
- 17% of DHW and 29% of furnaces had CO levels in flues gas greater than 50 PPM
- Observation of gas leaks 10% of units, typically located near the gas meter/piping.





Description of Implementation Errors:
There would have been greater potential combustion safety and indoor air quality issues, had the BA team not addressed CAZ testing issues by: 1) replacing low

efficiency atmospherically vented mechanical equipment with correctly sized high efficiency sealed combustion and 2) installing ASHRAE 62.2 compliant ventilation.

Risks:

- Considerable potential health and safety risks from increased occupant exposure to combustion flue dangerous byproducts such as carbon monoxide, etc. from back drafting.
- Considerable potential health and safety risks from reduced mechanical room ventilation/infiltration may increase the concentration of natural gas in the mechanical room resulting from any future leaks of the gas piping.

Required Corrections:

- Installation of sealed combustion DHW and furnace
- Installation of ASHRAE 62.2 compliant ventilation
- Installation of CO alarms in mechanical rooms
- Identification of any future natural gas piping leaks and occupant IAQ related issues

Applicable or Potential Guideline Documents:

- BPI combustion safety protocols; flue spillage, CAZ worst case, flue draft, gas leakage
- Manufacturer manual to ensure furnace heat rise within specifications
- UMC and manufactured gas piping sizing manuals and codes for demand boilers, requiring high gas flow rates

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DOE/GO-102012-3760 ▪ December 2012

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