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Cascade Apartments: Deep Energy Multifamily Retrofit

A. Gordon, L. Mattheis, R. Kunkle, L. Howard, and M. Lubliner
Washington State University Energy Program
BA-PIRC

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Prepared by:

A. Gordon, L. Mattheis, R. Kunkle, L. Howard, and M. Lubliner

Washington State University Energy Program

for

BA-PIRC

1967 Clearlake Road

Cocoa, FL 32922

NREL Technical Monitor: Stacey Rothgeb

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Definitions

ACH_n	Air changes per hour (natural)
BA	Building America
CFM	Cubic feet per minute
DHW	Domestic hot water
DOE	U.S. Department of Energy
ERV	Energy recovery ventilator
gpm	Gallons per minute
h	Hour
IAQ	Indoor air quality
IC	Insulated Contact
KCHA	King County Housing Authority
kWh	Kilowatt-hour
PSE	Puget Sound Energy
RH	Relative humidity
SHGC	Solar heat gain coefficient
SIR	Savings-to-investment ratio
TMY3	Typical Meteorological Year 3
TREAT	Targeted Retrofit Energy Analysis Tool

Acknowledgments

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Executive Summary

In 2009-10, KCHA implemented energy retrofit improvements in the Cascade multifamily community, located in Kent, Washington (marine climate.) The improvements, implemented in 108 (27 fourplexes) multifamily units included:

- Innovative dense packing insulation to the existing R-7 wall insulation for a combined value of R-14 (nominal). Also added dense pack insulation to R-4 rim joist areas for a combined value of R-14.
- Air sealing attics, and then adding 4 in. of cellulose to the existing insulation for a combined value of R-38.
- Removal and replacement of older double pane aluminum windows (U = 0.75, solar heat gain coefficient = 0.68) with new ENERGY STAR® vinyl windows (U = 0.30, solar heat gain coefficient = 0.30).
- Aggressive air sealing in conjunction with replacement of insulation and window replacement, resulting in a reduction in air leakage from 5.85 ACH_{50} to 3.38 ACH_{50}.
- Removal of failing R-19 insulation in the crawlspace air sealing and reinsulating to R-30.
- Replacement of older wood doors (U = 0.56) with insulated, code-compliant doors (U = 0.20).
- Converted existing KCHA-controlled whole-house exhaust bathroom fan running 8 h/day to occupant-controlled intermittent bath ventilation.
- Installed a KCHA-controlled continuously operated small single supply/exhaust energy recovery ventilator (ERV) in main living area, as the new whole-house ventilation system.
- As needed, additional retrofit of showerheads, aerators and compact fluorescent lamps (screw-in), provided at no cost to KCHA by the Washington Conservation Corps.

This research effort involved significant coordination from stakeholders KCHA, Washington State Department of Commerce, utility PSE, and Cascade tenants. Funding from KCHA's capital improvement budget combined with state low-income weatherization funds and utility incentives to leverage the retrofit efforts; these additional resources improved the cost effectiveness of KCHA's investment.

Washington State University worked with KCHA to assist in:

- Determining retrofit measure options with the Targeted Retrofit Analysis Tool (TREAT)
- Installing and quality assurance inspections of retrofit measures
- Utility billing analysis comparing 2 years of pre-retrofit with 1 year of post-retrofit data
- Field testing employing multiunit blower door testing and thermal imaging
- Monitoring temperature and relative humidity in a sample of units identified by KCHA with pre-retrofit moisture issues.

This report focuses on the following three primary BA research questions:

1. *What are the modeled energy savings using DOE low-income weatherization approved TREAT software?*

   TREAT estimated annual savings were 3,730 kWh per apartment, or $392 ($23/month) at the utility rate of $0.105. Whole-building (three-bedroom fourplex) site energy savings were 14,918 kWh/year, 30% compared to pre-retrofit (Table 5). Total estimated source energy savings are 50,198 kWh/year per building based on national source energy factors. While the two-bedroom units were not modeled, if one assumes similar savings for those units (an assumption borne out in the utility regression analysis), total modeled site savings for the 100 units in the Cascade community are 372,950 kWh/year; total estimated source energy savings are 1,254,976 kWh/year.

2. *How did the modeled energy savings compare with measured energy savings from aggregate utility billing analysis?*

   The utility billing analysis suggest total annual savings of 10,600 kWh per fourplex for the three-bedroom units, and 10,776 kWh per fourplex for the two-bedroom units, for an average of 10,691 kWh/year, a 22% reduction. While the overall savings is 71% of the predicted TREAT savings, the utility billing analysis suggests significant savings from the retrofit measures, with the majority of the savings (85%) coming from heating energy use.

3. *What is the Savings to Investment Ratio (SIR) of the retrofit package after considering utility window incentives and KCHA capital improvement funding?*

   Energy retrofit measure cost data were collected to determine the cost effectiveness of individual measures and the retrofit packages as a whole for the three-bedroom fourplex prototype. TREAT analysis indicated that the SIR varied considerably depending on whether or not utility incentives and capital improvement funds were leveraged. The SIR improves considerably if utility incentives and capital improvement funds associated with window and door replacements and Americorp contributions are not considered in the calculation.

   The full estimated cost of the energy saving retrofits was $26,234 per fourplex, and $655,850 for the entire community (does not include measures installed by the Conservation Corps). Of that figure (entire community), PSE contributed $67,321 for windows, and KCHA contributed $202,678 from its Capital Improvement Fund ($34,375 for doors, $168,303 for windows). The incremental costs associated with the DOE low-income weatherization funds were assumed to be $385,850 for the whole community, or $15,434 per fourplex.

   By combining capital improvement funds and utility incentives, KCHA was able to utilize weatherization funds to make the needed improvements, while achieving an SIR of greater than 1. Without PSE window incentives, the SIR was 1.02. With the PSE window incentive, the SIR increased to 1.17. If the KCHA window and door costs are removed from the calculation (arguably justified because window retrofit was implemented due to the failure of the existing windows) the SIR increases to 1.67—this is in effect the SIR for all DOE weatherization funded measures.

Additional benefits to the KCHA and the Cascade Apartments occupants include the use of capital improvement funds in order to extend the useful life of the buildings, avoid the cost of new construction, and reduce the impact on occupants (no occupants were displaced during the retrofits). Based on KCHA staff and occupant feedback before and after the retrofits, overall indoor air quality improved with the installation of the ERVs and education on their use. Each unit realized approximately $23 in monthly utility savings; these savings will continue throughout the life of the units.

Determination of SIRs for individual retrofit measures was not possible because there is no established methodology for identifying the contribution to reduced air leakage from dense wall pack insulation, window retrofits, or door retrofits (distinct from savings associated with reduction in conductive heat loss). Assigning air leakage reductions to insulation, window retrofits, and door retrofits in multifamily apartments is a key area for future work, in order to better assess the SIR of the individual measures.

1 Introduction and Background

Cascade is a low-rise multifamily community located in the marine climate of Washington State, and owned and operated by Building America (BA) partner the King County Housing Authority (KCHA). Built in the 1960s, the community is a complex of 25 two-story apartment buildings and two one-story apartment buildings. Each building has four apartments for a total of 108 units. The buildings are wood framed with pitched roofs and vented crawlspaces. The units are all electrically heated with zonal baseboard heat controlled by wall-mounted thermostats, and all units have 50-gal electric water heaters (note—these were not changed during the retrofits). None of the units have air conditioning.

Cascade is an ethnically diverse community, with members originating from Russia, Sudan, Ethiopia, and various cultures throughout the world. This leads to challenges in conveying instructions on operating the equipment as intended and the ability of occupants to accurately convey complaints or reservations concerning building operations. The energy retrofits sought to address several deficiencies including excessively high utility bills and moisture levels, conditions that directly impacted the financial and physical health of the community members.

Figure 1. Cascade Apartments

2 Modeling Methods

2.1 TREAT Analysis

In the design phase, the project collected energy efficiency measure cost information, in order to assess energy savings using an energy simulation software called TREAT (TREAT is an acronym for Targeted Retrofit Energy Analysis Tool) (Performance Systems Development Consulting, 2012).

The U.S. Department of Energy (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. TREAT is utilized by the low-income weatherization providers on multifamily projects as required by Washington State Department of Commerce, to access state funding 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 Program could not be used to assess complex multifamily structures such as Cascade (National Renewable Energy Laboratory, 2012), (Kruis, Christensen, & Wilson, 2011). TREAT also provides 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. No true-up of the space heating use was required, since it was within 10% of utility data based on TREAT true-up procedures. The TREAT file pre-retrofit energy use was "trued up," on the base load by adjusting the domestic hot water (DHW) use assumption from 17 gal/day/person to 15 gal/day/person. Researchers adjusted the TREAT pre-retrofit and post-retrofit models to better reflect findings from field inspections; blower door tests heating, ventilation, and air conditioning audits; and monitored temperature data.

Based on monitored temperatures on a subsample of homes (see Section 3.2 and Appendix A), the thermostat setting was assumed to be 68°F with 8-hour setback. For the TREAT analysis, researchers determined reasonable air leakage rates to be 0.29 ACH_n pre-retrofit and 0.17 ACH_n post-retrofit, based on field testing (see Section 3.1). This testing at Cascade is part of an ongoing BA research effort into determining envelope leakage rates in attached dwellings employing multiple blower doors (Griffiths, 2012), (Faakye, Arena, & Griffiths, 2013).

2.2 Utility Billing Analysis

Electric utility bills were obtained from Puget Sound Energy (PSE) through KCHA. Two sets of data were obtained for all the two-bedroom units (combined 52 units in 13 fourplexes) and all the three-bedroom units (48 units in 12 fourplexes) for January 2007 to July 2012. For the utility bill analysis, researchers focused on the 2 years prior to the start of the energy efficiency retrofits (December 2008 to November 2010) and the 11 months after the retrofit (September 2011 to July 2012).[1]

To account for the influence of weather on heating electricity use, electricity use was normalized to typical temperature conditions (Typical Meteorological Year 3 [TMY3]). Regression models of electricity use and degree days were developed for the pre- and post-retrofit periods for the two- and three-bedroom units. The degree day temperature base was varied for each of the four cases to obtain the best model.[2]

[1] The retrofits were completed in September 2011. Since the retrofits were done one building at a time, most of the buildings had been retrofitted by September 2011, so we are including it in the post period to increase the number of post-period months. Researchers do not think this has a significant impact on the results. If anything it would tend to slightly reduce estimated savings.

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

3 Data Collection Methods

3.1 Energy Audits

Energy retrofit measures were selected after conducting energy audits on the units at Cascade Apartments. These audits, conducted by KCHA staff, included multipoint blower door tests, assessing existing insulation, and observing moisture-related issues present in the units. These audits also included the use of BA partners' tools such as the Fluke Ti32 Thermal Imaging equipment and software and The Energy Conservatory blower doors and TECHLOG2 software. These audits are described in detail in Appendix B.

The results of the "guarded" multiunit blower door test are displayed in Table 1 for one representative fourplex, where all blower doors are running at the same time—this test measures only the leakage to the exterior for each unit. Table 2 shows results for "solo" (unguarded) blower door tests conducted for each individual unit (all units are end units, without other doors operating—this test measures both the leakage to the exterior and leakage between units). TECHLOG2 files are provided in Appendix B for the example fourplex in Tables 1 and 2. Further BA investigations with larger datasets are underway to evaluate the impact of using guarded or solo blower door tests for savings-to-investment ratio (SIR) analysis, and the larger implications for energy and indoor air quality (IAQ) (Griffiths, 2012), (Faakye, Arena, & Griffiths, 2013).)

Table 1. Whole-Building "Guarded" Blower Door Testing Results

	Pre	Post	Reduced
CFM_{50}	3,339	1,926	1,413
ACH_{50}	5.85	3.38	2.47
ACH_n	**0.29**	**0.17**	**0.12**

Table 2. Individual Unit "Solo" Blower Door Testing Results

Unit	CFM_{50}			ACH_{50}			ACH_n[3]		
	Pre	Post	Reduced	Pre	Post	Reduced	Pre	Post	Reduced
101	929	619	310	6.38	4.25	2.13	0.30	0.20	0.10
102	904	721	184	6.20	4.95	1.26	0.30	0.24	0.06
103	932	575	357	6.40	3.95	2.45	0.30	0.19	0.12
104	896	587	309	6.15	4.03	2.12	0.29	0.19	0.10
Sum	3,661	2,502	**1,160**	6.42	4.38	2.03	0.31	0.21	0.10

[3] Researchers determined ACH_n by multiplying the CFM_{50} by 60, then dividing that result by the product of the volume and an "n-factor." The n-factor used here was 21 (two-story, zone 3, shielded), using original methodology from Lawrence Berkeley National Laboratory based off the Lawrence Berkeley National Laboratory mode, a typical approach used by low-income weatherization programs (RES_Energy_V5).

The reduction in leakage for the "guarded" test was 0.12 ACH_n; for the "solo" test, the reduction was 0.10. For the purposes of this analysis, the end results of "guarded" versus "solo" testing are similar enough that the use of either in the TREAT analysis is expected to produce similar SIR for Cascade. The impact of air leakage test methodologies may have a more significant impact on other projects, and requires additional research.

3.2 Data Logging

Onset HOBO data loggers were installed in 12 units throughout the Cascade community. The units were selected primarily on the basis of moisture complaints. The data loggers recorded temperature and relative humidity (RH) levels at hourly intervals during the post-retrofit period beginning on February 1, 2012 through September 13, 2012. Analysis of the data recorded by the data loggers shows the interior temperature for the most part fluctuating in response to the outside temperature. The temperature information collected from the data loggers was used to help inform researchers about TREAT thermostat set point adjustments. The RH data provide some indication of the ability of the energy recovery ventilators (ERVs) to control humidity and provide insight into potential impacts of occupant lifestyle on RH levels (see Section 7 and Figure 9.)

4 Description of Retrofit Package

Working with local contractors, KCHA proposed nine retrofit measures designed to reduce energy consumption, increase comfort, improve IAQ and sound attenuation, increase building durability, and contribute toward community longevity.

Table 3 lists the retrofit measures proposed and installed in the Cascade community, the source of funding for the improvement measure, and the cost associated with that improvement. Note that the air sealing improvements were associated with the attic wall and rim joist insulation improvements, and the costs for air sealing are included with those measures.

Table 3. Estimated Energy Retrofit Measures Based on KCHA Costs per Measure

Measure	Funding	Pre-Retrofit	Post-Retrofit	Square Feet per Component	Cost per Fourplex
Air Seal and Insulate Attic	DOE Weatherization	R-38 (nominal)	R-38 (added 4 in.)	4,395 ft^2	$2,901 $0.66/$ft^2$
Dense Pack Walls	DOE Weatherization	R-7 (initial instal.)	R-14	4,360 ft^2	$6,192 $1.42/ ft^2
Dense Pack Rim Joist (Cantilever)	DOE Weatherization	R-4 (uninsul.)	R-14		$290 $2.10/$ft^2$
Install ENERGY-STAR® Windows	KCHA PSE	Double pane aluminum, no thermal break U-0.75[4]	Vinyl low-e + argon U-0.30		$9,425[5] ($21/ft^2 without PSE incentive)
Reinsulate Floor	DOE Weatherization	R-19 (nominal—poor condition)	R-30		$3,456 $0.79/$ft^2$
ERV (1 per Apartment)	DOE Weatherization	8 h @60 CFM; 0% efficiency	24 h @40 CFM (23 W); 66% efficiency	NA	$2,595[6] $649/unit
Doors (5 Total)	KCHA	U-0.56	U-0.20		$275/door

[4] Default U-value from 2012 IECC/Washington State Energy Code for a double-pane aluminum frame window with greater than ½-in. gap, low-e and argon fill (Washington State Building Code Council, 2012).
[5] Funding for the window replacement came from PSE ($6/$ft^2$).
[6] Does not include cost of asbestos removal as part of ERV installation.

Measure	Funding	Pre-Retrofit	Post-Retrofit	Square Feet per Component	Cost per Fourplex
DHW 100% Low Flow Sink Faucets/Aerators and Shower Heads	Conservation Corps	As found	100%—1.5-gpm shower heads and 0.5-gpm sink aerators_		$0[7]
Lighting	Conservation Corps	As found	Compact fluorescent lamps		$0[7]
Total Cost					$26,234 ($6,558/unit)

Source: KCHA

4.1 Attic

The existing Rockwool insulation was moved aside to identify opportunities to air seal and address any structural issues existing in the attic (see Figure 2). Once air sealing was complete, the displaced Rockwool was returned to its original place and topped off with 4 in. of blown-in cellulose for an overall rating of R-38.

During the process, it was discovered that boxes had been built around existing non-insulated contact (IC) light fixtures, pictured in Figure 3. These areas had no air sealing. The non-IC rated heat lamps were removed and replaced with airtight, IC rated Marley heat lamps.

Figure 2. Attic floor during and after retrofit

[7] Conservation Corps provided DHW fixtures and lighting at no cost to KCHA.

Figure 3. Non-IC rated light fixture (left); IC rated Marley heat lamp (right)

4.2 Walls

The original insulation installed in the wall cavities was a nominally rated R-7 foil-faced batt fiberglass batts (in a 2 × 4 wall), as shown in Figure 4. The existing insulation degraded over time, leaving many avenues for convective heat loss and a reduced capacity to reduce heat loss via conduction.

Figure 4. Foil-faced batt fiberglass wall insulation

KCHA chose to dense-pack the wall cavities with cellulose insulation, which reduces both convective and conductive heat loss, installed at a density of 3.5 lb/ft^3. The practice of dense-packing multifamily buildings is beginning to become more common for KCHA multifamily projects such as Newporter Apartments (Lubliner, et al., 2013).

Contractors working at Cascade initially did not believe dense-packing was a viable option. KCHA staff selected a contractor (Arrow Insulation) experienced in dense-packing and blower door testing multiunit buildings. Arrow Insulation is also working with PSE on a large-scale multifamily research project involving the installation of dense-pack insulation. These installations will be evaluated for their air-sealing benefit using "guarded" blower door tests (Puget Sound Energy, 2013). The installation of the dense-pack is shown in Figure 5.

Figure 5. Installation of dense-pack cellulose wall insulation

Other retrofit projects implemented by KCHA, including Newporter Apartments, included the installation of rigid foam board beneath the replacement siding, providing additional insulation and protection from water intrusion. In the case of Cascade, a combination of funding, logistics, and timing proved too large an obstacle to surmount, leaving the Cascade buildings without foam board installed beneath the exterior siding.

4.3 Crawlspace and Cantilevered Floors

The existing insulation found in the crawlspace and floor cantilever areas was found sagging against the securing cord in places, with numerous voids in the cavity. In addition, the insulation was host for organic growth. The existing R-19 insulation was removed and replaced with new R-30 insulation. Removal of the old insulation facilitated locating and sealing numerous air leaks in the floor cavity.

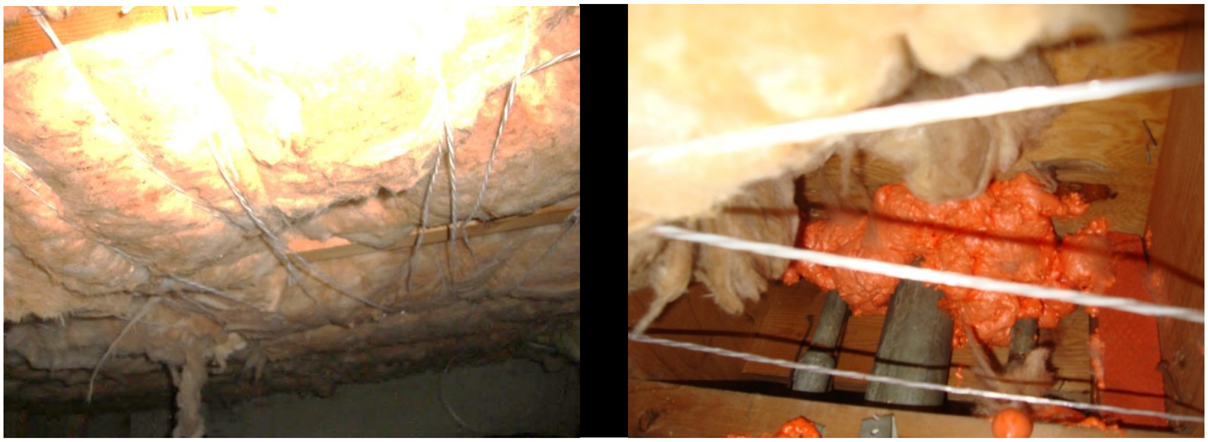

Figure 6. Crawlspace insulation pre-retrofit (left) and post-retrofit (right), with air sealing detail

4.4 Ventilation

Prior to the retrofit, a Panasonic Whispergreen exhaust fan acted as the whole-house ventilation system for each unit. This fan was located in the second-floor bathroom and hardwired to run 8 h/day at an average (measured) flow rate of 62 CFM (flows ranged from 13 to 82 CFM). Controls for the fans were covered with a blank faceplate to prevent tampering by the occupants. As part of the retrofit, these fans were converted to occupant-controlled spot ventilation fans, utilized to remove moisture and other pollutants associated with the upstairs bathroom.

During the retrofit, KCHA installed Panasonic Whisper Comfort ERVs in the main living area of each unit, open to the kitchen (see Figure 7). These ERVs are set by the housing authority to operate as a continuously operating whole-house ventilation system with an energy recovery rate of 66%. The nonvented range hood was not replaced in the retrofit due to cost and logistic constraints. Locating the ERV in main living area improves IAQ for the occupants by diluting particulates associated with cooking. These particulates are known to have health impacts.

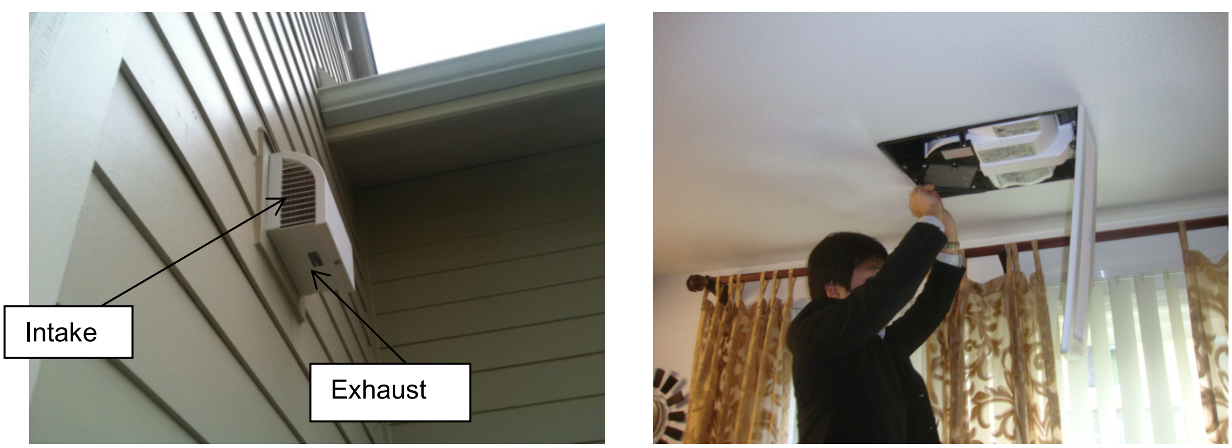

Figure 7. Exhaust/intake grille of ERV (left); a Panasonic representative inspects the ERV (right)

4.5 Windows

Double-pane, non-thermally broken aluminum frame windows (installed in the mid 1980s) were removed from the buildings in the Cascade community and replaced with ENERGY STAR-certified, vinyl-framed, double-pane, argon-filled windows, with a U-0.30 rating and solar heat gain coefficient (SHGC) of 0.30. While these windows provided gains in energy efficiency, they also addressed another IAQ issue by eliminating a thermal bridge in the aluminum frame of the old windows. During cold weather the aluminum frame became colder than the inside air, contributing to condensation on the surface and leading to some mold growth. Because the vinyl frames reduce thermal bridging, window condensation and mold growth are greatly reduced according to KCHA.

The windows installed during this retrofit include trickle vents, due to code requirements (the ERV was not centrally ducted); observations from KCHA suggests that residents are not using them. This is not uncommon in Washington State, regardless of the necessity of inlet vents (Gordon, Lubliner, Michael, Howard, & Kunkle, 2013).

As noted in Table 3, the windows were paid for as part of KCHA's capital improvement budget as well as utility incentives.

4.6 Doors

Cascade received new exterior doors as part of the retrofit. The existing doors, paper honeycomb core without a thermal break, were replaced by new doors with a solid urethane foam core and thermal break. The insulation level of the existing doors were assumed to be roughly R-1.8; the new doors were rated at R-5. Similar to the windows, the door purchase was funded by the capital improvement budget.

5 Savings-to-Investment Ratio Analysis

Cost data were collected from the contractors performing the retrofit work at Cascade. These data were then integrated into an SIR calculation, using TREAT. In TREAT, SIRs of greater than 1 are indicative of economically cost-effective weatherization measures. In this model, SIR calculation assumptions 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 DOE/Department of Commerce low-income funding for weatherization measures, KCHA was required to show an SIR of greater than 1 for the entire package. KCHA's SIR analysis looks at SIR based only on the amount of DOE funding contributed to the project. It does not account for all building renovation costs, as some renovations were not made for energy savings or funded through weatherization grants or incentives. Table 3, above, provides the source of funding for all retrofit measures and their associated costs.

TREAT performs two energy usage estimations, modeled analysis and billing analysis. Modeled analysis produces an estimated energy usage figure based solely on building and environmental input (location, appliances, dimensions, contruction material, air leakage, etc.). Billing analysis uses the same inputs but adjusts the space heating and/or baseload to reflect actual usage as shown through utility billing data, which is uploaded into TREAT. This process is called *truing up*. These numbers are then normalized to TMY3 data.

Building America researchers conducted three distinct sets of TREAT runs for SIR calculations. In all cases, the TREAT runs assume the energy savings for the entire retrofit. The three distinct cost scenarios were as follows:

1. Only the costs associated with the DOE-funded measures—wall, floor, and attic insulation, and the ERV.
2. All the above costs, plus the window and door replacement costs.
3. All the above costs, less the incentives from PSE.

From the housing authority perspective, it is not appropriate to include the leveraged KCHA and utility incentives in the SIR analysis. Following this assumption, the researchers assume that the energy cost of these measures is zero.

The SIR results are shown in Table 4.

Table 4. SIR Results

SIR Without PSE Incentives	1.02
SIR With PSE Window Incentive	1.17
SIR With No Window and Door Costs	1.67

6 Results

6.1 Utility Billing Regression Analysis

Figure 8 shows the total monthly electricity use for all units in Cascade.

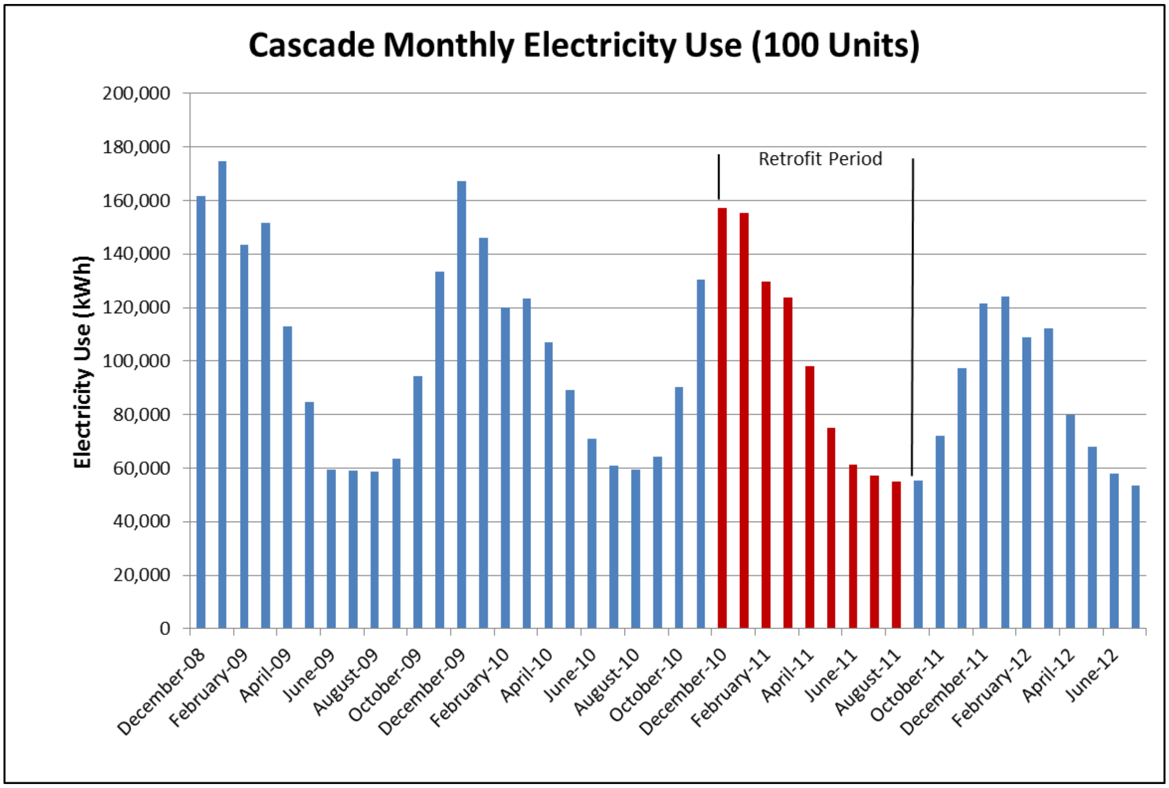

Figure 8. Monthly electricity use for all units in Cascade

There is approximately a 20% decline in the utility bills for the year following the retrofit.[8] The decline for the two-bedroom units is slightly more than for the three-bedroom units (22% versus 19%) This result is due to the much higher baseload in the three-bedroom units, which offsets some of the heating load and reduces the potential savings.

To account for the influence of weather on heating electricity use, electricity use was normalized to average temperature conditions (TMY3). The results of the weather normalization are shown in Table 5.

[8] Since there are only 11 months of post-period data, we assume electricity use in August 2012 is similar to July 2012.

Table 5. Weather Normalized Electricity Use for the Different Regression Models by Fourplex

Regression Model	Baseload (kWh)	Heating (kWh)	Total (kWh)	# of Data Points	Balance Point Temperature (F)	R-Squared
Two-Bedroom Pre	23,450	21,654	45,104	24	61	0.969
Two-Bedroom Post	22,605	11,723	34,329	11	57	0.992
Two-Bedroom Savings	845	9,931	10,776	–	–	–
Three-Bedroom Pre	31,895	21,193	53,089	24	61	0.967
Three-Bedroom Post	29,396	13,092	42,488	11	58	0.923
Three-Bedroom Savings	2,499	8,101	10,600	–	–	–
Average of all Fourplex* Pre	27,504	21,433	48,937	–	–	–
Average of all Fourplex* Post	25,865	12,380	38,245	–	–	–
Average of all Fourplex* Savings	1,639	9,052	10,691	–	–	–
Percent Savings	6%	42%	22%	–	–	–

* Includes both three- and four-bedroom units

Average electricity savings per fourplex building is 10,691 kWh, a 22% reduction. The majority of savings (85%) come from the reduction in heating electricity use. The analysis estimates more than a 42% reduction in heating electricity use. The estimated heating savings is greater for the two-bedroom units, while baseload savings is less, resulting in similar total estimated savings for the two- and three-bedroom units.

The greater heating savings for the two-bedroom units seems to be due to the much lower baseload energy use in these units compared to the three-bedroom units. This increases the relative heating load in these units and the potential savings.

Appendix C contains the regression models used for the normalization analysis.

6.2 Comparison of Measured and Modeled Results

The savings differed between modeled analysis (after true up) and the utility billing regression analysis, as shown in Table 6. Total predicted fourplex savings after true-up is 14,918 kWh, or 30%. The utility regression analysis suggests a savings of 10,600 kWh, or 20%.

While there is some disparity between measured and modeled results, these are consistent with similar research efforts. The total utility savings was 71% of the TREAT model prediction. According to Michael Blasnik, real-world savings are typically 50%–70% of predicted savings (Holladay, 2012). Note also that the space heat savings are 73% of predicted, and the baseload is 66%. As baseloads represent a higher and higher percentage of overall energy use, they have a disproportionate impact on the modeling.

Table 6. Comparison of TREAT Predicted Savings With Utility Data Regression Analysis for Three-Bedroom Fourplex

	TREAT Analysis				Utility Data Regression				
	True-Up Pre-Retrofit	Post-Retrofit	Predicted Savings	% Savings	Pre-Retrofit	Post-Retrofit	Savings	% Savings	% of TREAT Predicted Savings
Baseload	30,169	26,379	3,790	13%	31,895	29,396	2,499	8%	66%
Space Heat	20,000	8,872	11,128	56%	21,193	13,092	8,101	38%	73%
Total	50,169	35,251	14,918	30%	53,089	42,488	10,600	20%	71%
SIR Without PSE Incentive	–	–	1.02	–	–	–	–	–	–
SIR With PSE Window Incentive	–	–	1.17	–	–	–	–	–	–
SIR Without Window and Door Costs	–	–	1.67	–	–	–	–	–	–

7 Ventilation System Discussion

The existing kitchen hoods installed in the Cascade units recirculate air with grease filters in the kitchen rather than venting it to the outside and consequently present potential IAQ issues associated with particulates and moisture generated by cooking. The ERVs are located in close proximity to the kitchen; as such they can help to reduce these issues.

As noted above in Section 4.4, post-retrofit, the ERV provided all needed whole-house ventilation per ASHRAE 62.2 (American Society of Heating, Refrigeration and Air-conditioning Engineers, 2007). KCHA staff are responsible for operation and periodic maintenance of the systems (filter cleaning.) As noted above, occupants do not have control over system operation. The old exhaust fans, located in the upstairs bathrooms, provided occupant-controlled spot ventilation only.

Immediately following the installation of the ERVs, KCHA reported concern from some occupants that the continuous operation of the ERV would lead to higher utility bills; in fact, a few occupants tampered with their systems to shut them off. After education and consulting with KCHA staff, the occupants better understood and accepted the ERVs. Long-term feedback from occupants to KCHA suggested that the occupants are now satisfied with the ERVs.

Prior to retrofit, moisture issues were identified in 27 apartments, even with the operation of the existing exhaust whole-house ventilation system. Post-retrofit, BA researchers installed Onset HOBO data loggers (temperature and RH) in 12 of these units, as discussed in Section 3.2. Figure 9 provides a temperature stem and leaf plot for these units by month; Figure 10 provides the RH for these units. More detail on monitoring results can be found in Appendix A.

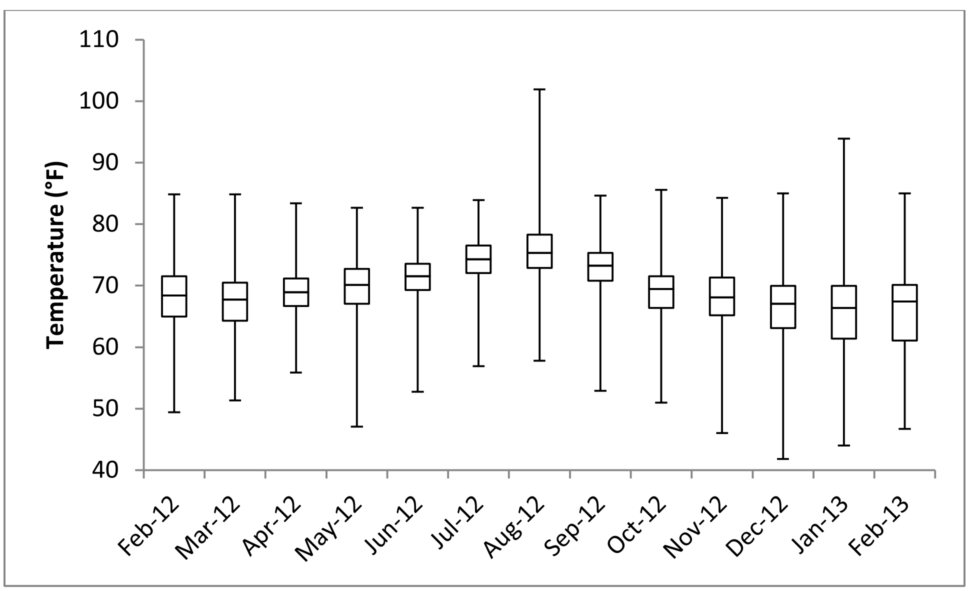

Figure 9. Temperature stem and leaf plot for 12 Cascade units by month, post-retrofit

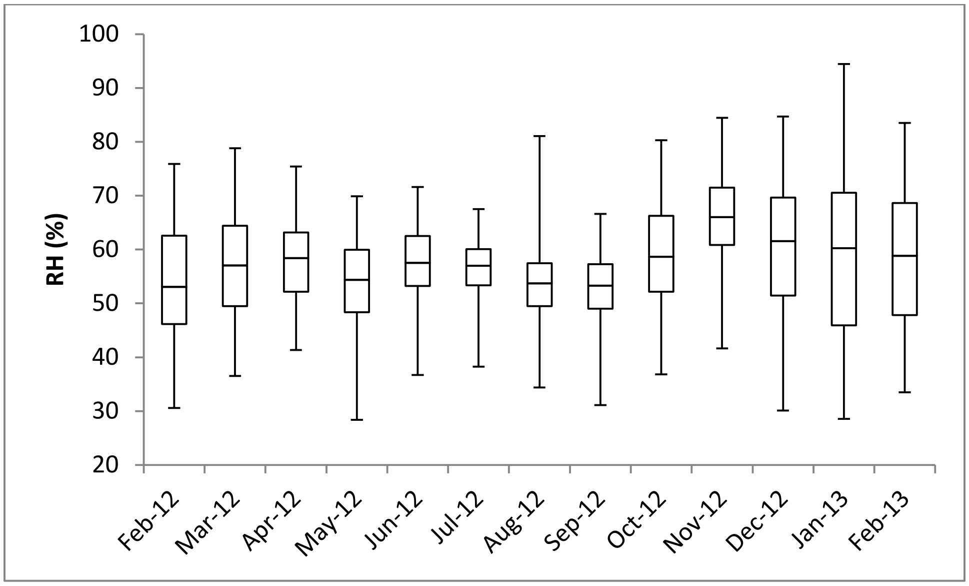

Figure 10. RH stem and leaf plot for 12 Cascade units by month, post-retrofit

It is important to remember that the monitoring subsample was provided by KCHA as a group of apartments with moisture problems identified pre-retrofit. Post-retrofit, the average RH of the monitored apartments is always higher than 55% during the heating season, which suggests that humidity control may still be an issue for these apartments. Appendix A provides the individual apartment data, which vary considerably.

KCHA has the ability to go back and recommission the timer control for the upstairs bath fan in order to increase the ventilation rate and provide additional moisture control on an as-needed basis. It is important to note that following the retrofit, KCHA reported moisture-related occupant complaints were reduced significantly.

8 Conclusions

What are the modeled energy savings using DOE low income weatherization approved TREAT software?

TREAT estimated annual savings were 3,730 kWh per apartment, or $392 ($23/month) at the utility rate of $0.105. Whole-building (three-bedroom fourplex) site energy savings were 14,918 kWh/year, 30% compared to pre-retrofit (Table 6). Total estimated source energy savings are 50,198 kWh/year per building based on national source energy factors. While the two-bedroom units were not modeled, if one assumes similar savings for those units (an assumption borne out in the utility regression analysis), total modeled site savings for the 108 units in the Cascade community are 372,950 kWh/year; total estimated source energy savings are 1,254,976 kWh/year.

How did the modeled energy savings compare with measured energy savings from aggregate utility billing analysis?

The billing analyisis suggests total savings of 10,600 kWh/year for the three-bedroom units, and 10,776 kWh for the two-bedroom units, for an average of 10,691 kWh/year, a 22% reduction (2,672 kWh per apartment average). While the average overall savings is 71% of the predicted TREAT savings, these results are typical of comparisons of modeled and measured energy use. The utility billing analysis suggests significant savings from the retrofit measures, with the majority of the savings (85%) coming from heating energy use.

What is the SIR of the retrofit package after considering utility window incentives and KCHA capital improvement funding.

TREAT analysis indicated that the SIR varied considerably depending on whether or not utility incentives and capital improvement funds were leveraged. The SIR improves considerably if utility incentives and capital improvement funds associated with window and door replacements and Americorp contributions are not considered in the calculation.

The full estimated cost of the energy saving retrofits was $26,234 per fourplex, and $655,850 for the entire community (does not include measures installed by the Washington Conservation Corps). Of that figure (entire community), PSE contributed $67,321 for windows, and KCHA contributed $202,678 from its Capital Improvement Fund ($34,375 for doors, $168,303 for windows). The incremental costs associated with the DOE low-income weatherization funds were assumed to be $385,850 for the whole community, or $15,434 per fourplex.

By combining capital improvement funds and utility incentives, KCHA was able to utilize weatherization funds to make the needed improvements, while achieving an SIR of greater than 1. Without PSE window incentives, the SIR was 1.02. With the PSE window incentive, the SIR increased to 1.17. If the KCHA window costs are removed from the calculation (arguably justified because window retrofit was implemented due to the failure of the existing windows) the SIR increases to 1.67—this is in effect the SIR for all DOE/State weatherization funded measures.

Additional benefits to the KCHA and the Cascade Apartments occupants include the use of capital improvement funds in order to extend the useful life of the buildings, avoid the cost of new construction, and reduce the impact on occupants (no occupants were displaced during the retrofits). Based on KCHA staff and occupant feedback before and after the retrofits, overall IAQ improved with the installation of the ERVs and education on their use. Each unit realized approximately $23 in monthly utility savings.

Relocating the whole-house ventilation system to the main area of the home per ASHRAE 62.2-2007 seems to have a positive benefit to the occupants. KCHA staff have noted a significant decrease in occupant IAQ complaints since the retrofits took place.

9 Recommendations

9.1 Ventilation

KCHA staff need to continue to engage new occupants on the use and purpose of the ERV, including KCHA's responsibility to provide ongoing maintenance.

Occupants also need to be educated in the continuous use of the ERV, as well as the spot use of the bathroom and kitchen fans to address moisture and other IAQ needs if they arise.

If KCHA staff observe moisture issues during ERV maintenance visits, or if tenants experience moisture issues, KCHA staff can increase use of the upstairs bathroom fan, and continue to monitor the situation.

9.2 Policy

This project clearly illustrates the variability of SIR calculations depending on leveraged funding. In this project, without leveraged funding, the window retrofit would not have been possible using current SIR calculations.

Determination of SIRs for individual air sealing retrofit measures was not possible because there is no established methodology for identifying the contribution to reduced air leakage from dense wall pack insulation (distinct from savings associated with reduction in conductive heat loss.)

As demonstrated at the Newporter Apartments and other KCHA retrofit efforts, installation of foam sheathing during retrofit is an achievable and cost-effective measure that can further increase the useful life of the buildings. Future projects should consider the use of foam sheathing from the planning stages.

9.3 Future Research

Assigning air leakage reductions to wall, floor, and/or ceiling air sealing measures in conjunction with wall, floor, and/or ceiling insulation in multifamily apartments is a key area for future work, in order to better assess SIR of individual measures. Future retrofit efforts should utilize results from the PSE study looking at air leakage control associated with dense pack wall and ceiling insulation, so that the individual contribution for each measure can be assigned for SIR or other savings analyses.

BA research continues on the use of multiblower door "guarded" testing versus unguarded testing, and its implication for SIR analysis and interapartmental IAQ issues.

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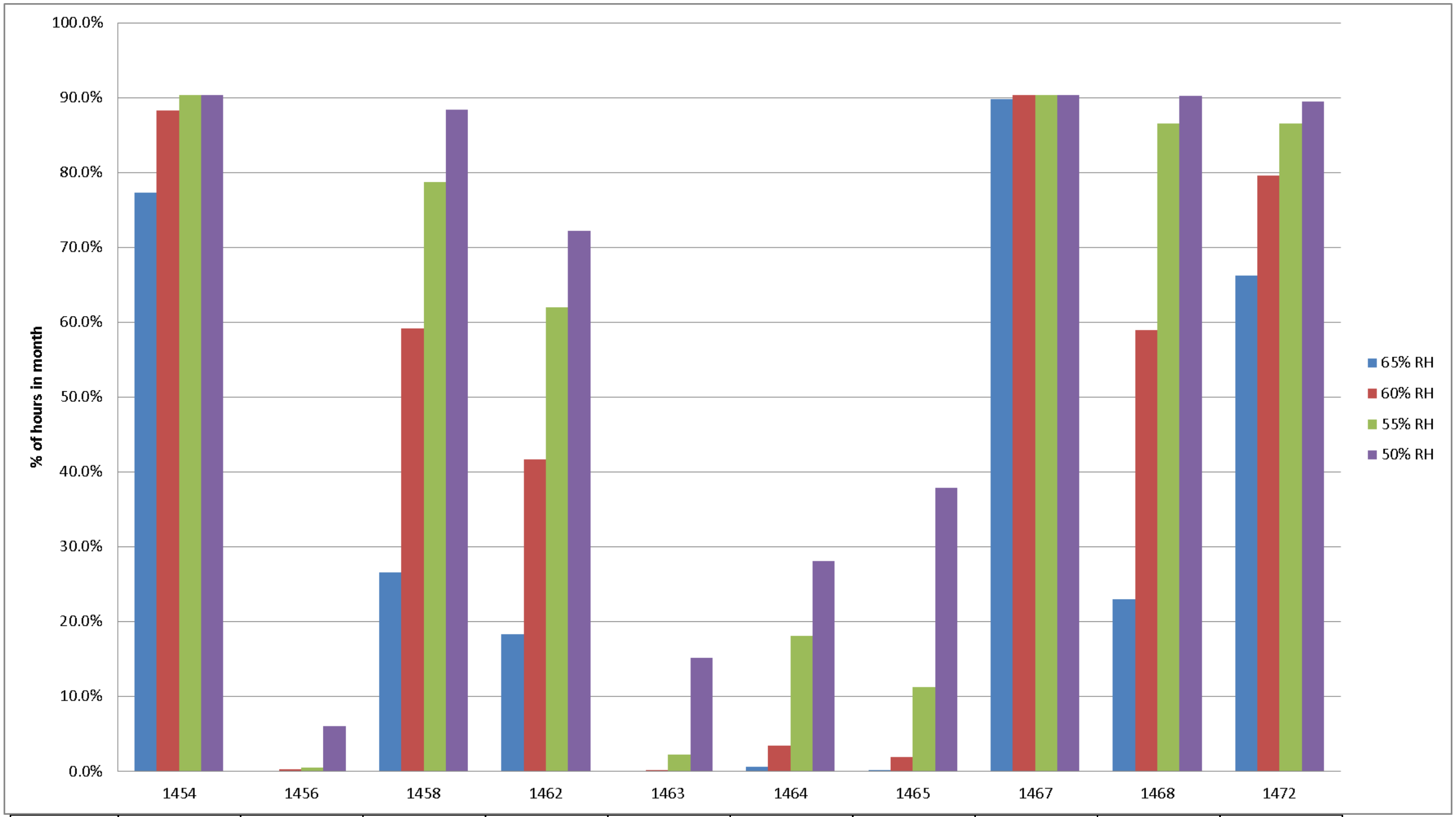
Appendix A: Relative Humidity Monitoring Results

Figure 11 shows the RH levels for the monitored units for a typical winter month, February 2013. The colored bars represent the percentage of hours in the month that the RH remained at or above the described level. The numbers in the table below the graph show the monitored high, low and average temperatures recorded. Researchers have similar data for the months February 2012 to January 2013.

Generally speaking, the monitored homes (high moisture complaints) had average temperatures of 65°–70°F. Two outliers, 1454 and 1467, had average temperatures below 60°F, and the highest RH, relative to the other homes. Unit 1467, which had the highest incidence of high RH, also had a bath fan that operated at a significantly lower rate (38 CFM) than the average flow rate of the homes in the study (62 CFM).



	1454	1456	1458	1462	1463	1464	1465	1467	1468	1472
min (°F)	46.7	71.2	63.3	57.4	63.3	56.6	54.7	55.2	64.5	55.9
max (°F)	64.0	80.0	71.9	85.0	77.6	73.4	75.5	69.8	74.4	84.5
average (°F)	58.3	73.6	68.0	70.9	69.9	67.1	67.4	59.1	68.1	61.1
Bath Fan (CFM)	68	57	64	76	41	49	67	36	64	73

Figure 11. RH and temperature for monitored units in Cascade, February 2013

Appendix B: Energy Audit Detail

Thermal Imaging

The Fluke thermal imaging equipment and software allow researchers to identify areas of thermal bridging, insulation gaps, moisture infiltration, and air infiltration. With these data in hand, researchers can formulate appropriate measures to address the problematic areas. Figure 12 and Figure 13 contain examples of images captured by the Ti32.

Figure 12. Air infiltration around a door

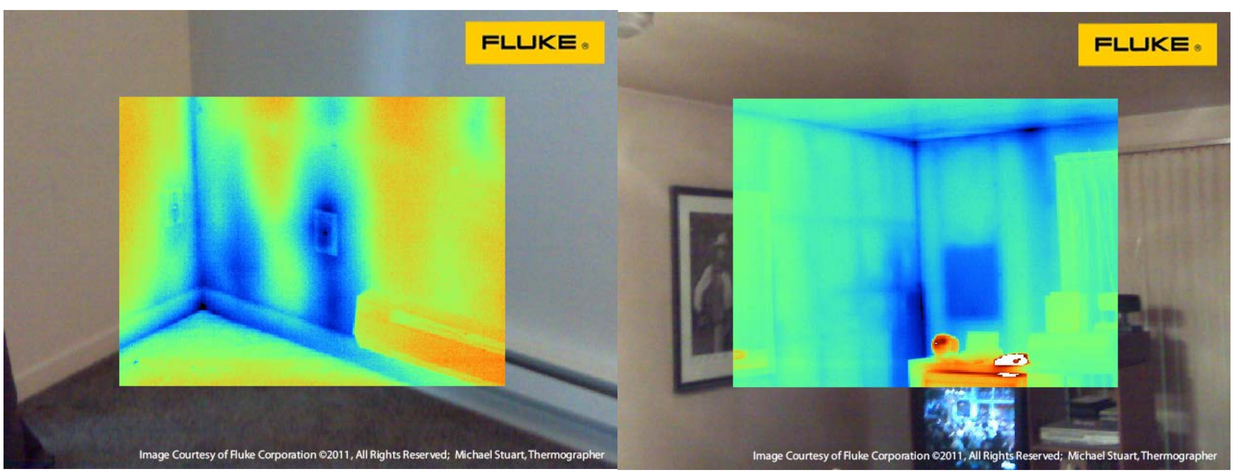


Figure 13. Air infiltration surrounding an electrical outlet (left); thermal bridging and air bypasses in walls and ceiling (right)

In addition to the KCHA audits, members of the Washington Conservation Corps visited each unit, and recorded the following information:

- An evaluation of lighting in place (number and type)
- Airflow of spot ventilation
- Water temperature, and low-flow faucet aerators
- Appliance model and make

- Environmental conditions.

Washington Conservation Corps members also installed low cost efficiency measures, such as compact fluorescent lamps as well as low-flow aerators and showerheads.

Multiunit Blower Door Testing

Determining the airtightness of multifamily buildings has been problematic for more than 2 decades. The difficulty lies in the fact that air leakage between apartments increases the apparent air leakage of the individual units.

Interior walls function primarily to partition a building's interior environment; as such they do not require the air impermeability characteristics of an exterior wall. Thus, when the blower door depressurizes a single unit, air from the adjoining unit or shared space is pulled into the tested unit and is essentially recorded as leakage.

In addition, the individual apartment units share a single crawlspace, common to all four units; most also have a common attic.[9] If this is not taken into account during testing, this "shared" leakage may be counted multiple times.

If the air leakage of the whole building is gauged by the added results of multiple *single*-unit blower door tests, the result will be an inflated estimate of exterior leakage, and will overestimate the potential savings achieved through proposed retrofit measures. In addition to the inaccuracies resulting from air leakage between units and shared spaces, there is also a very small degree of uncertainty per measurement during a blower door test that must be considered. Per single test, this impact is marginal; however, the impact becomes larger when four separate tests are added together.

Figure 14. Setup for multiunit blower door testing

[9] The buildings feature a fire wall bisecting the attic; however, some of the firewalls have large openings, mitigating or eliminating their effectiveness as an air barrier.

During the last 2 decades, researchers developed several methods to address this difficulty including the Detached-Unit Method, Pressure Equalization Method, Pressure Drop Method, and Single Point Method, among others. For this occasion, the Pressure Equalization Method was used to gauge the air leakage in the whole building as well as the individual units, both before and after the retrofit. The operating procedure for the Pressure Equalization Method requires each of the four units that comprise the building to have a blower door set up at the primary exterior door. The four units are then depressurized simultaneously, eliminating the air leakage between units and delivering accurate air leakage values for both the whole building and for individual units.

Table 7 illustrates the greater precision delivered via the multiunit blower door test. Individual unit air leakage measurements can be found in Table 2.

Table 7. Comparison of Whole-Building Air Testing Results and Sum of Individual Testing Results

Whole-Building Results			Sum of Individual Tests		
	Pre	Post		Pre	Post
CFM_{50}	3,339	1926	CFM_{50}	3,661	2,502
ACH_{50}	5.85	3.38	ACH_{50}	6.42	4.38
ACH_n	0.293	0.169	ACH_n	0.321	0.219

TECHLOG2

TECHLOG2 is a software program developed by The Energy Conservatory to control, monitor and store data from up to 16 blower door tests simultaneously (Energy Conservatory). TECHLOG2 is operated via a single laptop. Each blower door is directly controlled by a DG-700 manometer, manufactured by The Energy Conservatory, and each DG-700 is linked to a single laptop running TECHLOG2, which records the results of the multiunit blower door test. When used to perform energy audits in the Cascade community, TECHLOG2 recorded results of four blower doors operating simultaneously, recording pressure and airflow measurements at a rate of once per second. The range of the testing began at an induced pressure of –60 Pascals and finished at –20 Pascals, diminishing in 5 Pascal intervals over the course of the test.

Figure 15. Preparing TECHLOG2

TECHLOG2 provides a comprehensive record of the test, including airflow, calculated leakage areas, a graph of the correlation coefficient, as well as the fan flow and pressure of a particular unit at any point during the test. Figure 16 through Figure 19 provide example graphs of TECHLOG2 results for Building V.

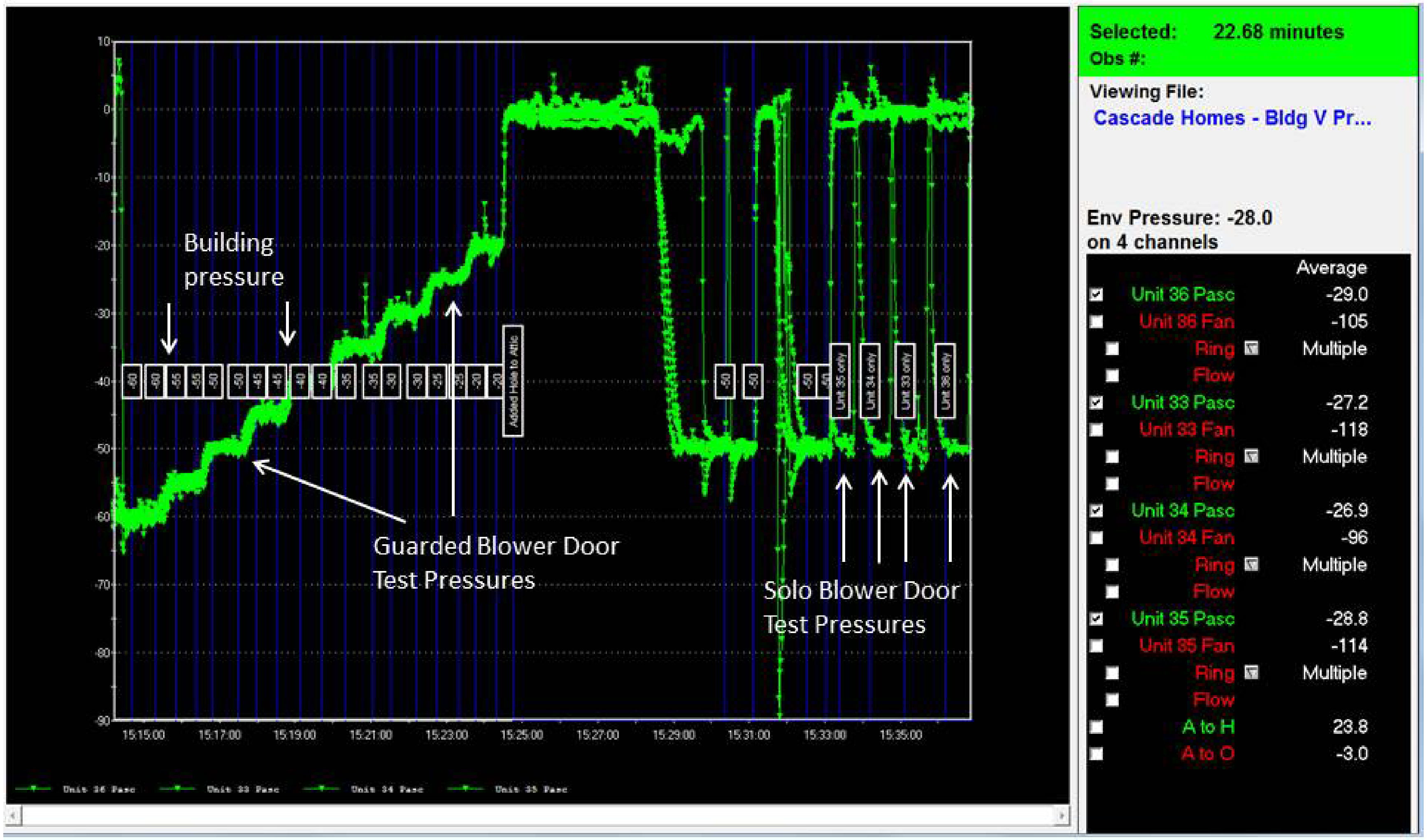


Figure 16. Building V, pre-retrofit testing, test pressures

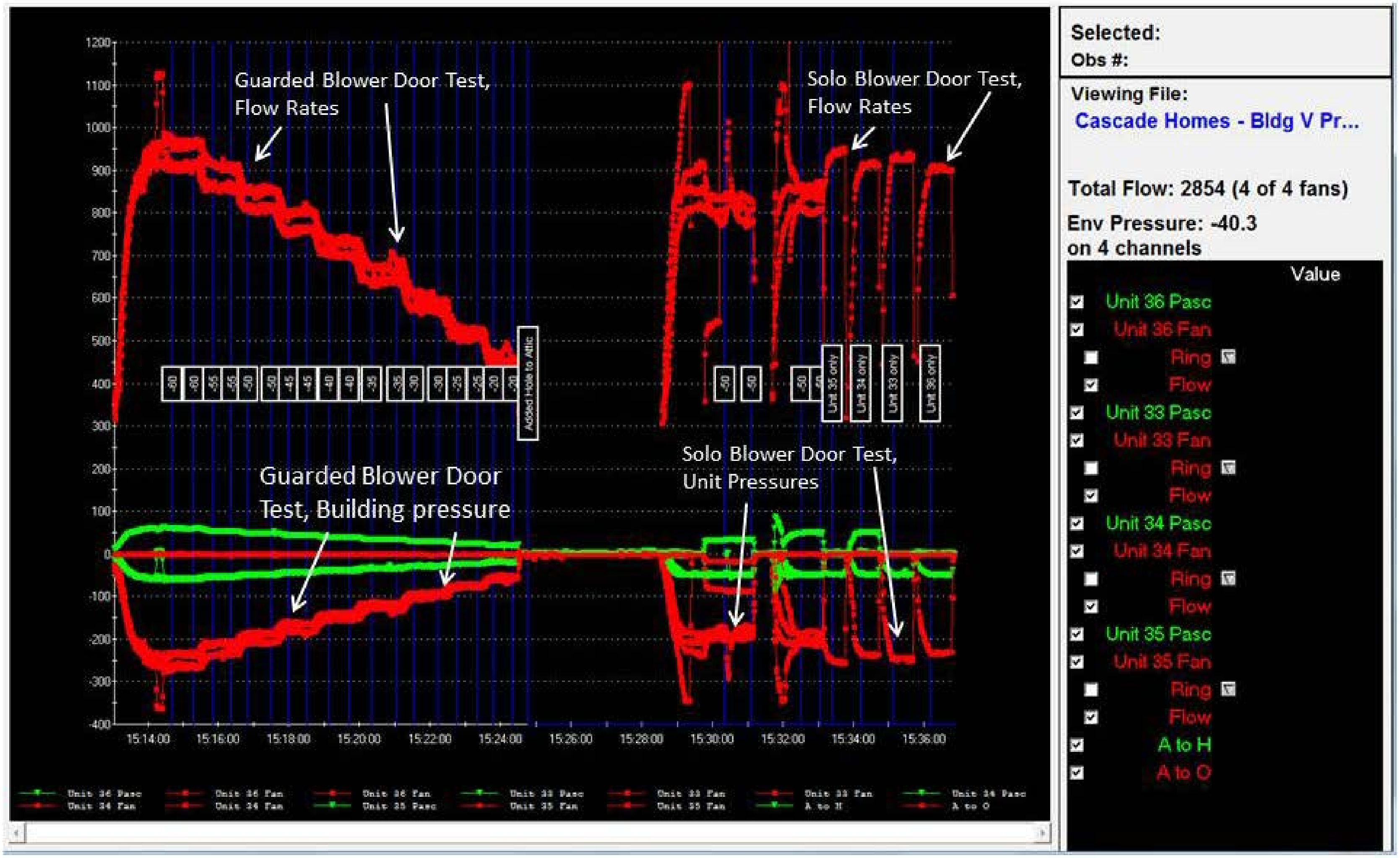


Figure 17. Building V, pre-retrofit testing, flow rates and building pressures

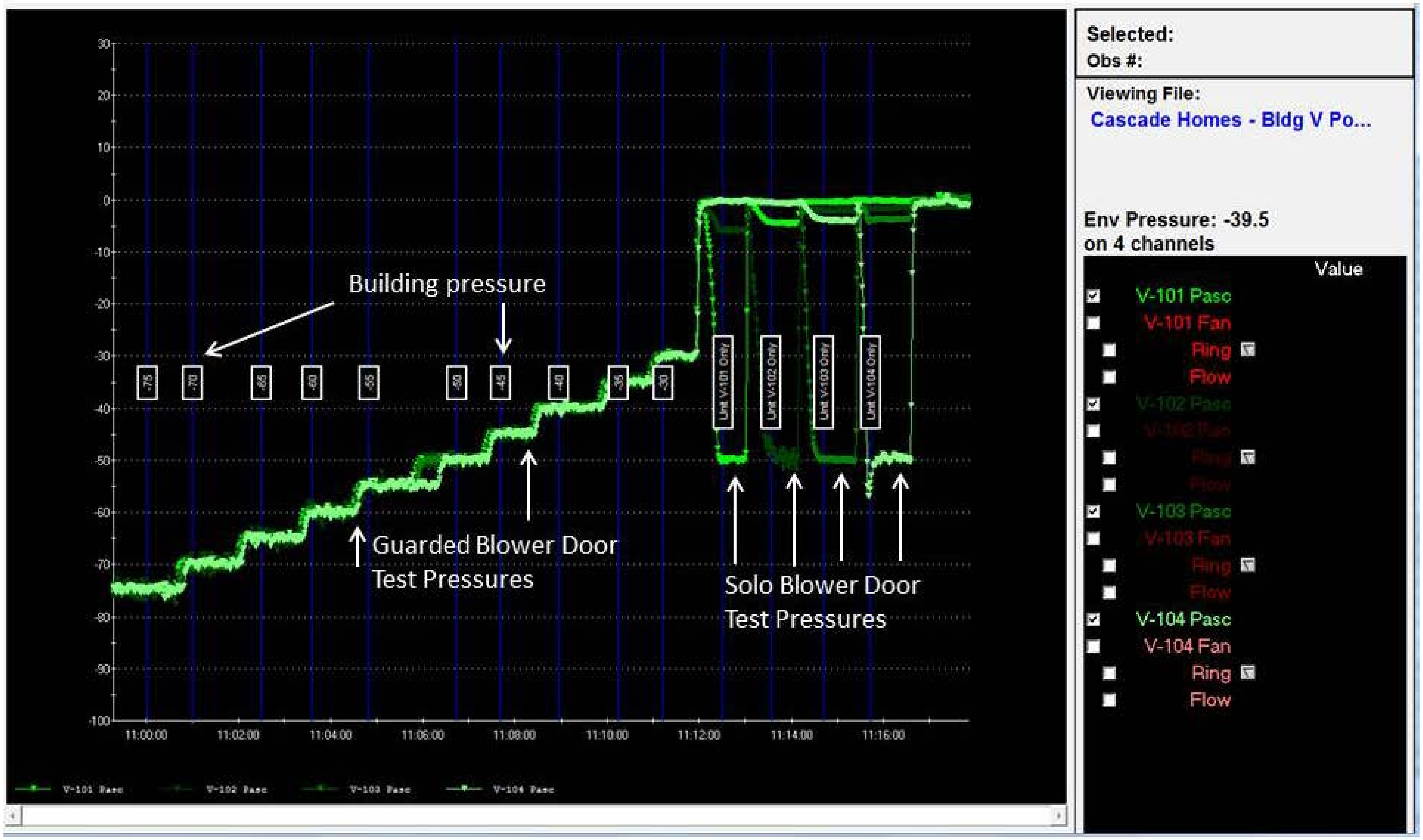


Figure 18. Building V, post-retrofit testing, test pressures

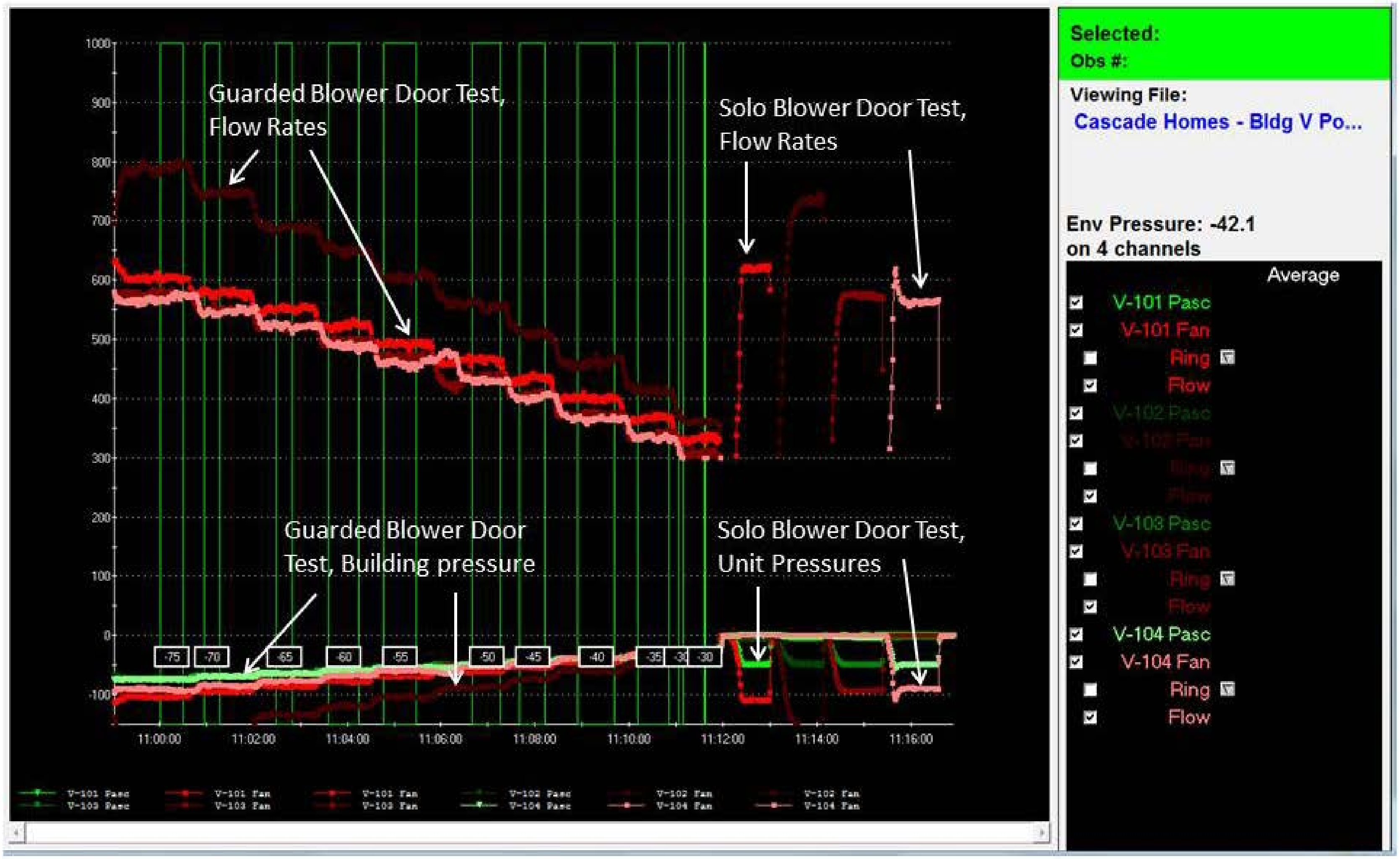


Figure 19. Building V, post-retrofit testing, flow rates and building pressures

Appendix C: Regression Analysis

Researchers used a spreadsheet regression analysis tool developed by Michael Blasnik to normalize the monthly utility electricity use to typical outdoor temperature conditions. The spreadsheet tool uses a Bayesian approach to select the best balance point based on R-squared and a prior estimate of balance point. The tool uses daily average temperature data (in this case from Sea-Tac Airport) to estimate degree days at different base temperatures. Note that monthly utility data are in aggregate form for all the two-bedroom and three-bedroom units, so there are just two sets of utility data.

Four regression models were developed for the weather normalization analysis: two-bedroom pre- and post-retrofit and three-bedroom pre- and post-retrofit. Figure 20 and Figure 21 show the regression data points for the two- and three-bedroom models. The regression model fits are good in all four cases, ranging from 0.92 to 0.99. The fit is poorest for the three-bedroom post-retrofit case. More post-retrofit data would make the results more robust. Note that the degree day temperature base is different for the pre- and post-retrofit models. This is expected because the post-retrofit building is more efficient. The base temperature reflects the outdoor temperature below which supplemental heat is required to maintain indoor temperature. Lower temperatures reflect a more efficient building. While the data for the pre- and post-retrofit cases seem to produce similar regression lines, because the post-retrofit cases have a lower slope and use a lower degree day base (there are fewer degree days), estimates of heating electricity use from the regression analysis are lower.

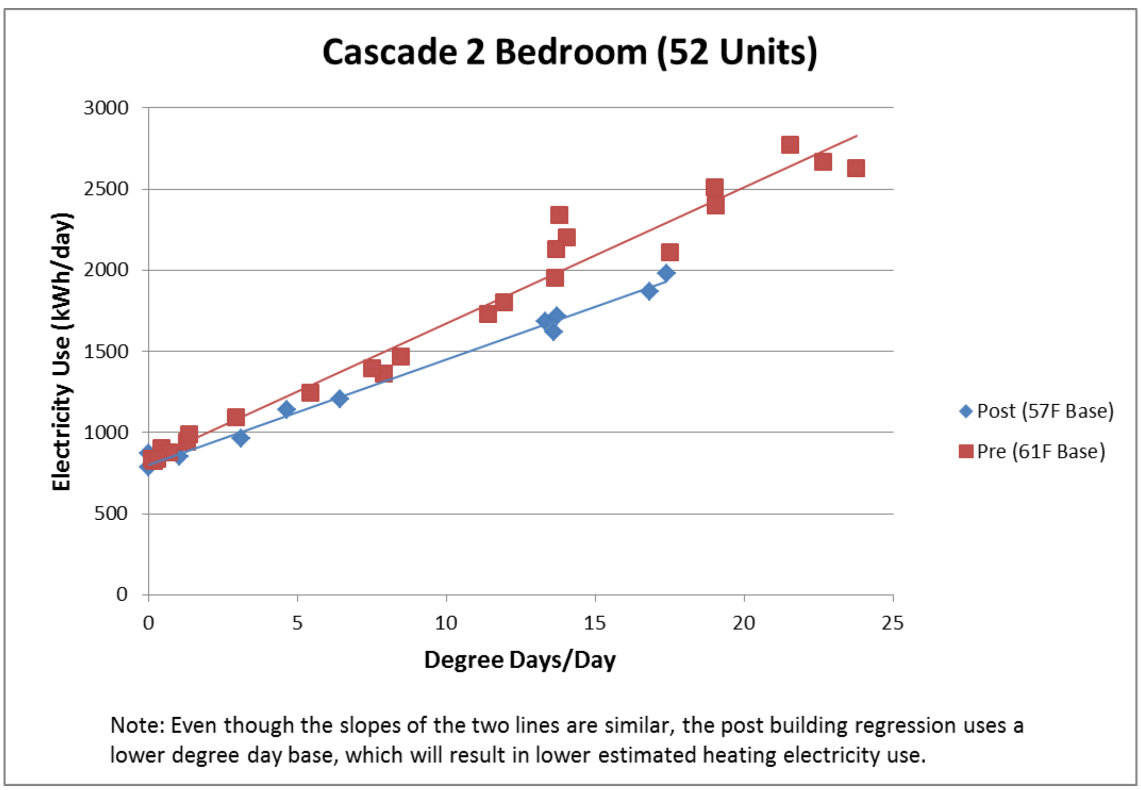


Figure 20. Regression analysis for Cascade two-bedroom units

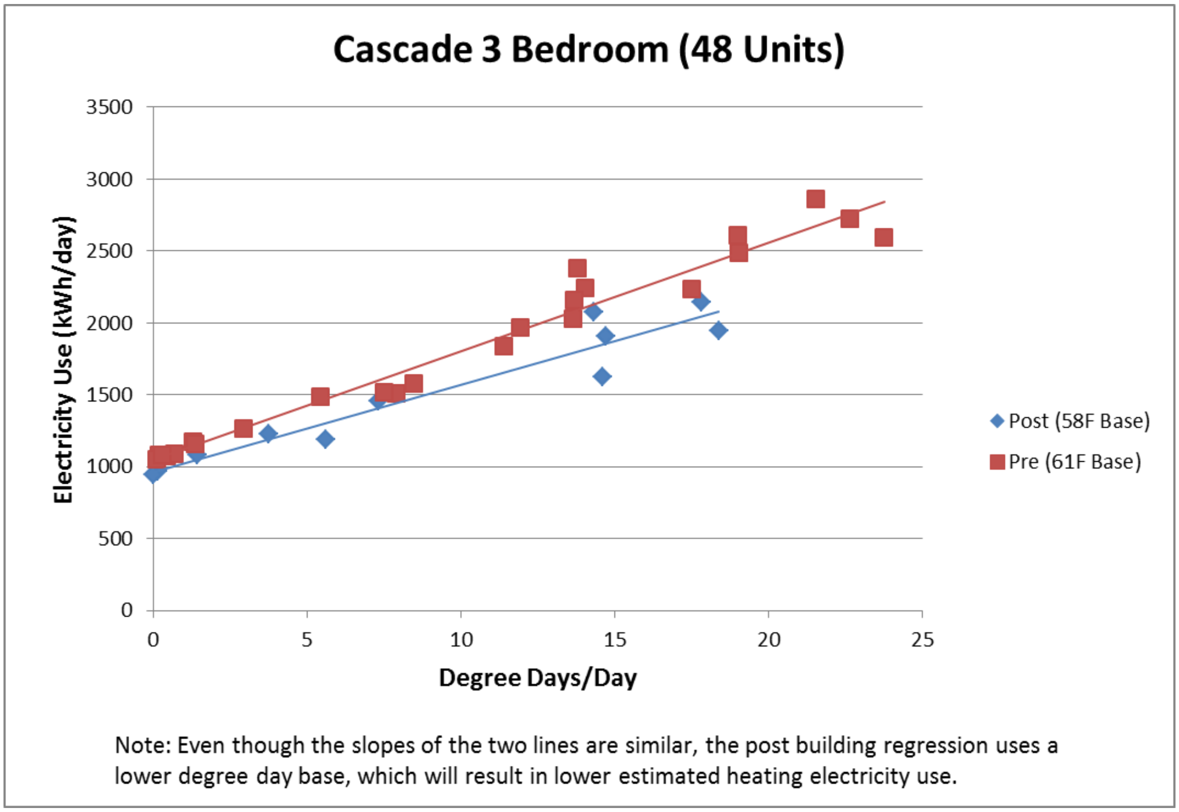


Figure 21. Regression analysis for Cascade three-bedroom units

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