Emerging Products

A Replicable and Scalable Near-Zero Net Energy Retrofit of Low-Income Multifamily Housing: Electric Energy Efficiency

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ABSTRACT

Currently, about 3.3 million low-income households rent housing in California. About 1.7 of them are spending more than half of their income on housing, and more than 16% of their income on energy costs. The Electric Power Research Institute (EPRI), along with the team from BIRAenergy, studied the technical and economic scalability of deep retrofits in affordable Multifamily (MF) housing and disadvantaged communities.

Thirty units at The Villages at Beechwood, in Lancaster, California, were retrofitted with packages of substantial Energy-Efficiency (EE) measures for natural gas and electric use, including light-emitting diodes (LED) indoor and outdoor lighting, weather stripping, smart thermostats, duct and envelope improvements, efficient appliances, deep EE measures, solar thermal, and solar photovoltaic (PV). Contractors also installed roof spray foam insulation, as well as emerging technologies like aerosol envelope sealing and advanced economizers in the common area. The project identified the measures' technical effectiveness, and provided an understanding of hidden costs, such as asbestos mitigation and tenant intrusion, that act as market barriers.

Tenant interviews conducted by Southern California Edison (SCE) identified significant improvements to quality of life, as well as the importance of addressing occupant disruption and property owner incentives for deep retrofits. Natural gas consumption was reduced by 50% for water and space heating, and tenant electric energy use was reduced by an average of 22%. In addition, 74 kW of PV was installed at the property, and when distributed among 100 units, reduced energy usage in the test units by 25%.

The team also found that, to improve scalability, incentive programs should modify current unit designs, adding benefits for property owners to compensate for any financial and in-kind investments. One of the significant findings was that deep efficiency measures could trigger unexpected costs, like asbestos mitigation and moving tenants out of their units, which could adversely impact economics. Training the line staff who conducts envelope retrofits is also a significant issue in achieving consistent energy savings. Solar energy leasing agreements with utilities and solar providers, in combination with programs like Virtual Net Energy Metering, could provide financial benefits to property owners, while a portion of the savings benefits the tenants.

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INTRODUCTION

Today, approximately 3.3 million low-income households rent housing in California, and a February 2016 Legislative Analyst's Office report revealed that about 1.7 million of them spend more than half of their income on housing. These low-income families require affordable, comfortable, healthy, and durable housing, with low rents and low energy costs. Multi-family property owners typically have rent caps to accommodate tenants who may have difficulty paying their rent. However, there remains a high turnover and/or moderate-to-high vacancy rates.

Low-income households typically occupy energy-inefficient housing, whether owned or rented, resulting in high energy use. A study by the U.S. Department of Health and Human Services stated low-income households can spend as much as 16.4% of their income on residential energy services, more than double what an average household spends. Inefficient buildings are typically difficult to condition properly, and often have poor air quality. Low-income families are often uncomfortable in inefficient, uncomfortable dwellings, and do not have the financial means to upgrade their properties or pay higher rent for the property owners to recoup an investment in retrofitting the rental properties with EE upgrades.

PROJECT PURPOSE

This project evaluated technical and financial models for scalability of deep, near-zero net energy (ZNE) retrofits, in existing low-income multi-family (LIMF) housing. The project was implemented at The Villages at Beechwood in Lancaster, California. This is a 100-unit, LIMF property, owned by LINC Housing, LLC, a non-profit owner and operator of low-income housing, and partner on this project. This property was chosen, in part, because its location has a climate requiring substantial heating and cooling energy loads, and it represents a large share of the low-income market. Each unit is individually metered and billed for electricity use; however, the entire facility is master-metered for gas, with the property owner responsible for paying for all gas use. The project studied 30 non-retrofitted units, which provided baseline data for direct comparison with those that were retrofitted. The project had three major goals:

1. Develop deep EE retrofits and integrate renewables (PV and solar thermal) to produce a practical retrofit package that would be as close to ZNE as possible.

2. Implement the retrofit as successfully as possible and evaluate the success of the retrofit.

3. Evaluate and suggest improvements to existing financial models and associated tools that should enable scaling of these retrofits across LINCs housing portfolio as well as California's LIMF market.

PROJECT PROCESS

This project developed, implemented, and evaluated EE retrofits in low-income housing, to improve the quality of life for these households. It was important to understand the current state of LIMF housing, and simultaneously understand customer (tenant and property owner) preferences. The team identified and applied appropriate technology interventions, including data collected from monitoring at the equipment level, in an attempt to pinpoint the impact of each EE measure. Another significant part of the work was developing a business model around comprehensive EE and solar retrofits. The team found it essential to work with and be attentive to the occupant-customer before, during, and after installing EE improvements, as well as to plan to avoid problems, and budget for the unexpected. In addition, the project also emphasized the importance of building a knowledge base of "real-world" cost estimates, to provide better insights into the cost effectiveness of key EE measures.

The project started with a thorough audit of the components and construction of current structures and their energy-consuming contents, as well as occupant interviews to survey small electric appliances and behaviors, including thermostat settings (both queried and observed), where possible. Audit information, including envelope components and areas, and equipment age and efficiency ratings were used to develop building models. Simulations were used to identify the units with high energy use and retrofitted packages of EE measures.

The EE measures installed in the tenant units included:

- Attic insulation, to place ducts in conditioned space
- Hand-installed envelope air sealing
- Duct leakage sealing and/or replacement
- Increased duct insulation
- "L" duct seals on Roof-Top Units (RTUs), with reflective paint
- Community-scale solar water heating
- High-efficiency boilers for community water heating
- High-efficiency tankless water heaters for duplexes
- Spray foam roof insulation (in one building)
- Smart thermostats
- Low-flow showerheads
- Refrigerators in select units (through the Energy Savings Assistance program)
- Improved piping for community water heating

These additional EE measures were installed in the common area:

- Aerosol sealing for building envelope, to reduce air leakage
- Smart thermostats and Heating, Ventilation and Air Conditioning (HVAC) fault detection and diagnostics systems
- Spray foam roof insulation
- RTU "L" duct spray foam sealing and insulation
- Automated economizer for rooftop units
- Smart plug strips
- 99% efficient tankless water heaters

In-depth HVAC system monitoring, combined with data from the Automated Metering Infrastructure (AMI) electric and gas smart meters, was used to verify the efficacy and performance of the EE measures.

PROJECT RESULTS

The installed efficiency measures were effective in delivering electric and gas energy savings to the low-income households. The retrofit performance evaluations were conducted using two approaches, the same units or buildings pre- and post-retrofit, and a control treatment method, for which there were identical, neighboring residence buildings, one that was retrofitted (treatment) and an identical that was not retrofitted (control). This second, control treatment method was important, because it provided a way to neutralize the impacts of various weather conditions during the monitoring periods, before and after the measures were implemented. This proved useful, because the weather in the post-retrofit evaluation period (2015–2016) was substantially warmer in the summer and colder in the winter, than during the pre-retrofit period (2014-2015). The change in summer temperatures correlated directly with increases in the energy used to cool the control group residences. The HVAC energy used for cooling the treatment group also increased, but the difference between the control and treatment groups showed a 50% reduction in cooling energy. Electric energy use showed a reduction of 22%, and gas usage was reduced by 60% for water heating and 23% for space heating, due to the EE measures installed. The estimated benefits of the individual measures are shown in Table 1 below, as percentages:

Table 1: Estimated Benefits of Individual Energy Efficiency Measures

Measure	Unit	Modeled (per unit)	Measured (per unit)
Envelope Improvement Package (ELECTRIC) – duct replacements, insulation and semi-conditioned attic, air sealing	kWh	45% (145 out of 239 Therms)	22% (based on RTU operation)
Envelope Improvement Package (GAS) – duct replacements, insulation and semi-conditioned attic, air sealing	Therms	60% (451 out of 753 Therms)	34% (based on RTU usage)
Air sealing ACH improvement	%	Not modeled	30%
Smart thermostats – average (electric)	kWh	5%	14% (estimated)
Smart Thermostats – average (gas)	Therms	5%	14% (estimated)
WH Improvements – Solar Thermal	Therms	55% (118 Therms)	70% savings (100 Therms/unit)
WH improvements – distribution improvement	Therms	35% (82 Therms)	
LED lighting	kWh	55%	Not measured directly
Spray Foam Roof Insulation	kWh	35%	17%

The measures that showed the greatest potential were spray foam roof insulation, solar thermal water heating, and re-insulating hot water distribution systems. While the duct insulation was effective, it also added substantial ancillary costs, due to required asbestos abatement. A side benefit of the duct insulation and sealing was additional envelope insulation, due to filling gaps with blown fiberglass. The tenants responded positively to smart thermostats, which included several different manufacturers' products. While energy savings were achieved with all the smart thermostats installed, certain products outperformed others. However, it was difficult to keep them connected with Wi-Fi updates, which could potentially result in reductions in long-term energy savings. A Heating, Ventilating, and Air Conditioning (HVAC) economizer (a device that draws in outside air to save on cooling costs) was also demonstrated to be beneficial but was measured over only a few winter months.

Installing solar photovoltaic (PV) was significant in reducing tenant energy bills. The net metering policies required the PV generation to be offset for all 100 units (it was designed for 30 ZNE project units) and the tenant bills could not be completely offset.

PROJECT BENEFITS

This project proved successful, showing a net energy reduction of about five kilowatt-hours (kWh) each day, per unit. Given that California has nearly seven million apartment residents, the potential for electric energy savings is about 12.75 gigawatt-hours each year. What does this mean for the low-income apartment tenant? The apartments with EE measures reduced their natural gas use by about 10%, and for the community, water heating natural gas use dropped 58%. For the community scale, this is approximately a 28% reduction in gas use, or about 14,400 therms annually (144 Therms/unit). Scaling this to the entire state, the net potential for energy use reduction is 1 billion therms in multifamily (MF) properties alone. Combining the gas and electric benefits, the potential benefit in Greenhouse Gas (GHG) reductions for California is 6.2 million metric tons of CO_2, primarily from the natural gas savings.

However, even beyond these energy and environmental benefits, there are substantial non-energy benefits that accrue to occupants and tenants of low-income communities. Quality-of-life improvements are a key benefit of EE upgrades. In one example, a mother referenced how better indoor temperature and humidity control, through better insulation, could help with her daughter's nosebleeds. In another, an occupant indicated how his comfort was significantly improved with the installed efficiency measures and smart thermostats.

It is essential to continue encouraging and supporting energy and non-energy benefits as part of future work on affordable and low-income communities. It is important to emphasize that incentives for EE must be provided to tenants, as well as to the property owners who must invest substantial effort in implementing these measures. The team also recommends financial models, similar to those used in the solar industry, be encouraged in the EE industry, and future research be conducted to fill any gaps in the data required by financial institutions, such as private and public banks.

ABBREVIATIONS AND ACRONYMS

A/C	Air Conditioning
ACCA	Air Conditioning Contractors of America
ACEEE	American Council for an Energy-Efficient Economy
ACH	Air Change per Hour
AMI	Automated Metering Infrastructure
Beechwood	The Village at Beechwood, Lancaster, CA
BeOpt	Building Energy Optimization (software)
Btu	British thermal unit
BPI	Building Performance Institute, Inc.
CA Hers	California Home Energy Rating System
CARE	California Alternate Rates for Energy
CC	Community Center
ccf	centum cubic feet, or 100 cubic-feet
CFA	Conditioned Floor Area
CFL	Compact Fluorescent Lamp
CFM	Cubic Feet per Minute
CSI	California Solar Initiative
CT	Current Transformer
CTCAC	California Tax Credit Allocation Committee
CUAC	California Utility Allowance Calculator
DAQ	Data Acquisition
DHW	Domestic Hot Water
DR	Demand Response
EE	Energy Efficiency
EEM	Energy Efficiency Measures

EIA	Energy Information Administration
EPIC	Electric Program Investment Charge
ESA	Energy Savings Assistance
ET	Emerging Technology
EUC	Energy Upgrade California
FDD	Fault Detection and Diagnostic
GHG	Greenhouse Gas
HACT	Housing Authority of Tulare County
HDD	Heating Degree Day
HEMS	Home Energy Management System
HEPA	High-Efficiency Particulate Air
HP	Horsepower
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
IOU	Investor-Owned Utility
IWH	Instantaneous Water Heater
LED	Light-Emitting Diode
LIHTC	Low-Income Housing Tax Credit
LIMF	Low-Income Multifamily
LINC	LINC Housing, LLC
MASH	Multifamily Affordable Solar Housing
MEL	Miscellaneous Electric Load
MF	Multifamily
MIDI	Middle Income Direct Install
NEMA	National Electrical Manufacturers Association
NG	Natural Gas

NGO	Non-Government Organization
NILM	Non-Intrusive Load Monitoring
NUAC	National Utility Allowance Calculator
OSHA	Occupational Safety and Health Administration
Pa	Pascal
PACE	Property-Assessed Clean Energy
PCT	Programmable Communicating Thermostats
PHA	Public Housing Authority
PIER	Public Interest Energy Research
PPA	Power Purchase Agreement
PPM	Parts Per Million
PV	Photovoltaic
RD&D	Research, Development, and Demonstration
RH	Relative Humidity
RTU	Roof-Top Unit
SCE	Southern California Edison
SEER	Seasonal Energy Efficiency Ratio
SCFH	Standard Cubic Feet per Hour
SoCal Gas	Southern California Gas Company
SDHW	Solar Domestic Hot Water
SFS	Single-Feature Substitutions
SOW	Scope of Work
SPF	Spray Polyurethane Foam
T-stats	Thermostats
TSV	Thermal Shower Valve
UA	Utility Allowance

UV	Ultraviolet
VAV	Variable Air Volume
VER	Very Efficient Retrofit
VNM	Virtual Net Metering
WCEC	Western Cooling Efficiency Center
WH	Water Heater
ZNE	Zero Net Energy

CHAPTER 1: OVERVIEW

About 3.3 million low-income households currently rent housing in California. According to a February 2016 Legislative Analyst's Office report [2], about 1.7 million low-income renter households spend more than half of their income on housing, and more than 16% of their income on energy costs [3]. Low-income families require affordable housing, with low rent and low energy costs, which also provide comfortable, healthy, durable shelter. On the other hand, MF property owners have rent caps, tenants who may have difficulty paying their rent, and can have high turnover and/or moderate-to-high vacancy rates. With a well-designed program supporting Very Efficient Retrofits (VERs), MF property owners could raise rents to at least partially offset financing VER costs, provided the total rent plus utility costs are lowered and the property is modernized. For low-income families, energy costs are a much higher proportion of income compared to the average, exacerbated by the condition of most MF buildings.

However, the Low-Income Multifamily (LIMF) market lacks the information to even consider VERs, and if they were interested, they do not readily have the means to design, finance, and implement EE retrofits, except possibly the most basic improvements. Exacerbating this situation is the fact that there are many MF buildings that are not energy efficient and are often quite inefficient. The property to be retrofitted in this project is a good example – the apartments use more energy than a typical square-foot home in Sacramento. The LIMF market presents a great opportunity to cost-effectively implement VERs.

There are approximately 2.7 million MF units that pre-date any energy standards, and about 3.7 million MF dwellings built prior to any significant impact from the energy standards. This target market is substantial, and the energy savings potential is very large, as is detailed in the cost-effectiveness section later in this document. The LIMF market has a substantial need for best-design, best-practice retrofit information. There also appears to be no practical way to determine the potential energy savings and resulting benefits to the property owners and their tenants, nor the technical and financial information for how to implement VERs, even if they chose to do so.

This project meets the LIMF market demand for EE, and the technical and financial information, packages, practices, and methods produced in this project will be applicable to the entire existing MF market, making the project more important.

The overarching goal of this project is to develop, demonstrate, and document the steps and components needed by LIMF property owners to make the process of VER-related business decisions both easy and straightforward. Figure 1 shows the process used to select and evaluate the EE measures.

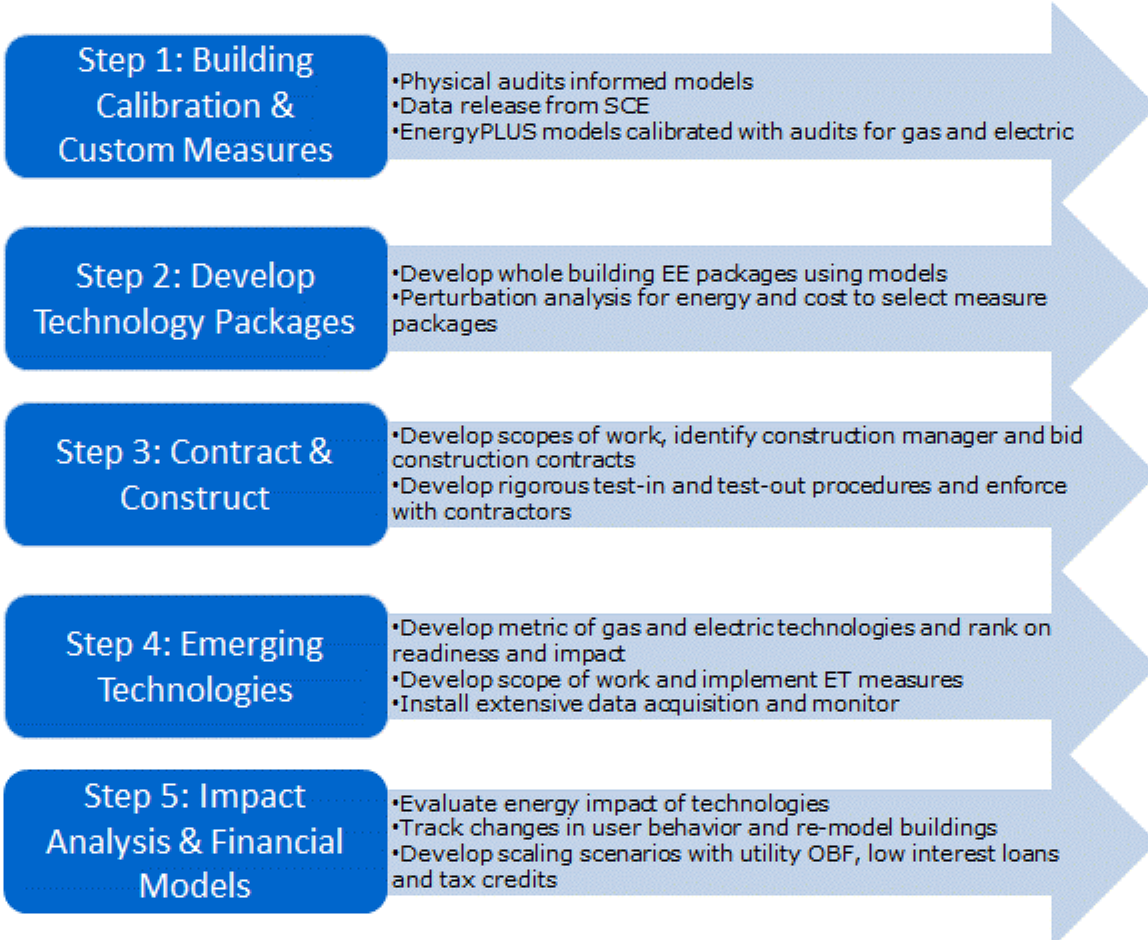


Figure 1: Overall Process for Project Execution

The project was implemented in a structured manner. It started with a thorough audit of the components and construction of current structures and their energy-consuming contents. Occupant interviews were conducted to survey small electric appliances, and behaviors including thermostat settings (both queried and observed) where possible. Audit information, including envelope components and areas, equipment age and efficiency ratings were used to develop building models. The models were simulated and adjusted to better fit the audit data, producing models that were calibrated to data from the actual buildings being modeled. With the calibration, high energy use could be identified and addressed with efficiency measures. EE measures were identified and analyzed to determine their individual impacts on energy use and other things that might alter their impacts, the relative difficulties implementing them, their availability, and relative scalability. In-depth HVAC system monitoring, combined with data from the AMI smart meters (both for electric and gas) were used to verify the efficacy and performance of the EE measures. Two sets of selected measures, one for the common area and one for the tenant units, were implemented and evaluated.

CHAPTER 2: ENERGY AUDIT AND ESTABLISHING THE BASELINE MODEL

2.1 SITE VISITS AND SURVEY

To conduct energy audits, the project started with site visits and energy use surveys. The research team visited the Village at Beechwood (Beechwood) site to collect the data needed to perform building energy simulations of the units, buildings, and overall complex. During the visit, the investigators measured the dimensions of the units and buildings (Figure 2) and recorded information regarding all of the energy-consuming devices and equipment, and performed tests to measure duct leakage (duct blaster test) and envelope leakage (blower door test). This approach was efficient, and in three days, the team determined the input parameters for all 100 buildings. This was achieved in two separate trips, one to physically view the units and as much of their construction components as possible. This one-day visit also allowed viewing several units to see their appliances. Then, a separate two-day trip was conducted to measure building envelope and duct leakages. After developing the computer models, another site visit followed, to investigate the duct systems in detail.

Figure 2 is a bird's-eye view of the entire property, with key energy systems, and Figure 3 shows one of the MF buildings at the Beechwood site.

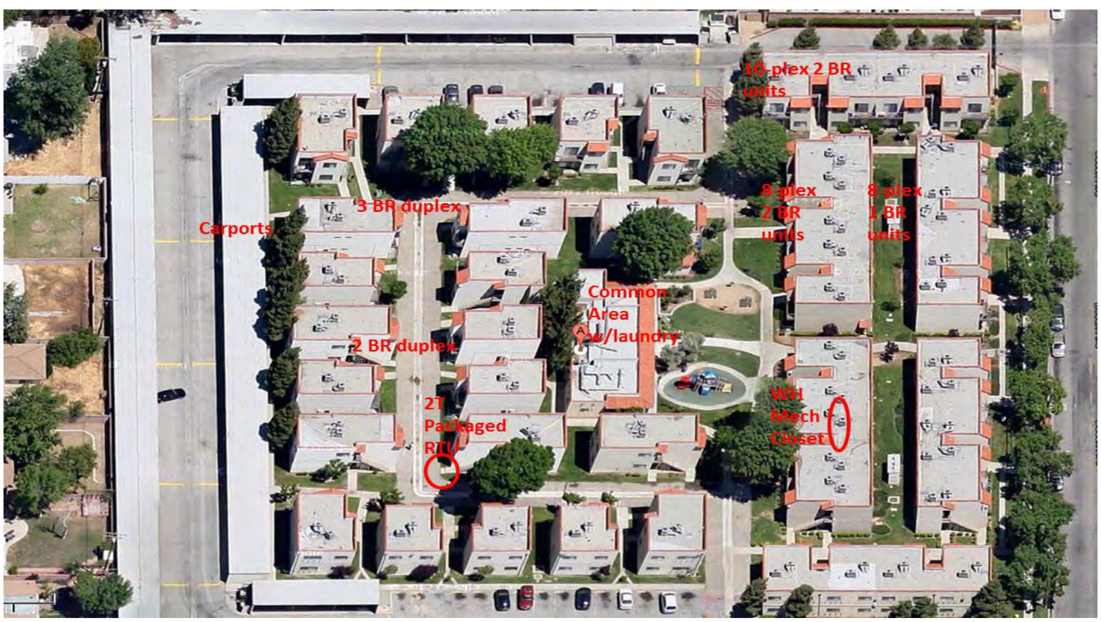


Figure 2: View of Beechwood Property, with Key Energy Systems Identified

Figure 3: Example of Beechwood Community Multifamily Construction

Computer-aided energy simulation models were developed to analyze building energy use. The models were developed in pieces, starting with a library of the different unit types, assembling the appropriate units into each building type. For this purpose, the team chose to investigate each of the different configurations of bedrooms and construction types. The spread of building types at the Beechwood campus is listed in Table 2:

Table 2: Matrix of Dwelling Unit Types and Numbers per Building

No. of Buildings	Bedrooms per Unit	Units per Building
2	1	10
2	2	10
2	2	8
11	2	2
11	3	2

The distribution of dwelling units and building types at Beechwood resulted in five different model types that can be assembled to represent the actual buildings at Beechwood. The unique configurations are provided in Table 3:

Table 3: Matrix of Beechwood Units and Buildings

Beechwood Building #	Bedrooms per Unit	Units per Building	Front Orientation
1	2	8	North
2	2	10	West
3	1	10	East
20	2	2	North
21	3	2	North

2.1.1 Initial Site Visit

Each of the computer models was developed based on actual buildings, for which energy audits were conducted. Upon an initial visit by the research team, the basic construction type was noted, and the building dimensions measured. The name plates of the rooftop units, furnace, and water heaters for Domestic Hot Water (DHW) were pictured and recorded. The roof-mounted packaged HVAC units on Building 1 were rated at 12 Seasonal EE Ratio (SEER) and 80% annual fuel utilization efficiency (Figure 4). The DHW outbuilding housed two gas-fired, 0.82 energy factor, 100 gallon tanks, which provide hot water to 26 units within Buildings 1 – 3. Figure 5 shows two of three DHW units per outbuilding. Another identical system provided hot water to Buildings 4 – 6. These systems had circulation pumps activated by demand for hot water, and wouldn't run if the water at the tap was already hot. Pumps were behind the tanks, and were not visible. The laundry room is well-equipped with 10 washers and 10 dryers, and is located in the back of the common area (Figure 6). The refrigerators were top-freezer style (Figure 7) and the ranges were standard gas fired (Figure 8). All windows were double-pane with metal frames (Figure 9). Figure 10 shows the ceiling insulation through a damaged exterior wall, which exposes an estimated two inches of fiberglass batt insulation.

Figure 4: Rooftop Packaged HVAC Units on Building 1

Figure 5: Domestic Hot Water Tanks

Figure 6: Washers and Dryers

Figure 7: Top-Freezer Refrigerators

Figure 8: Standard Gas Ranges

Figure 9: Double-Pane Windows with Metal Frames

Figure 10: Damaged Section of Exterior Wall, with Two Inches of Batt Insulation

Table 4: Miscellaneous Electric Loads (MELs) Used by Tenants

ELECTRIC USE	AVERAGE QUANTITY	NUMBER OF HOURS (AVG)	Watt Draw	Energy/Unit (kWh/yr)	Source
AIR CLEANER	0.04	2.00	400	65.70	Survey
BABY MONITOR	-	-	200	22.80	Survey
BLENDER	0.40	0.17	800	7.00	Survey
CABLE BOX	0.56	8.94	50	134.10	Survey
CLOCK RADIO	0.08	16.00	12	14.90	Survey
COFFEE MAKER	0.52	0.47	1,250	61.20	Survey
CURLING IRON	0.36	1.00	1,500	1.00	BA MELs
DEEP FRYER	0.08	0.14	600	20.00	BA MELs
DVD PLAYER/VCR	0.72	4.20	120	49.80	BA MELs
ELECTRICAL GRILL/GRIDDLE	0.08	0.14	1,100	180.00	Survey
ELECTRIC SHAVER	0.04	0.08	200	1.00	Survey
FAN (PORTABLE)	0.46	8.00	120	11.30	BA MELs
HAIR DRYER	0.44	0.50	1,850	41.10	BA MELs
HEATING PADS	0.08	0.03	800	3.00	Survey
FISH TANK	0.08	24.00	25	180.00	Survey
MICROWAVE	0.92	0.64	1,100	131.20	Survey
PRINTER	0.12	0.08	100	15.50	Survey
SLOW COOKER/CROCK POT	0.24	3.50	350	16.00	BA MELs
SUBWOOFER	-	1.00	600	68.30	BA MELs
TELEVISION	2.00	6.61	200	125.40	Survey
TOASTER	0.48	0.63	1,000	45.90	BA MELs
TOASTER OVEN	0.12	0.25	1,200	32.30	BA MELs
VIDEO GAMING SYSTEM	0.24	3.50	600	20.40	Survey
WAFFLE IRON	0.08	0.14	850	25.00	BA MELs
Total				1,273	

To help estimate the Miscellaneous Electric Loads (MELs), the team developed a questionnaire for the tenants regarding the variety and types of electric-powered equipment plugged into wall sockets. The Beechwood staff assisted in developing the questionnaire and personally interviewed approximately 30 tenants. Table 4 provides the details of MEL usage by tenants. The average MELs per unit, using the results of the occupant questionnaire, were estimated to be 1,273 kWh/yr., with a survey sample of n= 25.

2.1.2 SECOND SITE VISIT

A second site visit was conducted, accompanied by a certified third-party inspection firm. During that visit; blower door, duct blaster, and flow hood HVAC testing was conducted (Figure 11). The envelope leakage (blower door) test and duct blaster test measured leakage and evaluated the apartment units' thermal performance improvement, and identified impacts on the energy bills and occupant thermal comfort. The duct blaster test measured duct leakage by pressurizing ducts to 25 Pascals (Pa) and recording the Cubic Feet per Minute (CFM) needed to achieve a stable 25 Pa with the pressure-fan (duct blaster) sealed to the return, and all supply ducts sealed with tape. Blue painter's masking tape was used to attach equipment (duct blaster) to the apartment, and to seal any registers, windows, or doors. Envelope leakage (blower door) tests were conducted with all windows and doors closed (except the front door, where the blower door equipment and fan were installed). The apartment was tested at 50 Pa, and the CFM needed to reach 50 Pa was reported. If 50 Pa could not be achieved; the actual pressure was noted on the datasheet. Test results are summarized in Table 5, to assist in developing baseline simulation models.

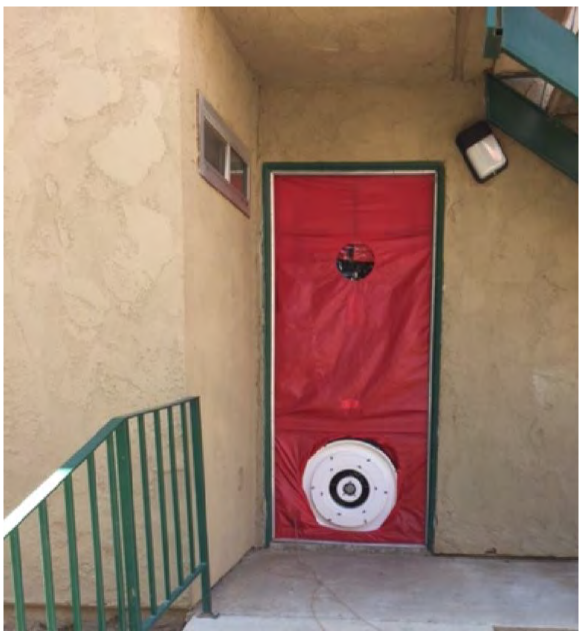


Figure 11: Blower Door Test in Progress

Table 5: Duct, Envelope, and HVAC Performance Test Results, Prior to Measures

Units								CFM	CFM			CFM		CFM
Test Pressure (Pa)								25	25	%	%	50		25
BLDG	UNIT #	Type	Up or Down Stairs	End or Middle Unit	Condi-tioned Floor Area	Air Condi-tioner Size (ton)	Air Condi-tioner Air Flow	Duct Leakage	Duct Leakage to Outside	% Duct Leakage to Outside	Duct % Leakage	Infiltration	ACH50	Air Flow Grid
3	20	1 BR	Up	End (10)	582	3	1092	177	123	31%	16%	1055	13.6	660
5	44	1 BR	Down	Middle (10)	582	3	1092	177	123	31%	16%	1350	17.4	575
1	7	2 BR	Up	Middle (8)	842	3	1092	192	168	13%	18%	1380	12.3	781
4	29	2 BR	Down	End (10)	842	3	1092	192	168	13%	18%	1570	14.0	654
27	98	3 BR	Up	Duplex	1045	3	1092	279	252	10%	26%	2059	14.8	827
21	85	3 BR	Down	Duplex	1045	3	1092	378	273	28%	35%	1744	12.5	634
					AVERAGE	3	1092	233	185	21%	21%	1526	14.1	689

2.2 DEVELOPING BASELINE ENERGY MODELS

The data collected from the survey, site visits, and performance test results was used to construct energy models of the buildings at Beechwood. Table 6 provides a list of the existing energy features, which were used to develop the base-case energy models for different unit types. These unit types were modeled using BEopt v2.0.0.6 – a building energy modeling software suite designed and developed by the National Renewable Energy Laboratory for simulating single-dwelling units, or for developing optimization analyses. BEopt provides a convenient user shell for EnergyPlus, one of the most sophisticated energy modeling engines available today. BEopt v2.0.0.6 was the most current version of BEopt, and the most current version of EnergyPlus v8.1 was used to run modeling algorithms. The building's energy-related features are listed in Table 5.

Table 6: Baseline Energy Features for Modeling Beechwood Apartments

Feature Modeled	Beechwood Base Case Package
Miscellaneous Electric Load	1273 kWh/year per unit
Heating / Cooling Setpoints	72 / 75
Interior Shading Coefficienct	0.95
Attic Insulation	R-6.4 cellulose in ceiling (Assembly U-Factor = 0.1220)
Roof Material	Light Colored Gravel (Absorptivity = 0.75, Emissivity = 0.91)
Wall Insulation	2" cellulose, 2x4 16" o.c. (Wall Assembly R-Value = 0.1250)
Exterior Finish	Stucco, light color (Absorptivity = 0.55, Emissivity = 0.90)
Window Types	Double pane, metal frame (E Factor = 0.76, SGHC = 0.67)
Window Area, Building 1	Front = 126 sqft, Back = 76 sqft
Window Area, Building 2	Front = 126 sqft, Back = 76 sqft
Window Area, Building 3	Front = 126 sqft, Back = 40 sqft
Window Area, Building 20	Front = 125 sqft, Back = 62 sqft, Right = 4 sqft
Window Area, Building 21	Front = 126 sqft, Back = 84 sqft, Right = 36 sqft, Left = 4 sqft
Air Leakage	14.1 ACH50
Refrigerator	Top-mounted freezer, 480 kWh/year
Dishwasher	318 kWh/year
Clothes Washer	On-Site Laundry Room
Clothes Dryer	On-Site Laundry Room
Lighting	100% Incandescent
Air Conditioner	12 SEER / 10.25 EER
Furnace	80% AFUE
Ducts	32% Leakage, Uninsulated
Water Heater	Multiplex: Shared portion of 100gal Boiler (0.80 EF)
	Duplex: 40gal Storage (0.62 EF)
Hot Water Distribution	Copper Tubing, trunk-and-branch architecture, uninsulated

BEopt v2.0.0.6 was unable to model MF buildings (i.e., to produce and provide EnergyPlus with the input values appropriate to buildings with more than five bedrooms). For this reason, multi-unit buildings with more than two dwelling units were "divided" into paired up- and down-stacked units for the two end-units, and the middle units, with adiabatic surfaces where the stacked units are bordered by another stacked pair, for each of the 1-, 2-, and 3-bedroom apartments. Each up-down pair was simulated using BEopt v2.0.0.6, and the results accumulated to produce simulation results for 8- or 10-plex buildings, all from component up-down unit pairs. This "built-up" arrangement is shown in Figure 12, which shows the adiabatic surfaces as black.

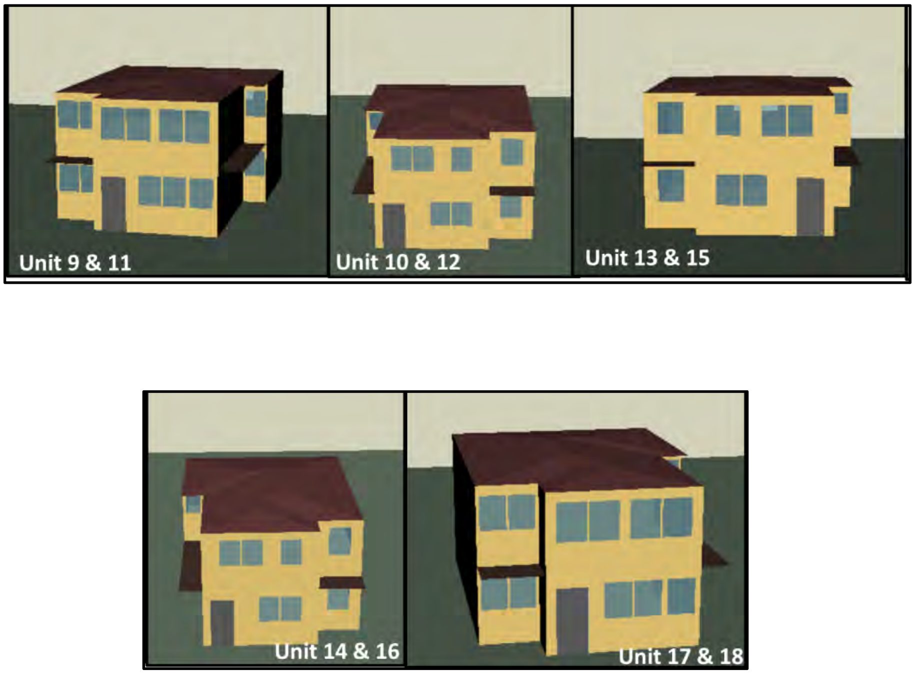


Figure 12: 3D Renderings of Input Geometries Assembled to Form Building 2

Figure 13 shows the "built-up" model (without adiabatic surfaces). A sample rendering of the various units used in the simulation are shown in the "built-up" input geometry (excluding the adiabatic surfaces).

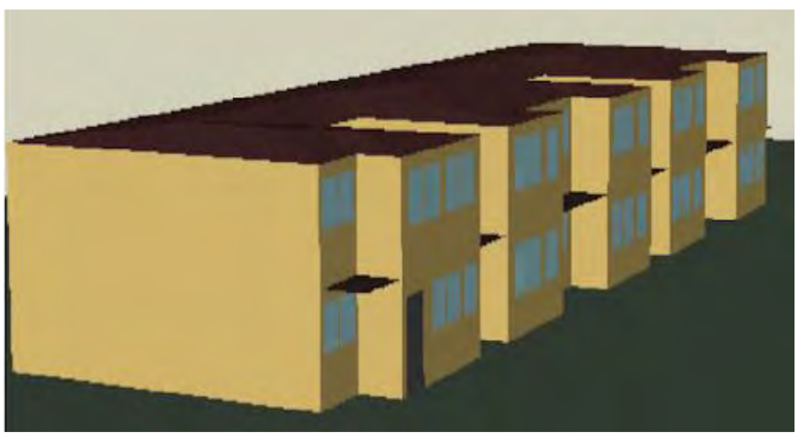


Figure 13**: 3D Image of "Built-Up" EnergyPlus Model Used in Building 2 Simulation**

As mentioned, this "built-up" approach is done because BEopt v2.0.0.6 was then the most advanced version, which couldn't simulate more than five bedrooms per model. At the end of the project, the team could simulate the entire building using BeOpt v2.6.0.2, and that set of results is discussed in Chapter 6. Thus, Building 21, a duplex of apartments with three bedrooms each, was unique in that each living unit was simulated individually. The input geometry model used for Building 21, with the adiabatic surfaces being either the foundation or the roof, was built up from the individual living units, and the results of the two models were combined into a duplex.

As previously described, to obtain a consistent value for modeling MELs, 1,273 kWh/yr produced a good baseline for the Beechwood duplex models. This value was determined from the questionnaire results. Sample simulation results are provided in Figure 14.

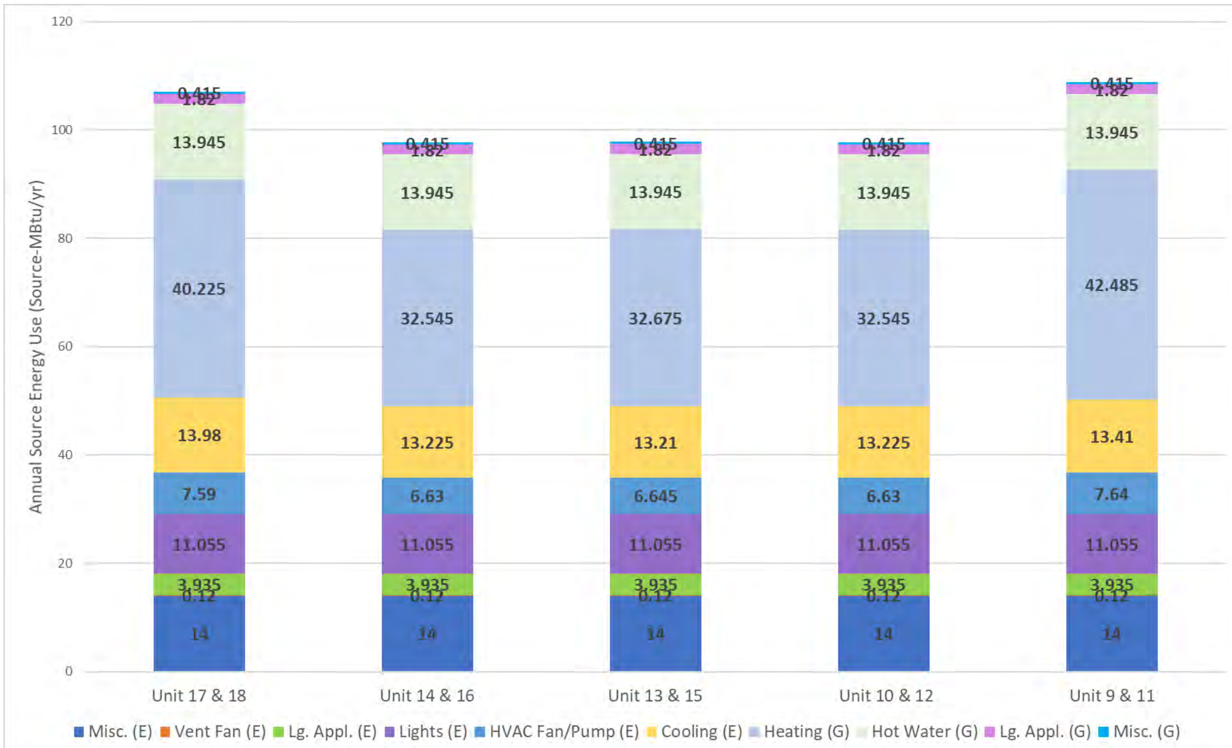


Figure 14: Source Energy End Uses for Five Models of Building 2 Units 9 – 18

2.2.1 Simulation Results of Baseline Energy Models

The energy output of the BEopt v2.0.0.6 models were compared to the actual energy used by the units, as determined from utility bills obtained from the utilities, with the occupants' permission. As shown in Figure 15 and Figure 16, the simulated energy use tracks the actual energy use very well, with the two data sets shown having an average monthly difference, across all the buildings' simulations, of ±5% (see Table 7 and Table 8). A comparison of the average simulated monthly electrical use of a unit in Building 2 and the actual average electrical use of a unit in Building 2 for 2011-2013 are shown in Figure 15. The calculated standard error for an average simulated month in Building 1 was 9%, compared to the availability utility billing data. However, the average error of the monthly electrical use, in all the models used in this study was 5%.

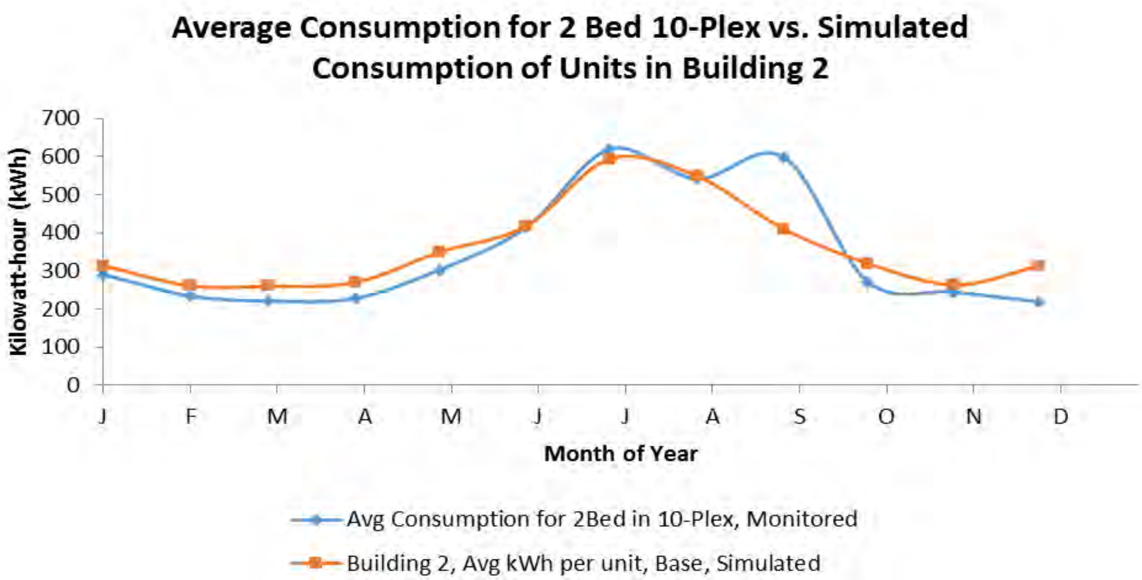


Figure 15: Comparison of Simulated and Actual Energy Use for a Single Unit

The accuracy of the various models was calculated individually, and also for the entire Beechwood community. Table 7 shows the difference errors calculated for the various models, as well as an approximation of the overall error of the site simulation.

Table 7: Analysis Indicating 5% Match between Model and SCE AMI Data

	Simulated, Avg Units, from 2nd Pass (kWh)					Monitored, Avg Unit (kWh)					Error, per unit, per month					
Monitored Monthly Schedule	Building 1, Avg kWh per unit, Base	Building 2, Avg kWh per unit, Base	Building 3, Avg kWh per unit, Base	Building 20, avg unit, Base, kWh	Building 21, avg unit, Base, kWh	Avg Consumption for 2Bed in 8-Plex, Monitored	Avg Consumption for 2Bed in 10-Plex, Monitored	Avg Consumption for 1Bed in 10-Plex, Monitored	Avg Consumption for 2Bed Duplex, Monitored	Avg Consumption for 3Bed Duplex, Monitored	Avg Consumption for 2Bed in 8-Plex, Monitored	Avg Consumption for 2Bed in 10-Plex, Monitored	Avg Consumption for 1Bed in 10-Plex, Monitored	Avg Consumption for 2Bed Duplex, Monitored	Avg Consumption for 3Bed Duplex, Monitored	Total
J	314	314	261	406	420	332	290	254	399	387	-5%	8%	3%	2%	9%	3%
F	262	261	218	334	343	259	234	207	361	329	1%	12%	5%	-7%	4%	3%
M	261	260	217	332	344	263	220	211	291	304	-1%	18%	3%	14%	13%	10%
A	267	270	217	285	403	232	227	201	230	289	15%	19%	8%	24%	40%	21%
M	335	349	276	304	512	341	302	289	283	370	-2%	15%	-4%	7%	39%	11%
J	397	417	337	362	589	514	414	373	409	612	-23%	1%	-9%	-12%	-4%	-9%
J	576	593	496	562	806	707	620	592	665	1,052	-19%	-4%	-16%	-15%	-23%	-16%
A	532	548	454	522	759	594	542	508	518	818	-10%	1%	-11%	1%	-7%	-5%
S	401	409	331	362	591	614	599	555	423	853	-35%	-32%	-40%	-15%	-31%	-30%
O	323	320	257	308	475	348	271	262	184	356	-7%	18%	-2%	67%	34%	22%
N	263	263	220	337	357	251	244	236	179	316	5%	8%	-7%	88%	13%	22%
D	313	313	260	405	419	296	219	196	312	324	6%	43%	33%	30%	29%	28%
	4,245	4,316	3,545	4,518	6,019	4,751	4,182	3,883	4,251	6,008	-6.2%	8.9%	-3.2%	15.4%	9.6%	4.9%

The Beechwood complex is master-metered for all natural gas used throughout the complex. Thus, there is no granularity to the available data for the natural gas consumption at the Beechwood complex, so the natural gas use cannot be resolved with complete confidence either for the building or for the individual-unit level. The research team simulated every unique building type on the Beechwood campus, including the common area, and compiled these simulation results into a simulated master-metered natural gas use to correspond to that from the utility bill. This comparison of the simulated Beechwood community's natural gas consumption was compared to the consumption recorded by SoCalGas during 2011-2013 (Figure 16). The calculated standard error of Beechwood's natural gas use for an average simulated month was 5%, compared to the available utility bill.

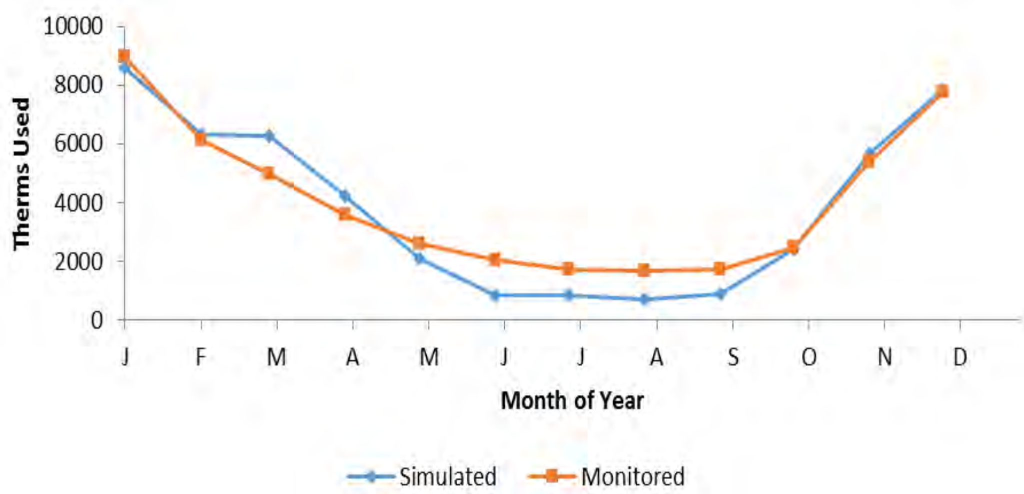


Figure 16: Comparison of Modeled and Actual Natural Gas Consumption

The accuracy of the natural gas simulation was also determined, in this case for the site. The results of the Beechwood community's modeled natural gas consumption, compared to the average master-metered natural gas utility bill from 2010-2013, is shown in Table 8.

Table 8: Master-Metered Natural Gas Bill for Beechwood Community (in Therms)

	Simulated	Monitored
January	8,587	8,972
February	6,303	6,145
March	6,265	4,949
April	4,221	3,592
May	2,114	2,602
June	858	2,054
July	823	1,743
August	686	1,677
September	876	1,703
October	2,435	2,474
November	5,652	5,391
December	7,863	7,736
Total	46,683	49,038
Difference		-4.8%

CHAPTER 3: VERY EFFICIENT RETROFIT PACKAGE

Once the baseline model and simulation were complete, they were used to build a library of efficiency measures and their individual impacts that could be combined into a VER package, from which the team could extract and test a cost-effective set of energy-saving measures. The installation and operation of the package needed to be as non-intrusive to the tenants as possible, and easy to install. Therefore, the design objective was to create an effective, unobtrusive, and inexpensive solution. The process used to evaluate, and rank measures was discussed in Task Report 2.3 (one of three separate reports submitted to the (CEC) [17], and the results were used to develop the near-ZNE packages, which were essentially VER packages plus solar generation. The process used to develop the VERs packages is outlined in the flowchart in Figure 17, which also shows how this process was divided into three separate subtasks (2.1, 2.3, and 2.4), each outlined in a different color.

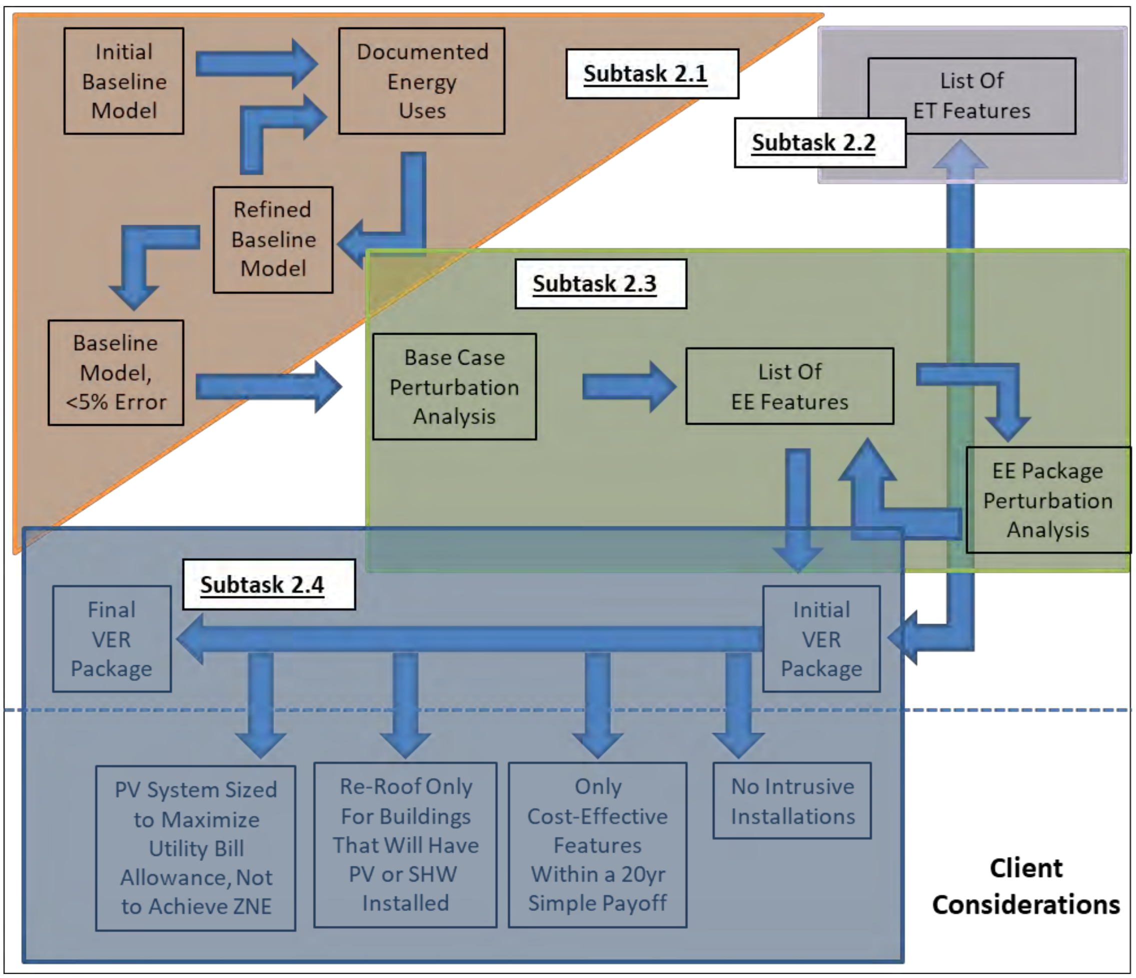


Figure 17: Process Diagram for Energy-Efficiency Package Development

Subtasks 2.1, 2.3 and 2.4 were covered in separate reports to the CEC. In consideration for the development of the best package of measures for this project, the evaluation included the following: individual efficiency improvements, (including their impacts, costs, and barriers), and the incorporation of PVs and solar water heating (including a re-roof insulation prior to solar collector installation). The report of work performed under Subtask 2.1 covered the development of Beechwood's baseline models and simulation results. Subtask 2.3 covered the development of a method and system for ranking efficiency measures, and Subtask 2.4 provided a description of the final VER packages, as well as package rationale. Task 2.2 evaluated emerging technologies, and was not directly related to VER package development – it was discussed in an entirely separate, independent report.

This chapter describes the process of developing VER packages containing EE features, targeting near-ZNE, and exploring and potentially developing financial strategies that make VER implementation cost-effective to the property owners. The first section of this chapter describes the methods developed to select and rank the project's VER package EE measures. The second section describes the process used to evaluate the VERs and select the most appropriate set(s) of efficiency measures, which became the final VER package for this project.

3.1 Methodology of Ranking EE Measures for VER Package

Energy models of the different building types were generated using a method to build the multiplex buildings from two-unit stacked modules, as described in Chapter 2. The modeling technique involved making computer models of the buildings, using pairs of stacked units (top and bottom units that shared a foundation, roof and walls) using adiabatic surfaces for any walls also shared with neighboring stacked units. All the permutations of end- and middle-units were modeled and simulated. The results from these two-unit models were combined to produce a full, multi-unit building simulation (8-plex or 10-plex; duplexes were modeled directly). A sample rendering of the various units used in the simulation is shown in Figure 18, in the "built-up" input geometry.

Figure 18: Built-Up Energy-Plus Model of 10-Unit Apartment Building

Beyond evaluating the heating, cooling, lighting, and water heating loads, it was important to estimate MEL usage, to accurately model the buildings' energy performance. To estimate the MELs of an average unit, a survey questionnaire was developed by working with the property management staff, who asked tenants about the electric appliances and devices they had plugged into their wall outlets, to determine when and how they were used. The collected data was used with the modeling software to modulate estimates of average MEL usage, and was incorporated into the dwelling unit simulation results. The input parameters are shown in Table 9.

Table 9: Base-Case Energy Features Used to Model the Beechwood Apartments

Modeling Parameter	Beechwood Base Case Package
Miscellaneous Electric Load	1273 kWh/year per unit
Attic Insulation	Ceiling Assembly U-Factor = 0.1220
Roof Material	Light colored gravel (Absorptivity = 0.75 , Emissivity = 0.91)
Window Types	Double pane, metal frame (E Factor = 0.76, SGHC = 0.67)
Air Leakage	14.1 ACH50
Refrigerator	Top-mounted freezer, 480 kWh/year
Dishwasher	318 kWh/year
Lighting	100% Incandescent Lighting
Air Conditioner	12 SEER
Furnace	80% AFUE
Ducts	32% Leakage, Uninsulated
Water Heater	Multiplex: Shared portion of 100gal Boiler (0.80 EF)
	Duplex: 40gal Storage (0.62 EF)

3.1.1 Identification of Potential VER Measures and Reasons for Rejection

Once the baseline model and simulation were completed, the research team started on building a library of efficiency measures for potential inclusion in a VER package. EE measures were identified to reduce energy consumption in all end uses, including space heating, space cooling, HVAC and other fans impacting thermal comfort, water heating and hot water distribution, lighting, large appliances ("white box appliances"), and miscellaneous electricity and gas uses. After the identification process, various metrics for each energy feature were recorded, including: the potential energy savings, cost, availability, practicality, and energy savings, as well as ease-of-installation factors, such as how obtrusive/unobtrusive is it for the occupants, and do they need to temporarily vacate (for less than a day) or move out (at least overnight) and/or does the unit need to be cleared of its contents. The process used to develop the near-ZNE packages followed the methodology outlined in the flowchart in Figure 17.

Data collection was needed to develop packages that were as non-intrusive as possible. As mentioned, the level of intrusiveness of each potential retrofit feature was a consideration during the EE measure selection and ranking process, as was the overall intrusiveness of each potential measure package. Some measures could only be practically installed while the tenants were away during the day, whereas other measures required the unit to be unoccupied and emptied of furniture and decorations, most likely requiring that such measures be installed only when the units were flipped from one tenant to the next.

Beechwood has historically operated at about 95% occupancy, with tenants staying a year or more. Measures requiring units to be vacant before installing one or more of the VER features were rejected for implementation in any of the VER packages, because it would have resulted in significant scheduling and accompanying cost problems, and would have delayed the VER package completion by months or years while waiting for a tenant change. These measures were still evaluated as part of an emerging technologies effort to evaluate whether such installation limitations could be eliminated in the future, as well as to provide data to compare cost/benefit with other measures. Thus, an informed decision could be made as to whether to install such measures when occupants changed, or wait for future measure improvements. The retrofit process typically required a few days to complete, creating some level of occupant inconvenience.

3.1.2 Sorting and Classifying Potential VER Measures

Beyond those measures that required units to be empty, the first level of sorting was based on the team’s experience with each measure. Modeling parameters, availability, cost, practicality, difficulty or skill level, and installation training were all considered. Measures known to fail one or more of these selection criteria were rejected from further consideration. For instance, the building owner instructed the team not to consider installing foam cladding on the walls due to the resulting cost, noise, and general disruption of tenants’ lives. The remaining measures were evaluated using simulations to determine the relative efficiency savings for each measure, taken independently. That is, after baseline completion and calibration, each potential measure was individually added to the baseline model, to determine its own impact on energy use. Single-measure impact analyses were performed, and data compiled. Purchase and installation costs, as well as notes regarding practicality and availability, were added to this compilation of single-measure efficiency benefits. This data compilation provided the basis for comparing each measure’s potential to be included in a VER package, based on relative efficiency, cost, availability, and installation properties. This analysis process and its results were termed a “perturbation” or “sensitivity” analysis, and did not measure any interactions between measures. A partial list of the findings of this perturbation analysis is provided in Table 10.

Table 10: Example Energy Impact Analysis

Single Feature Replacemet #	Base Case Single Feature Replacement Package
1	R-20 XPS Roof
2	Ducts in Conditoned Space
3	R8 Ducts, 7.5% Leakage
4	3.0 ACH50
5	56 sqft SHW
6	8.4 ACH50
7	0.29 / 0.31 Windows
8	Duct Sealing
9	R-13, Gr. 1 Walls
10	Radiant Barrier
11	R13, Gr. 3 Walls
12	100% LED
13	16 SEER AC (2-Stage)
14	0.96 EF Tankless Condensing DHW
15	0.21 / 0.21 Windows
16	Cool Roof
17	Min T24 Performance Frig & DW
18	2013-T24 Low Slope Roof
19	Home Energy Management System
20	2 Smart, Premium Ceiling Fans
21	Induction Cooktop
22	6 Smart, Premium Ceiling Fans
	Base Case, Building 20, avg unit

Simulation results from the sensitivity analysis are shown in Figure 19 and Figure 22 as stacked-bars, providing the total unit energy for each measure perturbation and its impact on the major energy end uses. The single efficiency feature added to the base case is identified by a number corresponding to the feature number in the left-most column of Table 10, labeled "Single Feature Replacement #". Note that while interactions between measures were not available for analysis using this approach, there could have been impacts on energy end uses beyond those typically associated with each efficiency measure. For instance, a significant decrease in lighting energy achieved by replacing all lighting with Compact Fluorescent Lamps (CFLs) or Light-Emitting Diodes (LEDs) could have also resulted in increased heating energy and decreased cooling energy, because there was less waste-heat produced by the interior lighting.

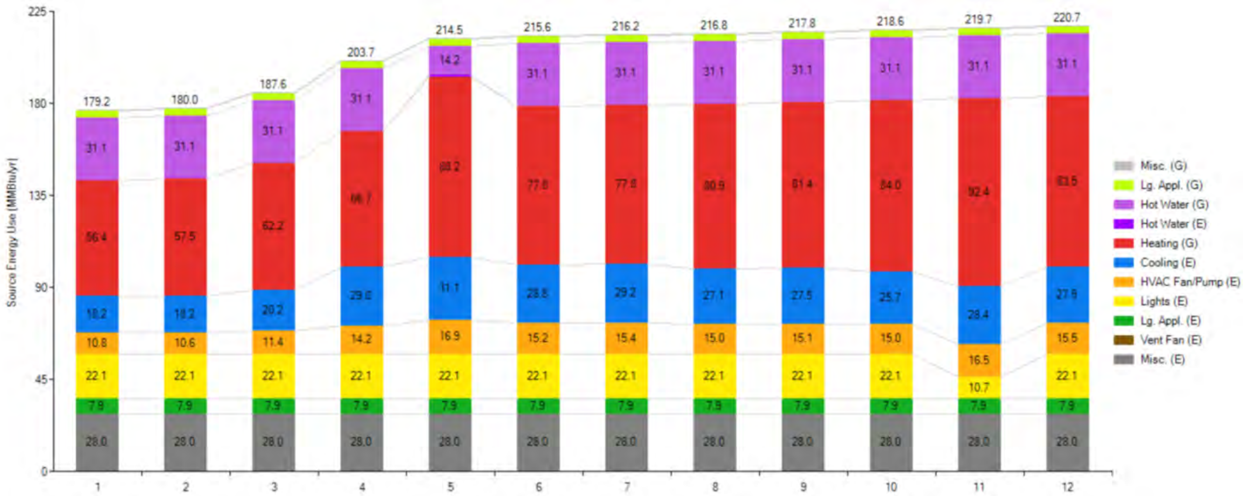


Figure 19: Single-Feature Replacement Analysis with VER Measures 1 – 12

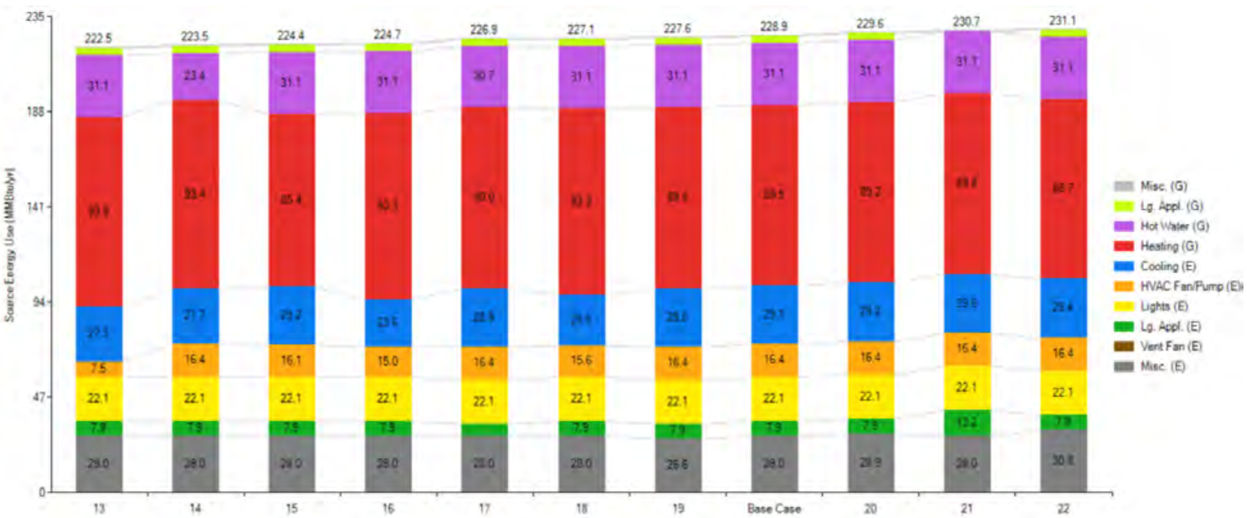


Figure 20: Single-Feature Replacement Analysis with VER Measures 13 – 22

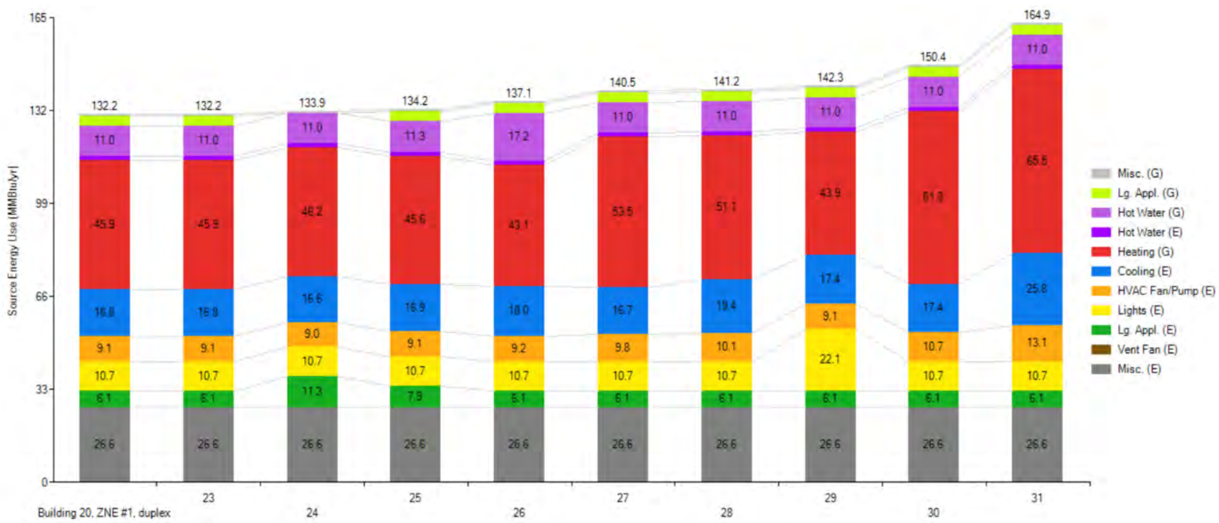


Figure 21: Single-Feature Replacement Analysis with VER Measures 23 – 31

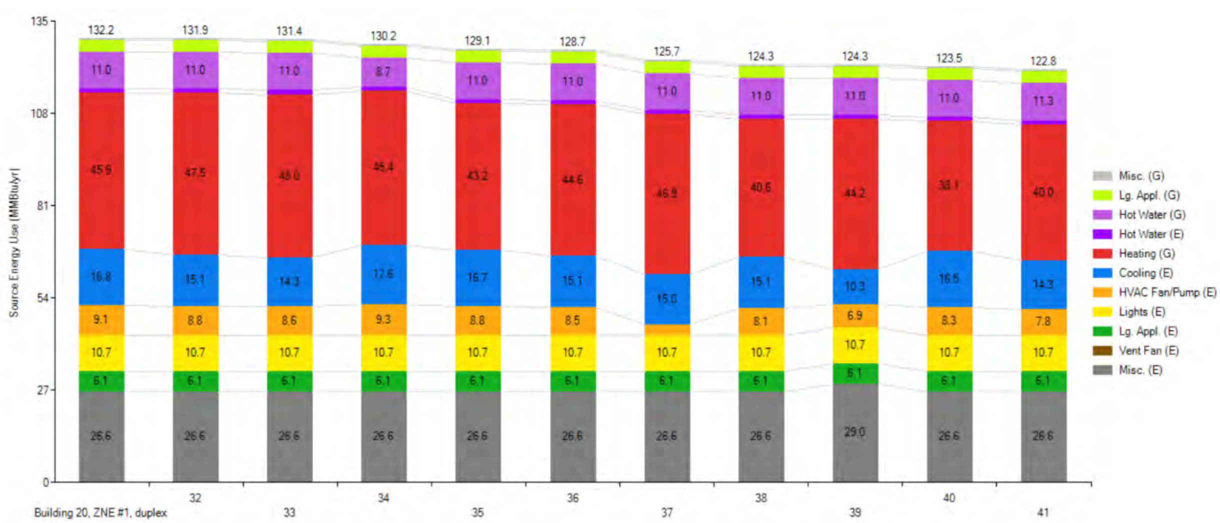


Figure 22: Single-Feature Replacement Analysis with VER Measures 32 – 41

Table 11: Source Energy and Cost Impacts of Single Features Tested in Perturbation Analysis

Single Feature Replace-ment #	Base Case Single Feature Replacement Package	Source Energy Use (s-Mbtu/yr)	% Source Energy Savings	Cost of Feature	Cost : Benefit ($/kBtu)	Annual Estimated Change in Utility Bill	Simple Payback (Years)	Used in Initial VER Packages?	Notes
1	R-20 XPS Roof	179.2	22%	$ 4,871	$ 0.10	$ 453	11	Y	Only used with PV install
2	Ducts in Conditoned Space	180.0	21%	$ 4,871	$ 0.10	$ 448	11	Y	1st Choice for Ducts
3	R8 Ducts, 7.5% Leakage	187.6	18%	$ 1,949	$ 0.05	$ 378	5	Y	2nd Choice for Ducts
4	3.0 ACH50	203.7	11%	$ 2,214	$ 0.09	$ 210	11	Y	Only used in duplex
5	56 sqft SHW	214.5	6%	$ 2,885	$ 0.20	$ 102	28	Y	
6	8.4 ACH50	215.6	6%	$ 1,476	$ 0.11	$ 111	13	Y	
7	0.29 / 0.31 Windows	216.2	5%	$ 5,140	$ 0.41	$ 104	49	N	
8	Duct Sealing	216.8	5%	$ 2,406	$ 0.20	$ 108	22	Y	3rd Choice for Ducts
9	R-13, Gr. 1, Cellulose Walls	217.8	5%	$ 4,826	$ 0.44	$ 98	49	N	
10	Radiant Barrier	218.6	4%	$ 494	$ 0.05	$ 98	5	N	Denied by contactors, due to roof type
11	R13, Gr. 3, Cellulose Walls	218.5	5%	$ 4,826	$ 0.47	$ 92	53	N	
12	100% LED	219.7	4%	$ 1,045	$ 0.11	$ 113	9	Y	
13	16 SEER AC (2-Stage)	222.5	3%	$ 1,200	$ 0.19	$ 86	14	N	Current AC has not met expected life
14	0.96 EF Tankless Condensing DHW	223.5	2%	$ 910	$ 0.17	$ 48	19	Y	Only in duplex
15	0.21 / 0.21 Windows	224.4	2%	$ 5,188	$ 1.18	$ 36	143	N	
16	Cool Roof	224.7	2%	$ 1,476	$ 0.36	$ 56	27	N	Current Roof has not met expected life
17	EnergySTAR Frig & DW	226.8	1%	$ 1,934	$ 0.97	$ 23	86	Y	Incentivized, Potential for more savings
18	2013-T24 Low Slope Roof	227.1	1%	$ 4,871	$ 2.77	$ 29	169	N	
19	Home Energy Management System	227.6	1%	$ 600	$ 0.50	$ 15	41	Y	Potential for 2.5x savings
	Base Case, Building 20, avg unit	**228.8**	**0%**	**$ -**	**$ -**	**$ -**	**n/a**		
20	2 Smart, Premium Ceiling Fans	229.6	0%	$ 800	$ (0.99)	$ (9)	-86	N	
21	Induction Cooktop	230.7	-1%	$ 1,879	$ (1.07)	$ (32)	-58	N	
22	6 Smart, Premium Ceiling Fans	231.1	-1%	$ 2,400	$ (1.08)	$ (28)	-86	N	

Table 12: Perturbation Analysis of the VER Case

Feature #	VER Case Single Feature Replacement Package	Source Energy Use (s-Mbtu / yr)	% Source Energy Savings	Cost of Feature	Cost : Benefit ($/kBtu)	Annual Estimated Change in Utility Bill	Simple Payback (Years)
23	Ducts Sealed to 7.5% Leakage, not in Conditoned Space, no insulation	164.9	-25%	$ 2,406	$ (0.07)	$ (153)	-16
24	Envelope not sealed (14.1 ACH50)	150.4	-14%	$ 2,214	$ (0.12)	$ (77)	-29
25	No LED or CFL lighting (original lighting)	142.3	-8%	$ 70	$ (0.01)	$ (60)	-1
26	Ducts Sealed to 7.5% Leakage, not in Conditoned Space, R8 duct insulation	141.2	-7%	$ 4,871	$ (0.54)	$ (42)	-116
27	Envelope Sealed to 8.4 ACH50	140.5	-6%	$ 1,476	$ (0.18)	$ (34)	-43
28	No 0.96 EF tankless condensing DHW	137.1	-4%	$ 910	$ (0.19)	$ (22)	-42
29	No EnergySTAR Refrigerator or Dishwasher	134.2	-2%	$ 1,934	$ (0.97)	$ (11)	-173
30	Induction Cooktop	133.9	-1%	$ 1,879	$ (1.11)	$ (15)	-126
31	No HEM	133.7	-1%	$ 600	$ (0.40)	$ (8)	-75
	VER Case	**132.2**	**0%**			**$ -**	
32	2013-T24 Low-Slope Roof	131.9	0%	$ 4,871	$ 0.05	$ 4	1101
33	Cool Roof	131.4	1%	$ 1,476	$ 0.02	$ 8	184
34	56sqft SHW	130.2	2%	$ 2,885	$ 0.03	$ 7	436
35	0.21 / 0.21 Windows	129.1	2%	$ 5,188	$ 0.05	$ 13	394
36	Radiant Barrier	128.7	3%	$ 494	$ 0.00	$ 18	27
37	16 SEER AC (2-Stage)	125.7	5%	$ 1,200	$ 0.01	$ 39	31
38	R15, Gr. 3, 2x4 16" o.c. Walls	124.3	6%	$ 2,431	$ 0.02	$ 36	67
39	Ceiling Fans, Smart, High Eff, 100% Coverage	124.3	6%	$ 5,834	$ 0.06	$ 42	138
40	0.29 / 0.31	123.5	7%	$ 5,140	$ 0.05	$ 37	139
41	R20 XPS Roof	122.8	7%	$ 4,871	$ 0.05	$ 44	111
41b	R15 Ballasted Roof Sections	122.8	7%	$ 2,373	$ 0.02	$ 44	54

To further evaluate the features to find the best packages, a full VER package was established using the highest-scoring features from the sensitivity analysis. Each feature's contribution to the VER was evaluated by simulating the building using a large number of the most cost-effective features, then removing and replacing each measure, one at a time, with all others remaining. This single-feature perturbation analysis provided insights on feature contributions when applied as a group, and interactions between measures. This approach, unlike the sensitivity analysis, brings out some of the measures' interactions because, when an individual measure is removed (or downgraded to the baseline value), the amount of interaction is lessened or eliminated, depending on whether the measure was incorporated in the baseline or with removal of a feature contributing to the interactions. The sensitivity analysis was performed on features 1 - 41, and a list of findings was captured in Table 11 and Table 12. Table 13 shows the results of the perturbation analysis from the VER case, showing how the final package feature list was derived and how it could change. The VER case used here was for Building 19, a duplex of two-bedroom units, so the building leakage for this case was 3.0 specific leakage area, and the water heater was 0.96 energy factor.

The most promising measures (based on the studies' simulation results, including for each feature the energy savings, feature cost, and any limitations for each measure) were envelope tightening and low-leakage ducts in conditioned space. These measures rose to the top of the list because of their large energy savings, relatively low cost, and, while definitely intrusive to the tenants, the residents can remain in their units while the contractors are installing the retrofits. Although these two measures require the occupants to vacate their units during normal working hours while construction is taking place, tenants can return during each evening-night-morning period, while the workers are gone. Additional measures that provided adequate savings in the sensitivity analysis, but not in the short list of measures (such as R-20 roof, and higher-efficiency HVAC systems) were those which were more expensive, or required unacceptable installation methods, such as replacing features that were only halfway through their anticipated useful lives, or for which the installations would have been too intrusive for unit occupancy.

Roof insulation was initially evaluated both as R-20 rigid foam underneath, and as part of re-roof efforts. This combination was not practical, because the existing roofs were in good condition and were estimated to have half of their lives remaining (about 15 years), and it was prohibitively expensive to replace and add foam mid-term. However, it is still unclear whether this approach should have been employed in Building 3, which would be retrofitted with Solar Domestic Hot Water (SDHW) collectors, making a re-roof practical to avoid having to remove the solar collectors within their useful lives. Similarly, although higher-efficiency HVAC units would have been cost-effective replacements for units that were at the end of their useful lives, the HVAC units were also at about half their lives, having been replaced at least once. The resulting economics were not sufficiently favorable for LINC to go to the expense of renting a crane to replace units that were expected to last another 8 – 10 years.

Roof insulation was also reviewed using R-15 ballasted roofing insulation. These are rigid foam insulation modules, with lightweight cement covers to protect the foam and provide ballast to keep them on the roof. This insulation approach could be used on all the buildings, providing the advantage of extending the existing roofs' lives by keeping them covered and protected from ultraviolet (UV) light and high heat. The undersides of the roof-insulation modules are grooved, to allow water to run off and not be trapped underneath. The modules can also be cut to fit around the HVAC systems and other obstacles. Discussion of this measure is warranted, to determine the best method to evaluate potentially delaying re-roofing from a 10-year to 20-year horizon.

There were also discussions regarding the underground piping from the central boilers to the multiplexes, including whether it was insulated, and if not, the size, length, and buried-depth of the plumbing. If not insulated, the losses would be considerable, and once exposed, the pipes would be simple to insulate. However, the cost of exposing the pipes was also unknown, and if exposed using machinery, there would be a significant risk of damaging the piping. So, while this was a very interesting and potentially cost-effective measure, additional discussion and perhaps data is required before moving forward.

The initial EE measures of the VER package consisted of: tightly-sealed ducts that were heavily insulated to thermally isolate them (modeled as being in conditioned space); low air-infiltration via envelope air sealing; solar water heating for the multiplexes, including a re-roof on the building that would support the solar collectors (with or without adding foam); condensing boilers for the first 100-gallon hot water backup for the multiplex's solar DHW system; and condensing tankless water heating for the duplexes. There was also an option to include solar water heating at the duplexes.

The packages included: replacing all lamps with LEDs or CFLs available through SCEs ESA program; new, more-efficient refrigerators (available through the ESA program for refrigerators manufactured prior to 1999); Programmable Communicating Thermostats (PCTs) and Home Energy Management Systems (HEMs) for each apartment unit. The initial package matrix is provided in Table 13 (these are simulation results from prior to pilot installation verification and analyses). Baseline features are highlighted in red, and the upgraded measures in blue, with the additional option of rooftop foam modules in green.

Table 13: Final VER Package Descriptions from Perturbation Analysis

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 21, Units 83 - 84)	ZNE #1c (Building 21, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)	Incremental Cost Per Each unit	Units of Costing
ZNE Package #	Baseline	1	1	1	2 (Alternative Package)	3	4 (SDHW)	4 (SDHW)		
Misc Electric Loads	1273 kWH/yr per unit	1273 kWH/yr per unit	1273 kWH/yr per unit	1273 kWH/yr per unit	1273 kWH/yr per unit	1273 kWH/yr per unit	1273 kWH/yr per unit	1273 kWH/yr per unit	$600	per unit
Unfinished Attic	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	R-15 Ballasted Foam Roof Membrane (Em = 0.4, Abs = 0.8)	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	$3.26	per sqft roofspace
Insulation Blown into reachable attics bays	2" fiberglass batts	7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor		7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor	$0.00	25% unit roof area
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	$0.00	per sqft CFA
Refrigerator	18 cu ft., EF = 15.9, top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	$0.00	per unit
Diswasher	318 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	$959	per unit
Lighting	100% Incandescent	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	$0	per unit
Ducts	Uninsulated, 32% Leakage,	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	$2,464	per unit
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF) Duplex: 40gal Storage (0.62 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)				$0.00	
						Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)	$910	per unit
Solar Water Heating	None	Everyday Energy; 24 panels total, evacuated tube drainback	Everyday Energy; 24 panels total, evacuated tube drainback	Everyday Energy; 24 panels total, evacuated tube drainback	Everyday Energy; 24 panels total, evacuated tube drainback				$1,280	per unit
							SunEarth EV 40 collector w/ 80 gal Rheem heat exchange tank	SunEarth EV 40 collector w/ 80 gal Rheem heat exchange tank	$2,885	per unit
Conditioned Floor Area, per unit	0	738	738	582	582	738	738	1017		
Cost, per unit		$ 5,303	$ 5,303	$ 5,303	$ 7,200	$ 4,933	$ 7,818	$ 7,818		

The VER package matrix shows the measures and their costs, which were used to estimate a simple package payback period. A summary of these estimates is shown in Table 14 (the estimated cost of solar panels was $1/W, but the installed PV cost, after rebates, is closer to $2/W). In combination with the simulation results, the cost/benefits can be calculated for the key packages. Once the final package(s) were chosen, firm costs could be determined from bids (possibly resulting in some reassessments). The resulting final features and their energy savings estimates and costs could be used to develop different possible financial models that may impact altering rent calculations or change some cost/savings assumptions in the existing financial models, or develop new models and policies.

During the initial assessment, it was determined that the ducts were old flex ducts, with no inner lining, and considerable dust and dirt. As a result, they were leaky and thermally poor. A "pilot" installation and evaluation of proposed duct improvements and envelope air sealing was to be conducted in June, to evaluate a novel approach to thermally isolating the ducts, which the team posits would perform as well as ducts in conditioned space. The results of the pilot study will be a key factor in determining the final VER package.

Table 14: Economic Analysis of VER Packages with and without PV

Building #	Base Case Electrical Bill (CARE)	Base Case Natural Gas Bill ($0.91 / therm)	VER Case Electrical Bill (no PV)	VER Package Cost, w/o PV	VER Case Natural Gas Bill ($0.91 / therm)	Annual Utility Bill Savings	Simple Payoff (years)	VER Case Electrical Bill (PV installed)	VER PV Size, per unit	VER Package Cost, w PV ($1/W)	VER Case Natural Gas Bill ($0.91 / therm)	Annual Utility Bill Savings	Simple Payoff (years)
20	$411.03	$ 321	$278	$ 7,884	$ 257	$ 197	31	$146	0.85	$ 8,736	$ 257	$ 329	27

3.2 IDENTIFICATION OF THE VER PACKAGE

This report describes the process of identifying the EE measures in the final VERs to be installed within the project's timeline. To facilitate this research, the team integrated new features into BEopt. These new modeling techniques predicted the best package for the occupied units. Pilot installations were conducted for the selected package, to verify effectiveness before installing the measures in the rest of the units.

A pilot retrofit installation was conducted in July 2014 to test the removal, replacement, sealing, and thorough insulation of the ducts, as well as to evaluate how well the units could be air-sealed. The ducts were exposed by removing the dropped ceiling that encloses the duct chase. In the test units, the ceiling was examined and determined to likely contain asbestos, so ceiling material removal and disposal was performed by a certified asbestos abatement professional. As determined in the preliminary evaluations, the existing ducts were old, poorly-sealed, poorly-insulated flex ducts. After gaining access, the ducts were removed and replaced with new, R-8 flex-ducts, which were carefully installed and sealed to minimize leaks. The new ducts were also encased in insulation prior to fitting the opening with new drywall. The main purpose of the pilot was to ensure the proposed approach would provide a relatively easy method for replacing the current duct system with tight, superinsulated ducts, garnering savings similar to ducts in conditioned space. The pilot was successful in this regard. Another key efficiency measure is sealing the envelope. In the pilot, this was done manually. The package would also include: SDWH for the multi-unit buildings; a condensing water heater for duplexes; a PCT; and a HEMS. None of these were evaluated in the pilot.

Installed measures included those from the utilities' ESA programs, along with measures paid for with Public Interest Energy Research (PIER) grant funds. The SoCalGas ESA program paid for weatherization, including weather stripping, door shoes and sweeps, door replacements, switch and outlet gaskets, locksets, and minor interior repairs that may have affected energy performance. The ESA program also paid for water measures such as faucet aerators, shower heads, and Thermostatic Shower Valves (TSVs). SCE's ESA program provided refrigerator replacements (for fridges manufactured through 1998), interior CFL bulbs, and smart power strips for homes with media or computer setups. These additions helped reduce the overall retrofit cost, and therefore increased its cost effectiveness.

3.2.1 Pilot Evaluation of VER Package

The pilot site evaluation required the same process as the full-size retrofit conducted later. The same retrofit contractor was employed. The process was conducted in two apartment units, and included the cost to move from poorly-insulated, leaky ducts to air-tight, and well-insulated ducts. This process is equivalent to putting the ducts in conditioned space (an R-value that performs the same as if the ducts were in a conditioned area), and air-sealing the envelope. During the pilot, once the duct chase area was opened, it was found that connecting ceiling bays were available for blowing in insulation, followed by sealing air paths between the building interstitial spaces and the duct chase. This was a field-determined scope addition, and therefore likely a somewhat higher cost than if planned from the beginning of the pilot. Approximately 180 square feet of ceiling insulation was installed in the second-floor unit. The asbestos removal may not have been necessary for similar post-1980 buildings (this may apply to similar buildings elsewhere).

In addition to standard envelope and duct air leakage tests, a temperature probe with on-board storage was installed in the collar connecting the kitchen supply duct to the grill, to record duct air temperatures before and after the retrofit. This was a simple approach to creating a basis for comparing the retrofit's actual effectiveness with the simulation results. Duct and envelope leakage were measured before ("test-in") and after ("test-out") the retrofits were performed. This data provided a clear demonstration that prior to the retrofits, the envelope and ducts had substantial leakage, and that post-retrofit, the contractor had achieved the target air sealing for the envelope and ducts. Smoke tests were performed to visualize the leakage in the pre-retrofit ducts. The results of the test-in and test-out leakage measurements are summarized below, along with pictures of the ducts, the smoke tests, and thermal imaging prior to removal. Pre-retrofit leakage values of around 22% were measured during test-in:

Test In: Duct Leakage

Unit #17 – 2-ton unit, (177) CFM @25p, 22.1% leakage

Unit #18 – 2-ton unit, (181) CFM @ 25p, 22.6% leakage

During the pilot, when the ceiling was removed to expose the ducts, and prior to their removal and retrofit, their leakage was visualized by smoke test with a thermal camera. Figure 23 shows a thermal view of a duct connecting to the main supply distribution box. The dark blue areas on the thermal camera screen are cold air from the AC unit leaking out into the duct chase. These were typical of the installations in both units. Figure 24 shows a duct collar connected to the duct distribution box. The round duct collar has metal mastic-sealed tabs on each side of the distribution box to hold it securely in place. The tabs are clearly visible, surrounded by cold conditioned air leaking around the connection.

Figure 23: Thermal Camera

Visual inspection of the original ducts found tears in the flex duct, and the thermal imaging camera identified noticeable leakage. The thermal camera also detected leakage at register boots in both apartments. Smoke tests, performed separately in each apartment, resulted in smoke filling the chase cavities and hallway areas. Using a flashlight to visually inspect the inside of the return in Unit 17 revealed gaps at the connections of the ridged pipe of the return-duct system (Figure 24). The return from the downstairs unit runs through the interstitial space around the upstairs unit, and when the smoke test was performed on the downstairs unit, smoke leaked into the upstairs unit (with the ceiling removed) via the leaks and interstitial space connections.

Unit #18 had high leakage at the supply plenum, confirmed by how quickly the hallway was consumed with smoke. We also found poor connections at all supply distribution connections, and large gaps after removing the insulation wrap and flex ducts.

All the existing flex ducts were removed and replaced with new, R-8 flex ducts that were connected to register boots, "Y" connectors, and transition collars using standard practices as defined by the Air Diffusion Council and required by the California Investor-Owned Utilities' (IOU) efficiency programs. Corrections and repairs to the steel connector parts of the duct systems in units 17 and 18 were made using Mastic, to seal all register boots and the inner and outer joints of the plenum sheet metal. The reducers and "Y" rigid sheet metal connectors were also treated this way, sealing all accessible seams in the sheet metal connectors and boxes. The supply plenum was taken apart at the distribution cutout collars, and then repaired, reinstalled, and sealed. Several of the connection gaps in unit 17s return were sealed with foam, using a long, quarter-inch tube connected to a foam canister. With this technique, the team was able to reach and seal return-pipe joints approximately 8′ inside of a 20′ run of 14″ rigid pipe.

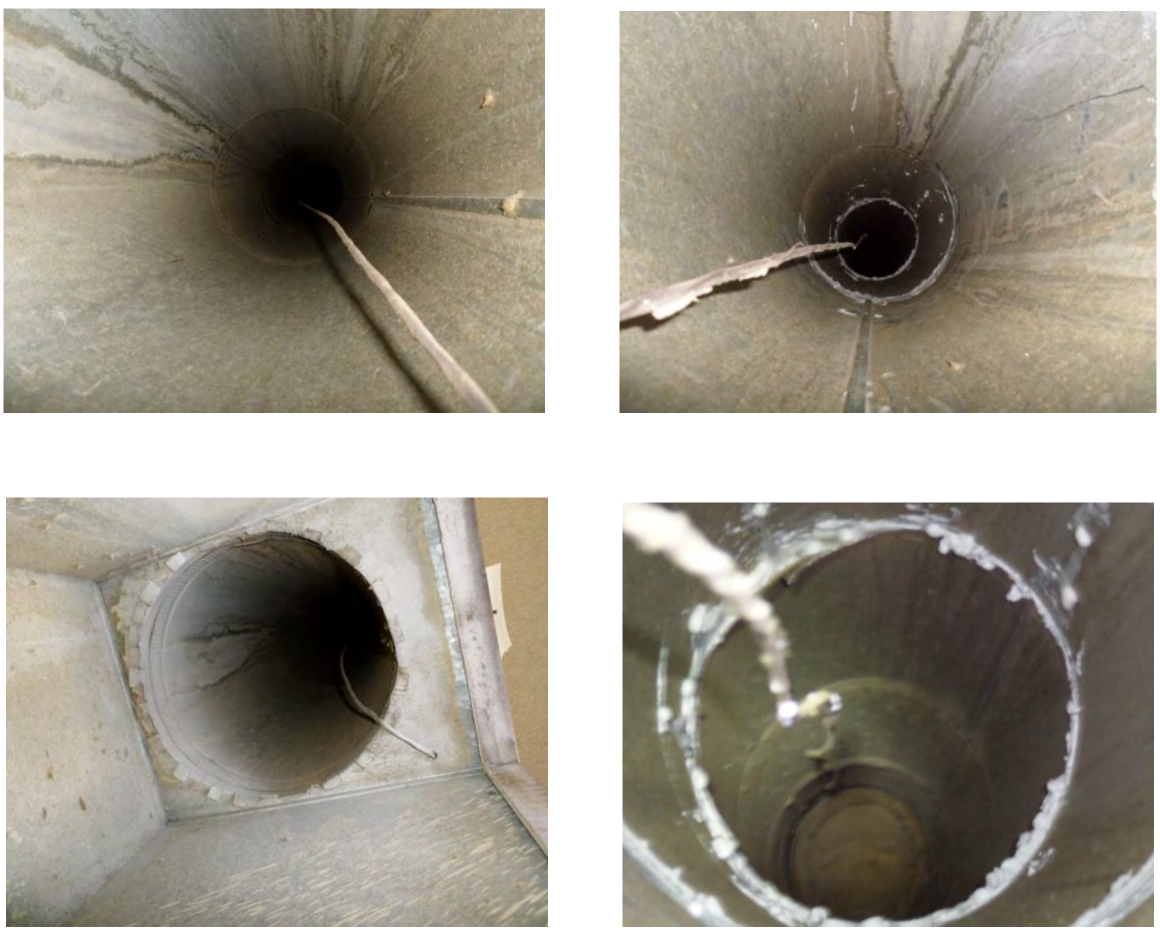


Figure 24: Application of Expansive Foam to Ducting Joints for Sealing

New R-8 ducts of 6″, 8″, and 10″ diameter were installed to replace the same inner-diameter size of original ducts. Boots and distribution collars were sprayed with adhesive to improve duct bonding to sheet metal; the junction of duct-to-collar was made with approved tape, and nylon zip ties were applied over the taped junction, to provide mechanical strength and a fully-secure seal. The post-retrofit leakage was as follows:

- Duct test after sealing in units #17 - #18
- Unit 17 - 2-ton unit, (118) CFM @ 25p, 14.7% leakage
- Unit 18 - 2-ton unit, (110) CFM @ 25p, 13.7% leakage

With the drop ceiling below the duct plenum removed, it was discovered that, in unit 18, some ceiling bays between truss members were accessible from the duct chase. The original 3″ rockwool insulation (originally R-13) was in place, and there was 7″ of air space in each bay, above the existing batt insulation. Loose-fill insulation was blown into these bays, filling the available 7″ of space and reaching as far into each accessible bay as possible. The addition of 7″ of loose-fill fiberglass to the original R-13 batt provided total insulation of approximately R-22. The areas that were treated included the living room and the two bedrooms, for a total area of approximately 182 square feet. This is a coverage of about 25% of the total ceiling area for a two-bedroom unit, of which the total floor area is 732 square feet (Figure 25).

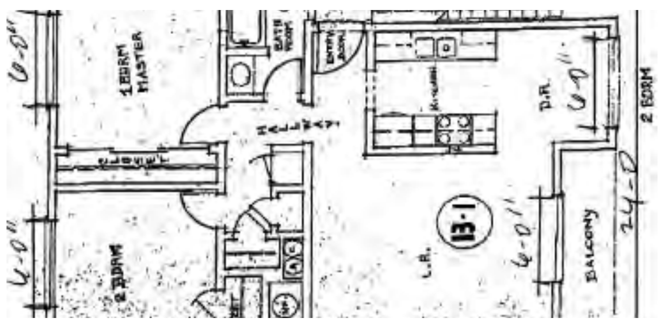


Figure 25: Two-Bedroom Unit Floor Plan

The air path connections between the duct chase and ceiling bays, and other interstitial spaces, were closed with R-19 batt and air-barrier material to stop air leakage between these different areas. R-19 batts were placed all around the edges of the duct chase, followed by applying additional blown fiberglass, to fill the hall and entryway drop-ceiling duct chase volume as much as possible. This additional duct insulation was about R-22.

Due to framing obstruction, the return cavity in unit 17 was difficult to reach with the fiberglass blowing machine hose. Due to ceiling asbestos, there was no opportunity to increase the opening. Thus, it was not possible to fill the return chase with insulation.

During the actual retrofit, this problem could have been solved as follows: additional acoustic ceiling could be removed in the hall closet (approximately 2′ x 3′ on the ceiling and

8″ x 24″ on the wall near the return). Which closet (linen or coat closet), and the actual dimensions may vary by apartment type and location. The return and supply chase cavity in unit 17 could also be accessed via the unit 18 walk-in closet by removing drywall to create an opening of approximately 12″ x 15″.

Envelope air-leakage paths were consistent in units 17 and 18, and were also consistent with our experience in the other buildings. Leaks were found and sealed at the following locations:

- Interior and exterior outlets and switches
- Exhaust hood above stove at top of cabinet, and hood filter screen
- Exhaust fan in restroom
- Supply water lines and drain at wall under kitchen sink
- Around all windows and the sliding glass door
- Smoke detector wall junction box
- Light junction boxes in bedrooms and hallways
- Supply registers in living room, kitchen, and bedrooms
- Bedroom #1 wall drain clean out for adjacent restroom

The following corrections were made at these locations in units 17 and 18, to reduce or eliminate air leakage:

- Installed foam gasket cover plates on electric outlet and switch-box covers[1]
- Sprayed foam around large gap at the top of the cabinet vent cutout for the kitchen exhaust fan and vent pipe, and installed damper in exhaust vent and taped foil at connecting vent pipe joints
- Sprayed foam around supply lines and drain at drywall cutout openings
- Applied caulk at metal window frames and drywall edges[2]
- Applied caulk along sliding door frame edges
- Sprayed foam around box, drywall gap, and cutout inside box
- Sprayed foam at light fixture box and drywall gap
- Sprayed foam in gap around bedroom #1 cleanout and drywall
- Sealed supply register boot with spray foam in gap between drywall and boot edge

We were unable to correct the exhaust fan in the bathrooms due to the manufacturer's design function. After the ducts, drop ceilings, and envelope seals were replaced, blower door tests were performed to measure envelope leakage post air-sealing.

[1] Note: not all wall outlets were done in unit 18 due to large furniture in living room and bedrooms

[2] Note: the water drain opening at bottom of windows have no hinge covers, manufacture design

Blower door air tightness test results, post retrofits:

Unit 17: Square feet (842), Volume (5692 cubic feet), Climate Zone (14), N-factor (24)

Initial Intake Reading	810 CFM @ 50p
Final Reading	227 CFM @ 50p

Unit 18: Square feet (842), Volume (5692 cubic. feet), Climate Zone (14), N-factor (24)

Initial Intake Reading	957 CFM @ 50p
Final Reading	258 CFM @ 50p

3.2.2 VER Package Options for Occupied Apartment Units

Building energy models for occupied units were constructed in BEopt v2.3.0.1. A wide variety of individual efficiency measures were evaluated to build VER packages. The VER options for two of the largest contributors to energy losses (those that provided the largest opportunities for savings) were evaluated in the pilot, described earlier in this document. The pilot proved the duct sealing and insulating approach, as well as the envelope air sealing, performed as modeled. The combined simulation and pilot study results provided the research team with four different VER packages that could be installed by LINC. These packages are termed "VER Options". The differences are in the DHW system retrofit options, as follows:

Option 1 Included a SDHW system, a reroof of Building 3 (including the addition of approximately R-21 roof insulation prior to installation of the SDHW), and replacement of the existing DHW distribution piping.

Option 2 Identical to Option 1, but without reroof or roof insulation.

Option 3 Instead of SDHW, replaced the central storage boilers with a central battery of Instantaneous Water Heaters (IWHs) and installed a single 100-gallon backup storage tank, per manufacturer recommendations, and replaced DHW pipes.

Option 4 In place of the central boiler system and underground DHW distribution piping, added a series of IWHs to each building, sufficient to handle the DHW load from each building.

After 17 models were completed per option (for a total of 68 models), the options were organized in a table, according to the relative site energy savings for each. This is shown in Table 15.

Table 15: Example of Annual Per-Unit Savings Calculation

			Base Case						VERS Case, opt 1					
			Utility Bill Data	BEopt v2.3.0.1 Models										
Building #	Apt #s	Total # of Units	kWh used per unit		kWh per 2 units	% Difference from Bill Data, per unit	Therms per year, Per unit	Therms per year, Per 2 units	kWh used per yr, per unit	% kWh Savings per unit	kWh per 2 units	Therms per year, Per unit	Therms per year, Per 2 units	% therms saved per unit
1	1,3	2	4,939	4,445	8,889	-10%	354	708	3,615	19%	7,230	123	246	65%
1	2,4	2	4,939	4,637	9,274	-6%	309	618	3,641	21%	7,282	104	207	66%
1	3,7	2	4,939	4,637	9,274	-6%	309	618	3,641	21%	7,282	104	207	66%
1	4,8	2	4,939	4,455	8,910	-10%	362	724	3,618	19%	7,236	128	255	65%
2	9, 11	2	4,438	4,439	8,878	0.02%	362	723	3,721	16%	7,442	153	306	58%
2	10, 12	2	4,438	4,708	9,416	6%	309	618	3,763	20%	7,527	126	251	59%
2	13, 14	2	4,438	4,910	9,819	11%	256	513	3,764	23%	7,529	126	251	51%
2	15, 17	2	4,438	4,708	9,416	6%	309	618	3,763	20%	7,527	126	251	59%
2	16, 18	2	4,438	4,466	8,932	1%	347	695	3,641	18%	7,283	123	246	65%
3	19, 21	2	3,908	3,897	7,793	-0.3%	314	628	3,205	18%	6,410	114	227	64%
3	20, 22	2	3,908	3,887	7,773	-1%	287	574	3,186	18%	6,372	93	186	68%
3	23, 25	2	3,908	3,887	7,773	-1%	287	575	3,187	18%	6,375	93	186	68%
3	24, 26	2	3,908	3,887	7,773	-1%	287	574	3,186	18%	6,372	93	186	68%
3	26, 28	2	3,908	3,915	7,829	0.2%	302	604	3,295	16%	6,589	105	209	65%
20	80, 81	2	4,632	4,487	8973	-3%	318	636	3,589	20%	7,178	185	371	42%
21	85	1	7,237	7251	n/a	0.2%	466	n/a	4,839	33%	n/a	288	n/a	38%
21	86	1	7,237	7153	n/a	-1%	514	n/a	4434	38%	n/a	310	n/a	40%
avg, per unit						-0.9%								

The kWh/yr data in the annual per-unit savings table had to be modified in a few different ways before it was as correct as possible, due to the limitations of BEopt as described in detail in the Subtask 2.1 report. The engineering estimates applied to the BEopt simulation results are as follows:

- The SDHW pump energy was subtracted from the kWh/yr for each unit, because it must be master metered and not charged to the tenants.
- BEopt was not able to calculate the therms the underground pipes lost to the ground; therefore, we developed estimates using engineering principals and local weather and other information. These estimates were applied to all models with underground pipes, including all cases in which the underground DHW distribution pipes were replaced with new, insulated underground pipes. This fix was not applied to pipes that were not underground.
- The data in Table 15 was used to determine model accuracy (compared to the kWh/yr shown on the utility bills) and to summarize the end use per unit to show in a final table.
- The final VER package table tracks the $/yr spent on the utilities, this included calculating the annual savings of the VER package. An example of the final VER package table is shown in Table 16.

Table 16: Example of Energy and Cost Analysis for the Final VER Package

Building	EE Cost ($/unit)	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
			Base	VER	Sav.	Base	VER	Sav.
Building 1	$ 4,660	Energy	333	114	219	4,543	3,629	915
		Cost	$ 307	$ 105	$ 201	$ 467	$ 373	$ 94
Building 2	$ 4,660	Energy	317	131	186	4,646	3,731	915
		Cost	$ 291	$ 120	$ 171	$ 478	$ 384	$ 94
Building 3	$ 4,660	Energy	295	99	196	3,894	3,212	682
		Cost	$ 272	$ 91	$ 180	$ 401	$ 330	$ 70
Building 20	$ 3,555	Energy	318	185	133	3,887	3,187	699
		Cost	$ 293	$ 170	$ 122	$ 400	$ 328	$ 72
Building 21	$ 3,555	Energy	490	299	191	7,202	4,637	2,566
		Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

An energy and cost table was constructed for each near-ZNE option, and the total VERs costs and savings from these tables were incorporated into a master VER table to show the costs and energy-saving benefits. These tables quantify the results and provide a basis for deciding which of the final VER options would be installed.

Worksheets showing each of the four VER options' cash flow are calculated and presented separately, and contain the data tables needed to make final calculations. The first table contains the features used in each VER package for the specified VER option, including feature costs. Table 17 provides an example. Gas savings data was migrated from the "Annual Per-Unit Savings" worksheet into the "Cash Flow" worksheet (example in Table 18).

Table 17: Example of Feature-Cost Table Employed in Cash Flow Calculation

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)	Incremental Cost, per unit	Units of Costing
Misc Electric Loads	Unmonitored	Home Energy Management System					$ 600	per unit
Unfinished Attic	Ceiling, 2" cellulose, R-6.4, gr. 3	Ceiling, R7 batt	Ceiling, R7 batt	Re-Roof, 1.25" (R8) membrane, 7" (R22) blown-in	Ceiling, R7 batt	Ceiling, R7 batt	$ -	per sqft roofspace
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage					$ 2,500	per unit
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50					$ -	per sqft CFA
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)					$ -	per unit
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)	$ 455	per unit
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes					$ 271	per unit
Solar Water Heating	None	Everyday Energy; Evacuated tube drainback					$ 1,289	per unit
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head	$ -	per unit
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new	$ -	per unit
Lighting	Incandescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting					$ -	per bulb
Cost, per unit		$ 4,660	$ 4,660	$ 4,660	$ 3,555	$ 3,555	$ 144,702	per 32 units

Table 18: An Example of Annual Gas Savings for the Calculation Cash Flow

	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)		
Annual Gas Bill Savings, per unit	$ 201	$ 171	$ 105	$ 122	$ 175	$ 4,761	per 32 units

Cumulative payments made against loans used to cover package installations were also investigated alongside a review of the simple payoff that would occur when LINC used grant money for the install. These payments were tracked in Table 19 to calculate the net cost (or gain) incurred from installing the VER packages into the occupied units. This table shows amortized payments, calculated time (in years) to positive cash flow, average annual savings over the loan periods (20 and 30 years), and the total amount paid against the loans. Similar tables were made for the 20-year and 30-year amortization schedules. The 20-year "Amortized Payments" table for occupied units with VER option #1 is shown.

Table 19: Example of VER Option #1, 20-Year Amortization and 40-Year Cash Flow

	20yr Cash Flow, Ammortized							
	Year	Payment Due	Annual Gas Bill Savings, per unit (2.5% inflation)	Cumulative Payments	Annual Gas Bill Savings, per unit (2.5% inflation, 2.5% Price Escalation)	Cumulative Payments	Annual Gas Bill Savings, per unit (2.5% inflation, 4% Price Escalation)	Cumulative Payments
1	2015	$ (16,110)	$ 5,362	$ (10,748)	$ 5,362	$ (10,748)	$ 5,362	$ (10,748)
2	2016	$ (16,110)	$ 5,496	$ (21,361)	$ 5,630	$ (21,227)	$ 5,711	$ (21,147)
3	2017	$ (16,110)	$ 5,634	$ (31,838)	$ 5,912	$ (31,425)	$ 6,082	$ (31,175)
4	2018	$ (16,110)	$ 5,775	$ (42,173)	$ 6,208	$ (41,328)	$ 6,477	$ (40,807)
5	2019	$ (16,110)	$ 5,919	$ (52,364)	$ 6,518	$ (50,920)	$ 6,898	$ (50,019)
6	2020	$ (16,110)	$ 6,067	$ (62,407)	$ 6,844	$ (60,186)	$ 7,347	$ (58,782)
7	2021	$ (16,110)	$ 6,219	$ (72,298)	$ 7,186	$ (69,110)	$ 7,824	$ (67,068)
8	2022	$ (16,110)	$ 6,374	$ (82,034)	$ 7,545	$ (77,675)	$ 8,333	$ (74,845)
9	2023	$ (16,110)	$ 6,533	$ (91,611)	$ 7,923	$ (85,862)	$ 8,875	$ (82,080)
10	2024	$ (16,110)	$ 6,697	$ (101,024)	$ 8,319	$ (93,653)	$ 9,451	$ (88,739)
11	2025	$ (16,110)	$ 6,864	$ (110,270)	$ 8,735	$ (101,029)	$ 10,066	$ (94,783)
12	2026	$ (16,110)	$ 7,036	$ (119,344)	$ 9,171	$ (107,967)	$ 10,720	$ (100,173)
13	2027	$ (16,110)	$ 7,212	$ (128,242)	$ 9,630	$ (114,448)	$ 11,417	$ (104,866)
14	2028	$ (16,110)	$ 7,392	$ (136,960)	$ 10,111	$ (120,446)	$ 12,159	$ (108,817)
15	2029	$ (16,110)	$ 7,577	$ (145,494)	$ 10,617	$ (125,939)	$ 12,949	$ (111,978)
16	2030	$ (16,110)	$ 7,766	$ (153,837)	$ 11,148	$ (130,901)	$ 13,791	$ (114,297)
17	2031	$ (16,110)	$ 7,960	$ (161,987)	$ 11,705	$ (135,306)	$ 14,687	$ (115,719)
18	2032	$ (16,110)	$ 8,159	$ (169,938)	$ 12,291	$ (139,125)	$ 15,642	$ (116,187)
19	2033	$ (16,110)	$ 8,363	$ (177,684)	$ 12,905	$ (142,330)	**$ 16,659**	$ (115,638)
20	2034	$ (16,110)	$ 8,572	$ (185,222)	$ 13,550	$ (144,890)	$ 17,742	$ (114,007)
21	2035	$ -	**$ 8,787**	$ (176,435)	**$ 14,228**	$ (130,662)	$ 18,895	$ (95,112)
22	2036	$ -	$ 9,006	$ (167,428)	$ 14,939	$ (115,723)	$ 20,123	$ (74,989)
23	2037	$ -	$ 9,232	$ (158,197)	$ 15,686	$ (100,037)	$ 21,431	$ (53,558)
24	2038	$ -	$ 9,462	$ (148,734)	$ 16,470	$ (83,567)	$ 22,824	$ (30,734)
25	2039	$ -	$ 9,699	$ (139,036)	$ 17,294	$ (66,273)	$ 24,308	$ (6,426)
26	2040	$ -	$ 9,941	$ (129,094)	$ 18,159	$ (48,114)	$ 25,888	$ 19,462
27	2041	$ -	$ 10,190	$ (118,904)	$ 19,067	$ (29,047)	$ 27,570	$ 47,032
28	2042	$ -	$ 10,445	$ (108,459)	$ 20,020	$ (9,027)	$ 29,362	$ 76,394
29	2043	$ -	$ 10,706	$ (97,754)	$ 21,021	$ 11,994	$ 31,271	$ 107,665
30	2044	$ -	$ 10,973	$ (86,780)	$ 22,072	$ 34,066	$ 33,304	$ 140,969
31	2045	$ -	$ 11,248	$ (75,532)	$ 23,176	$ 57,241	$ 35,468	$ 176,437
32	2046	$ -	$ 11,529	$ (64,003)	$ 24,334	$ 81,576	$ 37,774	$ 214,211
33	2047	$ -	$ 11,817	$ (52,186)	$ 25,551	$ 107,127	$ 40,229	$ 254,440
34	2048	$ -	$ 12,113	$ (40,073)	$ 26,829	$ 133,955	$ 42,844	$ 297,284
35	2049	$ -	$ 12,415	$ (27,658)	$ 28,170	$ 162,126	$ 45,629	$ 342,913
36	2050	$ -	$ 12,726	$ (14,932)	$ 29,579	$ 191,704	$ 48,595	$ 391,507
37	2051	$ -	$ 13,044	$ (1,888)	$ 31,058	$ 222,762	$ 51,753	$ 443,260
38	2052	$ -	$ 13,370	$ 11,482	$ 32,610	$ 255,372	$ 55,117	$ 498,378

Results of utility bill savings calculations from the "Final VER Package" tables, and average annual savings from the "Amortized Payments" table were used to determine simple payoff and years-to-positive cash flow, respectively. These results were entered into Table 20, showing the number of years to repay the investment.

Table 20: An Example of Payoff Period Employed in Cash Flow Calculation

	Payoff Period, in Years					
	Simple Payoff(2.5% inflation), in yrs	Simple Payoff (2.5% inflation, 2.5% Price Escalation), in yrs	Simple Payoff (2.5% inflation, 4% Price Escalation), in yrs	Amortized Payoff (2.5% inflation, 0% NG price esacalation, 5% APR), in yrs	Amortized Payoff (2.5% inflation, 2.5% NG price esacalation, 5% APR), in yrs	Amortized Payoff (2.5% inflation, 4% NG price esacalation, 5% APR), in yrs
20yr Mortgage	30	23	20	37	28	25
30yr Mortgage				42	31	25

3.2.3 VER Package Options for Community Center

This chapter discusses the methods initially employed to develop the VER package, and also describes the final VER package that was installed in the Beechwood common area.

After the pilot site work at the two apartment units was completed, the research team did a similar analysis of the community center. First, a baseline model was made, and then the model's accuracy was determined. Finally, the VER package was designed. The models' site energy results were organized into a table, and VER package savings were determined. An example is shown in Table 21.

Table 21: Annual Community Center Savings Calculation with VER Option #2

Beechwood Community Center in CBECC (ducts outside)		Hybrid CBECCC and BEopt	Beechwood Community Center in BEopt v2.3						
	Base Case	Base CC Total (estimated CBECC & BEopt)	ZNE #2 (Common Area)	ZNE #2 (Laundry room, El. dryers)	ZNE #2 (Laundry room, gas dryers)	ZNE #2 Outdoor Lighting (LED)	ZNE Community Center, Total (estimated)	% Savings, estimated	$Saved per year
Spc Heat	679	2,979	-	299	299	-	299	90%	$ 430
Spc Cool	5,027	6,836	3,127	372	372	-	3,499	49%	$ 535
IAQ Vent	94	291	698	164	164	-	862	-196%	$ (92)
Ins Light	1,506	17,500	1,483	264	264	5,220	6,967	60%	$ 1,690
Appl & Cook	759	1,483	847	7,330	645	-	1,492	-1%	$ (1)
Plug Lds	2,694	1,600	1,600	-	-	-	1,600	0%	$ 0
TOTAL	**10,759**	**29,852**	**7,755**	**8,429**	**1,744**	**5,220**	**14,718**	**51%**	**$ 2,427**
% Error	-71%	-19%							
Spc Heat	772	1,197	649	-	-	-	649	46%	$ 505
Wtr Heat	176	221	63	19	19	-	82	63%	$ 128
Appl & Cook	21	206	19	-	188	-	207	-1%	$ (1)
TOTAL	**969**	**1,538**	**731**	**19**	**207**	**-**	**938**	**39%**	**$ 552**
Annual Savings									**$ 2,980**
$ 0.16	/kWh								
$ 0.92	/Therm								

All cash flow and payoff tables were then merged into a final worksheet that combined these figures with the results of the community center VER package. The worksheet calculated the savings using gas savings data from occupied units and all community center utility bill savings in two separate final tables. This resulted in the different occupied unit cases for community center VER options #1 and #2.

The initial community center VER package was chosen using different criteria from that of the residences. The research team revised the VER package because of experiences gained from the pilot site and apartment unit retrofit processes, as well as internal and external EE measure discussions. However, a list of the initial VER package contents is shown below:

1. Envelope sealing to 3 ACH50, with aerosol
2. Sealing, insulating, and protecting the ducts, or moving them into conditioned space
3. Possible roof-mounted package unit replacement
4. Upgrading the community center's dedicated boiler to an IWH
5. Conversion to 100% LED exterior lighting, including all security lighting
6. Possible replacement of all clothes washers with ENERGYSTAR®-rated units

In addition to these features, rooftop PVs were also considered. The possibility of installing PV on the rooftop of the community center raises the potential importance of replacing the roof and the possibility of increasing the ceiling insulation, and increases the practicality of bringing the ducts into the building, into conditioned space. When there was no PV on the roof, the existing roof could remain, and the above features would be the extent of the package. This is "Community Center VER Package #1". A variant of Package #1 could include increased roof insulation, if it were determined that the ducts and the roof were best encapsulated in spray foam. When there was PV on the roof, the team strongly recommended that the roof be replaced and the roof or ceiling insulation be increased to at least R-20, as part of the re-roof. This is "Community Center VER Package #2".

3.2.4 Final VER Package of the Common Area

The final VER package of the common area included weatherization improvements, installing typical and high-efficiency lighting fixtures (such as LEDs), sealing duct and building envelope leakage, and using "free-cooling" by leveraging cool outside air. Reroofing with polyurethane spray foam and re-ducting was performed by the same process to improve the building's energy performance, improve duct performance, and reduce air infiltration. The field testing and energy monitoring processes are not repeated in this section; only the unique field testing plans for the common area are described here.

1. *Reroofing using polyurethane spray-foam with an elastomeric coating*. The community center's exposed roof and HVAC ducts experienced reduced air leakage and improved insulation levels. Spray Polyurethane Foam (SPF) insulation provided air sealing and a layer of insulation. The objectives of installing SPF on the common area building were to evaluate the cost and efficacy of SPF for duct and building air sealing, provide an insulating layer on the roof and exposed ducts, and to focus on

issues unique to MF applications, specifically how to deal with the possibility of sealant traveling from one apartment to another, or being wasted through large penetrations to piping chases. The two primary research objectives were to: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in the Beechwood common area; and 2) estimate the first-cost savings, as well as heating and cooling load reductions, that could accrue from this type of sealing.

2. *Aerosol space-sealing technology*. This technology was previously tested to seal leaks in building envelopes, both in laboratory tests and in actual homes in the field. However, it was the first field test of sealing a MF dwelling using this kind of technology. The primary purpose of this project was to test the practical effectiveness of the aerosol-based envelope sealing methodology in a MF building application, and to estimate the first-cost savings, as well as heating and cooling load reductions that could accrue. The building sealing technology was developed by researchers at the UC Davis Western Cooling Efficiency Center (WCEC). Previous tests showed a 50% reduction in leakage areas, and researchers believed there was a potential to further reduce the building's leakage area. The technology used a compressed nitrogen nozzle to aerosolize the liquid sealant and disperse pressurized sealant into the house. The sealant followed small air streams that formed in and around leaks. The aerosol mass caused the particles to hit the edges of the leaks, and some of the particles stuck to the edges. Over time, an aerosol particle deposit built up in and around the leaks, sealing them. This task focused on the issues that were unique to MF applications; specifically, how to deal with the possibility of sealant traveling from one apartment to another, or being wasted through large penetrations to piping chases. Aerosol technology research had two primary objectives: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in Beechwood's common area; and 2) estimate the first cost savings, as well as heating and cooling load reductions, that could accrue from this type of sealing.

3. *Economizer upgrade to utilize cool outside air*. Beechwood's common area was a residential-sized building, with an operating schedule (7:00 a.m. – 6:00 p.m.) similar to an office. It was equipped with two rooftop units including six tons of refrigeration (4 ton + 2 ton) to serve office space for two facility managers, a laundry room, two restrooms, and a gathering space. Economizers are not typically required for rooftop units (RTUs) that are less than 4.5 tons (i.e., economizers on air conditioning (A/C) units larger than 54,000 Btu/hr according to California Title 24-2013 Building Code). So, adding the economizing component required the metal economizing piece and control piece to be special ordered prior to upgrading the RTUs. Lancaster is located in California Climate Zone (CZ) 14, which is characterized by wide temperature swings from day to night (see the historical weather information for California CZ 14 in Figure 26. Hot summer days are typically followed by cool nights, providing an excellent opportunity to use economizers to night-flush the building and take

advantage of cold early-morning outside air to provide free cooling. There are four types of economizers on the market: dry bulb, enthalpy, differential enthalpy, and integrated differential enthalpy. The dry bulb and enthalpy options have only one sensor, but the other two options require two sensors, so their configuration and maintenance are more complicated. As the name states, the dry-bulb economizer lets cool outside air inside, based on the outside air's dry-bulb temperature, regardless of its humidity. The enthalpy economizer determines outside air based on humidity. The right type of economizer should be determined by the CZ and the building's control needs. Climate Zone 14 has hot, dry summers, eliminating the worry of excess outside air moisture entering the building. The retrofitted common area was small, and there was a preference for easily-configured controls. Thus, the dry-bulb economizer was the right choice for this building and its climate.

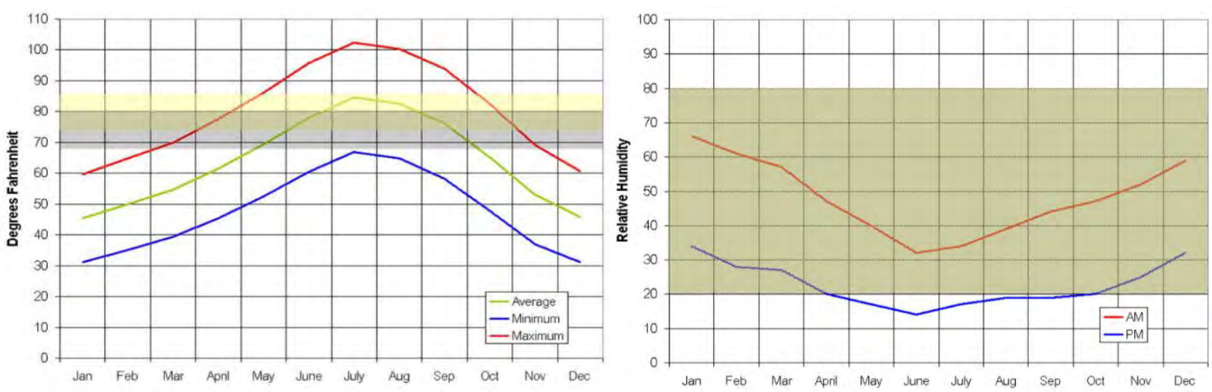


Figure 26: Climate Zone 14 Temperature and Relative Humidity

3.2.5 SUMMARY

This chapter covers the methods used to determine the recommended VER packages based on information gathered from site audits, surveys, and energy simulation models. The package options for the occupied units are summarized in Table 22 - Table 25.

Table 22: VER Package Option 1

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Unfinished Attic	Ceiling, 2" cellulose, R-6.4, gr. 3			Re-Roof, 1.25" (R8) membrane, 7" (R22) blown-in		
		Ceiling, R7 batt	Ceiling, R7 batt		Ceiling, R7 batt	Ceiling, R7 batt
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes				
Solar Water Heating	None	Everyday Energy; Evacuated tube drainback				
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incandescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Table 23: VER Package Option 2

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Unfinished Attic	Ceiling, 2" cellulose, R 6.4, gr. 3	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes				
Solar Water Heating	None	Everyday Energy; Evacuated tube drainback				
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incandescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Table 24: VER Package Option 3

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Bank of commerical tankless DHW (0.95EF), with shared backup boiler (0.80 EF) and cirulation pump				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes				
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incandescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Table 25: VER Package Option 4

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incandescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

The final VER package table tracks the $/yr spent on the utilities, and includes a calculation of annual VER package savings. An example of the final VER package table is shown in Table 26 - Table 29.

Table 26: Example Cost Effectiveness Determination of VER Package Option 1

Occupied Units VER Package, Option #1	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	114	219	4,543	3,629	915
	Cost	$ 307	$ 105	$ 201	$ 467	$ 373	$ 94
Building 2	Energy	317	131	186	4,646	3,731	915
	Cost	$ 291	$ 120	$ 171	$ 478	$ 384	$ 94
Building 3	Energy	295	99	196	3,894	3,212	682
	Cost	$ 272	$ 91	$ 180	$ 401	$ 330	$ 70
Building 20	Energy	318	185	133	3,887	3,187	699
	Cost	$ 293	$ 170	$ 122	$ 400	$ 328	$ 72
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Table 27: Example Cost Effectiveness Determination of VER Package Option 2

Occupied Units VER Package, Option #2	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	114	219	4,543	3,631	912
	Cost	$ 307	$ 105	$ 201	$ 467	$ 373	$ 94
Building 2	Energy	317	131	186	4,646	3,731	915
	Cost	$ 291	$ 120	$ 171	$ 478	$ 384	$ 94
Building 3	Energy	296	103	193	3,894	3,229	665
	Cost	$ 272	$ 94	$ 178	$ 401	$ 332	$ 68
Building 20	Energy	318	185	133	3,887	3,219	667
	Cost	$ 293	$ 170	$ 122	$ 400	$ 331	$ 69
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Table 28: Example Cost Effectiveness Determination of VER Package Option 3

Occupied Units VER Package, Option #3	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	168	166	4,543	3,519	1,025
	Cost	$ 307	$ 154	$ 152	$ 467	$ 362	$ 105
Building 2	Energy	327	172	155	4,606	3,581	1,025
	Cost	$ 301	$ 158	$ 143	$ 474	$ 368	$ 105
Building 3	Energy	296	158	137	3,894	3,213	681
	Cost	$ 272	$ 145	$ 126	$ 401	$ 330	$ 70
Building 20	Energy	318	185	133	3,887	3,220	667
	Cost	$ 293	$ 170	$ 122	$ 400	$ 331	$ 69
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Table 29: Example Cost Effectiveness Determination of VER Package Option 4

Occupied Units VER Package, Option #4	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	164	169	4,543	3,519	1,025
	Cost	$ 307	$ 151	$ 156	$ 467	$ 362	$ 105
Building 2	Energy	327	168	159	4,646	3,581	1,065
	Cost	$ 301	$ 155	$ 146	$ 478	$ 368	$ 110
Building 3	Energy	296	155	141	3,894	3,213	681
	Cost	$ 272	$ 142	$ 130	$ 401	$ 330	$ 70
Building 20	Energy	318	185	133	3,887	3,220	667
	Cost	$ 293	$ 170	$ 122	$ 400	$ 331	$ 69
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

The same method was applied to the common area for its VER package. Although the final package was refined in Phase 2 based on considerations taken into account as the research team gained project experience, the initial VER package is still shown here for report completeness. Package options are described in Table 30 - Table 32.

Table 30: Example of Community Center VER Package Option 1

	Common Area and Laundry Room	
Features	**Base Case**	**ZNE #1**
Envelope Leakage	7	3
Community Center A/C	12 SEER	16 SEER AC (2-stage)
Community Center Furnace	80% AFUE	80% AFUE
Laundry A/C	4 SEER A/C	14 SEER H/P
Domestic Hot Water	100g, 0.8 EF	0.96 EF tankless
Lighting	CFL (interior), HID (exterior)	LED
Clothes Washer	Standard (EF = 2.47)	ENERGYSTAR (EF = 1.41)

Table 31: Example of Community Center VER Package 2

	Features Occupied Units Base Case	ZNE #1
Roof	Graveled	R8 Membrane
Refrigerator	Pre-1999	New
Envelope Leakage	7 ACH50	3 ACH50
Ducts	Uninsulated, 31% Leakage	R22, 10% Leakage
DHW	100g, 0.8 EF	0.96 EF Tankless
Lighting	CFL (ins.), HID (ext.)	LED
Clothes Washer	Standard (EF = 2.47)	EnergySTAR (EF = 1.41)
MELs	No control	HEM

Table 32: Example of Community Center VER Package 3

	Features Common Area + Laundry Room Base Case	ZNE #1
Roof	Graveled	R17 Ballasted Foam
Envelope Leakage	7 ACH50	3 ACH50
Community Center A/C	12 SEER	16 SEER (2-stage)
Community Center Furnace	80% AFUE	80% AFUE
Laundry Room HVAC	None	14 SEER Heat Pump
DHW	100g, 0.8 EF	0.96 EF Tankless
Lighting	CFL (ins.), HID (ext.)	LED
Clothes Washer	Standard (EF = 2.47)	EnergySTAR (EF = 1.41)

CHAPTER 4: EMERGING TECHNOLOGIES

Emerging technologies are typically defined as those which have undergone limited testing, are not fully market ready, and could possibly be near-commercial scale or commercialized in the next three years (exact definitions vary). The research team defined emerging technologies as those which could potentially fit into existing utility emerging technologies programs. Based on these considerations, the possible emerging technologies were gathered through a Technical Advisory Committee consisting of representatives from SCE and SoCalGas. Emerging technologies that could be installed either in the common areas or in tenant units were considered. To create this effect, two tenant units were isolated as ET units (Building 11, three-bedroom units).

Most emerging, pre-commercial technologies have not made their way into building models. This makes it difficult to include them in packages of EE retrofits, such as the VER analysis conducted in the previous chapter. As a result, we used the same data acquisition and analysis methodology to conduct a separate evaluation of these measures. In some cases, such as with smart thermostats, which have a significant amount of pilot testing behind them, we included estimated savings in the models, based on other field tests. A key item to note is that even if the technologies did not make it to the implementation list, significant time was spent examining these opportunities, and lessons were learned from each investigation.

Based on utility input, we conducted an analysis of the various evaluated technologies, based on criteria including:

1. The technologies' fit with the construction type
2. The technologies' maturity level (if there was a perceived high risk, it might not have been a good fit)
3. Any past research conducted on the technologies
4. Potential observable energy savings from the technologies being part of a measure package
5. The impact of the installation process on customers

4.1 Emerging Technologies Considered for Evaluation

We held several technical group meetings, then met with all utility partners on March 26, 2015 to develop a comprehensive list of possible technologies for consideration, including:

1. A gas-condensing tankless water heater, for laundry
2. High-efficiency RTU w/Fault Detection and Diagnostic (FDD) and variable-speed indoor fans
3. Foam roof insulation, cool roof and insulated ducts (with existing roof removed)
4. Aerosol envelope sealing
5. Ozone retrofit kits (cold water)
6. Moisture-sensing dryer retrofits
7. Bi-level LEDs
8. Weather bug testing for smart thermostats
9. Non-Intrusive Load Monitoring (NILM) systems
10. Thermostats with EE and DR capability
11. Solar thermal with evacuated tubes
12. Boxing and ducts in semi-insulated spaces
13. HEMS (wireless access)
14. Insulated underground piping
15. Messaging for behavioral change
16. Post-installation surveys
17. Rooftop unit economizer control retrofit
18. Navien 99% efficient gas tankless water heaters, for residential applications
19. On-demand recirculation, for residential
20. Pilotless ranges
21. Shower Start (City Gardens) – customer experience
22. Mini splits with DR
23. Other heating options (backup wall furnace, condensing gas backup)

4.2 Technology Analysis

Table 33: Analysis of the Technologies

Technology	Fuel	Brief Tech Overview	Disposition
1. Gas-condensing tankless water heaters, for laundry	Gas	Reduces water heater usage	Eliminated from consideration in favor of ozone retrofit
2. High-efficiency RTUs w/ FDD (and variable speed indoor fans)	Both	High Seasonal EE Ratio (SEER), variable-speed HVAC units that also perform fault detection for EE	Not all features are available for the four-ton (largest) unit in the common area.
3. Foam roof insulation, cool roof and insulated ducts (existing roof removed)	Both	Insulates common-area roof and exposed ducts with foam insulation	Scope of Work (SOW) prepared, work bidding in progress
4. Aerosol envelope sealing	Both	Seals leaky wall and envelope with aerosol sealing	SOW completed, preparation in progress
5. Ozone retrofit kits (cold water)	Gas	Adds ozone to cold water to clean laundry without hot water	Product selected and being procured for installation in common area
6. Moisture-sensing dryer retrofits	Gas	Senses clothing dryness and turns dryer off as early as possible	Found a vendor; early-stage technology, evaluating risk to laundry equipment
7. Bi-level LEDs	Electric	Changes external light brightness	Being considered as part of Building 11 ET measures.
8. Thermostats with EE and DR capability	Electric	Smart communicating thermostats reduce energy use	Installed three different technologies (Nest, Ecobee, Nexia) in tenant apartments, along with

			Wi-Fi hotspots
9. Weather bug testing for smart thermostats	Both	Overlay optimization software uses weather data to reduce HVAC energy use.	Working with vendor to access Ecobee thermostats via API, to apply overlay optimization.
10. NILMS	Electric	Enables low-cost disaggregation of end-use loads.	Evaluating three technologies from LoadIQ, Chai Energy, and Bidgely.
11. Solar thermal, with evacuated tubes	Gas	Evacuated tube solar collector	Installed for apartments
12. Boxing and ducts in semi-insulated spaces	Both	Reduces duct leakage and gets ducts into conditioned spaces	Completed for all tenant units
13. HEMS (wireless access)	Both	Enables centralized energy use management	Eliminated from consideration due to complicated technology, not amenable to customer adoption
14. Insulated underground piping	Gas	Insulates central water heating system piping	Completed as part of tenant measures
15. Messaging for behavioral change	Both	Provides in-home devices that give feedback	Replaced for consideration in favor of NILMs
16. Post-installation surveys	Both	Surveys help understand impacts	To be conducted
17. RTU retrofits with economizer controls and fresh air ventilation	Both	Substantial energy savings possible through economizer (for extreme Lancaster weather)	Seeking suppliers. Difficult to find products that can retrofit to small commercial units.
18. Navien 99% eff. gas tankless water heaters for residential	Gas	Highest-efficiency gas	Procured and will be installed in Building 11

applications		tankless water heaters	tenant unit
19. On-demand recirculation for residential	Gas	Considered for reducing central water heating system energy use	Included as part of piping upgrades for centralized water heating
20. Pilotless ranges	Gas	Reduces cooking gas use	Requires new appliances; not viable within budget
21. New refrigerators	Electric	Reduces electricity use	ENERGYSTAR appliances not viable within budget. SCE program requires out-of-pocket for tenants, but project cannot pay tenants.
22. Shower starts	Gas	Reduces water use when waiting for hot water	Evaluated by LINC in other properties, found to be ineffective
23. Mini splits, with DR	Electric	Ductless systems eliminate duct loss	Not implemented due to fuel switching concerns, which is not allowed in EE programs in Southern California
24. Ductless heat pumps, with gas backup	Both	European unit (Daikin Altherma) provides combined space and water heating with condensing boilers	Trying to procure from Belgium, still difficult to get. Dealer says not qualified under Title 24 Bldg. Code.
25. Wall furnaces	Gas	Increases ductless heating efficiency	Gas lines not available inside tenant units; not viable

4.3 TECHNOLOGY IMPLEMENTATION

After analyzing these technologies, many did not make the grade for the retrofit, due to cost or availability issues. However, they would be great candidates for evaluation through other earlier-stage technology demonstrations funded by the Energy Commission or utility emerging technologies programs. Here are brief discussions of these measures:

Aerosol envelope sealing: This technology is in development by WCEC. At the time of project launch, it had been tested in other homes, with limited implementation, but there was potential for it to be used as cost-effective envelope sealing. However, because application was disruptive to tenants, it was only implemented in the common area.

Smart thermostats: This technology advanced significantly in program adoption during the project and was implemented. However, a lack of reliable Wi-Fi in low-income housing became a significant barrier.

Moisture-sensing dryer retrofit kits: These kits save gas and have good potential. However, concerns regarding their warranties and customer perception (low run times for the same cost) prevented us from testing them in this project. They may provide a substantial benefit, if manufacturers install them in new dryers.

Ozone purification systems: These also save gas; however, when the laundry's water heating was monitored, it revealed the heater was not operating, so there were no savings from implementing this technology.

Catalyst variable-speed control upgrade: This technology was studied for the potential to upgrade single-speed A/C systems to variable speed. However, the size and cost of the A/C units (including the common area units) proved to be a barrier.

Belimo ZIP Economizer: This was a lower-cost implemented retrofit. The ZIP Economizer incorporated ZIP-code based enthalpy optimization and showed substantial potential.

Ilios engine-driven heat pumps: This is an interesting gas energy generation and efficiency technology. However, the systems were too large for the units, and after significant research, they were not implemented.

Ductless mini splits, with gas heating: The team supports ductless mini splits as effective retrofit options for existing buildings. They offer the following benefits:

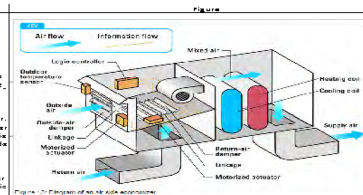
- Eliminates duct loss from thermal transport and leakage
- Avoids opening walls and insulation, and resulting contaminant issues
- Provides variable speed operation for more cost effective and local cooling
- Compatible with smart thermostats that increase customer satisfaction

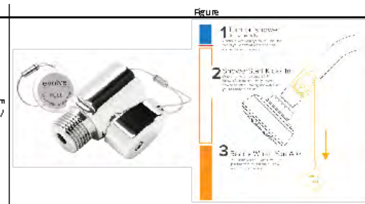
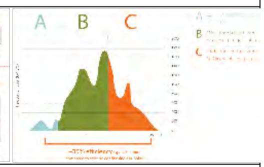
For customer economics, it's necessary to keep the gas heating option. A ductless mini split with condensing gas backup is available through Daikin in Europe (Belgium, France, etc.). However, the team was unable to import it to install in this project. The gas backup also prevents potential issues with electric distribution systems due to electric heat elements in heat pumps and eliminates the need to run additional electrical lines. This is one technology that should be pursued and evaluated with greater effort.

4.4 DETAILED ANALYSIS AND SPECIFICATIONS OF EMERGING TECHNOLOGIES

The team considered the individual technologies listed in Table 34.

Table 34: Specifications of the Emerging Technologies Considered by Team

ET Measures		Tech Description	Pros	Cons	Barriers to test	Website	Figure
Rooftop unit with economizer control	Dry Bulb Economizer	When there is a call for cooling, a temperature sensor determines if outside air is at or below a certain temperature setpoint (e.g., 55 F), the outside air damper is controlled allowing more outside air coming in to be mixed with return air to provide cooling.	1. Demand control ventilation to provide fresh air when CO_2 is high 2. Electric energy saving by cooling with outside air thus reduce mechanical cooling	Outside air may be low enough in temperature but may be too humid for occupant comfort.		Tech Description: [1]. Steven T. Taylor, Hwakong Cheng. Economizer High Limit Controls and Why Enthalpy Economizers Don't Work. "http://www.cmfnh.com/documents/ASHRAE_Journal_OA.pdf". November 2010 [2]. Airside Economizer. http://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency_economizer_airside. Product Example: [Carrier] http://dms.hvacpartners.com/docs/1009/public/0c/48-50h-t-2t.pdf	
	Enthalpy Economizer	Similar to the dry bulb economizer, the enthalpy economizer requires a temperature sensor and a relative humidity sensor to calculate the outside air enthalpy. Then the outside air enthalpy is compared with a setpoint	1. Demand control ventilation to provide fresh air when CO2 is high 2. Electric energy saving by cooling with outside air thus reduce mechanical cooling	If the coil is dry, this method can bring large error and also impacts energy consumption. If the coil is humid, this method is fine.			
	Differential Enthalpy Economizer	These use two sensors. One measures the return air enthalpy, while the other measures outdoor air enthalpy. Dampers are modulated for optimum and lowest enthalpy to be used for cooling.	1. Demand control ventilation to provide fresh air when CO2 is high 2. Electric energy saving by cooling with outside air thus reduce mechanical cooling	1. It requires four sensors and thus the most expensive and the most prone to sensor error. 2. It is not the most high efficient method, not even in theoretical			
	Catalyst	It is a complete HVAC energy efficiency upgrade that includes several new components, adds 5-8 new sensors and an easy-to-install pre-wired kit	1. Converts CAV to VAV and reduces fan energy use and integrates economizer controls 2. An easy/fast to install product			http://transformativewave.com/Contents/Item/Display/55 Brochure: [1] http://transformativewave.com/Media/Default/docs/CATALYSTlite-Product-Brochure.pdf [2] http://transformativewave.com/Media/Default/docs/CATALYST-Product-Brochure.pdf	
Navien 99% gas tankless water heaters (Navien NPE-Standard)		Gas tankless water heaters use high-powered burners to quickly heat water as it runs through a heat exchanger	1. Saves standby energy for keeping water warm in the tank 2. Higher energy efficiency	1. Some complaints about customer service are found online 2. Higher initial cost on equipment and potentially wiring/plumbing 3. Capability of simultaneous tasks and potential temperature swing. 4. More readings are available at: http://www.waterheaterrescue.com/pages/WHRpages/English/Longevity/tankless-water-heaters.html	1. Hard to verify the cost effectiveness. 2. Warranty of product is hard to test	Product: http://us.navien.com/_DATA/ProductDocument/2014/12/8/[1]_Navien%20NPE-A-S%20Brochure%2014-1205.pdf	
On-demand hot water recirculation		Recirculates the ambient temperature water in the hot water lines (water that is normally lost down the drain) back to the water heater. This way it saves hot water.	1. Up to 80% faster in heating water than just letting the water run down the drain (data referred to product website) 2. The water savings comes from the fact that you no longer have to run water down the drain waiting for hot water. 3. The energy savings comes from the reduction in water running down the drain that then has to be treated for sewage.	1. CS-100 does not provide installation kit but cS-100PF product should include all installation kit (comment referred to Amazon customer review).	Hard to establish a water usage baseline overtime to quantify the actual savings.	Product: D'MAND Kontrol® Systems: http://www.gothotwater.com/hot-water-systems/how-it-works	
Pilotless Ignition Gas Range		With the spark ignitor system, electricity simply sparks when control is turned to the LITE position. Gas is simultaneously released and ignites when it comes in contact with the spark.	1. Pilotless ignition saves energy by eliminating lighting the burner. 2. Saves energy by around 30% less gas than typicl pilot range uses. Since no standling pilot light, no gas is used unless it is needed. (Data referred to geappliance.com) 3. The cooktop surface is cool to touch when not in use because there is no pilot light burning continuously		Hard to establish a baseline to quantify the energy savings. Because using gas burners is customer behavior related and is hard to find an exact baseline	Tech Description: http://www.geappliances.com/search/fast/infobase/10000751.htm. Product:	

ET Measures		Tech Description	Pros	Cons	Barriers to test	Website	Figure
ShowerStart		The thermostatic shut-off valve allows the shower to save the hot water when it becomes warm for the people (behavioral waste)	1. Eliminate behavior waste by saving water and energy during shower warm-up. 2. Does not interfere showerhead's feel or flow. 3. Compatible with virtually all showerheads and shower arms (1/2" NPT fittings) 4. In california, 10%	Refer to customer reviews on Amazon. Negative comments mostly come from : 1. Reliability 2. Customer service (comment referrred to Amazon customer review)	Hard to establish a baseline to quantify the energy savings. Because taking shower is customer behavior related and is hard to find an exact baseline	Tech Description: http://thinkevolve.com/shop/showerstart-tsv/ Product:	
Aerosol Envelope Sealing		Aeroseal is a system that uses an aerosol-based sealant mist to seal the leaks in ductwork	The technology works fast, doesn't require a contractor to crawl through attics or punch holes in walls and the simple payback can be in less than two years	N/A		Tech Description: http://wcec.ucdavis.edu/aerosol-building-envelope-sealing-demonstration/ Product:	
Moisture sensing retrofit for dryers	SAMSUNG Electric Dryer	Samsung 7.4Cu. Ft. Steam Electric Dryer	Moisture sensor is already included and heavy duty of 7.4cu. Ft.	Need to replace existing dryer		http://www.hhgregg.com/samsung-7-4cu-ft-steam-electric-dryer/item/DV48H7400EW?cid=PLA-11906630-218918&mr:referralID=1ca614c8-ff17-11e4-8fa7-001b2166c62d	
	Moisture sensor upgrade	Stop the dryer (or send a signal to user) when the clothes are dry by a retrofit with relative humidity sensor	1. Energy saving 2. Protect clothes being overheated	N/A	N/A	Tech Description: http://hackaday.com/2014/05/28/a-smart-clothes-dryer/ Product:	
LED bi-level		Bi-level fixture controls present an opportunity to save energy by dimming light levels when areas are unoccupied. Bi-level lighting controls can also turn off perimeter light fixtures for much of the day in areas that receive sufficient daylight to meet lighting needs.	Energy saving from LED is significant. Imeplemeting bi-level will further improve the energy savings.	LED itself is already energy efficient; adding an additional LED bi-level control may extend the payback period of the lighting upgrade package.	Hard to differentiate/quantify the energy saving % from the LED or from the bi-level control	Product: Bi-Level Luminaire -- Maximize Energy Savings with Controlled Light Levels. http://www.columbialighting.com/content/products/literature/literature_files/co1042.pdf	
Daikin Altherma		Daikin Altherma : The split has an outside unit and an inside unit. The outdoor unit absorbs heat from the outside air and raises it to a temperature high enough to supply heating for the house. This thermal energy then warms the Altherma hot water tank, which in turn supplies hot water for general household use and also the hot water that flows through the household heating system.	1. Depending on the outdoor temperature, the Altherma heat pump chooses between heat pump and gas boil to supply both domestic hot water and heating load 2. Can be integrated with existing radiator and pump work thus an easy/cheaper energy efficiency option.		Needs people that have experience to install properly	Tech Description: http://www.daikinme.com/minisite/hybridheatpump/Advantages/ Product:	 
Messaging for behavioral change		New behavior changes (e.g., new tenants) can impact baseline. An updated message can help on an up-to-date baseline to quantify the energy savings	Integrates occupants behavior into the energy use optimization, which can be very helpful for residential homes.	It requires occupants to engage in behavior change. It can be hard for some people	For low-income homes, behavior energy use waste may only take a small percentage. So it is hard to identify the impact of behavior changes		
Post-installation surveys		Take surveys after ET installations to assist measurement & verification	Easy to implement and gets feedback from occupants	The design of questionaire plays an important role in the success	The survey may be biased based on the group of people selected		

CHAPTER 5: DATA ACQUISITION AND MONITORING

Data acquisition and monitoring required a site-specific strategy to collect data from multiple sources into a data warehouse. Beechwood had 100 units total, as shown in Figure 27. The buildings outlined in red were the 32 test-case units for data monitoring, and the buildings outlined in blue were the 14 units to be monitored as baseline and the common area. The data acquisition plan consisted of several systems to collect data and deposit it in their own locations. Then, the research team conducted data analysis based on the data from those systems, which included: 1) an EPRI data acquisition system; 2) an NILM system for building-wide electric load monitoring; 3) field test datasheets; 4) natural gas usage data from SoCalGas; 5) solar PV data; 6) smart thermostat data; and 7) electric consumption and billing data from the website of WegoWise, a company that remotely analyzes building energy consumption.

5.1 EPRI DATA ACQUISITION SYSTEM

The EPRI data acquisition system was installed in a total of 46 apartment units and required 23 data monitoring boxes. Each system monitors two units in the duplexes. The 46 apartments included all 28 units in Buildings 1, 2 and 3 (Building 4 was monitored as a control unit) and Buildings 14, 19, 20, 21. Figure 27 shows Data Acquisition (DAQ) 1, DAQ-2, DAQ-3, and DAQ-4 were data acquisition sub-systems that gathered data from the units and transmitted it to the EPRI database. The solid line connections shown in the figure represent dry contacts (hard-wired connections), and dashed lines represent wireless data transmission. The data is collected at one-minute intervals, but the EPRI data server could process data at longer intervals (such as every 15 minutes) if required. In each unit, two types of information were collected on site: thermal data (temperature and Relative Humidity (RH) and power data (voltage and current); this enabled the units' comfort and energy performance to be evaluated.

Figure 28 shows the data-acquisition system of Building Complex #4, including the Modbus DAQ-3 wire connections (RS-485). This Modbus connection layout also applies to DAQ-1, DAQ-2, and DAQ-4. Thermistors were located in the duct systems to sense the temperature of supply air, return air, and exhaust air. One outside air senor was located at Unit 36 to measure temperature and RH. Thus, the differences between inside and outside unit temperatures could be identified to calculate the cooling load. Clamp-on Current Transformers (CTs) and voltage meters were used, enabling the measurements to calculate energy consumption. The detailed DAQ-3 wire connections are shown in drawings in the next section.

The AC units were labeled with the apartment's unit number, and each duplex had two rooftop AC units, as shown in Figure 29. In addition, the data-collection box was also assigned with a number (in yellow background with red border). Thus, a box ID of "1 B4

U29, 30" represents the data collected by Collection Box #1 (located in building complex 4) from Units 29 and 30 (the duplex on the right in Figure 30).

Figure 27: Data-Monitoring Plan for Beechwood

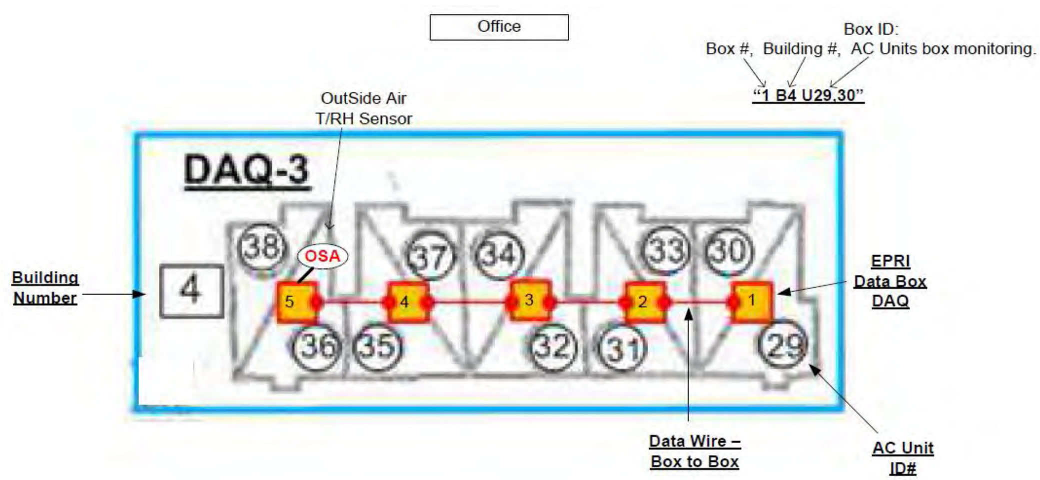


Figure 28: Data Acquisition Naming Rules

Figure 29: Air Conditioning Units on a Duplex Unit

EPRI's data acquisition system could collect data at one-minute intervals, but the data server could process longer intervals of data (such as every 15 minutes or hourly) if requested. Figure 30 illustrates Beechwood's data acquisition system setup. This system monitored 32 test-case units (outlined in red) and 14 baseline units (outlined in blue). Thus, the data-monitoring system covered all 46 RTUs and required 23 data-monitoring boxes in total, and each system monitored two units of the duplexes. DAQ-1, DAQ-2, DAQ-3, and DAQ-4 were data-acquisition stations that gathered data from the units and transmitted it to EPRI's database. EPRI had a technical team dedicated to ensuring reliable database operation, and the data acquisition plan was scalable, depending on the size of the community and the data points being monitored.

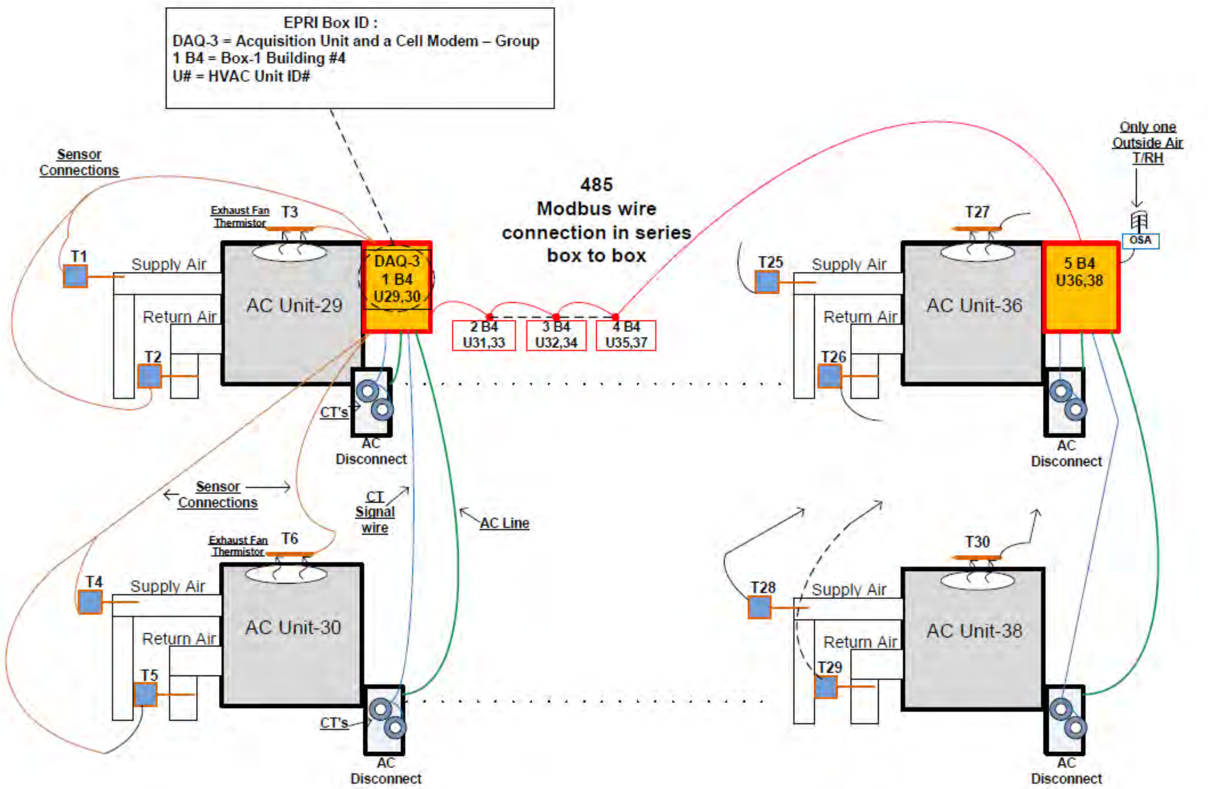


Figure 30: Individual Data Acquisition Unit Layout

In Figure 31, the data acquisition box is shown in greater detail. The AcquiSuite data acquisition block was the "brain" of the data acquisition system, which allowed the team to program the data sampling time and the desired data format. The AcquiSuite block constantly polled data at the programmed rate from the Flex IO module and the Power Transducer module. These two modules were connected with the temperature and RH sensors and the CTs, respectively, and made the data available for the AcquiSuite to poll. Each data acquisition box was standalone, hosted its own cell modem and power supply, and was protected with a National Electrical Manufacturer's Association (NEMA) box for durability.

As mentioned earlier, the data acquisition boxes covered 30 units and the common area as the treatment group, plus the 10 apartment units as the control group. Figure 32 illustrates the data acquisition systems, which gathered data from the units and transmitted it to the EPRI database. The solid line connections shown in the figure are dry contacts (hard-wired connections), and dashed lines represent wireless data transmission. The RTU's electrical data (voltage, current, and real power), outdoor air conditions (temperature and RH), duct temperature readings (each apartment unit's supply air, return air, and exhaust air) and the solar thermal system's flow rates and temperature readings were recorded in the EPRI database and prepared for download.

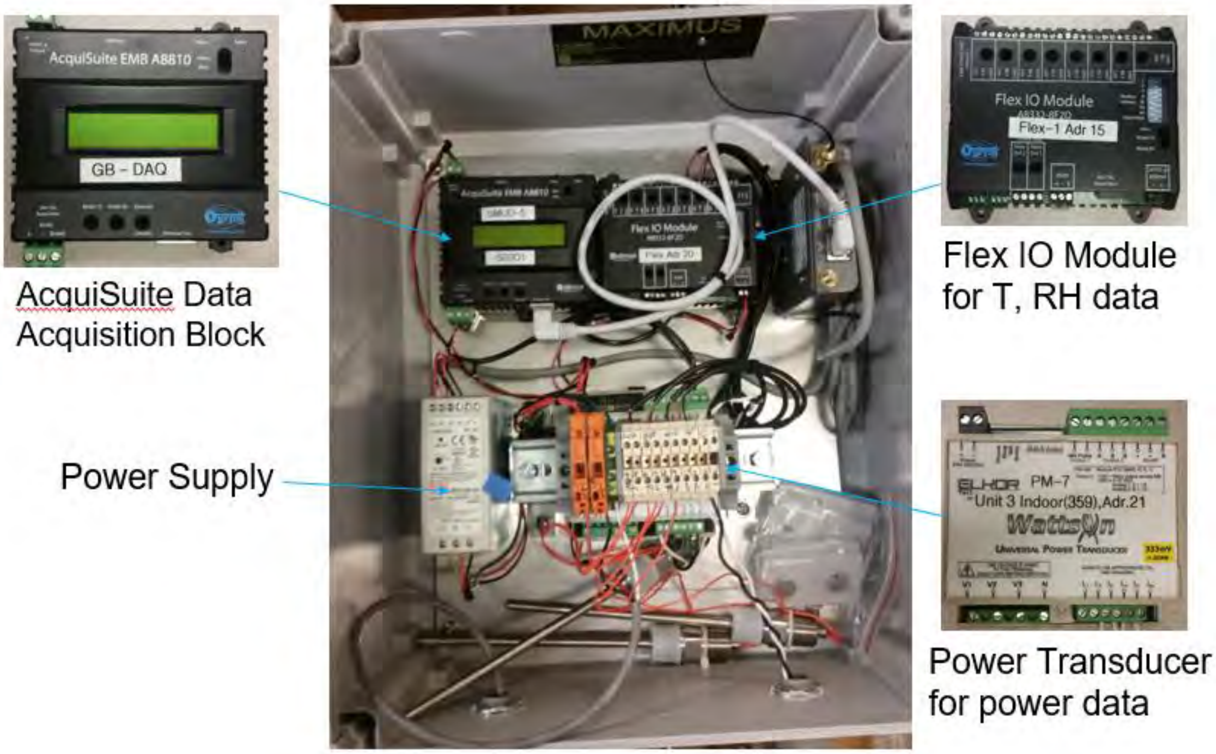


Figure 31: Utility-Grade Data Acquisition Box

Figure 32: Overview of EPRI Data Acquisition System Layout

In addition, the solar thermal system, installed in the summer of 2015, effectively reduced the use of gas heaters for hot water needs in Buildings #1, #2, and #3. The monitoring system was established to measure the inlet water temperature T1 (Figure 33), inlet water volume flow rate W1, and outlet temperature T10, to calculate the heat transfer rate of the solar thermal system. The water recirculation temperature readings and the tank's temperature outlet enabled us to calculate the tank's heat loss rate. The monitoring plan allowed us to calculate solar thermal system's overall EE. The solar thermal system reduced natural gas use for the retrofitted units, and significantly improved overall efficiency.

Amatis flow meters, installed by Everyday Energy, measured the hot water flow between the solar panels and the water tank (Figure 34), and monitored solar thermal and PV data.

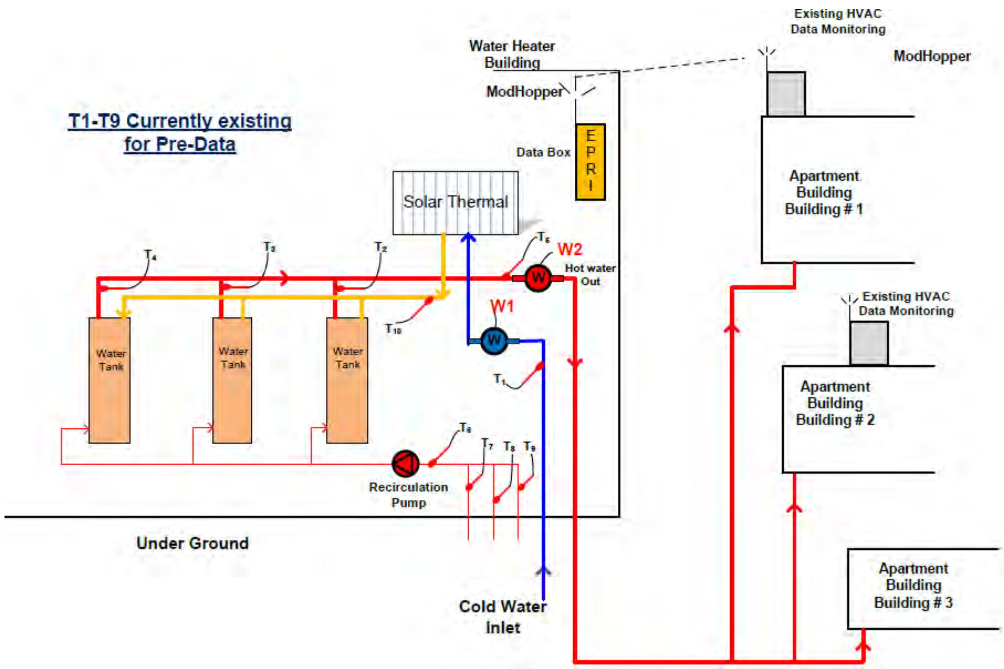


Figure 33: Hot Water Monitoring System Setup

Figure 34: Water Flow Meter Data Collected at Community Water Heating System

5.2 NON-INTRUSIVE LOAD MONITORING

In addition to the EPRI data acquisition system, the team installed NILM technology on Building 1 (covering Units 1 – 8) for proof of concept (Figure 35). The system was installed to collect whole-apartment level data, and it was the first time using this type of system to collect MF community data. NILM uses current and voltage signal analysis to identify the end-use devices as they operate. Some of these technologies can drill down to the level of identifying individual appliances, which helps better understand plug load usage. The team previously conducted an extensive NILM survey and lab evaluation. The research team employed LoadIQ's NILM system and installed it at the facility's main electrical distribution panel with high-frequency sampling sensors and used relevant algorithms to analyze the various unit's energy use. The LoadIQ's EI.X™ series is a cloud-based platform that uses software to identify and track energy consumption and power quality for specific loads. The total load was disaggregated to obtain specific load energy use (such as for lighting, plug, and HVAC loads). Because the sensors were located on the main electrical panel, this equipment was not intrusive to the homes or buildings. LoadIQ installed two EI.4 units at the center panel for each bank of four utility meters. Each EI.4 had four measurement "lines". Each line measured a single apartment, featuring two CTs rated for measuring each phase (A/B) downstream of each utility meter. The data collected by the LoadIQ NILM system is shown in Figure 36.

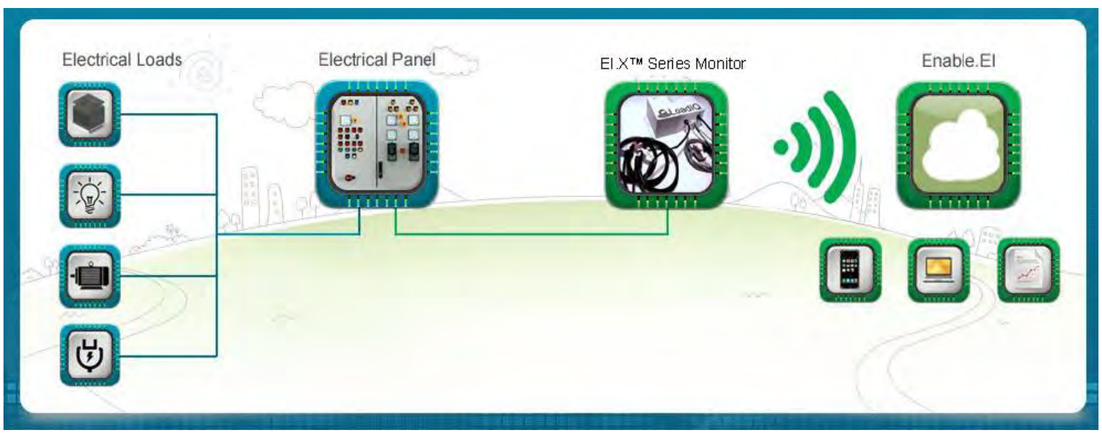


Figure 35: NILM System Topology

The NILM measurements consisted of the following components:

1. *Current measurement*: The electrician created conduit knockouts from the center panel to the lower left and right circuit breakers. The knockouts enabled the EI.4 CAT5 cables to be fed from the center panels to the respective wires downstream of the meter.
2. *Voltage measurement*: A brief disruption of electrical service was required at two apartments – one on each bank of four meters – to install voltage sensors on each phase (A/B). Alternatively, piercing voltage connectors could be used without powering off the circuit breakers. The voltage sensor powers the EI.4s.
3. *Wi-Fi*: The project provided Wi-Fi (via premise-based router or hotspot) for LoadIQ to access and maintains a VPN connection to each EI.4.
4. *Data sharing*: LoadIQ managed a VPN connection to the EI.4 units, and shared the login for EPRI to view and download the data.

Figure 36: NILM System Collected Data on Building 1

Figure 37 shows the NILM system being installed. The NILM system was installed on Building 1 (an 8-plex) and was monitoring Units #1 - #8, until the hotspot lost its connection. The NILM system collected data through CTs, to monitor the residences' total energy use, and disaggregate to individual load types. The metered data was uploaded to LoadIQ's cloud through a Wi-Fi connection, in this case using a hotspot located in the case with LoadIQ's EI.X.

Figure 37: Retrofit process of Non-Intrusive Load Monitoring System

5.3 FIELD TESTS

The project incorporated many EE measures, including standard weatherization improvements, installation of typical, high-efficiency equipment and measures, and novel approaches to increase the MF dwelling unit efficiency. The novel aspects were tested and verified to improve HVAC distribution system efficiency by replacing the existing supply ducts with new, R-8 flex-ducts, and by making proper connections so new duct and connection leakage was near zero. After the supply ducts were replaced, the entire duct system was buried in insulation to further increase duct-system efficiency. During this process, we were able to install some roof insulation. After the old ducts were removed and before the new ducts were installed, loose-fill fiberglass insulation was blown as far into the attic bays as possible. To reduce air leakage to and from each dwelling unit, duct chase air leakage paths were sealed off. This was achieved while the duct chase was open and ducts were not present; all areas surrounding the duct chase that were accessible from the chase and that provided an air-path from the chase to other parts of the building (for example, the interstitial space in the building consisting of open areas in the walls, and other spaces internal to the building but not part of the living area) were sealed using air impermeable materials and caulk. This reduced building envelope air leakage.

The team conducted envelope leakage, blower door, and duct blaster tests to measure leakage and evaluate the apartment units' thermal performance improvement, as well as to identify energy bill and occupant thermal comfort impacts. The duct blaster test was to measure duct leakage by pressurizing ducts to 25 Pa. This involved recording the CFM needed to achieve a stable 25 Pa with the pressure-fan (duct blaster) sealed to the return, and all supply ducts sealed with tape. Blue painter's masking tape was used to attach the duct blaster to the apartment, and to seal any registers, windows or doors. The envelope leakage (blower door) tests were conducted on the apartment with all windows and doors closed (except the front door, where the blower door equipment and fan were installed). The apartment was tested at 50 Pa and the CFM needed to reach 50 Pa reported; if 50 Pa could not be achieved, the actual pressure was noted on the datasheet.

The team conducted envelope sealing after the envelope leakage (blower door) test and duct blaster test. The following steps were conducted for that purpose:

1. While the envelope was depressurized, the blower door identified major leaks using smoke pencil or other techniques.
2. Sealed detected leaks and/or installed new weather stripping in typical places (this included weather stripping and/or sealing around the entry door, sliding door, windows, and exterior floor and ceiling joints).
3. After sealing was complete, the team conducted the blower door test to assess actual leakage. Target leakage was 3.0 ACH50, which is, for one, two, and three-bedroom units, 233, 295, and 407 CFM50, respectively. If envelope leakage was higher than the target value, we attempted to find and seal additional leaks to reduce leakage to or below the target. This ensured the final CFM50-measured values were equal to (or less than) the targets specified.
4. Sealed rooftop supply and return duct segments. The "L" ducts between the RTUs and the roof (or roof penetrations) had to be sealed and painted. To further seal leaks and cover existing mastic, light-colored UL-181-approved duct mastic was applied to all accessible connections in these duct segments between the RTUs and the roof. After the mastic cured, both duct segments were covered with white reflective roof paint.
5. Replaced the ducts as necessary, with the replaced or retrofitted ducts to be no more than 80 cfm at 25 Pa leakage level (the target was 10% of unit nominal airflow – that is, for 400 cfm/ton x 2ton = 800cfm; 10% = 80 cfm).
6. Installed the exhaust duct from the range hood.
7. Restored the ceiling.

After these steps were completed, the team conducted duct and envelope leakage tests, with the results recorded in the testing sheet (sample shown in Figure 38).

Date of Test	UNIT # (from Front Door)	Test In (✓)	Test Out (✓)	Envelope Leakage Test with Ducts uncovered (Depressurized): CFM to Pressurize Apt to 50 Pa	Picture (✓)	Envelope Leakage Test with Ducts uncovered (Pressurized): CFM to Pressurize Apt to 50 Pa	Picture (✓)	Duct Test with Blower Door Pressurize Apt & Ducts 25 Pa (Registers Covered): CFM (at 25 Pa)	Picture (✓)		
7-29-15	10		✓	799@50	✓	995	✓	191 Blower 626	✓		
	12		✓	718	✓	902	✓	170 702	✓		
	9		✓	855	✓	961	✓	216 [illegible]	✓		
	36	✓		1010	✓	1058	✓	329 980	✓		
	38	✓		971	✓	1021	✓	310 773	✓		
	15	[illegible]	✓	811	✓	984	✓	175 710	✓		
	14		✓	760	✓	966	✓	229 679	✓		
	44		✓	1028	✓	1068	✓	157 778	✓		
7-30-15	5		✓	821	✓	880	✓	137 680	✓		
	7		✓	947	✓	890	✓	198 [illegible]	✓		
	4		✓	893	✓	979	✓	133 677			
	1		✓	746	✓	842	✓	158 587			
	19		✓	410	✓	503	✓	161 523			
	28		✓	786	✓	842	✓	122 589			
	25		✓	627	✓	778	✓	140 [illegible]			
	26		✓	587	✓	727	✓	140 502	✓		
	33	✓		1005@[illegible]	✓	1134@461	✓	249 832			
	34	✓		1056@453	✓	1107@47.6	✓	[illegible] 819		202	✓
	32	✓		890	✓	985	✓	311 [illegible] 728		205	✓
7-31-15	31	✓		1245 [illegible]	✓	1608 [illegible]	✓	316 1190		233	✓
	35	✓		895	✓	1480 [illegible]	✓	776 1010		189	✓
	37	✓		955	✓	1023	✓	250 [illegible]		155	✓
	29	✓		980	✓	1004	✓	318 928		323	

Notes:
1. Blower Door pressure and depressurize to 50 Pascals (Pa)

Figure 38: Final Commissioning Blower Door Testing Sheet Data

5.4 Natural Gas Use Data from SoCalGas

The RTUs' space heating natural gas use data was monitored for eight apartment units from the retrofitted group (30 units) and 14 apartment units from the baseline (70 units), because of the cost of adding monitoring systems. SoCal Gas provided data updates on a monthly basis (Table 35). The RTU natural gas data was analyzed, along with the apartment units' ventilation electric loads, during the heating season (Table 36).

Table 35: List of Monitoring Points for Gas Use

Appliance	Number	Equip. Sizing to Monitor
RTUs	20	40,000 Btu
Water heater closet – 3 WH 100-gallons each between 200k – 270k Btu	2	~750,000 Btu each
Duplex water heaters – 50-gallons each	5	50,000 Btu
Laundry – water heater	1	270,000 Btu
Laundry – dryers aggregate of 5 dryers @25,000 Btu/hr.	1	125,000 Btu
Cooking – not sure of sizing (if possible)	10	~ 40,000 Btu

Table 36: Gas Use Monitored Point

Meter Label #	Monitored Point
1	Unit 7 RTU
2	Unit 6 RTU
3	Unit 9 RTU
4	Unit 13 RTU
5	Unit 18 RTU
6	Unit 19 RTU
7	Unit 25 RTU
8	Unit 26 RTU
9	Unit 29 RTU
10	Unit 37 RTU
11	Unit 35 RTU
12	Unit 43 RTU
13	Unit 44 RTU
14	Unit 45 RTU
15	Unit 71 RTU
16	Unit 72 RTU
17	Unit 71/72 water heater
18	Unit 81 RTU
19	Unit 82 RTU
20	Unit 81/82 water heater
21	Unit 85 RTU
22	Unit 86 RTU
23	Unit 85/86 water heater

24	Unit 97 RTU
25	Unit 98 RTU
26	Unit 98/97 water heater
27	Laundry Room water heater
28	Common Area RTU
29	Common Area RTU
30	Bldg 20 Tankless Water heater
36	Unit 71/72 Duplex Total Usage
37	WH Closet 1 water heater
38	WH Closet 2 water heater
39	Unit 81/82 Duplex Total Usage
40	Unit 85/86 Duplex Total Usage
41	Unit 98/97 Duplex Total Usage
42	Laundry Room 10 dryers

5.5 Solar PV Data

MF rooftops can provide valuable real estate space and add extra value by generating electricity from renewables, such as PV. Beechwood, like many communities, provides rooftop space for mounting PV and solar thermal systems, not only on the apartments, but also on the parking structures. This project retrofitted 30 units. While the PV system was sized to cover the 30 units toward reaching ZNE, the system was connected to provide electricity for the entire community. The research team conducted data analysis for this community's solar system as if it were installed for the 30 apartment units to reach near-ZNE. Figure 39 shows snapshots of the PV system and its monitoring interface.

Figure 39: Solar PV System and the Data Monitoring System User Interface

5.6 HEMS Smart Thermostat Data

The HEMS ecosystem enabled us to control many areas of the thermostat interface, such as lighting, security, and blinds control. This project only focused on climate control, but the controls could be expanded to other end uses, as the major home automation product providers offered networked controls that covered HVAC, lighting, and plug loads. These controls could be provided from the aggregation platform through a user-friendly interface. Smart thermostats were installed in 30 units, and enabled setting climate control schedules directly on the user interface, or remotely via smart phone or computer. Ecobee, Trane Nexia, and Nest thermostats (10 of each brand) were installed in the apartment units, as listed in Table 37.

Table 37: Smart Thermostat Brands and their Installed Apartment Unit Numbers

Ecobee	Trane Nexia	Nest
Building 1 Unit 3	Building 1 Unit 1	Building 1 Unit 2
Building 1 Unit 4	Building 1 Unit 5	Building 1 Unit 8
Building 1 Unit 7	Building 1 Unit 6	Building 2 Unit 11
Building 2 Unit 10	Building 2 Unit 9	Building 2 Unit 12
Building 2 Unit 13	Building 2 Unit 15	Building 2 Unit 14
Building 2 Unit 17	Building 2 Unit 16	Building 2 Unit 18
Building 3 Unit 21	Building 3 Unit 20	Building 3 Unit 19
Building 3 Unit 22	Building 3 Unit 24	Building 3 Unit 23
Building 3 Unit 26	Building 3 Unit 25	Building 3 Unit 27
Building 20 Unit 84	Building 3 Unit 28	Building 20 Unit 83

The project found that some occupants enjoyed the smart thermostats' easy-to-use features, and they provided positive feedback on comfort improvement. However, it was also found that reliable internet connections were an issue, since most occupants don't have Wi-Fi connections. The project provided hotspots, but only 1/3 of those hotspots remained functional after three months of installation. In 2016, the thermostat settings had to be re-initialized, but still could not be fully brought back online. This was because the tenant turnover rate was high at Beechwood, and they unplugged the hotspots frequently for various reasons, which would cut off the smart thermostat connections. The only thermostat that remained connected was the one in the common area, where the Wi-Fi was professionally maintained for business purposes.

5.7 Electricity Usage and Billing Data

LINC Housing uploaded all the electricity use data onto the WegoWise website (Figure 40: WegoWise Page for Downloading Data). However, the data that could be released to LINC, and consequently the team, was limited by the apartments that had customer data sharing agreements with SCE. Because of the high turnover rate, individual apartment energy usage and bill data were not significant enough to study occupant behavior and preferences.

Figure 40: WegoWise Page for Downloading Data

CHAPTER 6: PROCUREMENT, INSTALLATION, COMMISSIONING, AND OCCUPANT EDUCATION

6.1 VER PACKAGE PROCUREMENT

The project installed a package of energy-efficient retrofits in five Beechwood MF buildings (two 10-plexes, one 8-plex, two duplexes, one two-bedroom, and one three-bedroom). The VER packages are identified in Chapter 3. This section describes their equipment and material details, including budgeted, expected, and actual costs incurred. This chapter also includes information regarding VER components and packages, and a cost-comparison analysis. The final VER packages were HEMS, Cool Roof, Air Leakage/Ducts, Refrigerators, Lighting, PV System, SDHW, and Insulated Hot Water Pipes & High-Efficiency Water Heater Upgrades.

- The HEMS package included installing 30 wireless thermostats. Three different models (10 of each) were identified for installation: Trane, Ecobee, and Nest. Along with the thermostats, T-Mobile hotspots were provided to facilitate wireless programming capabilities for the residents.
- The Cool Roof package installed on the 10-plex building was comprised of a Sprayed Applied Polyurethane Foam Roofing System (SWD brand closed-cell spray foam). This included priming the roof deck with SWD 2000 sealer, applying 1.5-inch thick SWD Quik-Shield 125 (2.5-3.0 lb.) density polyurethane foam to the roof surface (R 9.45), applying 1929-F Quik-Shield elastomeric base coating, applying 1929-F Quik-Shield white elastomeric top coating, and broadcasting #6 granules into the wet finish coat.
- Inside the dwelling unit, the dropped-ceiling drywall was removed, along with asbestos-containing materials from the "popcorn" ceiling texture and drywall taping compound, exposing the duct chase above (this removal was completed by a certified asbestos mitigation technician). Once the asbestos technicians cleared the space, the existing accessible ducts were removed and discarded. After the old ducts were removed, and before the new ducts were installed, the open and empty duct chase provided access to some ceiling bays between ceiling joists, as well as interstitial building space. Loose-fill fiberglass insulation was blown into the accessible attic bays, reaching as far into the bays as possible. This additional insulation was not part of the original measure package but was identified during the pilot unit work as an opportunity to increase energy savings without adding much to the project cost.
- Existing refrigerators were replaced with current ENERGYSTAR models through SCE's Direct Install program.
- 252 existing light fixtures, consisting of various wall pack fixtures (both Metal Halide and CFL) along with T8 florescent lamps and recessed cans were replaced with LED fixtures.
- The PV system is grid-tied, and interconnects with Beechwood's existing electric

distribution system. It consists of 84 kW/DC of PV modules mounted on existing carport structures, and seven inverters with a total output of 70 kW/DC power.

- The Solar Thermal System consisted of 12 collectors (from Jiangsu Sunrain Solar Energy Co. Ltd. Model TZ58/1800-30R) that were installed on the roof of the 10-plex building. A 1,250-gallon water tank, with heat exchanger, was installed along with a monitoring system.
- The existing buried hot-water circulation lines were abandoned and replaced with identically-sized, new PEX hot water lines, wrapped with FoamGlas insulation and placed over sand bedding. Two of the three existing 100-gallon water heaters were removed. The third existing water heater remained and was augmented by a hot water preheater provided by the Solar Thermal System. A new high-efficiency condensing water heater, Rinnai RU98i, was installed in Building #20, replacing an existing 50-gallon water heater.

Table 38 enumerates the VER packages' estimated budgets.

Table 38: Comparison of Preliminary Budget to Contracted and Actual Costs

VER Package	Budget	Expected	Actual
HEM	$ 9,850.00	$ 7,448.00	$ 7,227.00
Cool Roof	$ 48,000.00	$ 46,489.00	$ 51,759.00
Air Leakage/Ducts	$ 231,000.00	$ 239,308.00	$ 243,689.00
Refrigerators	$ -	$ -	$ -
Lighting	$ 35,252.50	$ 35,252.50	$ 35,252.50
PV System	$ 341,000.00	$ 341,000.00	$ 341,189.37
Solar Hot Water	$ 89,980.00	$ 89,980.00	$ 89,980.00
High Efficiency Boiler	$ 6,350.00	Included in Insulated HW Pipes	Included in Insulated HW Pipes
Insulated HW Pipes	$ 24,000.00	$ 69,670.00	$ 70,302.00
Total	**$ 785,432.50**	**$ 829,147.50**	**$ 839,398.87**

- HEMS models were not selected until prior to installation. The budget amount included a material allowance. Once selected and purchased direct, the actual costs were less than anticipated.
- The cost increase related to installing the cool roof was the result of two issues. The first was removing the gravel material that was on the existing roof. Removing this material was not anticipated at bid time but was recommended by the installer. The 1.5" of foam roof required the mechanical roof mounted pads to be raised. During the execution of this work, it was recommended that 10 sheet metal pans be added to the mechanical roof curbs to mitigate possible water intrusion.

- The cost increase from the air leakage/duct package was related to correcting errors the roofer made while executing their work, such as cutting the thermostat wires, and causing a hole to form in the roof sheathing and drywall ceiling.

The underground piping related to insulating the hot water pipes had the greatest difference between budgeted to actual costs. The hot water circulation was unknown at the time the budget was created, and therefore difficult to estimate. The scope was also increased, based on the selected bidder's recommendation, to include replacing some old valve boxes and upgrading the insulation material. During work execution, some water main repairs were required, which also added to the cost.

6.2 VER Package Installation and Commissioning

The EE measures installed in the 28 apartment units comprised the first installation phase of this research project, addressing deep energy retrofits in MF buildings that were between 30 and 40 years old at the time of project execution, and that had few improvements (for example, new windows) since original construction. The contractor was asked to prepare to adjust practices as needed, to minimize disruption to the tenants, and to provide the appropriate level of work quality to achieve aggressive EE gains. The EE measures included standard weatherization improvements, installing typical high-efficiency equipment and measures, and taking novel approaches to increase MF dwelling unit efficiency. The novel aspects had been tested and verified to improve the efficiency of the HVAC distribution system. By replacing the existing supply ducts with new R-8 flex ducts, and by making proper connections, new duct and connection leakage was near zero. After the supply ducts were replaced, as much of the entire duct system as possible was buried in insulation to further increase duct-system efficiency. Part of the ductwork was exposed above the roof, where the supply and return ducts connected to the RTUs. When the roof foam was sprayed, these exposed sections were coated with about ¾" of foam. After installing blow-in ceiling insulation and sealing unwanted air paths, the old, removed ducts were replaced with new, R-8 ducts, using proper connection processes and procedures. Just prior to replacing the dropped ceiling, the entire chase was filled with insulation to thermally isolate the ducts. Figure 41 shows some of the duct retrofitting process.

6.2.1 Installation of High-Performance Ducts and Duct Sealing

Duct sealing was installed to reduce air infiltration and improve the apartment units' thermal performance. The entire process consisted of eight steps, listed in the following section as Step A (Test-In) through Step G (Test-Out). Steps A, D, and E were done sequentially, and Steps B and C were completed by the time Step E was completed (Figure 41). Steps A-E were performed on a maximum of two units simultaneously, and if two were performed simultaneously, they were stacked in pairs.

Figure 41: Retrofits to Achieve High-Performance Ducts

A. Test-In: The following tests were performed on each unit prior to any improvements, and on the work day immediately preceding Step D. The test results were recorded on a data sheet (Figure 42).

   1. *Duct Blaster Test*: Duct leakage was measured by pressurizing ducts to 25 Pa and recording the CFM needed to achieve a stable 25 Pa with the pressure fan (duct blaster) sealed to the return, and all supply ducts sealed with tape. Only blue painter's masking tape was used to attach the duct blaster to the apartment, or to seal any registers, windows, or doors.

   2. *Duct Blaster with Blower Door*: Test 1 (duct blaster) was repeated, but with the blower door installed, and by pressurizing the ducts and the apartment to 25 Pa. The CFM needed to achieve a stable 25 Pa with the duct blaster was recorded.

3. *Envelope leakage (blower door) test*. The envelope leakage test was performed on the apartment, with all windows and doors closed (except the front door, where the blower door equipment and fan were installed). The apartment was tested at 50 Pa, and the CFM needed to reach 50 Pa was reported. If 50 Pa was achieved, the actual pressure was noted on the datasheet.

These are the test steps:

- Perform the blower door test by pressurizing the apartment with the HVAC registers (both supply and return) taped closed.
- Repeat the blower door test by depressurizing the apartment with the HVAC registers (both supply and return) taped closed.
- Repeat the blower door test by pressurizing the apartment, with all the HVAC registers covered.
- Repeat the blower door test by depressurizing the apartment, with all the HVAC registers uncovered.

Figure 42: Blower Door Testing Sheet Data of the Final Commissioning

B. Envelope Sealing: This was performed only after test-in, as follows:

1. While the envelope was depressurized, used the blower door test (with smoke pencil or other techniques) to identify major leaks to be sealed.

2. Sealed leaks and/or installed new weather stripping, in typical places as well as any identified during test-in and/or while the unit was pressurized, specifically to find and identify leaks; included weather stripping and/or sealing, as appropriate, around the entry door, sliding door, windows, and exterior floor and ceiling joints.

3. After sealing was complete, used the blower door test to find actual leakage. Target leakage was 3.0 ACH50, which was, for 1, 2, and 3-bedroom units, 233, 295, and 407 CFM50, respectively. If envelope leakage was higher than the target value, we attempted to find and seal additional leaks, to reduce leakage to or below the target.

C. Sealed Rooftop Supply and Return Duct Segments: The "L" ducts between the RTUs and the roof (or roof penetrations) were sealed and painted. This step was done at a time after each unit's test-in, and before test-out. Light-colored UL-181-approved duct mastic was applied to all accessible connections in the duct segments between the RTUs and the roof to cover the existing mastic and to seal any leaks. After the mastic cured, we covered both duct segments with white, reflective roof paint. Care was taken not to disturb the existing mastic.

D. Ceiling Removal and Asbestos Abatement: This step was done in conjunction with Step E, to minimize disruption to the tenants, who were out of the units during retrofit working hours, and back in the units between 5:00 p.m. and 8:00 a.m. each day, for a maximum of four days for a pair of units.

1. Removed all existing drop ceiling (entry and hallway outside bedrooms) using proper asbestos abatement protocol and disposed of asbestos-containing drywall at a legal dump site and provided documentation of legal disposal. Asbestos removal scope and work practices included: full negative pressure, containment with High-Efficiency Particulate Air (HEPA) filtration, and wet method with HEPA vacuuming. Occupational Safety and Health Administration (OSHA)-compliant respiratory protection and suits were used.

2. Removed existing, accessible supply flex ducts, and replaced them with R8 flex duct. All connections were performed according to duct-sealing standards.

3. Sealed return joints. This was a repeat of the note at the top of this section. During the pilot, it was determined that there was very limited access to the return duct, which was metal with joints connecting duct sections. Leakage typically occurred at these joints, which were not accessible from the outside, and which we therefore attempted to seal from the inside. We determined the most reasonable approach was to use an aerosol-sealing approach to seal the joints in the hard-ducted returns. The research team worked with WCEC at UC Davis to find a qualified contractor, or a good approach to outfitting and training the LINC contractor of choice for the bulk of the retrofit work.

4. Verified that the final duct leakage met or exceeded the performance goal of no more than 10% total duct leakage. Some pictures of the retrofitting process are shown in Figure 43.

    - Performed a duct-blaster test, as described in Section A.1. Duct leakage was not to be more than 80 CFM_{25}.
    - If this goal was not met, diagnostic measures would have been taken to find leaks and seal them, then we would have repeated prior test steps as necessary until the duct leakage target of 80 CFM_{25} was met.


Figure 43: Duct Retrofitting in Progress

- Tested duct leakage after installing new ducts in both units. Final duct leakage was to be no more than 80 cfm at 25 Pa (target 10% of unit nominal airflow - 400 cfm/ton x 2ton = 800cfm; 10% = 80 cfm).
- Used unfaced batt and loose-fill insulation materials to completely fill duct chase space, to maximize supply and return duct insulation. Applied batts prior to replacing drywall and applied loose-fill after drywall was in place (inserted through hole[s] made in plenum and repaired afterwards). After completing this step, we estimated the average insulation thickness for each of supply and return and recorded this number when the retrofit was completed.

D. Range Hood Exhaust: After test-in, but prior to test-out, we installed a damper in the exhaust duct from the range hood.

E. Restored Ceiling: We installed 5/8" drywall to replace the removed drop-ceiling, mudded and taped the drywall to create a smooth finish, and painted.

F. Test-Out: After completing steps A-G, we completed test-out procedures and followed the Duct Leakage and Envelope Leakage test steps. The goal leakage rates were met and verified by tests during and after sealing the ducts, and while sealing the envelope. Nonetheless, this test-out was performed after all retrofit steps were verified to meet the performance goals described in this section.

1. Re-tested duct leakage after installing new ducts in both units. Final duct leakage was no more than 80 cfm at 25 Pa (duct test-out).
2. Performed blower door test-out for envelope leakage. Target leakage was 8.5 ACH_{50}., which was, for 1, 2, and 3-bedroom units, 636, 807, and 1112 CFM_{50}, respectively (807 CFM_{50} for the prescribed 2-bedroom units).

Location / Material	Extent of Asbestos Contained
Acoustic Ceiling Materials	**Throughout Apartments except kitchen and Baths**
Drywall Joint Materials	**All Wall and Ceiling Drywall Joints**
Silver HVAC Duct Mastic	**Roof-Mounted HVAC Ducts**
Grey Roof Penetration Mastic	**Roof Penetrations on All Buildings**
Exterior Stucco	All Exterior Walls (Stucco)
Vinyl Flooring and Adhesives	Kitchen and Bathroom Flooring materials
Transite Vent Pipes	Roofs of all Buildings

G. After removing the ceiling and exposing the ducts, the materials were inspected using an appropriate asbestos contractor.

6.2.2 Water Heating in the Multiplexes

The apartment units' efficient water heating (Figure 44) problem was solved by using SDHW with a gas backup. This solar option was installed by Everyday Energy. The research team reroofed building #3 and placed the solar thermal system on the rooftop. This is a list of the components required to install the system:

- (24) evacuated-tube solar water-heating collectors from Jiangsu Sunrain Solar Energy Co, Ltd., Model: TZ58/1800-30R
- (2) 1,250-gallon water tanks, with heat exchangers
- Crane rental
- Custom pipe covers

- Engineering and permits
- New electrical circuit installation
- Slab and fencing for tank
- Five-year small system monitoring

Figure 44: Water Heating in Mechanical Closet

The gas backup was provided by a boiler that had been purchased to replace an old, recently-failed boiler. This system required replacing the existing distribution piping from the central boilers to the buildings. This was achieved by abandoning the existing piping, and installing new, 2″-diameter insulated copper water distribution lines on the roof of one of the buildings (Figure 45).

Figure 45: Solar Thermal System Installation and Commissioning

6.2.3 Home Energy Management System

Smart thermostats were installed as the centerpiece of the HEMS ecosystem (Figure 46). This allowed controlling of many points of the thermostat interface, including; lighting, security, and blinds, in addition to the primary function of allowing users to set climate control schedules directly on the user interface, or remotely from their smart phones. Ecobee, Trane Nexia, and Nest thermostats (10 of each brand) were installed in the apartment units; their installed photos are shown in Figure 47. With the occupants' permission, the HEMS system was configured to collect occupant interaction (such as thermostat temperature adjustment). This information assisted in separating technological and behavioral energy use aspects.

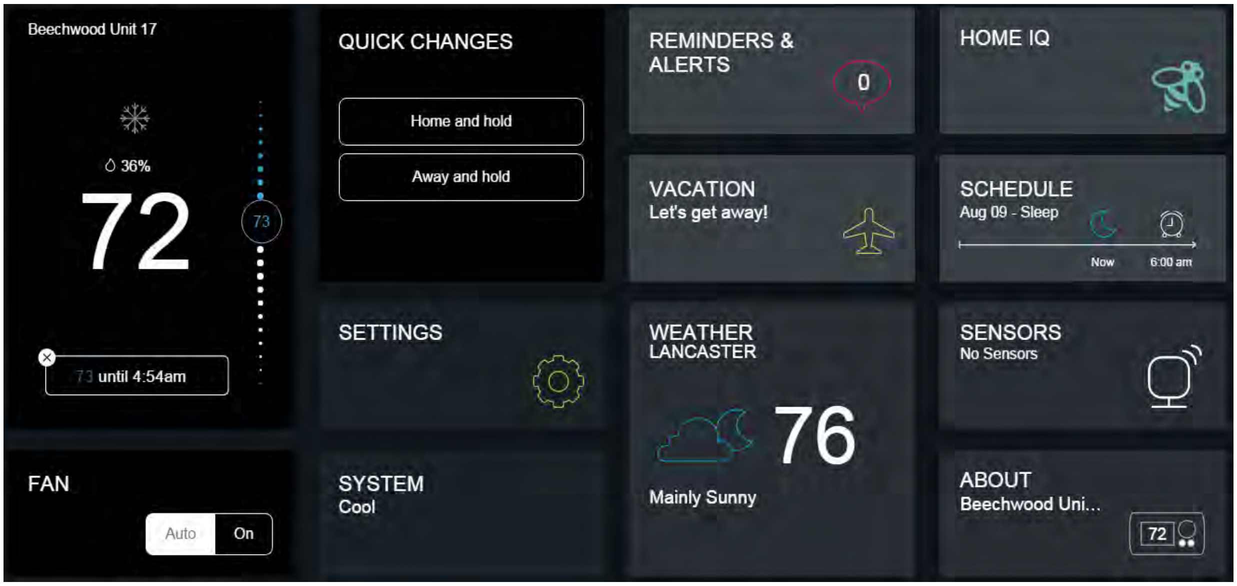


Figure 46: Smart Thermostat Control Interface

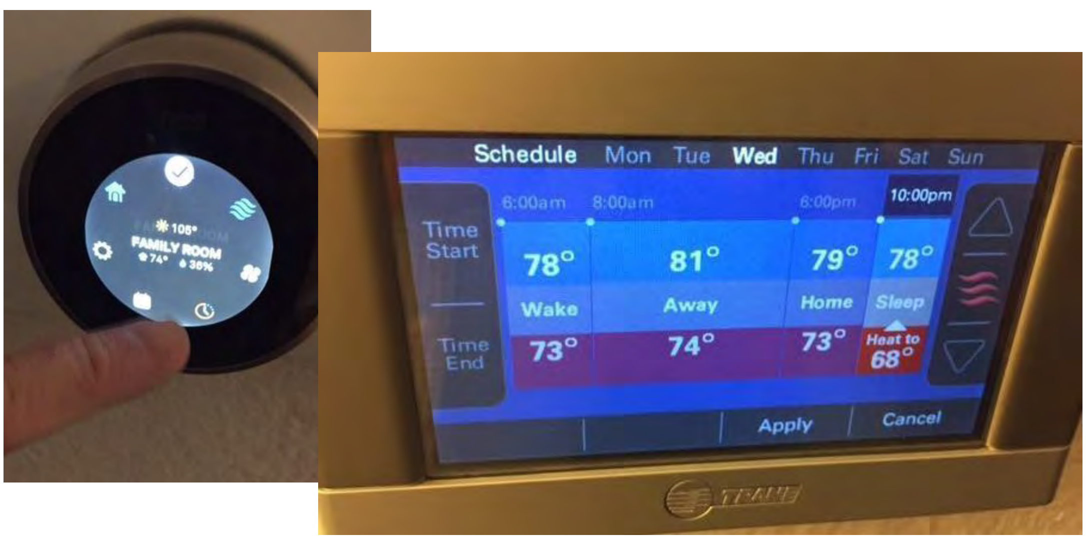


Figure 47: Installation and Commissioning of Home Energy Management System

6.2.4 Installation of Reroofing Using Polyurethane Spray Foam with Elastomeric Coating

This measure was included in the VER package. The roof and HVAC ducts exposed above the roof of the community center benefited from reductions in air leakage and improvements in insulation levels. SPF provided air sealing and a layer of insulation. This task focused on the issues that are unique to MF applications, specifically how to deal with the possibility of sealant material traveling from one apartment to another or being wasted through large penetrations to piping chases. Two primary objectives of employing aerosol technology were: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in the Beechwood common area, and; 2) estimate the first-cost savings and heating/cooling load reductions that could accrue from this type of sealing.

SPF is formed when two liquid components are mixed at a 1:1 ratio inside a specialized spray gun, which generates tiny bubbles with isocyanates, polyols, catalysts, and a non-ozone-depleting blowing agent, when the mixture is sprayed. The bubbles can expand 30 to 50 times larger than its original volume to insulate the roof. SPF is widely used for residential and commercial buildings with old and leaky flat or low-slope roofs. SPF offers high R-value that resists solar heat gains and offers long service life that should last for the life of the house and only requires UV-resistant coating every 10 to 15 years. SPF is water resistant; water leakage only occurs if a foreign object penetrates the foam, producing a hole in the roof.

6.2.5 Aerosol Building Envelope Sealing Technology

The building sealing technology shown in Figure 48 was developed by researchers at UC Davis WCEC. Previous tests have shown a reduction of 50% in leakage areas. The researchers believed it had potential to further reduce the building leakage area. This technology used a compressed nitrogen nozzle to aerosolize the liquid sealant and disperse it, under pressure, into the house. The sealant followed small air streams that formed in and around the leaks; however, the mass of the aerosol caused the particles to hit the edges of the leaks, at which point some of the particles would stick to the edge. Over time, a deposit of the aerosol particles would build up in and around the leaks, sealing them.

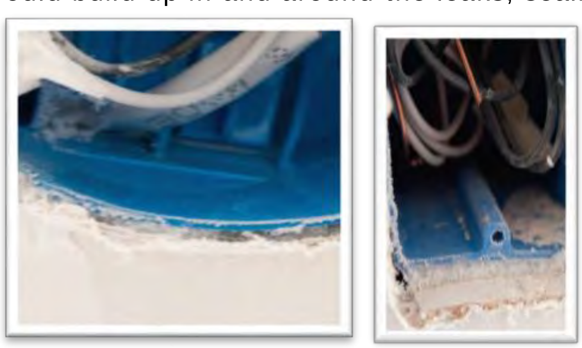


Figure 48: Aerosol Space-Sealing Test for Air Change Rate

Building envelope aerosol sealing had a much shorter time in the market compared to aerosol-based duct sealing. In the case of envelope sealing, the technology for enabling and controlling the process, namely a blower door, was already in widespread application throughout the state. At the time of project execution, the blower doors could maintain the required pressure difference across the building envelope, and they had software to track leakage while the aerosol did the sealing. The remaining issues revolved around the best choice of sealant material or injector, as well as application-specific issues. Good progress on the former was made by PIER, with WCEC support.

6.2.6 Economizer on Common Area Rooftop Units, to Utilize Cool Outside Air

The Economizer circulates fresh outside air into the building and encourages a healthier environment for occupants by minimizing stale air recirculation. It also extends RTU life, if settings such as temperature set points and the minimum outside air damper position are correctly established, because compressor work is reduced when more outside air cooling is used.

The installed economizer was compliant with California Title 24 Building Code. The dampers were low-leakage at 3% to 5% when exceeding Title 24's 10% at 1" w.g. The economizer installation (Figure 49) was installed on the two-ton and four-ton Carrier RTUs, and the energy-saving impact was estimated by switching the compressor staging, when the outside air met the criteria. The field test focused on the energy savings from the compressor switching, using less mechanical cooling to provide comfortable indoor air.

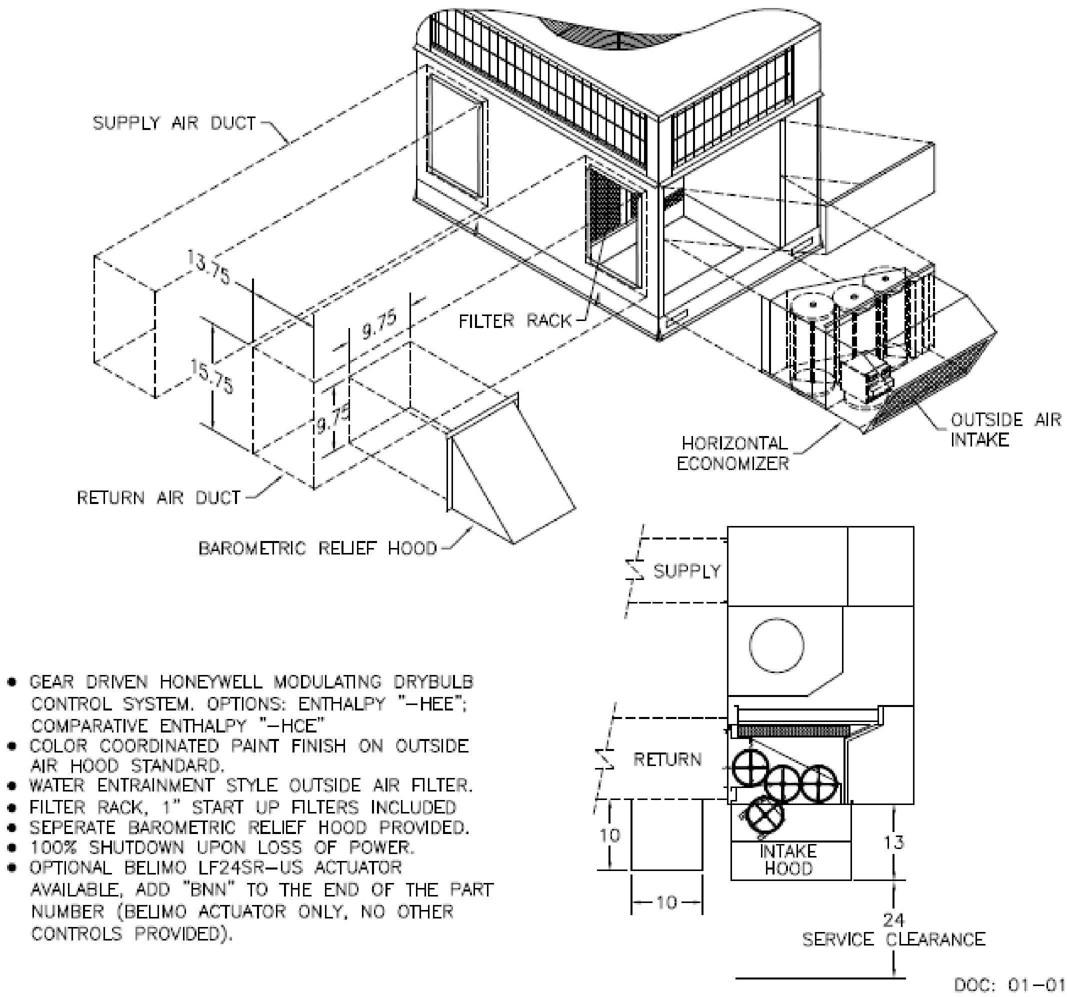


Figure 49: Dedicated Horizontal Economizer

6.2.7 Tankless Water Heater

Tankless water heaters were installed, to provide instantaneous-heating DHW. The efficiency was approximately 20% higher; because the water tank was eliminated so standby power would no longer be a concern. In addition, the tank size was not an issue. If the water use amount was large, the tankless water heater provided constant hot water. The technology itself was not new at the time of project execution, but due to high up-front costs, the simple payback could be as high as 20 years or more.

6.3 EVIDENCE OF POST-RETROFIT INSTALLATIONS

The images in this section show evidence of post retrofit installations (Figure 50).

Figure 50: Post-Retrofit Installations

6.4 Methods Developed to Assist Installation and Commissioning

6.4.1 Method to Obtain Cost Estimates

LINC hired a construction management firm to provide some preliminary pricing based on the scope being considered. This exercise led to further VER package definition, as well as budget establishment. This same construction management firm subsequently created an "Instructions to Bidders" document that was circulated to bidders for the HEMs, Cool Roof, Air Leakage/Ducts, and Hot Water Piping Insulation and Water Heater Upgrades. Separate from this effort, multiple bids were solicited for the PV and Solar Thermal packages. The Lighting Retrofit work was contracted and managed through a utility incentive program.

6.4.2 Method to Choose Subcontractors

Some packages, like refrigerators and lighting, were also dealt with directly through utility incentive programs. To find qualified bidders for the other VERs, the team consulted the Energy Upgrade California website, which provided access to a database of licensed contractors who had experience in energy retrofit work. We also contacted local vendors who had previously worked on the property and were familiar with the facility. Various team members also made recommendations, based on contractors and relationships from previous projects. More than 15 contractors were given an invitation to bid. Of these, 10 contractors attended a job walk, and ultimately provided pricing. These contractors' proposals were compared and leveled to determine the lowest-cost qualified bidder.

6.4.3 Method to Obtain Final Cost Estimates for Packages

As described above, an Invitation to Bid was distributed to solicit interest for those packages that were not being installed through a utility incentive program. Contractors who responded with interest received the Instructions to Bidders document, and attended a job walk for SOW clarification. When the proposals were received, they were reviewed for accuracy and completeness, and the lowest qualified bidder was selected.

Because HEMS was a relatively new technology, it ultimately required that the team work directly with the vendors to purchase the thermostats, as these models were not readily available in local home improvement stores.

6.4.4 Method to Optimize Packages to be within Budget while Maintaining VER Goals

One good example of optimization was that during the bid process, the plumber suggested the insulation material be installed around new hot water lines. The insulation product, FoamGlas, proved to be a superior product to the one recommended for bidding.

Careful consideration and significant time went into the preliminary planning and budgeting phase of the project; thus, final costs were relatively close to those projected.

6.5 Discussion of Variances

Asbestos mitigation was the single-largest variance between the original planning and final costs of the actual retrofits, and the limiting factor of retrofit installation. Issues included:

1. Access to most of the ceiling area to install insulation
2. Limited access to the ducts; for instance, we were sometimes unable to find practical ways to access the return ducts to seal them
3. Variability in duct locations – the asbestos was removed by an asbestos contractor, who cut an opening where instructed. The instructions came from the contractor, who had limited information regarding duct locations, and there was no way to adjust the opening because the area was sealed off during the retrofit to contain and abate any free asbestos.

In addition, below is a breakdown of the different variances:

- Variances from the original EE package designs, and reasons for the variances:
  - Asbestos in the acoustic ceiling and drywall mud not only greatly affected costs, but reduced duct work and insulation effectiveness.
  - Blow-in attic insulation was an added measure. This could have been much more effective for less money, if not for the asbestos.
  - Common-area aerosol sealing left sealant in the carpet and furniture, which required additional effort to clean.
  - Using hotspots for Wi-Fi caused internet connection issues, which made smart thermostat and NILM data collection difficult.

- Descriptions of the EE package installations, and any important variants from the anticipated installation processes:
  - Asbestos was the biggest factor. The field crew did not receive the correct test-in/test-out procedure, so additional field quality control and training was required. The crew was not fully trained on measuring air leakage; thus, some test results were questionable (especially the duct leakage to the outside, which was consistently measured incorrectly).

- Descriptions of any installation variants, and how they were mitigated or otherwise handled:
    - The existing ductwork varied from one building to the next, but the crew was able to expend more effort and skillfully replace the ductwork. They also smoke tested the ducts to find and seal leaks in the RTUs (after the initial duct replacement and sealing work). WCEC satisfactorily cleaned the aerosol sealant.

- Anticipated impacts on EE package performance due to any installation variants:
    - The insulation levels and coverage over the bedrooms and living rooms varied, depending on existing framing conditions (like the mid-span blocking that may or may not have been installed between the joists at the time the building was constructed).

- EE training was provided to tenants:
    - Everyday Energy trained some of the tenants on PV array installations. Smart thermostat installers trained some of the tenants, if they were at home during installation.

CHAPTER 7: VER PACKAGE POST RETROFIT: OCCUPANT EDUCATION, EVIDENCE AND CUSTOMER FEEDBACK

Customer education was accomplished through training and education events. Occupants of the retrofitted homes experienced improved comfort levels. For example, an occupant mentioned that her child could now sleep at night because the retrofit provided a much cooler space. EPRI, LINC, and SCE co-hosted customer education events covering topics such as ZNE and the energy upgrades performed on site. Customer interviews and education materials are documented.

7.1 EDUCATION OPPORTUNITIES FOR OCCUPANTS

As part of the solar PV retrofit, Everyday Energy conducted training on solar installation basics, and provided certificates to the occupants who passed the course. One of the biggest outcomes of this effort, more than the training itself, was the confidence and pride it instilled in the participants (Figure 51). The tenants were also connected with local job centers, to further leverage their learning in the solar installation business. Based on the success of the training, LINC partnered with entities such as Grid Alternatives, who have sizeable training components, for future solar installation projects.

Figure 51: Occupant Interview and Education Event

7.2 Tenant Interviews

SCE interviewed the tenants after installation, to get their input on the retrofits and to gauge customer satisfaction (Figure 52- Figure 54). The overall feedback reflected greater comfort and quality of living. The occupant interviews were conducted by Lori Walker of SCE's Customer Insights team, who summarized the following points from video clips of occupant interviews, and also provided implications from customer interviews (Figure 55).

Figure 52: Occupant Interviewed for Comments on the Near-ZNE Retrofit

This occupant was very happy with the retrofit. She stated it was ". . . very good – you turn on the air and the house gets cold in a matter of minutes."

Figure 53: Occupant Interviewed for Comments on the Near-ZNE Retrofit

This occupant complimented the EE retrofit, and said, ". . . the insulation kept the (conditioned) air in the apartment longer," which saves energy.

Figure 54: Occupant Interviewed for Comments on the Near-ZNE Retrofit

This occupant estimated she would be able to keep her bill at around $30 - $35 per month, which would fit her budget. Prior to the retrofits, her energy bill would sometimes go up to $150 per month. She smiled and commented, "It is a big change."

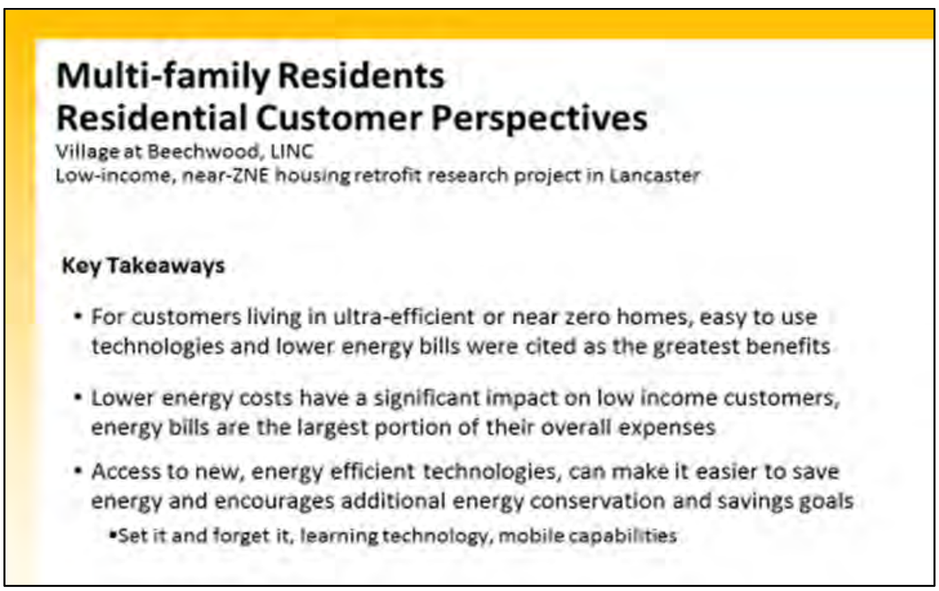


Figure 55: Key Takeaways of Customer Interview (courtesy of Lori Walker, SCE)

- Residents were thankful for the energy upgrades, and happy to be part of the test project.
- Not everyone experienced lower energy bills, but many reported 20-50% reductions.
- The upgrades did not alter any of the residents' energy behavior.

- All residents reported the heating and cooling was very effective and efficient, and that their homes quickly reached and sustained desired temperatures.
- Residents who downloaded the app were happy to be able to control their heating and cooling from their smartphones (some had technical difficulties post-setup).
- The expectations of savings resulting from the retrofits had to be explained to the customers so they could understand the billing impacts.

Some of the residents were concerned with bill increases coinciding with the retrofits. When this was investigated further, one of the identified causative effects was the change from SCE to the City of Lancaster Community Choice Aggregation (CCA). The combination of losing the California Alternate Rates for Energy (CARE) rates provided by SCE, and the additional transfer fees from becoming part of the CCA, showed up as an increase on tenant bills. If this is a consistent pattern, then even if CCAs on average show small reductions in energy charges for their constituents, there is a concern that there might be skewing, with prices increasing for low-income tenants and high-income tenants seeing reductions.

CHAPTER 8: DATA ANALYSIS

8.1 DATA ANALYSIS PLAN

The team leveraged EPRI's past experience in large-scale data collection and using existing data sources from residential buildings for EE analysis to identify, synthesize, and manage data from multiple sources. The team also used the appropriate advanced analytical tools to assist in making decisions. This required the team to develop a suitable data monitoring plan at the beginning of the project, then establish a data warehousing strategy that collected data from many sources. Lastly, the team developed suitable statistical tools to analyze these datasets. The method is scalable to any size residential community, for EE and ZNE analysis. These are the steps in the data collection and analysis plan:

1. Choose the right data. 1) AMI data included recording household electric energy consumption on an hourly (or more granular) basis. An energy monitoring and load disaggregation system leveraged granular AMI data to understand household energy use patterns and occupant behavior; 2) thermostat data and/or duct temperature data showed the temperature set points and room temperature recordings, which reflected heating and cooling patterns, occupant comfort levels, building energy performance, and HVAC upgrade potential, and comparing data across similar homes in the community and nearby locations helped identify target households; 3) monthly natural gas consumption data, together with outside air temperatures, helped us understand household energy performance; 4) billing data showed electric bill amounts; 5) solar PV and/or solar thermal-related energy data was collected; 6) commissioning data (or worksheets) showed onsite improvements, and ensured equipment and upgrades were installed and operating as expected. The data collection plan required the team to collect data from multiple sources into a warehouse and correlate many channels and leverage them into the data analysis.

2. Develop a site-specific data acquisition strategy to collect data into the data warehouse. This step is described in detail in Chapter 5.

3. Employ suitable tools and conduct data analysis. This step was conducted in six stages:

    - The first stage was the simulation analysis, which continued through the entire project. The purpose of the simulation analysis was to identify the VER package's EE measures and their energy-saving contributions.
    - The second stage focused on EE improvements after duct sealing, insulation, and smart thermostats were implemented in June and July of 2015. Data collected from May to September of 2015 (five months of data) was used for analysis. This stage of analysis showed significant impacts on HVAC energy reduction and improved occupant comfort.

- The third stage was conducted in October 2016, after most 2016 summer data was collected, so the research team could compare the pre- and post-retrofit and investigate the EE improvements and community electricity and gas usage impacts.
- The fourth stage focused on the entire premises, based on NILM technology, to study load shapes and low-income community customer behavior.
- The fifth stage focused on energy use in the common area.
- The sixth stage focused on electric and natural gas use, as well as billing data for the entire Beechwood community, in the absence of individual unit data.

8.2 First Stage: Simulation Analysis

Simulation analysis occurred throughout the entire process of this project. When the research team started, simulations were conducted as part of the energy audit process to establish the baseline energy use for the various apartment and building types (see Chapter 2 for a full description of building energy-use modeling, simulation results, and the standard Single-Feature Substitution (SFS) and perturbation analyses used to evaluate the data). Chapter 2 provides in-depth explanations of how the models were built, how building simulations were run, the input data used, and typical simulation results.

In addition, there is a 3-D rendering of Building 1, which the modeling software used input data to produce. This enables visual verification of model accuracy. Simulations were conducted to evaluate the VER packages, both feature-by-feature and as a whole package (see Chapter 3). The simulation results identified the potential energy savings of each VER package's EE measures.

At the final project stage, the team employed simulations to identify energy savings by measure, using a calibrated simulation model. The data shown and discussed in this chapter are results from simulation software calibrated against measured data, where possible. Such simulation calibrations have been performed on several different projects, using new and retrofit homes, and single-family and MF buildings. Building simulation results and comparisons to measured data, where available, are discussed in this chapter.

8.2.1 Simulation Analysis of Building 1

After providing the physical dimensions of Building 1, the team developed the BEopt energy model. The latest version (2.6) was the first to allow input from low-rise buildings with fewer than four stories. This version, as shown in Figure 56, also provided a building rendering, which was useful in checking the simulation input data. Using the simulation results from the hourly models, the team investigated the impact of various EE measures on the improved baseline features.

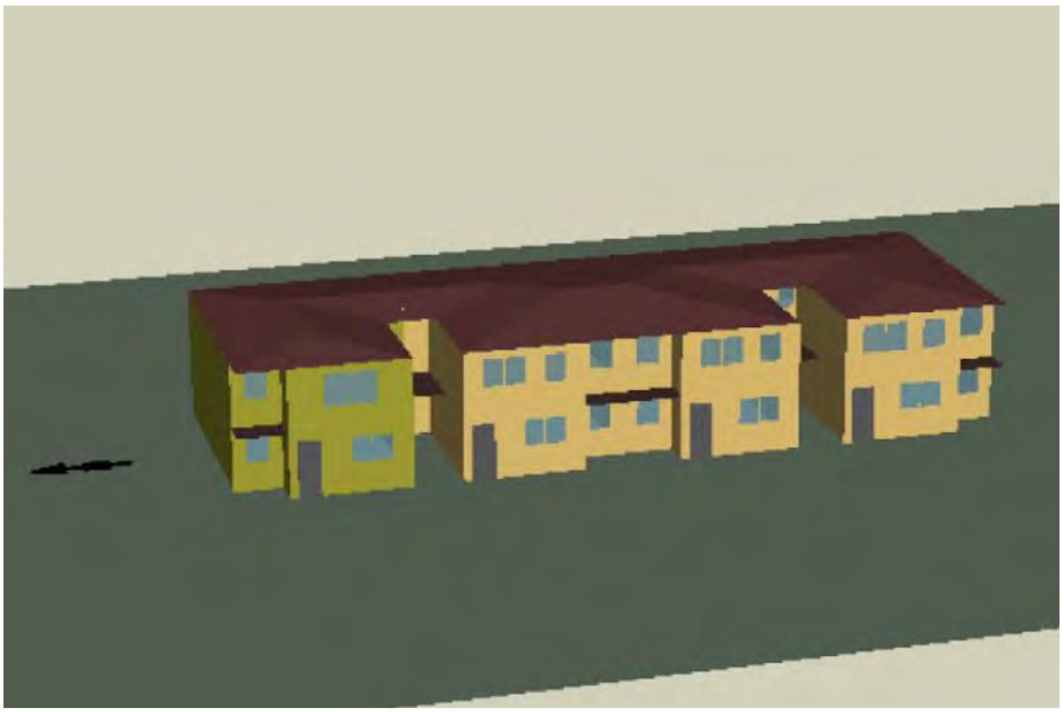


Figure 56: 3D Rendering of Building 1 (Units 1 – 8)

Figure 57 is a graphical representation of the site energy impacts of each individual EE measure in Building 1's baseline model. It shows a series of stacked bars, each providing the results of a full-year simulation, with each modeled energy end use represented as a block within a column of blocks. The blocks in each column are color coded by end use type. The left-most column shows total site energy use, in MMBtu/yr, prior to any retrofits. The total of all the end uses is 327.7 MMBtu/yr, as indicated at the top of the bar.

The next bar (to the right) provides simulation results when one of the EE features was improved from the baseline, as well as the impacts on all end uses when the single feature was made more efficient. This is a SFS (or sensitivity) analysis, and in this case the improvement is in the amount of MELs. The savings (5% in this case) was chosen from a few fixed percentages. The BEopt input values are based on historical data from studies in which occupants were provided training on how to decrease the electricity used when plugging electric appliances into outlets and turning them on. The overall savings was low (1.2 MMBtu/yr) and distributed across three end uses: MELs, space heating, and space cooling. The changes in space heating and cooling were due to a reduction in the waste heat generated by all appliances on, or on standby, within the space.

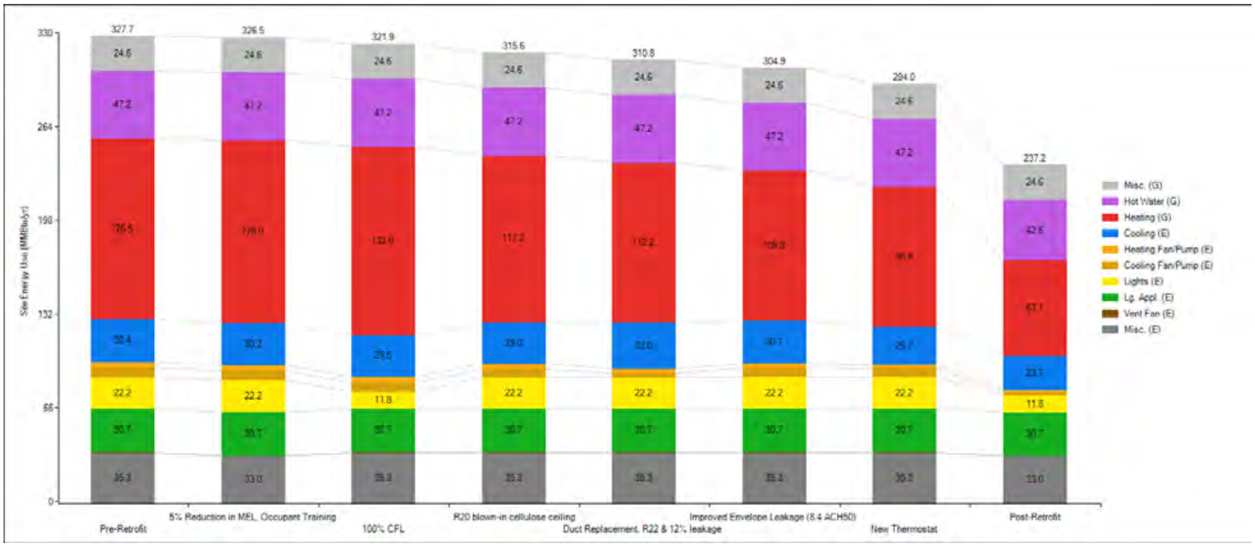


Figure 57: Building 1 Site Energy Use

The next five bars (to the right of the MELs bar) provide the same type of information as the first two, except they are each for different efficiency features. Each bar, except the first (far left) and last (far right), provides results from SFS analyses, showing the changes (if any) to each end use, as well as the sum of all end uses, shown as the total annual energy use for each of the single-feature replacements. As indicated by the description below each bar, this set of analyses tests the impacts of these improvements: providing MELs training, upgrading lighting to CFLs, upgrading ceiling insulation to R-20, upgrading ducts and increasing the surrounding insulation to R-20, including reducing leakage to 12% of total airflow, tightening the envelope to reduce air leakage in and out of the home, and installing smart thermostats. For detailed descriptions of each feature, including baseline values and incremental improvements, see Chapter 4. The last bar on the right is the combination of all measures in the VERs package, including any interactions between features and any diminished returns due to more than one feature affecting the various end uses.

Figure 58 shows whole-building (eight two-bedroom units) results from the same SFS analyses as plotted previously, except this figure reports electricity only, and in units of kWh/yr. All the other characteristics for the analysis in this figure are the same as in the previous figure. Notice also that the value of each end use is provided in the center of the bar. These graphical features are to help visualize changes in a single end use compared to its neighbor.

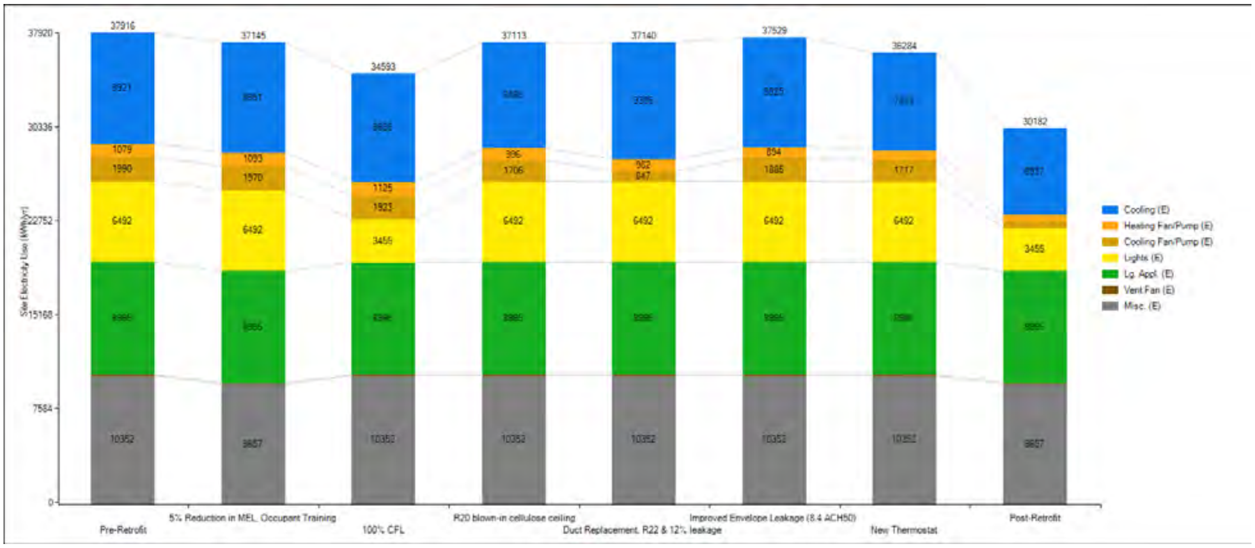


Figure 58: Building 1 kWh Use

Table 39 shows the Building 1 average, per unit, and the differences in electricity use across end uses for the SFS analysis, for which results are shown graphically in Figure 58. Numbers in parentheses are negative values.

Table 39: Building 1 kWh Savings

Site Electricity Savings (Average kWh/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Misc. (E)	-	87	-	-	-	-	-	87
Vent Fan (E)	-	-	-	-	-	-	-	-
Lg. Appl. (E)	-	-	-	-	-	-	-	-
Lights (E)	-	-	380	-	-	-	-	380
Cooling Fan/Pump (E)	-	3	8	35	137	13	34	183
Heating Fan/Pump (E)	-	(1)	(6)	11	12	23	32	64
Cooling (E)	-	8	33	57	(57)	12	139	255
Total	-	96	415	103	92	48	205	968

Figure 59 represents whole-building natural gas budgets. All the other characteristics for the analysis in Figure 59 are the same as in Figure 58.

Figure 59 represents whole-building natural gas budgets. All the other characteristics for the analysis in Figure 59 are the same as those in Figure 58.

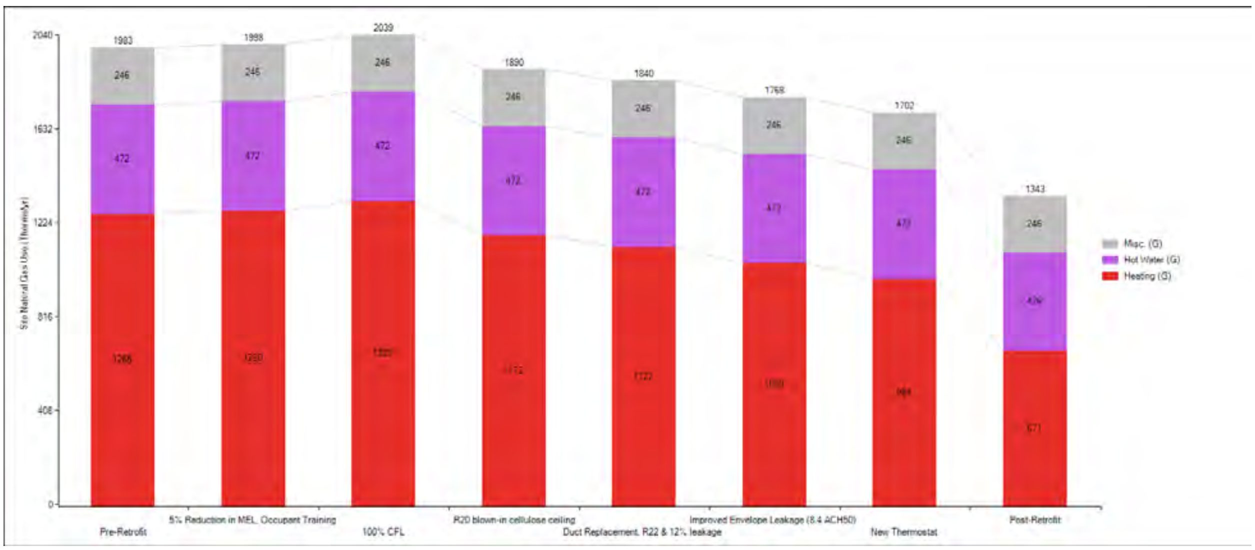


Figure 59: Building 1 Therm Use

The results in Table 40 show average therm savings, per unit, for Building 1. This table is essentially the same as the previous one, except it provides the changes in natural gas end uses for each SFS compared to the baseline pre-retrofit, reported in therms.

The percent savings per each individual EE measure, when added to the Building 1 baseline model, was also calculated from the SFS simulations. Table 41 provides the predicted savings for each of the VERs as a percent savings of total energy use produced for each EE measure.

Table 40: Building 1 Therm Savings

Site Natural Gas Savings (Average Therms/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Heating (G)	-	(2)	(7)	12	18	27	35	74
Hot Water (G)	-	-	(0)	0	-	0	-	6
Misc. (G)	-	-	-	-	-	-	-	-
Total	-	(2)	(7)	12	18	27	35	80

Table 41: Percent Site Energy Savings of Each Feature in Building 1

	% Savings
5% Reduction in MEL,	-1%
100% CFL	-3%
R20 Attic blown-in cellulose, ceiling	5%
Duct Replacement, R22 & 12%	7%
Improved Envelope Leakage	11%
New Thermostat	14%
VER Package	32%

In the percent savings shown in Table 41, the savings were negative for the first two features (reduced MELs and upgrading lamps to CFLs). These negative values were due to an increase in required space heating energy. In each case, there was a decrease in waste heat generated by the feature, but the amount of space heating required to compensate for the decreased waste heat from the more efficient cases were greater than the energy savings from the improved feature. Thus, the total energy savings for these two features are negative, compared to their base cases. However, if calculated in time-dependent valuation (TDV), these features produce savings.

8.2.2 BUILDING 2 SIMULATION ANALYSIS

As with Building 1, the Building 2 model was simulated using BEopt v2.6. A graphical representation is shown in Figure 60. Using simulation results from the hourly models, the team investigated the impact of various EE measures on the improved baseline features.

Figure 60: 3D Rendering of Building 2 (Units 9 – 18)

All the other characteristics for the analysis of the result for the Building 2 model are the same as for the previous model. Figure 61 is a series of stacked bars, showing the results of a full-year simulation for Building 2 (the whole building of ten two-bedroom units) in the same format as the previous model's results. The total of all the end uses for the Building 2 base case is 394.5 MMBtu/yr, as indicated at the top of the bar. The overall savings when MELs were improved (1.5 MMBtu/yr) is similar to the previous model. Figure 61 shows the site energy impacts of the individual EE measures on the Building 2 baseline model. Figure 62 shows results from the same SFS analyses, but for electricity only (in units of kWh/yr).

All the other characteristics for the analysis of the result for the Building 2 model are the same as for the previous model. Figure 61 is a series of stacked bars, showing the results of a full-year simulation for Building 2 (the whole building of ten two-bedroom units) in the same format as the previous model's results. The total of all the end uses for the Building 2 base case is 394.5 MMBtu/yr, as indicated at the top of the bar. The overall savings when MELs were improved (1.5 MMBtu/yr) is similar to the previous model. Figure 61 shows the site energy impacts of the individual EE measures on the Building 2 baseline model. Figure 62 shows results from the same SFS analyses, but for electricity only (in units of kWh/yr).

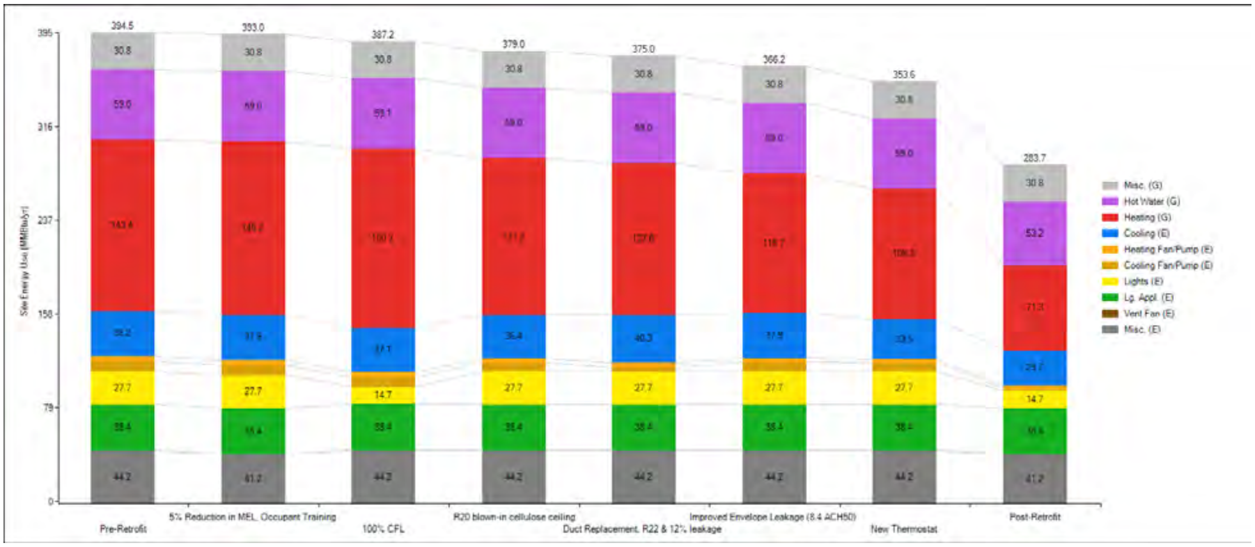


Figure 61: Site Energy Use of Building 2

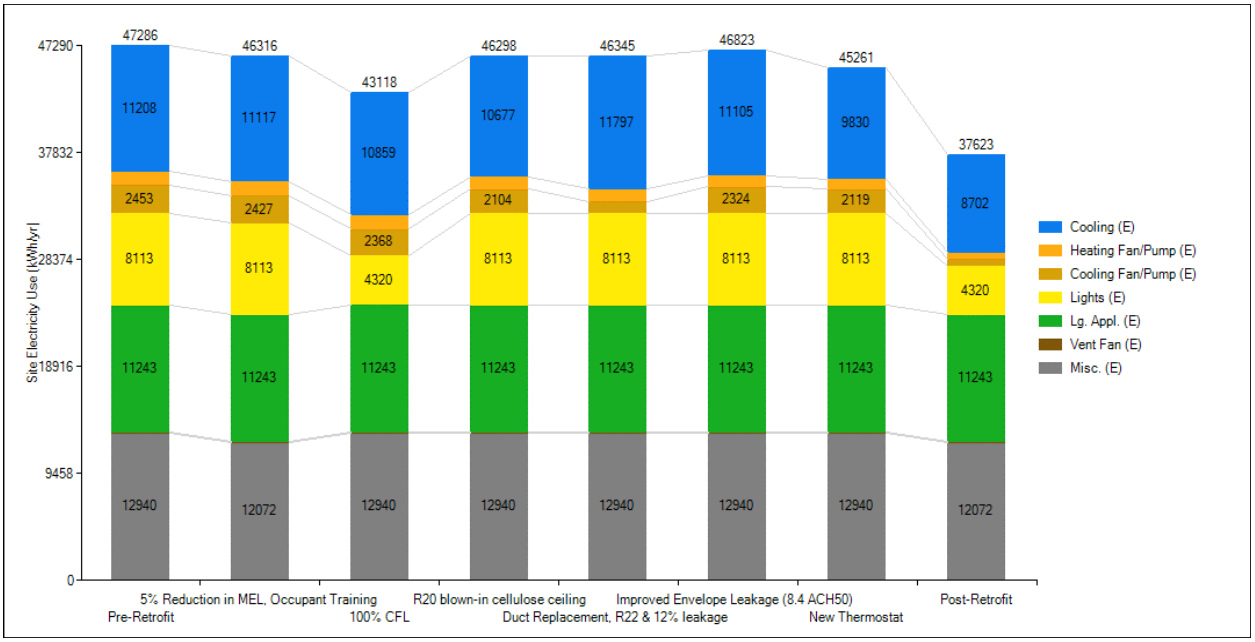


Figure 62: Building 2 Electrical Energy Use

Although Building 2 faces east, its savings trends are similar to previous results. As with the previous models, Table 42 is a numeric chart showing the average per-unit differences in electricity use across end uses from the SFS results in Figure 62.

Table 42: Building 2 kWh Savings

Site Electricity Savings (Average kWh/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Misc. (E)	-	87	-	-	-	-	-	87
Vent Fan (E)	-	-	-	-	-	-	-	-
Lg. Appl. (E)	-	-	-	-	-	-	-	-
Lights (E)	-	-	379	-	-	-	-	379
Cooling Fan/Pump (E)	-	3	9	35	142	13	33	188
Heating Fan/Pump (E)	-	(1)	(6)	11	11	23	31	62
Cooling (E)	-	9	35	53	(59)	10	138	251
Total	-	97	417	99	94	46	203	966

Figure 63 represents whole-building natural gas budgets. Table 43 shows results from the same analysis, but in units of therms/yr.

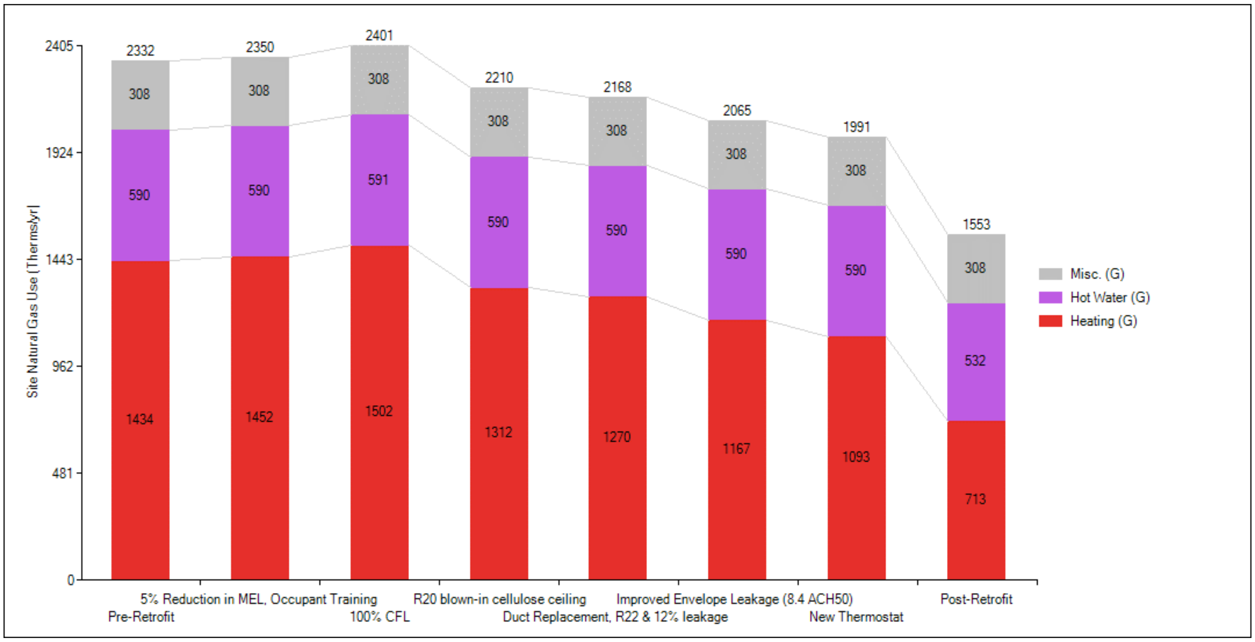


Figure 63: Building 2 Therm Use

All the other characteristics for the tabulated results from Table 42 are the same as in the previous model. The results in Table 43 are tabulated from the above figure, for an average per unit for Building 2.

Table 43: Building 2 Therm Savings

Site Natural Gas Savings (Average Therms/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Heating (G)	-	(2)	(7)	12	16	27	34	72
Hot Water (G)	-	-	(0)	0	-	0	-	6
Misc. (G)	-	-	-	-	-	-	-	-
Total	-	(2)	(7)	12	16	27	34	78

The percent savings per each individual EE measure for the Building 2 baseline model, shown in Table 44, was formatted the same as the previous models, in percent site energy savings (MBtu/MBtu).

Table 44: Percent Site Energy Savings of each Feature in Building 2

	% Savings
5% Reduction in MEL, Occupant Training	-1%
100% CFL	-3%
R20 Attic blown-in cellulose, ceiling	5%
Duct Replacement, R22 & 12% leakage	7%
Improved Envelope Leakage (8.4 ACH50)	11%
New Thermostat	15%
VER Package	33%

8.2.3 Building 3 Simulation Analysis

Building 3 was modeled using the analysis outlined for the previous two models. A graphical representation of Building 3, generated using BEopt, is shown in Figure 64.

Figure 64: 3D Rendering of Building 3 (Units 19 – 28)

Building 3, unlike the other two buildings, had spray-foam insulation and a protective layer added to the roof, in addition to an SDHW system. Simulation results were then treated in the same manner as the previous two models. The individual EE measures' site energy impacts on the Building 3 baseline model are shown in Figure 65.

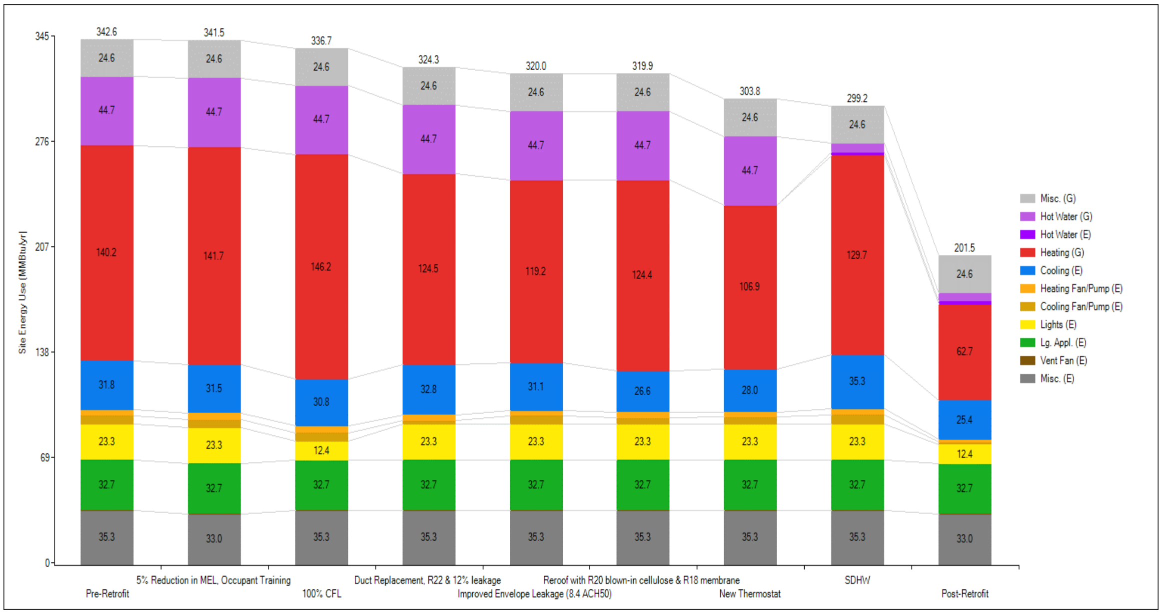


Figure 65: Building 3 Site Energy Use

Results for Building 3 (for the whole building of ten one-bedroom units) were treated the same as for the two previous models, except Building 3 received spray-foam roof coating with a protective layer applied prior to installing an SDHW system on the roof. The Building 3 base case was 342.6 MMBtu/yr, and savings from MEL improvement (1.1MMBtu/yr) was similar to the two previous models' results. Figure 66 shows the results from Building 3 in units of kWh/yr.

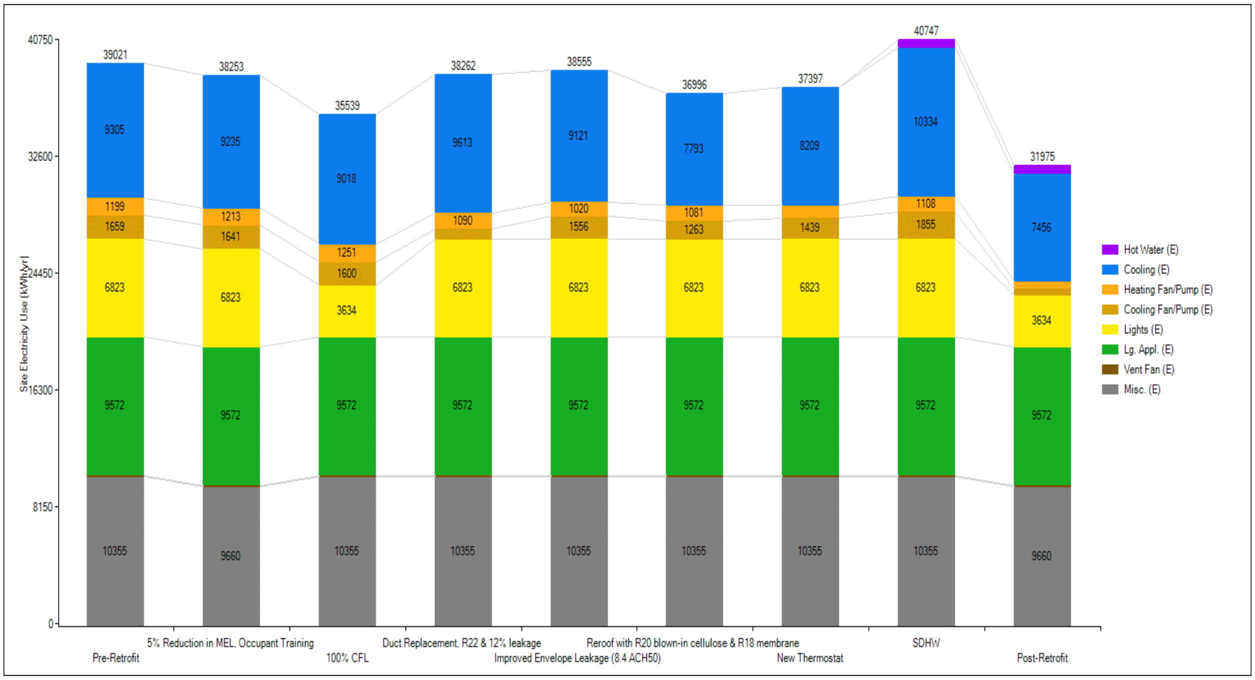


Figure 66: Building 3 kWh Use

With the exception of adding spray-foam insulation and a SDHW system to Building 3, the other kWh savings results trends are similar to results from the two previous models, despite being west-facing and containing one-bedroom units. As with the previous two models, Table 45 is a numeric chart, summarizing average per-unit results from Figure 66. However, Building 3 had the additional retrofits of roof spray insulation (labeled "Reroof" in Table 45) prior to installing a SDHW system. The results reflect that difference, compared to previous building models.

Table 45: Building 3 kWh Savings

Site Electricity Savings (kWh/yr)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	SDHW	Post-Retrofit
Misc. (E)	-	695	-	-	-	-	-	-	695
Vent Fan (E)	-	-	-	-	-	-	-	-	-
Lg. Appl. (E)	-	-	-	-	-	-	-	-	-
Lights (E)	-	-	3,189	-	-	-	-	-	3,189
Cooling Fan/Pump (E)	-	18	59	958	103	396	220	(196)	1,240
Heating Fan/Pump (E)	-	(15)	(53)	108	179	117	308	91	659
Cooling (E)	-	70	287	(308)	185	1,512	1,096	(1,029)	1,849
Hot Water (E)	-	-	-	-	-	-	-	(592)	(586)
Total	-	768	3,482	759	466	2,025	1,624	(1,726)	7,046

Figure 67 shows results from the Building 3 analysis, also for the whole building, but in therms/yr.

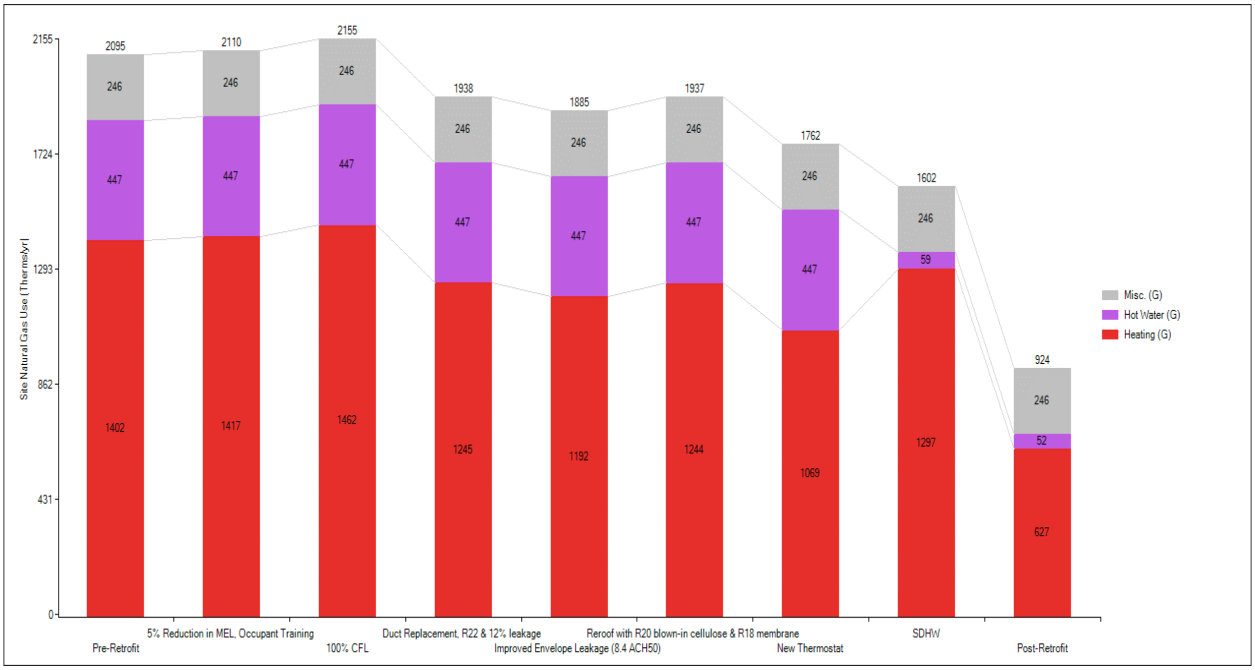


Figure 67: Building 3 Therm Use

Table 46 shows Building 3 averages, per unit.

Table 46: Building 3 Therm Savings

Site Natural Gas Savings (Average Therms/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	SDHW	Post-Retrofit
Heating (G)	0	-1	-6	16	21	16	33	11	78
Hot Water (G)	0	0	0	0	0	0	0	39	40
Misc. (G)	0	0	0	0	0	0	0	0	0
Total	0	-1	-6	16	21	16	33	49	117

Table 47 shows the percent savings per each individual EE measure for the Building 3 baseline model, in MBtu/MBtu.

Table 47: Percent Site Energy Savings of each Feature in Building 3

	% Savings
5% Reduction in MEL, Occupant Training	-1%
100% CFL	-3%
Reroof with blown-in cellulose & R8 membrane	7%
Duct Replacement, R22 & 12% leakage	10%
Improved Envelope Leakage (8.4 ACH50)	8%
New Thermostat	16%
Solar Hot Water	24%
VER Package	56%

8.2.4 Simulation Analysis Conclusions

Developing the Beechwood VER package followed a consistent and thorough process to find the optimal retrofit set to suit the buildings and clients (details are in Chapter 2 of this report). This section reviews VER performance expectations. The team intended to evaluate the packages using monitored data while comparing the simulation results. Unfortunately, that could not be done for several reasons, including that it was virtually impossible to evaluate natural gas savings due to the entire complex being master metered. We found no analytical method that could manipulate the master-metered gas use to reliably separate the 28 retrofitted units from shared use in the laundry and community center. In addition, there were data capture and download problems. Nonetheless, conclusions can be drawn from the simulation results, which were generated by team members with extensive experience in modeling, simulation, and calibration.

Aside from adding SDHW or roof insulation for all three building model analyses, the two most effective features were reducing the building envelope leakage to 8.4 ACH_{50} and adding PCTs. The VER package was predicted to save about 30% of the total per-unit energy use, and by adding spray-foam insulation to the roof and installing a SDHW system, savings were predicted to be over 50%. However, actual savings were less than predicted.

Based on the team's depth of experience and discussions, they believed the expected thermostat-related savings likely suffered from significant changes in pre- and post-retrofit settings, due to take-back allowing the tenants to afford to set their thermostats to be more comfortable and use more energy in the process. To achieve the savings smart, connected thermostats could provide, they had to be connected to master controllers, with regulated savings. Such oversight would have required significant culture changes and may not have been feasible in the near term.

Savings from reduced envelope leakage and the community hot water retrofit (including the SDHW) and new storage and distribution components may have been achieved, but at a high cost for the hot water retrofits, particularly the new distribution system. Duct savings were likely accomplished in the two pilot retrofits, but similar savings were probably not reached in some or most of the other units. This may have been due to expectations of high-quality work done in the pilots, setting high hopes for the retrofits, but that likely were not attained in the standard retrofits due to dominating construction practices to push to get the job done quickly.

In addition, there were difficulties obtaining expert quality assurance resources throughout the process, because of the community's relatively remote location. The duct retrofit also required asbestos abatement, which made its costs too high to realistically recover within any current financing period. More research is required to find simpler, more practical VERs that may have lower energy-savings goals, but that, if cost-effective and financing problems could be solved, may be performed much more broadly, producing greater total energy savings.

8.3 Second Stage: Initial Analysis of Envelope Improvement

This second stage of analysis focused on each retrofitted household's A/C unit energy use before and after the retrofit, as well as the comparison between retrofitted households and the control group (baseline). Most of the retrofits were implemented during June and July. The collected data shows some of the apartments' A/C unit energy use was more weather-driven, meaning the cooling load followed the pattern of outside air temperature. However, some units' electric use was less correlated with the weather, which could be for many reasons, such as the apartment units being vacant, being less-occupied during the day, or having compromised thermal comfort to save electricity. Thus, only the weather-driven electric energy patterns from the retrofitted group (Unit #1 to Unit #28) and the control group (Unit #29 to Unit #38) were selected to compare energy performance at this stage of data analysis. Unit #30 was selected as a baseline example, and Unit #14 was selected as the retrofitted example. In Figure 68, the time-series graph on the left shows a comparison between the daily average outside air temperature and the AC unit's average daily power consumption. Both units' energy consumption was weather driven, and the team observed a consistent energy pattern for Unit #30 (as a baseline), but a gradually reduced pattern for Unit #14, due to the EE retrofit implemented in the June and July timeframe. The graph on the right shows monthly AC energy use; the percent increase from July to August was reduced, as shown in the comparison of Unit #14 to Unit #30.

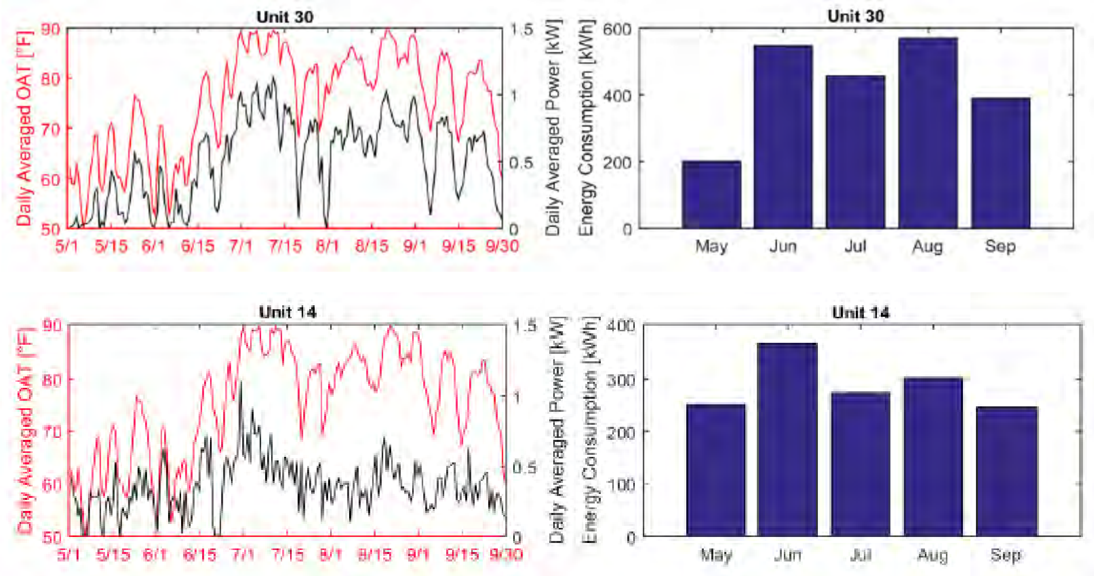


Figure 68: Envelope Improvement of a Unit in Control Group Unit vs. Baseline

To better understand the household thermal characteristic change after installing duct sealing and insulation, the research team conducted further analysis using the A/C unit's daily energy use (in kWh) and the average outside air temperature. As shown in the charts, the team first plotted each day's outside air temperature and A/C unit energy use (one dot represents one day) and color-coded the dots for each month. Linear regression lines were drawn, based on each month's dots. The team observed Unit #30 had a consistent energy consumption pattern throughout the observed months, as the regression lines had similar slopes and, in this case, intercepts – whereas Unit #14's energy consumption patterns were changed due to the implemented retrofit (Figure 69). For Unit #14, the regression line slopes for May and June were higher than July, August, and September, meaning the retrofit changed the apartment's thermal characteristics, and its energy use was more efficient during those months. Thus, the second stage of analysis shows envelope improvement made a difference in thermal characteristics and improved the EE.

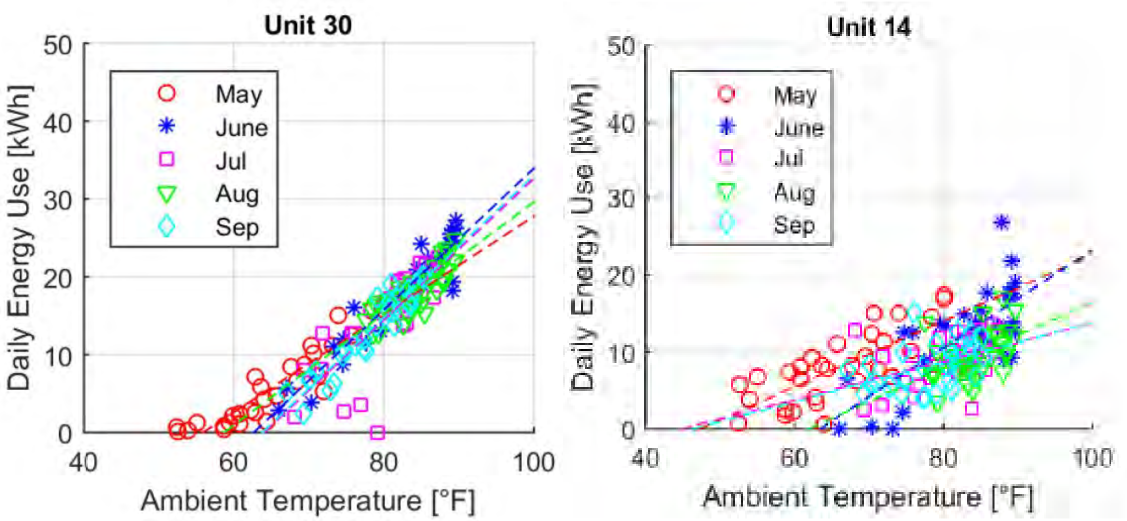


Figure 69: Thermal Characteristic Analysis of Control Group vs. Treatment Group

8.4 Third Stage: Pre- and Post- Retrofit Analysis of Apartment Units

8.4.1 Electric Data Analysis

The third stage of analysis was conducted after most of the data was collected in October 2016, to compare the 30 apartments' pre- and post-retrofit energy use and correlate the treatment and control groups' energy use.

The research team noticed 2016 was a much warmer year than 2015 – the cooling degree day was 27.7%, 7.4% and 43.7% more in May, June, and July, respectively, as shown in Figure 70.

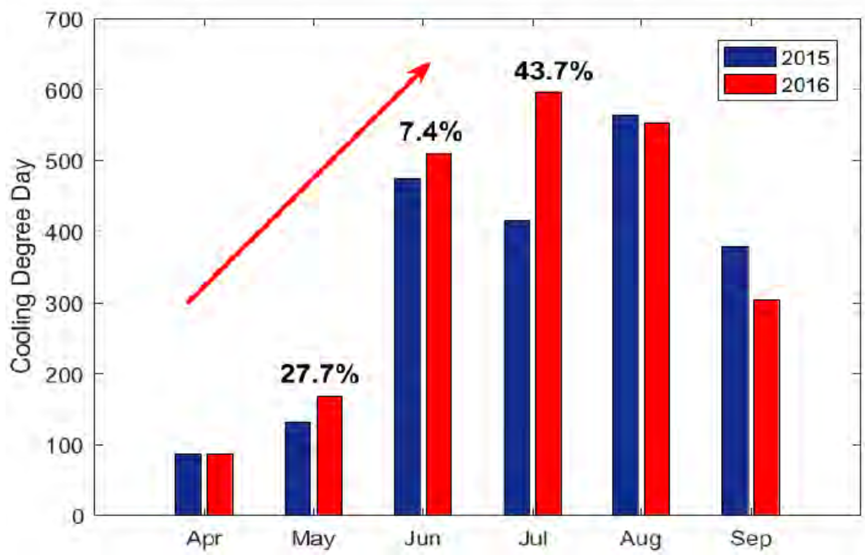


Figure 70: Cooling Degree Day Comparison, Summers of 2015 and 2016

Thus, the retrofit group's energy use actually increased in 2016, if directly compared with 2015 data. Figure 71 shows the much-hotter summer of 2016 drove up A/C unit cooling, resulting in more energy use in May, June, and July. Given the results, the team researched how the control group's energy performance compared to the treatment group. Figure 72 shows the energy use in one control group also increased with the patterns of the hotter summer months, and the team discovered the energy use differences were greater than those of the treatment group, since A/C energy use is strongly behavior driven. The research team found that some occupants also had some level of difficulty with scheduling the installed smart thermostats, partly due to the user interface, but also because the occupants changed frequently over the course of the project. The research team conducted further analysis to understand the cooling and heating seasonal energy use for all units, and additionally reviewed the impacts the thermostat brands had on energy use.

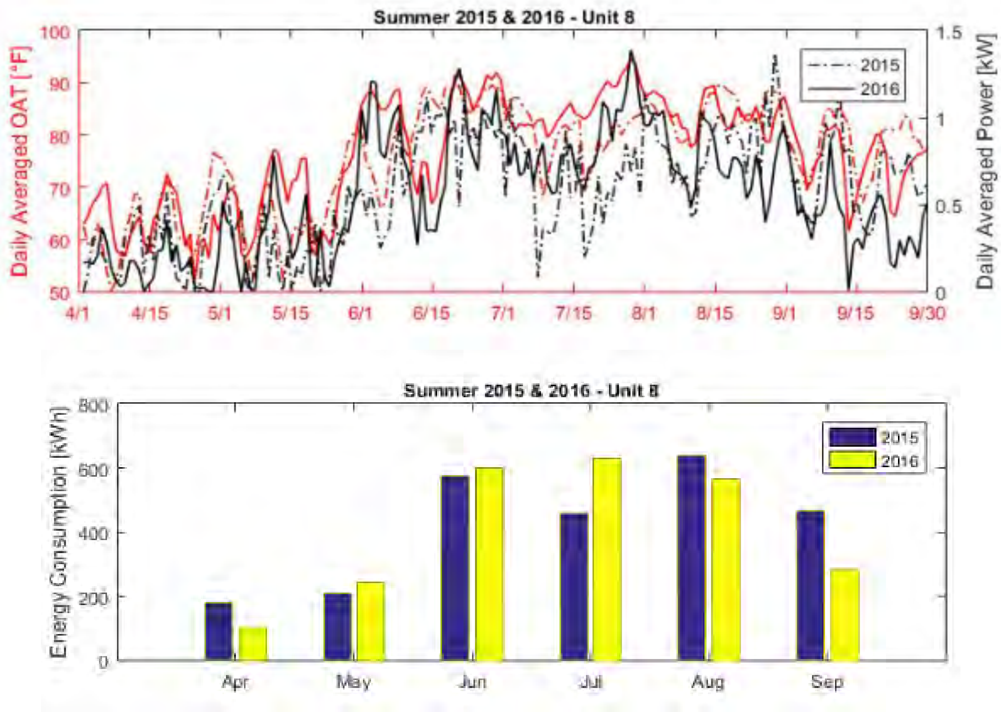


Figure 71: Electric Energy Consumption of One Rooftop Unit in Treatment Group

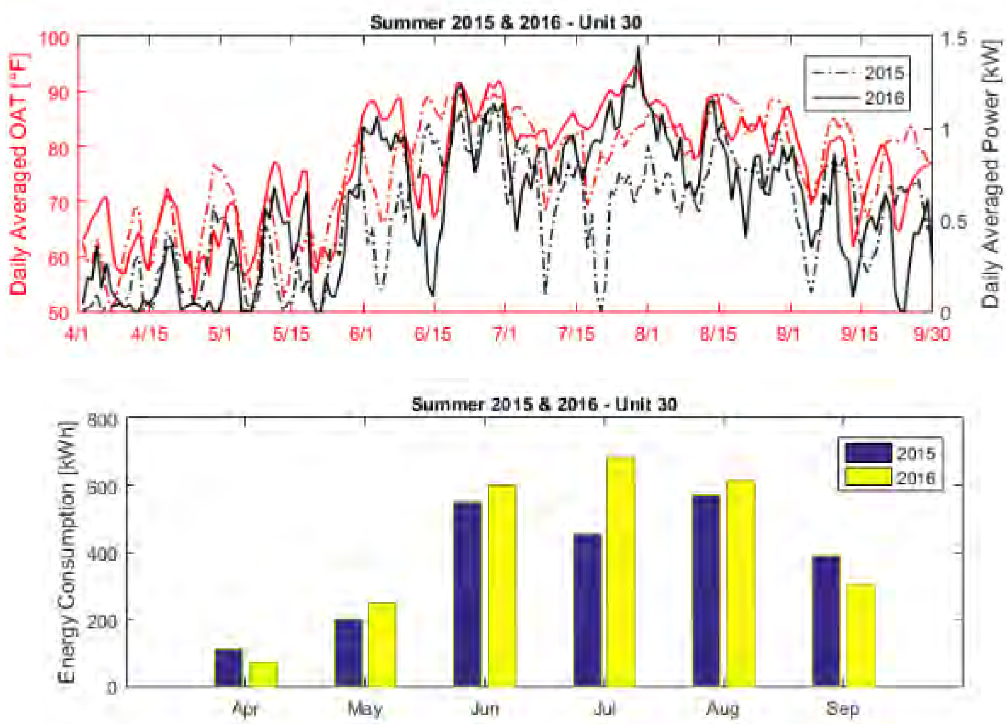


Figure 72: Electric Energy Consumption of One RTU in Control Group

In Figure 73, the RTU energy use is plotted, since the data monitoring system was set up in April of 2015. The energy use includes the A/C unit compressor and ventilation fans, reflecting winter and summer ventilation load plus summer cooling loads. Lancaster weather indicates the summer season is around six months, from April to September, with the rest of the year considered winter. April 2015 to December 2015 (six months of summer and three months of winter) were used to compare January 2016 to September 2016 (six months of summer and three months of winter) for heating and cooling seasons.

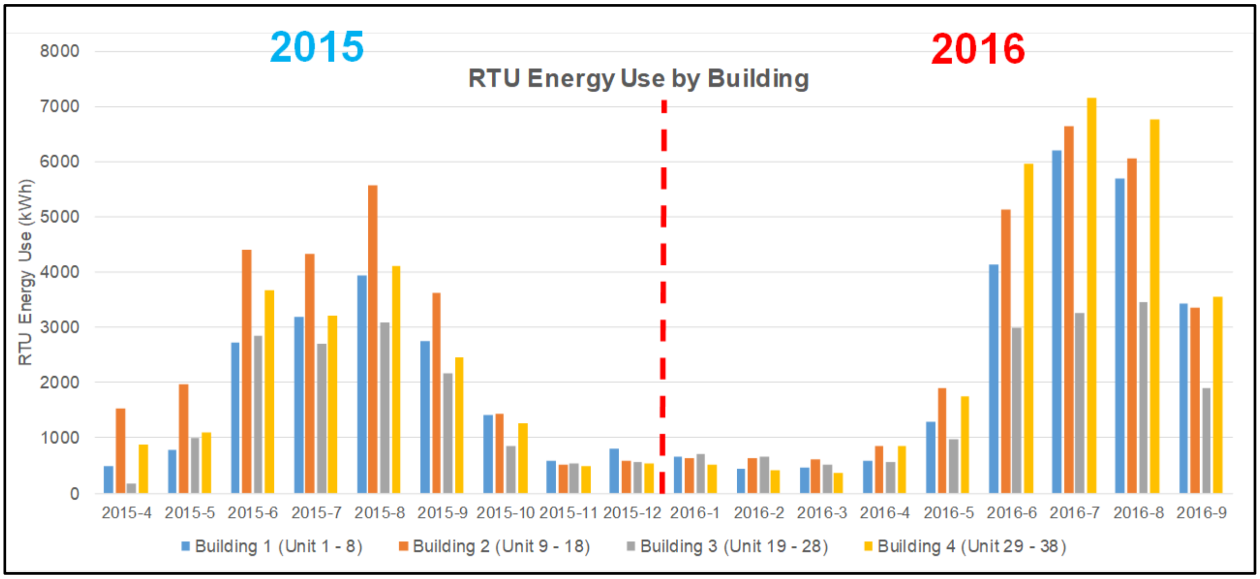


Figure 73: Monthly Electric Energy Use of RTUs of Building 1 – 4 in 2015 and 2016

Figure 74 shows the treatment group (Buildings 1, 2, and 3) all consumed more cooling energy and ventilation in 2016 than in 2015. Specifically, Building 1 (Units 1 – 8) consumed 37.2% more; Building 2 (Units 9 – 18) consumed 7.7% more; and Building 3 (Units 19 – 28) consumed 7.7% more. The control group, Building 4 (Units 29 – 38) also consumed more cooling and ventilation energy in the A/C units, which was 53.9% more due to the hotter summer of 2016.

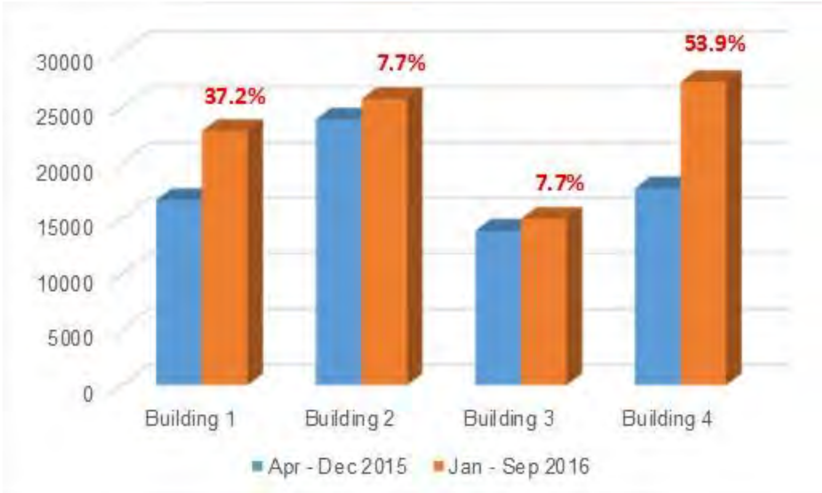


Figure 74: Comparison of RTU Electric Energy Use between 2015 and 2016

The research team further compared the "difference of differences" – the energy use reductions between the 2015 and 2016 treatment and control groups (Figure 75). Building 1 (Units 1 – 8) consumed 5.97% less energy than the control group in 2015, and 16.18% less than the control group in 2016 – a 10.21% improvement in 2016. Building 2 (Units 9 – 18) consumed 34.89% more energy than the control group in 2015, and 5.62% less energy than the control group in 2016 – a 40.51% improvement in 2016. Building 3 (Units 19 – 28) consumed 21.58% less energy than the control group in 2015, and 45.14% less energy than the control group in 2016 – a 23.56% improvement in 2016. The research team believed the analysis of the building level averaged out behavior-driven factors, and the "difference of differences" analysis indicated the EE improvements resulting from implementing the VER package in Buildings 1, 2, and 3.

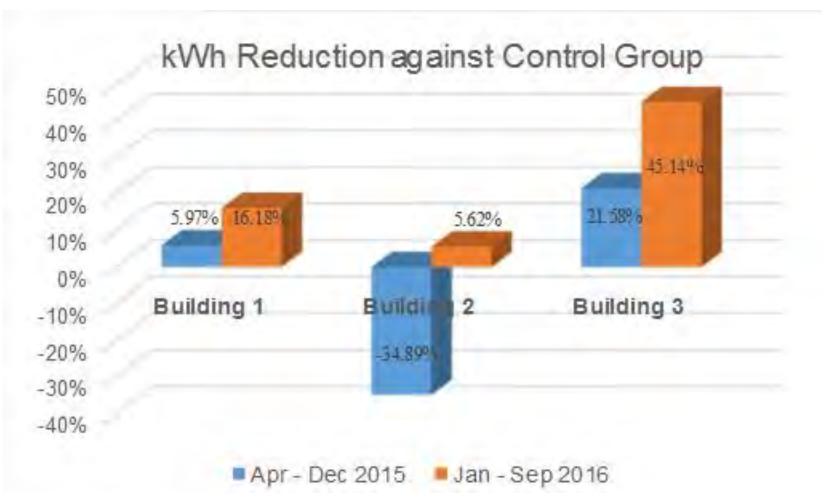


Figure 75: Comparison of Energy Use Reductions between Treatment and Control

This project installed smart thermostats for HEMS in the control group, but also wanted to test their effectiveness between product manufacturers. The project installed Ecobee, Trane Nexia, and Nest Thermostats in the apartment's units (10 of each brand), and the research team conducted further analysis to compare the energy use of A/C units that were controlled by those three thermostat products. The monthly energy use also covered nine months (six months of summer, three months of winter) in 2015 and 2016, to compare the ventilation and cooling loads controlled by the thermostats (Figure 76).

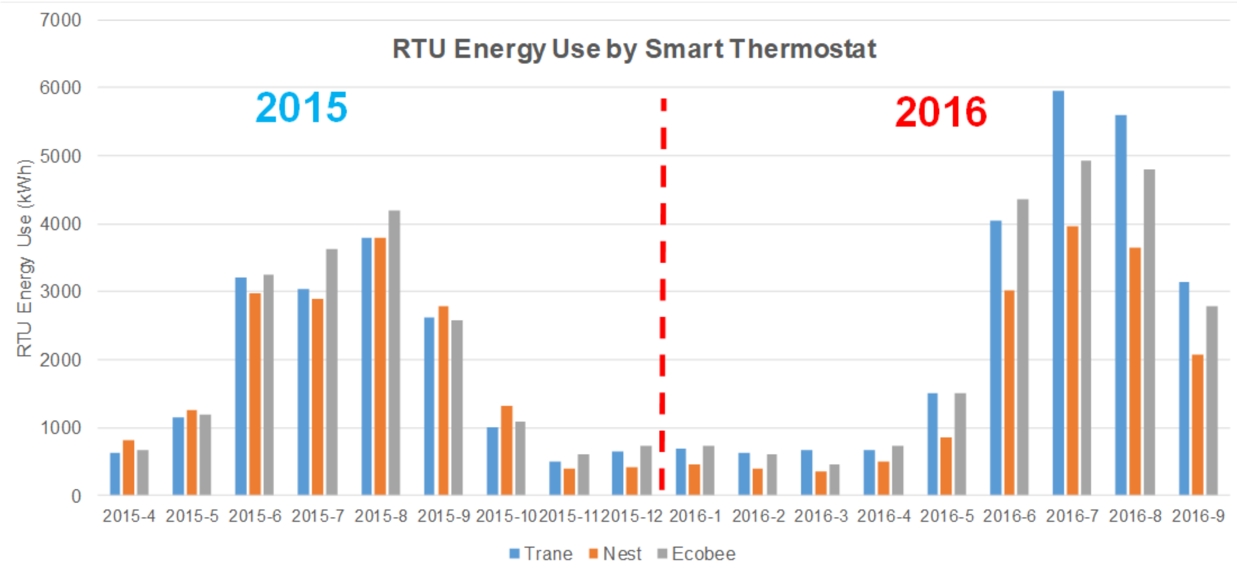


Figure 76: Monthly RTU Electric Energy Use Controlled by Smart Thermostats

Not all thermostat groups consumed more energy, despite the much hotter weather of 2016 (Figure 77). The Trane Nexia and Ecobee thermostat groups consumed more energy in 2016, but the Nest thermostat group reduced even more energy consumption in 2016 than in 2015. Specifically, the Trane Nexia thermostat group (Units 1, 5, 6, 9, 15, 16, 20, 24, 25, and 28) consumed 37.8% more; the Nest thermostat group (Units 2, 8, 11, 12, 14, 18, 19, 23, 27, and 83) consumed 8.2% less; and the Ecobee thermostat group (Units 3, 4, 7, 10, 13, 17, 21, 22, 26, and 84) consumed 16.5% more. Since each group's energy use was observed as both increased and decreased, the research team again conducted the "difference of differences" analysis to compare with the control group and draw a conclusion on these thermostat brands' performance.

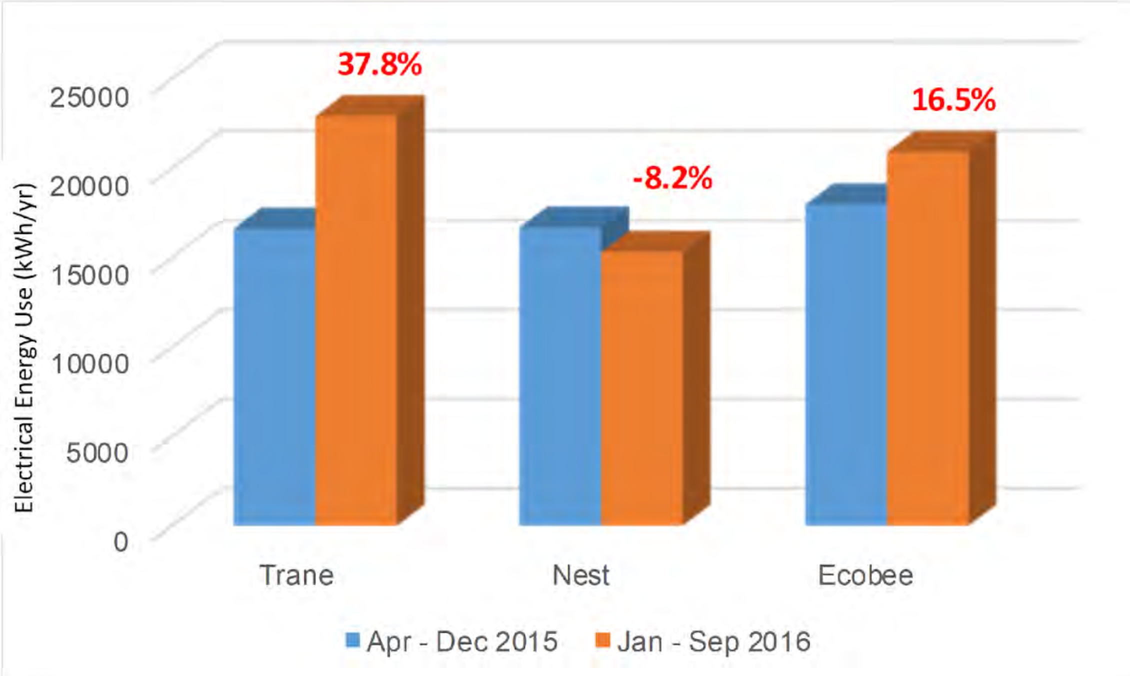


Figure 77: Comparison of Electric Energy Usage of RTUs Controlled by Three Different Thermostat Brands

The Trane Nexia thermostat group (Units 1, 5, 6, 9, 15, 16, 20, 24, 25, and 28) consumed 6.46% less than the control group in 2015, and 16.2% less in 2016 – a 9.74% improvement in 2016 (Figure 78). The Nest thermostat group (Units 2, 8, 11, 12, 14, 18, 19, 23, 27, and 83) consumed 6.09% less than the control group in 2015, and 44% less in 2016 – a 37.91% improvement in 2016. The Ecobee thermostat group (Units 3, 4, 7, 10, 13, 17, 21, 22, 26, and 84) consumed 1.09% more in 2015, and 23.51% less in 2016 – a 24.6% improvement in 2016. The results show the smart thermostats further enhanced EE on top of the VER packages installed on site, and Nest thermostats seemed to drive up more savings. Only 10 apartment units for each thermostat brand was too small a sample size to draw any conclusions on capabilities, but the analysis still provided some insights on the EE potentials of the HEMS installed in those buildings. Historically, smart thermostats have encountered some difficulties in penetrating the low-income MF community.

However, the research team received some very positive feedback on smart thermostats, and tenants were using the thermostats to set up their heating and cooling schedules. During a routine check in, one tenant expressed her satisfaction with the smart thermostats installed in her apartment. She showed the research team and maintenance group the weekday and weekend schedules she set up on the thermostat’s control panel, as well as the setup page on her smartphone. The research team also found some other tenants who didn’t quite care about the new technology, but still operated the smart thermostats as on/off controls – they simply shut off the thermostats when they were not at home, or when the thermal comfort level was reached. This group of tenants preferred the simple control of traditional thermostats, and their indoor air temperatures, humidity levels, and energy use were observed to be similar to the control group.

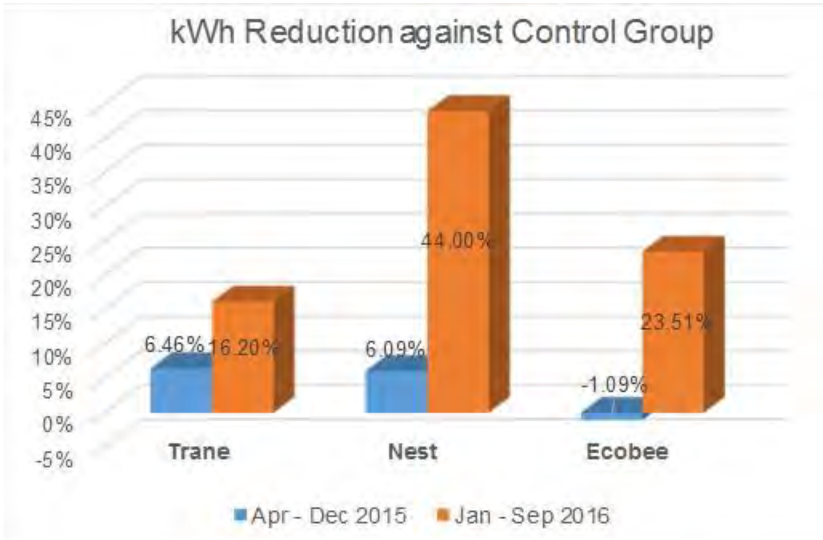


Figure 78: Comparison of RTU Electric Energy Reduction between Treatment and Control, by Thermostat Brand

In addition to the differences between thermostat brands, the variances between VER packages installed on Buildings 1, 2, and 3 (for example, spray foam roof implemented on Building 3, but not on Buildings 1 or 2), the research team found energy use in the apartment units was so behavior driven that even if the apartment units were equipped with the same VER packages and the same thermostats, the energy use could still be significantly different (Figure 78). The research team compared Unit 1 and Unit 9, which had Trane Nexia thermostats installed for this study. Figure 80shows the occupant in Unit 1 kept the smart thermostat on during the one observed week, and the supply and return air temperature patterns were steadier than in 2015, when HVAC load was controlled by a traditional thermostat (Figure 79).

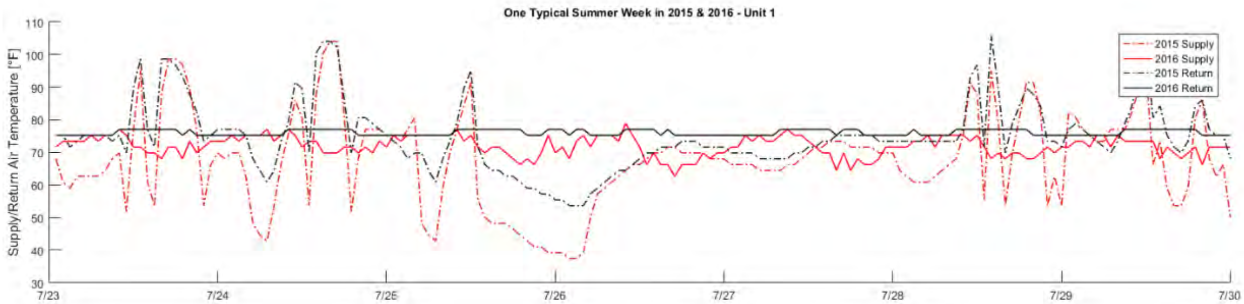


Figure 79: Supply and Return Air Temperature Comparison, Typical Summer Week

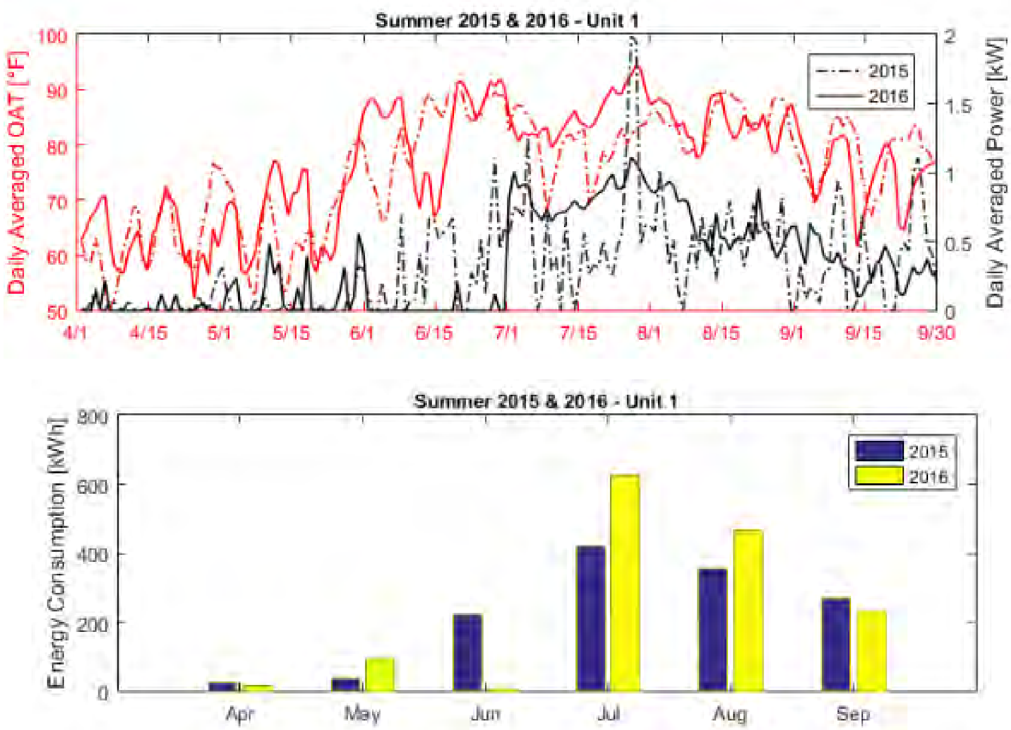


Figure 80: Outdoor Air Temperatures and Electric Energy Consumption of the RTUs on Apartment Unit 1

Figure 81 shows the occupant in Unit 9 operated the smart thermostat on or off, so the supply and return air temperature patterns were still similar to those of 2015 – the supply and return air temperatures could go up to 120°F when the thermostat was turned off. Occupant behavior resulted in a completely different RTU energy use pattern, reflected in the monthly energy use kWh. Therefore, the VER packages could be designed to retrofit the buildings and apartments and make them energy efficient and ready for near-ZNE, but actual energy use will depend on how the occupants set the thermostat schedules and how they use the loads. This is one lesson learned from this project. Occupants should be informed that near-ZNE apartments do not equate to near-zero utility bill apartments.

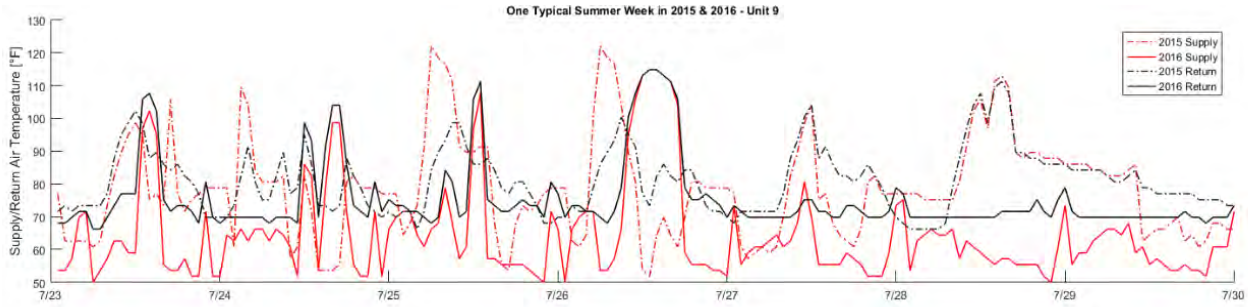


Figure 81: Supply and Return Air Temperature Comparison, Typical Summer Week

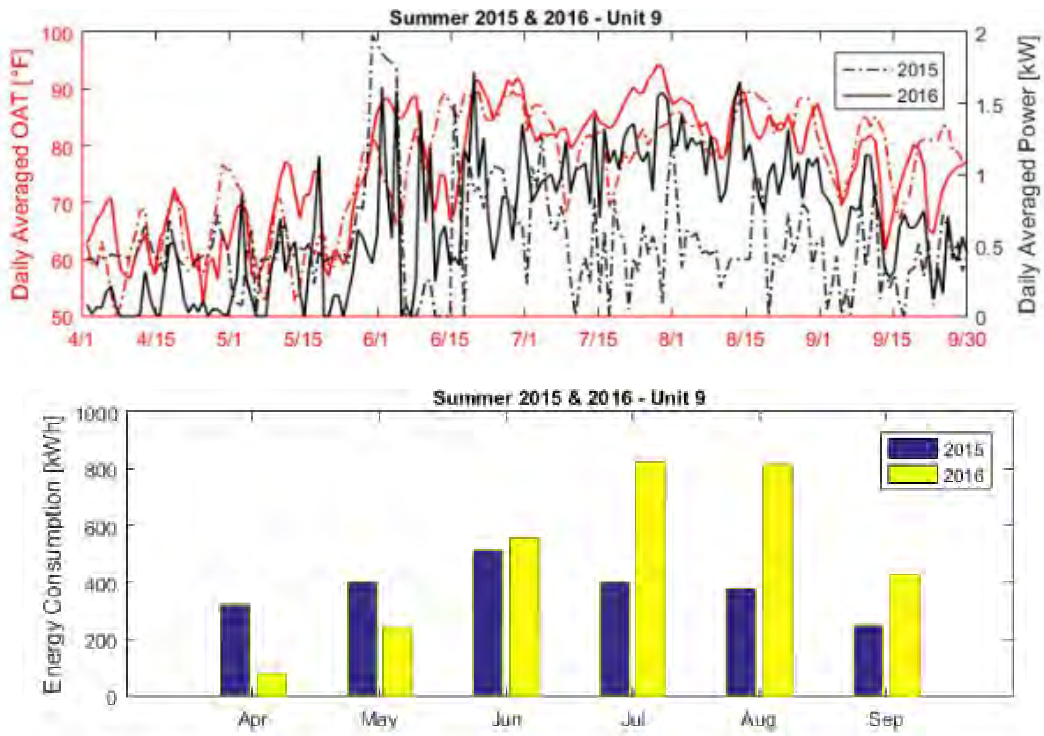


Figure 82: Outdoor Air Temperatures and Electric Energy Consumption of the RTUs on Apartment Unit 9

8.5 Fourth Stage: Non-Intrusive Load Monitoring of Whole Premise

Building 1 was used as a pilot site, to test NILM technology for proof of concept (Figure 83). The technology was typically used for commercial buildings or single-family homes, and it was the first time it was deployed in a MF building, to disaggregate load for analysis.

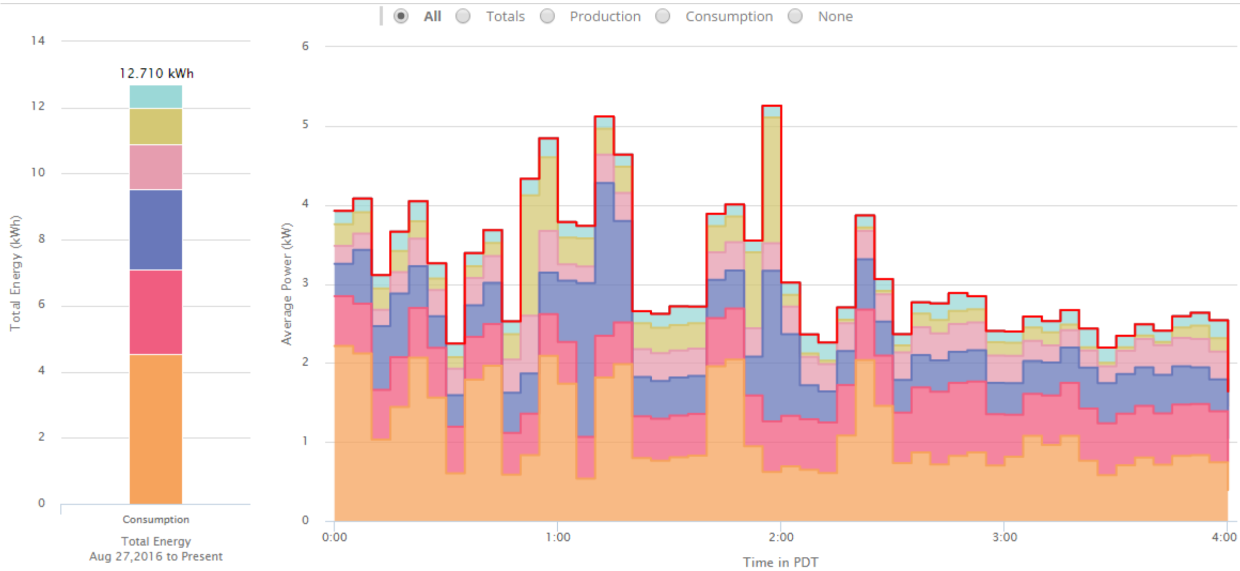


Figure 83: Non-Intrusive Load Disaggregation Using Building 1 as a Pilot Site

8.6 Fifth Stage: Common Area

The common area's energy performance has improved with the addition of aerosol insulation, foam roof insulation, duct improvements, and an economizer. The blower door test results in Table 48 show gradual envelope improvement, after implementing aerosol sealing, foam roof insulation, and duct insulation step-by-step. The CFM change reduced by 490 in a depressurization test, and 1,280 in a pressurization test at 50 Pa. The results show the envelope tightened significantly with the VER installation, and infiltration/exfiltration rates were reduced. Figure 84 shows the common area's indoor air temperature was kept at 72°F, which the research team logged on a Sunday night. The weekend schedule was 60°F setpoint for cooling and 85°F for heating, and the indoor air temperature was kept in the comfortable range, which shows the insulation level significantly improved.

Table 48: Common Area Blower Door Test Results

Blower Door Test All tests conducted @ CFM 50 Pascals (+-)	BASELINE CFM 12/4/14	CFM After Aerosol Seal applied 5/9/16	Incremental CFM Change	% of Original CFM Leakage	Incremental Air Leakage Change	CFM After Foam Roof/Ducts plus Economizers added 10/11/16	Incremental CFM Change	% of original CFM leakage	Incremental Air Leakage Change	Final CFM/ Change from Baseline
Whole Building Test Depressurized CFM -50 Pascals	3,950	3,645	-305	92%	-8%	3,460	-185	88%	-4%	-490
Whole Building Test Pressurized CFM +50 Pascals	4,495	4,010	-485	89%	-11%	3,215	-795	72%	-17%	-1,280

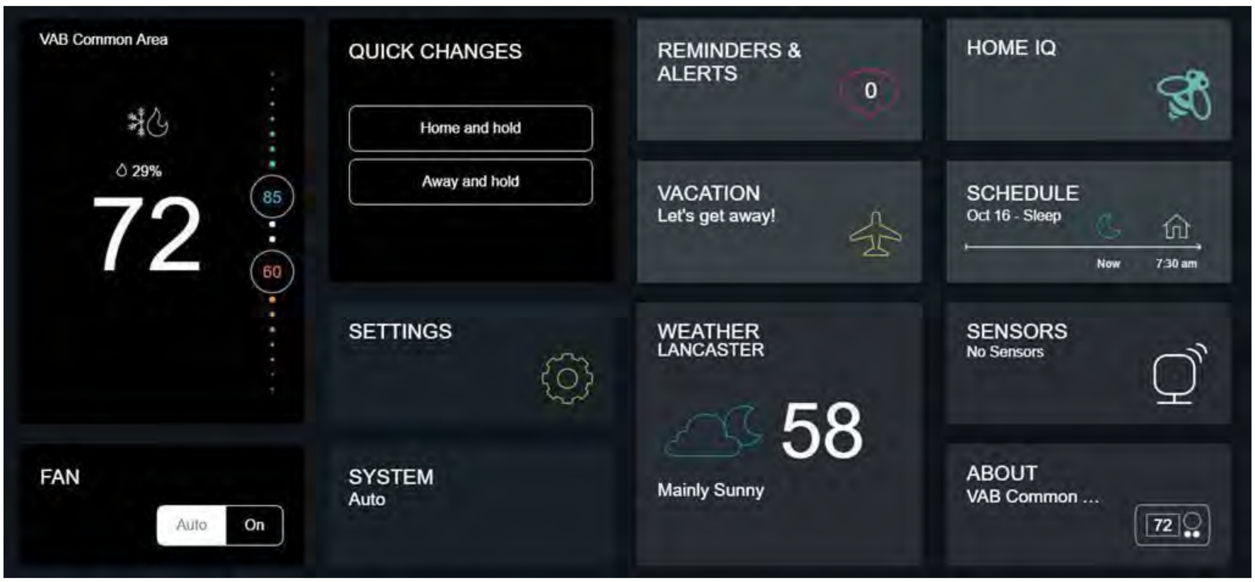


Figure 84: Common Area Smart Thermostat Interface on a Summer Sunday Night

Figure 85 shows a month-by-month comparison of four years of electric energy use. Most of the retrofit work at the common area started in May 2015, and the data shows significant energy reduction starting in June 2015 as a result of the VER package including; LED lights, aerosol sealing, re-roofing, re-ducting, smart thermostats, and economizers (the last two items started operation in Fall 2016). Most energy savings resulted from the improved building envelope and more-efficient RTU operations. Therefore, regression analysis was conducted based on data before June 2015 (blue dots) and after June 2015 (orange dots) to investigate the electric energy use vs. cooling degree days in Figure 86. The graph shows that the much-improved building envelope and reduced RTU operation helped lower energy use by roughly 36% during the cooling season, as illustrated in the reduction of intercepts in the two linear regression curves from 8,957 kWh to 5,746 kWh.

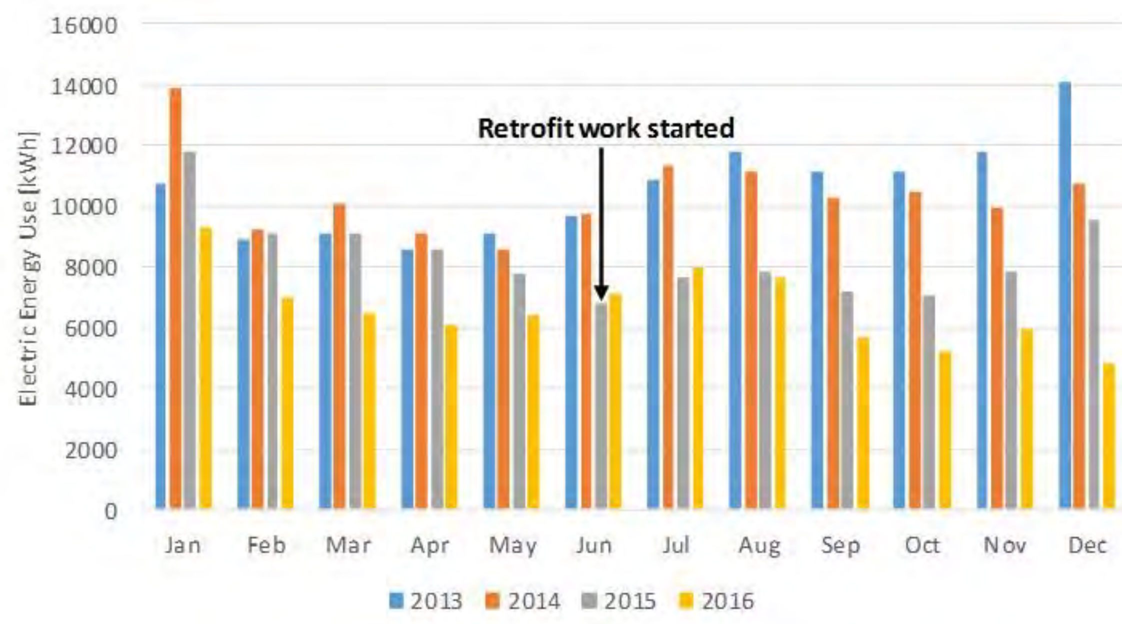


Figure 85: Electric Energy Use of Last Four Years

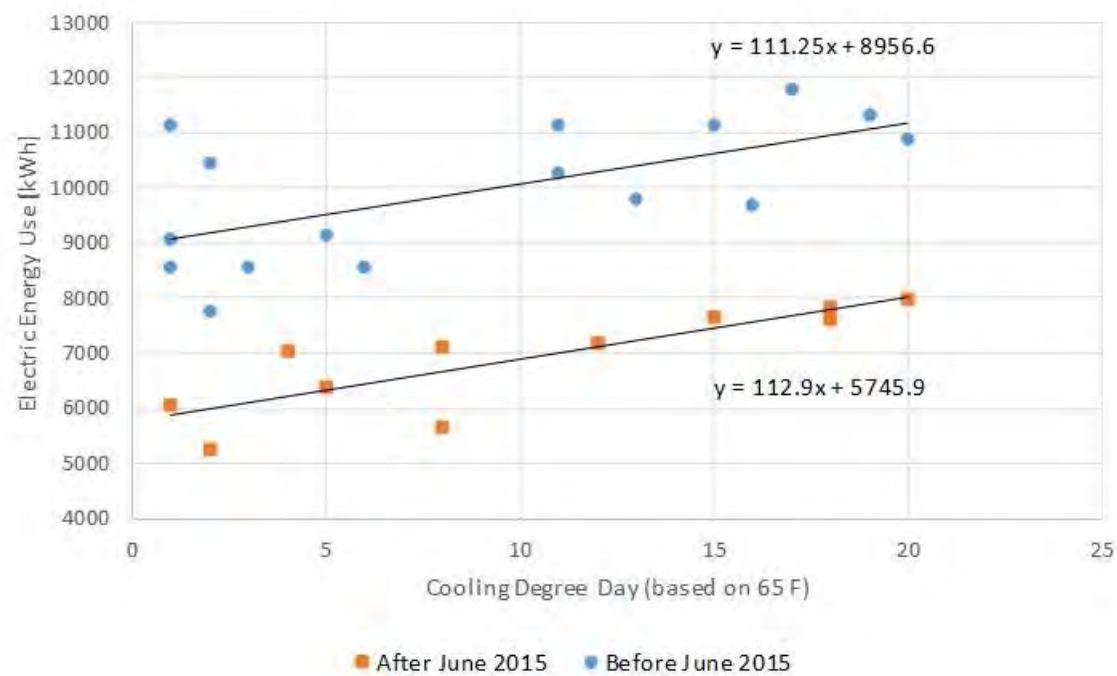


Figure 86: Common Area Electric Energy Use, Before and After Envelope Retrofit

Economizers were installed in the common area in October 2016 to let cooler outside air inside (when it is cool enough), thereby reducing the need for mechanical cooling and saving electric energy. Lancaster is in California CZ 14, which is characterized by wide swings in temperature from day to night, as shown in Figure 87. Hot summer days are typically followed by cool nights, thus providing an excellent opportunity to use economizers to night-flush the building and take advantage of early-morning cool outside air to provide free cooling. There are four types of economizers on the market: dry bulb, enthalpy, differential enthalpy, and integrated differential enthalpy. The dry bulb and enthalpy options adopt only one sensor, but the other two options require two sensors, so they require more complicated configuration and maintenance. As the name states, dry bulb economizers allow low-temperature outside air inside, based on the outside air dry-bulb temperature, regardless of the outside air humidity. Enthalpy economizers determine outside air based on humidity. The correct type of economizer to use should be determined by the CZ and the building's control needs. CZ 14 has hot and dry summers, which eliminates the need of worrying too much about outside air moisture being brought into the building. The common area that was retrofitted was a small-sized building that prefers controls with an easy configuration. Thus, the dry-bulb economizer was the right choice for this building and its climate.

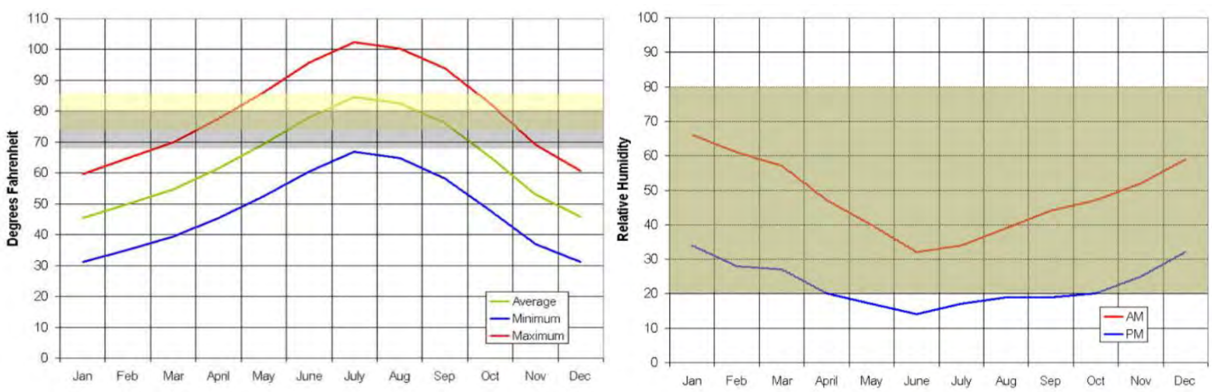


Figure 87: Historical Weather Statistics of California Climate Zone 14

Upgrade work was implemented on both of the two-ton and four-ton RTUs, and their power usage was monitored, along with supply, return, and exhaust air temperatures and RH. The dry-bulb economizer allowed more cool outside air into the building and allows fans to be operated to night flush the building when not occupied (Figure 88). Operational changes were monitored to document changes in energy use.

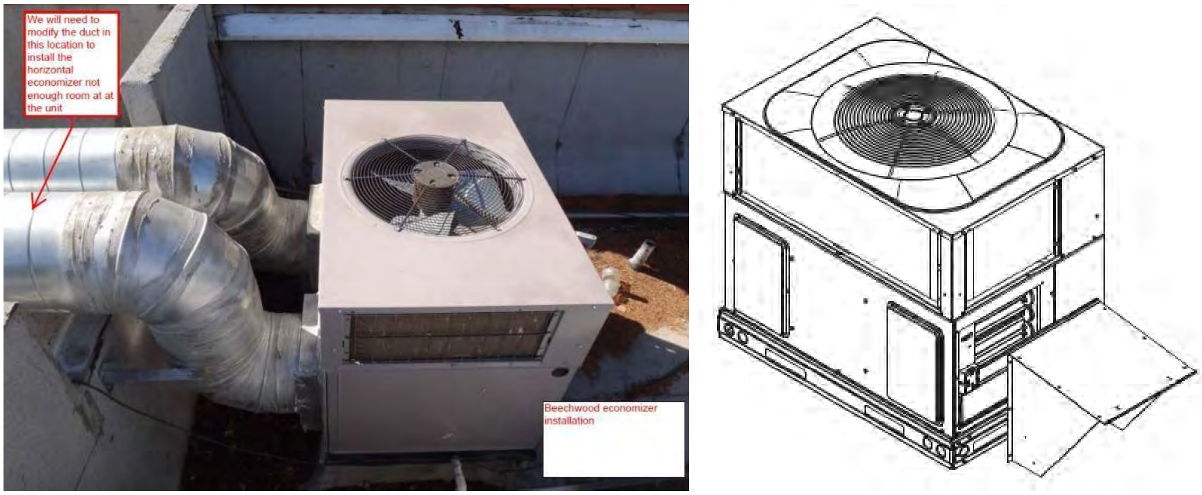


Figure 88: Economizer Upgrade of Common Area RTUs

Economizers circulated fresh outside air into the building and encouraged a healthier environment for occupants by minimizing stale air recirculation, which improves occupant comfort. Figure 89 shows the economizer can cause expected comfortable hours to reach 96% of the year. The team collected the indoor dry bulb temperatures and RH and plotted the data on a psychrometric chart to compare actual results and expected values. While the data meets the "96% comfortable" level, it is inside the "comfortable" band.

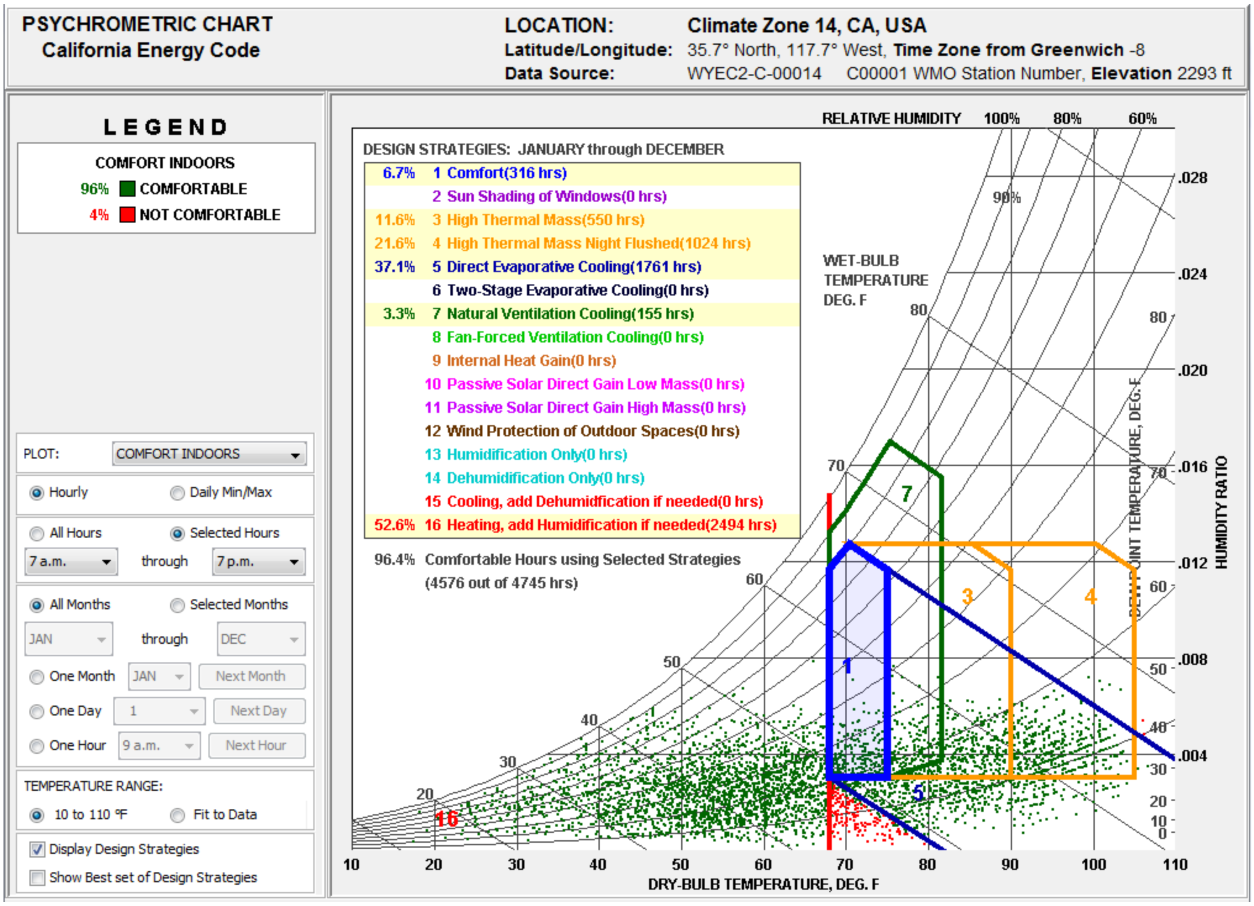


Figure 89: Expected Indoor Comfort Level with Economizer Retrofit

8.7 Cost Effectiveness of the VER Package and Possible Solutions to Split Incentives

As detailed in previous sections, the VER package significantly reduced energy use in retrofitted buildings and individual dwelling units, when compared to non-retrofitted control buildings and individual dwelling units. Next, we wanted to determine the VER package's cost effectiveness. This section details how this was determined, and analysis results.

8.7.1 Calibrated Computer Models and Simulations

To evaluate the cost effectiveness of the VER package installed in the Beechwood buildings, the research team first had to understand the accuracy of the computer models used to determine savings. The models included diverse assumptions, such as weather (from a standard weather file containing many years of hourly average temperatures and other weather factors), heat released into the building by its occupants, and electricity used by small devices plugged into wall sockets. Algorithms, through a series of calculations, accurately predicted the effect of changing the efficiency of elements in the simulated building – for example, walls, roof insulation, and window characteristics. Calculation accuracy resulted from simulations that had been improved over many years to be very accurate when using highly-controlled assumptions. Other home elements, such as changes in A/C efficiency, could also be accurately simulated if assumptions such as the thermostat setpoint correctly represented the occupants' thermostat settings. MELs were the most difficult end use to accurately model for producing a precise simulation.

As part of the initial Beechwood audits, research staff surveyed occupants about the small electric devices they had plugged into their wall sockets – for example, what devices did they have, and how were they typically used? To answer these data needs, survey staff were given a list of questions and common small electric devices, developed several years ago and refined over the years for other research projects that also required accurate simulations. The occupant was asked to complete a survey form to identify the devices they had and how they were used: how often, how long, when they were not in use, when they were unplugged or plugged in, and left on, off, in standby mode, etc. The survey also asked about thermostat set points and how the occupants used their thermostats (steady, set-back, accelerator, etc.). The staff was also instructed to look at the thermostats (with tenant permission) to directly observe the actual settings and record them on the form, next to the occupants' claimed settings. As is typical, the survey findings were quite varied, but provided insights and commonalities the team used to calibrate their models. Two assumptions that were significant (but usual) elements of tuning the models for calibration were thermostat setpoint temperatures for heating and cooling, and MEL settings. However, in the Beechwood analysis, the weather changed significantly from pre-retrofit to post-retrofit, requiring special tuning for these weather effects.

The hourly output from the BEopt computer models were calibrated using the standard weather files (TMY3 datasets), local hourly weather data from the previous year (2015), and then-current weather. These comparisons allowed the team to understand the differences between the hourly temperature data in the TMY3 weather file simulation and the actual temperatures in the monitored data. For example, from January 2014 to September 2016, the calibrated 2015 models had an average -4% difference compared to billing data, and the calibrated 2016 model had an average -8% difference compared to billing data.

Figure 90 and Figure 91 are overlay plots of calibrated simulation results and actual monitored data. The calibrations included increasing or decreasing the energy used for heating or cooling, in proportion to the differences between the TMY3 average weather and the actual weather from a nearby weather station. During the cooling months, individual A/C compressor and fan kWh usage was scaled, and during the heating months, individual furnace therm usage was scaled, using the % temperature difference between the weather file and the actual recorded weather. For instance, if the temperature in the TMY3 file was 20°F during an hour in January 2014, and 30°F on the same day, same hour in 2015, the energy for heating for that hour was scaled 20/30.

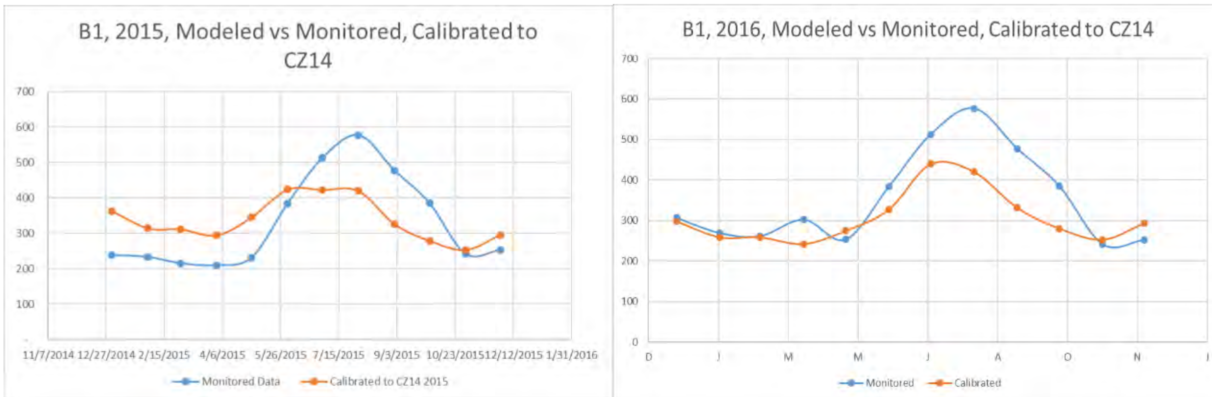


Figure 90: Building 1, Actual vs. Modeled kWh (per Month), 2015 and 2016

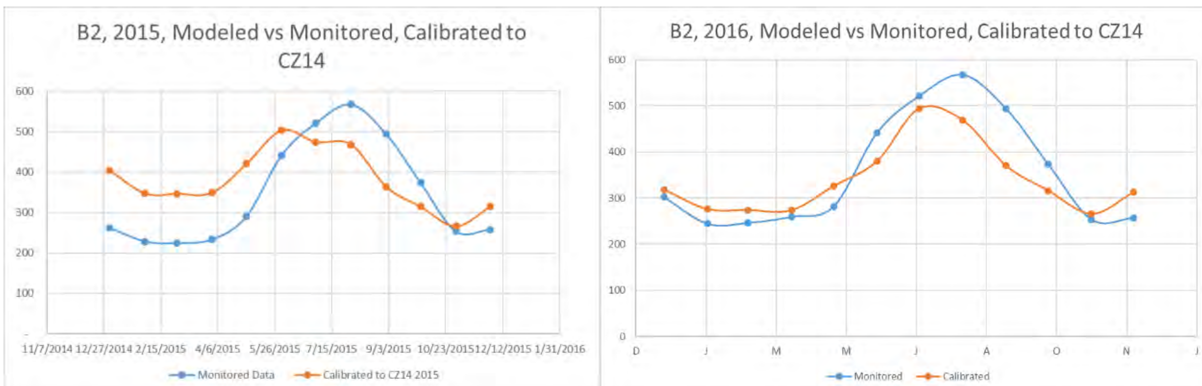


Figure 91: Building 2, Actual vs. Modeled kWh (per month), 2015 and 2016

8.7.2 END-USE ENERGY FROM CALIBRATED MODELS

The team was interested in the amount of energy used for each end use, because that information could be helpful in identifying future actions and behaviors that could further reduce energy use. Optimally, this detailed information would be obtained through precise monitoring at the single electric breaker level. However, that level of detailed monitoring was not planned, budgeted, or performed for the Beechwood project. The next-best option was to use the simulations, which represented accurate yearly averages and had similar end-use energy (which varies daily, and by month and season) load-curve shapes. Using this logic, simulation results from the calibrated models were recorded by end use. That data was used to develop percentages of the total electricity and total natural gas for each end use. The end-use percentages (per end use) were multiplied by the total electricity or natural gas, to estimate the amounts of energy used for each end use.

The calculated average energy end-use savings values for the Beechwood residences are shown in Figure 92 and Figure 93. All of the end-use savings are positive in Figure 92, except for SDHW electricity use. SDHW was a retrofit as part of the VER, so the SDHW, which uses electricity to pump water through the active solar system shows as a decrease in energy savings, because there were no SDHW pumps prior to system installation. Figure 93 shows a significant net natural gas savings from the pre-retrofit to the post-retrofit scenario, more than making up for the new SDHW electricity end use.

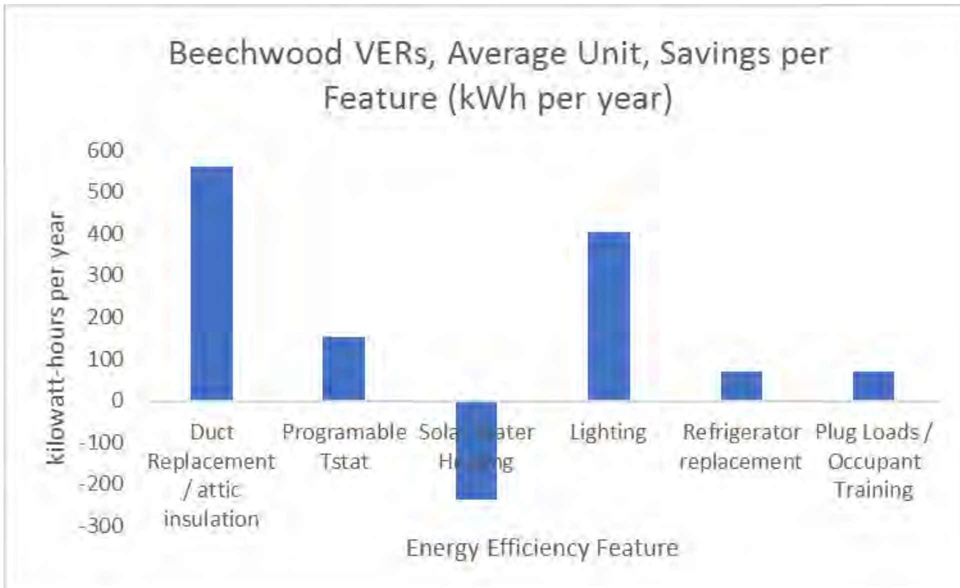


Figure 92: Post-Retrofit Electricity Savings, by End Use

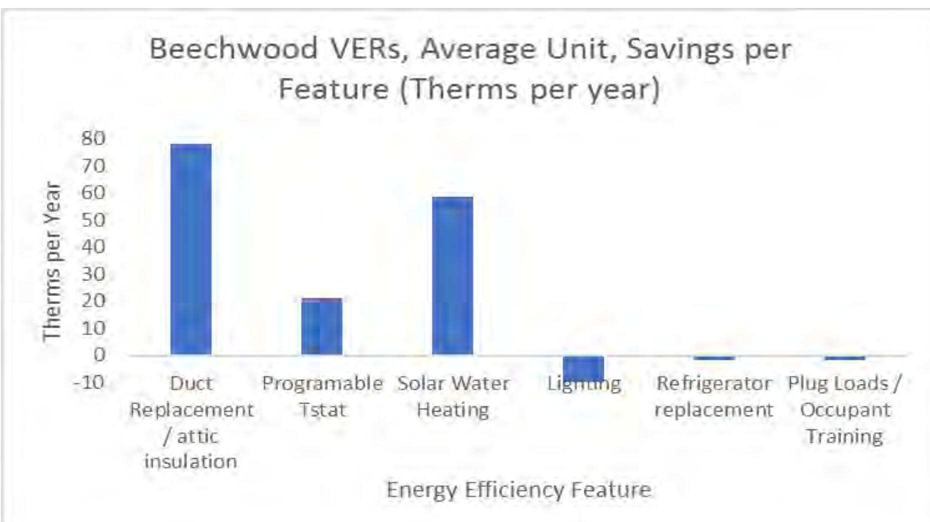


Figure 93: Post-Retrofit Natural Gas Savings, by End Use

There is negative savings for natural gas and electricity, but in this case, the negative savings is due to lighting. This small increase in lighting energy from natural gas is the result of a small rise in the heating load caused by cooler, more energy-efficient lighting than existed before.

8.7.3 Residence VER Package Energy and Energy Cost Reductions

Figure 94 shows the VER package's cost effectiveness. A ring chart shows the distribution of energy-cost savings produced by each efficiency measure in the Beechwood VER retrofit. This graph provides a clear visualization of the relative importance of each VER feature, as predicted by the calibrated models. Some interesting highlights include the relative importance of the retrofits to the duct system, lighting, and PCT, and the relative lack of importance of the refrigerator, solar water heating, and plug loads. The refrigerator savings were small because recently, refrigerators moved from using substantial amounts of energy to relatively small amounts, resulting in diminishing returns. Conversely, MEL savings were small, because little was done to reduce MELs in this VER package. MEL reductions, at the time of project completion, came mostly from increasing small-electric device efficiency, as well as from making minor behavioral changes.

Interestingly, the large savings duct improvements were dramatically less than the simulation predicted, due to poor thermostat user behavior such as leaving the furnace or A/C on "high" when not at home or keeping spaces warmer than needed in the winter.

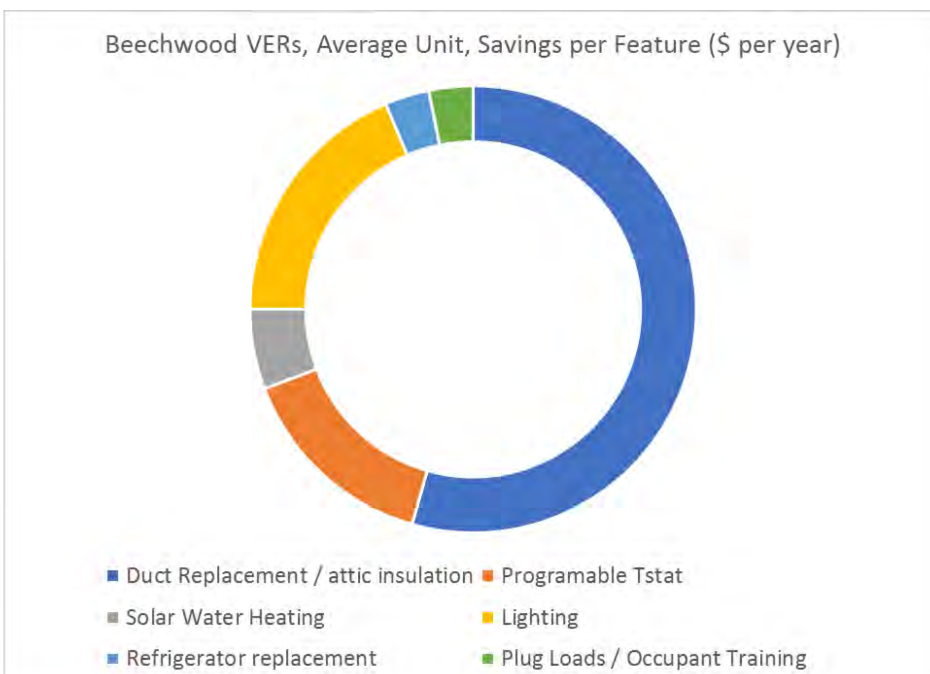


Figure 94: Chart of the Energy-Cost Savings, by Feature, Using Calibrated Model

The tabular data used to generate the ring chart in Figure 94 is shown in Table 49.

Table 49: Tabular Energy and Cost Savings from the VER Package

Savings Per Feature (Average Unit)	kWh / year	Therms / year	$ / year
Duct Replacement / attic insulation	560	78	$ 152.70
Programable Tstat	152	21	$ 41.54
Solar Water Heating	(236)	59	$ 16.26
Lighting	404	(10)	$ 52.11
Refrigerator replacement	70	(2)	$ 9.05
Plug Loads / Occupant Training	70	(2)	$ 8.96
VER Package	988	152	$ 281.52

To calculate VER package cost effectiveness, it was necessary to calculate the value of the energy savings, then the costs of the feature(s) that generates the savings. Figure 95 shows an example tabulation of energy and energy-cost savings. The third column shows the relative energy-savings values, with the duct replacement and insulation added to fill the drop-ceiling area containing the ducts and distribution box.

Actual kWh savings were extracted from monitored data, which was used to compare the test groups (with VERS) and control groups, and to determine the difference between the two, producing the savings. This had to be done carefully, and with high resolution, because use patterns and weather varies from year-to-year.

For this comparison, RTU data was preferred over SCE billing data, because it was more complete, including data from all 10 tests and controlled dwelling units. The SCE data did not have that level of depth.

Monitored RTU data spans April – June 2015, collected from pre-retrofit units. Post-retrofit data was collected from July 2015 – Sept 2016. SCE billing data spanned January 2014 – Sept 2016. The pre- and post-retrofit SCE data sets were incomplete. Using RTU data, the comparisons between pre- and post-retrofit could be made (shown in Figure 96). Results were unexpected – the retrofitted building energy use increased. Several analytical techniques were used to determine why the test energy use went up, and how to use this data to evaluate retrofit effectiveness and the trust about the results.

8.7.4 Separating the Confabulating Effects of Weather on Energy Savings

The weather in 2016 was substantially warmer in the summer and cooler in the winter, making pre- and post-retrofit energy savings calculations difficult. The four bars in Figure 96 show the results of paired data from test and control groups for the same three months, one year apart. This shows a major increase in kWh use for the same three months for the control group, and a small increase for the test group, when reduced post-retrofit energy use would be expected.

The months of April – June were used for the comparison in Figure 95, because this was the only available pre- and post-retrofit test and control data, for the same season, for cooling (although it was from early April). This comparison was important because it combined pre- and post- analyses, from most likely the same (or mostly the same) tenants, who probably had similar behaviors before and after the retrofits, and where the same months were used so the team could control for the significant weather changes between 2015 and 2016. Despite the fact that both the tests and the control buildings' energy use went up from 2015 to 2016, the control group RTU kWh data went up 51%, while the test group RTU kWh data went up 6%, producing a net savings of 45% for the test group compared to the control group. The SCE data, even though some of it was missing, produced the same results.

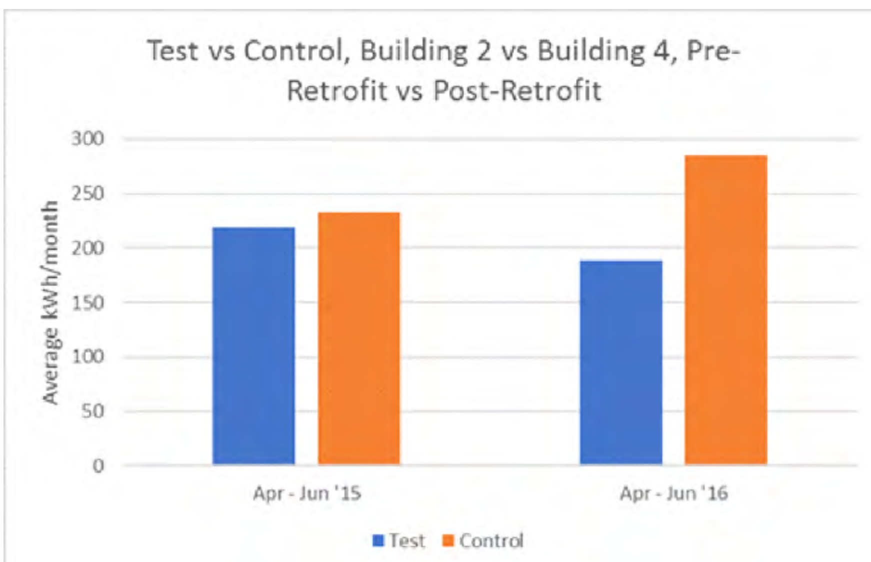


Figure 95: Three Months of Comparative kWh Data from Test and Control Buildings, Pre- and Post- Retrofit

The large impact of the much-warmer weather in the second year of a two-year test period merits further examination. The results of another analytical technique are shown in Figure 96. In that analysis, the differences in weather were used to extrapolate the measured kWh data recorded in 2014 and 2015 to what would be expected, based on the increase in summer temperatures, to the actual test unit kWh use. This approach to separating the weather effects from actual savings showed an average of 39%, with two of the buildings' savings at 44% and 45%.

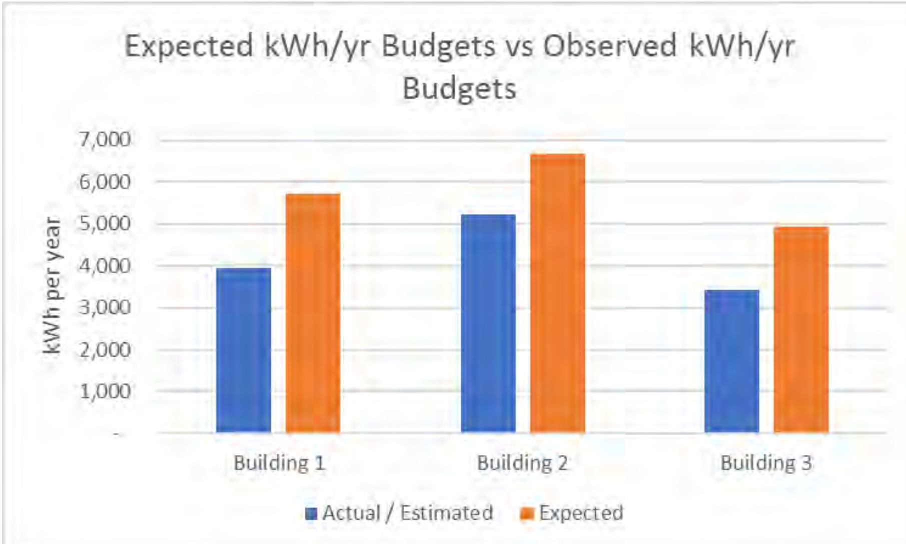


Figure 96: Differentiating the Effects of Weather Change from VER Energy Savings

8.7.5 Best Estimates of VER Package Energy Savings

In the previous section, the distorting effects of weather changes were separated from the VER package kWh savings, which were likely between 40% and 50%. To determine the cost/benefit ratio, actual energy savings are necessary. Having isolated the savings percentages, they can be used to convert back to energy units. The results are shown in Figure 97.

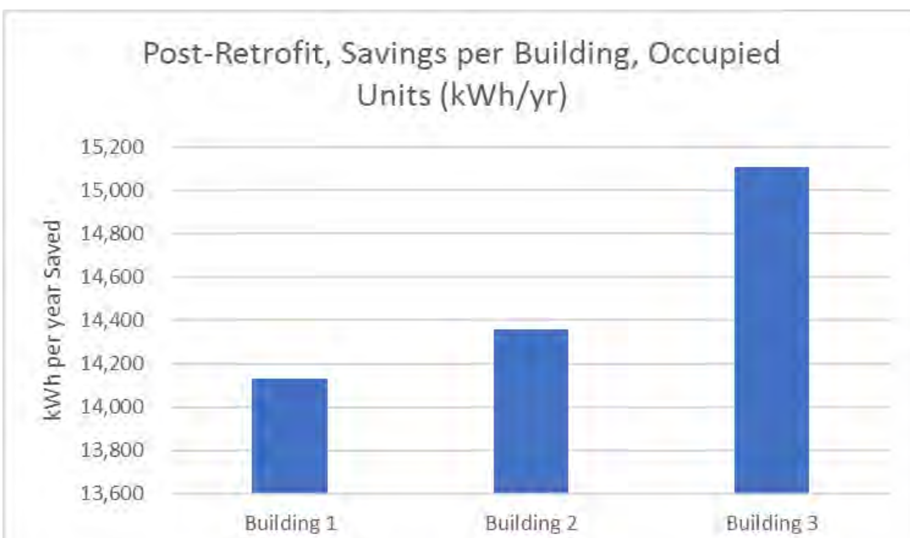


Figure 97: kWh Savings in the Three Test Buildings

The differences are amplified by the coordinate crossing the abscissa ("x" coordinate) at over 13,000 kWh rather than zero. The data was plotted this way to show savings similarities between Buildings 1 and 2, as well as the larger savings for Building 3 from the foam-insulated roof shaded by solar collectors. Table 50 shows tabulated kWh savings.

Table 50: Tabulated Energy Savings from VER Packages in the Three MF Buildings

Building #	2016 Savings, per unit (kWh/yr)	# of Units	Savings per Building (kWh/yr)
1	1,766	8	14,131
2	1,436	10	14,359
3	1,511	10	15,109
	Total	28	43,599

Once the electricity kWh savings were established, similar mathematical manipulations were needed to tease the natural gas savings, which is more difficult because the natural gas was master metered. Therms savings were determined using a method similar to that used to derive the kWh savings, and then extrapolating to a best-case scenario, due to it coming from master-metered data. Table 51 shows tabulated results.

Table 51: Tabulated Monthly Therm Savings

2016	
Month	Therms Savings
Jan	656
Feb	-1,130
Mar	73
Apr	237
May	1,083
Jun	95
Jul	434
Aug	446
Sep	373
Oct	2,327
Nov	-15
Dec	74
Total	4,653

8.7.6 Financial Analyses of VER Package Energy Savings and PVs

The kWh and therm savings, derived as presented above and analyzed, were converted to energy costs, and using those, various cost-effectiveness calculations were performed. Cost-effectiveness calculations clearly require accurate costs to perform the retrofits. The costs, and any incentives for VER installation, were obtained from the construction manager, Primus Energy, and SCE. PV costs were obtained from team meeting notes. The full costs of installing the VER package were verified with LINC, to derive the full costs of VER + PV. These construction costs are tabulated in Table 52.

Table 52: Estimated Costs for VER Package Retrofit and PV Installation

PV Installation	**$332,177**
EE (no Asbestos)	**$368,281**
Total Project Cost	**$926,805**

The kWh and therm savings from the VER packages (EE) were compiled into tabular form, and are shown in Table 53, along with some simple payback estimates. We calculated the VER savings value using known site energy costs. Based on the assumption that all units were occupied and paying rent, the best-case scenario rates (electricity savings compiled at $0.165/kWh, and $0.92/therm) apply to LINC. However, for most of the tenants, two simple payback estimates were calculated, with one assumption being that the benefits from the retrofits follow the meter. Under that assumption, consistent with current policy and rules, the payback to LINC would be 86 years. This is not a timeframe that encourages retrofits. With an alternate assumption that the savings were accrued by the party responsible for paying for the upgrades, in this case LINC, and using average utility rates similar to theirs, the payback period shortens to 32 years. This is still a long payback (longer than normal lending periods) but much improved from more than 80 years.

Table 53: Energy Cost Savings and VER Package Costs to Calculate Simple Payback

	$ Saved Per Year	Rate	Cost	Simple Payback
Gas	$4,280	$0.92	$ 368,281	86
Electric	$7,194	$0.17	$ 368,281	N/A
Total EE	$11,474	N/A	$ 368,281	32

PV was added to the natural gas and electricity costs and benefits, and the cost effectiveness of the analyzed PV+VERs package. The results are tabulated in Table 54, and the energy cost savings are illustrated in Figure 98.

Table 54: Differences in Simple Payback, with Different Recipients of Utility Savings Benefits

	$ Saved Per Year	Rate	Cost	Simple Payoff
Gas	$ 4,280	$0.92	$ 368,281	86
Electric	$ 7,194	$0.165	$ 368,281	N/A
Total EE	$ 11,474	N/A	$ 368,281	32
PV	$ 19,390	$0.165	$ 331,800	N/A
Gas + PV	$ 23,671	N/A	$ 700,081	30
EE + PV	$ 30,864	N/A	$ 700,081	23

	$ Saved Per Year	Rate	Cost	Simple Payback
Gas	$4,280	$0.92	$ 368,281	86
Electric	$7,194	$0.17	$ 368,281	N/A
Total EE	$11,474	N/A	$ 368,281	32
PV	$19,390	$0.17	$ 331,800	N/A
Gas + PV	$23,671	N/A	$ 700,081	30
EE + PV	$30,864	N/A	$ 700,081	23

Several different potential approaches are illustrated that could be considered to improve the financial ramifications of performing deep-energy retrofits. LINC's current situation, with gas master metered and electricity metered at the individual residences, and the savings benefits following the meters, the simple payback (without PV) is 86 years. If the current heavily-subsidized PV costs and benefits are added, the payback is reduced to 30 years. A superior solution for the property owner, or other party paying for the retrofits, would be for the entity paying for the upgrades to receive the benefits. With that scenario, the simple payback for funding the entire VER package and accruing both gas and electric savings is 32 years – still longer than the mortgage, and likely not tenable. Another option to be evaluated is if PV, with current incentives, is added to this better scenario, where the entity funding the upgrades (now electric, gas and PV) the payback is 23 years. This is likely an economic possibility for property owners, and is worth researching how it could be evaluated, as well as the possibility and/or likelihood of putting it into practice.

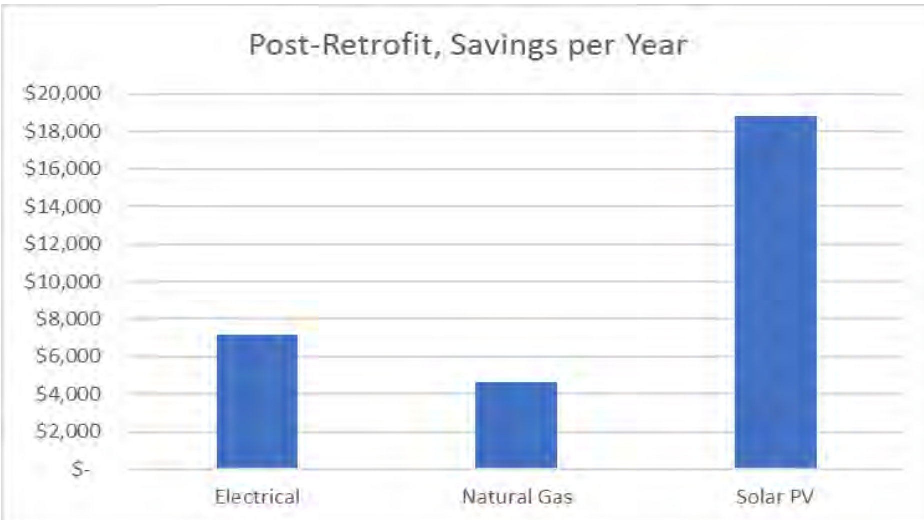


Figure 98: Energy-Cost Savings from the Entire VER Package for Electricity, Natural Gas, and PV

Thus, the best-case scenario for a realistic return on investment includes incentives, PV, and the EE returns resulting from implementing the VER package. Using these values, the project’s occupied unit success was evaluated.

Annual financial considerations were included to develop two additional cost-effective metrics (years to positive cash flow, and years to amortized payback), as shown in Table 55, to analyze the value of the package within the project itself, not just the best-case scenario.

In this case, returns were corrected for inflation (assumed at 2.5% over the next 30 years, and using the 2017 EIA projected price escalation) and for the increase in the price of fuel (also assumed at 2.5% over the next 30 years) [14]. Using these projections, financial calculations were performed based on a 30-year loan period. Simple payoff was calculated using 0% and 2.5% fuel-price escalations. Amortized savings included a combined 5% escalation for fuel and inflation. The results of this analysis are provided.

Table 55: Comparison of Different Cost-Effective Metrics

	0% Annual Increase	2.5% Annual Increase	5% Annual Increase	EIA Projected Escalation
Simple Payback	27	21		
Years to Positive Cash Flow			17	20
Years to Payback, Amortized			31	33

The analyses clearly shows that, if the investing party can collect the benefits, it may be a good investment to perform the VER package retrofits together with installing PVs (PV and EE costs are shown in Table 52). The billing savings shown in Table 53 were calculated on average Beechwood costs of $0.165/kWh and $0.92/Therm [14].

Current regulations require that energy-cost savings basically follow the meter, accruing to the party paying the meter-related bills, which is certainly the simplest accounting approach. With this policy and retrofit example, LINC spent $368,281 to perform deep VER package retrofits (not including asbestos abatement costs). In return, the annual gas bill would be reduced by $4,280, and the tenants in the 28 retrofitted dwelling units will, as a group, reduce their electricity bills by $5,886 annually, or $210 per unit, per year[3]. There is no economic driver for MF dwellings to be retrofitted by the building owners unless they pay all the utility bills, in which case their tenants have no financial basis for not wasting energy.

8.7.7 Deep Energy Efficiency – Need for Policy Updates and Change

PVs and efficiency are viewed and treated differently in the building, real estate, and financial industries. With PVs, one can accurately predict the weekly, monthly, and annual generation using PV modeling and simulation software, and literally bank calculated generation numbers. Because of this, actual PV array energy production can be directly measured either by viewing inverter output, or by some other method of monitoring the energy flowing from the array and ultimately into the electrical panel.

It is not so simple with efficiency, because it is integrated with energy use and spread across most of the wires in the electricity meter. However, it can be measured, and as shown in this section, even in difficult situations such as major weather changes, there are good correlations between predicted energy use and savings.

The models used to calculate building energy use and energy savings are every bit as good as the PV simulation models. However, the occupants make these correlations more challenging, and even change the quality and quantity of use compared to the simulation – for example, by using thermostats differently than modeled, or by using energy-consuming equipment not in the model. These appear to throw off the model and impact the accuracy, making the model appear to be incorrect. But the predicted savings are still there; they are simply masked by unanticipated events. If one were to track their PV generation not before it enters the electrical panel, but after, where it becomes part of the larger, "noisier" data, they would find that monitoring PV production under those conditions is similar to directly measuring energy savings from deep retrofits.

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[3] See next Section for thorough examination of the financial benefits of deep retrofits in MF housing.

That is an overly-simplistic comparison, but the reality is that sophisticated, accurate, relatively simple-to-use building energy modeling and simulation software is available today, and it can be used by qualified simulators to accurately predict energy savings due to efficiency retrofits. They can also predict PV generation, especially when cloud events and other normal phenomena are considered.

To foster change in support for efficiency upgrades, the efficiency community should stop differentiating themselves from the renewable community, and embrace its practices, if only to secure financing for deep retrofits as easily as for PV systems. In addition, state and federal policies should be updated to recognize efficiency as being thoroughly reliable. Policies that impact efficiency differently from local generation should be updated to view and treat efficiency equally to generation, especially in the financial community, so the same variety of financing vehicles is available for efficiency (purchase, lease, PPA, etc.) as for obtaining PVs.

CHAPTER 9: FINANCIAL MODELS FOR SCALABLE IMPLEMENTATION

To meet its energy and carbon reduction objectives, California must garner large energy savings from all building sectors, including LIMF properties, which operate on thin margins that are insufficient to support needed upgrades. A full menu of financial tools is critical to realizing these improvements. There are many barriers to financing efficiency retrofits in the LIMF market. The major barriers are identified in this chapter, including suggestions for addressing most of them.

The most difficult barrier is the "split incentive", which occurs between a landlord and a tenant. In program evaluation literature, this concept is sometimes referred to as the "principal-agent problem" [1]. It has long been a prominent concern of MF EE program designers. In fact, often when reports discuss challenges, the split incentive is the only market barrier that is explicitly mentioned [1]. The American Council for an Energy-Efficient Economy (ACEEE) notes that the split incentive barrier is in fact a market failure.

The split incentive barrier is directly linked to the individual financial responsibilities of the owner, tenants, and the entity that will pay for energy bills and improvements. This responsibility is usually tied to the type of metering at the property. If the property is master metered, the owner has a financial incentive to make energy improvements, but tenants have no direct financial incentive to reduce or conserve energy consumption, because they do not pay the utilities directly. At individually-metered properties, tenants pay the utility bills directly, so they have an incentive to save energy, but owners have no direct financial incentive to pay for energy improvements, since the tenant benefits from any improvements that reduce unit energy costs.

At Beechwood, the electricity was metered at individual units, but the natural gas was master metered. Split incentives occur when one party makes EE decisions, and another party bears the consequences. There are other factors to consider in this equation. LIMF tenants have minimal to no control over improvement decisions made at their properties and have limited income to invest in EE improvements. In addition, LIMF communities often have high turnover rates, further reducing any likelihood that tenants would invest in property improvements. Regardless of income, people typically do not make investments in properties they do not own. Complicating things even more is the fact that rents in affordable housing are regulated and restricted, and owners cannot simply increase rents as improvements are made.

Unfortunately, there is no financial model, playbook, or roadmap for addressing the barriers to arranging financing behind the deep, near-zero energy retrofits of a LIMF property while addressing the significant split incentive barrier. The team's experience during this research project was validated in the February 2017 report, *A Resilient Power Capital Scan: How Foundations Could Use Grants and Investments to Advance Solar and Storage in Low-Income Communities,* which cites that one of the most formidable barriers to high-efficiency

LIMF projects is that there is a lack of an integrated development finance model to use…." [2]. Lessons learned in high-end commercial markets driven by economics simply do not apply to LIMF developers who, when looking at retrofitting properties, are often also interested in the environmental, social, and public health consequences of their investments.

While some question its impact on MF housing energy consumption, the split incentive is real. For example, WegoWise, the company that remotely analyzed building energy consumption, wanted to know how much more energy apartment dwellers consumed when they didn't have to pay their bills directly. The company looked at 3,000 MF and affordable housing units throughout Massachusetts and found that tenants used 30% more Btu's per square foot when landlords had to pay the bills. The company also found that annual utility costs for landlords were 20% higher than when tenants directly paid the bills [3]. The company showed that consumers often tend to use more of something when they are not paying for it, and this applies to energy use in MF housing. While there are many other similar stories, this example identifies the barrier as a legitimate concern and one worth addressing in LIMF housing.

To address the split incentive barrier effectively, owners of MF property are responsible not only for financing energy improvements, but also for simultaneously educating tenants about energy usage, so investments in these improvements are not wasted. Property owners must consider strategies to access the rent stream to finance or pay back energy improvement costs not covered by energy incentives or rebate programs [4]. Generally, the owner has to increase the Net Operating Income for the property and find a pathway for recovering some of the energy improvement costs.

In an attempt to find this pathway, the team designed, tested, and implemented deep EE retrofits for 28 Beechwood LIMF apartments. In keeping with their mission statement, the owner of Beechwood (LINC Housing) is committed to providing affordable housing and keeping rents low as they invest in EE, solar and storage.

Our team researched potential Utility Allowance (UA) EE adjustments and other policies and measures that aim to provide owners a cost recovery mechanism in rents but rent caps and the reality of low-income families' limited ability to pay leaves a significant gap between LIMF property owners' and tenants' abilities to cover efficiency retrofit costs. This project focused on determining the most cost-effective EE and renewable energy retrofits to perform, finding government and utility incentives, and identifying financing vehicles that together make retrofits affordable, while keeping rental payments steady. Prior to discussing research details, it is useful to briefly highlight a handful of key findings and important lessons the team learned as they attempted to address the split incentive barrier during this project.

9.1 Key Findings

Our team made a number of important discoveries, including:

- Many of the financial tools we found and carefully considered, including UAs and UA calculators, were overly complex and difficult to understand and access.
- The human capital required for finding, evaluating, and negotiating between various finance programs and tools can be time consuming and labor intensive. The associated substantial soft costs can be significant impediments to EE gains.
- Despite using excellent educational and personal one-on-one communication tools to explain to tenants the value of changing energy-related behaviors, which results in less energy use, considerable energy savings were taken back after the improvements were installed, as some tenants actually *increased* their energy usage.
- Well-meaning programs run by the State of California, such as *Energy Upgrade California*, are not transparent, and have hidden costs and restrictions that make them challenging to use.
- Environmental remediation retrofit efforts, such as asbestos removal, are expensive and can lead to delays. They are also inconvenient and hard for tenants to schedule, since they are required to vacate the property for extended periods of time.

Additional important discoveries are mentioned in the following sections.

9.2 Motivation of Cost Effectiveness and Learning New Methods

There are five main conditions or triggers motivating MF owner investments, with varying degrees of impact [5]:

- Purchasing or refinancing the property (5% - 6% of LIMF properties refinance each year)
- Replacing aging, obsolete, or costly HVAC equipment (5% of HVAC units in MF properties are replaced each year)
- Attractive utility, tax, and government incentives
- Health and safety improvements needed in many older properties
- Optimizing the desirability of rental properties, to retain tenants and improve or maintain property values

One of the factors in LINC's decision to partner on this project was to jointly find and/or develop methods to make EE improvements more cost effective. These methods include technological and construction improvements that make retrofits more affordable, and finding utility incentives, government grants, and other incentives and programs that reduce costs, including new and innovative financing programs. Replacing aging equipment was another factor in LINC's decision to participate. For example, LINC was interested in replacing older kitchen appliances and replacing them with high-efficiency ENERGY STAR units. But without cost effectiveness and good financing tools, efficiency improvements could not be done. It is critical that growing numbers of low-income families have quality, affordable housing. To meet that need, the industry should have innovative financing solutions to implement cost-effective retrofit practices. To the extent possible, these financing solutions should reduce the required paperwork and be more mindful of tenant and landlord time. The project research team's experience proved that many current financing solutions include significant administrative burdens, which effectively exclude numerous programs from consideration.

9.3 Barriers Experienced During the Beechwood Project

The majority of recent MF EE reports available for review identify barriers, but there is a lack of information or methods for resolving these barriers [5]. Separating financial barriers from other barriers before designing specific solutions is no easy task. LIMF property owners reported that lenders often require onerous, prescriptive conditions for lending on LIMF property improvements, and often at higher interest rates on their loans. These barriers are straightforward and relatively easy to quantify over time. Other major barriers also tend to have financial components, and these components need to be carefully identified, examined and analyzed.

In the course of this project, in addition to simple cost and financing barriers, regulatory, administrative, legal, technical, programmatic, behavioral, convenience, and attitudinal barriers to performing retrofits were encountered. It is important to identify and separate the direct and indirect impacts that these other barriers can have on a project's financial health. Unfortunately, the line is blurred between some of these barriers and financial barriers, and overlap is common.

For example, technical, jurisdictional, and even weather-related issues produce construction delays of weeks or months, and these delays impact the project's bottom line, which is as financially burdensome as the theft of Wi-Fi devices or the "take back" effect (which occurs when tenants of recently-retrofitted apartments realize that energy bill savings are free to them, so they adjust their thermostats to use more energy). Tenants responsible for savings take-back often do not realize they are reducing the savings the property owner may have counted on in their calculations of building energy use, or energy-cost savings the owner may have used in predicting the savings results from "greening" the apartment complex, or their cash-flow or building value calculations used to justify and fund retrofits.

The following section highlights the key financial and related barriers faced by the research team, including the property owner, during the Beechwood retrofit:

1. Programmatic financial barriers were subject to the effects of split incentives, and related to restrictions, conditions, and eligibility requirements for specific funding sources, especially UA adjustments and California Utility Allowance Calculator (CUAC)

requirements, the Energy Upgrade California (EUC) Program, the California Solar Initiative Multifamily Affordable Solar Housing (MASH) Program, the ESA program, and the Middle Income Direct Install (MIDI) Program.

2. Unusually high cost barriers were related to environmental mitigation and asbestos removal efforts in each unit (the cost of asbestos abatement was nearly 70% of the cost of the efficiency retrofits, and more than 40% of the total cost).
3. Technical barriers, principally Wi-Fi and typical construction challenges associated with PV retrofit installations.
4. Behavioral and informational barriers, due to a lack of information or concern about energy use and its costs, what affects energy costs, and who is responsible for good energy behaviors and why. For example, at Beechwood, there was significant "take back" or reduction in energy savings due to tenants changing thermostat settings, trading energy and cost savings for comfort. Tenants often demonstrated take-back behavior because to them, the energy-cost savings was free. These tenants trade the "free" reduction in energy costs for adjusting the thermostat to improve comfort, using more energy. They typically did not consider the building owner's goal of retrofitting for efficiency, which, except for split incentives, was used to pay back the costs of the retrofit and/or increase the property value.
5. Access to tenant work space barriers, caused by a majority of stay-at-home tenants and varying tenant schedules, which made it difficult to coordinate timely energy improvement installations.

Each of these barriers and their potential solutions are detailed below.

1) Programmatic Financial Barriers

Utility Allowances

Gross rents paid to affordable housing property owners are offset for qualifying tenants based on income qualification and realistic utility costs. These standard UAs are set and adjusted annually by the local Public Housing Authority (PHA). Under federal regulation, "…the utility allowance (UA) schedule must be determined based on the typical cost of utilities and services paid by energy-conservative households that occupy housing of similar size and type in the same locality. In developing the schedule, the PHA must use normal patterns of consumption for the community as a whole, and current utility rates." Theoretically, adjusting this standard utility allowance to reflect savings from EE and renewable energy upgrades allows the property owner to capture these savings over time, to pay for the improvements. It effectively resolves the split incentive issue, particularly for the Beechwood project, because the units are individually metered for electricity. In practice, however, lowering the UA has been shown not to be a strong incentive for owners to install upgrades or to recover savings from their investments. The standard UA does not consider the age of buildings, size of units, number of units, levels of electricity and gas usage, long-term changes in utility rates, or changes in climatic conditions within a county. The standard UA for the Beechwood property was based on utility-cost averages for affordable housing properties across all of Los Angeles County. While Lancaster is located in the harsh, high-desert environment of CZ 14, the majority of affordable housing properties in Los Angeles County are located in calmer conditions near the coast, in CZ 6. Furthermore, existing gas and electric utility billing data demonstrates the standard UA for Lancaster is lower than actual consumption. These result in an unrealistic standard UA for Beechwood, which made it more difficult to calculate the true costs and benefits of a UA adjustment. The Beechwood project was not alone; a 2014 survey of California affordable housing property owners found that few have used adjusted UAs because of regulatory, administrative, and cost barriers [4].

The effectiveness of UA in resolving the split incentive barrier is based in part on the Beechwood housing assistance program. Because the lower UA lessens the amount of assistance they would otherwise have to pay, tenants receive less financial assistance. Affordable housing building owners such as LINC must raise rents to cover the shortfall caused by the lower UA adjustment. In these cases, the UA adjustment is actually a disincentive for property owners to consider EE and renewable energy upgrades. As part of its mission statement, LINC is committed to keeping their rents affordable, so after careful analysis, the UA adjustment was not used.

The California Utility Allocation Calculator (CUAC)

The research team determined the CUAC was the best way to use a calculated UA to take advantage of energy improvements. Officially recognized since 2009, CUAC is a tool designed to calculate project-specific utility allowances for low-income housing projects. The CUAC must be used by qualified professionals approved by the California Tax Credit Allocation Committee (CTCAC). On a Low-Income Housing Tax Credit (LIHTC) property like Beechwood [6], CUAC is limited to those properties constructed after 2009, or those properties with solar PV using MASH incentives, and *not* receiving other funding from sources that prohibit it. Because Beechwood units were built well prior to 2009, these restrictions eliminated units not impacted by PVs. This seemed a narrow opportunity, except that LINC decided to install PVs and institute Virtual Net Metering (VNM), qualifying the units, at least up to that point. However, if the current UA were not representative of the actual conditions prior to using the calculation (as with Beechwood) even after meeting all these conditions, the new allowance may still not achieve the desired result of adding to the net operating income (higher rent).

An initial application fee of $500.00 is required for CTCAC to begin reviewing planned upgrades. Total payments to CTCAC typically increase, based on the complexity of the project and CTCAC's review. While total fees cannot exceed $2,500, the total amount charged by the CTCAC analyst is not known until they complete their review. This uncertainty can discourage UA adjustment evaluation. CUAC requires extensive compliance documentation (for all 45 input variables) and a software purchase (the software required to run CUAC is almost ten years old). On top of these barriers, the software does not perform all of the necessary calculations, so separate spreadsheets are also needed. CTCAC may often be impossible and not attempted due to the associated overhead burden, and the uncertainty of any reasonable outcome before all calculations are done and remittance due.

In addition to the regulatory and administrative barriers to using UA adjustments for recovering of energy savings from upgrades, a final barrier was the unknown timeframe for recovering savings. Projected timeframes do not account for changes in occupancy, tenant energy consumption behaviors, PHA updates to the standard UA, or changing federal and state program requirements. LINC and team also determined that using the CUAC is better-suited to larger, more comprehensive upgrades than the Beechwood project. Despite CTCAC being an accurate tool for modeling building energy use, it also faced regulatory and compliance barriers. To rely on a UA adjustment as a means to finance upgrades was simply not viable or realistic.

There are several solutions to addressing the barriers of benefitting from UA adjustments. Given the various federal housing programs, varying UAs from location to location, as well as state process oversight, a more consistent tool for measuring electricity and gas usage would be beneficial. At the federal level, there were efforts underway to improve the use of UA adjustments for recovering cost savings. At the state and local levels, acknowledgement of climatic differences within each PHA and the ability to gather and analyze utility data would have also been beneficial to building owners. The Energy Foundation was funding the creators of the CUAC to design a National Utility Allowance Calculator (NUAC) in 2017.

One local California PHA developed a model UA adjustment option specific to solar PV, which holds promise. All PHAs use HUD's template to report UAs, breaking down electric and natural gas utility costs by end uses such as heating, A/C, refrigeration, cooking, water heating, water, sewer, and waste collection, among others. The Housing Authority of Tulare County (HACT) in California developed a solar UA, which offsets electricity consumption by the amount of PV production credits [7]. Tenant utility consumption baselines are estimated for each building type and unit size, applicable utility rates are applied to determine the amount of the utility allowance, and the solar offset is then calculated through a separate process and factored into the utility allowance calculation. HACT's model solar UA holds promise for affordable housing property owners who do not have access to cash flow, reserves, solar incentive programs, or research projects like Beechwood. This model program may be one option for generally improving the effectiveness of UAs, to benefit property owners and their tenants.

Energy Upgrade California (EUC) Program

EUC is a statewide, rate-payer funded initiative that uses a comprehensive "whole buildings" approach to EE through technical assistance and incentives for EE upgrades at single- and MF buildings. EUC was in its initial pilot stage during the Beechwood project design phase, and little was known about the program. Early in the project, the research team investigated, and after working closely with EUC program staff, decided not to pursue the program or its incentives, for several reasons.

EUC energy-modeling programs were simplistic compared with those used by the Beechwood research team. This explains why the benefits of several EE measures proposed by the project team were not recognized or credited by the EUC auditing team. In particular, the HVAC duct sealing and insulation in dropped ceilings did not meet the minimum EUC thresholds. The duct replacement was specific to the existing building and integrated duct chases and distribution system within the dropped ceiling. The simulations showed the duct retrofit performed as if the ducts were moved to conditioned space. While the approach was novel (which is probably the main reason EUC did not recognize it) it was proven to be very effective in reducing duct losses.

Additionally, the extent of testing and verification and the EUC-related costs that would be paid by LINC lacked the transparency of other similar programs. They were significantly higher than expected, and the installations had to be completed by EUC-approved contractors, all of which were problematic for LINC. In addition, most of the EUC-approved contractors were unknown to LINC staff and the research team. Having faced these barriers early in the process, the research team determined that projects much larger than the 30-unit retrofit at the Beechwood property would be better candidates for the EUC program. Coincidentally, upon completion of the original energy improvements that were not recognized by EUC audit staff, the savings from duct sealing and insulation *exceeded* what EUC program staff calculated.

LINC and the research team also planned on upgrading refrigerators with EUC or SCE incentives, which required replaced refrigerators to have been manufactured before 1999, which was not the case for Beechwood units. EUC programmatic barriers could be resolved by changing the program guidelines (if the program still exists when this report is published). For example, new EUC guidelines could include slightly newer refrigerators, and more than one level of incentive based on refrigerator age and test results for set vintages.

California Solar Initiative (CSI) Multifamily Affordable Solar Housing (MASH) Program

The project benefitted from incentives provided by CSI, which provides incentives for installing solar PV panels through its MASH program, and solar thermal water heating systems through the CSI-Thermal program. CSI significantly improves the return on investment of solar systems by reducing initial costs and helps justify installation.

MASH incentive levels vary based on PV panel performance, including such factors as installation angle, tilt, and location rather than system capacity alone. This performance framework ensured the Beechwood retrofit was optimally designed. The solar PV system does not have a method for LINC to directly recover its costs, but the incentive helped to significantly reduce the first-cost impact. Because Beechwood incorporated a value of non-originating material (VNM) system, the direct benefit of adding solar PV to the grid is delivered directly to tenants through bill credits (since the units are individually metered for electricity).

Due to the improper installation of VNM protocols for the electricity generated at the Beechwood common areas (mainly the laundry and community event rooms) LINC was billed, rather than credited, for the cost of electricity generated by the new solar panels. This error did not affect tenant utility bills, and contractors worked with the utility to resolve it. Because Beechwood is individually-metered for electricity and master-metered for gas, the cost savings from the SDHW system was credited directly to LINC, who purchased the system. Unlike the solar PV for electricity generation (which benefits the individual tenants), LINC will recover its SDHW system costs through future natural gas savings.

Overall, LINC and the research team faced minimal barriers with the CSI MASH program. The team found CSI staff to be efficient, helpful, and timely, which may be partially due to the fact that the program has been around a while; the online application process is straightforward and easy to understand, and the fees (based on system size) were straightforward. The only financial barrier LINC attributed to this program was the legal review required to resolve a budget issue with a MASH contractor who subcontracted some work. This legal barrier could have been resolved by using simpler and shorter MASH-provided contract templates, which protect the owner and require minimal legal review.

Since this early work with MASH, LINC has found the program to be more cumbersome than other projects. For example, simple requests for extensions due to common construction delays and project recalculations and costs must go through approved contractors. This can result in delays, as new people reevaluate and question original calculations that were previously approved. The research team believed these "re-reviews" are unnecessarily burdensome. The construction process is characterized by weather and technical delays, so the solution would be to minimize extra review of previously-approved calculations.

Energy Savings and Assistance (ESA) and Middle-Income Direct Install (MIDI) Programs

ESA and MIDI provide no-cost, direct-install upgrades for income-qualifying customers. ESA provides weatherization installations such as attic insulation, caulking, and weather stripping, as well as low-flow shower heads and faucet aerators. MIDI, which extends benefits to those who do not meet ESA's income requirements, also provides attic insulation, low-flow shower heads, and faucet aerators. Unlike ESA, MIDI provides duct sealing and testing, a significant energy-saving upgrade for many existing properties, and an upgrade targeted in the project planning stage. The program is available to income-qualified renters and homeowners living in single-family and MF dwellings. Program services are provided by vendors authorized by and under contract to the local utility.

These two no-cost programs typically face barriers for eligible customers in MF properties for several reasons, but mainly because tenants must get written approval from the property owner, who must also coordinate the installations while not benefitting directly from the savings. This was clearly not the case for the Beechwood project, as LINC initiated and led the process on behalf of the tenants. Beechwood also piloted two specific program improvements. First, LINC received additional coordination and support from a utility-appointed low-income program manager, who served as the project's main point of contact. This ensured all available incentives were identified and deemed eligible during the project's early planning phases. Importantly, the low-income program manager was able to perform some of the tasks normally performed by the property owner, thus freeing up time for the owner's staff.

Secondarily, as an alternative to tenants being required to apply individually and online, the Beechwood project used existing tenant data, collected by LINC, to demonstrate compliance with income qualifications. Because most tenants had limited or no internet access, this alternative compliance approach further streamlined the application process. The research team found many tenants lacked basic computer and internet skills and services, which could have slowed down the retrofit process.

These programs required LINC to work with multiple program-approved contractors, which was a notable barrier. LINC demands high-quality work on their properties and allowing multiple unknown contractors to install improvements required trust and new protocols within the company. This barrier was addressed through informal contractor vetting, reference research, and careful installation and post-installation savings examination.

2. Unusually High Environmental and Asbestos Costs

High first costs, and the inability to recover these costs through financial mechanisms, are a well-documented major barrier to LIMF housing retrofits. The Beechwood property contained asbestos, and it had to be removed before the new EE improvements could be installed. MF buildings built prior to the passage of the Comprehensive Environmental Response Compensation and Liability act of 1980 typically contain asbestos. Toxic construction substances must be abated prior to retrofits that might disturb the substances, and these abatements can be very expensive. The Beechwood asbestos abatement required cutting an access hole in the dropped ceiling to replace and insulate ducts and the HVAC distribution box. The abatement cost was almost 70% of EE improvement cost.

Asbestos is a known carcinogen, and its removal can be cost prohibitive. For example, total asbestos removal in a 1,500 square foot home built prior to 1980 can cost $20,000 to $30,000. Asbestos was commonly used as a fire-proof insulating material in mastics used to seal joints in ducts and pipes, vermiculite attic insulation, ceiling and wall acoustical tiles, cement asbestos siding, and floor tiles (and floor tile adhesives). OSHA must be involved to ensure licensed contractors follow all local regulations and requirements during the removal process. At Beechwood, the cost of asbestos abatement was nearly 70% of the EE retrofit cost, and asbestos abatement was more than 40% of the total retrofit cost. Abatement costs were offset by the grant awarded for this research project. Without this grant funding, asbestos abatement would have likely ruled out any retrofits requiring access to or work inside the apartments.

The research team also noticed a psychological barrier during the removal of the asbestos. Tenants were visibly concerned about exposure to asbestos after watching licensed contractors appear on the Beechwood site in required hazardous material suits. Despite early educational efforts about asbestos, some tenants were still concerned about the future impacts of removing the asbestos from their units. This barrier could be addressed by advanced educational efforts for all impacted tenants, and by providing contact information for trusted sources who can answer tenant asbestos questions.

3) Technical Barriers (Wi-Fi, PV Retrofit Construction)

The team encountered an unexpected data acquisition barrier. Ultimately, the research team collected less data than planned, due to the limited geographic area covered by Wi-Fi, and the fact that the Wi-Fi units (and later hot spots purchased to replace the Wi-Fi units) were either stolen, unplugged during the monitoring phase, or not allowed by the tenant. Essentially, Beechwood Wi-Fi coverage was limited to common areas, and would not cover the area where the newly-retrofitted units were located. The Wi-Fi units worked intermittently for the first three months, and then ceased to operate. To address this Wi-Fi limitation, the research team purchased individual hot spots for each unit (hotspots are physical locations where people may obtain internet access, typically using Wi-Fi technology via a wireless local area network and a router connected to an Internet Service Provider).

The team had to return to Beechwood to reinstall and set up these devices. A network of Wi-Fi hot spots was installed, so individual appliance use could be measured. Some of the hot spot devices (as well as smart thermostats) were removed (or reprogrammed, in the case of smart thermostats) by tenants when they moved. Also, some tenants refused to plug in the hot spots, which eliminated the opportunity to collect more specific energy data during the monitoring phase. According to LINC, the complex has a 25% annual resident turnover rate. Team members also had to re-educate tenants about the importance of not tampering with or removing equipment.

Prior to installing rooftop PVs on one of the buildings, its roof was supplemented with SPF and a weather-proof, wear-resistant solar roof. Before the SPF could be installed, preparations were required, two of which caused delays. One was insulating the supply and return ducts to the rooftop HVAC units. The other was determining whether the supporting curb was high enough to provide clearance between the ultimate height of the SPF and the bottom of the HVAC units to prevent the SPF from inadvertently adhering to the HVAC boxes, which would have become permanently affixed to the SPF roof in their current locations and, going forward, be a huge barrier to any retrofit or repair work on the roof or the HVAC units. The HVAC curb minimum height requirements were met, and the HVAC ducts insulated. These kinds of technical barriers are often expected. One solution to alleviate the issue of stolen, unplugged, or never-plugged-in Wi-Fi and hot spot equipment would be to incorporate a simple, one-page contract between the MF housing owner and the tenant, requiring or incentivizing tenants to plug in or return the monitoring equipment.

4) Behavioral and Informational Barriers

After the EE installations, some technology-savvy tenants reprogrammed their smart thermostats and changed passwords, which invalidated the usefulness of what little monitoring data we were able to collect. Therefore, adjusted thermostat settings impacted energy savings projections and invalidated expected differences and comparisons between the control group and newly-retrofitted units. This self-interested action is considered a behavioral issue. When forecasted versus achieved reductions are impacted negatively by actions like this, it is known as the rebound, or "take back" effect. The team could not be sure what the exact impact on forecasted reductions was after the tenants reprogrammed thermostats. The total microeconomic rebound is usually about 20% - 40%, when including all substitution and income effects, and the embodied energy in the EE improvements. [8]

Imperfect information is a key barrier to LIMF EE savings. One example is equipment and new technology performance. Tenants generally get one total electricity bill each month, so performance of individual devices such as refrigerators, solar panels, and A/Cs is hard to separate. Since tenants cannot see EE, it is difficult to show them the value of improved efficiency for a particular appliance. This could be addressed through more detailed educational efforts than those implemented at Beechwood, and by incentivizing tenants to leave the equipment alone. For example, a $25 gift certificate to a local retailer could be provided to tenants after monitoring was complete. This solution would not improperly impact tenant energy behavior, since it would reward them for simply not touching the monitoring equipment. Several tenants said they experienced greater comfort inside their units after the improvements, but some Beechwood savings were definitely reversed by the rebound effect and behavioral changes. In addition, formal tenant guidelines could be written and discussed with tenants. While time consuming, this method could help tenants understand the consequences of their actions. Tenants could also engage in the retrofits via an informal dashboard, designed to show the results of their actions on a monthly basis.

5) Access to Tenant Work Space

One key aspect of this EPIC research program was the team's attempt to be fully aware and mindful of the customers. It is important for both the property owner and their tenants to be pleased with the outcome of the retrofits. The team took extraordinary efforts to accommodate tenant schedules. Coordinating the retrofit work when the majority of LIMF tenants stayed at home during the day presented many challenges. The team evaluated the possibility of doing all the work at one time, temporarily moving all tenants at once versus doing the work on a unit-by-unit basis. The tenants were virtually of one voice that they would prefer to spend their nights and evenings in their own apartments and beds, and they were willing to stay out of their dwellings during the hours in which the team required uninterrupted access. The team developed a process to pack up near the end of each of the four days they or the asbestos specialists were working in the apartments, so the tenants could have dinner, sleep, and have breakfast in their own homes. Fortunately, the asbestos abatement was completed in one long day, leaving the team three more days to complete the retrofits in each unit. They ran two teams, staggered by two days, to share certain individuals who were particularly good at some aspect of the work, as well as certain equipment, such as insulation. This approach also required the work to be completed around existing furniture and other housing items and appliances, while avoiding doing any damage. The team worked hard to minimize disruptions to tenant schedules; the same was not always true of the tenants. It was not uncommon for someone to need something from their apartment. The team allowed access if it was safe, or let the tenants know when it would be safe. At the beginning of the project, the team had no way of estimating or planning for tenants to be home during working hours – typically 8:00 a.m. – 5:00 p.m., sometimes a little longer to satisfactorily store equipment and straighten and clean the work areas. One way to address this barrier in the future would be to survey existing LIMF retrofit tenants to identify how long, and at what times, they expect to be in their units during the retrofit project. This would help project planners considerably.

9.4 Conclusions and Recommendations

During this multiyear research project, much was learned about structuring LIMF financing and incentive programs. Six lessons learned, and recommendations are as follows:

1) UA reform is needed, and related tools, such as CUAC, have significant barriers. The Beechwood owner was unable to take advantage of the Los Angeles County UA because it was too low and does not match the more extreme Lancaster climate. Existing UAs are too low in many counties, which can effectively nullify their use. In addition, the CUAC, while accurate, has significant barriers that prohibit widespread use of the tool until they are addressed. It is complex, and requires the purchase of two different software packages that are almost 10 years old. In addition, the CUAC software will not perform all of the calculations necessary for CUAC approval, so extra Excel spreadsheets must be designed to accompany and supplement the CUAC modeling. This is a time-intensive process. Locating and obtaining personal technical assistance from the few available CUAC experts is challenging at best. Data collection is burdensome; some energy consultants who use CUAC regularly employ one full time employee (FTE) whose only job is to assemble the required data. These factors and others create significant barriers to CUAC and other UA applications. Calculating an accurate UA is a top priority early in the project development process, so reform is needed to ensure the UA-generated numbers are accurate and close to the actual numbers that will be experienced throughout the project. The research team recommends working closely with the State of California, HUD, and CUAC experts to develop more meaningful and easier-to-use utility allowances and tools. It seems obvious that additional sub- or intra-county UAs, or property or ZIP code-specific UAs, would be more valuable to owners and tenants in the future.

2) State-run finance and incentive programs need more transparency, easier access, and regular evaluation to help ensure viability and value. The research team discovered that accessing state programs, such as EUC, was difficult, time-consuming, and often confusing. The EUC introductory process should be simpler and faster, and the program details must be clarified. While negotiating with EUC program staff, the research team discovered too much data collection was required too early, resulting in wasted time. For example, the team was forced to turn over large amounts of data to the EUC staff and discovered too late in the process that the program would not fit Beechwood needs. Topics such as the expensive post-retrofit analysis, and the costs associated with the prospective Beechwood analysis, were largely skipped in early discussions with EUC program staff yet made their way into later conversations. This caught members of the research team by surprise; more transparency would have been helpful. Essentially, the cost of these post-retrofit measurements was prohibitive, and the team did not learn early enough about them. Accessing the correct EUC program resources required significant time and team effort, involving cumulatively hundreds of hours. Contacting the EUC contractor, waiting for

the contractor to appear, and then waiting for the results of their analysis and recommendations can be a time-consuming, slow, and patience-testing process.

The research team discovered other programs that were helpful, but perhaps needed fine-tuning. The MASH program is one example. Strict contractor requirements were burdensome, and approved contractor background information was not adequate to the owner. In addition, LINC stated that while working on other similar projects (after this one) the MASH program is becoming more inflexible by requiring recalculations of previously-approved changes, due to common construction schedule delays caused by weather, schedule conflicts, and contractor issues. The research team believes these program requirements should be relaxed to make it easier to do business with MASH, rather than more difficult. The research team also advocates for program eligibility criteria to be regularly evaluated and adjusted, based on energy savings potential and the current LIMF market, which may allow more appliances to be added to the list of program measures. For example, slightly-newer refrigerators could be considered for EUC inclusion, since a case could be made that the energy savings from these products is now cost effective.

3) Using a single-point-of-contact for stacking financing and incentive programs can save significant time and improve efficiency. As previously noted, staff time dedicated to researching, finding, evaluating, and comparing programs, and ultimately arranging the final Beechwood project financing stack, took considerable time. The research team took advantage of an offer from an IOU to provide a single-point-of-contact, the low-income program manager. This person helped ensure all available programs were thoroughly evaluated, and the interplay and restrictions between the programs was clearly understood. Due to often-complex eligibility requirements and the restrictions between using similar programs, the availability of one person with comprehensive knowledge of these requirements was beneficial to the research team. New program deadlines and launches occur throughout the year, so an expert is required. For example, the research team was interested in participating in an On-Bill Financing (OBF) pilot, but the pilot timing did not match the project timeline. Had the research team known about the timing earlier, they may have been able to rearrange project deliverables to participate in the pilot. Using the utility-provided low-income program manager gave an important, extra layer of assurance that all available programs had been considered.

4) Extra up-front tenant educational efforts can pay huge dividends at the end of the project. The research team discovered late that the majority of tenants were stay-at-home residents. Had the team known this earlier, the work plan could have been adjusted. Furthermore, 25% of the tenants moved and vacated the retrofitted properties during the project, sometimes taking the hot spot equipment required for relaying important energy use data to the research team. A simple, early, informal survey could have provided the team with this information and enabled them to plan more effectively. The team thought an informal contract between the tenants and the owner (perhaps a moral contract, not a financial contract) that outlined clear expectations and roles during the project, as well as the importance of obtaining accurate monitoring data, may have helped. At a minimum, it would have helped ensure tenants knew the importance of not moving hot spot equipment,

and keeping thermostats programmed at the temperatures set by the research team. Tech-savvy tenants actually reprogrammed thermostats during the evaluation phase, compromising data integrity. Setting the best policies to make sure LIMF tenants change their behavior and save more energy is no easy task. The research team believes that a small ($25.00-$50.00) gift card provided to tenants after evaluative data is collected is one solution to this issue. Extra tenant education on asbestos remediation, to help address concerns and prepare them to see contractors in hazardous material suits, is also recommended for similar-scoped projects.

5) Advance Wi-Fi coverage work may help ensure researchers receive important evaluative data. Three months into the data evaluation phase, the research team discovered Wi-Fi coverage was spotty, hindering data transmission. For future projects, if evaluation data is to be sent to evaluators via Wi-Fi, coverage should be tested early in the project, to avoid this potential technical barrier. Adding hot spots and other equipment later can be problematic. The research team believes that testing the property for needed and appropriate Wi-Fi coverage is an easy way to help guarantee the researchers receive data.

6) Joining a LIMF financing collaborative can save time and money. Solving the split incentive issue for LIMF housing requires many resources, including developers, tenant advocacy groups, NGOs, financing experts, state and federal government agencies, foundations, and others. To the extent possible, researchers in future comparable projects should find and join any relevant LIMF housing collaboratives. For example, the "Energy Efficiency for All" collaborative (http://energyefficiencyforall.org/) is dedicated to linking the energy and housing sectors together, to tap the benefits of EE for millions of low-income families [9]. They work with electric and gas utilities and their regulators interested in innovative EE program design, and they advise housing finance agencies on best practices in building owner engagement and finance products. The project is a partnership of the Energy Foundation, Elevate Energy, National Housing Trust, and Natural Resources Defense Council, and was made possible with funding support from The JPB Foundation. Collaboratives such as these provide off-budget technical and financial expertise that, for some projects, can make a sizable difference.

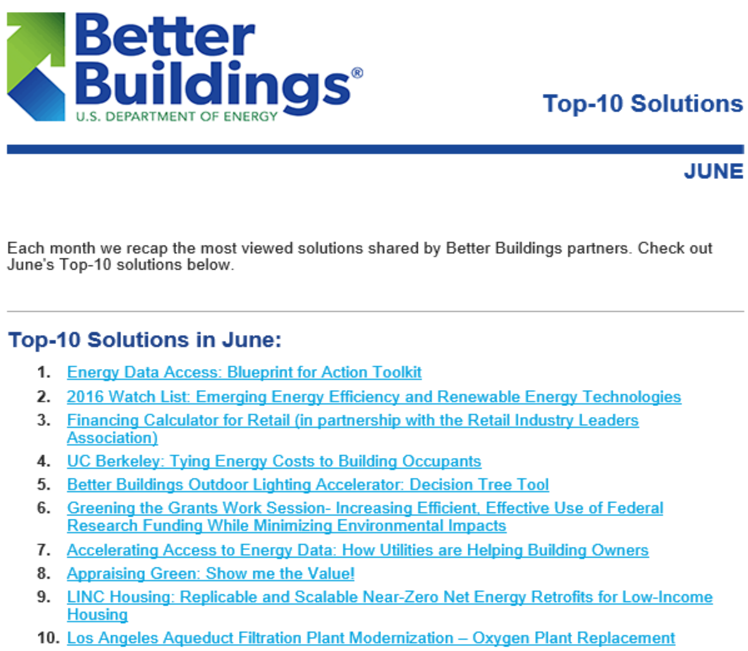
CHAPTER 10: TECHNOLOGY TRANSFER AND COMMERCIALIZATION PLAN

10.1 PUBLIC TECHNOLOGY TRANSFER

This project received significant attention from technical and general media and has been set as a model of near-ZNE retrofits for the LIMF building segment. The following sections provide a list of articles and media reports published about the project. The articles were written from different angles – green buildings, MF housing, low-income community, EE retrofit, occupant comfort improvement, and low-cost, replicable building solutions.

10.1.1. U.S. DOE BETTER BUILDINGS HIGHLIGHT OF BEECHWOOD PROJECT

The project has been listed on the U.S. Department of Energy's (DOE) Better Buildings permanent site. It received one of the top 10 views and was awarded "Top-10 Solutions" in June 2016 (Figure 99 - Figure 102) [13]. The Better Buildings site highlights the project overview, project design process, resident outreach, up-to-date research results, and methods used to conduct data monitoring and home energy management. The Better Buildings site has been following the project's progress, continuously updating the content as the team publishes technical articles and technology transfer materials to the public.



Better Buildings®
U.S. DEPARTMENT OF ENERGY

Top-10 Solutions

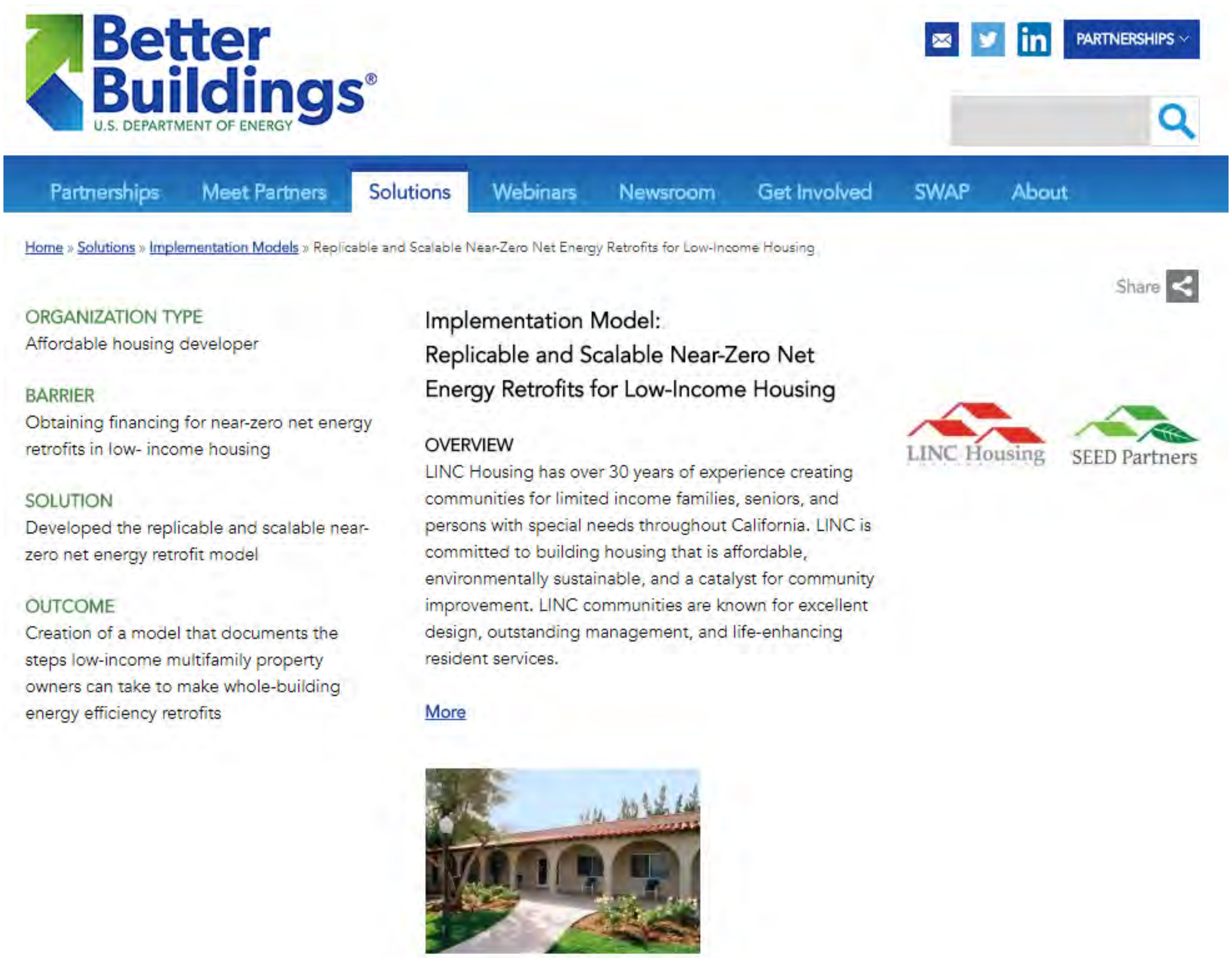
JUNE

Each month we recap the most viewed solutions shared by Better Buildings partners. Check out June's Top-10 solutions below.

Top-10 Solutions in June:

1. Energy Data Access: Blueprint for Action Toolkit
2. 2016 Watch List: Emerging Energy Efficiency and Renewable Energy Technologies
3. Financing Calculator for Retail (in partnership with the Retail Industry Leaders Association)
4. UC Berkeley: Tying Energy Costs to Building Occupants
5. Better Buildings Outdoor Lighting Accelerator: Decision Tree Tool
6. Greening the Grants Work Session- Increasing Efficient, Effective Use of Federal Research Funding While Minimizing Environmental Impacts
7. Accelerating Access to Energy Data: How Utilities are Helping Building Owners
8. Appraising Green: Show me the Value!
9. LINC Housing: Replicable and Scalable Near-Zero Net Energy Retrofits for Low-Income Housing
10. Los Angeles Aqueduct Filtration Plant Modernization – Oxygen Plant Replacement

Figure 99: **U.S. DOE Better Buildings "Top-10 Solutions," June 2016**



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ORGANIZATION TYPE
Affordable housing developer

BARRIER
Obtaining financing for near-zero net energy retrofits in low- income housing

SOLUTION
Developed the replicable and scalable near-zero net energy retrofit model

OUTCOME
Creation of a model that documents the steps low-income multifamily property owners can take to make whole-building energy efficiency retrofits

Implementation Model:
Replicable and Scalable Near-Zero Net Energy Retrofits for Low-Income Housing

OVERVIEW
LINC Housing has over 30 years of experience creating communities for limited income families, seniors, and persons with special needs throughout California. LINC is committed to building housing that is affordable, environmentally sustainable, and a catalyst for community improvement. LINC communities are known for excellent design, outstanding management, and life-enhancing resident services.

More

LINC Housing

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Figure 100: Detailed Description on U.S. DOE Better Buildings Permanent Site as an **Implementation Model of "Top-10 Solutions"**

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RETWEET
1

10:26 AM - 27 May 2016

1

Figure 101: Project on U.S. DOE Better Buildings Twitter Page, May 27, 2016

Figure 102: Project on EPRI Twitter Page, July 8, 2016

10.1.2 Technology Transfer to Public on General Media

The project received significant attention, as it is the first near-ZNE retrofit project in the LIMF building segment.

DOE's Better Buildings provided a thorough description of the projects, including the latest research results based on the ACEEE paper published in August 2016. Better Buildings mentioned how the project was started, as well as the team members, and stated the project objectives, including:

- Energy savings
- Improved reliability and system maintenance
- Cost savings and return on investment
- Scalability into the MF housing market
- Minimal resident disturbance during construction

Better Buildings provided a list of EE measures for this specific project, as well as the work related to similar low-rise, wood-frame garden apartments that are typical in California Table 56[11]. The design took into consideration that renovations would occur in occupied space, the buildings' accessibility limitations, the hazardous materials potential, and each measure's cost effectiveness. In addition to the VER measures, the team included on-site energy generation options in its analysis.

Better Buildings mentioned that the team calculated potential whole-building energy savings by simulating the impact of each proposed EE measure on energy use compared to the baseline. The results of this analysis provided the optimum cost-effective value for each measure, and its impact on energy use. The team created small packages of VERs and simulated their impact on energy use, to determine which set of efficiency measures would be most effective. The final package of VERs also included solar DHW and solar PV systems for resident loads.

Better Buildings mentioned that the implementation scope covered 30 of the 100 units at the Beechwood project site and installed approximately 50 sensors to collect data and evaluate each measure's effectiveness.

Table 56: DOE Better Buildings List of Selected VER Package EE Measures

	Measure	Feasibility
1	Thermostat Set Point Management: residents tend to keep their units very warm (many heated up to 75°F or higher)	Not easily enforceable
2	Increased Building Insulation: both wall and ceiling insulation were minimal and of poor quality installation	Neither practical nor cost-effective
3	Insulation of Hot Water System Underground Plumbing: system is uninsulated from the boilers to the building	Being explored to determine cost-effectiveness
4	Replacement of Laundry Equipment: runs at relatively low efficiency	Not cost-effective
5	Replacement of In-Unit Stoves and Ovens: old and run at low efficiencies	Will be evaluated on unit-by-unit basis
6	Lighting Retrofit: opportunities to replace all incandescent lighting with LEDs or fluorescents in both resident units and common areas of property	Feasible and leading measure candidates for VERs packages
7	Replace refrigerators beyond a certain age: Coinciding and coordinated with utility refrigerator replacement program	
8	Sealing of Envelope Leakage	
9	Sealing of Duct Leakage	
10	Sealing and Insulation of Building to Make Ducts in Conditioned Space, or Replacement and Heavy Insulation of Ducts	

Figure 103 through Figure 107 show project media coverage from local newspapers, MultifamilyBiz.com, Yahoo News, and SCE.com.

The Antelope Valley Times

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$2.46M retrofit at Lancaster low-income apartments

by The AV Times Staff • November 21, 2014

Developers join resident children for a ceremonial tree planting in September to celebrate the start of the pilot project. The project, taking place at The Village at Beechwood in Lancaster, is backed by LINC Housing and SEED Partners with Electric Power Research Institute as the project lead, in collaboration with BiraEnergy, California Energy Commission, the U.S. Department of Housing and Urban Development, Southern California Gas Company, and Southern California Edison.

Figure 103: Project Reported in the Antelope Valley Times on November 21, 2014

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First Affordable Housing Multifamily Near-Zero Net Energy Retrofit in California to Serve as Model

NOVEMBER 24, 2014

LANCASTER, CA - Work has started on the first near-zero net energy affordable multifamily retrofit in California. The $2.46 million sustainability retrofit project aims to bring energy inefficient, multifamily housing units at The Village at Beechwood (Lancaster, Calif.) to as near-zero net energy as possible, becoming a model for lowering energy and water costs for similar affordable housing communities nationwide.

"This work is important because we need to find a way to make multifamily housing more efficient," said Samara Larson, director of sustainability for LINC Housing and SEED Partners. "To date, there isn't clear data on how sustainability retrofits can be cost-effective, while reducing utility costs for owners and residents. This research project will give us that data so we can show the positive impact on costs and the environment."

Figure 104: Project Reported in MultifamilyBiz.com on November 24, 2014

MEDIA ADVISORY: $2.46 Million Sustainability Retrofit Begins at LINC Housing's Low-Income Apartment Community in Lancaster

MARKET WIRED September 15, 2014

LANCASTER, CA--(Marketwired - Sep 15, 2014) -

When: Monday, September 22, 2014 -- 3:30 to 5 p.m.

Where: The Village at Beechwood, 44063 Beech Avenue, Lancaster, CA 93534

What: The California Energy Commission and the U.S. Department of Housing and Urban Development have funded a pilot project that aims to retrofit low-income multifamily housing to be more energy and water efficient. The goal of this $2.46 million research project is to bring inefficient, multifamily housing units to as near-zero net energy as possible. This type of effort can become a model for lowering energy and water costs for similar affordable housing communities nationwide.

The Village at Beechwood is a 100-unit family community in Lancaster, Calif. SEED Partners is developing retrofit packages for individual units that are scalable and replicable. To date, two apartments have been completed with a net energy savings of about 70 percent. Now, the project has the green light to complete the additional 28 units in The Village at Beechwood research project.

Figure 105: Project Reported in Yahoo Finance on September 22, 2014

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Media Contact: Holly Ferris, Ferris Communications, (562) 429-6456, holly@ferriscomm.com

$2.46 Million Sustainability Retrofit Begins at
LINC Housing's Low-Income Apartment Community in Lancaster
First Affordable Housing Multifamily Near-Zero Net Energy Retrofit
in California to Serve as Model

LANCASTER, Calif., Sept. 29, 2014 — Work has started on the first near-zero net energy affordable multifamily retrofit in California. The $2.46 million sustainability retrofit project aims to bring energy inefficient, multifamily housing units at The Village at Beechwood (Lancaster, Calif.) to as near-zero net energy as possible, becoming a model for lowering energy and water costs for similar affordable housing communities nationwide.

"This work is important because we need to find a way to make multifamily housing more efficient," said Samara Larson, director of sustainability for LINC Housing and SEED Partners. "To date, there isn't clear data on how sustainability retrofits can be cost-effective, while reducing utility costs for owners and residents. This research project will give us that data so we can show the positive impact on costs and the environment."

Figure 106: Project Reported on LINC Housing Pressroom and LinkedIn Page

Transforming Multi-Family Housing in Lancaster, Calif., to be ZNE

Are energy-smart ZNE technologies a good investment in low-income residential communities? Our utility, Southern California Edison, is teaming with several other companies to demonstrate that ZNE retrofits can be practical to install, replicable in quality, and successful in delivering energy savings and positive economic impacts for both property owners and residents. Retrofitting construction on 30 multi-family units in Lancaster, Calif., began in May 2015.

Figure 107**: SCE.com, "Helping California Meet Goals for Zero Net Energy Homes by 2020"**

10.2 Technology Transfer to Research and Development Community

10.2.1 Research Papers Published by ACEEE

The ACEEE Summer Study on Energy Efficiency in Buildings is a biennial conference that gathers a diverse group of professionals to discuss the technological basis and practical implementation actions to reduce energy use and climate impacts associated with buildings. These research results were published for the 18th ACEEE conference in 2014, [15] and the 19th ACEEE conference in 2016 [16] (Figure 108 - Figure 109).

Replicable and Scalable Near-Zero Net Energy Retrofits for Low-Income Housing

Tushar R. Dutta, LINC Housing Corporation
Rob Hammon, BIRAenergy
Ram Narayanamurthy, Electric Power Research Institute

ABSTRACT

LINC Housing Corporation (with support from Kango Development) has partnered with Electric Power Research Institute (EPRI) and BIRAenergy to develop, demonstrate, and document the implementation of deep, near-zero energy (near-ZNE) retrofits of low-income multifamily properties in California, through a comprehensive turnkey approach including:

- Cost effective Very Efficient Retrofit (VERs) packages
- Rigorous monitoring to validate actual savings
- Financial tools
- One-stop delivery models
- Resident education

The VERs will be implemented at The Village at Beechwood, a 100-unit low-income property owned by LINC in Lancaster, California. The team is designing and evaluating VERs for different building and unit types. An estimated 50 sensors will be installed to collect data to evaluate each VER. Energy and demand savings will be facilitated through training of residents, providing each unit with a Home Energy Meter System (HEM) that is coupled to a "smart" electrical panel and smart meter. Each retrofit will include Demand Response appliances that are controlled by the HEM and the utility.

The effort launched in October 2013. The PIER Beechwood Team ("Team") is developing a baseline and VERs with construction slated for June-November of 2014. The presentation of this paper will likely reflect activities through the construction period. One year of post-retrofit energy data will be collected. LINC's Resident Services team will work intensively with residents throughout the process to encourage energy-wise behavior. The goal is to demonstrate scalable, replicable models and provide tools for implementation to multifamily property owners.[1]

Figure 108: Research Paper Presented at 2014 ACEEE Summer Study

Replicable and Scalable Near-Zero Net Energy Retrofits for Low-Income Housing

Ian Hammon-Hogan, BIRAenergy
Samara Larson, LINC Housing Corporation
Peng Zhao, Electric Power Research Institute
Ron Kliewer, Southern California Edison
Ram Narayanamurthy, Electric Power Research Institute

ABSTRACT

LINC Housing Corporation partnered with Electric Power Research Institute, BIRAenergy, Southern California Edison and Southern California Gas Company to develop, demonstrate, and document the implementation of deep, near-zero energy retrofits in low-income multifamily properties in California, through a comprehensive turnkey approach including:

- Cost-effective Very Efficient Retrofits (VERs)
- Rigorous monitoring to validate actual savings
- One-stop delivery models
- Resident education

The VERs were implemented at The Village at Beechwood, a 100-unit low-income property owned by LINC in Lancaster. The team designed solutions for and evaluated different building and unit types. Energy and demand savings were facilitated through resident engagement and installation of smart thermostats.

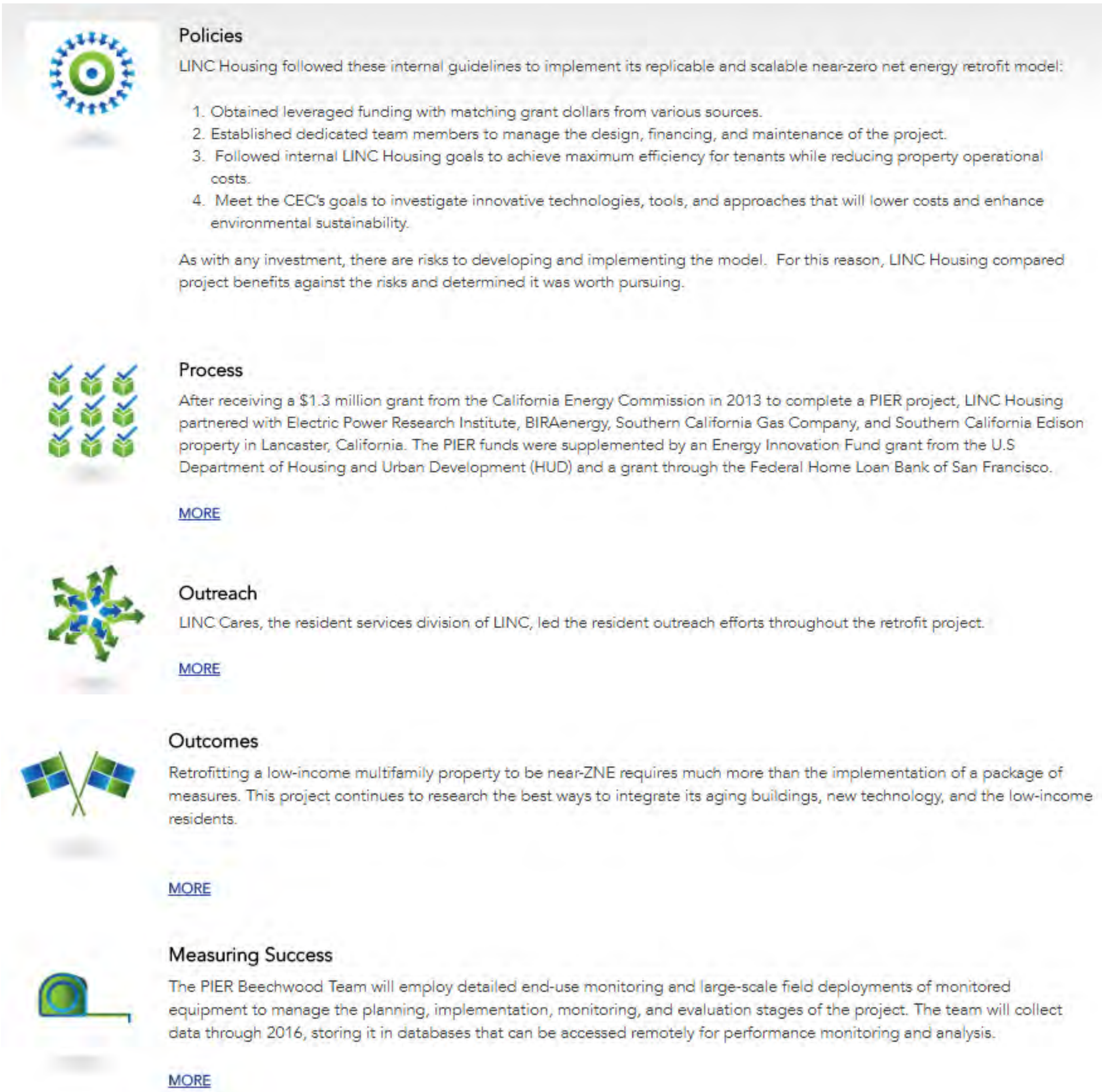
Launched in October 2013, the PIER Beechwood Team developed a baseline and VERs, with construction starting in 2015. Construction in the community building and implementation of emerging technologies will continue into 2016, as well as monitoring activities. One year of post-retrofit energy data is being collected from resident units. LINC's Resident Services team will work with residents throughout the process to encourage energy-wise behavior. This presentation will update initial findings presented in 2014 (Dutta, Hammon, and Narayanamurthy 2014), comparing design goals to actual results with lessons learned through the process. Presentation content will range from test data to resident interviews. The project goal was to demonstrate scalable, replicable models and provide tools for implementation to multifamily property owners. Real upgrade costs combined with estimated utility-bill savings represents a 20-year simple payoff, suggesting that this process could be scaled and maintain cost-effectiveness in the absence of grant funding.

Figure 109: Research Paper Presented at 2016 ACEEE Summer Study

10.2.2 Research Results Published on Department of Energy Better Buildings

DOE's Better Buildings published a thorough project description, including the latest research results based on two ACEEE papers published in 2014 and 2016. The Better Buildings site states that it understands retrofitting LIMF properties to be near-ZNE requires much more than implementing measure packages – it requires research and development efforts to integrate aging buildings with new technology, and scheduling work to interrupt the occupants' daily lives as little as possible.

Better Buildings mentioned that the retrofits focused on weather sealing the units, insulating ceiling spaces, and sealing and insulating the ducts that distribute air from the roof-mounted HVAC units to occupied spaces in the apartments. Better Buildings agreed that all of these measures increased the cooling system's effectiveness and efficiency, without replacing the units, and allowed the units to perform more efficiently during the hottest months. Figure 110 illustrates that clicking the "More" button on the website displays detailed descriptions of each section.



Policies

LINC Housing followed these internal guidelines to implement its replicable and scalable near-zero net energy retrofit model:

1. Obtained leveraged funding with matching grant dollars from various sources.
2. Established dedicated team members to manage the design, financing, and maintenance of the project.
3. Followed internal LINC Housing goals to achieve maximum efficiency for tenants while reducing property operational costs.
4. Meet the CEC's goals to investigate innovative technologies, tools, and approaches that will lower costs and enhance environmental sustainability.

As with any investment, there are risks to developing and implementing the model. For this reason, LINC Housing compared project benefits against the risks and determined it was worth pursuing.

Process

After receiving a $1.3 million grant from the California Energy Commission in 2013 to complete a PIER project, LINC Housing partnered with Electric Power Research Institute, BIRAenergy, Southern California Gas Company, and Southern California Edison property in Lancaster, California. The PIER funds were supplemented by an Energy Innovation Fund grant from the U.S Department of Housing and Urban Development (HUD) and a grant through the Federal Home Loan Bank of San Francisco.

MORE

Outreach

LINC Cares, the resident services division of LINC, led the resident outreach efforts throughout the retrofit project.

MORE

Outcomes

Retrofitting a low-income multifamily property to be near-ZNE requires much more than the implementation of a package of measures. This project continues to research the best ways to integrate its aging buildings, new technology, and the low-income residents.

MORE

Measuring Success

The PIER Beechwood Team will employ detailed end-use monitoring and large-scale field deployments of monitored equipment to manage the planning, implementation, monitoring, and evaluation stages of the project. The team will collect data through 2016, storing it in databases that can be accessed remotely for performance monitoring and analysis.

MORE

Figure 110: Research Results Posted on Better Buildings

10.3 PRESENTATIONS ON LOW-INCOME MULTIFAMILY BUILDING SEGMENT BY LINC HOUSING

LINC Housing was invited to webinars and meetings to talk about the experiences and lessons learned from this project. Figure 111 shows a presentation slide listing topics of information gained during the project, such as EE measures, financing and incentives, the retrofitting process, energy consumption, water use, energy audits, retro-commissioning, and the fundamental question of whether investing in "green" is a good choice for MF buildings. This presentation was useful for technology transfer to the LIMF community for education, training, and customer engagement purposes.

Figure 111: Topics from LINC Housing Presentation on Energy Management in Multifamily Housing

The presenter stated, "When we first started this work, there was a lot of discussion about whether building green was truly worth the investment. Those who jumped in at the start took a risk as to whether it would pay off for them the way their designers and consultants promised it would. Now, there's enough stock of buildings in the market that the value of the green building and its impacts can be shown – on asset values, rental rates, vacancies, and of course, on operating costs."

The presenter also said, "These results come from a variety of sources – there have been studies in many markets – commercial and single family, as well as MF, in various parts of the country. Repeatedly, they show that green buildings have value – to the people who buy and sell them, live in them, and work in them. People are more productive and more comfortable, and perhaps important to many of you today; green buildings also are more cost effective, in the long run, to operate."

The presenter spoke about the California ZNE goal for all new residential buildings to be ZNE by 2020, and for all new commercial buildings to be ZNE by 2030. The codes and standards require buildings to be more energy efficient, and specifically to be ZNE, in California (Figure 112 - Figure 113).

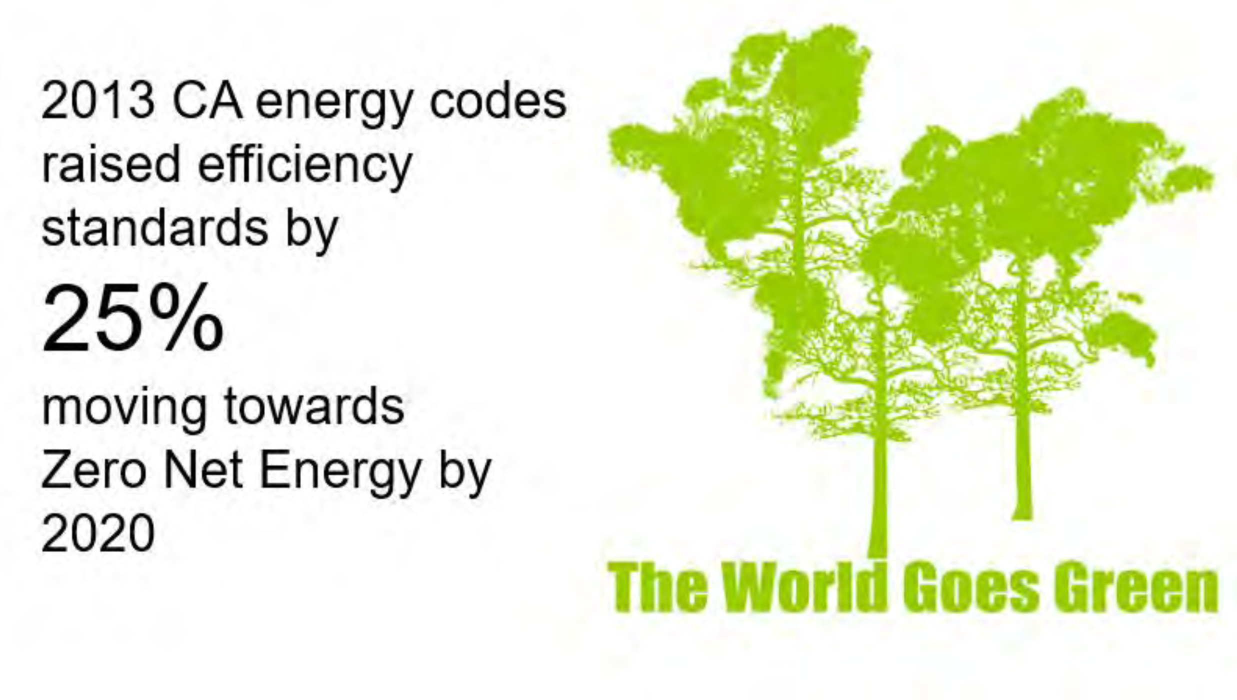


Figure 112: Impact of California Codes

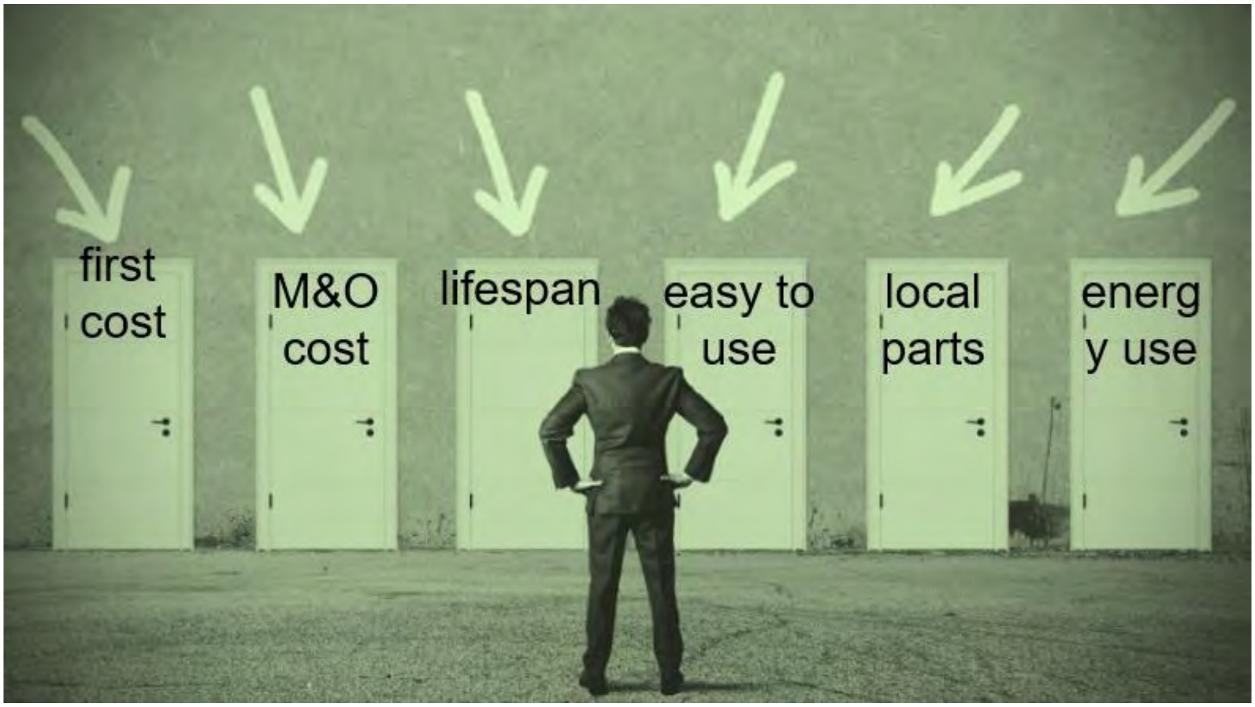


Figure 113: Different Aspects Affecting ZNE Designs and Decisions

The presenter stated that selecting energy efficient measures for retrofit packages is dependent on identified goals. She explained, "If you decide to install a SDHW system or a tankless hot water system, both will provide energy savings. But each has a different long-term impact in terms of maintenance, life span, overall energy costs – it may depend on whether you've set a goal of net zero energy, how you've decided to recover costs for water heating on that property, what your space needs are, how you plan to use your roof space. The up-front incentives for each are quite different. Both these things can meet the energy code requirements for efficient water heating, probably within the budget you've established. But each of them has very different results for all of these other goals."

The presenter mentioned that one of the things to look at on a project isn't a building system at all but relates more to the financing side. Many people are tailoring their choice of EE measures to take maximum advantage of the tax credits that may be available. Of course, tax credits are an ever-changing market, but two of the most commonly used at this time are the Energy Efficient Home Credit and the Solar Investment Tax Credit (Figure 114).

Figure 114: Methods of Financing ZNE Projects

The presenter explained that the Energy Efficient Home Credit provides a financial incentive for properties that choose to build more efficiently than a minimum standard. This is a federal tax credit, so the comparison is to the 2006 International Energy Conservation Code. If you work from the start with your design team, particularly your energy engineer, to align this requirement with the California codes, you can determine where you may need to adjust to meet this requirement and compare the financial benefit (both from the tax credit and any efficiency savings) to the construction cost increase related to any measures you are adding. You may find that it's not as significant as you might initially expect.

In addition, the presenter explained that the Solar Investment Tax Credit, also referred to as an energy tax credit, is currently worth about 30% of the "energy asset" costs. It can be used for system installation on existing buildings as well as new. This credit allows for a more straightforward analysis of the benefits. Many owners use this to install solar PV systems, to reduce the electricity costs for the building common areas, but as the cost of solar has come down, some owners have installed systems that provide credits to tenant bills and used this to justify marginally-higher rents in competitive markets. With the increasing cost of electricity, for some, this may become a more attractive amenity.

Irrigation water accounts for 50% of water use in low-rise MF properties. The presenter mentioned that it is also nearly half of the utility cost paid by the owner. So, irrigation water can be a big potential for savings (Figure 115).

Figure 115: Impact of Water Use

One area commonly overlooked for water reduction is washing machines (Figure 116).

The presenter mentioned that if the community has centralized laundry rooms, even if the supply and maintenance of the machines is outsourced, the utility costs are typically paid under the property's operating costs. Requiring vendors to supply energy-efficient equipment helps keep the costs down, both for the water and the energy to heat the water.

Figure 116: Water Use in Washing Machines

The presenter said that one way to take this a step further is to consider encouraging cold water washing to reduce energy use. A study conducted by the Alliance to Save Energy showed that in locations where there were price variations for cold, warm, and hot water washing, with the cheapest price offered for the cold water wash, energy use could be reduced by as much as 30%.

The presenter also stated that energy and insurance are the two biggest costs most owners have in their budgets that they cannot directly control, and when hit with price increases, they often have to scramble to make up the difference with cost reductions elsewhere.

Commercial electricity rates increased an average of more than 7% just from 2013 to 2014. Natural gas pricing has increased at about 5% per year, and these trends are expected to continue with no drop off in sight (Figure 117).

Figure 117: Energy Costs

Listed are some common EE retrofit measures including: lighting, HVAC, water heating, envelope sealing, pool pumps, and recirculation pumps (Figure 118). An energy auditor can evaluate the property or portfolio to determine where efficiency improvement opportunities are and choose the suitable EE measures. Some projects, such as lighting retrofits and pump upgrades, typically have very short paybacks and high returns on investment, with minimal up-front capital required. Getting an owner's interest and attention to pursue the work can be a challenge. Often, the best approach may be to look at a portfolio-wide solution, to maximize returns once the project has been approved.

The presenter mentioned that depending on how similar your building types and systems are, you may find it is more effective to approach your projects on a systems basis across a portfolio (for example replacing all of your hot water boilers with high-efficiency boilers) to gain economies of scale. Or, you may choose to look at all the improvements at one property where your energy costs are noticeably higher than any other property. Completing an audit can help you get the information you need to make informed decisions.

The presenter mentioned that there are different levels of audits. The simplest ones highlight straightforward opportunities, providing only general information on costs and savings. Deeper audits explore projects more thoroughly, providing more detailed information about costs and expected returns, often including information on possible utility rebates and incentives. These audits cost a little more and take more time to complete in return for delivering more comprehensive information.

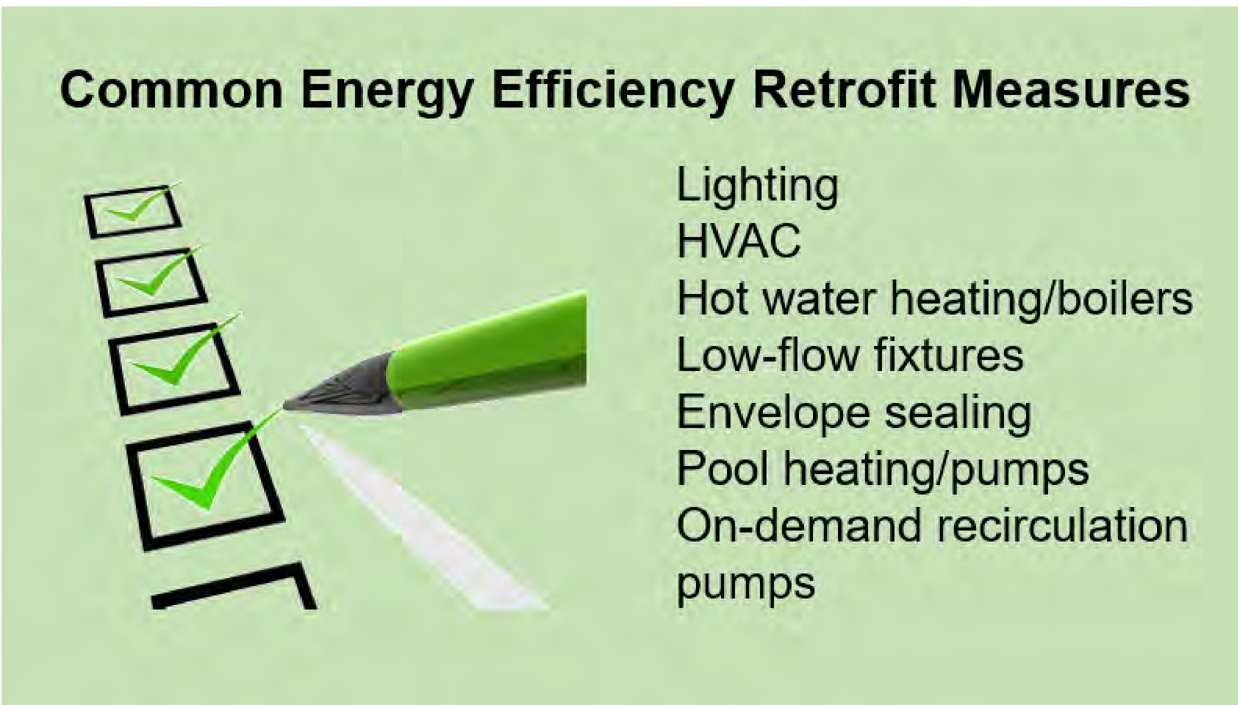


Figure 118: Common Energy Efficiency Measures

Another opportunity to take advantage of is retro-commissioning, also referred to as "building re-tuning" (Figure 119). It's been reported that up to 20% of the energy used in commercial buildings is wasted because of improper operations. Building re-tuning provides a way to have an immediate impact, especially in the often-overlooked small building market, which includes many MF buildings. Small buildings are usually those under 100,000 square feet, which frequently don't have centralized building automation systems. These buildings often have package units for heating and cooling, and are controlled by zone thermostats.

Figure 119: Building Retuning

The presenter stated that there are rebates and incentives available to offset the cost of EE upgrades (Figure 120). So before undertaking any EE work, whether new or retrofit, contact your local utility company or check out their website. Some utility programs may offer audits to help evaluate potential projects. The programs vary, and change over time, so be sure to check regularly. Some are based on specific equipment replacements, and others are whole-building approaches that provide incentives based on the total savings achieved. It may be worthwhile to find out what's available, as some programs cover a significant part of the incremental cost increase between standard and more-efficient equipment.

Additional new programs are always being designed to help pay for improvements. Two of the more recent developments are OBF and PACE. OBF allows you to borrow money for efficiency projects and repay it through your utility bill. The intent is that the savings achieved from the improvement will be put toward the payment, resulting in "bill neutrality" (essentially "no" increase in the monthly bill payment).

PACE is another alternative financing structure. Using approved lending programs, loans are repaid through an annual assessment of the project's property tax bills. Loan proceeds can be used for EE upgrades and renewable energy installations, and the approval process is designed to consider the savings achieved by the improvements.

Figure 120: Financial Incentives

Some mortgage lenders have also designed products to allow for additional borrowing capacity when a property is refinanced, to encourage owners to incorporate EE projects into their properties.

Regardless of financing structure, savings estimates will be a key point of discussion with lenders. Typically, something less than 100% of estimated savings will be assumed for the potential repayment.

10.4 TECHNOLOGY TRANSFER TO UTILITY INDUSTRY

SCE has dedicated significant effort to ZNE buildings. SCE.com lists all ZNE and near-ZNE projects within its territory, including this one [12]. These projects serve as utility research and field study pilot projects, to shape the development of California's ZNE building codes by providing technical, engineering, and planning support, as well as electricity-usage monitoring. The pilot projects also help enhance the utilities' expertise, ensuring that the renewable energy and EE components work together to deliver ZNE-level performance to meet California's ZNE goals. SCE's ZNE projects have been mainly focused on single-family homes, residential communities, MF developments, school and community college buildings, and low-rise commercial ZNE, most of which are all listed on the SCE website. A "ZNE by the Numbers" video showcases several of SCE's efforts, including the Beechwood project (Figure 123). Figure 122 to Figure 126 show information posted on SCE's site.

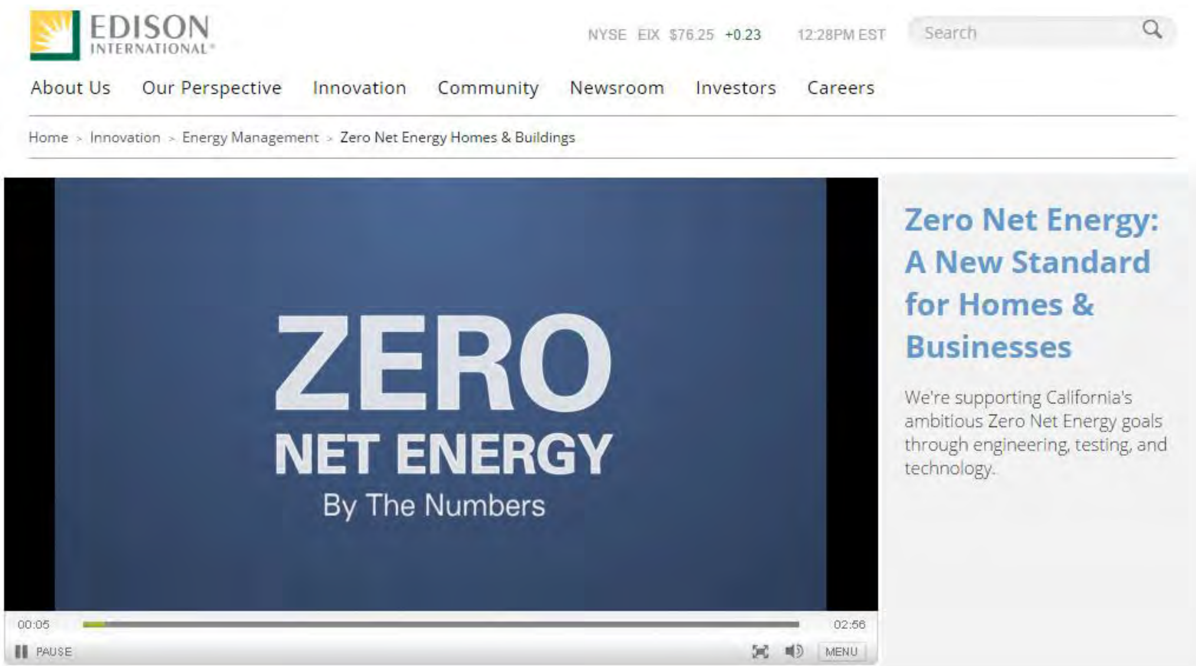


Figure 121: SCE.com ZNE Information

Figure 122**: SCE's** Description of the Beechwood Site

Figure 123: The Project Team Introduced by SCE

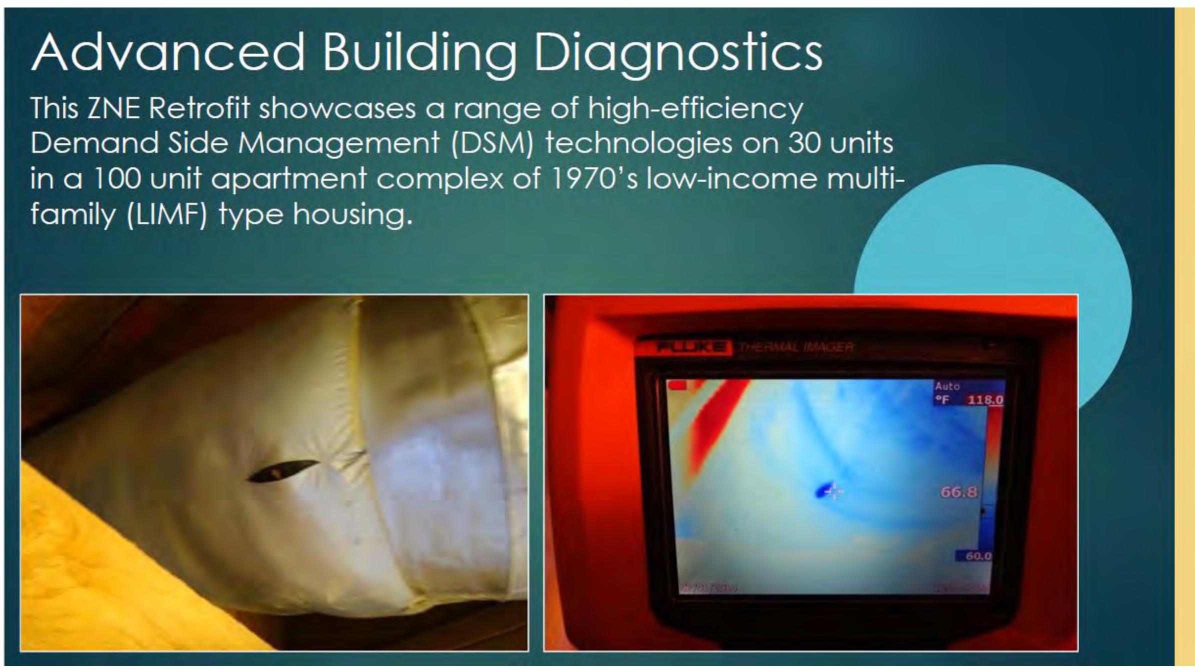


Figure 124**: Advanced Building Diagnostics Posted on SCE's Site**

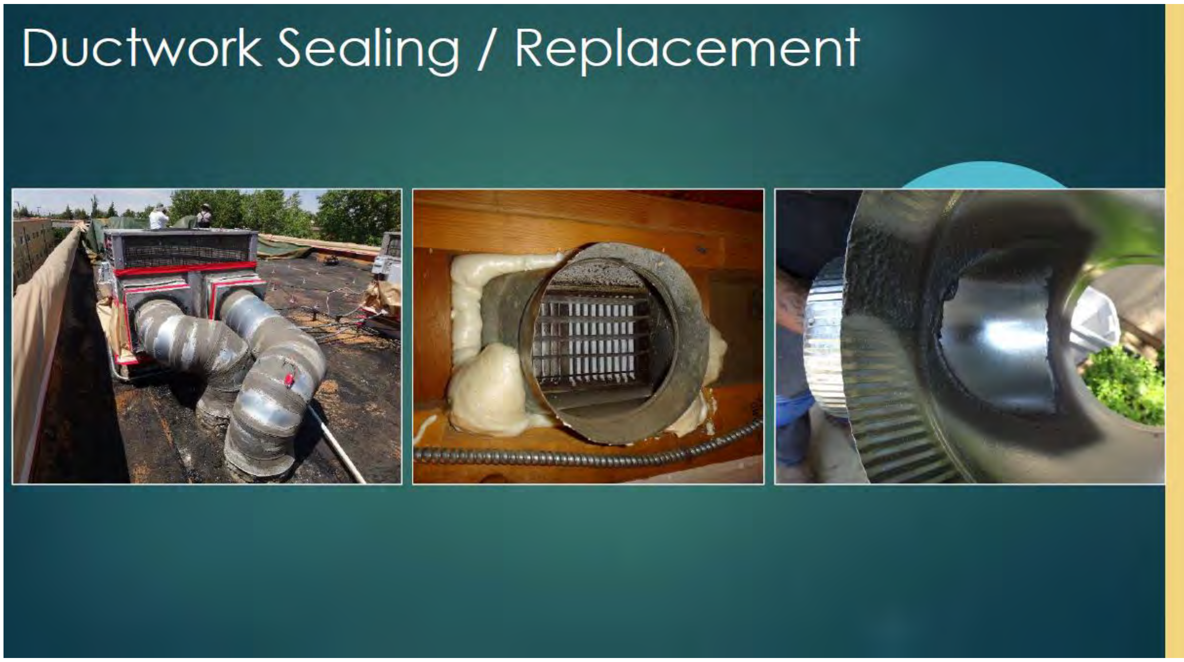


Figure 125: Ductwork **Sealing and Replacement Posted on SCE's Site**

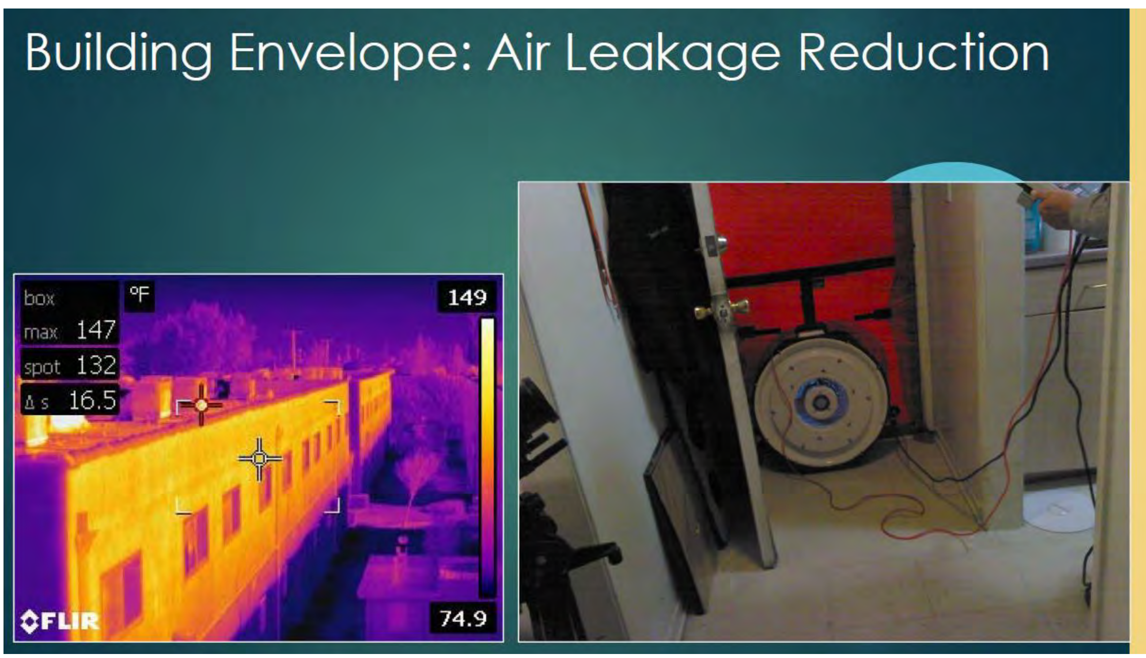


Figure 126**: Building Envelope Improvement Posted on SCE's Site**

10.5 BENEFITS TO CALIFORNIA RATEPAYERS

The project's energy benefits were in line with those estimated and proposed. The average electric energy use for the units in 2013 was about 22.5 kWh/day, and the net reduction from EE equates to 5 kWh/day/unit. Since California has about seven million apartment residents, the potential for electric energy savings equates to 12.75 GWh annually. The natural gas energy use reduction at the individual unit level was about 10%, and the water heating reduction was 58% at the community scale. For Beechwood as a whole, these benefits translate to a reduction of approximately 28% in gas usage, or about 14,400 therms annually (144 therms/unit). Scaling this to the state of California, the net potential for energy use reduction is one billion therms in MF properties alone. Combining the gas and electric benefits, the potential benefit for the state of California in terms of greenhouse gas (GHG) reduction is 6,200,000 metric tons of CO_2, primarily from the gas savings.

However, even beyond the energy and environmental benefits, there are substantial non-energy benefits that accrue to occupants and tenants of low-income communities. Quality-of-life improvements should be considered key benefits. In one example, a mother described how better indoor temperature and humidity control, through better insulation, could help with her daughter's nosebleeds. In another, an occupant indicated how his comfort was significantly improved by the measures and smart thermostats. And as part of the project, the job training provided for solar installation improved the morale and future job prospects of these families.

In summary, the team encourages consideration of both energy and non-energy benefits as part of future work on affordable income communities. The long-term benefits of this implementation include better health, cost savings, and economic opportunities for low-income tenants. It's essential to emphasize incentives for EE are also necessary, not just for tenants, but also for property owners who invest substantial effort in these measures.

CHAPTER 11: LESSONS LEARNED AND CONCLUSIONS

11.1 LESSONS LEARNED

1. Installation
    A. One of the most important lessons learned was that when a specialty contractor is chosen to perform the work, it is critical to the success of the project that the technicians have the full scope of work, in the order it needs to be performed. They also need to have the training to be able to understand the concepts, tools, and materials required to complete the tasks. It is not enough that the managers who bid the job understand the work and the nuances required to skillfully complete the job; this information must be passed on to the field crews. The fact that the field crews attempt to perform their work without having information critical to the successful implementation of their work is a recurring theme on many projects. This must be rectified, if projects requiring specialty skills and procedures are going to be successfully completed. This is particularly important with the less-understood and less-widely-practiced EE trades that work on existing buildings, retrofitting occupied buildings.
    B. Another item that can cost a project time and cost overruns is not having qualified construction management onsite at important project junctures. While construction work is underway, it is imperative that someone is onsite while all critical work is being performed. This person should know how work should be performed, and if it is not being performed correctly, have the authority to correct the situation, or at least document conditions and report the findings immediately. Examples of these critical times are when new phases of the work are being started, when multiple trades are onsite simultaneously, and especially when multiple trades have tasks that take place in and on the same building and may touch the same equipment or parts of the building and grounds.
    C. Perform a potential hazards survey as part of the initial site survey when considering a location for a project. Lead paint, asbestos, mold, and more can greatly increase costs. However, Beechwood is an example of real-world conditions that exist in many older buildings in dire need of energy upgrades.
    D. For buildings constructed prior to the early 1980's, be aware of asbestos. Abatement is very expensive and weighs heavily on cost effectiveness. Before initiating any kind of efficiency upgrade analyses, determine whether any asbestos is present, and if so, whether it can be avoided in the application of any upgrades, or if there are other ways to mitigate asbestos and costs of mitigation.

E. In the project planning process, budget for and include performing a pilot of the planned installations. Pilots provide opportunities to improve installation methods and may reveal options for improvements that were unanticipated.
F. Set up the project so that only small budget adjustments are allowed post-pilot. Set some small percentage of the total budget as the maximum allowed – if more than the fixed percentage is requested by the subcontractor, the property owner can opt to re-bid the main contract. If the contractor opts to re-bid, the job should be allowed to re-bid among other contractors. Make sure the contractor knows that re-bidding will open the project to re-bidding by all interested contractors.
G. Be mindful of potential opportunities for improvement made available by other upgrades. This is most important during pilots but could happen at earlier research phases or later construction stages.
H. Hire from the best, rather than the least-expensive contractors. The difference in quality will be more than made up by the improved energy savings from work done well, compared with work done adequately.
I. Monitor progress. Every contractor should be closely and carefully monitored by a knowledgeable party associated with the property owner. Almost every contractor needs to be monitored to maintain the quality of the work that they chose to bid. Also, don't let the contractor squeeze out of work they included in their bid. A knowledgeable subcontractor who performs quality work will bid the work properly in the first place (see previous lesson learned).

2. Simulations
    A. Verify a robust method.
    B. It is best if some of the final review time is done by a second modeler.
        i. Modeling is almost like big data, so it is highly error prone. At least one mistake per model is expected without a second eye to check the data.
3. Project Management
    A. Performing as much site work as possible simultaneously could reduce project overhead and contractor's bid prices, thus shortening the overall timeline of the project.
    B. Vampire load exists in induction cooktops.
    C. Heat pump heat strips can turn on at strange temperatures.
    D. Fiberglass UVA is delicate work, but absolutely can be done.
        i. It may be better than SPF, because it won't make noxious smoke if there is a catastrophic fire.
    E. It's hard to get a team that's used to 5 ACH50 to make 3.5 ACH50.
    F. Stay on top of the local city or county utility status changes. Lancaster switched away from SCE as the power provider part way through the project, causing billing issues for the tenants and headaches for management.

   G. Always give as much notice to the site manager as possible when scheduling work and site visits.
4. Economics
   A. People will pay for efficiency as a value-added feature.
5. Benefits
   A. When energy upgrades are performed on MF buildings, other non-energy benefits are realized as well. For example, indoor air quality can improve, tenant satisfaction can increase dramatically, and tenant turnover may decrease. Property values may increase.
6. Tech Transfer
   A. Additional effort is needed to educate tenants on how to use the smart thermostats. Very few tenants understand the capabilities of their thermostats, much less how to use them.
   B. Educate the maintenance crews about the upkeep of the various types of equipment.
   C. Educate the tenants (and all project participants), that ZNE does NOT mean there will be no utility bills.

11.2 CONCLUSIONS

Based on this research, it continues to be challenging to implement EE retrofits in existing low-income units to achieve a favorable return on investment without some rebates, incentives, or financial assistance. A LIMF owner is hard pressed to make the economic investment required for EE improvements without some additional financial help, especially for older MF units, which are more prone to have abatement issues such as asbestos, lead paint, or even mold. Mitigating these hazards adds significant cost to the retrofits, substantially increasing the payback period.

Due to the complexity of funding sources for EE measures, PV and related items, there is no single "one size fits all" scalable financial solution for funding these types of retrofit projects, though the team has identified that successful ZNE retrofits can be financed. If financing is not available in the amount needed to install a full package of measures, another option may be to fund a portion of the work, from which savings could support additional measures at a later time.

The measures chosen must make sense in several ways. The shortest return on investment is always a high priority. However, the most desirable measures would be those that not only save energy but add value to the occupants' lives, create more comfortable living spaces, and possibly add property and aesthetic value. Some measures can be included in a package that, when installed alone, wouldn't make much sense, but when installed together, are more effective – for example, by adding an air sealing measure to insulation, performance increases significantly.

LINC has followed up the project with a large-scale deployment of nearly 1.5 MW of solar through PPAs in six of their properties. Solar deployment will potentially reduce tenant energy bills; however, the lack of a financing model for EE prevents scaling EE measures similar to solar. Financial institutions, such as banks and third-party financiers, do not yet trust EE to consistently deliver returns over the long term. The team recommends future research initiatives focused on developing models substantiated by data that would increase the confidence of financial institutions in EE savings, and thus unlock the capital required for scaling near-ZNE retrofits in low-income housing.

APPENDIX A: EXAMPLE SCOPE OF WORK FOR VER MEASURE

SCOPE OF WORK: ENERGY EFFICIENCY UPGRADES FOR THE COMMON AREA COMMUNITY CENTER OF THE BEECHWOOD COMPLEX

Project and Technology Descriptions and Objectives -

The scope of work described herein is an EE retrofit of the common area in an LIMF building complex. This retrofit project is part of a research program to develop, install and evaluate packages of measures that can produce large, cost-effective efficiency gains in a LIMF environment. This set of efficiency improvements, or "package," has been developed for installation, monitoring, and evaluation at the Beechwood Community Center in Lancaster, CA. The package includes EE measures, solar thermal (hot water) and solar electric (PVs). A second component of this project is to identify, install, test/monitor, and evaluate new or under-utilized technologies or emerging technologies. A contractor, or set of contractors, is required to purchase and install the items and this document provides an overview of the project and a brief description of each technology. The description section is followed by a detailed scope of work (SOW) for installation of each item. That set of detailed SOWs should be the basis of the bid to do the prescribed installations. The emerging technologies to be installed include a method to use an inert aerosol to seal the leakage areas of the building, making the building more air-tight, efficient and comfortable. The aerosol space sealing technology has been developed by WCEC at UC Davis, and they will "install" that item. So, there is no detailed SOW for that component of this bidding document. The other emerging technologies include spray-foam roofing and duct insulation and sealant, economizer control, laundry-dryness dryer control, ozone generator and insertion into laundry washing machines to reduce or eliminate the need for detergents, "smart" electric extension-strips, catalyst demand-control ventilation systems and tankless water heaters.

The following is a brief description of each technology and the objective in installing and testing each technology. Following this descriptive section is the SOW for each individual technology:

Aerosol: The aerosol space-sealing technology has shown to seal leaks in building envelopes, both in laboratory tests, and, recently, in actual homes in the field. This will be the first field test of sealing a MF dwelling. The primary goal of this project is to test the practical effectiveness of the aerosol-based envelope sealing methodology in a MF building application and estimate the first-cost savings and heating/cooling load reductions to accrue from this type of sealing. The building sealing technology was developed by researchers at the UC Davis WCEC. Previous tests have shown a reduction of 50% in leakage areas. The researchers believe there is potential to further reduce building leakage areas. The technology uses a compressed nitrogen nozzle to aerosolize the liquid sealant and disperse the aerosol sealant under pressure into the house. The sealant will follow small air-streams that form in and around the leaks; however, the mass of the aerosol causes the particles to hit the edges of the leaks, at which point some of the particles will stick to the edge. Over time, a deposit of the aerosol particles builds up in and around the leaks, sealing them.

This aerosol sealant installation will be provided by WCEC and is not part of the SOW to be bid by other contractors. There is no corresponding reference to this technology in the next section. However, some coordination between this air-sealing technique and other technologies installed in this project may be required.

1) Reroofing using polyurethane spray-foam with an elastomeric coating: The roof and HVAC ducts exposed above the roof of the community center will both benefit from any reductions in air leakage and improvements in insulation levels. SPF can provide both air sealing and a layer of insulation. The objectives of installing this SPF on the common area building at The Villages at Beechwood are to evaluate the cost and efficacy of SPF for both the air sealing of the ducts and the building, provide an insulating layer on both the roof and the ducts exposed above the roof, and this task will focus on the issues that are unique to MF applications, specifically how to deal with the possibility of sealant traveling from one apartment to another, or being wasted through large penetrations to piping chases. Two primary objectives in this research of employing aerosol technology: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in the common area of the Beechwood complex, and 2) estimate the first-cost savings and heating/cooling load reductions expected to accrue from this type of sealing.

   SPF is formed when two liquid components are mixed at a 1:1 ratio inside a specialized spray gun, which generates tiny bubbles with isocyanates, polyols, catalysts and a non-ozone-depleting blowing agent when the mixture leaves the gun. The bubbles can expand 30 to 50 times larger than its original volume to insulate the roof. SPF is widely used for residential and commercial buildings with old and leaky flat or low-slope roofs. SPF offers high R-value that resists solar heat gains, long service life that should last the life of the house and only requires UV-resistant coating every 10 to 15 years. SPF is water resistant; water leakage only occurs if some foreign object penetrates the foam, producing a hole in the roof through which water can leak.
2) Catalyst demand control ventilation for rooftop air handlers: Catalyst is a packaged control system that converts Constant Air Volume (CAV) system to Variable Air Volume (VAV) system that yields energy savings in the range of 25% to 50%. The objective is to upgrade the existing system with a packaged system that already includes several components and sensors developed as an easy-to-install kit that provides demand-controlled ventilation and air-side economizing for energy and cost savings. The catalyst is controlled to provide maximum use of outside air for free cooling and assures proper ventilation based on the occupants in the room (by leveraging CO_2 sensors in the package). The product provides a reduced fan energy

reduction averaged at 69% and an improved air quality and quieter environment. The RTU's control and operation status are analyzed and translated into graphical information and reports for users to visualize through their phones or tablets that are connected to the internet.

3) Install Economizer retrofit kit on RTUs: An economizer can save substantial energy by introducing outside fresh air into the building when the outside temperature is at or below the inside setpoint. If no factory economizer retrofit kit can be found, the RTU's (4- and 2-ton), shall have custom economizers built and installed.
4) Smart power strips in the computer room: The common area is an ideal place to install smart power strips to save standby power consumptions, because the electric loads are constantly drawing current while idling, such as computer monitors, printers, TV and entertainment systems, etc. According to the U.S. DOE, about 5% of the electricity used in the United States goes to standby power. Smart power strips are a surge protector that turns off the peripheral items when the computer is off or goes to sleep mode, and these peripheral items are turned back on only when the "master" device is turned back on.
5) Tankless water heaters: Tankless water heaters use high-powered gas burners to quickly heat up water temperature as it runs through the heat exchanger, which saves standby energy that would have been lost in typical settings with water tanks for keeping the water warm, thus the heater is operated only when hot water is needed. Tankless water heaters can save up to 40% energy than traditional tank water heaters. The objective in this project is to investigate the efficiency of the tankless water heaters and investigate the energy and cost savings.

TASK DESCRIPTIONS

Task: Smart power strips in the computer room.

1) Step 1: Identify the appliances in the common area that should be controlled through the smart power strips (e.g., computers, printers, coffee makers, etc.), how many strips will be needed, and which device should be set as the "master" device. The peripheral items are shut off to cut standby power losses when the "master" device is turned off or goes into the sleep mode.
2) Step 2: Install the power strips with selected groups of devices. Monitor whether the power strips can turn off the peripheral items along with the "master" device.
3) Step 3: Report on work implemented and results.

Task: Tankless water heaters.

1) Step 1: Identify the equivalent Btu ratings of the tankless water heater that can replace the current three 100-gallon gas heaters.
2) Step 2: Install the tankless water heaters and develop methods to investigate the efficiency improvement (e.g., gas usage, run time, etc.).
3) Step 3: Investigate the energy usage reduction.
4) Step 4: Report on work implemented and results.

GENERAL CONDITIONS

Permits and Approvals: The sub-contractor(s) shall secure all necessary permits pertaining to their own SOW, and ensure the work is inspected and signed off by the local building and safety jurisdiction(s).

Commissioning (as appropriate): The sub- contractor(s) shall perform functionality checks on all equipment that the sub-contractors have installed on the project.

As-Builts: The General and the Sub-Contractors will provide the Project Team the As-Built drawings, construction notes and cut sheets for all equipment installed by the General Contractor (GC) and its sub-contractors. If no GC exists, the sub-contractors are obligated to provide As-Built drawings.

Clean-up: Each contractor will clean all areas (including all working areas and accessed area) daily to broom-clean standard or better when any work is performed. The contractors shall not leave any tools, equipment, or parts in any home or stored on site, accessible to the public. LINC Housing, Beechwood, EPRI (and their subcontractors) and SCE are not responsible or liable for any tools, equipment, or the like, misplaced or lost by contractors at the Beechwood site.

All contractors hired for the project will meet the following specific Service Requirements:

Compliance with regulations, codes and licenses: All work shall be done in accordance with all applicable federal, state, and local regulations, including California Code of Regulations, Title 24 Building Code, and CAL-OSHA, NEC, NFPA 70E. Only qualified sub-contractors s (licensed by the State of California in their appropriate fields) will perform the work. Each crew shall have at least one Journeyman level tradesman on the crew, at the jobsite at all times.

All work that requires a building permit shall be constructed in such a manner as to meet or exceed applicable building codes, and all such work will be approved (signed off) by the City of Lancaster Building Inspector.

Electrician

The electrical contractor shall determine the hazard/risk categories as defined by NFPA 70E and determine appropriate personal protective equipment to perform all electrical work and act accordingly.

Paint

All paint applied on the Beechwood project shall match the existing paint in sheen and quality with full coverage, one coat Primer, two coats paint, applied according to the Drywall Finishing Council's definition of Level 5 finish on a properly painted surface. These color and appearance requirements do not apply to the ducts or roof.

Plumbing (including SDHW)

All plumbing work shall be performed by Journeyman level workmen, using best industry-practices, meeting all applicable building and safety codes.

Plaster & Stucco

Will meet the requirements set forth in ASTM C 926, Standard Specification for Application of Portland Cement-Based Plaster and ASTM C 1063, Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster.

Roof Integrity

The contractor will maintain the weather-tight integrity of the existing roofs on the homes and community center that the retrofit work is being performed on. Any roof penetrations will be guaranteed not to leak in accordance with the Warranty provisions of this Agreement.

Heat Pump (HVAC)

Heat pump shall be sized and installed to meet CA HERS Standards and Air Conditioning Contractors of America's (ACCA) Standard 9.

HVAC Duct and Envelope Air-Sealing

Both envelope and duct leakage tests shall be performed according to CA HERS or BPI procedures. Duct and envelope leakage tests shall be performed both prior to any retrofit work on the building, as well as after the retrofit work is finished. The post-retrofit test results should show that the duct leakage and building envelope are substantially more air-tight (lower leakage rates) than pre-retrofit (the baseline test leakages).

DETAILED SCOPES OF WORK

Re-Roofing – General preparation of roof area

The entire roof of the Community Center

1. Verify that all roof penetrations and flashings are properly installed and secured. If any flashings are rusted through at any point, they shall be replaced. Verify that metal roof opening covers designated to receive polyurethane foam insulation are permanently secured.
2. Prepare surfaces using the specific methods recommended by the manufacturer for achieving the best result for the particular SPF substrate given the project conditions.
3. Provide masking protection as may be needed to prevent overspray of material on adjacent buildings and appurtenances, vehicles and portions of building not to be coated. Removal of all overspray as required. Mask building surfaces to terminate the foam and coating in a neat, straight line.
4. Clean surfaces thoroughly prior to installation.
5. Apply primer to all surfaces to receive foam of type and rate as recommended by the foam manufacturer.
6. Verify that existing edge metal is properly attached and secured, and that attachment is to a sound substrate. Any existing metal that is rusted through shall be replaced. Attachments must be in two rows staggered 3 inches (76 mm) on center.
7. Inspect all surfaces to receive spray foam insulation for structural soundness.
8. Remove and replace any wood nails, backing or other structural members that have lost their integrity.
9. Cut out and remove any wet substrate. Assure deck is properly cleaned, dried and primed prior to applying foam and coating.
10. Remove, raise or otherwise modify as necessary all existing roof-installed equipment to permit installation of roof system.
11. Mechanically attach all loose, slumping or otherwise deteriorated wall and penetration flashings with appropriate fasteners and plates.

12. Power broom, power wash and vacuum or otherwise remove all loose gravel, dirt, dust, oil, grease, etc. as may be necessary to create a strong bond between materials applied and existing roof.
13. Cover and protect all immovable objects and air intakes within area of spraying operations.
14. Verify that all roof drains and internal drain pipes are free of debris and draining properly prior to performing the re-roofing construction.
15. Drains should be at the correct elevation to match the specified height of the sprayed foam.
16. Mark all existing low areas where water ponds and areas with obviously poor drainage, in order to facilitate corrective procedures during roof system installation. Correct low areas by applying leveling foam of sufficient thickness in localized areas prior to applying the minimum specified foam thickness. There shall be no water ponding on the completed roof deck.

Surface Preparation - Metal HVAC Ducts

1. Clean exposed metal duct surfaces to be free of all rust, scale, dirt, grease, oil, chalking, paint or other contaminants.
2. Galvanized steel shall be primed using an acid wash primer.
3. Prime all metal with Bayblock Prime RI at the rate of 300 square feet per gallon.

Surface Preparation - Existing Built-up Roof

1. Power broom, power wash and vacuum or otherwise remove all loose gravel, dirt, dust, oil, grease, etc. as may be necessary to create a strong bond between materials applied and existing roof.
2. Exercise care in removing of gravel so as not to damage top layer of roofing felts. Do not allow large amounts of gravel to accumulate in any one location that might overload the roof deck structure.
3. Cut out all existing blisters, fish mouths, buckles, ridges, felt delamination, punctures and soft spots in an industry acceptable manner.
4. Repair membrane splits by removing the gravel and cleaning an area six inches wide on each side of split. Mechanically attach the membrane on each side of the split.
5. Inspect substrate thoroughly for moisture. If evidence of moisture is suspected, then special moisture detection method must be used to determine the exact locations of wet substrate. Wet substrate, if encountered, and other unsuitable materials shall be cut out, deck properly cleaned, dried and primed prior to applying foam and coating.
6. Mechanically attach all loose, slumping or otherwise deteriorated wall and penetration flashings in accordance with manufacturer's recommendations.
7. Prime all existing asphaltic substrates with Bayblock 100 at the rate of one gallon per 100 square feet.

SPRAY POLYURETHANE FOAM APPLICATION

1. Apply polyurethane foam in strict accordance with the manufacturer's specifications and application instructions.
2. Apply in a minimum of 1/2 inch (12.5 mm) thick passes and 1-1/2 inch (38 mm) maximum thick passes. Total thickness of the polyurethane foam shall be a minimum of 1 inch (25.4 mm), except where tapering is required to facilitate drainage.
3. Apply the full thickness of polyurethane foam in any area on the same day (3", R-17).
4. Applied to ensure proper drainage, resulting in no ponding water. Ponding water is generally defined as "an area of 100 square feet or more, which holds in excess of 1/2 inch (12.5 mm) of water as measured 24 hours after rainfall".
5. Terminate polyurethane foam neatly for a minimum of 4 inches (102 mm) above the finished roof surface at roof penetrations. Foamed-in-place cants shall be applied to allow a smooth transition from the horizontal to vertical surface and shall be applied prior to the application of additional foam lifts to achieve specified thickness. Mask building surfaces to terminate the foam and coating in a neat, straight line.
6. Finished polyurethane foam surface texture shall be "smooth to orange-peel", free of voids, pinholes and depressions. "Verge of popcorn" texture is acceptable if it can be thoroughly and completely coated. Popcorn and tree bark textures are not acceptable. Unacceptable foam textures must be removed and re-foamed prior to coating application.

APPLICATION OF ACRYLIC ELASTOMER ROOF COATING

1. Polyurethane foam surface shall be free of moisture, dust, dirt, debris and other contaminants that would impair the adhesion of the silicone coating.
2. If foam is exposed in excess of three days and additional foam thickness is necessary, or surface oxidation has occurred, the surface shall be primed before coats. Prime with Bayblock Prime NS primer applied at a rate of 200 square feet per gallon.
3. Spray and apply coating in accordance with the manufacturer's application instructions and precautions in the technical datasheet.
4. Apply acrylic elastomeric roof coating on the same day as the polyurethane foam application, and after the polyurethane foam has been allowed to cure a minimum of one hour. If the basecoat is not applied within 24 hours of polyurethane foam, remove and repair all signs of oxidation, or other damages as required by manufacturer.
5. If foam is exposed in excess of three days and additional foam thickness is necessary, or surface oxidation has occurred, surface shall be primed before coating with acrylic elastomeric roof coating. Prime with Bayblock Prime NS applied at a rate of 200 square feet per gallon.

6. Acrylic elastomeric coatings shall be applied in a minimum of three separate coats by spray or roller at the rate of 1-1/4 gallons per coat per 100 square feet.
7. Allow each coat to cure a minimum of 12 hours before proceeding with successive coats. Second and successive coats must be applied within 48 hours to ensure good adhesion. Allow top coat to cure a minimum of 72 hours without foot traffic.
8. Nominal thickness of the final dry film protective elastomeric acrylic coating system shall be an average 33 mils with a minimum of 28 mils.
9. Edges of the roof shall be pre-coated in a "picture framing" fashion so as to have at least one additional coat on the edges than the field of the roof.
10. Mask off metal and other surfaces not to receive coating.
11. All foam is to be coated. Coating shall be extended up and over all foam or vent pipes and terminate a minimum of 2 inches (51 mm) above the foam creating a self-terminating flashing.
12. Coat foam the same day of application, unless delayed by inclement climatic conditions.
13. Equipment Walkway Coatings: Roofing granules or a reinforced polyester mesh shall be installed around all mechanical equipment as indicated on the drawings. Install at least six feet around the perimeter as follows:
    A. Apply an additional coat of acrylic coating at the rate of 1-1/2 gallons per 100 square feet.
    B. Broadcast grade 11 roofing granules at a rate of 50 pounds per 100 square feet or lay down the reinforced polyester mesh while the coating is in a fluid condition.
    C. Seal granules or polyester mesh in by applying additional coating at the rate of 3/4 gallon per 100 square feet.

FIELD QUALITY CONTROL

1. Roof system manufacturer shall provide independent inspection firm to perform periodic follow-up inspections on the roof through a standard warranty inspection program at no expense to the contractor.
2. Any areas that do not meet the minimum standards for application as specified herein shall be corrected by the applicator. Manufacturer's inspection or verification shall not constitute acceptance of responsibility for any improper application of material.
3. Protect installed products until completion of project.
4. Touch-up, repair or replace damaged products before Substantial Completion.

Materials Definitions and Standards

The following materials are available through Bayer. Other manufacturer's products are acceptable, provided they meet or exceed the full list of properties of these Bayer materials. The full specifications of these listed materials are available from Bayer and are provided in the full document from which these sections were extracted.

<u>Bayblock</u> - A single component, water-based, general purpose primer for the preparation of most non-metallic surfaces for the application of elastomeric coatings and SPF. Suitable for built-up roofing, wood, concrete, SPF, aged asphaltic and other substrates.

Base Coat: Acrylic elastomeric coatings (e.g., Bayblock II Base) a technologically advanced, high-solids, fire retardant, thixotropic, acrylic latex coating uniquely formulated for the protection of sprayed-in place polyurethane foam insulation, stucco, concrete block, metal, single ply, and modified bituminous roofing. Acrylic latex coating shall have the following minimum properties.

Top Coat: e.g., Bayblock HT a technologically advanced, high-solid, alkali resistant, thixotropic, acrylic elastomeric coating uniquely formulated for the protection of sprayed-in place polyurethane foam, metal, polyurea, stucco, siding, and concrete.

SOW: Foam insulation Scope of Work[4].

[4] Extracted from protocol #075760 from Bayer Material Science

Scope of Work for Re-Roofing Using Polyurethane Spray Foam with an Elastomeric Coating

These installation procedures and protocols sections were extracted from a complete, but generic re-roofing protocol (#075760 from Bayer Material Science). Sections deemed pertinent were extracted, sometimes slightly altered, and compiled here to comprise the Scope of Work for retrofit-roofing of the building, and insulating and sealing the HVAC ducts on the roof of the community center building within Beechwood.

PROJECT CONDITIONS

A. Maintain environmental conditions (temperature, humidity, and ventilation) within limits recommended by manufacturer for optimum results. Do not install products under environmental conditions outside manufacturer's absolute limits.

B. Do not apply polyurethane foam or roof coating during periods of rain, snow, fog, and mist.

C. Do not apply the polyurethane foam when substrate or ambient air temperatures are below 50ºF (10ºC) or above 120ºF (49ºC), or when wind velocities exceed 15 mph. Do not apply polyurethane foam when the substrate surface temperature is less than 5ºF (minus 15ºC) above the ambient temperature.

D. Do not apply acrylic roof coatings at temperatures below 50ºF (10ºC) or when there is a possibility of temperatures falling below 32ºF (0ºC) within a 24-hour period.

E. Use windscreens during the application of the polyurethane foam and roof coating to prevent overspray onto surfaces not intended to receive foam and coating. Under no circumstances shall the polyurethane foam be applied when wind speeds exceed 15 mph.

DELIVERY, STORAGE, AND HANDLING

A. Store products in manufacturer's unopened packaging, clearly marked with the manufacturer's name, brand name, product identification, type of material, safety information, manufacture date, and lot numbers until ready for installation.

B. Store acrylic coating materials between 50ºF (18ºC) and 90ºFº (29ºC) with careful handling to prevent damage to products. If conditions exceed these ranges, special consideration in storage must be taken. Do not store at high temperatures in direct sunlight.

C. Protect all materials from exposure to moisture, overheating, freezing and other damage during transit, handling, storage, and installation.

Store and dispose of solvent-based materials, and materials used with solvent-based materials in accordance with requirements of local authorities having jurisdiction.

SAFETY REQUIREMENTS

A. Exercise care not to allow fumes from the polyurethane foam and coating materials to enter the building, using the following minimum precautions:

   a. Turn off all HVAC equipment and cover all intake vents and other potential sources of air entry into the building.

   b. Provide CO_2 or other dry chemical fire extinguishers to be available at the jobsite.

   c. Provide adequate ventilation for all work areas.

   d. Proper safety precautions shall be followed throughout the entire roofing operation. Conform to safety precautions of Spray Polyurethane Foam Alliance of the American Plastics Council's Recommendations for the Safe Handling and Use of Sprayed Urethane Foam and Coating Materials.

   e. Provide fire extinguishers and have them available on the roof and at all work sites at all times during roofing operations.

SOW: Smart power strips in the computer room and Beechwood offices.

Smart power strips (AKA "plug load timers"), will be installed to automatically turn equipment off when the equipment is not in use. The smart power strips will turn off equipment that has gone into low power mode while not in use. Note: The user will need to turn on the plug load timer switch in order to use any equipment connected to these strips.

SOW: Install Economizer retrofit kit on RTUs:

An economizer can save substantial energy by introducing outside fresh air into the building when the outside temperature is at or below the inside setpoint. If no factory economizer retrofit kit can be found, the RTU's (4- and 2-ton), shall have custom economizers built and installed.

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