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West Village Student Housing Phase I: Apartment Monitoring and Evaluation

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Alliance for Residential Building Innovation

June 2014

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Prepared for:

The National Renewable Energy Laboratory

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

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

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NREL Contract No. DE-AC36-08GO28308

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Prepared under Subcontract No. KNDJ-0-40340-03

June 2014

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Acknowledgments

Davis Energy Group would like to acknowledge the U.S. Department of Energy Building America program and their funding and support of development of this technical report as well as research that informed it. We would like to extend gratitude to the University of California, Davis and the developer West Village Community Partners for their ongoing cooperation throughout the design, construction, and monitoring stages of this project and their commitment to this project. In addition, we would like to acknowledge SunPower, Pacific Gas & Electric Company, Architectural Energy Corporation, and the Western Cooling Efficiency Center, for providing the team with data that was indispensable for this evaluation.

Definitions

ACH_{50}	Air changes per hour at 50 Pascals
ARBI	Alliance for Residential Building Innovation
DEG	Davis Energy Group
EEM	Energy efficiency measure
EER	Energy efficiency ratio
HERS	Home Energy Rating System
HPWH	Heat pump water heater
HSPF	Heating seasonal performance factor
HVAC	Heating, ventilation, and air conditioning
LCC	Life cycle cost
MEL	Miscellaneous electric load
PG&E	Pacific Gas & Electric
PV	Photovoltaic
RASS	Residential Appliance Saturation Study
SEER	Seasonal energy efficiency ratio
WVCP	West Village Community Partnership
VNM	Virtual net metering
ZNE	Zero net energy

Executive Summary

West Village, the largest planned zero net energy (ZNE) community in the United States, is a new neighborhood currently under construction on the University of California at Davis campus. The multiuse project combines energy efficiency measures (EEMs) and on-site renewable generation to target a community-level ZNE goal. The focus of this research conducted by the Alliance for Residential Building Innovation (ARBI) is on the 192 student apartments (16 buildings) that were completed in 2011 as part of the Phase I West Village multiyear build-out. The EEMs that are incorporated into these apartments, including increased wall and attic insulation, high performance windows, high efficiency heat pumps for heating and cooling, central heat pump water heaters (HPWHs), 100% high efficacy lighting, and ENERGY STAR® major appliances, contribute significantly to source energy reductions with an estimated 37% savings over the Building America Benchmark (Hendron et al. 2010) in hot-dry climates and 31%–39% Title-24 compliance savings. The implemented EEMs, and specifically the EEM package, have the potential to lead to market-ready solutions that cost-effectively provide comfort in multifamily buildings with efficient, safe, and durable operation.

The primary objective of this project is to evaluate the ability of the project to meet the Building America Project Management Milestone goals and the project's stated energy goals. This project presents an important opportunity to validate the cost effectiveness and performance of multifamily deep EEMs on a community scale. Utility billing data were used to compare measured versus modeled electricity use and to verify the accuracy of the modeling assumptions. This work seeks to address the following research questions:

1. How does measured energy use compare to modeled and were the expected energy savings achieved?
2. Was the the project able to achieve the stated energy goals?
3. How cost effective is this package of EEMs in a multifamly application?
4. What role do occupants have in high performance buildings and how well do tenants respond to energy education efforts by the developer?

Build-out of the community is ongoing, yet thus far the project has been a success, as demonstrated by the design and construction of buildings that incorporate cost-effective measures that reduce heating and cooling energy use significantly. Results have provided valuable insights and lessons learned into the largest planned ZNE community in the United States, which will be useful for builders, developers, researchers, and consultants alike.

Actual apartment energy consumption for the 16 Phase 1 buildings exceeds original model predictions by 18% over a 12-month period (March 2012 to February 2013). Average monthly apartment energy consumption profiles suggest that non-heating, ventilation and air conditioning (HVAC) use is likely the primary cause of the discrepancy. Electrical energy disaggregation indicated that for the predominant four-bedroom apartment type, modeled HVAC energy use over the 10-month period was overpredicted by 56%, while non-HVAC energy was underpredicted by 54%. This may be attributed to the "multiple household" effect, whereby student occupancy may tend to have more duplication of certain electronic devices (computers,

gaming stations, TVs, etc.) that would skew consumption away from what might be expected from more typical multifamily household assumptions.

As heating and cooling loads are driven down significantly with high performance homes, occupants may be the most influential variable in total home energy consumption, especially in milder climates. Measured non-HVAC base load at West Village averaged 85% of total apartment electricity over the 10-month period. As technology drives efficiency further, the impact of the occupant becomes increasingly important.

Annual energy use of the common area meters (serving the HPWH and building exterior lighting) was found to be 55% higher than projected. Half of the HPWHs were found to have ongoing issues resulting in excessive resistance heat operation, and it is theorized that improper initial commissioning due to lack of experience with the technology is the key issue. It is recommended that the installing contractor, either mechanical or plumbing with appropriate training, has sufficient experience with refrigerant systems.

It is clear that more in-depth and regular engagement with the tenants is necessary to ensure buy-in and participation from tenants on achieving the ZNE goals. Tenant education on basic energy efficiency strategies, creating a community energy and sustainability vision, and implementing and enforcing rules on excessive consumption (e.g., use of individual room refrigerators) are needed. Considering that this report summarizes the first full year of operation, we anticipate that West Village Community Partners and UC Davis will use the results of this initial evaluation to improve processes and quality control procedures to optimize community-wide performance. This may involve the addition of EEMs or photovoltaics where necessary, improved tracking and maintenance of energy-consuming components, and increased efforts to encourage and incentivize student participation in reducing energy use.

1 Introduction

1.1 Background and Motivation

West Village, the largest planned zero net energy (ZNE) community in the United States, is a new neighborhood currently under construction on the University of California at Davis campus. It's a multiuse project incorporating energy efficiency measures (EEMs) and on-site renewable generation to achieve community-level ZNE goals. It is designed to enable faculty, staff, and students to live near campus, take advantage of environmentally friendly transportation options, and participate fully in campus life. Sited on more than 200 acres, when complete the community will provide housing for almost 2,000 students, 343 homes for faculty and staff, a 10-acre recreation complex, and the first community college center on a university campus.

West Village began as a public-private partnership to develop much-needed housing for UC Davis students, faculty, and staff. Along the way, UC Davis and its development partner, West Village Community Partnership, LLC (WVCP), embraced the aspirational goal of making West Village a ZNE community. This decision was in part due to California's Energy Efficiency Strategic Plan (CPUC 2008) that all residential construction be ZNE by 2020 as well as the University's greenhouse gas reduction goals. Grants from the U.S. Department of Energy, California Energy Commission, and the California Public Utilities Commission supported design and development of this innovative ZNE community at West Village.

The focus of this research conducted by the Alliance for Residential Building Innovation (ARBI) is on the 192 student apartments that were completed in 2011 under Phase I of the West Village multiyear project. The EEMs that are incorporated into these apartments (see Table 2), including increased wall and attic insulation, high performance windows, high efficiency heat pumps for heating and cooling, central heat pump water heaters (HPWHs), 100% high efficacy lighting, and ENERGY STAR® major appliances, contribute significantly to source energy reductions with an estimated 37% savings (BEopt™ v1.1) over the Building America Benchmark in hot-dry climates. Title-24 compliance savings were 31%–39% depending on building and orientation. These EEMs, and specifically the EEM package, have the potential to lead to market-ready solutions that cost-effectively provide comfort in multifamily buildings with efficient, safe, and durable operation. These apartment buildings have also been certified Platinum under the Leadership in Energy and Environmental Design for Homes certification program.

The primary objective of this project is to evaluate the ability of the project to meet the Building America Project Management Milestone goals and the project's stated energy goals. This project presents an important opportunity to validate the cost effectiveness and performance of multifamily deep EEMs on a large scale, which has never before been done. Utility data are used to compare measured versus modeled electricity use and to verify the accuracy of the assumptions employed in the model. Incremental construction costs from the builder are used to evaluate cost effectiveness.

1.2 Research Questions

The primary research questions are the following:

1. How does measured energy use compare to modeled and were the expected energy savings achieved?

2. Was the the project able to achieve the stated energy goals?
3. How cost effective is this package of EEMs in a multifamly application?

Secondary research questions include the following:

4. What role do occupants have in high performance buildings and how well do tenants respond to energy education efforts by the developer?

2 Project Description

UC Davis' goal for West Village is to minimize the community's energy use and greenhouse gas production by reducing building energy use, providing on-site energy generation from a mix of renewable sources, and encouraging bicycle use and public transportation. Project goals were set by UC Davis in order to meet future campus and state greenhouse gas reduction and sustainability goals. Figure 1 shows the overall site plan for West Village with Phase 1 student housing outlined by the red line. Figure 2 and Figure 3 show the completed village square.

Nearly 10 years ago, Davis Energy Group (DEG) began coordinating with UC Davis to develop strategies for a highly efficient residential community to be built on UC Davis land. Results of previous work are summarized in the CARB's 2009 and 2010 Building America annual reports (CARB 2009, 2010), a report prepared for Chevron Energy Solutions (DEG 2010), an American Council for an Energy Efficient Economy paper (Dakin et al. 2010), and a 2012 ARBI Building America technical report focused on initial performance of the central HPWH as well as the overall construction quality assurance and quality control processes (Dakin et al. 2012).

Figure 1. West Village project site plan

Figure 2. Photograph of the completed village square surrounded by mixed-use and student housing buildings

(courtesy of University of California, Davis)[1]

Figure 3. Ramble A style apartment building showing exterior window sunshades, rooftop solar photovoltaics (PV), and high efficiency heat pumps

[1] West Village UC Davis (2011). *Apartment Living:* The new Viridian apartments overlooking the Village Square at UC Davis West Village. (Photo by Greg Urquiaga/UC Davis) [Web Photo]. Retrieved from http://westvillage.ucdavis.edu/image-gallery/20110914_west_village_7493.jpg/view on October 28th, 2011.

Construction of the first phase of student apartments began in 2010 and was completed in September 2011, in time for student arrival for fall quarter occupancy. This first phase consists of 16 three-story buildings, each with 12 units for a total of 192 units (see Table 1), and two similar building styles, Ramble A and Ramble B. In January 2011, the developer started taking reservations for leases on the student apartment buildings. By April, 80% of the units had leases reserved and by September when occupancy opened up nearly 100% of units were leased. Phase II consists of an additional 16 buildings of similar design that were completed for occupancy in September 2012. The final student housing phase, Phase III, was recently completed in time for fall 2013 occupancy. The scope of this report covers the performance of the 16 Phase I apartments only.

Table 1. Breakdown of Apartment Units for Phase I of the Student Apartment Ramble Buildings

	Conditioned Floor Area/Building (ft^2)	Bedroom	Number of Buildings	Total Number of Units
Ramble A	16,011	(6) 4-bedroom (6) 3-bedroom	13	156
Ramble B	14,202	(6) 4-bedroom (6) 2-bedroom	3	36
Total	–	–	16	192

2.1 Measure Details

Table 2 summarizes the EEMs incorporated in this project and their associated incremental costs. DEG and WVCP coordinated to develop incremental cost projections in 2009. These costs along with the projected energy savings were used to conduct economic evaluations and develop and optimize the EEM packages. The cost data provided were based on contractor bids and closely reflect actual costs.

Incremental costs for the EEMs for a Ramble A building (not including PV) were estimated at about $46,000 more than a building built to the regional builder standard (California's Title-24 energy efficiency standards, from here on referred to as Title-24) (CEC 2008). After factoring in Pacific Gas & Electric (PG&E) utility incentives for energy efficiency the incremental cost drops to just under $41,000. This equates to a net incremental cost of $3,380 per apartment or about $2.50/ft^2, not including PV systems.

Table 2. Student Housing EEM Package

Measure	Builder Standard (Title-24) Specification	West Village Specification	Incremental Cost Over Title-24/Building
Basic Building Characteristics			
Building Type/Stories	Multi Family, 3 stories		
# of Buildings and Units	16 buildings, 192 units		
Envelope Exterior Wall Construction and Insulation	2 × 6 16 in. o.c. R-19 Batt, Grade 3	2 × 6 16 in. o.c. R-21 batt w/1/2 in. R-3 exterior sheathing, grade 1	$5,418
Foundation Type and Insulation	Slab – Uninsulated		
Roofing Material and Color	Asphalt shingles Reflectivity = 0.20, Emissivity = 0.85	Cool Roof Rating Council-certified roofing product reflectivity = 0.25, emissivity = 0.85	$0
Ceiling Insulation	R-38	r-49 blown cellulose	$791
Radiant Barrier	Yes		
House Infiltration – Blower Door Test	No, 7.0 ACH50	Yes, 5.0 ACH50	$0
Thermal Mass	None	½-in. Gypcrete on floors 2 and 3	$2,031
Envelope HERS Verifications	None	Quality insulation installation + blower door test	$4,200[2]
Glass Properties: U-Value/SHGC			
All Windows	Dual vinyl – 0.40/0.40	Gilwin Dual Vinyl – 0.32/0.23	$2,949
Heating, Ventilation, and Air Conditioning (HVAC) Equipment			
Heating Type and Efficiency	Heat pump/7.7 HSPF	Heat pump/8.5 HSPF	$9,763
AC Type and Efficiency	Heat pump/SEER 13/EER 10	Heat pump/SEER 15/EER 12.5	
Distribution Type and Details	Ductwork, R-6 in attic	Ducted, R-6 in conditioned space on floors 1 and 2, attic on floor 3	
Verify Duct Leakage	Tested, <6%		$1,200

[2] $2,400 for QII and $1,800 for blower door.

Measure	Builder Standard (Title-24) Specification	West Village Specification	Incremental Cost Over Title-24/Building
HERS Verifications	Tight ducts <6%	Tight ducts <6%, refrigerant charge, high EER (12.5), Cooling coil airflow ≥350cfm/ton, fan Watt draw ≤0.58 W/cfm, Cooling right sizing (per Manual J and S)	
Water Heating Equipment			
Water Heater Type and Efficiency	Individual gas storage water heater, Energy factor = 0.57	Central A. O. Smith Heat Pump, coefficient of performance 2.9 @ 65oF.	$6003
HW Distribution		Recirculation, Timer + Temperature	
Appliances and Lighting			
ENERGY STAR Appliances	None, standard efficiency dishwasher, fridge, and clothes Washer	Dishwasher/fridge/washer	$6,000
Dryer Fuel	Electric		
Oven/Range Fuel	Electric		
Miscellaneous Load Control	None		
Fluorescent Lighting Package	~30%	100% w/vacancy controls	$12,840
		Total Incremental Cost	$45,792
		Utility Incentives	$5,229
		Net Incremental Cost	$40,563

[3] Cost savings include elimination of gas lines and venting

3 Methodology

The scope of this technical report focuses on the evaluation of total apartment energy use, total Phase I community energy use, and the ability to meet the project's stated energy goals.

3.1 General Technical Approach

ARBI worked with WVCP, SunPower and PG&E to obtain monthly utility data and generation data from the PV monitoring systems for each of the apartments. Measured energy consumption and PV generation are compared to energy estimates from modeling. Additionally, DEG is reporting on lessons learned from WVCP's perspective and future improvements to encourage engagement and further reduce energy use from West Village occupants.

3.2 Data Collection

To evaluate energy use and generation, DEG worked with WVCP and SunPower to obtain and evaluate monthly utility data and PV generation data from each of the apartments and common area meters. Measured energy consumption and PV generation were compared to energy estimates from modeling.

Energy data was collected from two sources: PG&E utility meter data[4] and SunPower's monitoring website.[5] SunPower monitors both total PV system production and total building energy consumption on a 5-minute interval basis. Originally, the analytical approach was to compare the consumption and production values, from SunPower's monitoring website, on an hourly basis to assess Phase I performance. Unfortunately, due to errors in the SunPower equipment, the reported consumption values from SunPower were inaccurate and therefore had to be eliminated from the datasets. The errors in the SunPower consumption data were discovered when comparing the monthly PG&E net consumption values to the difference of the SunPower consumption and generation values.

In place of the SunPower consumption data, a combination of SunPower production and PG&E net energy use was used to evaluate energy production, energy consumption and net energy on a monthly basis for each individual meter (192 apartments and 16 common area meters). PG&E utility data were provided as monthly net energy values. Daily SunPower production data was aggregated into monthly values corresponding to the PG&E billing periods for direct comparison. Energy consumption was then calculated as the difference between these two values according to the following equation.

$$\textit{Net Energy} = \textit{Energy Consumption} - \textit{Energy Production} \quad (1)$$

In this relationship, net energy is positive if the apartment unit or common meter consumed more than it produced and negative if it produced more than it consumed.

[4] The uncertainty of the net energy measurement is minimal provided the high accuracy of revenue-grade electricity meters. The meters used at West Village are General Electric's kV2c meter with a reported accuracy of ±0.2% for energy and demand.

[5] SunPower uses Continental Control System's Wattnode WNC-3Y-208-MB for PV energy production measurements with a reported accuracy of ±0.5% for energy.

The majority of data presented in this report represent the 10-month period between March 2012 and December 2012, over which the two data sources coincide (see Table 3). Unfortunately, the useful data ranges of available data for the two data streams did not seamlessly align. The PV systems were installed, permitted, and operational by November 2011, at which point PG&E switched over to a net energy meter. However, the SunPower monitoring meters came online sometime between February and June 2012. The majority of the meters were operational and accurately reporting PV production by March 1, 2012. For those SunPower meters that were not operational by this date,[6] the PV systems themselves were assumed to be operational. This assumption appeared to be valid after reviewing the net meter data for those units. For the systems without operational production meters, the generation data were extrapolated back to March 1, 2012, using production from PV systems with similar capacity and orientation and which had later PV production that aligned well. Once a SunPower meter was determined to be operating properly, any subsequent days with zero or missing production data were assumed to be instances where the PV system was actually nonoperational.[7]

Table 3. Valid Date Ranges for Collected Data

	PG&E – Net	SunPower – Production
Start Date	November 2011	March 2012
End Date	December 2012	January 2013

Annual consumption and production were estimated by further extrapolating PV production back through January 2012. Annual PV production was estimated by using the 11-month PV production data, as listed in Table 3, and the monthly fractions of annual production provided by NREL's PVWatts calculator,[8] which projects monthly system performance based on nominal size, location, orientation, etc. (February 2012 production was estimated to be 5% of annual production based on PVWatts). January 2013 production was used as a proxy for January 2012 production. Annual consumption was subsequently calculated for the January through December 2012 period using actual PG&E net data and the estimated annual production according to equation 1.

3.3 Data Evaluation

Data evaluation was conducted to compare energy consumption, energy production, and net energy for the following groups:

- Individual apartments
- Building common meter (central HPWH and building exterior lighting)
- By apartment type (two-, three-, and four-bedroom)

[6] 74 SunPower monitoring meters were not operational as of March 1, 2012. By May 1, 2012 all but five meters were operational.

[7] One exception to this assumption is when the reporting connection to the PV system is lost but the PV system is still generating; in this case, once the connection is regained, the PV system reports the aggregate generation across all of the days when the connection was lost. In these instances, the total generation value is accurate but needs to be dispensed across the previously lost days.

[8] http://www.nrel.gov/rredc/pvwatts/

- By building type (Ramble A and Ramble B)
- Phase I student housing community in its entirety.

Comparisons were also made to original eQUEST modeling estimates for each apartment type. Due to the limitations of BEopt with multifamily buildings, the BEopt software[9] was not appropriate to use for this evaluation. However, assumptions used in the eQUEST model largely followed the Building America Research Benchmark Definition (Hendron 2008) with the following differences.

- Cooling thermostat set point of 78°F
- Heating thermostat set point of 70°F
- A multiplier of 0.58 (42% reduction)[10] applied to miscellaneous electric load (MEL) usage to better align annual consumption with multifamily MEL usage presented in the 2009 Residential Appliance Saturation Study (RASS) (KEMA 2009)
- Altered vacation schedules as follows:
    - Winter break – 2-week holiday break in January
        - Assumes no occupancy
        - 20% lighting levels
        - 67% MELs
        - Weighted average heating thermostat setback temperature of 65°F
    - Spring break – 1 week in early April
        - Assumes 50% occupancy
        - 50% lighting levels
        - 78% MELs
        - Weighted average thermostat setback of 82°F cooling and 65°F Heating
    - Summer break – 2 months in summer (July/August)
        - Assumes 50% occupancy
        - 50% lighting levels
        - 78% MELs
        - Weighted average cooling thermostat setback temperature of 82°F.

The eQUEST energy model was re-evaluated using and Actual Meteorological Year (AMY) weather file from the Sacramento Metropolitan Airport (KSMF) National Oceanic and

[9] BEopt v1.1 was used to evaluate a single four-bedroom apartment unit to provide estimated Benchmark savings of 37% as stated previously.
[10] During the original design Building America used state specific multipliers, which for California was 0.77. The additional reduction corresponds to a 25% decrease beyond the 23% attributed by the state multiplier.

Atmospheric Administration weather station. These results were used for comparison to actual energy consumption.

Apartment Energy Usage Disaggregation

Initially, DEG planned on disaggregating heating and cooling energy use from the base loads using SunPower hourly energy consumption. Since these data were unavailable, ARBI was left with only monthly energy consumption to use as a basis for disaggregation.

Monthly electricity usage for each apartment was disaggregated into two main categories: base load and space conditioning. The Ramble student apartments are all-electric and use heat pumps for both space heating and cooling; therefore, the process was simplified to evaluating a single fuel only. The HPWHs are centrally metered and not considered in this disaggregation. The base loads for a given residence were estimated from the "shoulder" seasons, which are times during spring and fall that have little or no space conditioning. These seasons are necessary to disaggregate the base load end uses from the temperature or seasonally dependent HVAC end uses. Average energy use during the spring shoulder season (March–May) was used as the monthly base load for each unit. Monthly multipliers for lighting energy from the Building America House Simulation Protocols (Hendron et al. 2010) were applied to this base load to estimate the seasonality of the use of interior lights. The difference between the monthly adjusted base load and the average total apartment energy use was then taken as heat pump energy consumption. The cooling season was assumed to be April through September with the remaining months in the heating season. Averages across the Phase I population were taken to estimate average disaggregated energy use for each of the three unit types (two-bedroom, three-bedroom, four-bedroom apartment) and are presented in the results.

3.4 Cost Effectiveness

An economic analysis of the EEM package was completed to evaluate and compare the life cycle costs (LCCs) for the Title-24 builder standard base case and the proposed ZNE package using various financing scenarios. The evaluation terms are presented in Table 4. First year utility costs were estimated using current year (2013) PG&E's rates for the Davis region. Replacement costs were assigned for lighting, the heat pump, and the HPWH. Any scenario was considered to be cost effectiveness given the evaluation terms if its LCC was less than that of the base case. PV cost effectiveness was not evaluated in this report.

Table 4. Evaluation Terms for Life Cycle Costing

Evaluation Period	Real Discount Rate[11]	Fuel Escalation Rate	Financing Interest Rate
20 Years	3%[12]	3%[13]	5%

[11] A real discount rate is the discount rate which factors in the effects of inflation.
[12] 3% is taken from the DOE 2010 real discount rate (U.S. Department of Commerce 2010).
[13] Fuel escalation rates are very uncertain, 3% is an estimate only.

4 Results

4.1 Occupant Behavior

General feedback from WVCP after this first year of occupancy is positive. Student housing retention from year 1 to year 2 has been relatively high at around 40%. While WVCP has continued to market the energy and sustainability components and occupants generally appear excited about these features, there is no evidence that they factor into the renters' decision process. This appearance of excitement does not necessarily translate into engaged occupants, especially since they do not pay for their energy use and do not have access to information about how much energy they use. Residents do have the ability to access an online SunPower account that provides hourly electricity consumption and PV production, but the SunPower consumption data are not valid and is of little value to occupants. SunPower and WVCP held three training sessions throughout the past year on how to access and interpret the data available from the website. Around 75–100 residents attended these sessions. Instructions for creating an account were left in every apartment at the beginning of each lease. As of December 2012, only 27 residents have established accounts (this includes students from both Phase I and Phase II).

WVCP continues development of a methodology for holding residents responsible for exceeding monthly utility usage targets, since excess use has direct cost implications for WVCP. Energy modeling conducted by DEG was revised to evaluate the expected monthly apartment electricity consumption by apartment type (number of bedrooms) using the worst orientation and after removing any vacation schedules. Originally, WVCP's plan was to monitor and notify residents after any month they had surpassed the consumption allotments. After the second notification, a fee would be assessed to the apartment occupants. Due to difficulty in processing monthly apartment consumption data, they have not yet begun sending these notifications. Each apartment unit is metered individually, resulting in 13 bills per building (12 apartments plus the common meter). This situation creates the laborious task for WVCP of reviewing and analyzing each utility bill singularly. Additionally, current utility regulations limit the ability of property managers to charge fees to tenants for utilities. In California, the only utility they are allowed to charge for is cold water consumption. However, the amount they can charge for cold water use is potentially very minimal and it costs WVCP to read each cold water meter. On other properties where they have implemented a similar methodology and charged for cold water usage, the cost to read and assess the charges was greater than the income from the charges. Currently at West Village there is a cold water meter at each apartment, but they are not reading any of them.

While this strategy involves penalizing occupants for excess use, WVCP is alternatively considering adoption of a program that incentivizes residents for achieving low energy use below the predefined threshold. Further evaluation of which strategies will be most successful, from a cost-effective, motivational, and legal standpoint, is ongoing.

The apartments were initially designed to include a central energy consumption display and smart power strips in each bedroom that could be programmed and controlled remotely. The devices, developed by GreenWave,[14] were to be installed in each of the apartments to provide a means of reducing plug load energy use. Due to conflicts with the wireless communication between this device and the installed Internet infrastructure, these products were removed from

[14] http://www.greenwavereality.com/solutions/

the apartments before they were fully functional early in 2011 and will likely not be reinstalled. This feature was an advertised component to students for the 2011–2012 leasing year and residents were excited about it since it may have resonated with how they typically access and control information in a digital manner. While WVCP is not actively researching other products, WVCP is still interested in incorporating such a service in current or future phases of the project.

Since build-out of the West Village community continues, the WVCP team has been focused on leasing activities and ensuring all buildings and systems are operational, and has not had the opportunity to focus as much as it would like on tenant engagement. However, the current WVCP team is enthusiastic about expanding educational activities and increasing resident engagement in order to explain the occupant’s role in a high performance building and better translate the community vision.

Several proposed ideas include a monthly educational series and community-level competitions for energy use reductions. In late 2012, there was a pilot competition underway in which WVCP and Architectural Energy Corporation are monitoring electricity by major end-use in 24 apartments scattered throughout the Phase I and II community (Risko 2012) . Twelve of the units were part of a control and the other 12 were given feedback on their energy use, in the hopes of educating residents and encouraging behavioral changes that will reduce their energy use. These residents were provided with a list of tips and sent regular updates on their current usage, how they were performing in relation to others in the competition, and personalized advice for how to quickly bring their consumption down. WVCP reports that participants appeared to be very receptive to feedback. Architectural Energy Corporation is expanding this monitoring effort to 120 additional apartments that will continue through the end of 2014. Another behavioral evaluation underway is with the UC Davis Western Cooling Efficiency Center and Toyota. They recruited 50 individual occupants in 50 separate apartments to participate and have provided all of them with three specific energy-saving behaviors including hang drying clothes, turn off computers at night, and reduce showering time. Half of these participants are provided with an in-house “button,” which they are instructed to push each time they perform one of these energy-saving acts. The device provides verbal positive feedback to the participants and records the activity. This evaluation continued for 2 months.

4.2 Apartment Building Energy Use

The Phase I Ramble buildings consist of 12 apartments each, composed of two-, three-, and four-bedroom units. Aside from the apartment units, each building has a single common meter on which the central HPWH and exterior lighting are connected.

Apartment Unit Energy Use

Average apartment consumption (no domestic hot water use) by unit type (number of bedrooms) is compared to eQUEST modeling estimates (using Annual Meteorological Year weather data) in Figure 4. Average actual consumption over a 12-month period exceeded projected use by 23% for both the three-and four-bedroom units, while the two-bedroom units indicated 4% lower than projected usage.

The monitored monthly use profiles follow a similar trend seasonally with the exception of the two-bedroom apartments that demonstrate a pronounced dip in energy use from May through September 2012, which would seem to indicate lower average summer occupancy. With two occupants there is a greater chance that both occupants will be gone over the summer compared to apartments with three or four occupants. On average, the three-bedroom and four-bedroom apartments appear to be fully or partially occupied during the summer. The load reductions that were predicted in the model based on expected vacancy during the summer months are not observed in the data.

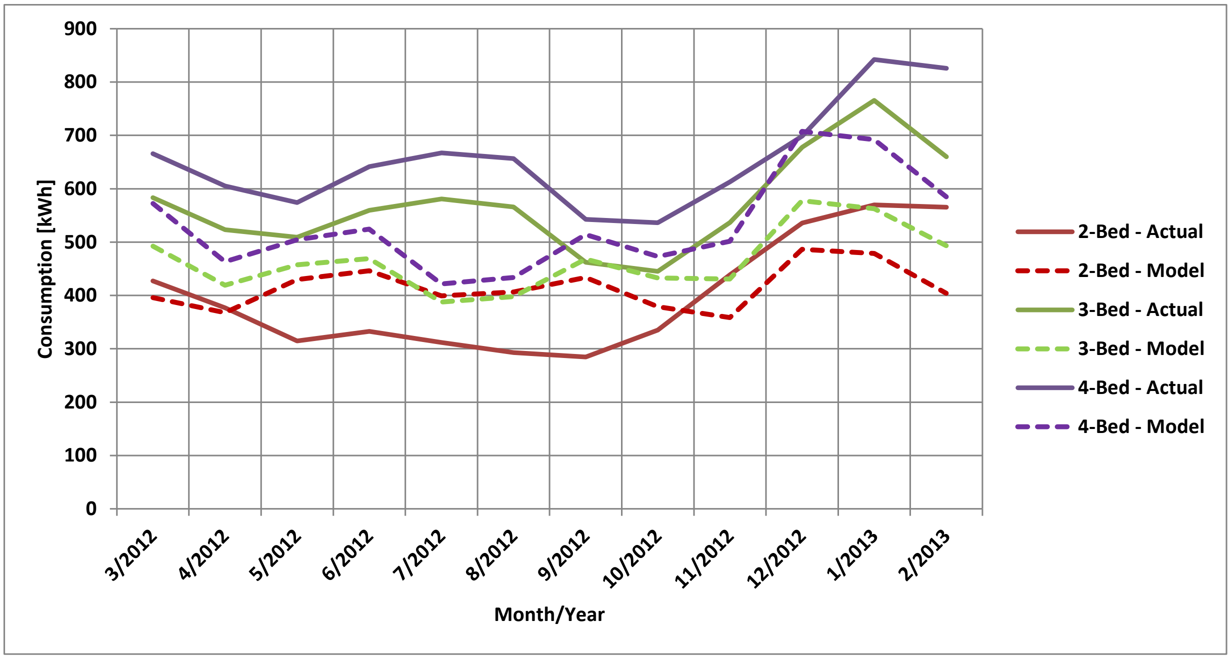

Figure 4. Modeled and actual average monthly consumption values for each apartment type (by number of bedrooms)

Figure 5 presents a histogram comparing the ratio of "actual-to-modeled" 10-month energy consumption for each of the 192 apartments (modeled use shown as black bar at 100%). There is a wide variation in annual consumption with roughly a 4:1 ratio between high and low usage apartments. Roughly half of the apartment units have consumption values within 25% of modeled predictions and about 85% of the three- and four-bedroom apartments consume more energy than what was predicted. Only 39% of the two-bedroom apartments consume more energy than predicted. Figure 11 through Figure 13, in the Appendix, are additional graphs that show this comparison by apartment type.

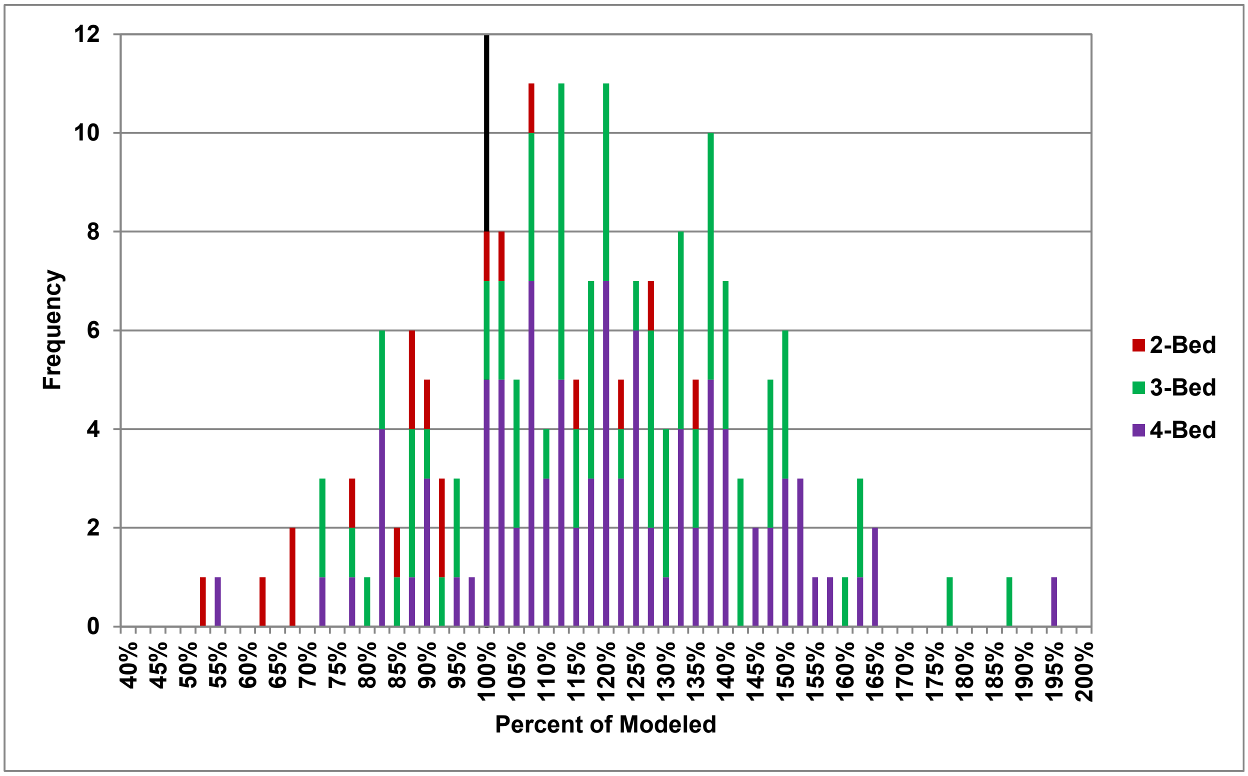

Figure 5. Histogram showing individual apartment energy consumption variation

Heating and cooling energy use was disaggregated from all other energy (lighting, appliances, and plug loads). This is shown in Figure 6 for the average four-bedroom apartment (see the Appendix for the results for all apartment types). The 12-month heating and cooling energy use is 54% lower than projected values, but the base load energy use is 54% higher than projected values (green dotted lines) and total energy use for the average four-bedroom apartment is 23% higher than projected values. Space conditioning may be lower due to some combination of occupants using less aggressive thermostat set points than assumed (78°F in cooling and 70°F in heating), occupants relying on the ceiling fans during the summer, and the apartments performing better than expected thermally. One hypothesis for the high base load consumption is the "multiple household" effect, whereby student occupancy tends to have more duplication of certain electronic devices (computers, gaming stations, TVs, etc.) that would skew consumption away from what might be expected from the more typical multifamily household usage represented in the California RASS data. Entertainment and computing devices may likely be located in each bedroom instead of shared in the living area. While lighting may also be a contributing factor, it is theorized that it is less so than plug loads because of vacancy sensors installed throughout the apartments.

In order to compare actual non-HVAC energy use with current Building America assumptions, the original model was revised to use the MEL assumptions in the current House Simulation Protocols (Hendron et al. 2010). In addition to ARBI's 25% reduction to better align total MEL energy use with California RASS data, the California state multiplier of 0.77 was also removed, since this has been eliminated in the most current version of the House Simulation Protocols to keep assumptions consistent nationwide.[15] The four-bedroom apartments were selected for this comparison because they exhibited the most pronounced difference in base load consumption, and based off the conclusions of the "multiple household" effect, they would most likely have the greatest duplication of MELs. With this change, actual base load energy consumption is within 24% of modeled values, as shown in Figure 6 (gray dotted line). Although not shown in the graphic, if the vacation assumptions are also removed from the modeling estimates, actual base load energy consumption becomes only 17% greater than this revised modeling estimate.

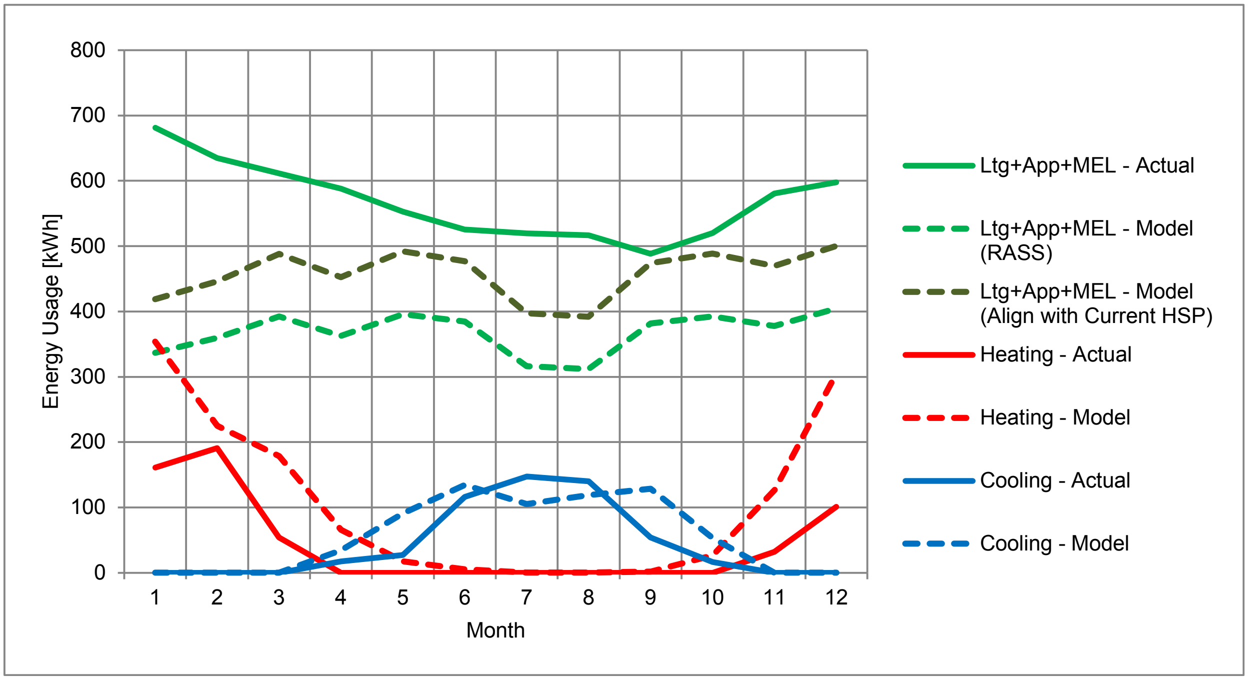

Figure 6. Average disaggregated energy use over 12 months (March 2012 to February 2013) for the four-bedroom apartments[16]

Domestic Hot Water and Common Meter Energy

Figure 7 compares modeling estimates for common meter energy consumption with actual consumption. Values for 14 common meters are averaged in the solid red line.[17] Actual consumption is much higher than original predictions. Seasonal variations in the water heating load are also more pronounced than estimated.

The water heaters are set up to operate primarily in heat pump mode and use minimal electric resistance heating for backup during times of high load or low outdoor air temperatures. There

[15] Note that this was a post-process alteration and therefore the change in MEL load did not affect space conditioning energy use.

[16] Disaggregation results are estimates only and are not based on submetering. Preliminary results from a parallel monitoring project that includes end-use submetering indicate that total HVAC may be higher than is estimated here and is primarily a result of system fans being operated continuously. Fan energy use not associated with heating and cooling operation will show up as base load energy in this disaggregation process, not heating and cooling energy.

[17] One building meter is not shown here because it supports a large site lighting load that cannot be separated from the common meter energy use. Another had unreliable or missing data for a portion of the year.

have been ongoing issues with heat pump operation, resulting in excessive resistance heat operation and consequently high electricity use. It is hypothesized that this is the primary result of the high energy consumption; however, it is possible that there are higher than estimated recovery loads. Further investigation is needed to better qualify the high energy use.

ARBI has installed detailed monitoring on one of the HPWH systems (ARBI 2013), which has provided performance data and helped identify potential operating problems. Monitoring has shown that when commissioned correctly system efficiencies track relatively well with manufacturer engineering performance data. Without proper feedback it has proved difficult to identify operational problems, which has led to systems running in electric resistance mode for long periods before the issue is recognized.

The Phase I heat pumps were installed by plumbers with no previous experience with HPWHs. After ARBI completed the installation of monitoring equipment in September 2011, it was quickly identified that the systems were not properly commissioned or operating correctly and were operating exclusively in electric resistance mode. Over the first year of operation, there have been several instances of heat pump operational issues, and several of the systems appear to be having more problems than others, resulting in high energy use. The water heaters installed in later phases have been installed and commissioned by mechanical contractors who may be more suited to install such systems given their experience with heat pumps. These systems do not appear to have the operational problems evident in Phase I and the installation/commissioning issues have not been present now that the installers are more familiar with the heat pumps.

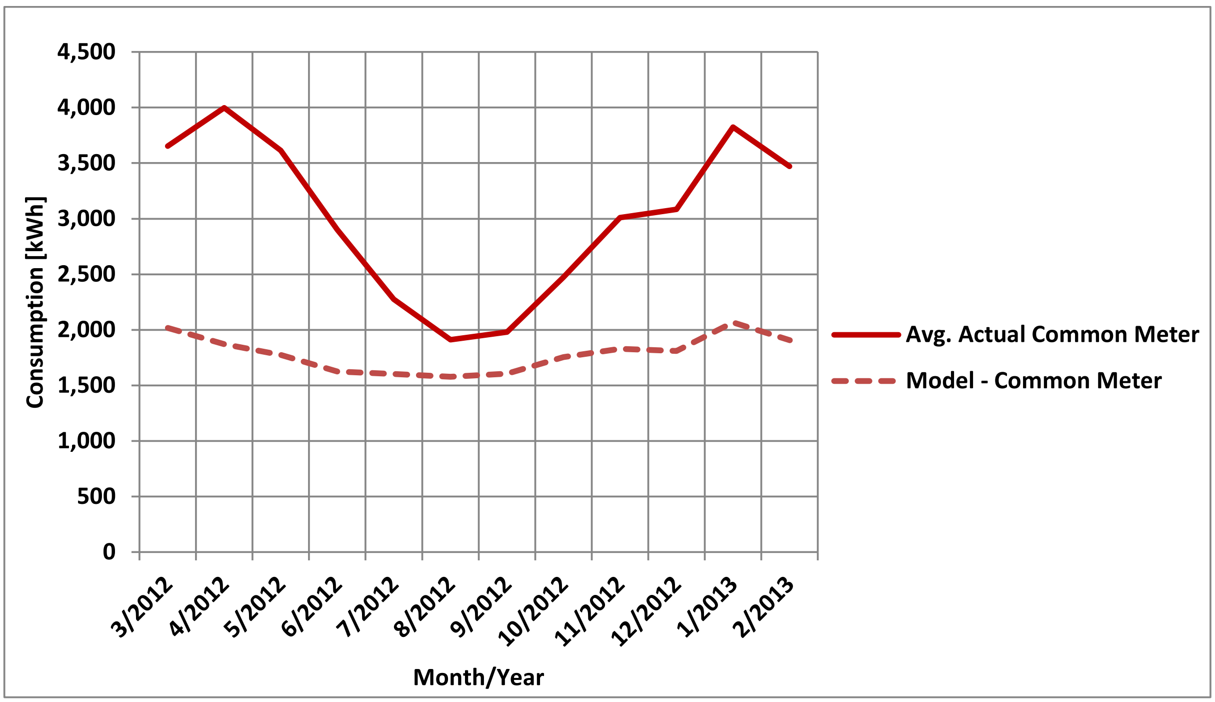

Figure 7. Monthly average common meter use compared to modeled (15 buildings)

Figure 8 shows the variation in common meter energy consumption across the 14 buildings. Only four of the buildings are operating within a reasonable range from the expected value (within 25%), with 10 buildings 34%–216% higher than modeling estimates predicted.

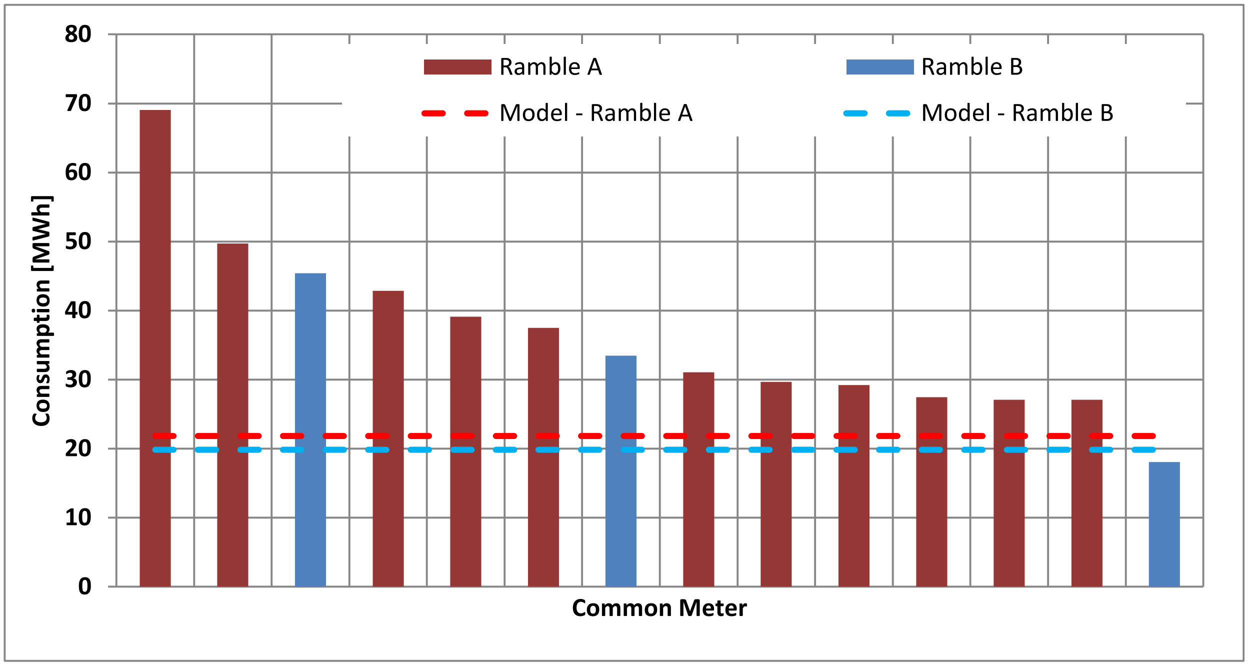

Figure 8. Actual common meter energy consumption for 14 buildings over 12 months (March 2012 to February 2013)

4.3 Phase I Zero Net Energy Evaluation

The first year's performance in regards to achieving project ZNE goals for the Phase I community was completed using monthly utility net meter and SunPower PV production data. This is a preliminary evaluation because the ZNE goals have been set for the entire community, which is still being built out. Because of the operational and installation issues with the HPWHs resulting in high energy use, energy usage for the common meters was separated out from the apartment meters.

Table 5 and Figure 9 show overall PV production is 4% greater than projected, suggesting good alignment with the SunPower model.[18] On the consumption side, apartment usage is 18% higher than projected, while common area usage is 55% higher than the original estimates. Overall, combined consumption is 28% higher than projected.

[18] In comparing monthly measured PV generation to theoretical generation estimated by NREL PVWatts, the two values correlated well for most of the months. However, in the period of July through October there is a fairly strong divergence as the actual generation data falls much more rapidly than the projected data. It is hypothesized that this is due to dust accumulation and hotter PV operating temperatures, which would be removed after the first significant rain of the season. Increased production might be realized if regular panel array cleaning is conducted during the summer. SunPower includes an assumption for reduced performance due to dirt accumulation in its annual projections.

Table 5. Projected and Actual Production, Consumption, and Net Energy Values

	Production (MWh)			Consumption (MWh)			*Net Energy (MWh)*
	Projected	Actual	% Diff	Projected	Actual	% Diff	*Actual*
Apartments	1,024	1,110	8%	1,163	1,377	18%	*267.3*
Common Meter	471	451	-4%	390	602	55%	*151.1*
Total	**1,495**	1,561	4%	**1,552**	1,979	28%	***418.4***

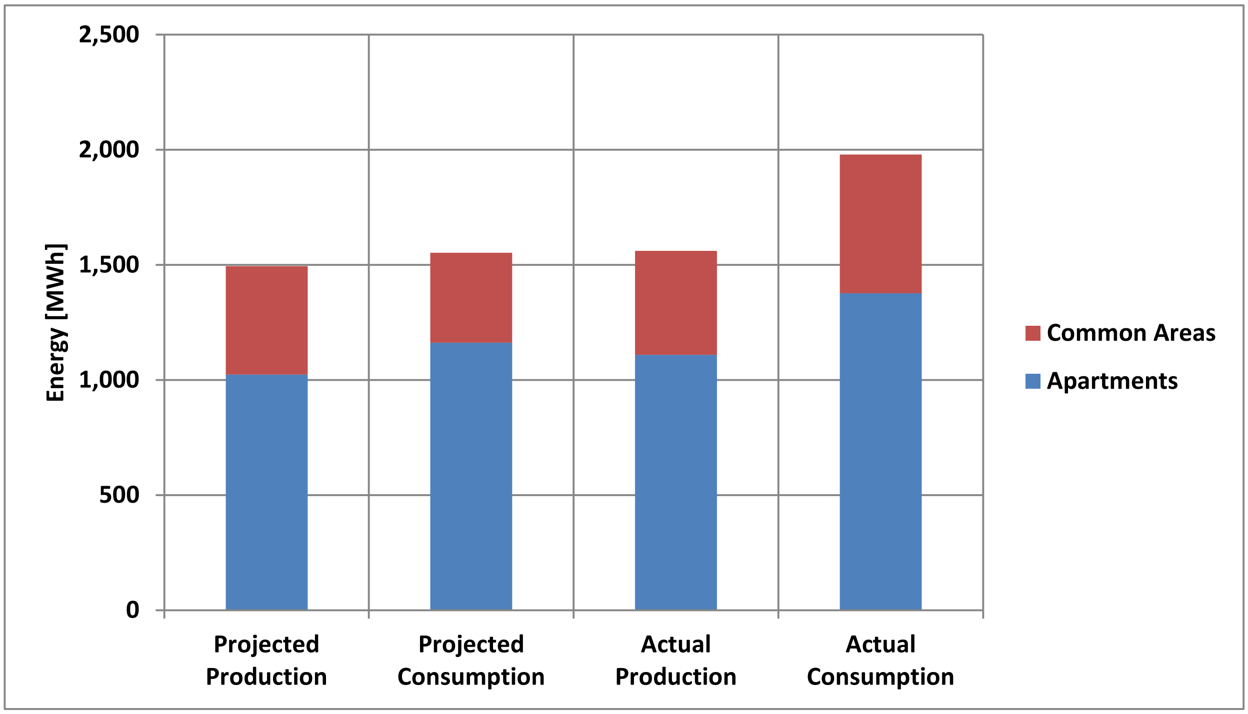

Figure 9. Comparison of annual Phase I consumption and production

Figure 10 presents monthly net, production, and consumption values over the entire Phase I community for the 12-month evaluation period. The net values are negative when production surpasses consumption and positive when consumption is greater than production. The community is a net producer for 3 months out of the year (May through July) with three months in the shoulder season (April, August, and September) when consumption roughly equals production. The magnitude of the summer net production is not large enough to offset the winter effect when consumption rises and PV production falls.

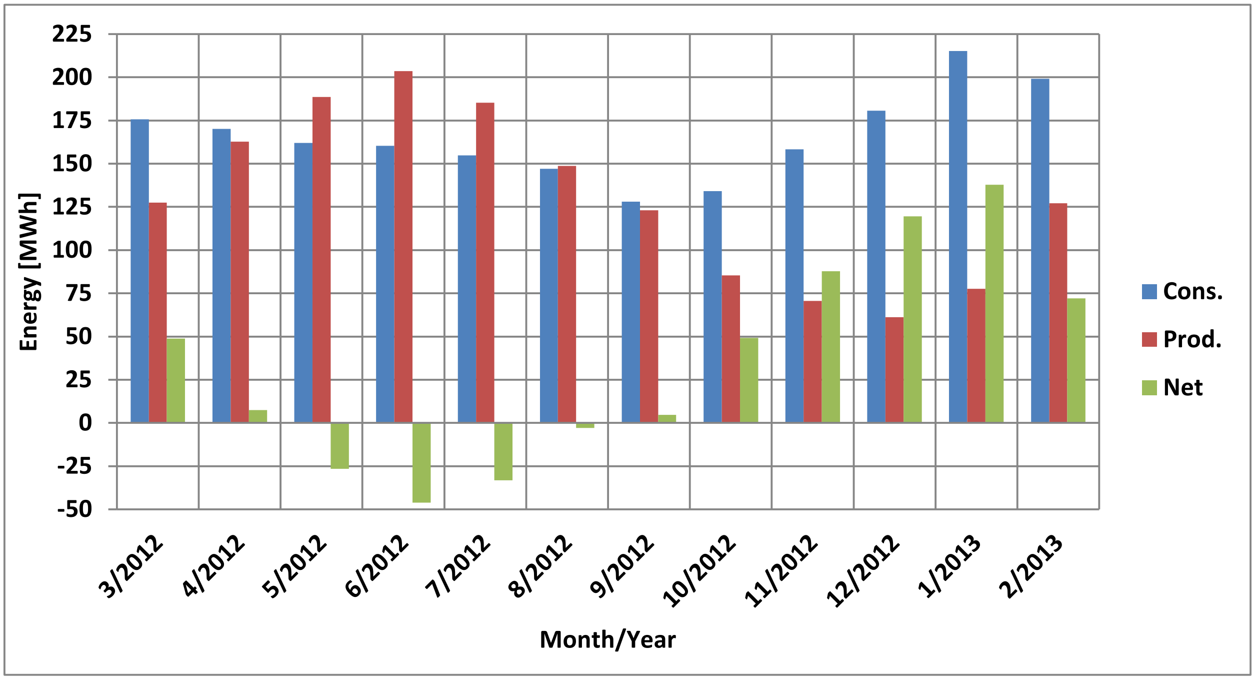

Figure 10. Total consumption, production, and net values for all Phase I buildings

4.4 Cost Effectiveness

An economic analysis of the package of EEMs was completed to evaluate cost effectiveness. There are no split incentives in this project since the developer investing the dollars in energy efficiency is also the utility bill owner. However, projects where tenants pay utility bills are presented with a unique set of challenges in justifying the investment to the developer.

Based on the results of energy data disaggregation, actual HVAC energy consumption appears to be lower than original estimates. It is also expected that once the operational issues are resolved on the HPWHs that system performance should be consistent with expectations. Actual domestic hot water recovery loads may be higher than estimated; however, higher draws would impact both the base case and improved cases. Provided that the majority of EEMs affect space conditioning and domestic hot water energy use, it was concluded that original model results can be used with some confidence to conduct a cost effectiveness evaluation. While high efficacy lighting and ENERGY STAR appliances were components of the EEM package, there are not sufficient data to separate these end uses from the total base load. The presence of vacancy sensors in each major space in the apartments reduces the impact of occupant behavior on total lighting hours and increases likelihood that lighting savings will be realized. The assumption upon which this cost evaluation is contingent is that the high base load seen in the above graphs is primarily due to increased plug loads.

Table 6 demonstrates the key inputs to the LCC evaluation that was conducted over a 20-year period. First-time costs and savings were calculated for a single Ramble A 12-unit building.

Results of the analysis are presented in Table 7. Four financing scenarios were evaluated. If the builder has sufficient equity on hand such that financing of the incremental costs for the EEMs isn't necessary, then the cost savings over the 20-year period are $18,793. Additionally, three different loan periods are presented; at 10, 15, and 20 years, all with a 5% interest rate. With a 20-year loan, the LCC savings are $15,316 or $578 per year.

Table 6. LCC Evaluation Key Input Metrics

Capital Incremental Cost	1st Year Electricity Savings	1st Year Gas Savings	Evaluation Period	Real Discount Rate
$40,563	-$1,040	$5,605	20 yrs	3%

Table 7. LCC Comparison of a Single Ramble A Building Compared to California Title-24 Standard

Financing Scenario	Total LCC	LCC Savings	LCC Savings/yr
Title-24 Base Case	$489,223	–	–
No Financing	$470,440	$18,793	$940
10yr Loan @ 5% Interest	$473,917	$15,316	$766
15yr Loan @ 5% Interest	$475,829	$13,404	$670
20yr Loan @ 5% Interest	$477,669	$15,316	$578

5 Conclusions and Discussion

This report evaluated the first 10 months of energy consumption data available for Phase I of the student housing building at West Village. Build-out of the community is ongoing, yet thus far the project has been a success, demonstrated by the design and construction of buildings that incorporate cost-effective measures that reduce heating and cooling energy use significantly. Results have provided valuable insights and lessons learned into the first planned ZNE community in the United States. Information gleaned thus far will be valuable for other developers and communities who may consider other community-level ZNE or high performance projects. Following are responses to the specific research questions.

1. *How does measured energy use compare to modeled and were the expected energy savings achieved?*

Total energy consumption for the 16 Phase 1 apartment buildings was found to exceed modeling projections by 28%. Apartment usage was found to be 18% higher than projections and the common area meter HPWH and building exterior lighting combined usage was found to be 55% higher than projected.

There is a great degree of variability in usage among the individual apartments. The factor of 4 ratio in usage from high to low use apartments (ranging from 45% to 200% of predicted 10-month values) suggests significant behavioral and occupancy variability. Average monthly apartment energy consumption profiles suggest that non-HVAC use is the primary cause for the discrepancy. For the four-bedroom apartments, energy use disaggregation showed HVAC energy use was overpredicted by 56% and non-HVAC energy use was underpredicted by 54%. Relying on the 2009 RASS for estimates of multifamily plug load usage was not ideal, given the fact that the student apartments are composed of multiple “households,” while statewide multifamily estimates in RASS are more heavily biased toward single households, with less duplication of energy consuming appliances and electronic gadgets. When MEL estimates were increased to reflect assumptions in the current House Simulation Protocols (Hendron et al. 2010), actual base load energy use still exceeds modeled by 24%. While it is accepted that MEL usage is affected by occupancy and unit floor area, an important conclusion from this study is that it is also highly dependent on occupancy type; e.g., student housing versus conventional multifamily, versus single-family housing.

Roughly half of the HPWHs have experienced operational issues resulting in excessive resistance heat operation and consequently high electricity use. WVCP and ARBI are currently investigating the details of these problems, but it is theorized that improper initial commissioning combined with difficulty in readily diagnosing system operation may be the primary cause. All the Phase I HPWHs were installed by plumbers with no previous experience with HPWHs. The HPWHs in future phases have been or are to be installed and commissioned by mechanical contractors. It is recommended that the installing contractor has experience with refrigerant systems, either mechanical contractors or plumbers with appropriate training, as they may be more suited to install such systems.

2. *Was the the project able to achieve the stated energy goals?*

The answer to this is yet to be determined. The West Village ZNE goals are defined on a community level and construction is roughly 50% complete at this stage. Occupant-supplied plug load energy use is higher than the initial assumptions used for modeling due to the "multiple household" effect, resulting in annual consumption above projections. WVCP and UC Davis continue to be committed to this goal and will use the results of this initial Phase I evaluation to improve implementation efforts and optimize performance. This may involve the addition of EEMs or PV where necessary, increased encouragement of student participation in reducing energy use, or adjusting future modeling assumptions.

3. *How cost effective is this package of EEMs in a multifamly application?*

Cost analysis demonstrates that the package of EEMs incorporated at West Village is cost effective compared to the Title-24 compliant construction under various common financing scenarios. During the design phase much attention was paid to selection of EEMs that were proven and cost effective. This is very compelling evidence to be presented to production builders in support of future similar projects.

There are several issues that make the cost effectiveness of NZE communities challenging:

- Under California regulation that was in place when the first two phases of student housing were permitted, virtual net metering (VNM) of onsite generation was not allowed. VNM allows for generation and consumption to be traded across meters within the community and is an attractive model for multifamily property managers who are also utility account owners. The result of this was that each individual apartment meter was connected to a unique PV array and inverter with its own net-metering account. Utility account owners are charged for additional consumption at the end of the year for any apartment that consumes more than they produce, and are reimbursed at far less than the electricity retail rate for apartments that produce more than they consume[19]. From a cost perspective to WVCP, minimizing utility bills requires that each individual apartment achieve net zero. It is critical that creative models, such as VNM, be allowed under regulatory framework to encourage participation in ZNE construction by developers and property owners. A VNM program has now (starting in Phase III development) been established in California for multifamily projects, but VNM is allowed on a per building basis only, not across property lines.
- Property managers that are also the utility bill owners are able to better justify the investment in energy efficiency in that they can reap the benefits of reduced utility bills. However, there are real challenges to controlling tenant energy consumption who are largely disconnected from their consumption. One option is to charge a premium for these features in monthly rent, which may increase awareness in some tenants but doesn't provide any direct feedback on usage. Other possibilities include setting utility caps in the rental agreement and assessing fees for tenants that over-consume. However, utility regulations in California make this difficult or impossible, as they prohibit property managers from collecting income from tenants for utility fuel consumption.

[19] Under AB 920 this rate is close to $0.04/kWh as of September 2013.

A project of this type highlights an encouraging point that a developer without previous experience with ZNE projects or installing EEMs could have such success, even given the regulatory difficulties and complexities present. With a constantly changing regulatory framework it is difficult to estimate what this model would look like for similar projects in other locations and with other developers

4. *What role do occupants have in high performance buildings and how well do tenants respond to energy education efforts by the developer?*

As heating and cooling loads in milder climates are continually driven down in high performance homes, occupants increasingly are becoming the most influential variable in impacting total home energy consumption. Measured non-HVAC base load at West Village averaged 85% of total apartment electricity (excluding water heating). Additionally, there is a great degree of variability due to occupancy and behavior across individual apartments with a factor of 4 ratio in usage from high to low use apartments. Some of this may be tempered during the design process through the installation of efficient hardwired lighting and appliances. However, as technology drives efficiency further, the impact of the occupant becomes increasingly important, primarily as reflected in their use of electronic devices. This is an important consideration given that modeling is relied upon heavily to size PV systems to meet project ZNE goals. Without feed-in tariffs or central distributed generation, achieving ZNE on a unit-by-unit basis becomes very complicated.

While occupants generally indicate interest in the efficiency of the West Village community, it is clear that more in-depth and regular engagement is necessary to increase the likelihood of achieving the community ZNE goals. Tenant education on basic energy efficiency strategies, creating a community energy and sustainability vision, and implementing and enforcing rules on excessive consumption (e.g., use of individual room refrigerators) are needed. Limited energy education efforts have been implemented as of publication of this report. However, WVCP is currently pursuing other strategies to help improve overall performance. Several proposed ideas include a monthly educational series and community level competitions for energy use reductions. WVCP is considering adoption of a program that incentivizes residents for achieving low energy use below a predefined threshold. Further evaluation of what strategies will be most successful, from a cost-effective, motivational, and legal standpoint, is still necessary.

References

ARBI (2013). "Multi-Family Heat Pump Water Heater Evaluation". Prepared for Building America by the Alliance for Residential Building Innovation. To be published in 2013.

CARB (2009). 2009 Annual Progress Report Budget Period 2 (BP2). Attachment YY: West Village Zero Energy Community Report. Prepared for the U.S. Department of Energy by the Consortium for Advanced Residential Buildings. December.

CARB (2010). 2010 Annual Progress Report Budget Period 3 (BP3). Attachment Y: Technical Paper – Zero Energy Communities: UC Davis' West Village Community. Prepared for the U.S. Department of Energy by the Consortium for Advanced Residential Buildings. December, 2010.

CEC (2008). "2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings." California Energy Commission. CEC-400-2008-001-CMF. December.

CPUC (2008). California Long Term Energy Efficiency Strategic Plan. California Public Utilities Commission. September.

Dakin, B.; Backman, C.; Hoeschele, M.; German, A. (2012). *West Village Community: Quality Management Processes and Preliminary Heat Pump Water Heater Performance*. Prepared for Building America by the Alliance for Residential Building Innovation. Accessed June 2014. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/west_village_hpwh.pdf.

Dakin, B.; Hoeschele, M.; Idrees, O. (2010). "Zero Energy Communities: UC Davis' West Village Community." ACEEE Summer Study on Energy Efficiency in Buildings. Washington, DC: American Council for an Energy Efficiency Economy, August.

DEG (2010). "UC Davis West Village Community Energy Study". Prepared for Chevron Energy Solutions by Davis Energy Group. May, 2010.

Hendron, R. (2008). *Building America Research Benchmark Definition*. Golden, CO: National Renewable Energy Laboratory, NREL/TP-550-44816. Accessed June 2014. http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/44816.pdf.

Hendron, R.; Engebrecht, C. (2010). *Building America House Simulation Protocols*. Golden, CO: National Renewable Energy Laboratory, NREL/TP-550-49246. www.nrel.gov/docs/fy11osti/49246.pdf.

KEMA (2009). 2009 California Residential Appliance Saturation Study. Prepared for the California Energy Commission. CEC-200-2010-004-ES. October.

Risko, G. (2012). "Preliminary Results: ZNE Related Verification & Assessment for the West Village Apartments Development". Prepared for Pacific, Gas, and Electric Company by Architectural Energy Corporation. February, 2013.

U.S. Department of Commerce (2010). "Energy Price Indices and Discount Factors for Life Cycle Cost Analysis – 2010". Prepared for the United States Department of Energy (DOE) Federal Energy Management Program by the U.S. Department of Commerce.

Appendix: Supplementary Evaluation Graphs

Figure 11 through Figure 13 show the observed range in energy consumption compared to model predictions for all apartments by apartment type.

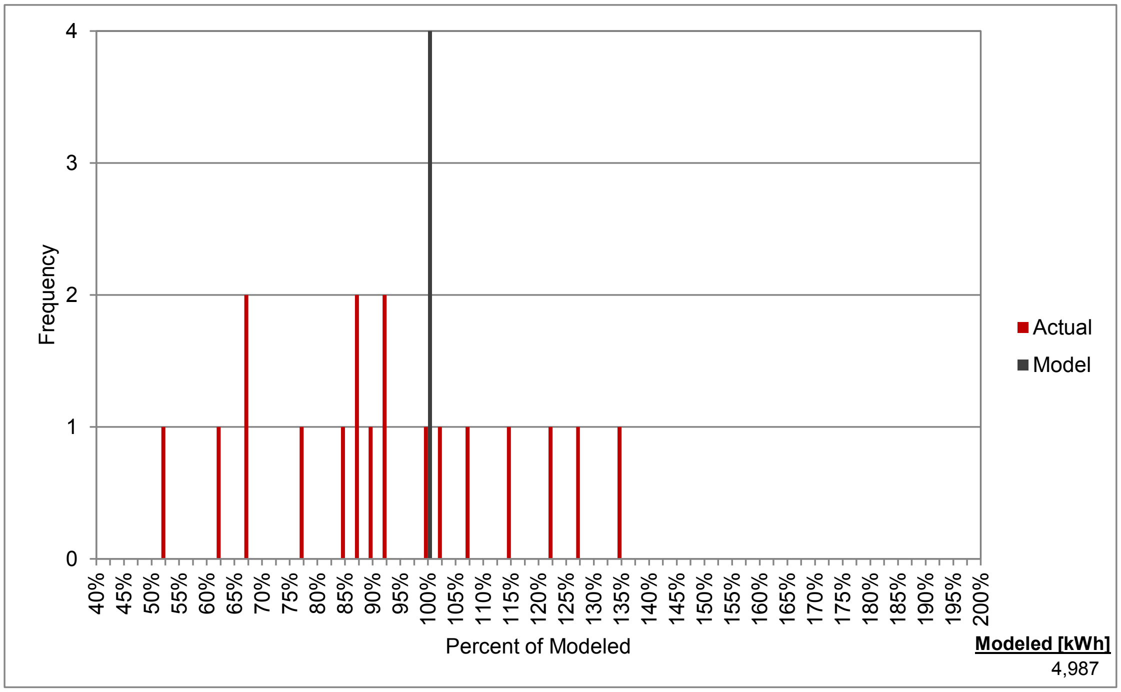

Figure 11. Histogram showing variation in energy consumption over 12 months (March 2012 to February 2013) for all two-bedroom apartments

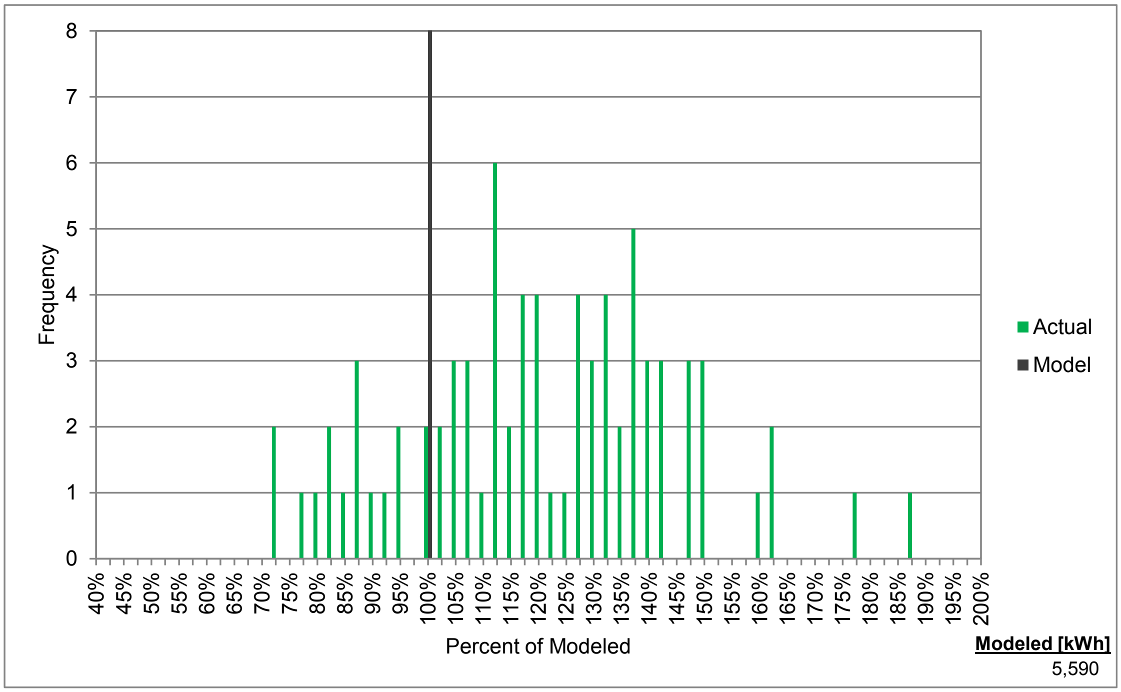

Figure 12. Histogram showing variation in energy consumption over 12 months (March 2012 to February 2013) for all three-bedroom apartments

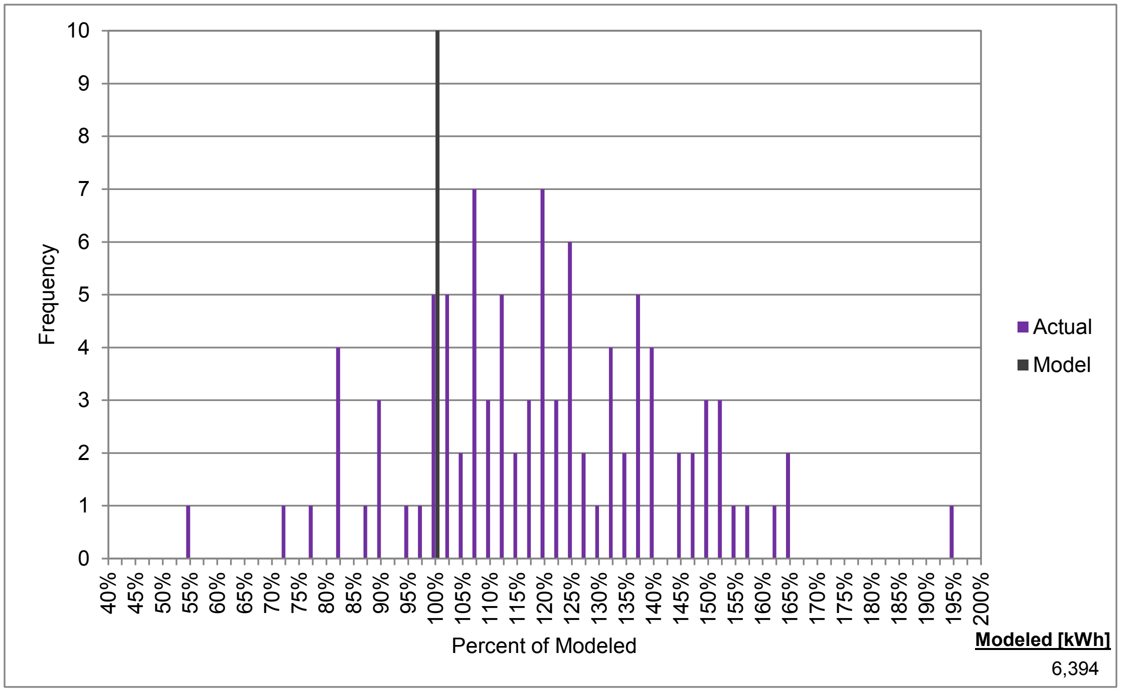

Figure 13. Histogram showing variation in energy consumption over 12 months (March 2012 to February 2013) for all four-bedroom apartments

Figure 14 through Figure 16 demonstrate the results of data disaggregation for the three-bedroom and two-bedroom apartments, respectively.

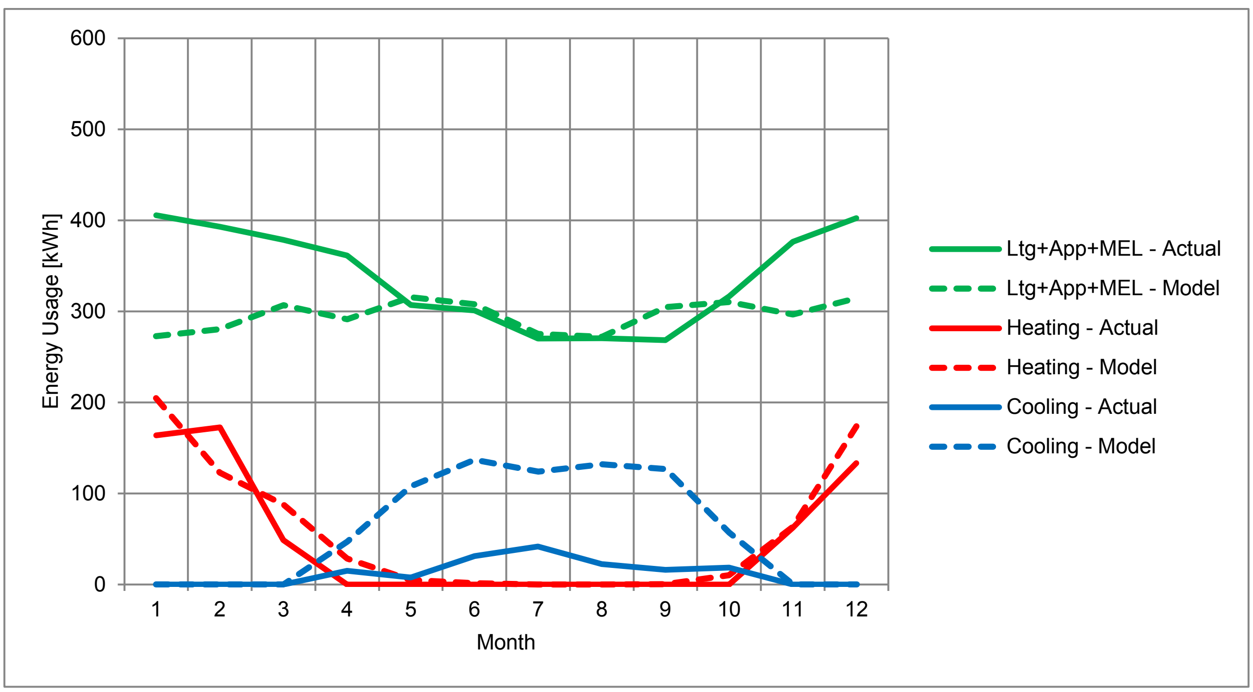

Figure 14. Average disaggregated energy use over 12 months (March 2012 to February 2013) for the two-bedroom apartments

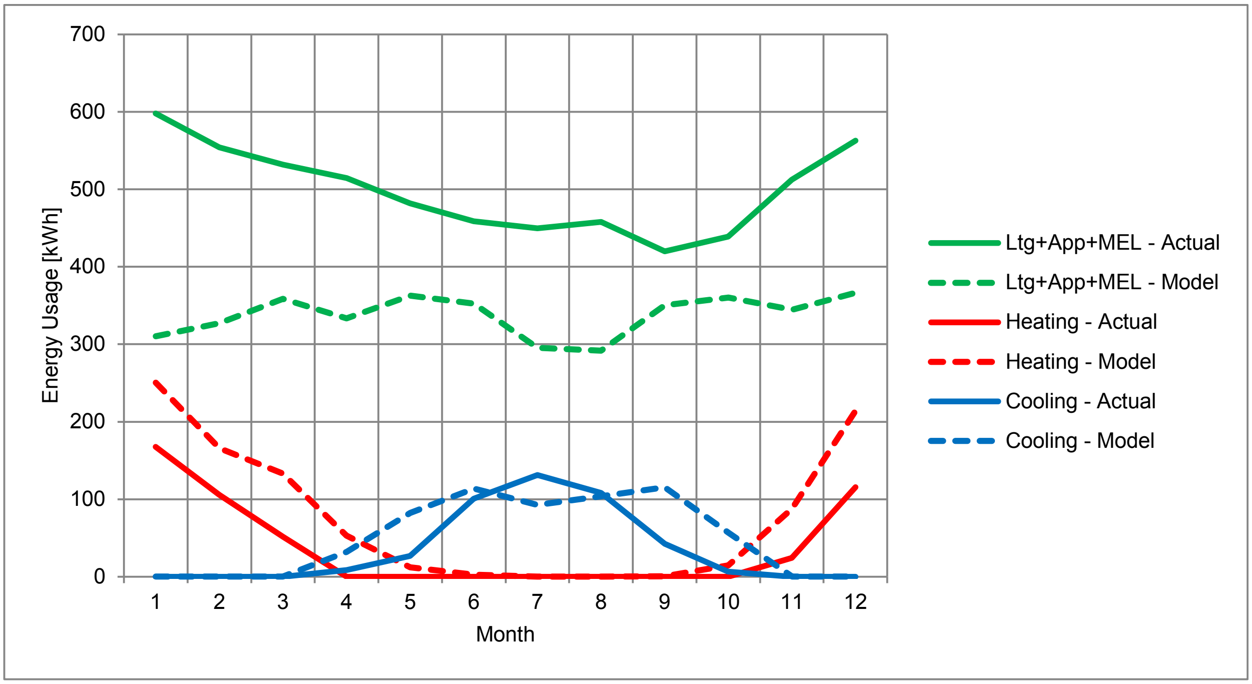

Figure 15. Average disaggregated energy use over 12 months (March 2012 to February 2013) for the three-bedroom apartments

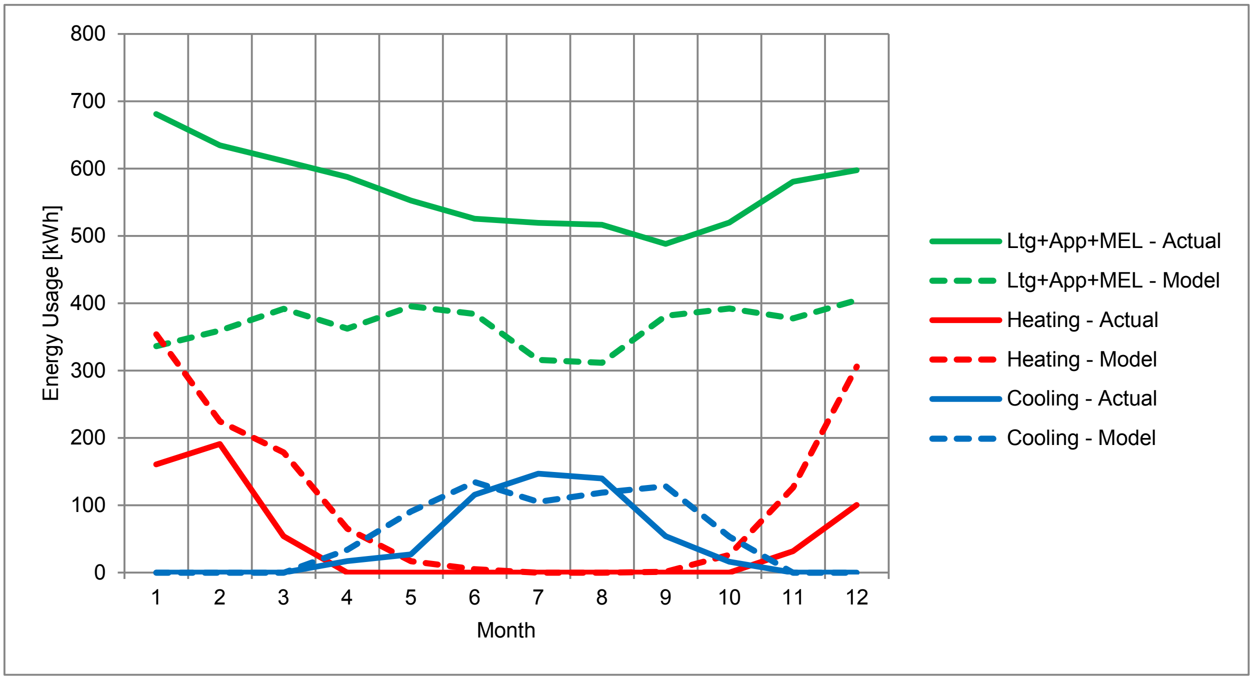

Figure 16. Average disaggregated energy use over 12 months (March 2012 to February 2013) for the four-bedroom apartments

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