Early Performance Results From A Zero Net Energy Community

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ABSTRACT

West Village, a multi-use project at the University of California Davis, represents a ground-breaking sustainable community incorporating energy efficiency measures and on-site renewable generation to achieve community-level Zero Net Energy (ZNE) goals. Sited on over 200 acres, when complete the community will provide housing for almost 2,000 students, 343 homes for faculty and staff, mixed-use buildings, and other amenities. The project's vision is to maximize the community's sustainability by reducing building energy use, utilizing renewable generation, and encouraging alternative forms of transportation. The project has completed construction of 683 student apartments over a three year period. Data collection efforts to date include ongoing logging of PV generation and apartment level utility consumption, detailed monitoring of innovative systems, and occupant behavioral surveys. This paper will discuss results from Phase I student housing (192 apartments), including:

- How successful the student housing segment is in reaching the zero net energy goals;
- What role occupants play in achieving community goals;
- What role central heat pump water heating plays, and performance results; and
- Lessons learned in shifting from building to community level zero net energy goals.

Introduction

West Village is a planned ZNE community on the UC Davis campus. It is a multi-use project incorporating energy efficiency measures 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. Student housing was completed in three phases with the first phase of housing open in the fall of 2011.

This paper summarizes the operation results of the 192 student apartments that were completed in 2011 under Phase I of the West Village multi-year project. The energy efficiency measures 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[1] in hot-dry climates and 31%-39% Title-24 compliance[2] savings depending on building and orientation. These apartment buildings have also been certified Platinum under the LEED for Homes certification program.

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[1] Building America Benchmark is a baseline for building performance, developed by National Renewable Energy Laboratory (NREL) for Building America teams.

[2] Title 24 compliance refers to the California Energy Code. Percent compliance is based on a time dependent valuation of energy based on space heating and cooling and water heating performance.

The scope of this paper focuses on the evaluation of total apartment energy use, total Phase I community energy use, and the ability to meet the project's stated ZNE goals. The paper will also report on HPWH performance in Phase I student apartments. Utility data is used to compare measured versus modeled electricity use and to verify the accuracy of the assumptions employed in the model.

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.

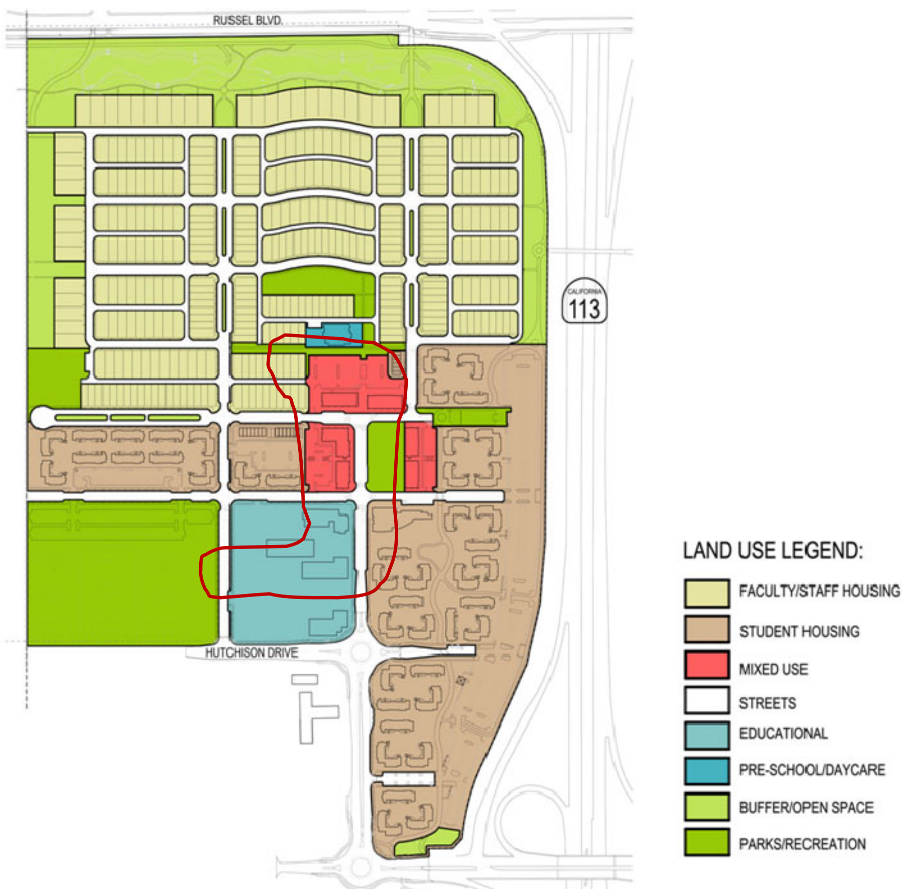

Figure 1. UC Davis West Village Site Plan. *Source:* UC Davis.

Nearly ten years ago, UC Davis began developing strategies for a highly efficient residential community to be built on UC Davis land. Results of previous work on the project are summarized in a report prepared for Chevron Energy Solutions (DEG 2010), several ACEEE papers (Dakin, Hoeschele, Idrees 2010; Finkelor et. al. 2010; & Price et. al. 2012), and a 2012

Building America technical report focused on initial performance of the central HPWH as well as the overall construction quality assurance and quality control processes (ARBI 2012).

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. 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 paper covers the performance of the sixteen Phase I apartments only.

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

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

The initial intent of the community was for a centralized PV facility and a micro-grid to optimize utilization of renewable energy in the community. Due to regulatory and cost constraints, the community was built primarily with rooftop PV systems. Each apartment has its own dedicated PV system and utility meter[3]. Since the developer owns all the PV systems, they chose to be the utility account owner for all the apartments. As a result, utilities are included as part of the rent and students do not pay for their energy use. In addition, there is no energy consumption feedback available to the tenants. 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 to provide a means of reducing plug load energy use. Because these devices created problems with the broadband communications, resulting in slow and interrupted internet connections, the systems were removed from all apartments before occupancy.

Methodology

General Technical Approach

Monthly utility data and hourly PV generation data for each of the apartments were obtained through utility bills and the PV monitoring systems, respectively. Measured energy consumption and PV generation are compared to energy estimates from modeling completed during the design phase of the project (DEG 2010). Utility and PV generation data was also used to evaluate performance of the central heat pump water heaters (HPWHs) serving the apartments. Additionally, one of the HPWHs was monitored in detail to evaluate performance relative to manufacturer's performance specifications.

[3] Due to recently passed legislation, future phases included virtual net metering on a per building basis.

Data Collection

To evaluate energy use and generation, Davis Energy Group (DEG) worked with the developer and PV contractor 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: utility bills provided monthly net meter energy use and the PV supplier's monitoring website provided PV production data. Production data and net energy use were used to calculate monthly energy consumption for each individual meter (192 apartments and 16 common area meters). Daily PV production data was aggregated into monthly values corresponding to the utility billing periods for direct comparison. Energy consumption was then calculated as the difference between these two values according to the following equation.

$$\textit{Net Energy} = \textit{Energy Consumption} - \textit{Energy Production}$$

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.

The majority of data presented in this report represents a full year, between March 2012 and February 2013, over which the two data sources coincide. While PV systems were mostly operational by November 2011, most of the PV monitoring meters did not come online until later making it impossible to estimate energy consumption until March 1, 2012. There were still some meters that did not report PV production until June of 2012, but the PV systems were operational. For the systems without operational production meters, the generation data was extrapolated back to March 1st, 2012, using production from PV systems with similar capacity and orientation and which had later PV production that aligned well.

Data Evaluation

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

- Phase I student housing community in its entirety
- Individual apartments
- Building common meter (central HPWH and building exterior lighting)
- By apartment type

Comparisons were also made to original modeling estimates for each apartment type. Modeling assumptions largely followed the Building America Research Benchmark Definition (Hendron 2008) with the following differences.

- Cooling thermostat setpoint of 78^oF
- Heating thermostat setpoint of 70^oF

- A multiplier of 0.58 (42% reduction)[4] applied to miscellaneous electric load (MEL) usage to better align annual consumption with multi-family MEL usage presented in the 2009 Residential Appliance Saturation Study (RASS) (KEMA 2010)
- Vacation schedules adjusted to align with the school year.

The energy model was re-evaluated using actual meteorological year (AMY) weather file from the Sacramento Metropolitan Airport (KSMF) NOAA weather station. These results were used for comparison to actual energy consumption.

Apartment Energy Usage Disaggregation

Monthly electricity usage for each apartment was disaggregated into two main categories: baseload and space conditioning. The 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 baseloads for a given residence were estimated from the "shoulder" seasons, which are times during spring and fall which have little or no space conditioning. The difference between the monthly adjusted baseload 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 (2-bed, 3-bed, 4-bed apartment) and are presented in the results section.

Heat Pump Water Heater Analysis

A central heat pump water heater (HPWH) is installed at each apartment building, serving 12 apartments. The HPWH is connected to each building's common meter. The HPWH delivers 140 degree water to a 120 gallon storage tank. A second 120 gallon storage tank with electric resistance elements is used to provide backup and boost water temperatures as needed.

The monitoring strategy focused on characterizing HPWH performance (capacity, power, and efficiency) as a function of hot water load, varying return water temperatures, and outdoor temperature effects. A minimum twelve month monitoring period was completed to adequately capture seasonal performance effects associated with climate, cold water inlet temperature variations, and hot water load variations during the course of the academic year. Water heating energy flows were calculated on a 15 second interval basis using water side measurements (flow times temperature difference). HPWH efficiency was calculated on a fifteen minute basis by dividing the HPWH energy delivered by the energy consumed. The planned approach for evaluating HPWH performance evaluation involved utilizing full-load data to develop a performance map describing system performance as a function of inlet water temperatures and outdoor air temperature.

[4] 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.

Results

A summary of the first year's performance in regards to achieving project zero net energy goals for the Phase I apartments community is summarized in Table 2. Energy usage for the common meters with the central heat pump water heaters was separated out from the apartment meters. 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. Total performance was 79% of the zero net energy (ZNE) goals over the 12-month evaluation period.

Table 2. Projected and Actual Production & Consumption for Phase I of the Student Apartments

	Production (MWh)			Consumption (MWh)			% Actual Production / Consumption
	Projected	Actual	% Diff	Projected	Actual	% Diff	
Apartments	1,024	1,110	8%	1,163	1,377	18%	81%
Common Meter	471	451	-4%	390	602	55%	75%
Total	1,495	1,561	4%	1,552	1,979	28%	79%

Apartment Building Energy Use

A comparison of actual average apartment consumption (no DHW use) by unit type (number of bedrooms) to modeling estimates (using AMY weather data) is shown in Figure 2. Average actual consumption for both the 3-and 4-bedroom units exceeded projected use by 23%, while energy use of the 2-bedroom units was 4% lower than projected usage.

The monitored monthly use profiles follow a similar trend seasonally. One exception is the 2-bed apartments that demonstrated 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 3-bed and 4-bed 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 monitored data.

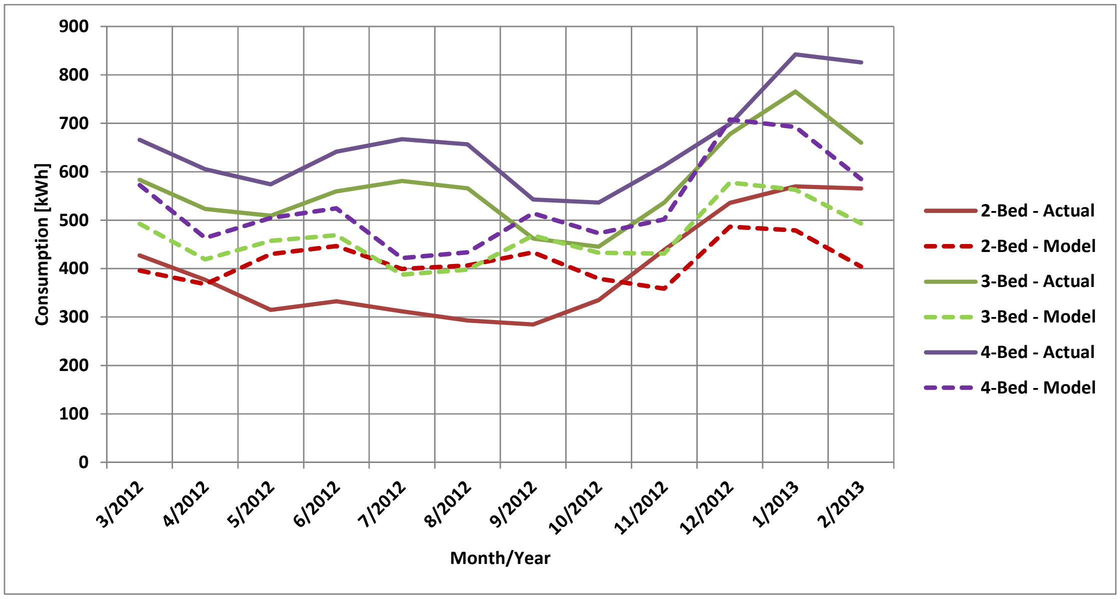

Figure 2. Modeled and actual average monthly consumption values for each apartment type (by number of bedrooms).

Figure 3 presents a histogram comparing the ratio of "actual-to-modeled" 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 3-bed and 4-bed apartments consume more energy than what was predicted. Only 39% of the 2-bed apartments consumer more energy than predicted. No specific occupancy data is available but the outliers on both the low and high ranges are thought to be the result of occupancy use and behavior.

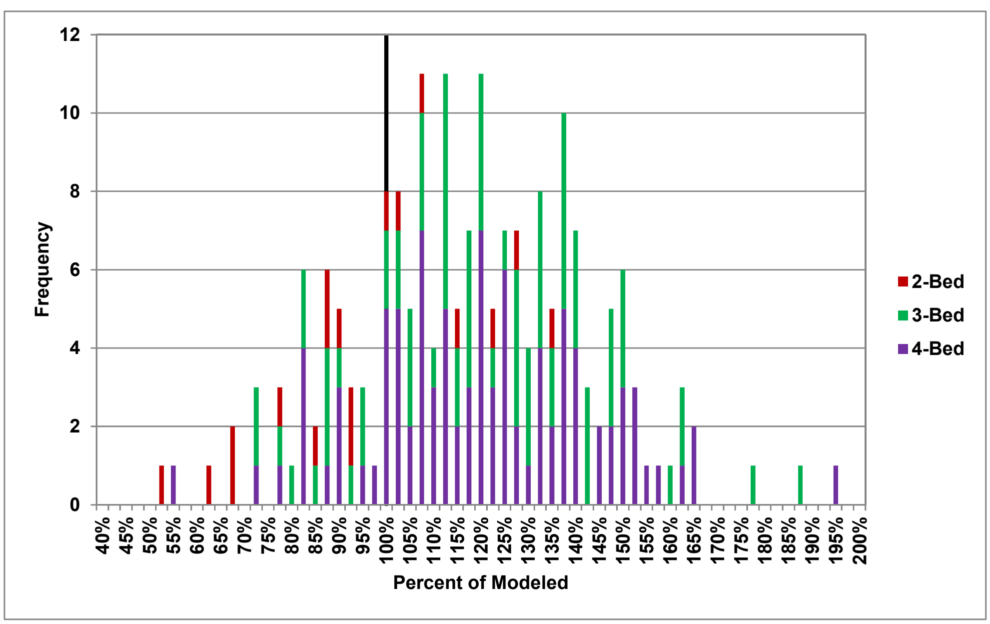

Figure 3. Histogram showing individual apartment energy consumption variation.

Based on results from disaggregation of the 12-month apartment utility bills, average heating and cooling energy use is 53% and 31% lower than projected values, respectively. Figure 4 shows monthly comparison for the 4-bedroom units. Conversely, baseload energy use (lighting, appliances, and plug loads) is 49% higher than projected values (green dotted lines) and total energy use for the average 4-bed apartment is 21% higher than projected values. One hypothesis for the high baseload 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 multi-family 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.

Since original modeling aligned plug load energy use with 2009 RASS data (KEMA 2010), baseload energy use using the current Building America House Simulation Protocols (Hendron and Engebrecht 2010) was also compared to actual baseload energy use. For the 4-bedroom apartments, actual baseload energy consumption is 24% higher than modeled assumptions, as shown in grey dotted line in Figure 4.

Preliminary results from a PG&E monitoring study (Risko 2013) monitoring a sample of approximately 120 of the student apartments at West Village show total HVAC energy use higher than modeled projections, primarily due to many occupants operating the heat pump with the system fan in "always on" mode. Fan energy use not associated with heating and cooling operation will show up as baseload energy in the disaggregation process, not heating and cooling energy.

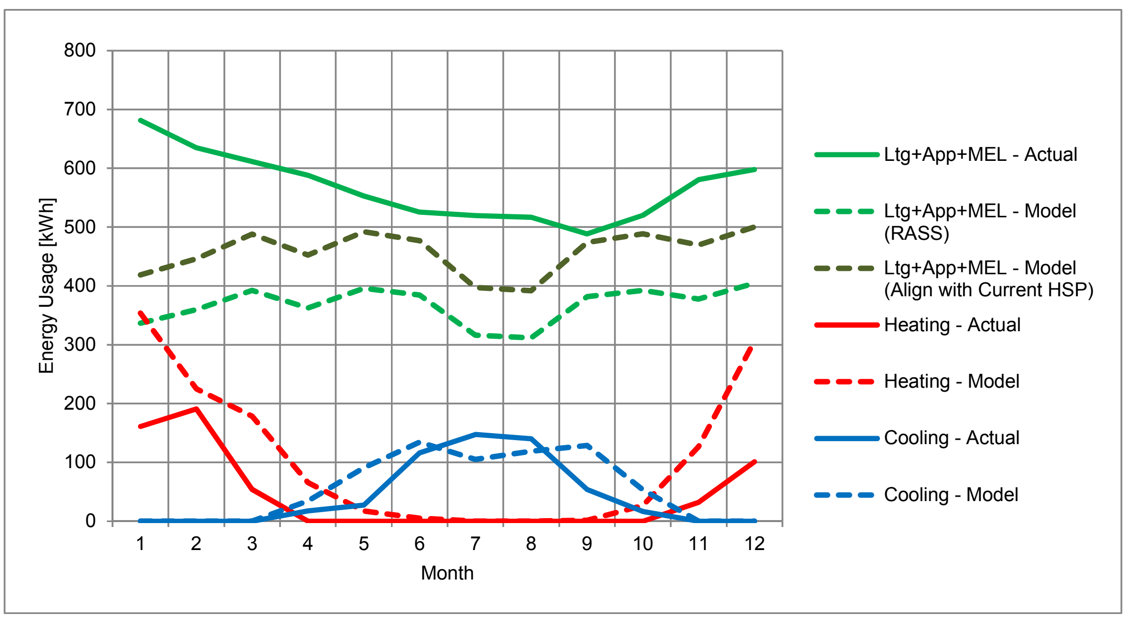

Figure 4. Average disaggregated energy use for the 4-bedroom apartments (Mar. 2012 to Feb. 2013).

Heat Pump Water Heater Performance

The installed heat pump water heaters are rated at a 3.3 coefficient of performance (COP)[5]. Modeled HPWH energy use assumed a 2.2 seasonal energy factor (EF) to account for cycling degradation and use of electric resistance elements for supplemental heating.

Monitoring of one of the HPWH systems provided performance data and helped identify operational problems. The water heating systems were installed by plumbers with no previous experience with heat pump water heaters. Based on data from HPWH monitoring, it was quickly identified that the systems were not properly commissioned and were operating exclusively in electric resistance mode. Over the first year of operation, there were several instances of heat pump operational issues.

Full load monitoring data over the year was evaluated to compare observed system performance relative to nominal equipment ratings. Figures 5 and 6 compare measured full load capacity and COP relative to outdoor air temperature with manufacture's published values. When the HPWH system operated as designed, actual energy use from the monitored HPWH system was close to projected values with the HPWH providing most of the water heating needs. Electric resistance operation was limited to when the HPWH failed and periods with high recovery loads in January. Measured capacities are ~10-20% lower than manufacturer published values, but measured heat pump flow rate and return water temperatures of 20 gpm and 125°F are not as favorable as manufacturer's data of 25 gpm and 100°F. Resulting full load COPs match well with the manufacturer's data (see Figure 6). Although overall steady-state COPs in the 3.0 to 4.0 range were in line with manufacturer's data, high standby parasitics (crankcase and pipe heaters in the outdoor heat pump), and frequent short cycling degraded the annual COP to 2.12.

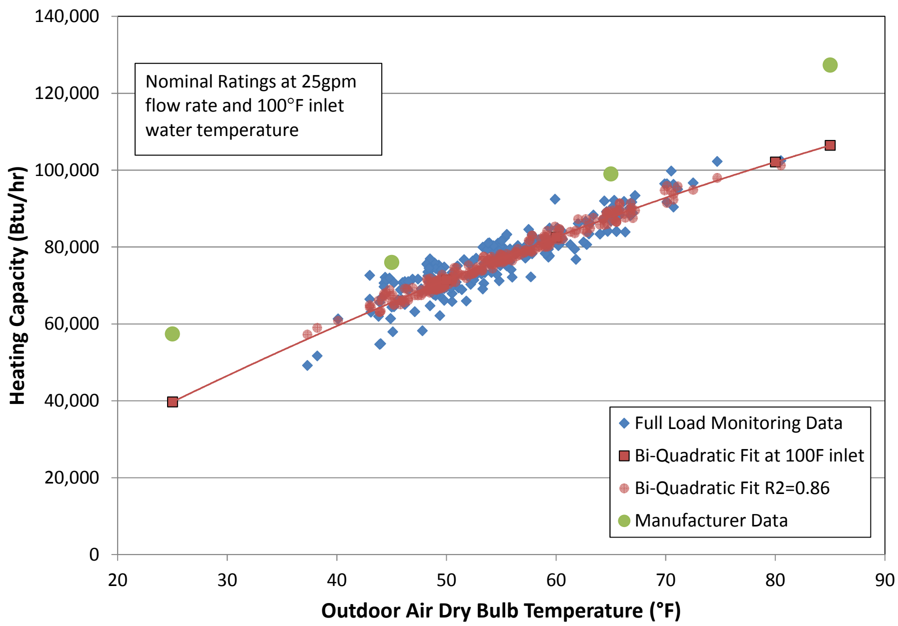

Figure 5. Full-load heating capacity as a function of outdoor dry bulb temperature.

[5] COP rating based on 25 gpm flow rate, 100°F entering water temperature, and 72°F entering air wet bulb temperature.

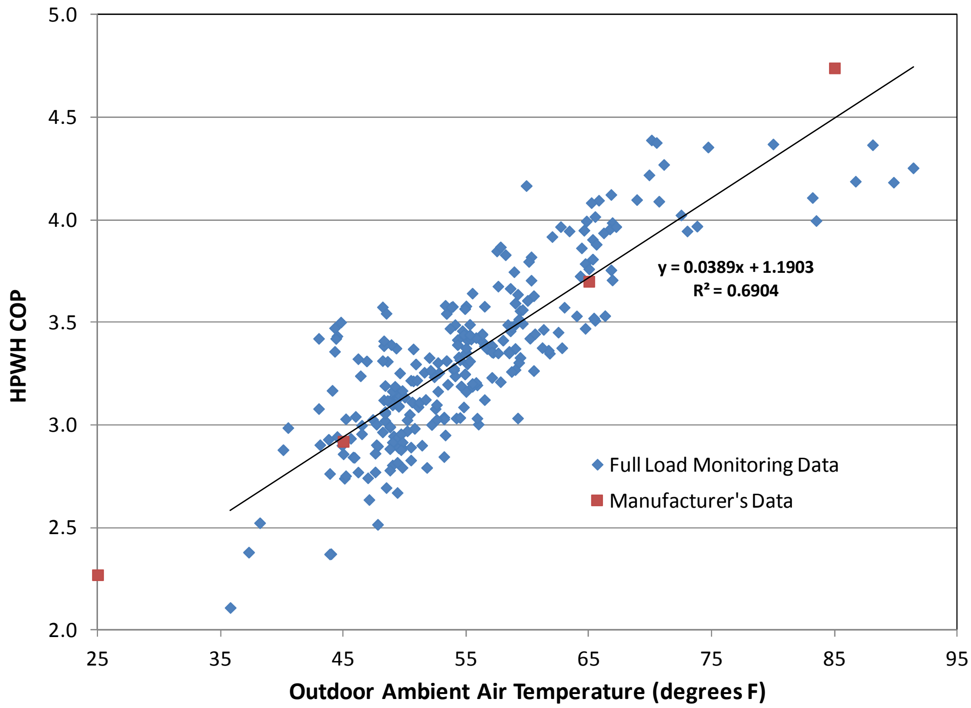

Figure 6. Full-load HPWH COP as a function of outdoor dry bulb temperature.

More detailed monitoring results and evaluation of central HPWH in other U.S. climates can be found in a 2013 Building America report (ARBI 2013).

Figure 7 compares modeling estimates for common meter energy consumption with average actual consumption. Common meter energy use includes both central HPWH and site lighting use. Actual common meter use, shown as the solid red line, is much higher than original predictions. Seasonal variations in the water heating load are also more pronounced than estimated. Roughly half of the HPWHs experienced operational issues resulting in excessive resistance heat operation and consequently high electricity use.

The water heaters are set up to operate primarily in heat pump mode and use minimal electric resistance heating for back-up during times of high load or low outdoor air temperatures. Because of ongoing issues with heat pump operation and reliability, excessive resistance heat operation and consequently high electricity use was observed. Due to lack of performance feedback, these operational problems were frequently left unnoticed until review of high utility bills. 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.

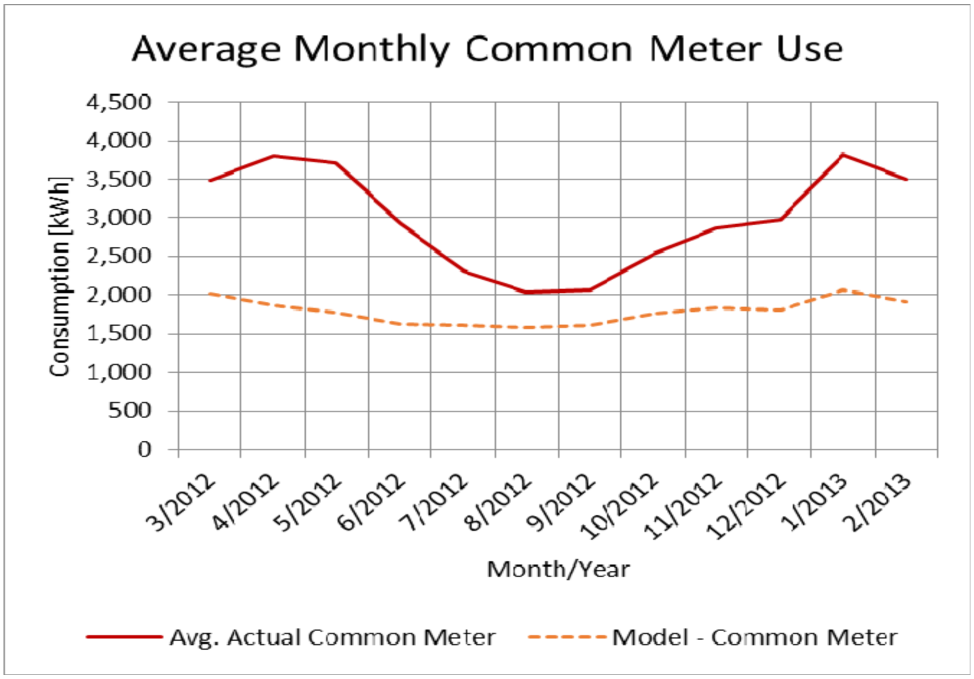

Figure 7. Monthly average common meter use compared to modeled (15 buildings).

Conclusions and Discussion

Build out of the West Village community is ongoing, yet thus far the project has been a success. While Phase 1 student housing is 21% short of achieving zero net energy (ZNE) goals in the first year of operation, a wide-range of factors must interplay precisely as modeled for the expected performance to be achieved. After feedback from the first year of operation and with ongoing construction of future phases, the West Village community is now in a good position to act on these lessons learned in a way that will increase the likelihood of achieving net-zero energy operation in the future. Results have provided valuable insights and lessons learned from this early example of a planned zero net energy community in the United States. Information learned thus far will be valuable for other developers and communities who may consider other community level ZNE or high performance projects.

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 heat pump water heater and building exterior lighting combined usage was found to be 55% higher than projected. Relying on the 2009 Residential Appliance Saturation Survey (RASS) (KEMA 2010) for estimates of multi-family plug load usage was not ideal given the fact that the student apartments are composed of multiple "households," while statewide multi-family estimates in RASS are more heavily biased towards single households, with less duplication of energy consuming appliances and electronic gadgets.

As heating and cooling loads in milder climates are continually driven down in high performance buildings, occupants increasingly are becoming the most influential variable in total building energy consumption. There is also a great degree of variability due to occupancy and behavior across individual apartments with a range of up to four times the usage from low to high use apartments. Some of this may be tempered during the design process through the installation of efficient hardwired lighting and appliances and controls. 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 in designing ZNE communities 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. Virtual net metering (VNM) on a building level is now allowed in California, but the first two phases of student housing were not allowed to take advantage of VNM.

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. Tenants do not pay for their utility bills and there is no energy consumption feedback available. The apartments were initially designed to include central energy consumption displays and smart power strips in each bedroom to help reduce plug load energy use. Without this or other similar types of feedback mechanisms, there is no incentive to conserve energy use, nor is there the ability to understand the impacts of their habits on energy use.

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. The developer is currently pursuing strategies to help improve overall performance. Several proposed ideas include a monthly educational series and community level competitions for energy use reductions. The developer is also considering adoption of a program that incentivizes residents for achieving low energy use below a pre-defined threshold. Further evaluation of what strategies will be most successful, from a cost-effective, motivational, and legal standpoint, is still necessary.

The developer is also responsible for tracking utility statements for 208 meters in this first phase of student housing alone. They were not initially set up to regularly review statements to identify potential performance issues. They are now investigating ways to identify high energy users early on and develop strategies to correct the issues involved.

HPWH Performance

Central HPWHs, when operating as designed, show promise as a good electric alternative technology to natural gas for heating water in ZNE projects. Based on monitoring of one system, heat pump operation was able to provide nearly all of the building's hot water needs, when operating properly. The primary cause for high common meter energy use has been HPWH performance and reliability. Monitoring has shown that when commissioned correctly, system efficiencies track relatively well with manufacturer engineering performance data. Additionally, monitoring highlights the importance of increased contractor and service personnel installation and commissioning training, especially given that the HPWH technology is fairly new. 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 installation and operational issues identified in Phase 1 assisted the developer in later phases of construction. Later water heaters installations were installed and commissioned by mechanical contractors who are 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 and commissioning issues have not been present in future phases. Additionally, alarm systems were installed on all of the HPWHs so that operational staff could address heat pump operational issues quicker.

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