

West Village Community: Quality Management Processes and Preliminary Heat Pump Water Heater Performance

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Alliance for Residential Building Innovation

November 2012

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**West Village Community:
Quality Management Processes and
Preliminary Heat Pump Water Heater Performance**

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-0-40340-00

October 2012

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Definitions

ACH50	Air changes per hour at 50 Pascals
ACCA	Air Conditioning Contractors of America
ARBI	Alliance for Residential Building Innovation
CARB	Consortium for Advanced Residential Buildings
COP	Coefficient of performance
DEG	Davis Energy Group
DHW	Domestic hot water
EEM	Energy efficiency measure
EER	Energy Efficiency Ratio
HERS	Home Energy Rating System
HPWH	Heat pump water heater
HVAC	Heating, ventilation, and air conditioning
PV	Photovoltaic
QII	Quality insulation installation
QA/QC	Quality assurance and quality control
SLA	Specific leakage area (dimensionless)
WVCP	West Village Community Partners

Acknowledgments

Davis Energy Group would like to acknowledge the U.S. Department of Energy Building America program and its funding and support of development of this technical report as well as research that informed it. In addition, we would like to acknowledge 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.

Executive Summary

West Village, a multiuse project underway at the University of California Davis, represents a groundbreaking sustainable community that incorporates energy efficiency measures and on-site renewable generation to achieve community-level goals of ultra high efficiency. The project, when complete, will provide housing for students, faculty, and staff, and maintain a vision to minimize the community's environmental impact by reducing building energy use, providing on-site renewable energy generation, and encouraging alternative forms of transportation. The focus of this research concerns the 192 student apartments completed in 2011 under Phase I of the West Village multi-year project. The developer implemented numerous aggressive energy efficiency measures that are estimated to achieve 37% source energy savings over the Building America Benchmark.

There are two primary objectives of this research. The first is to evaluate performance and efficiency of central heat pump water heaters for domestic water heating in ultra-efficient buildings. The second is to evaluate the effectiveness of quality assurance and quality control processes in ensuring proper system startup and operation and documenting compliance with efficiency programs. This research additionally recommends measures to promote successful implementation of quality processes in large-scale, high performance communities.

1 Introduction

1.1 Background and Motivation

University of California, Davis (UC Davis) West Village is a new campus neighborhood under construction on UC Davis land adjacent to the core campus in Davis, California. West Village 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. When complete, the 200-acre community will consist of housing for almost 2,000 students, 343 homes for faculty and staff, a 10-acre recreation complex, and possibly the first community college center on a university campus. Faculty and staff housing will be priced at below-market values, and student residences will be competitively priced.

This research focuses on the 192 student apartments that were completed in 2011 under Phase I of the West Village multiyear project. The numerous aggressive energy efficiency measures incorporated into these apartments include central heat pump water heaters (HPWHs), high efficiency heat pumps for heating and cooling, increased wall and attic insulation, high performance windows, 100% high efficacy lighting, and miscellaneous electrical load (MEL) controls. These measures are estimated to save 37% over the Building America Benchmark for hot-dry climates. The package of measures incorporated at West Village has the potential to lead to market-ready solutions that cost-effectively provide comfort in multifamily buildings while being efficient, safe, and durable.

Along with the growing interest in ultra-efficient buildings, the need for efficient and reliable electric water heating equipment becomes increasingly important. The West Village development aspires to generate all its energy needs, on an annual basis, from on-site clean and renewable resources. In alignment with this goal, the developer chose to create an all-electric development.

To heat water efficiently, centralized HPWHs were selected for each student apartment building. Compared to electric resistance water heaters, HPWHs are more than twice as efficient and, hence, offer the potential for significant water heating energy savings. Roughly 40% of U.S. households currently use electric resistance water heaters, which make the technology a potentially valuable solution on a national scale (DOE 2009). The Building America Hot Water Standing Technical Committee has identified the gap in the knowledge of field performance of HPWH as a barrier to market adoption.

Although there has been a lot of recent research on single-family HPWH performance, there is considerably less research on larger central HPWH systems. In part, this is because there are few central HPWH installations and even fewer product options for central installation. As opposed to single-family HPWH, which are self-contained units, central HPWH systems are split systems in which an outdoor heat pump is paired with a hot water storage tank of sufficient capacity to meet the building's domestic hot water (DHW) loads. The HPWH installed at West Village is a commercial-scale unit, nominally rated at 127,000 Btu/h. While previous field testing of single household HPWHs showed lower-than-rated performance due to a variety of factors (Amaranth and Trueblood 2010; GTI 2010; PGE 2010), monitoring of this central HPWH will help aid the understanding of the effect of usage patterns on system efficiency. The hot water usage patterns of the West Village units are more diversified than those for a typical single-family application

because they are student-occupied residences. Demonstrating HPWH field performance in a multifamily application will provide useful information on the in-situ benefits and costs.

In 1999, California began implementing field verification and diagnostic testing of duct leakage and building envelope leakage by third-party Home Energy Rating System (HERS) raters into the Title 24, Part 6 of the California Building Efficiency Standards compliance procedures. Since that time, third-party HERS verification and testing measures have expanded to include quality insulation installation (QII), equivalent to ENERGY STAR's Thermal Bypass Checklist, and additional HVAC-related verification and testing measures designed to ensure that HVAC systems are installed correctly and to design specifications.

Yet, because of poor construction practices and projects that are cost driven to the lowest bidder, proper building construction practices are frequently not followed. Previous California studies identified poor quality insulation installations (voids and compression of insulation), poor air sealing, and poorly operating mechanical systems due to improperly charged air conditioning equipment, inadequate airflow, and leaky ductwork on homes without HERS inspections (DEG 2002; Proctor et al. 2011). Several of these tests and inspections are required elements in ENERGY STAR, utility, and green building programs and key elements in any quality assurance and quality control (QA/QC) process. Since these tests and inspections have been in place for several years, Alliance for Residential Building Innovation (ARBI) was interested in determining how beneficial the tests and inspections are in ensuring proper installation and if they result in improved construction quality and system performance.

1.2 Research Questions

The primary objective of this project is to evaluate performance and efficiency of the central HPWHs as a strategy to provide efficient electric water heating in ultra-efficient all-electric buildings and in buildings where natural gas is not available. In addition, effectiveness of the quality assurance and quality control processes were evaluated to identify recommendations for large-scale, high performance communities.

The following research questions will be answered in this study:

- What is the measured performance and reliability of the central HPWH and how does it compare to expectations from modeling and manufacturer claims?
- In construction of the apartments, which quality control mechanisms were effective and which processes need improvement for successful implementation of a large-scale high performance community?

Monitoring of the HPWH was initiated at the end of 2011 and will continue for a full year. Therefore, preliminary monitoring results of the HPWH are presented.

2 Project Description

UC Davis's goal for West Village is to minimize the community's energy use and greenhouse gas emission by encouraging bicycle use and public transportation, reducing building energy use, and providing on-site energy generation from a mix of renewable sources.



Figure 1. Photograph of the completed village square surrounded by mixed use and student housing buildings

(courtesy of University of California, Davis)¹

In late 2008, the Davis Energy Group (DEG) began to work with Chevron Energy Solutions (CES) and developer West Village Community Partners (WVCP) to design, evaluate, and quantify the cost effectiveness of energy-efficiency packages for each of the key building types in the project. The goal was to develop optimal efficiency strategies and packages to accomplish the ultra high efficiency objective that would be offset, annually, by on-site renewable energy generation.

In 2009, DEG worked with CES and WVCP to develop energy efficiency measure packages for the multifamily and mixed-use buildings. Results of this work were described in case studies (CARB 2009; CARB 2010; DEG 2010; Dakin et al. 2010).

¹ West Village UC Davis (2011). *Apartment Living*. [Web Photo]. Retrieved from http://westvillage.ucdavis.edu/image-gallery/atct_album_view?b_start:int=0&-C= on October 28, 2011.

Construction of the first phase of student apartments began in 2010 and was completed in September 2011, in time 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). The buildings are of two similar styles, Ramble A and Ramble B. Ramble A is 16,011 ft², and has six, 4-bedroom and six, 3-bedroom apartments. Ramble B is 14,202 ft² with six, 4-bedroom and six, 2-bedroom apartments. Phase I of the project was completed and occupied by September 2011. All phases of the project are scheduled to be completed at the end of 2013. The buildings completed under Phase I are being certified under the LEED for Homes certification program. Along with providing the certification services, DEG also provided third party HERS verification and testing for these buildings for LEED certification.

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

	Number of Buildings	Total Number of Units
Ramble A	13	156
Ramble B	3	36
Total	16	192

Energy efficiency measure (EEM) packages were developed and finalized using an iterative process involving all stakeholders. DEG initially provided a list of potential EEMs for each building type. The project team evaluated and amended the list, vetting it through a process that considered the community energy and cost goals, as well as the builder’s feedback and concerns. Since WVCP had limited experience constructing high performance buildings, DEG supplied substantial documentation to support the case for individual measure cost effectiveness.

At the request of WVCP, DEG performed additional evaluations of certain measures and packages. DEG conducted parametric simulation runs to better illustrate the interaction between individual measures and identify the most cost effective measures. This preliminary exercise helped WVCP better understand the relative benefits of individual measures and illustrated that the cost savings of a package of EEMs is not necessarily equal to the sum of individual EEM savings. For example, WVCP initially had reservations about implementing rigid foam insulation under exterior horizontal siding due to lack of familiarity with installation. However, they decided to include it in the EEM package after modeling demonstrated the measure’s significance to total energy savings.

Several HVAC and water heating system types were evaluated, including central electric boilers for water heating, central gas boilers for space and water heating, individual tankless water heaters for space and water heating, and central HPWH, as well as several solar water heating options. To simplify offsetting building energy use with on-site renewables, the development team chose all-electric buildings. Based on DEG’s analysis, the builder selected air-source heat pumps for space conditioning and central HPWH for domestic water heating. Later fine tuning of system costs by the developer resulted in lower incremental costs for the HPWH than originally estimated.

Later iterations of the West Village Ramble building design included exterior window shading as both a building architectural feature and an energy efficiency measure. The horizontal and

vertical shading elements reduce solar gains entering the individual apartments (Figure 2). While the exterior shading elements were not cost effective as an efficiency measure alone, the developer chose to incorporate them in the south-, east-, and west-facing facades of the student buildings for aesthetics and comfort. The developer also felt that the exterior shades put a visual element to the buildings that celebrated the goals of the community.



Figure 2. Exterior window sunshades on the student apartment buildings

(courtesy of University of California, Davis)

2.1 Measure Details

Table 2 summarizes the energy efficiency measures and their associated incremental costs incorporated in the student housing Ramble buildings. DEG and WVCP completed the incremental cost evaluations for the EEMs in 2009. WVCP provided most of the cost information with DEG's assistance in determining costs for EEMs for which WVCP had little or no experience. These costs, along with the projected energy savings, were used to conduct economic evaluations and develop and optimize the EEM packages. Costs are presented for a single building, Ramble A, which includes 12 units. Total incremental cost is estimated to be about \$56,000 more than a building built to code (Title 24 regional standard), not including photovoltaic (PV) systems. With utility incentives for energy efficiency, the incremental cost is \$50,763. This equates to a net incremental cost of \$4,230 per apartment. DEG continues to work with WVCP to provide final as-built cost data.

Table 2. Student Housing Energy Efficiency Measure Package

Measure	Specification	Incremental Cost
Basic Building Characteristics		
Building Type/Stories	Multifamily, 3 stories	
Number of Buildings	16	
Total Number of Units	192	
Envelope		
Exterior Wall Construction	2 × 6, 16 in. o.c.	
Exterior Wall Insulation	R-21 batt with ½ in. R-3 exterior sheathing	\$5,418
Shared/Party Wall Insulation	R-21 Batt	
Foundation Type and Insulation	Slab—uninsulated	
Roofing Material and Color	Cool Roof Rating Council rated roofing product	
Ceiling Insulation	R-49 blown cellulose	\$791
Roof Deck Insulation	N/A	
Radiant Barrier	Yes	
House Infiltration - Blower Door Test	Yes, SLA 3.0	
Thermal Bypass Inspection - QII	Yes	
Thermal Mass	½ in. Gypcrete on floors 2 and 3	\$2,031
Glass Properties: U-Factor/SHGC		
All Windows	Gilwin dual vinyl—0.32/0.23	\$2,949
HVAC Equipment		
Heating Type and Efficiency	Heat pump/8.5 heating seasonal performance factor	\$9,763
Air Conditioning Type and Efficiency	Heat pump/Seasonal Energy Efficiency Ratio 15 /Energy Efficiency Ratio 12.5	
Heating and Cooling Distribution	Ductwork	
Duct Location and Insulation	Conditioned space/R-6	
Verify Duct Leakage	Tested, <6%	\$5,400
Verify Refrigerant Charge Credit	Yes	
Verify High EER	Yes	
Verify Cooling Coil Air Flow	Yes	
Verify Fan Watt Draw	Yes	
Verify Cooling Right Sizing	Yes, Manual J and Manual D	
Mechanical Ventilation	Exhaust, standard	
Water Heating Equipment		
Water Heater Type and Efficiency	Central A. O. Smith heat pump, COP 2.9 at 65oF.	\$0
HW Distribution	Recirculation, timer+temp	
Appliances and Lighting		
ENERGY STAR Appliances	Dishwasher/refrigerator/washer	\$6,000
Dryer Fuel	Electric	
Oven/Range Fuel	Electric	
Miscellaneous Load Control	GreenWave, energy usage displays	\$10,800
Fluorescent Lighting Package	100% with vacancy controls	\$12,840
	Total incremental cost	\$55,992
	Utility incentives	\$5,229
	Net incremental cost	\$50,763

Following is a brief description of the measures including installation, verification, and documentation procedures. HERS measure verification is in accordance with the California Title 24 HERS verification procedures (CEC 2008).

2.1.1 Thermal Envelope

2.1.1.1 Walls

The exterior wall construction is 2 × 6 framing, 16 in. o.c. with R-21 cavity batt insulation. Additionally, ½ in. of rigid insulation sheathing is installed on the exterior side of the wall to reduce the thermal bridging effects due to framing. Appropriate procedures were employed to ensure structural rigidity when mounting the insulation layer and exterior finish to the framing. The insulation contractor had to ensure the homes comply with Title 24 QII criteria to minimize thermal bypass and achieve full credit for the installed insulation. An air barrier was installed and all gaps and penetrations caulked or otherwise sealed to prevent air movement between conditioned and unconditioned space. All insulation was inspected by a HERS rater; wall insulation was inspected before drywall was installed.

2.1.1.2 Ceiling and Roof

The attic space is insulated at the ceiling level with R-49 blown cellulose. The insulation contractor had to ensure the homes comply with Title 24 QII criteria to minimize thermal bypass and achieve full credit for the installed insulation. A continuous radiant barrier is installed at the top chords of the roof truss and rafters under the roof deck as well as on all vertical surfaces such as gable end walls. The material and installation procedures conform to appropriate ASTM standards. The installed composition shingle roofing product is rated and labeled by the Cool Roof Rating Council.

2.1.1.3 Airtightness

The units are constructed to a specification of 5.25 air changes per hour at 50 Pa (ACH50) or lower, which is equivalent to 3.0 specific leakage area (SLA) to minimize unintentional infiltration and exfiltration.² Penetrations and gaps are caulked or otherwise sealed to prevent air movement between conditioned and unconditioned space. A blower door test was performed by a HERS rater at 50 Pa in compliance with ASTM E779 standard to quantify the leakage rate.

2.1.2 Mechanical Systems

2.1.2.1 Heating and Cooling

Both space heating and cooling are provided by a high efficiency heat pump. Cooling and heating loads, equipment size, and duct size calculations were performed in accordance with Air Conditioning Contractors of America (ACCA) Manual J Residential Load Calculations, Manual S Residential Equipment Selection, and Manual D Residential Duct Systems, respectively. Two-ton heat pumps were sized and specified for all two bedroom units, and all three and four bedroom units were sized and specified with three-ton heat pumps. Nameplate energy efficiency ratio (EER), minimum cooling coil airflow, and air handler fan power draw was verified by a HERS rater. No more than 12 linear ft of ductwork (including the air handler) is installed in

² In California, the California Energy Commission multiplies specific leakage area or SLA by 10,000 to make the numbers more manageable.

unconditioned space. This requires visual verification by a HERS rater for credit under Title 24. All outdoor units are located on the ground outside the building.

2.1.2.2 *Water Heating*

An initial evaluation of HVAC and water heating options was completed for the developer with the base case being individual gas storage tank water heaters. Based on the evaluation, WVCP chose to install central HPWHs. Electric and solar water heating was favored because the development team decided early on to eliminate natural gas from the project. Solar water heating was initially considered but eliminated due to high installation bids and limited roof space for both solar thermal collectors and PV. Individual HPWH were eliminated due to interior space limitations. Incremental costs for the central HPWH were initially estimated at \$1,100 per apartment (\$12,800 per building), but based on bids from contractors and manufacturers, the incremental cost was reduced to \$500 per apartment. By eliminating gas lines and venting, and by gaining interior floor space that was needed for water heaters in the base case, the developer estimated incremental cost savings of \$50 per apartment. For the study, a zero incremental cost was used.

An A.O. Smith (formerly E-TECH) central HPWH system (nominal 127 kBtu/h capacity at 85°F ambient and 100°F inlet water temperature) is installed at each building. There are two, 120-gal storage tanks, both of which have three electric resistance elements totaling 54 kW. A hot water recirculation loop pump that serves the building is controlled by return water temperature and by a timer which shuts it off at night. See Figure 3 through Figure 5 for photographs of the water heating system and monitoring equipment.



Figure 3. HPWH installed on Ramble Building #1



Figure 4. Flow meter installed on the hot water supply line leaving the heat pump unit



Figure 5. Two hot water storage tanks with electric resistance auxiliary heat and water piping. Flow meter and temperature sensor can be seen on the hot water supply line between the two tanks.

2.1.3 Lighting and Appliances

2.1.3.1 Lighting Design

All hardwired lighting is high efficacy lighting. The apartments include a combination of hard-wired linear fluorescent and CFL fixtures. Vacancy sensors are installed in each room.

2.1.3.2 Appliance Selection

Dishwasher, refrigerator, and clothes washer are all current ENERGY STAR-qualified models.

2.1.3.3 Miscellaneous Electric Loads

To provide tenant education on home electricity use and encourage energy savings, energy consumption displays are installed in each unit along with miscellaneous and lighting load controls that can be accessed remotely through the use of smart phones or computers. Monetary penalties are applied for high electricity consumption.

2.1.4 Photovoltaic System

SunPower SPR-225 and SPR-445 modules are installed to service both the student apartment and mixed use buildings. A total of 1.07 MW capacity will provide electricity for the 16-student apartment Ramble buildings in Phase I. Roughly half of the PV panels are installed on the building rooftops and the other half are in a central park. Each apartment has a net metering account with the local utility (Pacific Gas and Electric Company). Because utilities are paid by the developer, it will include a flat monthly utility charge in the rent. Individual unit arrays are sized between 2.6 kW and 4.7 kW depending on the size and orientation of the unit. A separately metered, 19.13-kW PV system is sized for the central HPWH system at each building.

2.2 Preliminary Savings Estimations

BEopt v1.1 was used to model source energy savings for the largest apartment (four-bedroom). Savings are predicted to be 37% over the Building America Benchmark and 22% over the regional standard (Title 24) without PV. Predicted savings exceed the 2011 Building America goal of 30% for hot-dry climates. Apartments were modeled as single detached units because, at the time of this study, BEopt did not have the modeling capabilities for multifamily units or shared walls. End units on each floor were modeled individually and the worst-performing unit type was identified and used for reporting purposes. Additional BEopt modeling limitations include:

- HPWH performance - BEopt v1.1 can't model water heaters with energy factors above 1.0. For this study, we used BEopt v0.9 to model the HPWH because, although BEopt v0.9 can't model HPWHs, it can model electric water heaters with a coefficient of performance (COP) greater than one. To account for some backup electric resistance use, we derated the COP from 2.9 (rated) to 2.2 (simulated). The results of the v0.9 HPWH run were used to modify the revise the hot water energy usage of the v1.1 results.
- Modeling of central water heating systems on the student apartments, including central hot water recirculation. We estimated hot water recirculation energy use from earlier Title 24 modeling of the entire building using DOE-2.

3 Methodology

The scope of this technical report focuses on two primary research topics: monitoring of the HPWH and the effectiveness of the QA/QC process. The remainder of this report is separated according to these two topics. See the Building America test plan for additional details (ARBI 2011).

3.1 Heat Pump Water Heater

3.1.1 General Technical Approach

DEG is collecting one year of detailed data on a single central HPWH to quantify its performance over a range of operating conditions and usage patterns. DHW energy delivery is monitored using water side measurements. Monitoring data are carefully reviewed and analyzed in order to develop a performance map for the HPWH over a range of operating and outdoor conditions.

3.1.2 Operating Conditions

The current manufacturer suggested that the HPWH operate to maintain 140°F in the first storage tank. The resistance elements in each tank operate when the tank temperature falls below 120°F. A tempering valve limits the supply water temperature to the building to 120°F. The system will operate in this mode at least until mid-January. At that time, the developer may lower the setpoint if DEG finds that it can increase system efficiency while maintaining performance. Preliminary indications under fall weather conditions suggest a lower HPWH setpoint and reduced “Tank 1” setpoint can be implemented without compromising supply water temperatures.

3.1.3 Measurements

The site is equipped with a data logger and cellular modem for continuously collecting, storing, and transferring data to the DEG host computer. Sensors are scanned every 15 seconds, and data is summed or averaged (as appropriate) and stored in data logger memory every 15 minutes. A full year of 15-minute data will be collected. Monitoring commenced in the third quarter of 2011 and will conclude in the third quarter of 2012.

3.1.4 Monitoring Data Points

Table 3 lists the measurement points that will be monitored on a continuous basis. Key water side data points are shown in the piping diagram in Figure 6.

Table 3. Measurement Points

Point No.	Abbreviation	Description	Location	Sensor Type	Sensor Manufacturing/ Model
1	TAO	Temperature, air, outdoors	Outdoors, near heat pump	RTD, 4-20ma	RM Young 41372VF
2	RHO	Relative humidity, outdoors		RTD, 4-20ma	
3	TWRECIRC	Temperature, water, recirculation	Mechanical room—DHW	Surface thermocouple	Gordon Watlow
4	TWHPS	Temperature, water, heat pump supply	Mechanical room—DHW	Immersion thermocouple	Gordon Watlow
5	TWHPR	Temperature, water, heat pump return	Mechanical room—DHW	Immersion thermocouple	Gordon Watlow
6	TWH1	Temperature, water, electric heater inlet	Mechanical Room—DHW	Immersion thermocouple	Gordon Watlow
7	TWH2	Temperature, water, DHW supply	Mechanical room—DHW	Immersion thermocouple	Gordon Watlow
8	TWCS	Temperature, water, cold water supply	Mechanical room—DHW	Surface thermocouple	Gordon Watlow
9	FLHP	Flow, heat pump supply	Outdoors, near heat pump	Flow meter	Onicon F-1100
10	FLDHW	Flow, DHW	Mechanical room—DHW	Flow meter	Onicon F-1100
11	EHP	Energy, heat pump	Mechanical room—service panel	Power meter	Wattnode/WNB-3D-240-P
12	EWH1	Energy, electric heater	Mechanical room—service panel	Power meter	Wattnode/WNB-3D-240-P
13	EWH2	Energy, electric heater	Mechanical room—service panel	Power meter	Wattnode/WNB-3D-240-P
14	SCIRC	Status, recirculation pump	Mechanical room—DHW	Status	Hawkeye
15	FLRecirc	Flow, recirculation return	Mechanical room—DHW	Flow meter	Onicon F-1300

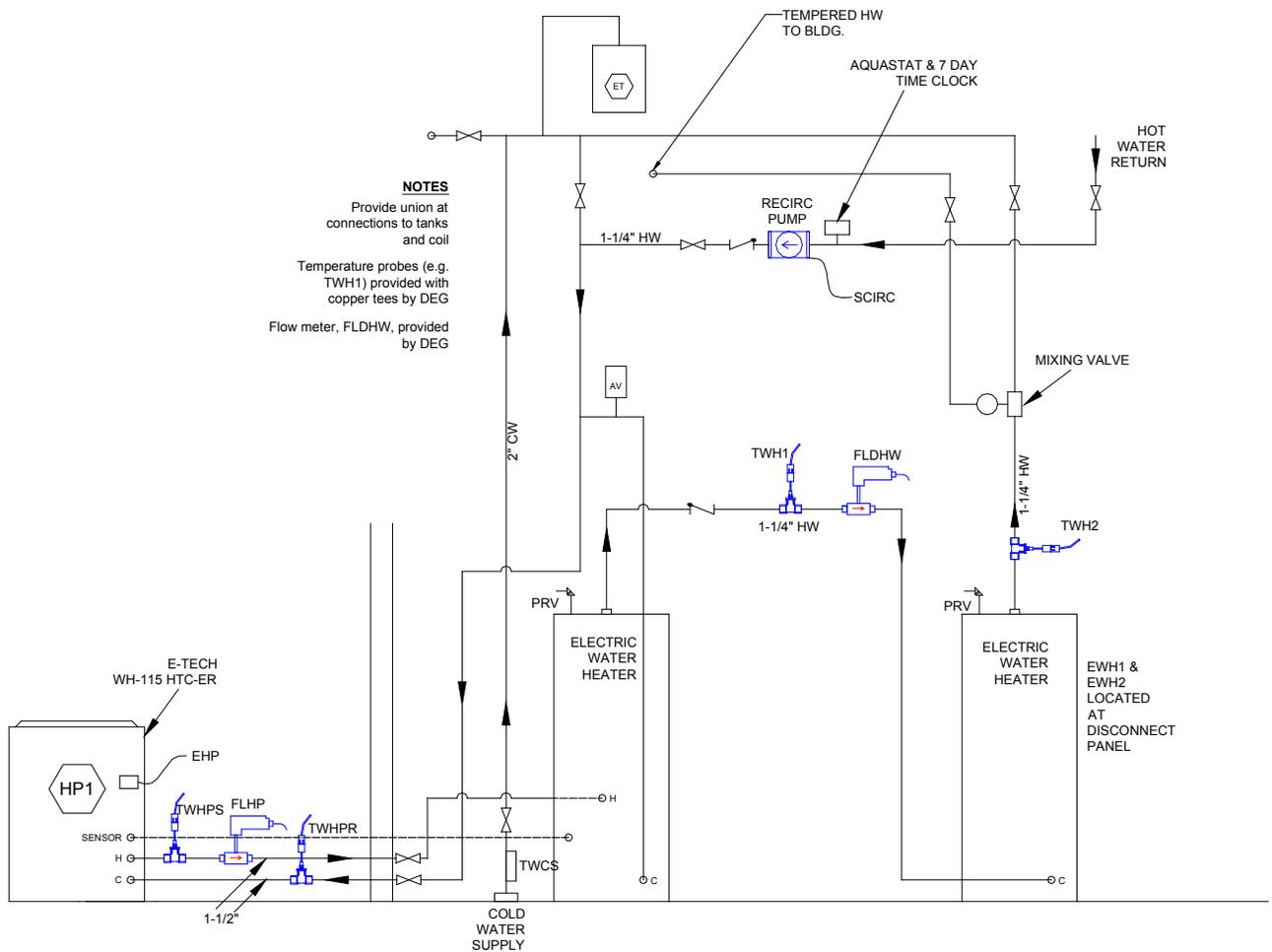


Figure 6. Water heating monitoring sensor locations

3.1.5 Equipment

3.1.5.1 Data Logger Specifications

Data Electronics data loggers (Model DT-50) collect and store monitoring data. Analog inputs are single-ended type (referenced to ground). Digital inputs are used for power monitors and status signals; high speed counter inputs are used with water flow meters. The data loggers are provided with an RS232 communications interface and battery backup.

3.1.5.2 Sensor Types and Specifications

Table 4 lists the types of sensors used for the various monitoring points and their performance specifications. Sensor selection was based on functionality, accuracy, cost, reliability, and durability. Specific model numbers are listed as examples; similar models by other manufacturers may be used. Signal ranges for temperature sensors correspond approximately to listed spans.

Table 4. Sensor Specifications

Type	Application	Mfg/Model	Signal	Span	Accuracy
RTD	Outdoor temperature and RH	Vaisala HMY60	4–20 mA	14°–140°F 0%–100%	±0.5% °F ±2% RH
Type T Thermocouple	Immersion water temperatures	Gordon Watlow Type T	~11mV at 500°F	Range = –328° to 662°F	±0.4%
Flow Meter	Water flow		Pulse		
Large Power Monitor	Heat pump power	Wattnode/WNB-3D-240-P	Pulse	CTA/60	±0.5%
24VAC Relay	Status	Hawkeye	Dry contact	n/a	n/a

3.1.6 Computation of Monitoring Variables

3.1.6.1 Water Heating System Performance

Hot water loads, heat pump unit energy use, resistance element energy use, and recirculation pump energy use is monitored. Ambient temperatures and water temperatures are measured to facilitate development of a performance map of the system that can inform future model development. Measured performance will also be compared to manufacturer’s performance data. Losses from the recirculation system are treated as part of the DHW load. Measured temperatures and calculated energy are based on 15-second data and filtered based on flow events.

Equation 1 determines domestic hot water energy delivered to the units:

$$Q_{delivered} = FLDHW \times (TWH2 - TWCS) \times 8.33 \quad (1)$$

Where

FLDHW	=	domestic hot water flow (gal)
TWH2	=	supply water temperature from water heater (°F)
TWCS	=	cold water supply temperature (°F)
8.33	=	specific heat of water ³ in Btu/°F·gal

Energy contribution from the HPWH is calculated by Equation 2:

$$Q_{HP} = FLHP \times (TWHPS - TWHPR) \times 8.33 \quad (2)$$

³ Over the range of expected temperatures the less than 0.5% variation in specific heat is considered to be within acceptable measurement error.

Where

FWHP	=	heat pump water flow (gal)
TWHPS	=	supply water temperature from heat pump (°F)
TWHPR	=	return water temperature to heat pump (°F)

Measured electric use of the HPWH and electric backup water heater are converted to site Btu using Equation 3 and Equation 4. Recirculation pump power is assumed to be constant during pump operation. Pump power was measured with a one-time measurement, which is used to calculate energy consumption from monitored pump status.

$$E_{HP} = EWHP * 3412 \text{ (Btu)} \quad (3)$$

$$E_{elec} = EWH * 3412 \text{ (Btu)} \quad (4)$$

$$E_{pump} = EPMP * 3412 \text{ (Btu)} \quad (5)$$

Where

EWHP	=	electric use of heat pump water heater (kWh)
EWH	=	electric use of backup water heater (kWh)
EPMP	=	electric use of recirculation pump (kWh)

The effective heat pump and system efficiencies are calculated according to Equation 6 and Equation 7.

$$\text{Effective Heat Pump Efficiency} = Q_{HP}/E_{HP} \quad (6)$$

$$\text{Effective System Efficiency} = Q_{delivered}/(E_{HP} + E_{elec} + E_{pump}) \quad (7)$$

3.2 Quality Assurance/Quality Control Effectiveness

3.2.1 General Technical Approach

Due to the large scope of this project and the deep efficiency measures that were implemented, it was essential to provide a certain degree of quality assurance and quality control throughout the construction process. Phase I of the West Village project is being certified under LEED for Homes. In addition, the builder is participating in Pacific Gas and Electric’s California Multifamily New Homes (CMFNH) utility incentive program. Both programs require certain third-party HERS inspections and tests and provide credit for additional third-party HERS testing. The builder hired Allen Amaro of Amaro Construction Services, who has extensive experience as a verifier in California, to provide the third-party HERS services and coordinate with the construction team. Davis Energy Group and Allen Amaro were responsible for on-site inspections and one-time tests to verify proper installation and implementation of many of the energy features. DEG worked with the HERS rater to identify quality control issues discovered through the process and to determine measures to correct deficiencies, to determine the value provided by third-party HERS rater in the construction process, and to identify deficiencies in the existing process that could be improved. Results are specific to California projects that incorporate HERS testing for energy code compliance and for adherence with utility incentive or green building programs, but results are relatable to other programs’ QA/QC processes.

3.2.2 Measurements

DEG and the HERS rater collected data from the following short-term tests (sampling was conducted where appropriate):

- Thermal Bypass/QII inspections: Visually verify quality insulation installation and building envelope sealing.
- Visually inspect windows, insulation values, duct location (conditioned space) and mechanical equipment, including air conditioning EER.
- ACCA Equipment/Duct Sizing: Review equipment sizing methodology.
- Tight Envelope/Blower Door Testing: Test each apartment using standard protocols to measure per-unit apartment envelope leakage.
- Verify tight duct testing: Conduct duct blaster tests to ensure duct tightness and minimal leakage to outside.
- Conduct HVAC system airflow tests to verify proper airflow. Measure air handler fan power.
- Verify refrigerant charge by direct measurement of subcooling or superheat or by inspecting refrigerant charge gauges at time of commissioning.

In addition to the above HERS-specific inspections and tests, other building measures, like windows (U-factor and SHGC), lighting, and appliances were inspected to ensure that the units were built to meet the design intent. Preinspection meetings were held with the construction team so that all responsible parties were aware of the planned inspections and tests and the associated quality criteria.

4 Results

4.1 Heat Pump Water Heater

4.1.1 System Commissioning

The value of commissioning was highlighted by our experiences with the HPWH monitoring at the West Village project. After monitoring equipment was installed and commissioned in September 2011, DEG immediately observed that the entire water heating load was being met by the electric resistance storage water heaters, which were set at 120°F. There was also a control issue whereby the heat pump circulation pump and evaporator fan were operating, but the compressor was not. Because the fan and pump appeared to be operating normally, it was not obvious that the compressor was not operating by simple visual observation. WVCP and the installing plumber were notified, and the equipment manufacturer was brought in to assess the situation. An A.O. Smith representative inspected the installation in late September and determined that a remote immersion sensor for the heat pump had not been installed. A.O. Smith provided a temperature sensor, which was installed on the tank jacket. Subsequent monitoring showed that the heat pump still did not operate, and the electric resistance storage tanks continued to provide all hot water. Once notified, the installer found the temperature setting on the heat pump was too low. The manufacturer also felt that the current location for the tank sensor was resulting in inaccurate readings. In October, A.O. Smith directed the installer to relocate the temperature sensor in a thermal well inside the storage tank. The system was then set up per manufacturer recommendations: 140°F heat pump setpoint, 120°F resistance heat setpoint in each tank, and 120°F tempering valve setting to the recirculation loop. With this approach, the HPWH is the primary heating source, with electric resistance heating only called during high load situations in which the tank temperatures fall below 120°F. The downside of this strategy is that the high heat pump setpoint will lead to lower HPWH efficiency. If the setpoints for both heat pump and storage tank water heaters can be lowered without compromising hot water delivery temperatures, the heat pump can operate at higher efficiencies.

Since the temperature sensor was moved to the tank well, the system has operated reliably and almost exclusively without the need for electric resistance heating. At this time, system modifications are being completed on the other 15 units at the complex. Preliminary monitoring results, based on three months of winter operation, suggest that the combined system efficiency (HPWH with supplemental electric storage resistance heat) is approximately 2.6, not factoring recirculation energy. The preliminary field efficiency is close to the rated HPWH COP of 2.9. Detailed performance evaluations will be completed as a more extended dataset is collected in 2012.

Without the benefit of monitoring, the system malfunction would likely not have been noticed for some time. This experience highlights the need for proper system commissioning, especially with unfamiliar technology or systems with multiple units and multiple setpoints. Apparently, the standard level of commissioning for these units is to verify HPWH operation by observing outdoor unit fan operation and checking performance by observing hot water supply at the building. Clearly, more sophisticated processes need to be followed in the future. Ideally, the manufacturer would provide a simple set of measurements including power (or amperage draw) and HPWH supply and return water temperature as a basic commissioning check.

4.1.2 Heat Pump Water Heater Performance

Preliminary performance data is being presented at this time as DEG works through the various HPWH system commissioning issues. Initial data collected in early October includes data when the system was operating solely in electric resistance heating mode. During this period, which also experienced the more favorable system operating conditions of early October (warmer inlet water temperatures, lower recirculation loop losses), the average daily electrical consumption was approximately 57 kWh/day. In November, with the HPWH operating reliably, average daily electrical consumption totaled about 42 kWh/day and daily hot water loads averaged roughly 340 gal/day, or less than 30 gal/day per apartment. The observed 30 gal/day load is lower than anticipated during the initial project modeling phase, but likely can be attributed to water-conserving appliances, including low flow showerheads, efficient clothes washers, and, perhaps, lower-than-expected hot water use for food preparation and dish washing.

A simplistic comparison of the 57 kWh/day electric heating use with the 42 kWh/day HPWH use does not take into account changes in hot water load, and colder November inlet air and water temperatures, which affect the energy comparison. A more thorough energy use study will be conducted as monitoring is completed in 2012.

Figure 7 plots key monitoring data for November 21 through November 27. Fifteen-minute temperature data are plotted on the left axis; average power demand on the right. Water temperature of the supply to the tempering valve and the return from the recirculation loop are identified. All hot water demands, with the exception of a brief interval on the morning of November 21, were met solely by the HPWH.

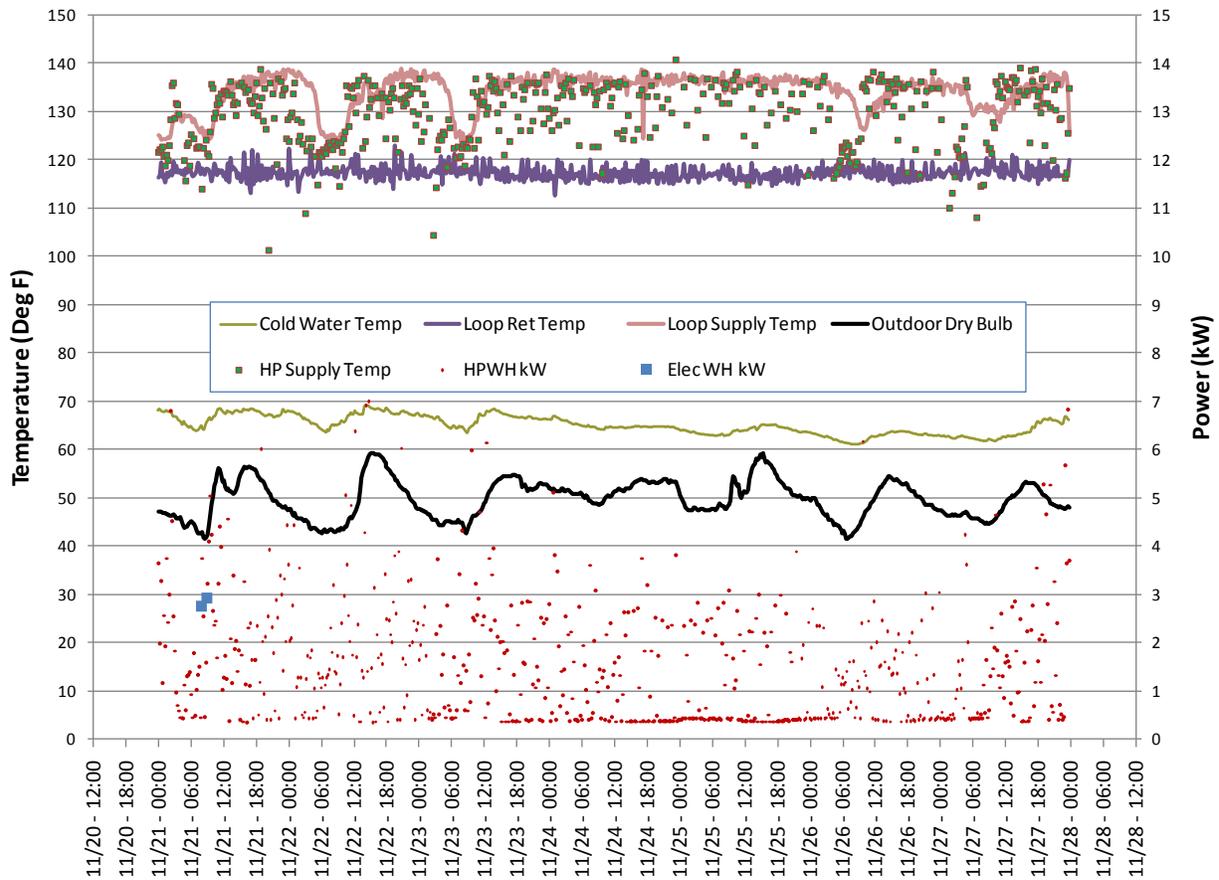


Figure 7. West Village HPWH system monitoring data (November 21–27, 2011)

4.2 Quality Assurance/Quality Control Effectiveness

DEG evaluated the HERS inspection process and procedures used at West Village as part of LEED for Homes and California’s field verification and diagnostic testing services. The builder was very supportive of the HERS process even though the company had minimal experience building in California, following Title 24 energy code requirements, or using the HERS process. Builder representatives followed the process from beginning to end, which was very useful for continuity and quality assurance.

Two principal types of HERS QA/QC measures implemented: envelope measures, specifically QII, and diagnostic testing of mechanical systems. See Section 3.2.2 for a list of HERS measures included in this project. See the Title 24 Reference Appendices for details of the requirements (CEC 2008). The following is a description of the process and lessons learned.

4.2.1 Home Energy Rating System Measure Summary

4.2.1.1 Quality Insulation Installation (QII)

The QII credit under Title 24 is granted for correct installation of insulation and sealing of penetrations to create a substantially airtight envelope with sufficient thermal breaks between conditioned and unconditioned spaces. This is similar to the Thermal Bypass Inspection Checklist required through the ENERGY STAR program. To verify this measure, the HERS rater conducted two inspections at the following stages:

- After framing was complete and before insulation was installed to inspect air sealing measures covered by insulation.
- After insulation and before drywall to verify that batt insulation completely fills the cavities without gaps or voids.

During the first inspection, the rater trained representatives from all the pertinent trades (insulation, framing, mechanical, plumbing, electrical, and builder) on the QII verification process (see Figure 8). The rater defined what would be required of each contractor to pass the final inspection and explained the intent of the protocols and inspections. This initial training helped establish a working relationship between the rater and the trades and was an essential part of the process to create an understanding that the HERS rater was part of the team. In the typical process, HERS raters do not visit the project until after insulation is installed, at which point identified defects create extra work for the contractor and delays in the construction process. At this point, the insulation contractor and builder are often responsible for correcting issues and the other trades are not given any feedback about the defects. Because of the value of this initial meeting, DEG has written this initial QII training into all its LEED contracts.



Figure 8. Initial QII training with subcontractors

Under Title 24 procedures, building sampling is allowed for HERS verification. Initially, the expectation was that once a standard quality of workmanship was attained, verified sampling would be conducted on a minimum of one in every seven units. During inspections, however, there were consistently enough defects that required remediation that the rater never felt comfortable with allowing sampling. Some of the common problem areas included improper sealing around draft stops, top plates, and around window frames, as well as missed insulation in

interstitial cavities. The regulations state that any gap greater than 1/8 in. must be addressed. Often, the HERS rater had to point out insulation deficiencies in these problem areas. The supervisors, who participated in walk-through inspections with the HERS rater, gained knowledge and understanding of the issues and were eventually able to identify and catch most problem areas in the field. In contrast, the installation crew had a high turnover rate; crew members were often hired with little or no experience and were not trained on QII procedures, which resulted in ongoing insulation quality issues.

4.2.1.2 Mechanical Verifications

There were six HERS measures that required coordination with the mechanical contractor. While there was a representative from the mechanical team present at the initial training for QII, specifics of the mechanical measures were not covered during that meeting. When it came time to verify these measures, it was determined that the mechanical contractor was working with a previous version of Title 24 documents and was unaware that any HVAC HERS measures were required. The contractor was resistant to work with the team and felt that testing was outside of the scope of work. Fortunately, the developer was able to work with the contractors and consulting team to resolve the issues.

Similar to the QII verification, most HERS raters only go onsite to verify an installation and communicate with the subcontractors only if defects need to be remedied. In this case, the rater coordinated visits such that measure verification was done simultaneously by the contractor and the rater. For example, refrigerant charge was verified at the time of air conditioner charging and duct leakage was tested when the installer tested the ducts.⁴ To verify contractor gauge accuracy, the contractor and the rater periodically compared their gauges' reading on a single unit. In this style, the rater helped the contractor move through the process while ensuring quality workmanship at the same time. This process allows for immediate feedback to the contractor and rectification of any problems, as well as saves time for both the rater and the contractor since it can eliminate additional trips to make corrections.

Results of refrigerant charge, airflow, fan power draw, and EER verifications all showed that the units were installed per specification. Only minimal changes were required on some units to meet the required specifications. Duct leakage testing of the first installations did show unacceptable values (>6% of system airflow) and required substantial remediation. Primarily, this was a result of a lack of sealing at connection points such as between boots and registers. Once the contractor became aware of installation practices that contribute to duct leakage, the problems were avoided on later installations.

4.2.1.3 Building Infiltration/Blower Door Testing

In California, the mechanical contractor is typically responsible for infiltration testing procedures prior to HERS rater verification. This is because the mechanical contractor is more likely to be familiar with use of the blower door equipment and testing procedures. However, the tightness of the envelope is a byproduct of the work done by almost all trades including the framer and

⁴ Under Title 24 all HERS measures need to also be tested and verified by the installer. There are exceptions if the installer agrees to use the HERS rater's values and waive their right to test it themselves. This is often done with measures such as building infiltration and duct leakage where the installer doesn't own the necessary equipment.

insulation, plumbing, and electrical contractors. DEG's experience has been that few mechanical contractors want this responsibility and/or have the proper equipment and training. At West Village, like most other projects for which blower door testing is required, the mechanical contractor subcontracted testing and verification to the HERS rater.

Problems can arise if the blower door tests demonstrate infiltration values above those in compliance with Title 24 or other programs. When remediation is necessary, it can be difficult to identify the source of infiltration. Further, matching the source of infiltration with the accountable trade contractor is difficult. As an alternative, some builders re-run the Title 24 building compliance software using the higher tested leakage values in hopes of still meeting the minimum performance criteria.

Blower door testing at West Village was completed on a per unit basis, without isolating leakage to outside from leakage to neighboring units. Measured blower door test results were lower than the 5.25 ACH50 threshold specified in Title 24. Measured blower door tests showed the units achieved ACH50 values between 2.83 and 5.12 with an average of 3.73 (equivalent to 2.13 SLA). In this case, because envelope leakage was lower than the threshold, no remediation was necessary. This is in part attributable to the training and commissioning of the building envelope and sealing measures under QII.

4.2.1.4 ACCA J/S/D Equipment and Duct Sizing

LEED for Homes requires room-by-room load calculations and duct sizing procedures for each unit using ACCA Manual J, S and D methodology or equivalent. Since January 2011, this is also required by California code for all new HVAC installations. At present, most builders, contractors, and building officials are not aware of the code, so participation in LEED helps make the project team aware of the requirements. This requirement is a good policy to ensure that a design-based methodology is used to size equipment and ductwork, but there are no provisions in the LEED for Homes program or in the California code for checking the accuracy of calculations. Neither code officials nor LEED for Homes Green Raters are qualified to accurately review these calculations, so there is still the risk of oversized equipment being installed. The software tools that are commonly used are good, but it is very easy to enter incorrect data and get inaccurate results. Also, using the software does not ensure that installation of ductwork is consistent with the design.

4.2.2 Home Energy Rating System Provider Registration

Under the current version of Title 24, the California Energy Commission requires online registration of low-rise residential projects that use HERS measures. The goal is to generate a database to track the implementation of HERS measures and establish trends in the building market. An online registry is managed by the HERS provider, which in turn trains and manages the HERS raters. Currently the sole HERS provider in California is CalCERTS. The builder, energy consultant, subcontractors, and HERS rater must coordinate with CalCERTS to register the project and document the implementation and verification of HERS measures using its online service. This project was the first experience for many of the team members with the online service, which has been required for low-rise residential buildings since January 2010. The process was further complicated by the large number of units. For example, the mechanical installer had to submit seven forms for each of the 192 units equaling 1,344 different uploads. Unfortunately, CalCERTS does not have any tools for summarizing the project status to gauge

the pass rate or percent completion. DEG attempted to quantify how the units performed in testing from the CalCERTS website and found the task so tedious that, instead, acquired the data from the HERS rater's hard copies.

Because of the time commitment of registration, it is important to begin the process early in the project to help the subcontractors, energy consultants, and the HERS rater properly budget their time. Additionally the builder must realize that the cost of implementing each HERS measure is not only the incremental cost of any materials but also an incremental cost of time associated with the registration process.

5 Conclusions and Recommendations

5.1 Heat Pump Water Heater

During 2011, limited monitoring data were collected on HPWH operation at one building in West Village. The most valuable part of the monitoring was that it identified performance issues with the HPWHs and gaps in the commissioning procedures that contributed to the performance issues. The data showed that the evaporator fans and circulating pumps were operating, but the compressors were not. Water heating setpoints were programmed to favor electric resistance operation. Without the information from the data, it is not clear how long the systems would have remained in electric resistance heating mode. Since identifying the problem, the developer has engaged the manufacturer and the installing plumber to correct the problem on all buildings. Monitoring data were indispensable in that process.

Since the system was properly commissioned, it has been running reliably with heating provided almost exclusively by the HPWH. As the winter months begin, it is expected that more resistance heating will occur as water heating loads increase, inlet water temperature falls, and outdoor temperature reduces heat pump capacity. Monitoring will continue at least through the summer of 2012. DEG will work with the developer to test an alternative control strategy that should result in improved HPWH performance. Findings will be presented in a 2012 technical report.

5.2 Quality Assurance/Quality Control Effectiveness

The current quality control process of using third party HERS raters to test and verify operation and installation of key building components is far from perfect. At West Village, the QA/QC process did, however, ensure that elements of the building design were installed to a higher standard than they would have been without the process. In general, we learned that, in the absence of a HERS rater, workmanship will revert to previous quality levels and result in under-performing buildings. The current construction market is so cost driven that training is a minor afterthought for many contractors. With high rates of turnover, especially among lower-paid positions that do not require experience or education, investing in employee training is not deemed cost effective.

Most employees who install batt insulation are not sufficiently qualified or trained to meet the standards of QII. QII procedures and inspections have been in place in California since 2005, but, in both DEG's and the HERS rater's experience, proper installation of batt insulation and envelope sealing does not occur unless a third-party HERS rater is inspecting, catching mistakes and ensuring that mistakes are corrected.

In California, HVAC contractors are required by code to test duct leakage for all newly installed ducted HVAC systems. Based on experience from the HERS rater, contractors do not typically field test duct installation unless a HERS rater is verifying duct leakage as part of the project.

Additional field training of HERS raters is imperative. Current HERS rater training for certification is content intensive and does not allow for detailed instruction on important topics or adequate field experience with the testing equipment. Continuing education programs and apprenticeships are rare. There can be significant variation in verification results across HERS raters with different degrees of training and experience.

Especially in large developments such as West Village, it is difficult to determine whose role it is to coordinate QA/QC and provide the necessary training. Generally Title 24 consultants and HERS raters provide bids for standard energy modeling and verification services, respectively. If a company's bid incorporates coordination, the company is often outbid and loses the job. However, in the absence of coordination and training support, the HERS rater often ends up expending substantial effort on the back end. Most building companies do not have employees or a representative with the overall building science and QA/QC experience necessary to provide this coordination.

There are several improvements that can be made to expedite the online HERS registration process in California. Inputting HERS information to the online registry is a fairly new requirement and, at present, there is only one approved HERS provider in the state (CalCERTS). The current data entry process is cumbersome and time consuming for the builder, contractor, and HERS rater. There are frequent issues with the online registry that slow the process further. To reduce data entry time, the provider should offer a single form for all applicable HERS measures instead of a separate form for each measure and each unit. Builders and contractors would benefit from more information and better training on the additional requirements and costs associated in the HERS registration process. Most trades are not familiar with these changes and may not have the computer skills to accurately and efficiently enter the data.

Based on our experience from this project, we make the following recommendations:

- Bring a HERS rater on early in the process so he or she can train and coordinate with the construction team and conduct verifications at the appropriate project stage.
- Establish a consistent work force that is involved from the initial training through the installation process to promote consistent work quality and minimize remediation efforts. This is difficult or impossible for a subcontractor to ensure, but ultimately it provides labor cost savings.
- Incorporate energy specifications in the construction drawing set that goes out for bid. Explicitly spell out the measures that will require third-party HERS rater verification and testing, along with the subcontractor responsibilities in meeting these measures. Contractors often work off drawing sets and are expected to have thoroughly inspected them and fully understand all components of the job. Incorporating energy details may minimize uncertainty about the requirements of the job and, hence, construction defects and rework.
- In early communication with the builder, the HERS rater should describe which HERS measures and energy code requirements apply. Often, builders will have seen the requirements and hired the HERS rater accordingly but may not have an understanding of what to expect from the process and which subcontractors will be affected by the process.
- In preliminary meetings between the HERS rater and the contractors, explicitly cover what is expected of each trade. When outlining requirements for QII, representatives from the builder, insulation, framing, mechanical, plumbing, and electrical contractors should attend. Hold a separate meeting to discuss mechanical measures with the mechanical contractor and, if appropriate as in the case of hydronic systems, the plumbing contractor. In early meetings, all expectations should be addressed, including

which materials are appropriate for use (caulking, etc.), any local requirements, and relevant code changes.

- For effective QII verification, the HERS rater must conduct an inspection at the framing stage before insulation to inspect caulking and sealing that will be covered with insulation, and after insulation is installed but before sheetrock. Caulk and seal inspections are especially important in multifamily projects where shared walls and chases provide additional opportunities for leakage.
- HERS registry should provide an easy-to-access summary of HERS measures and test results by project. Currently the registry is not set up to easily report this information in a summary format, making it very difficult for the builder, building department, or others to view.
- Require that all installed HVAC systems be sized using a design-based methodology like ACCA J, S, and D. Proper sizing is important for avoiding oversized equipment and improperly sized ductwork. It is always recommended that the HVAC sizing be reviewed by qualified individuals to guarantee that proper sizing and the systems be performance tested at completion.

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DOE/GO-102012-3582 • November 2012

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