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SACRAMENTO'S ZERO-ENERGY HOME COMMUNITY

The first step in designing a zero-energy home is to significantly reduce the home's overall energy use. The rest is fairly easy.

by MIKE KEESEE AND ROB HAMMON

PREMIER HOMES

Premier Gardens is a 95-unit infill project designed for entry level first-time homebuyers. Roof-integrated PV panels (RIPV) are standard.

A record number of new homes have been built in Sacramento, California, in the past few years. This boom in new-home construction is leading to increased demand for electricity, raising utility bills and taxing local electrical utility systems. While renewable technology exists to make homes that produce as much electricity as they need, these high-tech homes are not yet marketable to the vast majority of homebuyers, who would find the first costs prohibitive. It is possible, though, to make the homes marketable by combining the best practical energy efficiency features with solar electricity. That's the strategy that the Sacramento Municipal Utility District (SMUD), the customer-owned electricity provider in Sacramento, is using to meet its growing need for residential electricity.

Since 2003, SMUD has been working with DOE's Building America program through a consortium of industry partners, called the Building Industry Research Alliance (BIRA), to make the latest technology for new homes more readily available to builders. A Building America near-term strategy is to help builders create homes that use 60% less energy, including electricity and gas, on an annual basis compared to similar homes that meet the strict California Title 24 energy efficiency regulations. Renewable energy systems can then easily meet the home's energy needs on an annual basis. These homes, which combine energy efficiency features and PV systems, have been labeled Zero-Energy Homes (ZEHs), in reference to the DOE program that originated this approach. (For a discussion of zero-energy homes, see "Zero Home Energy?" *HE* March/April '04, p.2.)

Table 1. Premier Gardens Specifications

	Model 2248	
Dimensions	2,248 ft²	
Foundation	Concrete slab on grade	
	Base T24	ZEH
Walls		
Wall (exterior)	13	13 + R-4.2/ 19 + 4.2 (2x6)
Wall (Garage)	13	13
Floor (above garage)	No	No
Roof		
Roof (attic)	30	38
Roof (at furnace)	19	19
Infiltration test	No	Yes
Roofing	Concrete flat tiles	Concrete flat tiles
Glazing: (Dual pane, vinyl frame with spectrally selective glass)		
U-factor		
Slider (horiz)	0.42	0.37
Slider (vert)	0.42	0.37
Fixed	0.42	0.33
Patio	0.42	0.34
SHGC		
Slider (horz)	0.50	0.32
Slider (vert)	0.50	0.32
Fixed	0.50	0.35
Patio	0.50	0.33
Space heating & cooling		
Furnace: AFUE (House)	0.80	0.91
AC Split: SEER	10.00	14.00 TXV
Duct Insulation/ Location	4.2 (attic)	Buried in insulation (R-13 Equivalent)
Duct Testing	Yes	Yes
ACCA *Manual D*	Yes	Yes
Domestic hot water		
Water heater size	40 gal	Tankless
Energy Factor	0.62	0.82
Distribution type	Standard	Pipe insulation
Third party inspection & tests	Not required	Yes
Fluorescent lighting	Standard	All permanent fixtures
PV System	Not applicable	GE Energy 2188 AC CEC PV System
HERS Score	80	90

Title 24 energy budget (kBtu/year)			Reduction in energy use
Heating	17.23	12.08	30%
Cooling	9.83	3.81	61%
Water heating	10.64	7.28	32%
Total	37.70	23.17	39%

Central air conditioning is a standard feature in new homes built in Sacramento and a major factor in the growth of SMUD's peak electrical demand. SMUD is partnering with the Building America program because it believes that ZEH communities can reduce their peak demand while dramatically reducing new homeowners' utility bills.

Premier Gardens

In 2004, SMUD led a collaborative effort between Premier Homes, a regional production home builder headquartered in Roseville, California; DOE; the National Renewable Energy Laboratory (NREL); ConSol (the BIRA lead team); and GE Energy to build the first all-ZEH community in Sacramento. Premier had offered solar-energy systems as an optional upgrade on earlier projects and proposed including solar as a standard feature in its first Sacramento project, Premier Gardens. Premier Gardens is a 95-unit infill project designed for entry level, first-time homebuyers, and Premier Homes was looking for a way to differentiate its product in a very competitive market dominated by large corporate production home builders. SMUD and ConSol suggested that Premier could add value to Premier Gardens by designing it as a ZEH community. Premier agreed, and the stage was set for building.

The first step in designing a ZEH is to significantly reduce the home's overall energy use. This enables the home builder to install a smaller, less expensive PV system to meet the home's electrical needs. Working with Premier, ConSol assembled an efficiency package that was agreeable to all members of the team and that was the same across all five models featured in Premier Gardens, sized from 1,285 ft² to 2,248 ft² (see Table 1).

ConSol estimated that the energy efficiency measures would reduce the models' total heating, cooling, and water-heating use by 39%–41%, using 2001 Title 24 assumptions and compared to the same model homes with typical features that just meet Title 24 minimum requirements. They also estimated that, if in addition to the heating, cooling, and water heating improvements, incandescent lighting was replaced with fluorescent lighting and standard appliances were replaced with Energy Star-rated appliances, total electrical and natural gas usage would be reduced by 44%–59% and 22%–23%, respectively, compared to baseline data for non-Title 24 energy consumption from the 1997 Pacific Gas and Electric (PG&E) residential survey. Based on these analyses of the Premier model homes, it was estimated that adding a 2kW PV system could reduce the home's net annual electrical use to zero.

PV Performance Counts

One of the major goals of SMUD's ZEH program is to encourage local home builders to adopt newly introduced roof-integrated PV (RIPV) products. The Premier Gardens ZEHs feature a 2.2 kW AC RIPV system manufactured by GE Energy.

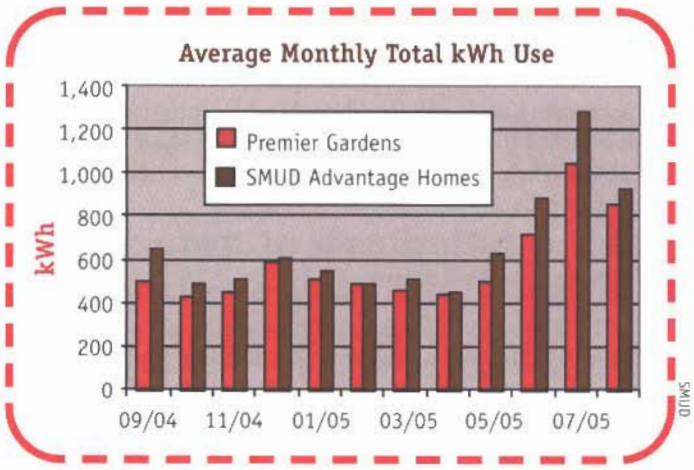

Figure 1. The 12 months of data indicate that the Premier ZEHs use less gross electricity than the SMUD Advantage homes.

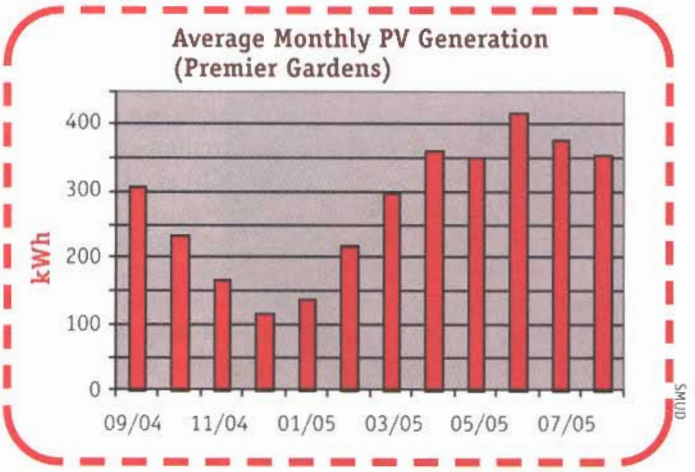

Figure 2. The PV systems in the Premier Garden ZEHs are supplying approximately 50% of the electricity used in the home—an average of 3,333 kWh, out of the total average of 7,007 kWh consumed.

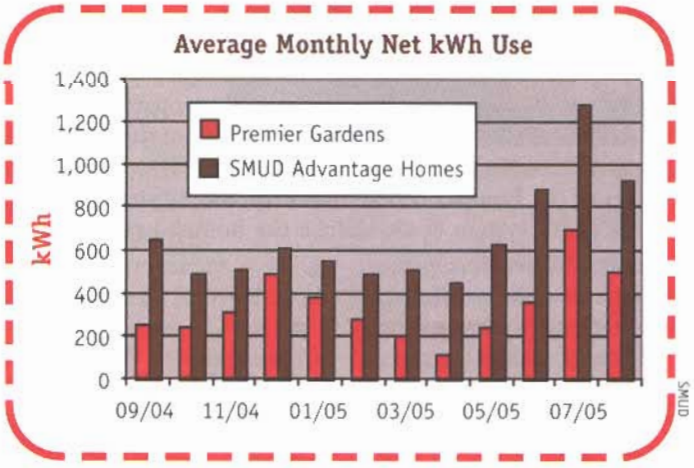

Figure 3. The net electricity use for the Premier homes is 54% less than that for the control group.

The GE Energy solar-electric system consists of 48 GT-55 modules and an SMA Sunny Boy 2500 inverter. The system also features a special PV meter supplied by SMUD to record the energy output of the solar-electric system, which appears on the homeowner's monthly electric bill along with their electricity use.

As part of its ZEH research efforts, SMUD is also evaluating the performance of new RIPV products, now available from several manufacturers. Of particular concern is whether high roof temperatures will affect the performance of these products. SMUD's PV Performance Index is a software tool for evaluating PV system performance based on local, real-time weather data. Weather data are collected from a local weather station and used to estimate PV production based on individual PV system characteristics. This baseline PV production number is then compared to actual monthly PV system production meter reads. To date, the GE Energy RIPV systems are performing exceptionally well, consistently exceeding—by approximately 10% on average over the course of one year—the estimated kWh production.

ZEH Performance

In addition to allowing SMUD to evaluate new PV technology, the Premier Gardens project has enabled SMUD to analyze the impact of ZEH features on customers' energy use and bills. A Premier Homes competitor built 95 non-ZEH homes adjacent to Premier Gardens. These homes are similar in size to the Premier Gardens homes and are marketed to the same demographic. They are SMUD Advantage Homes, with cooling energy usage estimated to be 35% lower than that of a standard Title 24-compliant home. SMUD is comparing Premier Gardens ZEH energy use, utility bills, and peak electric demand to the energy use, utility bills, and peak electric demand of these non-ZEH homes. Monthly meter data are being collected from both the Premier Gardens homes and the SMUD Advantage homes, which are being used as a control group.

The ZEH homes have two meters—a meter that records PV generation of electricity, and a meter that records net-electricity use; the latter is used for billing. Gross electricity use is the sum of the PV generation and the net-electricity use. Using the same approach that it used to estimate PV production, ConSol estimated that the annual electricity savings due to efficiency measures alone would be 26%–37%, depending on the home model and whether the Premier homeowner installed a gas or an electric clothes dryer. (A gas stub in the laundry was part of the efficiency package, allowing the con-

SMUD

The PV systems in the Premier Gardens ZEHs are supplying approximately 50% of the electricity used in the home—an average of 3,333 kWh annually, out of the total average of 7,007 kWh consumed.

sumer to choose a gas clothes dryer, which is more energy efficient than an electric clothes dryer.) These energy savings estimates are lower than those using a comparison to a Title 24 base, partly, at least, because the neighboring homes are SMUD Advantage homes.

SMUD is performing long-term monitoring on all the project homes over the next two years. The first set of homes was occupied starting in July 2004. By September 2004 approximately 20 homes in each community were occupied. A full year of data measured from September 2004 through August 2005 for these homes forms the basis of the following analysis.

The 12 months of data indicate that the Premier ZEHs use less gross electricity than the SMUD Advantage Homes (see Figure 1). However, the energy savings were less than predicted. On average, the ZEH homeowners used 13% less gross electricity than the non-ZEH homeowners and 22% less electricity (gross) than the average SMUD gas-heated residential customer, who uses 750 kWh per month. The discrepancy between the predicted and the actual energy savings is probably due, at least in part, to the fact that the model underestimated miscellaneous electricity use in all the homes (plug loads attributable mostly to consumer electronics and lighting such as table and floor lamps). The PV systems in the Premier Gardens ZEHs are supplying approximately 50% of the electricity used in the home—an average of 3,333 kWh annually, out of the total average of 7,007 kWh consumed (see Figure 2).

The net electricity use for the Premier homes is 54% less than that for the control group (see Figure 3). This is well under the predicted 77%–97%, partly because the control group consists of energy-efficient SMUD Advantage homes. We also believe that the miscellaneous plug loads are substantially higher than the estimate from the 1997 PG&E data, which would further explain the difference between the actual and predicted savings for the Premier homes.

Because the SMUD electricity rates are tiered, it is instructive to compare electricity bills as well as electricity use. The data show that the estimated amount of energy used by both the ZEHs and the non-ZEH SMUD Advantage homes is less than the actual amounts of energy used. However, the absolute magnitude of the savings is exactly as predicted. This result supports the contention that an end use other than those impacted by the efficiency improvements—miscellaneous plug load—is substantially larger than was estimated.

The ZEH homeowners' average annual electricity bills were 59% lower than the bills for non-ZEH homeowners—$350 versus $860; and 60% lower than the average monthly bills for SMUD residential gas-heated customers, at $876 (see Figure 4). (Figure 5 compares average monthly electricity bills for ZEH and non-ZEH homeowners.)

Consumer behavior has a major impact on the results presented in this article. The sample size is currently small. Next year it will be possible to revisit this analysis using all 95 homes from each of the two groups. Until then, it is interesting to note that there was a wide variability in electricity use among the current owners of both ZEH and non-ZEH homes. It is also interesting to note that even in months with relatively less sunshine or months with high electricity use, ZEH homeowners paid significantly less for electricity than non-ZEH homeowners; several of them received an electric bill credit for excess electricity production.

Potential Peak Demand Impact of ZEHs

One of the benefits of distributed solar energy is that it can produce power during summertime peak periods. This is particularly true for a utility like SMUD, where summer peak demand can be over twice as high as winter peak demand. The growth in SMUD's elec-

trical demand is driven largely by new homes, and its system load profile nearly matches the average new home's load profile on the system's peak day (see Figure 6). This confirms the assumption that the new homes' load contributes to the setting of coincident peak electrical demand.

Data collected from a sample of 30 SMUD customers participating in other PV programs indicate that PV systems can reduce a home's peak electrical demand by as much as 13% (0.4 kW). Similarly, analysis of a model home with a southwestern-oriented 2 kW AC PV system showed its features could reduce the home's peak demand by approximately 20%. Combining efficiency measures, such as 14-SEER air conditioning, with properly oriented solar systems in a ZEH has the potential to reduce peak demand even further in new homes. Monitored energy use and solar-production data from an Elk Grove, California, ZEH model home showed a potential peak demand reduction of up to 2.6 kW per home (see "SMUD's ZEH Experience").

With this in mind, SMUD has embarked on a two-year study of the impact that the Premier ZEHs have on peak demand. July 2005 was one of the hottest months in Sacramento weather history, which dates back to 1877. This provided an excellent opportunity to test the effectiveness of the ZEHs in reducing summer peak demand. The average daily high (98°F) was about 4°F higher than the normal daily high (average daily high recorded 1971-2000), and the average daily low (65°F) was the highest in Sacramento history for that month. Therefore, the average customer used about 13% more energy in July 2005 than in July 2004. More importantly, the district set a new record system peak demand. A record peak of 2,959 megawatts (MW) was set at 5 pm on July 15. This represented a 5% increase from the peak of 2,809 MW set on July 22, 2003. SMUD's new peak demand occurred on the fourth 100°F+ day of a seven-day heat storm, in which new peak demand records were set on three consecutive days, July 13-15, 2005.

Average 15-minute interval peak demand data from the Premier Gardens ZEHs and the adjacent SMUD Advantage homes for the month of July showed that the ZEHs had a significantly lower peak demand (see Figure 7). This is especially significant because the non-ZEH homes were SMUD Advantage homes, designed to use at least 35% less cooling energy than homes built to the Title 24 cooling energy standards. For the month of July, the peak demand at 5 pm was 55% less for the ZEH homes than it was for the non-ZEH homes (1.3 kW versus 2.9 kW). The ZEH peak demand savings also held up during the midst of a heat wave. The average peak demand savings from noon to 7pm on the hottest days bear this out (see Table 2).

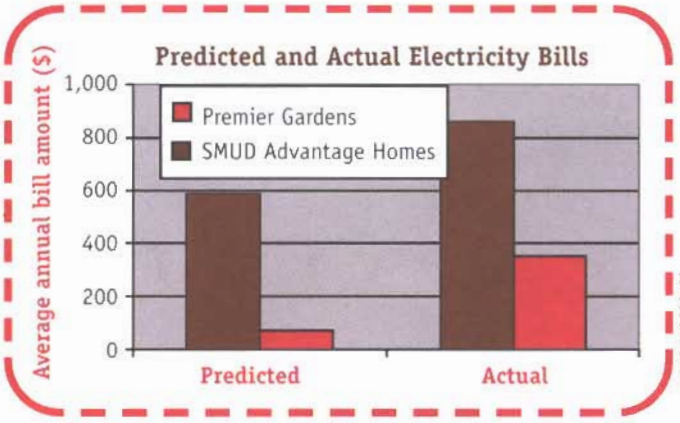

Figure 4. The data show that the estimated amount of energy used by both the ZEHs and the non-ZEH SMUD Advantage homes is less than the actual amounts of energy used. However, the absolute magnitude of the savings is exactly as predicted.

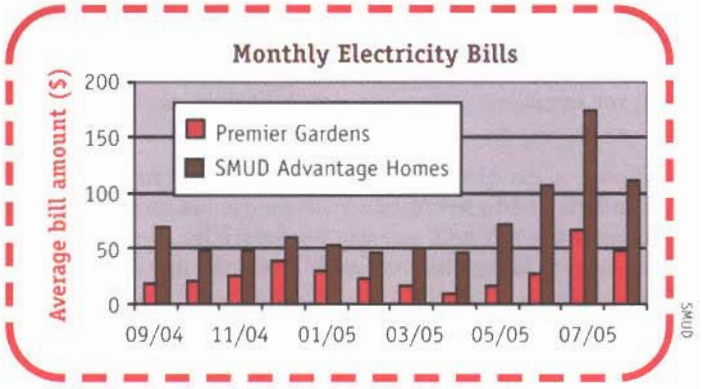

Figure 5. Results support the contention that miscellaneous plug loads are substantially larger than was estimated for all the homes in the study.

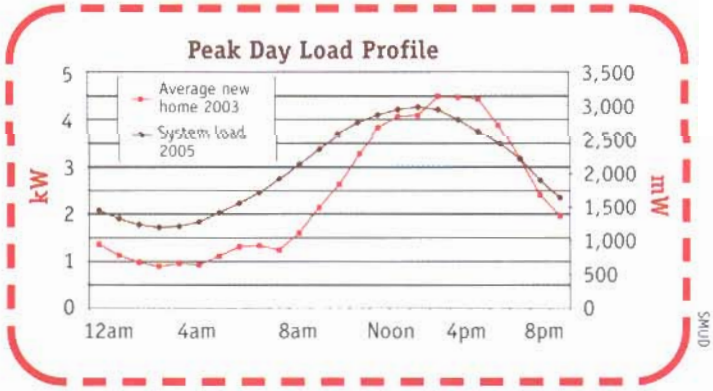

Figure 6. The growth in SMUD's electrical demand growth is driven largely by new homes, and its system load profile nearly matches the average new home's load profile on the system's peak day.

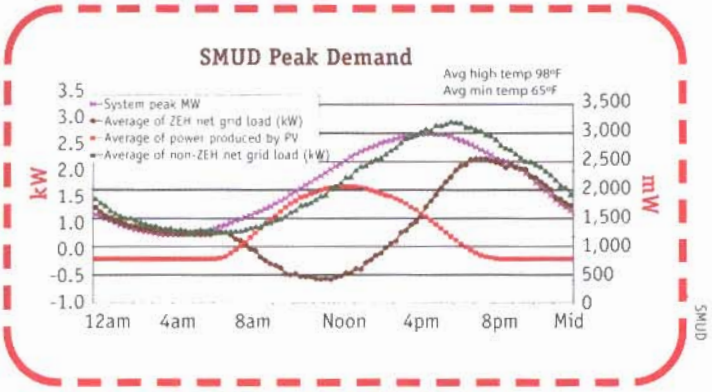

Figure 7. Average 15-minute interval peak demand data from the Premier Gardens ZEH and the adjacent SMUD Advantage homes for the month of July showed that the ZEHs had a significantly lower peak demand.

Table 2. Average Peak Demand

Noon–7 pm

Date	ZEH	Non-ZEH	Difference
July	0.69 kW	2.51 kW	73%
July 9–15	0.63 kW	2.51 kW	75%
July 15	1.14 kW	3.09 kW	63%

Zero-Energy or Zero-Peak Homes?

Under the Building America research program, DOE's minimum near-term research goal is to reduce whole-house energy use in production homes built in hot-dry climates by at least 30% compared to the Building America research benchmark. Working with ConSol, SMUD set the more ambitious goal of reducing the Premier homes'

SMUD's ZEH Program Experience

SMUD has been working toward the goal of achieving Zero Energy Homes since 2001. Beazer Homes was the first builder to construct a ZEH in Sacramento; it was called the Beazer Powerhouse. The Powerhouse featured a package of energy efficiency measures, including SEER-14 air conditioners; R-20 duct and R-38 attic insulation that was estimated to reduce annual electricity usage by 25%; and a 3,300W AC roof-integrated solar system designed by Atlantis Energy Systems, Incorporated. On average, the Powerhouse PV system provides over 60% of the electricity consumed by the home.

In 2003, SMUD began working with DOE's Building America program on ZEHs. Morrison Homes became the first builder to participate in the Building America ZEH effort with their Lakeside community in Elk Grove, California, where zero-energy was offered as an optional upgrade to home buyers. The Lakeside ZEH was designed to reduce total electricity and gas utility bills by 60%, compared to bills for a typical new home. It featured a comprehensive package of energy efficiency measures, including

- low air infiltration;
- vinyl, low-e, spectrally selective windows;
- SEER-14 air conditioner with thermal expansion valve (TXV);
- AFUE 0.92 furnace;
- ACCA-designed HVAC with short duct runs;
- 0.82 energy factor instantaneous water heater;
- insulated hot water pipes;
- fluorescent lighting;
- independent, third-party inspection and testing (to qualify as an Energy Star home); and
- Gecko rooftop-integrated PV system, 2 kW AC AstroPower GT-55.

The Morrison ZEHs exceeded California's stringent Title 24 standards by 35%–41%, depending on the model.

In October 2005, Treasure Homes opened Sacramento's newest ZEH community—Fallen Leaf at Riverbend, a 32-unit infill project. Fallen Leaf is SMUD's most ambitious ZEH project, combining state-of-the-art energy efficiency measures; BP Solar's new low-profile, roof-mounted 2 kW AC Integra solar-electric system; and green building practices in homes that are estimated to exceed the 2005 Title 24 energy standards by 40%. In addition to the energy efficiency features found in the Lakeside and Premier Gardens homes—features such as mechanically designed heating and air conditioning systems, spectrally selective glass windows, fluorescent lighting, and tightly sealed ducts—the homes at Fallen Leaf include

- an attic radiant heat barrier;
- Tyvek House Wrap; and
- a Smart Vent fresh air system (the Smart Vent is a whole-house fan that automatically circulates filtered outdoor air throughout the home via the home's HVAC ducts with all doors and windows secure).

The homes built in Fallen Leaf at Riverbend also meet the requirements of the California Green Builder (CGB) program. Developed by the California Building Industry Association as a voluntary, performance-based program, CGB is one of the most comprehensive builder-driven initiatives in the nation and includes an independent, third-party verification of plans and construction. Green Builder features found in the Fallen Leaf homes include

- energy efficiency;
- reduced greenhouse gas emissions;
- at least 50% reduced construction waste to landfills;
- engineered foundations—10-inch-thick concrete slab, reinforced with 5/8-inch steel rebars;
- water-saving landscaping, irrigation methods,and controls;
- low-flow showers and toilets; and
- engineered-wood products.

Peak Demand Monitoring Methodology

To study the impact ZEHs have on peak demand, we consulted SMUD's Pricing and Rates and Metering groups. They designed a monitoring experiment comparing the peak demand of the ZEH to that of the non-ZEH homes. This experiment was designed to achieve a 90% confidence interval with a +/- 10% margin of error. A sample of 18 randomly selected homes in each community is being monitored with 15-minute interval meters. Pricing and Rates developed a random selection process based on comparably sized homes in each community, and on the distribution of those homes, to chose the sample. Of the PV systems found in the ZEH sample, 11 (61%) face south, 5 (28%) face east, and 2 (11%) face west. The Table summarizes the sample distribution from each subdivision.

Table. Sample Distribution of Monitered Homes

Premier (ZEH)		SMUD Advantage (Non-ZEH)	
Floor Area (ft^2)	# of Samples	Floor Area (ft^2)	# of Samples
1,285	2	1,610	3
1,503	4	1,720	3
1,625	2	1,850	2
1,846	4	2,000	2
2,248	6	2,042	3
		2,384	5
Total	18		18

SMUD's Metering group installed and calibrated MV-90 recording meters at the designated sites to record 15-minute interval data for ZEH and non-ZEH energy use (kWh) and peak demand (kW), and for power produced by the ZEH PV system. (SMUD uses the MV-90 data monitoring system to analyze SMUD's system loads.) Data from the MV 90 recording meters are being collected by district meter readers as part of their monthly electric meter reads. Metering staff then compile these data into Excel spreadsheets that are easily manipulated into daily, weekly, and monthly energy use; peak demand; and PV power production averages.

MV-90 recording meters were installed in April 2005 after the two subdivisions were fully occupied. In May 2005 the Metering group began downloading data and developing a data report format. The first complete energy use data reports were received in June 2005. Monitoring will continue over the next one to two years to determine the long-term impact of ZEHs on peak demand.

electricity and gas consumption—including PV system production—by 60% relative to the more stringent Title 24 baseline. According to simulations done on the Premier models, the energy efficiency measures in these homes would reduce electricity and gas consumption by 39%. Adding the PV system would reduce total energy consumption by a total of 63% relative to Title 24 for heating, cooling, and water heating; and to the 1997 PG&E residential survey data for other end uses.

As noted above, the residents of the Premier homes are using about 13% less electricity than their neighbors in SMUD Advantage homes, and the PV systems in the Premier homes are providing approximately 50% of that electricity. Unfortunately, the SMUD research team has little data on natural gas use in the two communities. Limited data provided voluntarily by two Premier residents show that they are consuming about half as much natural gas as the average PG&E customer—23.5 versus 45 therms per month. Of course, no conclusions can be drawn from a sample of two homes. Nonetheless, the energy performance of the Premier homes has been impressive. More importantly, Premier Gardens homeowners are enjoying substantial savings on their electricity bills, and presumably on their natural gas bills as well. Follow-up studies are planned to provide more detailed evaluations of electricity and gas savings, as well as peak demand reductions in these paired neighborhoods.

SMUD is most impressed by the impact of the Premier Gardens ZEHs on peak electrical demand. Although they were not specifically designed to reduce peak demand, the data collected from July show that peak demand in Premier Gardens homes is significantly lower than that in other new homes.

According to SMUD's Pricing and Rates group, SMUD's peak is driven largely by new-home energy use. Peak load data from 2003 show that more than 70% of the district's peak load growth—40 MW of the 56 MW total—was attributable to new homes added to the district's system. Moreover, the average peak demand of a new home was 4.48 kW. The average peak demand for a Premier ZEH was 2 kW, or almost 55% less. (For more on peak load monitoring, see "Peak Demand Monitoring Methodology.") Furthermore, these impacts on peak demand can be improved by optimizing for peak rather than annual energy use. The goal at Premier Gardens was to optimize for annual energy use, using south orientations wherever possible, and giving equal preference to east or west orientations where south-facing roof surfaces were not available. The sample group of homes providing detailed demand data include south-facing (61%), east-facing (28%), and west-facing (11%) roofs. The east-facing roofs are contributing little or nothing to peak reduction. To optimize the community for peak demand reduction, the PV arrays should be oriented west; south should be the second

choice; and east orientations should be minimized. The data from Premier Gardens will be analyzed to explore these effects, and to help in the planning of future zero-peak communities.

In addition, updated information is needed to learn what impact residential new construction is having on SMUD's current peak demand growth. (For example, is this growth still being driven by residential new construction?) Additional information is also needed to determine what impact various electricity end uses, especially plug loads, have on a home's peak demand, and what ZEHs could do to reduce peak demand in the average new home. ZEHs could also mitigate the impact of new home growth on SMUD's distribution system by extending substation capacity and/or by providing local voltage support. Further research is needed to quantify the transmission and distribution impact of the large-scale deployment of ZEHs. Finally, more than two years of monitoring will be required to verify the persistence of peak demand savings in Premier homes, especially if plug loads are increased in those households.

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For more on Building America's Zero-Energy Homes, go to www.eere.energy.gov/buildings/building_america/about.html#ze.

www.homeenergy.org/links.html