# Impact of Distributed Energy-Efficiency with Solar on Peak Load


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**ABSTRACT**

One of the advertised benefits of distributed solar energy is its ability to produce power during summertime peak periods. This is particularly true in Southwestern states, where summer peaks can be over twice the capacity of winter peaks. To date, however, a limited base of empirical data has been developed to quantify the peak shaving benefit.

The Sacramento Municipal Utility District (SMUD) has been working with the Building America Research Alliance (BIRA, led by ConSol), one of the U.S. Department of Energy's (DOE) Building America teams to encourage local production-home builders to build and sell homes that are designed to produce nearly as much electricity as they consume. These homes combine state-of-the art, energy-efficient construction and appliances with commercially-available solar-electricity systems. The near-term goal is to reduce a new home's total energy bill (electric and gas) by at least 60%.

In 2004, SMUD and BIRA worked with Premier Homes to develop a subdivision-scale zero electricity home (ZEH) project called Premier Gardens. By coincidence, Premier Gardens was built adjacent to a very similar, but non-ZEH subdivision of similar size, affording an unprecedented opportunity to compare the effectiveness of the ZEH design in reducing customer's energy use, utility bills, and, more importantly, peak demand. Both projects were completed and fully occupied in 2005.

This paper provides the results of monitoring of the Premier Gardens ZEH project for more than 1 year of occupancy, including the impact a new ZEH has on annual energy bills and use and peak demand compared to the neighboring control homes.


## Background

Central air conditioning is a standard feature in new homes built in Sacramento and a major factor in SMUD's peak electrical demand growth. In fact, the majority of SMUD's recent load growth is from residential air conditioning. To address this problem, SMUD is partnering with the DOE Building America program through a consortium of industry partners called the Building Industry Research Alliance (BIRA). SMUD is partnering with the Building America Program because the District believes ZEH communities can reduce its peak demand while dramatically reducing new homeowners' utility bills.

The goal of the Building America program is to develop by 2025 practical means that can be used by production builders to build marketable zero energy home communities. Working toward that goal, SMUD has encouraged local production homebuilders to build and sell near-zero energy homes. These near-zero energy homes ("ZEH" in this paper) combine state-of-the art, energy-efficient construction and appliances with commercially available solar-electricity or photovoltaic panels (PVs), typically integrated into the homes' roofs to produce as much electricity as they use over the course of a year and reduce a new home's total annual energy bill, including both electric and gas, by at least 60%.

In 2004, SMUD and ConSol (BIRA team lead) collaborated with Premier Homes to build the first all-ZEH community in Sacramento: Premier Gardens. Premier Homes is a regional production homebuilder headquartered in Roseville, California. Premier Gardens was a 95 unit "in-fill" project designed for entry-level, first-time home buyers, and Premier Homes was looking for a way to differentiate its product in a very competitive market dominated by large, corporate production homebuilders. SMUD and ConSol suggested that Premier could add additional value to Premier Gardens by designing it as a Zero Energy Home community; Premier agreed.

**Figure 1. Premier Gardens ZEH Community: 95 Highly Energy-Efficient Homes with 2 kW (AC) Solar Systems**

The first step in designing a ZEH is to significantly reduce the home's overall energy use, which enables the homebuilder to install a relatively small photovoltaic system to meet the home's electrical needs and, more importantly, helps to reduce the ZEH's overall costs. 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; this efficiency package included:[1]

- Low air infiltration;
- Vinyl, low-e, spectrally selective windows;
- 92 percent efficient furnace (AFUE .92);
- SEER 14 with TXV air conditioner;
- Engineered and right-sized heating and cooling HVAC system;
- Tankless water heater with a .82 Energy Factor;
- Insulated hot water pipes;
- Fluorescent lighting for all permanent light fixtures; and

[1] Five model homes were sold at Premier Gardens: 1,285, 1,503, 1,26, 1,846, and 2,248 square foot homes

- Third-Party inspection and testing of the home's energy efficiency features, including the quality of the insulation installation, duct-leakage test, HVAC register flows, and house air-leakage.

ConSol estimated that the energy efficiency measures would reduce the homes' total heating, cooling and water heating use by between 39% and 41%, depending upon the home model, using California's Title 24 assumptions and compared to the same model homes with typical features to just meet Title 24 minimum requirements. They also estimated that, in addition to the heating, cooling and water heating improvements, substituting fluorescent for incandescent lighting, and Energy Star for standard appliances could reduce total electrical and natural gas usage 44%-59% and 22%-23%, respectively. The baseline data for non-Title 24 energy consumption was obtained from the 1997 PG&E residential survey that provides average energy uses for various end uses. Based on these analyses of the Premier model homes, it was estimated that adding a 2 kW (2,003 watt AC[2]) could reduce the home's net annual electrical use close to zero.

## ZEH Energy Use and Electric-Bill Impacts

The Premier Gardens ZEH project offers an unprecedented opportunity to compare the impact that ZEH features have on customer's energy use and bills. Adjacent to the Premier Gardens project, a competing homebuilder built 95 similarly-sized homes marketed to the same demographic; these neighboring homes were efficient, SMUD Advantage homes, but not as efficient as the Premier ZEH homes and did not have PV roofs[3]. The Premier Gardens ZEH energy use, utility bills, and electric peak-demand can be compared to the energy use, utility bills, and electric peak-demand of SMUD customers living in the adjoining non-ZEH homes.

Monthly meter data is being collected from both the Premier Gardens homes and the neighboring SMUD Advantage homes, which are being used as the control group. The ZEH homes have two meters, a PV meter that records the generation and a net-electricity meter that records the net energy use that is used for billing. Gross electricity use (from the grid plus the PV generation) is the sum of the two. ConSol estimated that the annual energy savings due to efficiency measures alone would be between 26% - 37% depending upon the model and whether the premier homeowner installed a gas or electric clothes dryer – a gas dryer stub was part of the efficiency package. These energy savings estimates are lower than those compared to a Title 24 base because the neighboring homes are SMUD Advantage homes with energy-efficiency measures installed to reduce cooling by approximately 35%.

Data is being collected on all homes, with the occupancy of the first set of homes starting in July 2004. By December 2005 there were 57 homes occupied in both communities. A full year of data, January 2005 through December 2005 for these two sets of 57 homes each form the basis of the following analysis.

These twelve months of data indicate that the Premier ZEHs use less electricity and have lower electricity bills than the control homes. However, the energy savings were less than predicted. On average, the Premier Gardens homeowners used 10 percent less electricity

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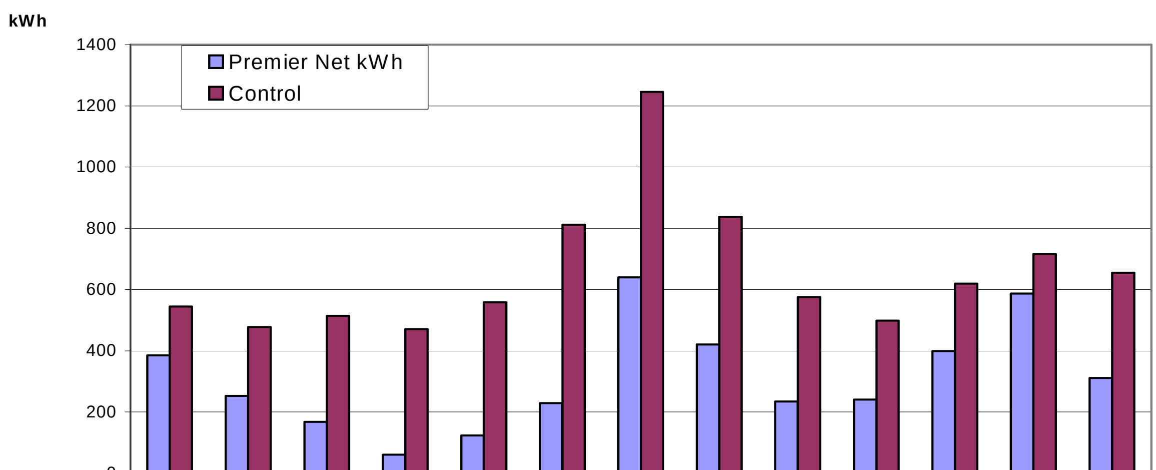
[2] SMUD insists on rating solar systems on their true AC rating.

[3] SMUD Advantage homes require a 35% reduction in cooling energy compared to the base Title 24; these neighboring homes have 10 SEER air conditioners.

(ignoring the contribution from solar) than those living in the non-ZEH homes and 21% less electricity than the average SMUD gas heated residential customer at 750 kWh per month. The discrepancy between the predicted and actual energy savings are likely due, at least in part to an underestimate of the miscellaneous electricity use in all the homes ("plug loads" attributable mostly to consumer electronics and lighting such as table lamps).

The PV systems in the Premier Garden ZEHs are supplying approximately 47% of the electricity used in the home, average 3,329 kWh of the total average 7,066 kWh consumed. Note that the PV systems are oriented to face either east, south or west, depending upon available roof space on each home.

The net energy use for the Premier homes is reduced by 52% compared to the control homes (see figure 2). This again is less than predicted, partially because the control group is energy efficient SMUD Advantage homes that have energy-efficiency features designed to reduce cooling by 35% compared to Title 24. Again, it is also likely that the miscellaneous plug loads are substantially higher than the estimate from the 1997 PG&E data.




| | Jan,05 | Feb, 05 | March, 05 | April, 05 | May, 05 | June, 05 | July, 05 | Aug, 05 | Sept, 05 | Oct, 05 | Nov, 05 | Dec, 05 | Monthly Avg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Premier Net kWh | 385 | 252 | 168 | 61 | 123 | 229 | 640 | 421 | 234 | 241 | 399 | 587 | 312 |
| Control | 545 | 478 | 514 | 471 | 558 | 812 | 1246 | 838 | 575 | 498 | 619 | 716 | 655 |

Figure 2. Comparison of Monthly Average Net Electricity (kWh) Consumption

Because the SMUD electricity rates are tiered (higher rates for higher uses), it is instructive to compare electricity bills as well as electricity use. The Premier Gardens homeowners average annual electric bills were 54 percent lower than the non-ZEH homeowners, $371 versus $812, and 58 percent lower than the average monthly SMUD Residential gas-heated customer bill at $876. Figure 3 provides a comparison of average monthly electricity bills.

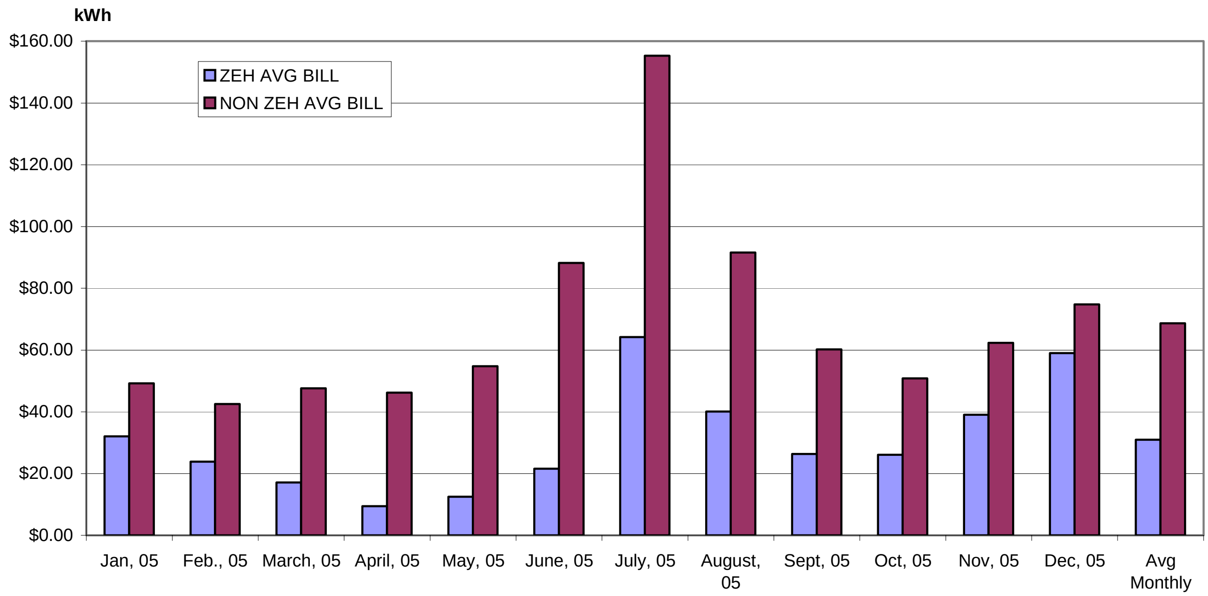



**Figure 3. Comparison of Average Monthly Electric Bills**

The annual average bills for ZEH and Controls are represented by the paired bars on the right side of Figure 3 – these can be compared to the predicted results represented by the paired bars on the left side of Figure 4. These data show that the estimated energy uses for both ZEH and controls are less than the actual bill amounts. However, the absolute magnitude of the savings is close to predicted. This supports the contention that an end-use other than those impacted by the efficiency improvements is substantially larger than in the original estimate. We suggest that the likely candidate is miscellaneous plug loads.

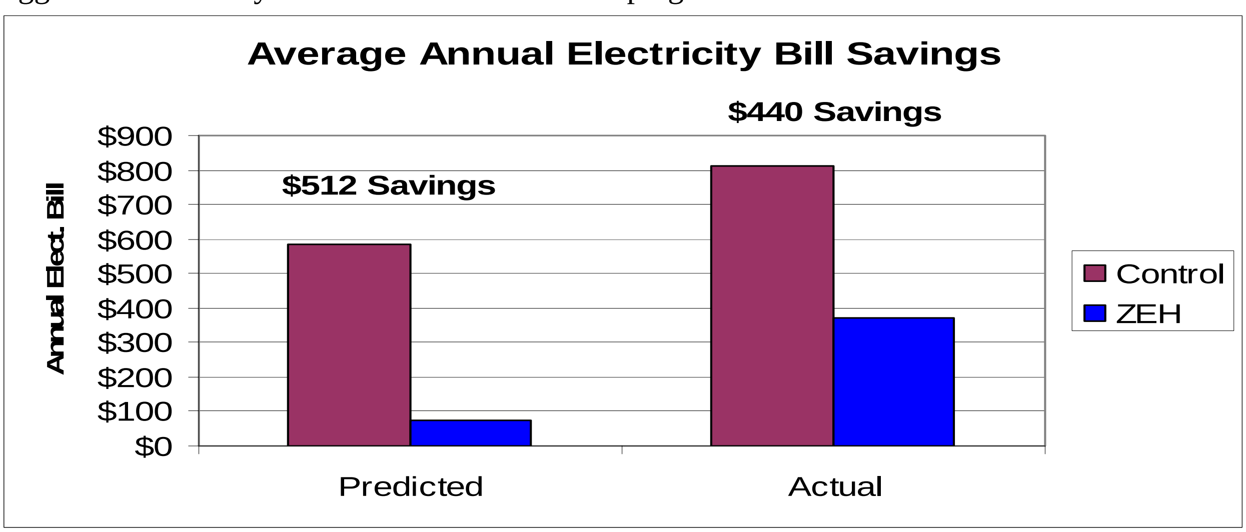
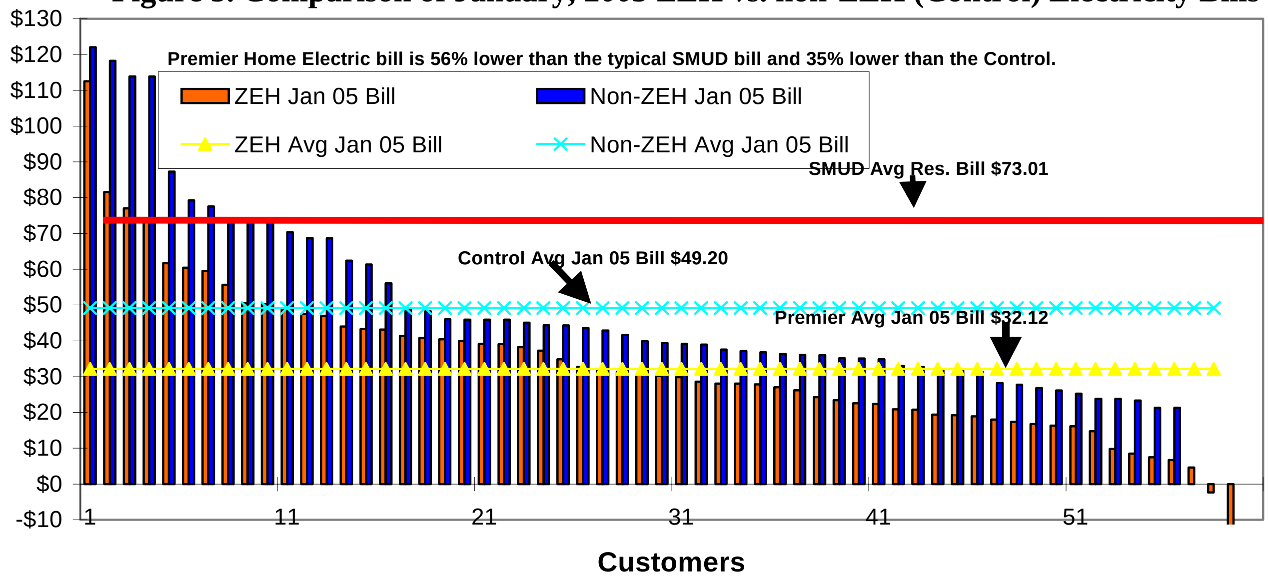



**Figure 4. Predicted vs. Actual Average Annual Electric Bills**

Limited data provided by PG&E indicates that the Premier ZEH residents' use 39% less gas compared to the Control group, 23.1 vs. 37.8 therms per month, and 49% less gas compared to an average PG&E customer at 45 therms per month. These figures indicate substantial natural gas bill savings for the Premier ZEH residents as PG&E's gas prices are tiered with gas prices averaging well above a $1/therm. However, we have not been able to secure average monthly bill data to confirm this. Additional follow up studies are being planned to provide more detailed evaluations of both gas and electric energy savings.

Consumer behavior has a major impact on energy consumption; therefore it is instructive to view the wide variability of electricity use among the current homeowners. Figures 5 and 6 illustrate actual monthly bills for the occupied homes, plotting from highest energy users in each population to the lowest. It is interesting to note that even in low solar months or high electric usage months, the ZEH homeowners experienced significant electric bill reductions with several customers receiving an electric bill credit for excess electricity production.

**Figure 5. Comparison of January, 2005 ZEH vs. non-ZEH (Control) Electricity Bills**



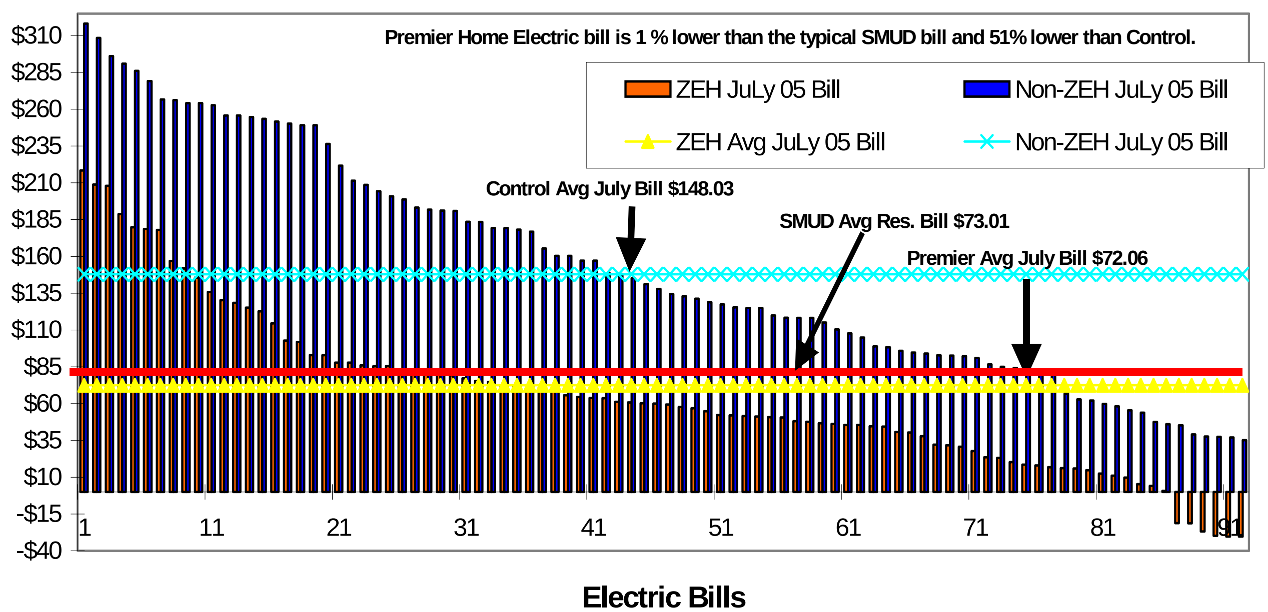
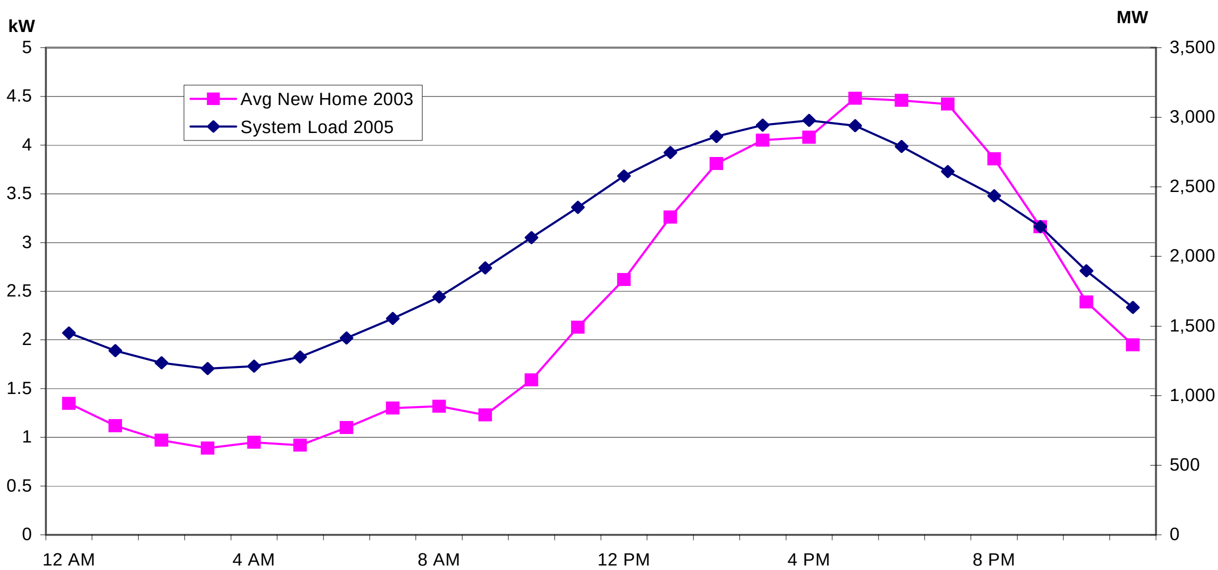



**Figure 6. Comparison of July, 2005 ZEH vs. non-ZEH (Control) Electricity Bills**

## ZEH Peak Demand Impact

SMUD's electric demand growth is largely driven by new homes. The new-home contribution to the District's peak demand growth is reflected in Figure 7. SMUD's system load profile nearly matches the average new home's load profile on the system's peak day (July 15, 2005), confirming the contribution of new homes' load to setting coincident peak electrical demand.

**Figure 7. System Peak Day Load Profile Compared to Average New Home Load Profile, 7/22/03**




With this in mind, SMUD has embarked on a long-term (two-year) study of the impact the Premier Gardens ZEHs has on peak demand. SMUD's Pricing and Rates and Metering groups were consulted for assistance in setting up this study. They designed a monitoring experiment comparing the peak demand of the ZEH to the non-ZEH homes that would achieve a 90% confidence interval with a +/- 10% margin of error; the resulting sample, 18 randomly selected homes in each community, ZEH and control, are being monitored with 15-minute interval meters. As part of this sample, Pricing and Rates developed a random selection process based on comparably sized homes and their distribution in each subdivision to be used in selecting which homes to be monitored. The orientation of the PV systems found on the ZEH sample includes 11 south facing (61%), five-east facing (28%) and two west facing (11%) solar systems.

SMUD's Metering group installed and calibrated MV-90 recording meters at the designated sites to record 15-minute interval data for energy use (kWh) and peak demand (kW) for both control and ZEH homes, and for power produced by the ZEHs' PV systems. The first complete energy use data reports were received in June 2005. Monitoring will continue over the next few years to ascertain the long-term impact of ZEHs.

July 2005 was one of the hottest months in Sacramento weather history, which dates back to 1877. Thus it provided an excellent opportunity to test the effectiveness of the ZEH in reducing summer peak demand. The average daily high (98 degrees F) was about 4 degrees higher than the "normal" daily high,[4] and the daily low temperature of 65 degrees was the highest in Sacramento history for that day. As a result, the average SMUD residential customer used about 13 percent more energy in July 2005 when compared to July 2004. More importantly, the District set a new system peak demand. A new system peak of 2,959 MW was set at 5 pm on July 15th, and represented a 5% increase from the previous peak of 2,809 MW set on July 22, 2003. The District'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.

Demand data compiled from the Premier Gardens ZEHs and adjacent non-ZEH homes show that ZEHs can have a significant impact on a home's peak demand. The graphs that follow show average 15-minute interval peak demand from the Premier Gardens' ZEHs and adjacent non ZEH homes for the month of July, the week of July 9-15th (the week in which a new peak demand was set), and the peak day, July 15th.

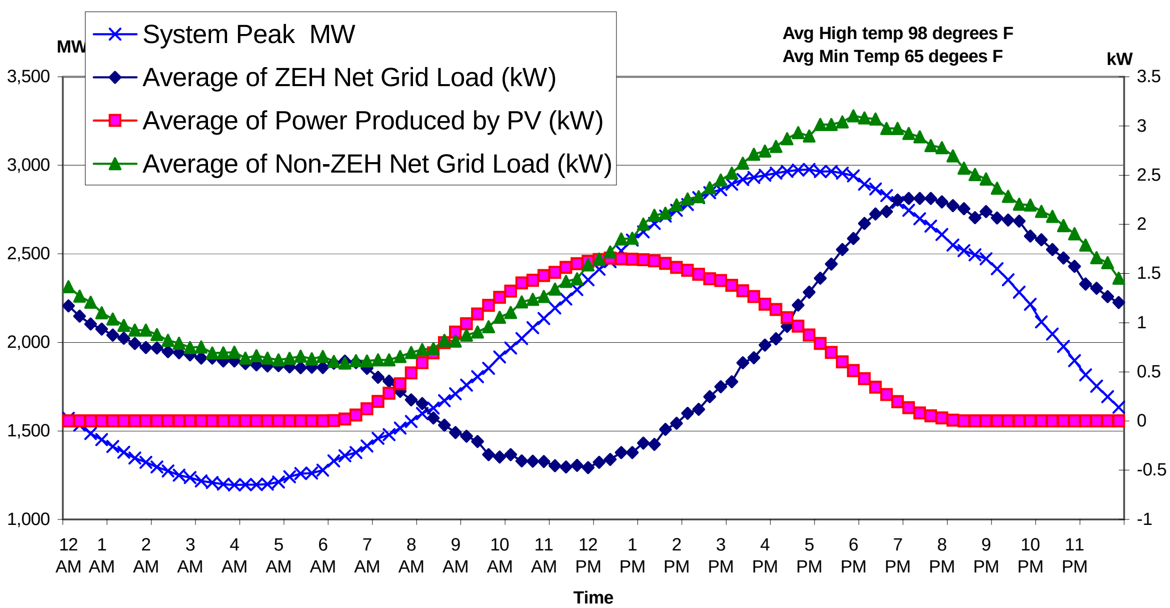



**Figure 8. Average 15 Minute Interval Peak Demand ZEH vs. Control for July, 2005**

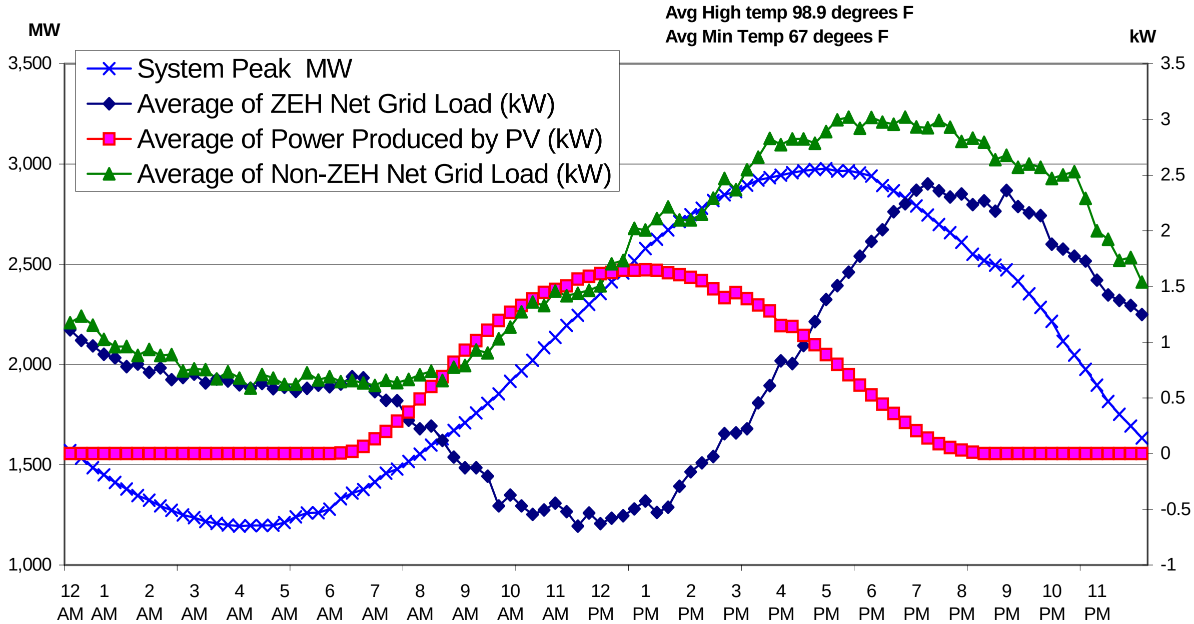



**Figure 9. Average Peak Demand for July 9-15, 2005**

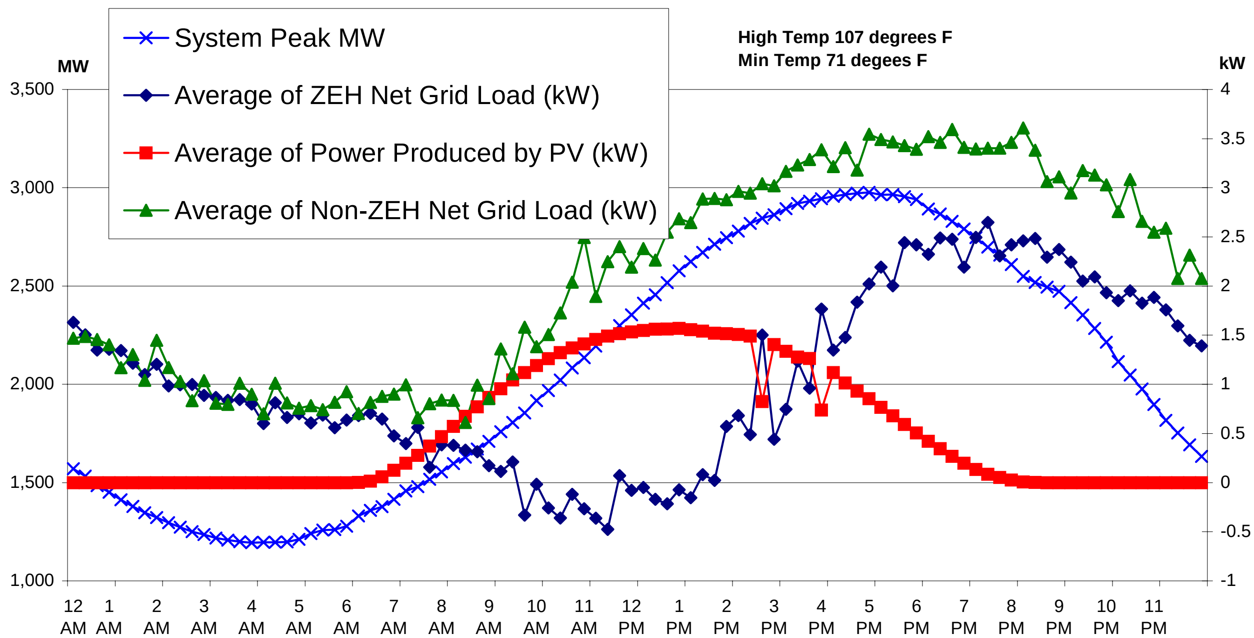



**Figure 10. Average Peak Demand for July 15, 2005**

[4] The normal daily high is the average daily high recorded between 1971-2000.

As the graphs 8-10 in figures show, the ZEHs' peak demand was demonstrably lower than the adjacent, non-ZEH homes. This is especially significant as the non-ZEH homes were SMUD Advantage Homes designed to use 35% less cooling energy than homes built to the Title-24 cooling energy standards. For the month of July, the ZEHs' peak demand at 5 pm was 59% less than the non-ZEH homes (1.3 vs. 2.9 kW). The ZEH peak demand savings also held up during the midst of an extreme "heat storm", being 47% lower for the week of July 9-15$^{th}$ and 43% lower on the peak day, July 15$^{th}$. Average peak demand savings from noon-7pm were also significant (see table 1 below).

| Noon-7pm Avg. Peak Demand Savings | | | |
|---|---|---|---|
| Date | ZEH | Non-ZEH | % Lower |
| July | .069 kW | 2.51 kW | 73% |
| July 9-15 | 0.63 kW | 2.51 kW | 75% |
| July 15 | 1.14 kW | 3.09 kW | 63% |

**Table 1. Average Peak Demand Savings**

## Orientation Effects on ZEH Peak Demand Impact

The solar arrays on the homes are integrated into the roofs of the Premier Gardens homes and they face from east to west, through south. Of the 95 homes, 23, or 24%, of the homes have PV arrays that face east. Table 1 provides the details of the BIPV orientations. While an east-facing array will provide approximately 90% of the annual production that will be produced by the south-facing arrays, which was the design constraint for Premier Gardens, it will not have as great effect on peak.

As mentioned earlier, SMUD placed digital meters on 18 of the homes in each of the near-ZEH Premier Gardens community and in the control community. The SMUD analysis group determined that 18 homes from each community would provide a 90% confidence level that the results would represent the entire community; they also chose the homes to be monitored with these digital meters. The near-ZEH homes had two meters each, one to record solar generation and one to record net energy use from the SMUD grid.

As shown in Table 2, five of the 18 homes with digital metering (28% of the sample) have east-facing arrays, with the remainder being split between south (11, 61%) and west (2, 11%). The digitally-metered homes provided 15-minute interval data for solar generation and net energy use for the Premier Gardens homes, and total electric use for the control homes. Using this data, BIRA was able to characterize the generation for each of the 3 orientations of

PV arrays, and to separate the Premier Gardens data for each home into gross energy use, and solar generation. Using this data, along with site maps of the subdivision, BIRA was able to evaluate the impacts of shifting the east-facing arrays to face west, as well as the practical possibility of making such orientation choices in future residential developments.

Table 2. Orientation of PV Systems at Premier Gardens

| Orientation of PV Systems at Premier Gardens | | | | |
|---|---|---|---|---|
| | Acutal of all 95 | | SMUD's Sample of 18 | |
| | # | % | # | % |
| **SW** | 1 | 1% | | |
| **S** | 54 | 57% | 11 | 61% |
| **E** | **23** | **24%** | **5** | **28%** |
| **W** | 17 | 18% | 2 | 11% |
| **Total** | 95 | | 18 | |

Table 1 shows that the noon-7pm average peak demand savings was over 60% lower than the control home. This noon-7pm time period was chosen so as to cover the peak periods for most summer-peaking electric utilities.

SMUD's peak demand for 2005 occurred at 5pm on July 15. The July data provides a smooth data representative of that from the peak day; therefore, data from the month of July are used to represent the impact of a large number of homes on peak demand on a peak day. Figure 11 illustrates the performance of the near-ZEH and control homes for the month of July.

Figure 11.  Average 15 Minute Interval Peak Demand ZEH vs Control, July 2005

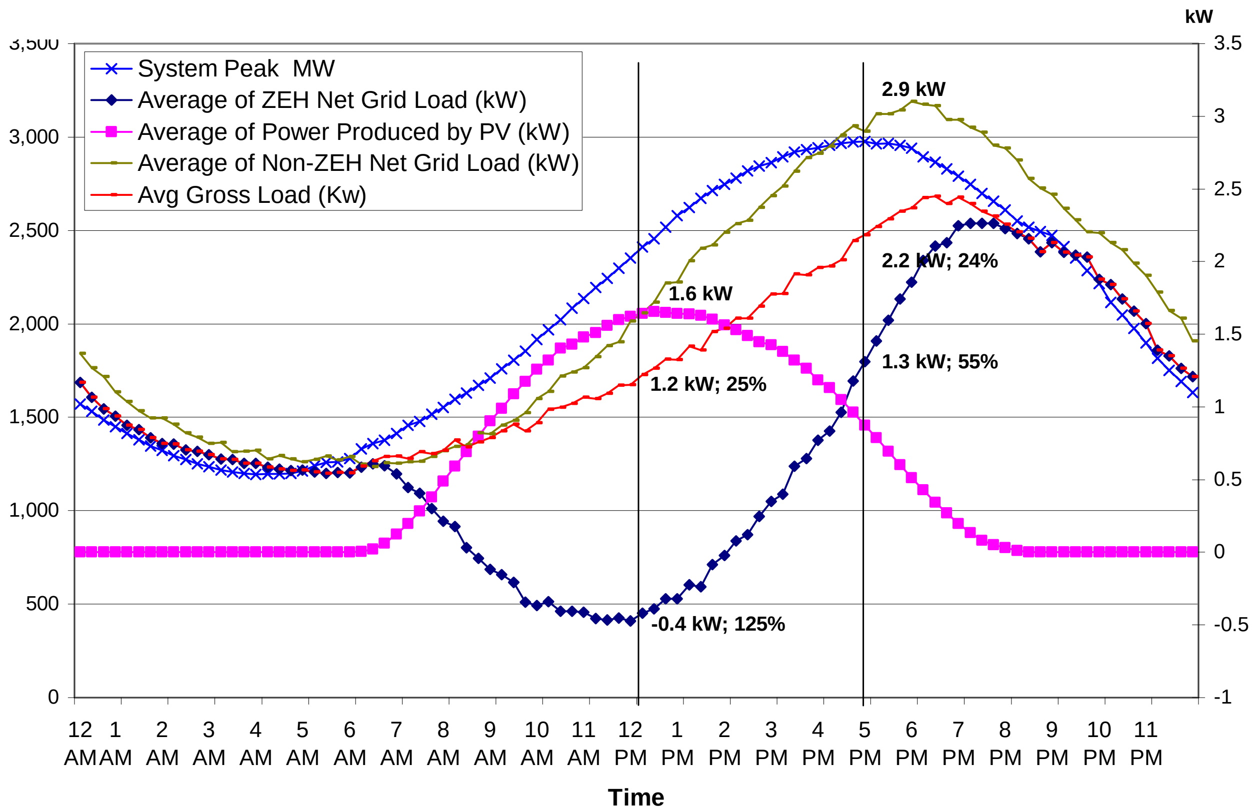
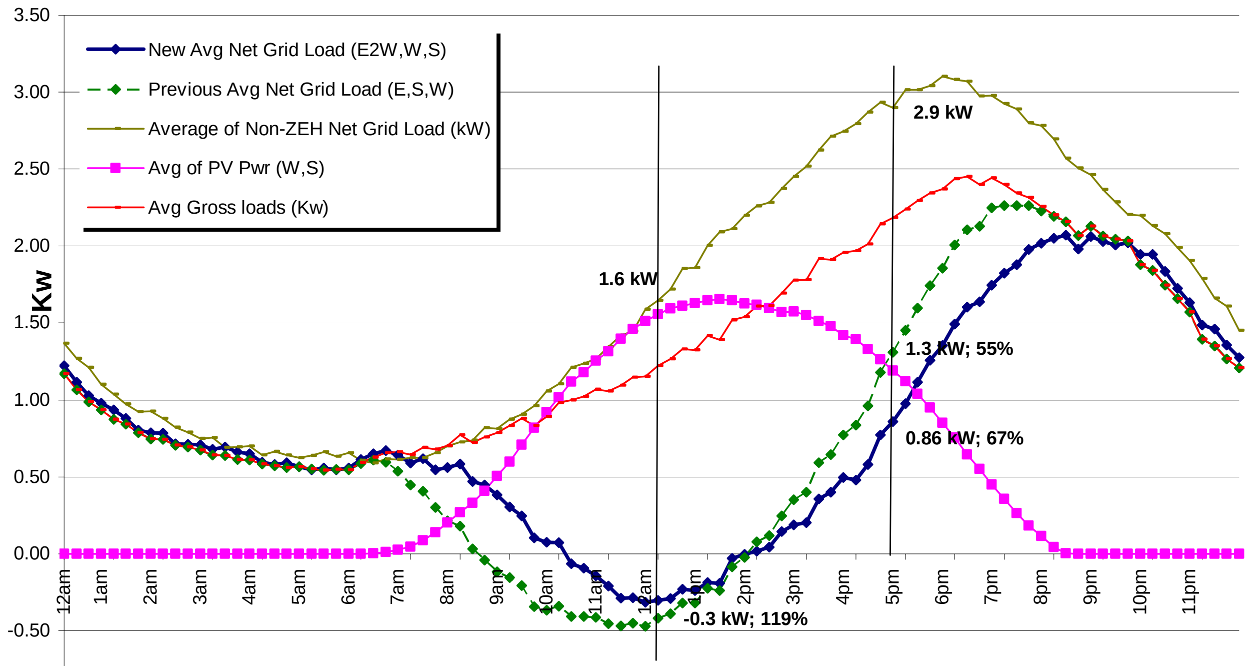



Figure 11 illustrates the near-ZEH demand as the net (dark blue) and the gross (red) electricity uses, and the solar generation (pink). The gross electricity use was derived by adding the generation back to the net. This curve illustrates the following results:

1. the near-ZEH homes peak demand was 55% lower than the control homes at the 5pm peak time for SMUD, and
2. 24% of this reduction was the result of the energy-efficiency attributes of the homes.

Gross-electricity-use curves were produced for all 18 near-ZEH homes from which SMUD provided digital data. For the 5 homes in this data set whose PV arrays were facing east ("east-array homes"), new net demand curves were produced by subtracting the average west-facing generation curves from the gross demand curves of these homes. This new data was then used to provide a new average net generation curve for the population of 18 homes. This data is provided in Figure 12.

Figure 12. Peak Demand near-ZEH vs Control, July 2005; no East-Facing Arrays



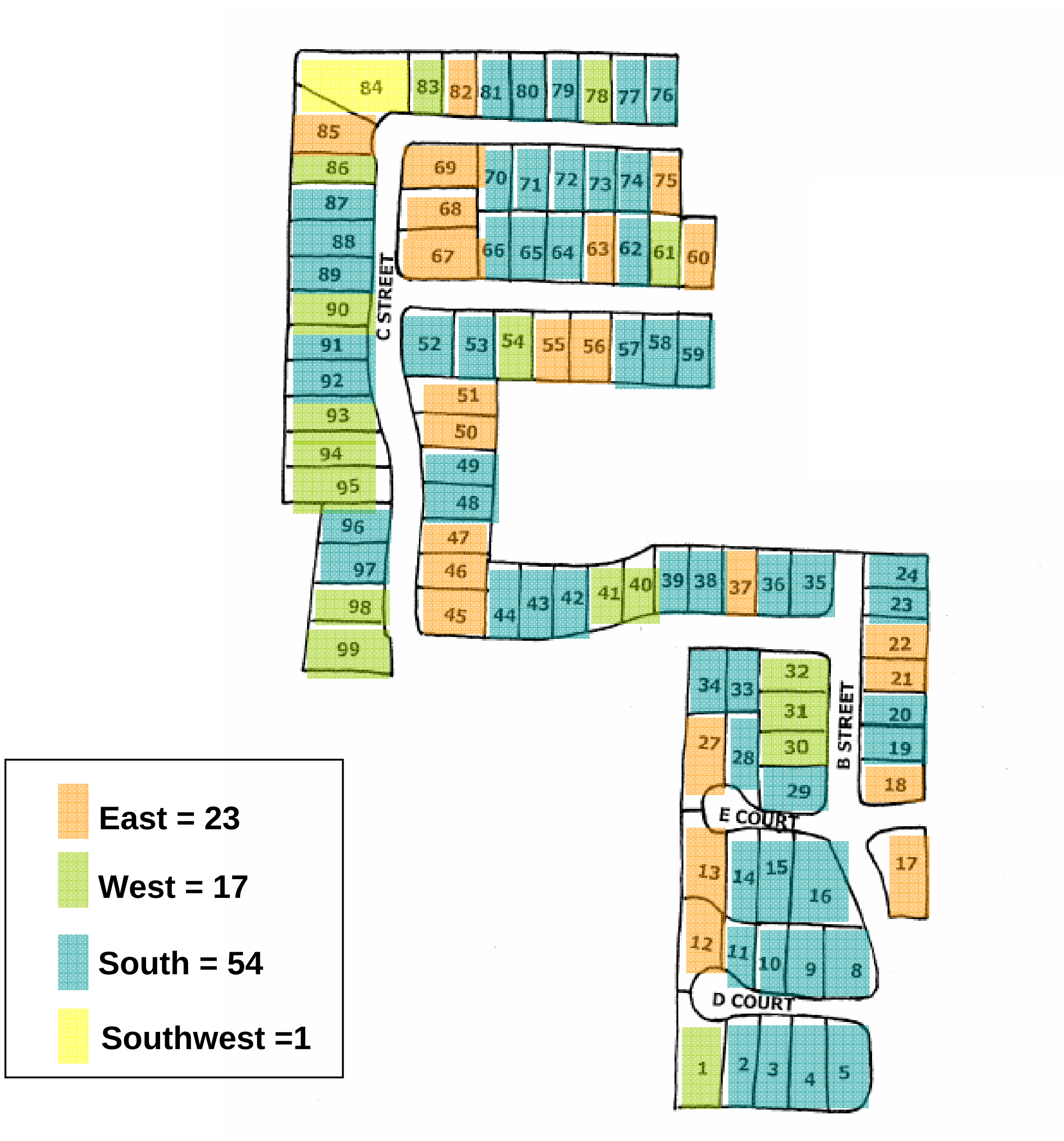

The dark blue curve in Figure 12 shows the revised average demand curve for the near-ZEH homes when there are no east-facing arrays. The original (actual) demand curve that includes the east-facing arrays is dark green in this figure. As can be seen in Figure 12, the demand reduction is improved from 55% to 67% by "moving" the arrays from facing east to facing west. This revised data set has the same 18-home population, but has 11 homes with arrays facing south and 7 with arrays facing west.

In addition to improving the performance of the community in reducing the demand at the peak time (5pm), this array placement also moves the time at which the solar generation drops to zero by approximately 1 hour, providing load support later in the day.

This exercise shows that solar-array orientation should be a factor in the design of the subdivision. To determine the feasibility of minimizing east-facing arrays for future developments, the plot-map and roof-designs for Premier Gardens were analyzed. Figure 13 illustrates the Premier Gardens subdivision as it was built, with the PV array orientation color-coded. This illustration shows that the arrays were:

23 East-facing,
17 West-facing,
54 South facing, and
1 Southwest facing.

Figure 13, Premier Gardens, As-Built, Color-Coded by Solar Array Orientation.




The roof layouts for the east-facing arrays were carefully examined to determine whether it would have been possible to install the PV arrays on the west-facing roof rather than east-facing. As is shown in figure 14, had it been a design constraint, it would relatively easy to install 19 of the 23 east-facing arrays on the west-facing rather than on the east-facing roofs. The remaining 4 west-facing roofs had architectural details that prohibited placing the arrays on the west roofs. However, should it become a stipulation of subdivision layout, it would have been possible to either place other models on these 4 lots or build the mirror-image designs for these 4 homes so that all of the arrays would face between west and south.

Figure 14, Premier Gardens, Optimized for Solar Orientation, Color-Coded by Solar Array Orientation.


This research demonstrates that a community built to Building America standards, where the energy use is reduced by over 50% through a combination of energy-efficiency and on-site renewable generation (PV), summer electric peak-demand can be reduced by two-thirds if the PV arrays are oriented between south and west. Furthermore, in the example Premier Gardens community, had PV orientation been limited to orientations between west and south, it would have been relatively easy to have met this array orientation restriction in all but 4 homes. Given sufficient time and builder motivation, it would have been possible to change the architecture on these remaining 4 lots to permit the arrays to be installed on the west-facing roof.

This experience has demonstrated the importance of engineering/design meetings early in the subdivision design process. To optimize the impact of solar orientation, consideration needs to be given early on to home and roof solar access.

## Zero Energy or Zero Peak Homes?

The current Building America research program minimum research goal is to reduce whole-house energy use for production homes built in hot-dry climates by at least 30% from efficiency measures alone compared to the Building America Research Benchmark.[5] Working with ConSol, SMUD set a more ambitious goal of reducing the Premier Gardens homes' electricity and gas consumption, including the homes' PV system production, by total of 60% relative to the then-current (2001) Title 24 standards and PG&E estimates of other end-uses. According to simulations done on the Premier Homes models, the homes' energy efficiency measures would reduce electric and gas usage by 39 per cent; and adding the PV system would reduce electric and gas consumption by a total 63 percent. [6]

While the actual energy savings have not met the predictions, Premier Gardens homeowners are enjoying substantial electric and natural gas bill savings. More important to SMUD, although the homes were not specifically designed to reduce peak demand (5, or 28%, of the homes have east-facing PV roofs), the aggregate demand from the Premier Gardens homes was significantly reduced compared to that from the neighboring community.[7]

According to SMUD's Pricing and Rates group, SMUD's peak is driven largely by new home energy use. Peak load data from 2003, (the date of SMUD's last peak demand mark) show that more than 70% of the District's peak load growth, 40 MW of the 56 MW added to the District's peak demand, was attributed to new homes added to the District's system. Moreover, the average peak demand of a new home was 4.48 kW. The Premier Gardens' ZEHs average peak demand was 2.02 kW, almost 55% less than the 2003 new home average peak demand.

ZEHs also have the potential to mitigate the impact new home growth has on SMUD's distribution system by extending substation capacity and/or providing local voltage support. Further research is required to quantify the T&D impacts associated with large-scale deployment of ZEHs. SMUD and ConSol are exploring opportunities to evaluate the benefits of ZEH neighborhoods within SMUDs distribution system.

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[5] See Building America Residential System Research Results: Achieving 30% Whole House Energy Savings Level in Hot-Dry and Mixed-Dry Climates, October 2005, NREL/TP-550-38201

[6] Ibid., p. 130.

[7] data collected from July 2005, including the SMUD system-peak day