

California Solar Initiative

**RD&D** ■ Research, Development, Demonstration  
■ and Deployment Program



Final Project Report:

## Low-cost ZNE Retrofit: Monitoring & Evaluation of a Zero Net Energy Retrofit Homes with Energy Storage, Demand Response, and Home Energy Management Systems

Grantee:

**BIRAenergy**

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***[www.CalSolarResearch.ca.gov](http://www.CalSolarResearch.ca.gov)***

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# Preface

The goal of the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program is to foster a sustainable and self-supporting customer-sited solar market. To achieve this, the California Legislature authorized the California Public Utilities Commission (CPUC) to allocate **\$50 million** of the CSI budget to an RD&D program. Strategically, the RD&D program seeks to leverage cost-sharing funds from other state, federal and private research entities, and targets activities across these four stages:

- Grid integration, storage, and metering: 50-65%
- Production technologies: 10-25%
- Business development and deployment: 10-20%
- Integration of energy efficiency, demand response, and storage with photovoltaics (PV)

There are seven key principles that guide the CSI RD&D Program:

1. **Improve the economics of solar technologies** by reducing technology costs and increasing system performance;
2. **Focus on issues that directly benefit California**, and that may not be funded by others;
3. **Fill knowledge gaps** to enable successful, wide-scale deployment of solar distributed generation technologies;
4. **Overcome significant barriers** to technology adoption;
5. **Take advantage of California's wealth of data** from past, current, and future installations to fulfill the above;
6. **Provide bridge funding** to help promising solar technologies transition from a pre-commercial state to full commercial viability; and
7. **Support efforts to address the integration of distributed solar power into the grid** in order to maximize its value to California ratepayers.

For more information about the CSI RD&D Program, please visit the program web site at [www.calsolarresearch.ca.gov](http://www.calsolarresearch.ca.gov).

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## CSI ZNE-Retrofit Home Performance

### I. Executive Summary

As part of a previous, larger California Solar Initiative RD&D Project to evaluate a new PV<sub>AC</sub> kit,<sup>1</sup> an existing home was retrofitted with both the PV test-product and an efficiency retrofit package. This combination was calculated to make the home a Zero Net Energy<sup>2</sup> (ZNE) retrofit. The retrofit package included energy efficiency, demand response (DR), energy management system, intelligent battery storage system and the PV. This package was developed using building energy-use modeling software and the resulting package has all the elements of an integrated demand-side management system (IDSM). Reports from this prior project are available on the CSI RD&D Program and BIRAenergy websites<sup>3</sup>. The home is a 1278 ft<sup>2</sup> single-story home, occupied by a family of four including two small children, in an inland valley east of San Diego, California.

This follow-on project collected additional fifteen-minute interval data for an 18-month period, resulting in approximately 4 years of energy use and generation data from the occupied home: 1.5 years pre-retrofit and 2.5 years post retrofit. The performance of the ZNE design and IDSM features and their impacts on energy reduction and summer peak-demand were examined.

Baseline data collected prior to the retrofit was used to calibrate the BEopt-EnergyPlus simulation software to within 5% of the actual monthly energy use. The predictions from the calibrated software of the ZNE package on home energy use were validated, also within 5%, using post-retrofit simulations, including annual, monthly, and daily energy use and demand load shapes. The retrofit package included an intelligent battery system, and

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<sup>1</sup> CSI RDD&D #2 Project to evaluate a new AC-PV kit from GE titled: Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy

<sup>2</sup> A zero net energy home combines substantial energy-efficiency with on-site PV generation such that the home produces as much energy as it consumes, on a net, annual basis. This ZNE home was designed to be zero site energy, as well as zero net electricity. The current CA definition of ZNE employs Time Dependent Valuation of Energy rather than site energy.

<sup>3</sup> [https://biraenergy.com/projects/CSI\\_Retrofit-ZND-IDSM/](https://biraenergy.com/projects/CSI_Retrofit-ZND-IDSM/)

<http://calsolarresearch.ca.gov/funded-projects/74-low-cost-smart-grid-ready-solar-re-roof-product-enables-residential-solar-energy-efficiency-results>



the 15-minute data of battery function and the impacts on demand load-shapes provided the data needed by another CSI project<sup>4</sup> to develop a computer model of the storage system.

The efficiency features provided a 70% reduction in energy use and a low, flat demand curve. The smart storage system provides the capability to shape residential loads to assist the utility with grid optimization, while being transparent and unobtrusive to the homeowner. Ownership and value of such systems are yet to be resolved.

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<sup>4</sup> CSI RD&D #4: EPRI Grid Impacts Study. For more information, please see:  
<http://calsolarresearch.ca.gov/funded-projects/109-demonstration-of-locally-balanced-zne-communities-using-dr-and-storage-and-evaluation-of-distribution-impacts>

## II. Background - ZNE and IDS M Retrofit

Using energy-modeling software “BEopt” (Building Energy Optimizer)<sup>5</sup>, a package of efficiency measures was developed to decrease energy losses through the building’s envelope, increase efficiency of space heating and cooling systems, water heating and distribution, and most of the kitchen appliances (the package specified to be both high efficiency and capable of communicating for DR). The efficiency package was designed to integrate with the PV system to achieve annual net-zero energy. The energy-efficiency features used in the ZNE design are provided in Appendix A; details regarding the development of the energy-efficiency package and ultimate design and installation are provided in a report from the initial CSI-funded project.<sup>6</sup> Appendix B provides a comparison of the retrofit ZNE package, and the 2008 Title 24 base case requirements.

The ZNE home is single story with 1278 ft<sup>2</sup> of conditioned floor area. It is located in an inland valley east of San Diego, California with hot summer days. Throughout the two CSI research projects, it has been occupied by a family of four including two small children.

In the CSI Solicitation #2 research project, baseline data collected prior to the retrofit was used to calibrate the BEopt-EnergyPlus simulation software such that the simulation results were within 5% of actual energy use. Post-calibrations, energy-use predictions of the ZNE package on home energy use were also validated to be within 5%, including annual, monthly, and daily energy demand as well as load shapes.

## III. Data Sources and Description

BIRAenergy used data from multiple data acquisition systems as the basis for the analysis, including the PV system, the Sunverge Solar Integration System (SIS), direct monitoring of the electrical panel using *e-gauge*, and data from the utility electricity meter.

### 1. Primary Data Sources

The energy-use data collected was electrical power measured in watts or watt-hours and each measurement was time-tagged. The time-tag was composed of year/month/day/hour/minute. The data are in electronic format, primarily in Excel spreadsheet files. The data are stored in folders that identify the source of the data. Within each folder, data are further identified by year and month of collection.

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<sup>5</sup> Residential energy modeling software developed and distributed by the National Renewable Energy Laboratory: <https://beopt.nrel.gov/>. BEopt is a user interface to the U.S. D.O.E. energy simulation software package Energy Plus. BEopt was developed to automate optimization of residential energy-efficiency feature-packages designs. BEopt has found greater use as a more generalized research tool for building scientists for a wide spectrum of energy-use and energy-efficiency research.

<sup>6</sup> CSI RDD&DSol#2: Low Cost Zero Energy Retrofits: [http://biraenergy.com/project\\_reports](http://biraenergy.com/project_reports).

Data was collected and stored in a cloud-based database accessible to members of the research team. The utility meter data was provided by the homeowner through SDGE's web-based customer interface 'Green Button' access and included the actual electric meter values in kWh at 15-minute intervals; this data was in XML format. BIRA converted the XML data to Excel spreadsheet format and stored it in the database. BIRA also downloaded the data from the other data acquisition systems and stored it in the database.

The **utility electricity meter data** was received from SDGE in 15-minute intervals ("15-minute data"). This data started in July 2012 and goes through January 2016. Post-processing is used to reduce 15-minute data to hourly and daily interval data.

The research data is stored as a database on servers accessible by BIRAenergy. Other research teams can be granted use of the data for relevant research projects. Contact the authors of this report for access to the data.

**PV data** was retrieved from the PV system's monitoring subsystem. The PV information system delivered daily power production from October 2012 to the end of the project, December 2015.

The **SIS battery system** provided a wide variety of selectable data points and intervals for the operation and performance of the system. The data begins in October 2013 and runs through December 2015.

An **eGauge monitoring system** was installed to collect data from the large **home appliances**. eGauge uses Current Transformers (CTs) installed on various circuits in the main power panel to measure power drawn by the oven, air conditioner, water heater, clothes dryer, and PV system. eGauge was installed in May 2014 and one-minute data are available from May 2014 through the present. Data is missing from June through July 2015 when the system suffered a breakdown.

## *2. Weather Data for BEopt Simulations*

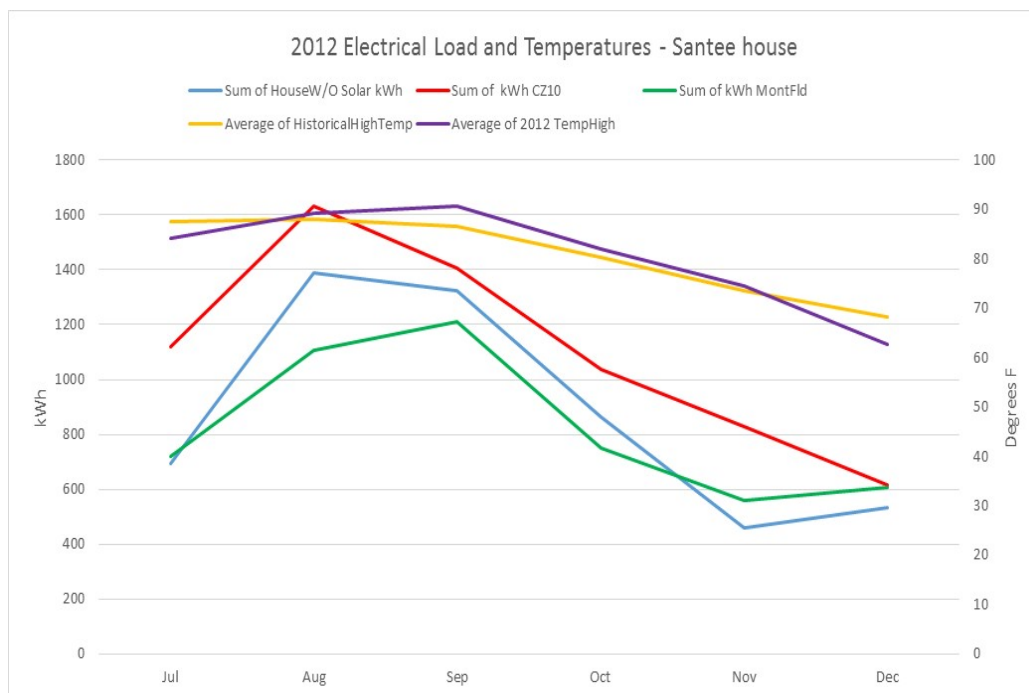
An important simulation input for BEopt is the **weather data** file. The research house is located in Santee, California, which is in Climate Zone 10 (CZ10) as defined by the California Energy Commission. The area covered by this CZ includes a diverse set of microclimates; the CZ weather file relies strongly on Riverside weather. Alternative weather data for a location near Santee was explored to provide a more accurate match to the research site. A complete and compatible weather file was located for Montgomery Field, an airport several miles from the research house and at the same elevation as the Santee home. This weather data provided simulation results that more closely matched the home's actual energy use.

Peak demand from the home is significantly driven by residential cooling which is driven by high outdoor temperatures. The high temperatures in CZ10 weather data and a Weather Underground station located within a mile of the research house were compared to the 10 Year average weather for Montgomery Field as a first evaluation of the correlation to the actual Santee weather. [Figure 1](#) shows a close correlation between the measured high temperatures (purple) and the 10 Year Average Highs (yellow).



Simulations of the baseline home (pre retrofits) were performed using CZ10 weather file and the Montgomery Field weather file. These simulations results were compared with home's actual energy use under baseline conditions. Two simulations, one using the CEC CZ10 weather file and the other using the Montgomery Field weather file, were plotted along with actual monitored energy use for the last half of 2012 – i.e., the home prior to the retrofits.

When simulated using CEC CZ10 weather, the home uses more energy in the hot summer months than it does when simulated using the weather file from the nearby Montgomery filed. This is consistant with summer temperatures being higher in inland Los Angeles area than inland San Diego, where Santee is located. [Figure 1](#) shows the comparisons of electricity loads for the baseline home. The blue line shows the actual energy load of the home for 2012. The red line shows the simulation using the CZ10 weather file. The green line shows the simulation using the Montgomery Field weather file.



**Figure 1. The 2012 daily high temperatures for Santee (Purple) show close correlation to the average of the historical daily high temperatures (Yellow). The Montgomery Field simulation (Green) shows the closest correlation to the Actual Home (Blue).**

## IV. Data – Evaluation of ZNE

### 1. Overall Performance

Electricity use was collected from the Santee ZNE home from July 2012 to January 2016. The brown curve in Figure 2 shows six months of electric data for the baseline house in 2012, prior to any modifications. This curve shows the typical load expected during the summer months.

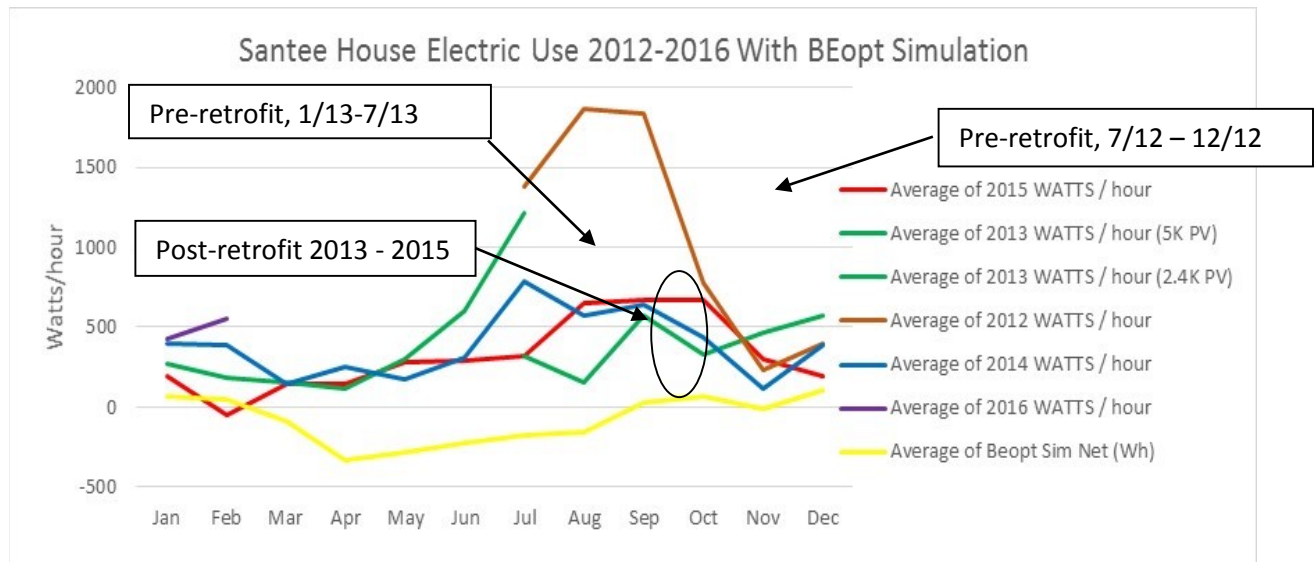


Figure 2. Simulations and monitored energy use of ZNE retrofit. The data in this graph are from several different years, showing electricity use both pre- and post-retrofit. Baseline data (brown data curve, 2012) are pre-retrofit, and illustrate typical summer peaking electricity use. The ZNE retrofit occurred in July 2013 (disconnect in green curve at July 2013). Post ZNE-retrofit electricity use is illustrated by the green curve for the second half of 2013 and continuing through to the end of the project (all of blue and red curves 2014 - 2015). The yellow curve is a BEopt simulation of the home with the ZNE retrofit.

Notice that the pre-retrofit peak is almost 2kW, whereas the post-retrofit peak is less than 0.8kW.

In October 2012, a 2.5 kW<sub>AC</sub> PV system was installed, and in July 2013 the PV system was upgraded to 5kW, high efficiency features were retrofitted into the home and IDS equipment installed, including communicating thermostat, kitchen appliances and clothes washing and drying equipment, and the Nucleus home energy monitor and DR controller. A 10 kWh intelligent battery system, Sunverge SIS, was also installed.

Figure 2 shows annual plots of average hourly electrical use by month from July 2012 through January 2016. The data are generally consistent with yearly variances occurring in the summer months when the family's usage patterns change due to occupancy (vacations) and local weather. The data show

increased summer usage due to operation of the A/C system and increased winter usage due to higher hot water demand (electric water heater<sup>7</sup>) and central heating.

The brown curve in [Figure 2](#) shows the second half of 2012, when the baseline data (whole house meter data) was recorded. The high level of energy use during the hot summer months prior to the retrofit (brown curve, July – Dec 2012, and first half of green curve, Jan – July 2013) is most likely AC usage; there was no detailed end-use monitoring at that time. The green curve shows the home from Jan to July 2013 with 2.5kW of PV on the roof, and, post-IDSM retrofit from July to Dec 2013 (in July 2013 the energy-efficiency retrofits were installed and the PV system was increased to 5kW per the ZNE design). The discontinuity in the green curve (July 2013) is consistent with the timing of the retrofits and the flat energy-use begins with the retrofit (July 2013) and continues throughout the remainder of the evaluation period – July 2013 through Dec 2015. The blue and red curves are data from 2014 and 2015 with the full ZNE – IDSM package installed. The yellow curve is the BEopt simulation of the ZNE home.

Note that the annual energy use curves post-retrofit are flat compared with the pre-retrofit, baseline conditions for the brown (2012) and green (first half of 2013) curves. While the simulation of the ZNE home (yellow curve) lies below the other curves, the generally flat shape of the simulation mimics the post-retrofit energy use data.

When compared to actual house net energy, the BEopt model shows the house produces more energy than it uses and has an overall lower net energy. This difference is due, in part, to the addition of the Sunverge Battery System. The Sunverge SIS system was programmed to charge its batteries using PV energy generated in off-peak hours that exceeds the homes energy demand. The SIS was also programmed to discharge stored electricity when insolation and PV output have substantially declined, co-incident with maximum outdoor temperatures and peak electricity demand due to cooling. This programed discharge from the SIS compensates for the imbalance of demand and generation, the SIS discharges electricity stored in its batteries resulting in an overall leveling-out of the demand curve. See [Figure 2](#), the Brown curve is typical home with afternoon electricity demand and the other curves are actual annual demand curves from the test home with IDSM or the simulation of same.

Neither the charging nor discharging of the batteries is 100% efficient. In addition, PV panels in this home have micro inverters at the output of each panel that convert the DC generated by the solar cells to AC by the integrated micro-inverters. The batteries operate on DC electricity, so the AC electricity produced by this PV system is converted back to DC for storage in the battery system, incurring additional losses. This unintended design effect results in an additional, unmeasured loss of efficiency. With this inefficiency and slightly higher than anticipated miscellaneous electricity use, the actual annual energy-use curves are greater than zero. While this house does not quite achieve net-zero, the

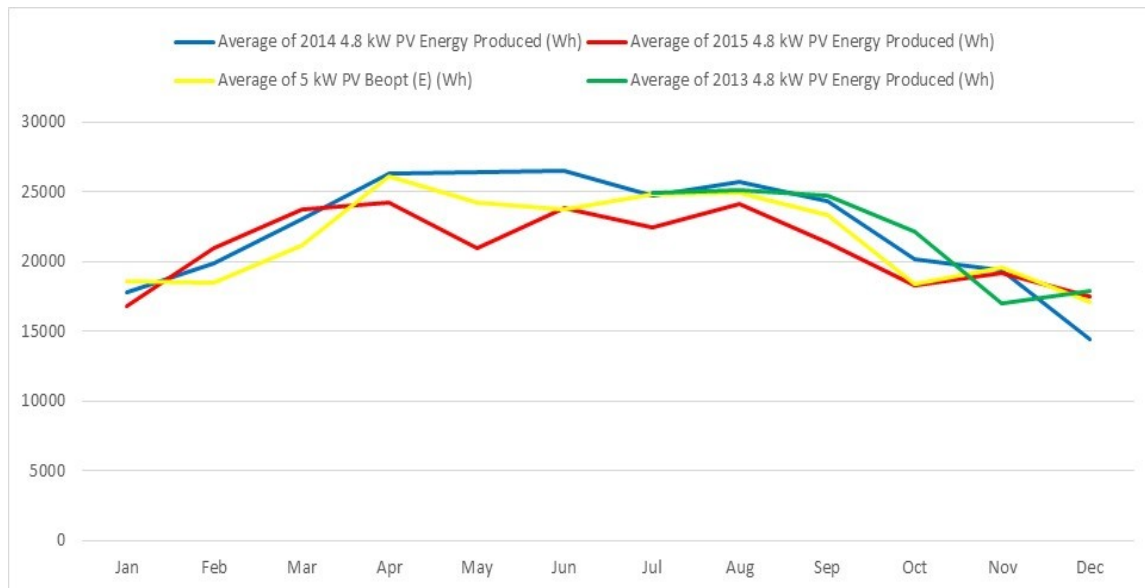
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<sup>7</sup> As part of the energy efficiency improvements, the gas water heater was replaced with a high efficiency electric heat pump water heater (HPWH).

difference between the net-zero simulation and actual energy use over the approximately three years of monitoring are within about 500W/month, as shown in [Figure 2](#).

The current versions of BEopt cannot simulate an intelligent battery system, such as the installed Sunverge SIS. The yellow curve shown in [Figure 2](#) reflects the original design intent and expectations for ZNE, absent energy use or losses due to two additional conversions between AC and DC, as well as losses due to charging or discharging the batteries. Sunverge, the manufacturer of the SIS battery system estimates their round-trip efficiency through the battery system at about 89%

Both actual PV production and BEopt simulation of annual electricity production are shown in [Figure 3](#). This comparison of simulated to actual generation in indicates a very close correlation. Given minimal differences between simulation and actual generation, BEopt does a credible job simulating the AC PV system – even though BEopt models a typical DC PV system.



**Figure 3. Monthly averages of PV production from 5kW PV system over 3 years, and BEopt simulation (yellow). Three years of PV production are compared along with a BEopt simulation of the same size PV system.**

## 2. Air Conditioning and Large Appliance Energy Use

End-use data from several large appliances including the air conditioning system were examined. Large appliances were monitored at the electrical box and individually simulated for comparison between BEopt simulations and actual energy use. [Figure 4](#) shows a comparison of air conditioning energy use in 2014 – 2015 with the BEopt simulation results for the same period. Note that the occupants consistently use about twice as much energy for air conditioning than is predicted by BEopt. This could be due to the fact that the home is occupied by a family of four, with three of the four at home most of the time (stay-at-home mom and two small children). This is a significant contribution to under-prediction of energy use by BEopt on this particular occupied home.

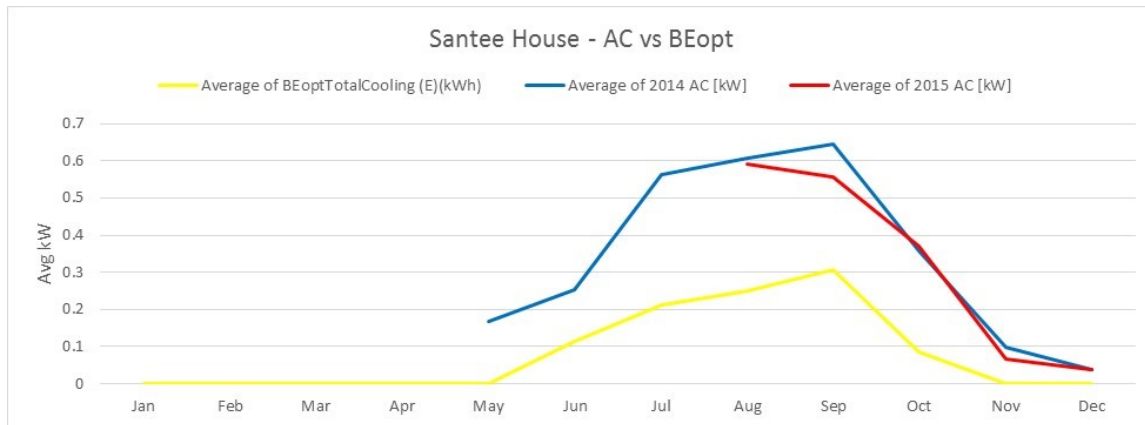


Figure 4. Comparison of electricity use for air conditioning (blue, red), compared to BEopt predictions (yellow).

Figure 5 is a graph of energy used for large appliances (refrigerator, range, oven, clothes washer/dryer) and for water heating. BEopt provides guideline values for appliances and miscellaneous electric loads(MELs). BIRAenergy has developed a survey for owner/occupants to help accurately predict energy use by these important but not well understood end-uses. Values for modeling appliances and MELs for this ZNE-retrofit the appliances and MEL devices in the home and how they are used. The result is that BEopt predicts slightly more energy used in the simulation than actually measured, making the predictions conservative.

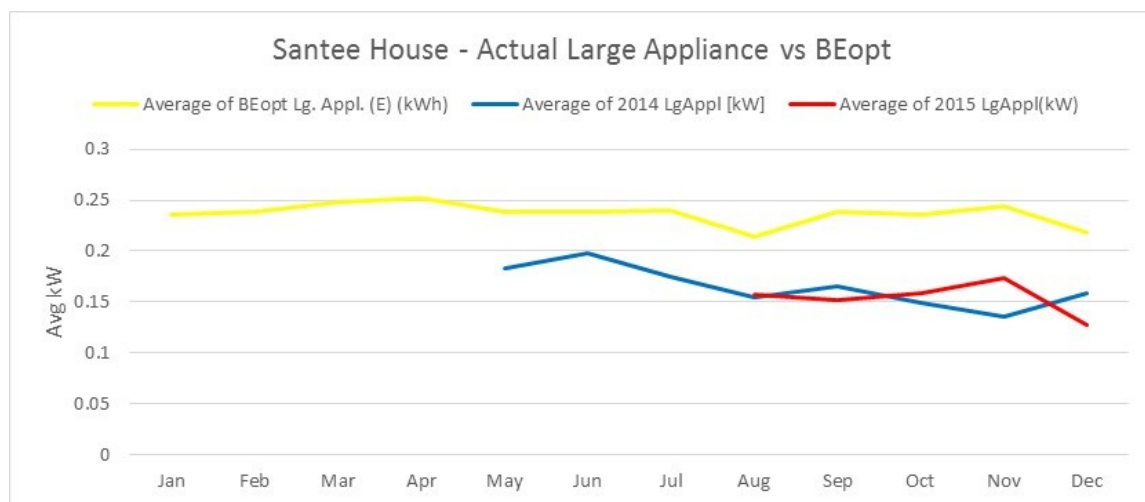


Figure 5. Comparison of energy demand from large appliances for two years and BEopt predictions.

The ZNE efficiency package for the home includes a heatpump water heater (HPWH). The particular HPWH installed in the home is now known to have reliability problems, and we know that the homeowners had problems with their HPWH. For instance, we put the HPWH on “e” mode, which was supposed to enable only the HeatPump, and to disable resistance heating. By itself the HPWH switched to “hybrid mode” which uses resistance heating to supplement hot water recovery when needed and can be quite often. This is at least part of the explanation for the differences between BEopt and actual

energy use in 2014 as shown in Figure 6. The HPWH was repaired by a trained service technician in 2015, and the correlation between BEopt and actual energy use by the HPWH improved.

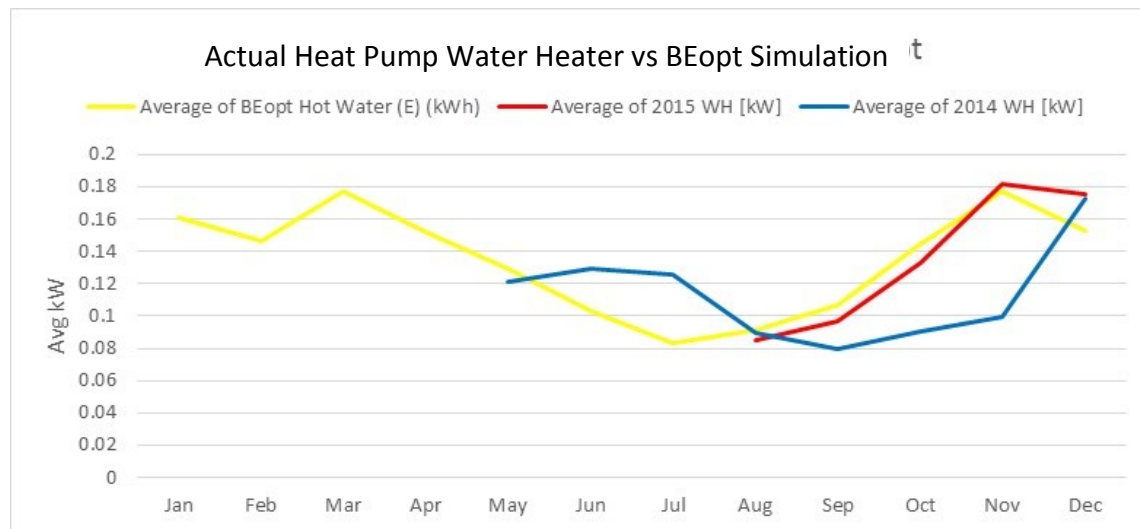


Figure 6. Comparison of energy demand from Heat Pump Water Heater for two years and BEopt predictions.

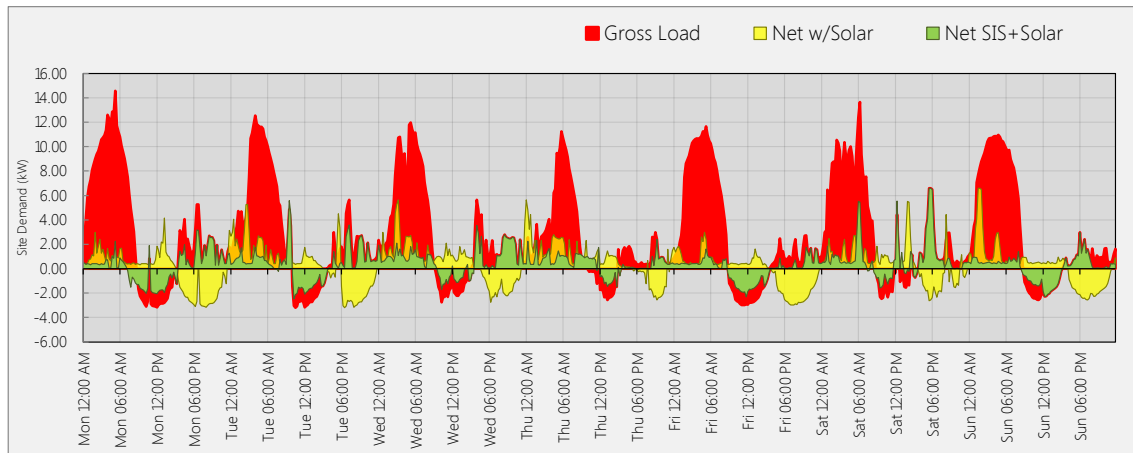
### 3. IDSM Package Impact on Peak Demand

PV peak production occurs at mid-day, assuming no shading impacts. The peak demand from most of California (and from this ZNE home) is typically between 6PM and 7PM. The generation peak occurring earlier than the demand peak generally results in excess generation typically being sent to the grid until early- to mid-afternoon. This excess energy generated by the PV system is typically less valuable than that needed from the grid during the late-afternoon peak. Later in the day, when the demand from the home is in excess of generation, electricity is drawn from the grid for use in the home. However, if the excess electricity generated earlier in the day were stored in a battery for use in the late afternoon, it could save the consumer on their energy bills, assuming an appropriate time-of-use or similar tariff were available. This approach also relieves local demand during peak periods and can reduce the slope of the increased demand late in the day as the PV generation declines. Both of these scenarios are beneficial to the grid and its operation.

Figure 7 is a composite diagram of the home electricity demand, showing the average total demand for each day of the week, by hour of the day. This figure shows the total electricity demand, un-moderated by PVs or batteries (red), the net of total demand and PV production (yellow) and management of loads and production by the SIS battery system (green). This illustration shows the reduction in peaks and overall flattening of both high and low demands.

From a grid-management perspective, the green net curve is easier to manage than the gross load curve (red). If all homes on the grid were to behave like the green curve as opposed to the red curve, not only would grid management be simpler, but the makeup of generation plants could be cleaner. With a

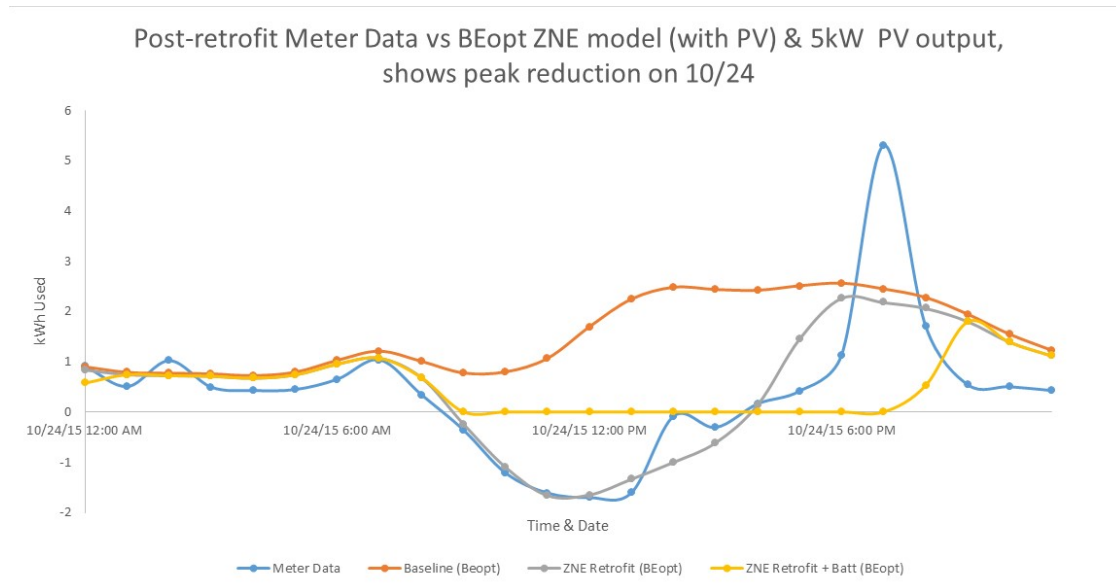
substantially reduced need for fast spin-up generation (or “peaker”) electricity generation plants, greenhouse gas emissions could be reduced.



**Figure 7. Composite graph of total home electricity demand (red), and demand from the utility meter when generation from the rooftop PV is included (yellow), and the net demand when the SIS manages use and storage of PV generation and electricity needed from the grid (green). Data is the average for each day of the week for the month of October 2013.**

**Figure 8** shows hourly demand from the electricity meter on a single day (10/24/2015) as well as BEopt simulation for the same day. The actual data and the simulation track fairly closely for most of the day. However, there is a rather large spike in demand from the home in the early evening. Such spikes were not uncommon events in this home, and they very likely occur in other homes with similar occupancies and similar large appliances. A detailed data analysis for that day showed that the spike in energy use at about 6PM was due to both the air conditioner compressor and the electric clothes dryer operating at the same time and with a similar profile (see **Figure 9**). It is not possible to anticipate the occurrences of coincident, short, on-off cycles from appliances including air conditioner, heat pump water heater, and electric clothes drier because they are all influenced or a direct result of randomness in occupant behavior, including the use of large appliances. Given that they are not possible to predict due to the human element, at a minimum, they are treated here as random events and ignored in this analysis which is focused on overall demand flattening and reduction. In **Figure 8**, the simulation (grey) and actual meter data (blue) track each other fairly well through the peak period. The long, high, afternoon electricity use characteristic of the pre-retrofit home energy use is eliminated and is negative for most of the afternoon in the ZNE home. In the late afternoon, as the PV production is decreasing, the ZNE home uses less energy than either the pre-retrofit or the BEopt model.





**Figure 8.** Simulation and metered data for the test home on a late “summer” day (autumn, but hot). Note the relatively good tracking of the meter data (blue) and simulation (grey), as well as the relatively smooth and low afternoon demand. The spike in electricity use at 6PM in this figure is due to simultaneous electrical draws from the Electric Clothes Dryer and the air conditioner compressor.

Figure 9 provides more details of the actual energy use of the large appliances for the days surrounding the data in Figure 8 and the coincident-load spikes such as that in Figure 8. Every day during the hot season, the AC is used and the average daily amount of energy being used is variable but predictable since it is the end of summer and warm weather still occurs. We have not attempted to validate the BEopt predictions of on-off cycles of the air conditioner, which would be required to anticipate most coincident-load spikes. Similarly, the electric clothes dryer is somewhat predictable on a daily basis, and there is insufficient information regarding overall occupant behavior to predict coincident spikes. An example of such a coincident load occurred when the dryer was used at 6 PM on October 24 and 12 PM on October 25 and around 12 PM on October 26 for these 5 days. The HPHW is cycling in a somewhat predictable manner and reflects the fairly constant need for hot water throughout the day. The HPHW, when operating simultaneously with the air conditioner, for instance, together can produce a coincident load – see Figure 9, shortly after 6PM when the air conditioner and HPHW produce a coincident load spike, with some additional contribution from the oven.



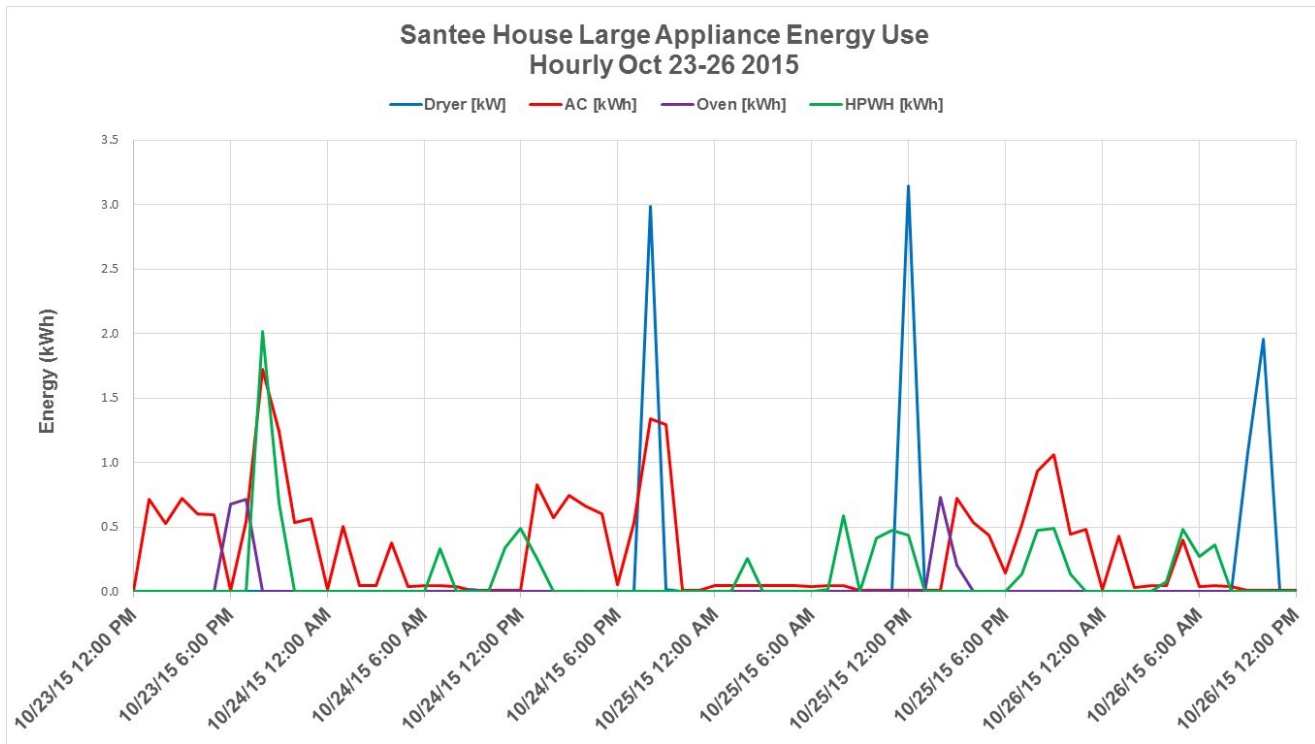


Figure 9. Energy use by four large appliances over four days in October 2015 at the Santee House.

To obtain a better understanding of the contribution of the large appliances to overall house energy use, the average electricity usage of large appliances was calculated on a monthly basis, washing out the hourly events. This data is shown in Figure 10. The air conditioner is the predominate user of energy during the summer months and is negligible during the winter months. The HPWH is used throughout the year but the energy use is somewhat higher in the summer and lower in the winter. The electric clothes dryer and the oven are also used throughout the year and the energy draw is roughly the same, or even a little higher during the winter. Figure 10 clearly shows that the predominate load in the summer is the air conditioner, and this is where demand response, contributions from PVs and batteries, as well as occupant information and training should be focused. The coincident-load spikes are interesting, but not a critical factor in reducing peak loads at present.

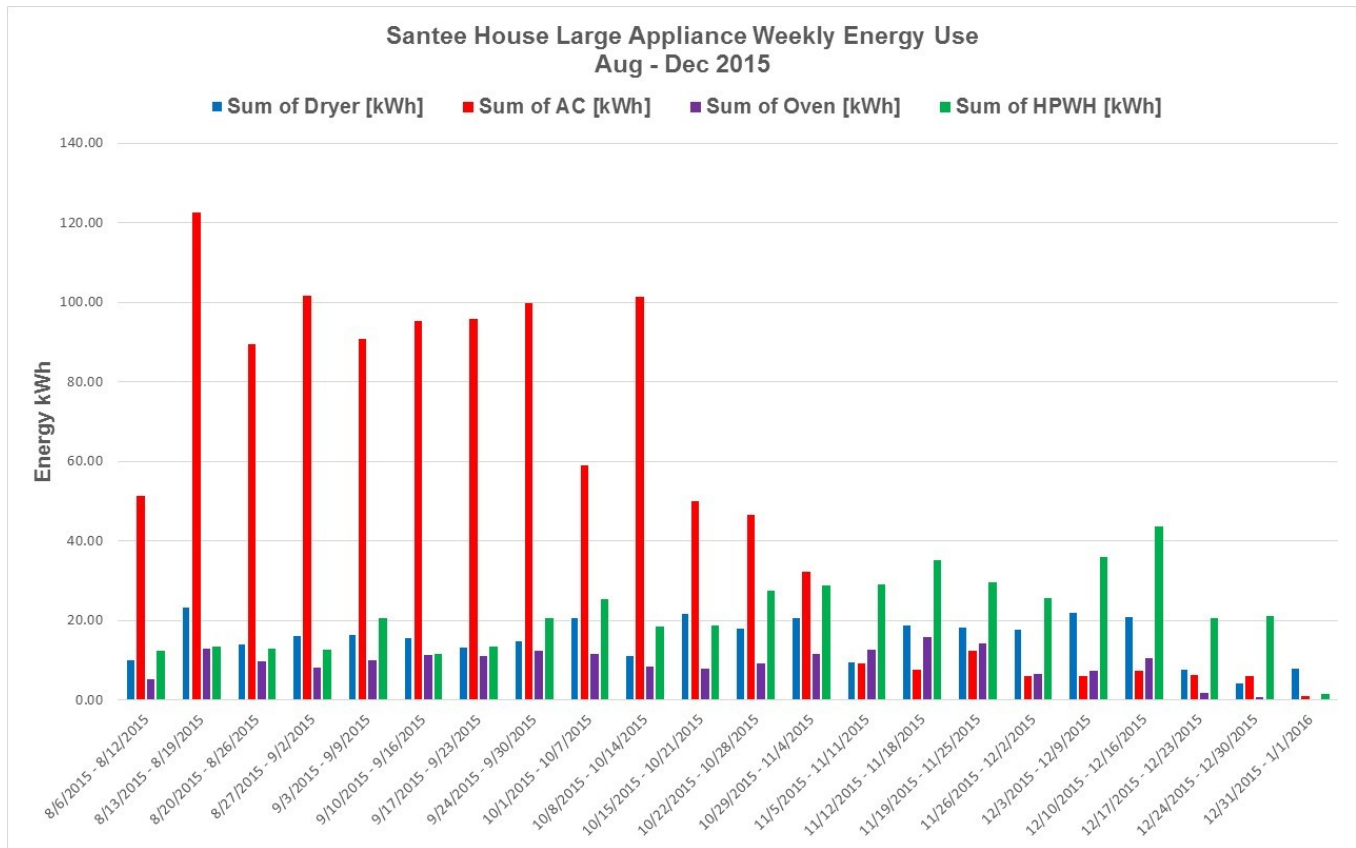


Figure 10. Weekly sum of energy used by the Large Appliances at the Santee House from August to December 2015.

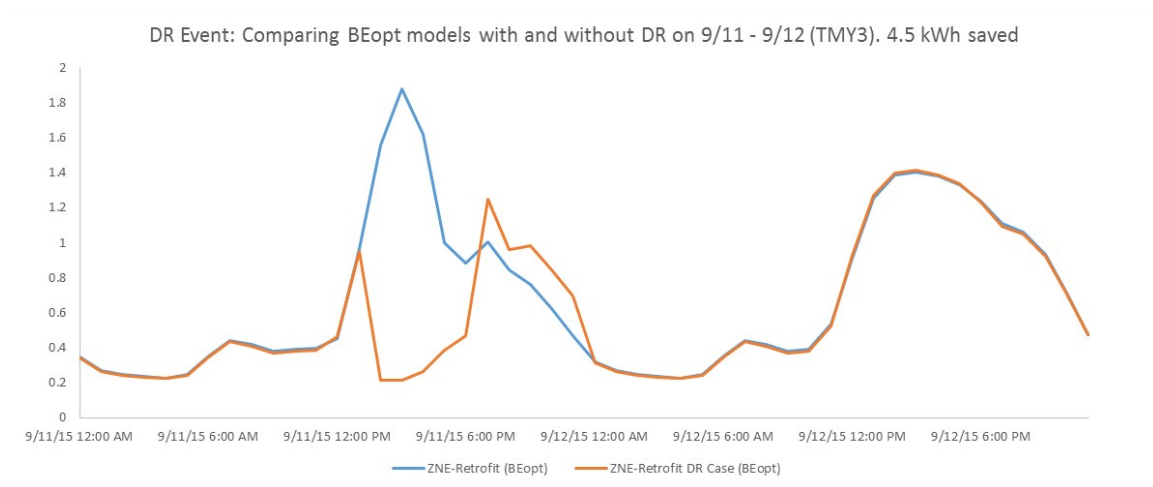
#### 4. Demand Response from ZNE-IDS Home

General Electric (GE) was a partner in the initial CSI RD&D Solicitation #2 research project where the demonstration home was retrofitted to be ZNE. The ZNE retrofit design included kitchen, and clothes washing and drying appliances that are energy efficient, and include communication capabilities and are DR-enabled. These GE DR-appliances and PV system were designed to connect with the GE Brillion Nucleus to provide energy-use information to the home's occupants as well as connect to the utility DR system either through the smart meter or via the web.

The Nucleus installed in this home was nonfunctional and could not be made to work despite performing all tests and diagnostics available from the manufacturer, calls to the manufacturer, and good engineering efforts. Once it was realized that the Nucleus was not functional a request was made for a replacement unit, but GE had provided the appliances prior to the start of this project, and by the time the home was retrofitted, GE had divested itself of that business unit and no longer had any Nucleus devices. The problem encountered was that the main communications device, the "Nucleus" would not maintain a connection to even a single appliance for more than a few minutes. GE has withdrawn from the communicating appliance market, disbanded the section of their appliance division that developed and supported communicating appliances, and no longer supports the Nucleus system.

The failure of the Nucleus, coupled with loss of product support made it impossible to perform a physical test of the DR system, however DR events were simulated. The DR event, setup in BEopt was very large, both in terms of the duration of the event (6 hours), and the breadth of the event, which included disabling all the DR-enabled appliances, the clothes washer and dryer, dishwasher, water heater, and thermostat. A DR event of this magnitude would be quite inconvenient for a family like the one in this study.

The impacts of the modeled DR event are shown in Figure 11. The afternoon peak is reduced from about 2kW to 0.2kW, or about 2kW demand reduction. The total event saved 4.5 kWh.



**Figure 11. Effect of DR event on daily energy load curve. Both curves are simulations of the same days, Sept 11 - 12, 2015, with the DR occurring between 12PM and 6PM on the 11<sup>th</sup>, and impacting all DR-enabled appliances: clothes washer and dryer, dishwasher, water heater, and thermostat.**

Demand-Response is more appropriate to existing standard homes than ZNE homes. This conclusion is based on the data in Figures 8 and 11. Figure 8 shows the hourly electricity demand of the baseline and ZNE versions of the test home on a typical hot day. During mid-day hours the ZNE has a negative demand, and the Baseline home requires about 3 kW more electricity than the ZNE home; this difference decreases as the day goes on and insolation decreases; by 6PM the difference is small, and they have converged by 9PM. Figure 11 shows that the peak demand of the ZNE is less than 2kW. Figure 11 also shows a substantial inversion of the peak demand resulting from the DR, but the effect is small because the ZNE home demand is small throughout the day. The predicted demand from the ZNE home during the peak demand hours of 4PM – 7PM is about zero at 4PM and increases to about 2 kW by 7PM. The Baseline home demand is constant at about 2.5 kW throughout the peak period. Given these differences, DR will have a very small impact on the grid during peak hours, while the Baseline home holds constant at its peak demand throughout the peak period.

## Battery Model and Function

The Sunverge SIS intelligent battery system was operational in this test home early October 2013. The design intent was to explore the home's ability to reduce peak loads and to flatten the electricity load curve. Other impacts were also noted, including reducing the steep slope in the demand curve typical of an efficient home with rooftop PV, and illustrating a fast response for power from the batteries as PV generation falls off and cooling loads (among other demands) increase demand. The SIS has substantial programming capabilities that can be used to optimize its performance, including load tracking, however there were technical difficulties in implementing and testing these capabilities. The largest factor limiting the ability to evaluate the SIS was that the SIS was designed to work with a PV<sub>DC</sub> system and is not currently able to work directly with a PV<sub>AC</sub> system. For example, while the SIS is designed to perform load tracking, that was not possible in the demonstration home. The SIS could not directly track home loads and optimize PV output to batteries and/or loads because the SIS PV-input was designed for DC, and the installed PV system output was AC. In this installation, the SIS employed a fixed charge-discharge program based on Sunverge technical experience as opposed to real-time actions with this home and its electric loads.

A good model of battery functions is needed. BIRA intends to develop a battery algorithm that could be adopted and integrated into programs like BEopt. Developing such a model is beyond the scope of this project, but data from this project could be useful in the future testing and/or development of a battery algorithm and computer model<sup>8</sup>. An algorithm has been outlined and preliminary work completed to evaluate its relevance and application using data from this and other projects. Progress indicates that the algorithm can be implemented in Excel and used to modify hourly data from the simulation. The completed battery model is expected to provide accurate predictions of the impacts of batteries on daily demand curves; in particular, on the size and shape of peak demand. The algorithm will allow flexibility in modeling the battery's programming and resulting operation, with the program of battery operation unchanging once set, to examine long-term (months) effects of the battery operation.

## V. CSI ZNE - IDSM Retrofit – Conclusions

This CSI RD&D ZNE home has been a very valuable research demonstration that has provided a large amount of detailed data that has been useful in evaluation of the performance of a ZNE retrofit. As documented in this report, the data has proved useful in the evaluation of ZNE-retrofit performance compared with building simulations, the lack of effectiveness of DR in ZNE homes, and insights into the use of residential battery-storage, and their value to consumers and to utilities.

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<sup>8</sup> BIRAenergy has developed an algorithm that calculates battery function, and has coupled the algorithm with data similar to that from this project: hourly energy use, PV production and battery charging and discharging. That work was internally funded by BIRAenergy.

The data has provided insights into the performance of ZNE – IDSM retrofits. The efficiency package was developed to provide zero net energy on a site basis. While the retrofitted efficiency-package did not reach this goal, site electricity was reduced by over 70%, as determined by a comparison of baseline, pre-retrofit data to post-retrofit. Some of this shortfall is due to the heat pump water heater not performing as expected - it irregularly, but not infrequently called on the back-up electric-resistance coils rather than the heat pump. When this happens, the energy used to heat the water to the set-point is about one-third as efficient as the heat pump to heat the water. The heat pump is slower to heat the water in the tank, so when hot water demand is deemed by the heat pump controller to be too high to supply the hot water using the heat pump, the water heater switches to the resistance heat. This produces a much faster recovery time, but at a cost of about a factor of three in efficiency. Exacerbating programmed switches from heat pump to resistance heat when there is high demand while in hybrid mode, the heat pump water heater initially had a faulty control that would switch modes from “e-mode” (resistance heater locked out) to high-demand mode, which locks-out the heat pump and uses only the resistance heat to heat the water. This change in modes would remain until corrected by the homeowner. The manufacturer made a few service calls, and that problem was fixed, however, the intermittent use of resistance heat under high loads remained, whether in e-mode or hybrid mode.

This project also showed that DR as a peak-reduction tool is much more valuable in standard homes as compared to ZNE homes. The electricity use by the ZNE home is negative (i.e., net producer) over much of this period, and minimal over the remainder. Thus, the ZNE home does not have a peak to reduce during the peak period. In contrast, the Baseline home had a distinct and higher peak than the ZNE, which can be substantially reduced by DR actions during the peak period.

A residential intelligent-battery system was also evaluated in this project. The battery system was programed to charge during off-peak periods, and to discharge during peak-periods to reduce demand from the grid during the peak usage period, and when PV generation had substantially reduced due to loss in insolation in the late afternoon. This system and programming performed as intended, resulting in a flat load curve. However, that result is of more value to the utility than to the consumer, and ultimately the value of residential battery systems will hinge on utility acceptance and monetary support for them in the market.

The extensive data provided the basis for performance evaluation of an actual ZNE-IDSM retrofit over a two-year period plus about 18 months of control data. The ZNE data set consists of whole-house meter data plus coincident end-use data. This provides the ability to evaluate home performance ranging from whole-house to single (or multiple) end-use performance. These granular data-streams can be considered separately as well as integrated. The data provides sufficient detail to build a computer model of the home, and provide information regarding the use of Miscellaneous Electrical Loads (MELs). The behavioral data, including some basic information on the occupants, their use of MELs equipment, and home controls-data, coupled with the monitored performance data provide a unique opportunity for evaluating simulations and calibrating computer models.

Approximately three years of data can be available to others examining ZNE homes with IDSM principles. The collected data provides relatively high resolution (5min – 1 hr. depending upon the monitoring device) data from the entire home, from components, and from the utility meter (and interface to the grid).

The performance analyses of the ZNE-IDSM Retrofit home showed a 70% reduction in energy use and demand during the peak period. While the home did consume more energy than it produced (on a net, annual site basis), the design resulted in both a substantial decrease in annual energy from the grid and a distinct leveling of demand.

This project extended and expanded the data collected from this home and has provided exciting and valuable results regarding the potential for an intelligent battery system (Sunverge SIS) to manage energy and power on the consumer side of the meter. The resulting evaluation showed clear lowering and shifting of the electricity demand from the ZNE. The potential for batteries to mitigate problems with high market-penetration of PV systems was confirmed. The intelligent battery system both shifted peak and reduced the rapid change in demand suffered by efficient homes with PV. That is, the battery system mitigated the very rapid increase in electricity demand in the late afternoons. This rapid increase in demand is due to the combination late afternoon of increased demand from air conditioning, cooking and use of other electricity consuming devices with the rapid and concurrent reduction in PV generation. These remotely-programmable, intelligent battery systems provide significant value to utilities in both supporting PV homes on the grid and their role in simplifying grid behaviors; i.e., the improved management of peaks and troughs within the electricity supply system due to implementation of ZNE - IDSM designs for both new and retrofit applications. Widespread application could reduce risk of grid failures resulting from demand-extremes that are minimized or even eliminated in ZNE-IDSM homes.

This ZNE-IDSM retrofit design approach and package of features should be a consideration in new construction. The efficiency features provide a dramatic reduction in peak-demand from the home, and the smart storage system provides the capability to shape residential loads to assist the utility with grid optimization, while being transparent and unobtrusive to the homeowner. The costs of the retrofit hardware and their installation can be found in Appendix A and were collected in the CSI RD&D Solicitation #2 project. Fully integrated cost/benefit analyses are available in other reports<sup>9</sup>.

## **VI. Reference – Prior CSI Project:**

CSI RDD&D #2 Project to evaluate a new AC-PV kit from GE titled: Low-Cost, Smart-Grid Ready Solar Re-Roof Product Enables Residential Solar and Energy.

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<sup>9</sup> Korman and Hammon, CSI Task Report: Detailed Cost Analysis of Grid-Ready Plug-and-Play PV Kit ([link to report on BIRAenergy website](#))

## A. APPENDIX A: CSI ZNE Package Features

Item #	CSI ZNE EE Package Features	Installed Costs
1	R-49 attic insulation, blown-in cellulose, Grade 1	\$ 2,040
2	Radiant barrier, continuous, attic	\$ 1,955
3	Low-e/SHGC windows, U-factor .24, SHGC .27	\$ 5,200
4	Low-e/SHGC Patio Doors, U-factor .24, SHGC .27	\$ 5,100
5	100% LED lighting (indoor, outdoor, plug-in and hardwired)	\$ 1,600
6	Hand sealed building envelope, SLA 3.0 or better	\$ 2,125
7	18 SEER AC	\$ 13,900
8	95% AFUE Furnace	
9	Buried ducts in attic	
10	Ceiling fans, minimum ENERGYSTAR	\$ 750
11	GE Heat Pump Water Heater (note 1)	\$ 1,200
12	On-demand hot water recirculation system	\$ 875
13	R-2 insulation on exposed hot water pipes	\$ 200
14	Low flow sink faucet aerators, 0.5 GPM	\$ 75
15	Low flow showerheads 1.25 GPM	\$ 150
16	Energy Management System: GE Nucleus (donated, see note 2)	\$ 400
17	GE Refrigerator	donated, see note 3
	GE Clothes Washer	
	GE Dishwasher	
	GE Range	
	GE Clothes Dryer	
<b>Subtotal, EE Measures</b>		<b>\$ 35,570</b>
18	Sunverge SIS (note 4)	N/A
19	GE Insert Capture P&P PV System (5 kW) (note 5)	\$ 20,000
<b>Total (see notes below)</b>		<b>\$ 55,570</b>

Table A1. The features used in the CSI ZNE package and their associated actual costs (\$55,770, including installation). BEopt energy modeling software simulation results estimated an energy savings of 32% source-energy, from the energy efficiency measures alone (not including any savings from a HEM, SIS, or PV.) See notes for Table A1 in Table A2, below.



<b>Note 1: donated GE HPWH</b>	GE donated the Heat Pump Water Heater as part of their DR line of appliances. An estimated cost for the HPWH is included because an efficient water heater would likely be an integral part of an EE package, and in many cases, that EE water heater would be a HPWH.
<b>Note 2: donated Energy Management System</b>	GE donated the <i>Smart-Grid Ready Insert &amp; Capture Plug &amp; Play Retrofit PV System</i> , which in this case, included the Nucleus, a multipurpose device, including being a Home Energy Management system (HEM). An approximate cost for a HEM is included in the EE package because it would be an important candidate technology for the retrofit.
<b>Note 3: donated DR Appliances</b>	GE donated the listed appliances (as well as the HPWH and Nucleus HEM) that are their line of DR appliances. These appliances (listed items 17) are likely to be installed for remodeling reasons, as opposed to their contribution to cost-effective energy-efficiency package; with the exception of the refrigerator, the appliances are not the next most cost effective measures. However, they would be excellent additions to an EE package where new appliances are replacing older, less desirable ones. In addition, these GE DR-capable appliances might be included for their Demand Response capabilities as they were in this study.
<b>Note 4: Sunverge SIS</b>	The Sunverge SIS system was not part of the EE package and so is not listed here as a cost
<b>Note 5: donated GE PV System</b>	GE donated the PV systems in this project, their <i>Smart-Grid Ready Insert &amp; Capture Plug &amp; Play Retrofit PV System</i> . The cost is included here because a PV system is a necessary requirement of a ZNE retrofit. The cost is estimated at \$4/W, installed, based on the production cost estimate of less than \$4/W installed - the amount less being dependent upon markups.

**Table A2** Notes for Table A1, EE Package features.



## B. APPENDIX B: 2008 Title-24 Base Case Comparisons to ZNE Package

Feature	ZNE Package Features	Base Case
Misc. Electric Loads	Home Energy Management System	Building American Benchmark
Wood Stud		R11 Batt-Gr 3 2x4 16"o.c.
Exterior Finish		Stucco
Interzonal Walls		R11 Batt-Gr 3 2x4 16"o.c.
Unfinished Attic	Ceiling R49 Cellulose Blown-In Vented	Ceiling R38 Cellulose Blown-In Vented
Roofing Material		Asphalt Shingles Medium
Radiant Barrier	Radiant Barrier	None
Window Areas		17.9% Grey Homes F46 B28 L0 R26
Window Type	Milgard Windows, Slider (0.27 / 0.24)	1-Pane Clear Metal (0.67 / 0.76)
Infiltration	3 ACH50	10 ACH50
Mechanical Ventilation		None
Refrigerator	EnergyStar Side-by-Side Freezer	Standard Side-by-Side Freezer
Cooking Range		Gas Conventional
Dishwasher		EnergyStar
Clothes Washer	EnergyStar	Standard
Clothes Dryer		Gas
Lighting	100% LED Hardwired & Plugin	40% Fluorescent Hardwired
Air Conditioner	SEER 18 (2-stage), EER 15.5	SEER 10
Furnace	Gas, AFUE 95%	Gas AFUE 78%
Ducts	7.5% leakage, Buried Ducts	15% Leakage, R4.2 Insulation
Ceiling Fans	100% Coverage Eff Smart 4 °F	3 Fans Std Typical 0 °F
Water Heater	Gas Tankless Condensing	Gas Standard
Distribution	Uninsulated TrunkBranch Copper Demand	Uninsulated TrunkBranch Copper
PV System	5 kW	None

Table B1. A comparison of the as-built base case and the CSI ZNE package features, including 5kW PV. The base case features are in the right column. Features indicated under the heading ZNE Package Features include only the deviation from the as-built base case.