A Case Study in Reconciling Modeling Projections with Actual Usage

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ABSTRACT

A subdivision, built near Sacramento, CA was designed to incorporate advanced residential energy efficiency strategies as part of Department of Energy's (DOE) Building America (BA) program. Energy efficiency measures included attic radiant barrier, condensing furnace, high efficiency air conditioning, tankless gas water heater, efficient lighting, and third party building inspections. Detailed DOE-2 building simulation was used to project energy performance and utility bills. Analyzing one year of billing data obtained from these homes as well as 100 surrounding reference homes suggest that even when detailed data is known, energy simulation is not effective in characterizing energy by end use. Results show natural gas use on average was 36% lower than simulated projections and supports a study done on California compliance software model projections (KEMA et al. 2010). Electrical use patterns on the other hand varied from model projections inconsistently, due in part to anomalies not accounted for in the model. Results indicate that household variations in energy usage patterns and appliance penetration rates have a very strong effect on total energy use. This issue seems especially pronounced in mild climate regions of the country where miscellaneous plug loads, lighting, and large appliances can exceed 80% of the total electric use. Understanding and influencing homeowner behavioral patterns is important in delivering high performing homes to the market. Additional research into the effectiveness of energy control mechanisms, such as motion detecting lighting, phantom load controls, home energy displays, and educational programs are required in order to incorporate these savings into building simulations.

Introduction

Through the Department of Energy's (DOE) Building America (BA) program, homes participating must meet specified energy reductions goals. Davis Energy Group, part of the Consortium for Advanced Residential Buildings (CARB) BA team, provides consultation to builders to assist them in reaching energy goals. A post construction analysis verifies if these actual goals are met. This procedure includes comparing the high efficiency homes (referred to as BA Prototype homes) to surrounding reference homes. The BA prototype homes and reference homes are compared based on both actual energy use and simulated energy use. Additionally, the post construction analysis includes a homeowner survey for both communities to characterize miscellaneous energy use, e.g. pools, large aquariums, etc. and to determine home owner satisfaction.

During the analysis process it was observed that the simulated home energy use varied significantly when compared to observed energy data. The objective of this study is to present the findings of the analysis and to synthesize possible solutions to reconciling the difference.

Project Description and Background

The BA Prototype neighborhood lies within the 1,200 acre Whitney Ranch development located in Rocklin, California. It was built by Grupe Company of Stockton, CA. Founded in 1966, Grupe builds both residential and commercial buildings. Their primary market is Northern California, though they have completed projects in other states. The BA Prototype project consisted of 144 three-to-five bedroom homes between 2,168 and 2,755 square feet (six plan types). The BA Prototype home designs are inspired by traditional ranch homes built in the area.

Grupe's marketing strategy was to apply their "GrupeGreen" branding and make energy efficiency and PV systems standard in all homes. They also submitted the BA Prototype project for certification under the U.S. Green Building Council's LEED for Homes pilot program, making it the first LEED certified subdivision in California.

Construction of the first homes began in September 2005. Prices for the homes ranged from $489,000 to $529,470. Following the housing market crash, Grupe halted construction after 84 of the 144 homes were completed. Construction of the community is expected to resume after the market recovers.

Energy Features

Working closely with Grupe , Davis Energy Group evaluated energy efficiency measures to develop cost-optimal designs that would provide the best possible value to the home buyers, by achieving a positive cash flow (annual energy savings exceed the incremental annual mortgage costs for the energy improvements). In addition to the 2.4 kW DCSunPower SunTile™ building integrated PV systems installed on every home, the following energy efficiency measures were provided:

- High performance (Low-E^2) vinyl frame windows (U-Factor/SHGC = 0.35/0.32)
- Radiant barrier roof sheathing
- R-49 attic insulation with buried ducts
- Quality inspected wall insulation (R-13, soy foam used in some homes)
- Exterior R-4 foam wrap
- Compact fluorescent lamps for permanently wired lighting fixtures (30%)
- "SmartVent" ventilation cooling system
- Continuous fresh air ventilation system
- 94 AFUE variable speed furnace
- 13 SEER AC (15 SEER/12 EER air conditioners were added to some later homes)
- Tankless gas water heater (0.81 EF)
- Home run hot water piping using Crosslinked Polyethylene (PEX)

Methodology

Quality Assurance

In addition to participating in the Building America Program, this community also participated in USGBC's LEED for Homes program. As a requirement for participation in the

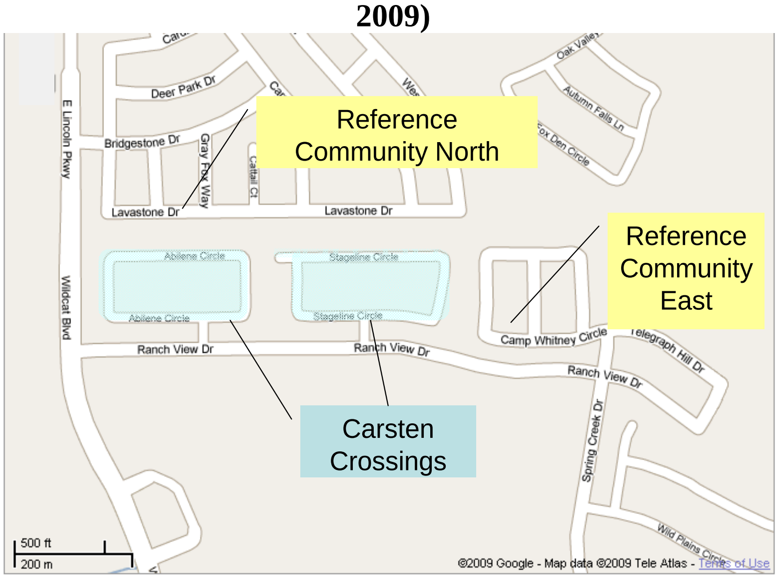
LEED for Homes program the BA Prototype homes must have third party verification for quality insulation installation, building envelope leakage, and duct leakage.

Short-term tests were conducted using the Home Energy Rating System (HERS) protocol to assure predicted home energy performance measures were achieved. Amaro Construction, a certified HERS rater, completed inspections to test duct leakage and building envelope tightness on a required sample of the homes (26 homes). Test results done the sample homes reported only two homes exceeded the target air infiltration rate of 3.0 SLA and none of the homes exceeded the target 6% duct leakage. The results of the test indicate that parameter estimation made during modeling were in line with actual home performance.

Reference Community Selection

To minimize bias due to elevation and climatic differences, reference homes to serve as controls were selected primarily on the basis of their close proximity to BA Prototype community. All are within a 0.5 mile radius (see Figure 2). The reference home communities were divided into two groups based on geographic location. Reference Community North was built between 2003 and 2004 and includes houses that range from 1,899 to 4,059 ft2. Reference Community East was built in 2006 and includes houses that range from 1,801 to 3,096 ft2.

Figure 1. Reference Community Vicinity to BA Prototype-Carsten Crossings (Google Maps 2009)



Though plans for the reference houses were not available, the builder of the houses in Reference Community East, indicated that their houses were built with R-13 wall insulation, Low-E² windows, radiant barrier roof sheathing, and Energy Star dishwashers. A walking inspection was made to visually verify that the reference homes are approximately the same size as the BA Prototype homes. Building characteristics, such as wall insulation, HVAC equipment ratings, water heater performance rating, and window properties are speculative, but it is assumed that the reference houses met Title 24 standards, and exceeded some minimum requirements. Reference Community North was permitted under the 2001 Title-24 standards, and Reference Community East was permitted under the 2005 standards. An inspection of utility bills yielded no significant differences in the energy use of the two communities.

Homeowner Questionnaires

A phone survey was conducted by Meta Research. Meta Research had difficulty matching telephone numbers to addresses, and despite offering $10 gift cards for completing surveys, few responded. The overall response to the survey was less then optimal with only fifteen Carsten Crossing homes and five control homes completing the survey.

Due to the low response from the phone survey, an informal door-to-door survey was also conducted with Carsten Crossing homeowners. The purpose of this survey was to enhance the characterization of these homes. The survey also was used to gauge user controlled loads. For example, the home owner was asked how many TVs the home had and the typical occupancy schedule. Additionally the homeowners were asked about comfort issues and general satisfaction with their homes. The responses were very similar to the phone survey with regards to a general feeling of year round comfort and low utility bills. Homeowners also exhibited undercurrent of curiosity about how their home performs compared to other homes and how to improve performance, with most homeowners asking for help to program their SmartVent controls.

Building Simulation

One Building America (BA) prototype plan was chosen that represented the median and the mode home size for BA Prototype. Plan 3 (2,667 sq-ft) was modeled post-construction incorporating all of the as-built building characteristics. Plan 3 was also modeled to represent the reference community homes. A set of measures was determined that generalized the building practices used for the reference homes.

The modeling software used was BEopt. BEopt (Building Energy Optimization) is an hourly energy model developed by the National Renewable Energy Laboratory. BEopt utilizes DOE 2.2 and TRNSYS to simulate building performance and cost. Additionally, BEopt is certified software to use on Building America projects. Both communities where modeled and results were reported in annual source energy (MBtu/yr), site electric use (kWh.yr), and site natural gas use (Therms/yr).

Utility Bill Analysis

Utility bill data for both the BA Prototype and Reference community were obtained with the assistance of the local utility. The utility bill data was reviewed to determine the base calendar year in which to compare BA Prototype and Reference house energy use. Unfortunately, not all of the billing data had congruent time frames or had consistent occupancy. However, a majority of the homes were metered from July 2007 to June 2008. The first level of screening eliminated users with intermittent use. Intermittent users were defined as any home that did not have a complete years worth of electricity use within the analysis year. The second level of screening eliminated houses with swimming pools. There were three BA Prototype homes and eleven Reference houses with swimming pools. The screened data was then analyzed to estimate statistical parameters, e.g. mean and standard deviation. Ultimately the goal produced a confidence interval that determined the utility savings produced by the BA prototype home.

Results

Simulation Results

Electric use, PV production, gas use and estimated utility bills costs are presented in Table 1. Utility bills are based on an electric rate of $0.11/kWh and gas rate of $1.2/Therm

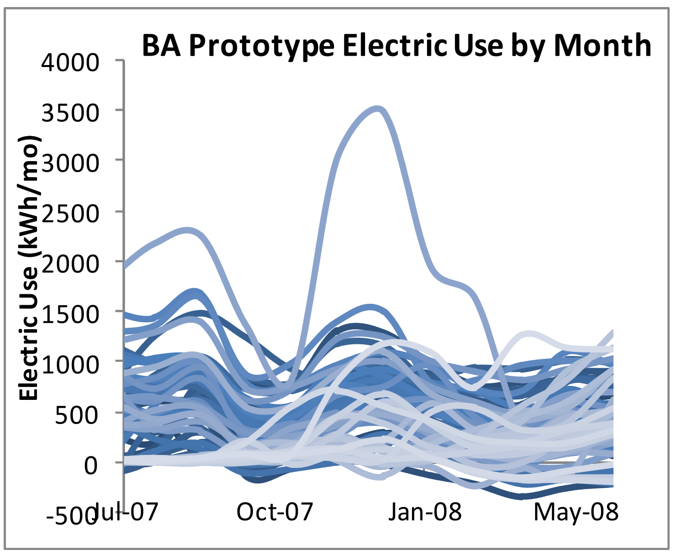
Table 1: Summary of Modeled Annual Energy Use and Costs

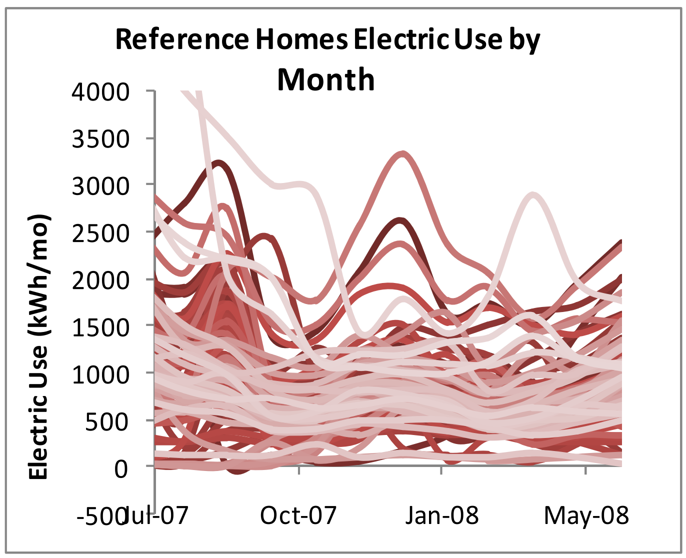
	Average Electric Use (kWh/yr)	***Average Natural Gas Use (Therms/yr)***	***Average Source Energy (MBTU/yr)***	**Average Utility Cost ($/yr)**
BA Prototype (w/PV)	6,250	594	137	1,400
Reference Community	10,552	724	200	2,030
Estimated Savings	4,302	130	63	630
% Savings Interval	40%	18%	32%	31%

Utility Bill Analysis Results

A total of 75 BA Prototype and 100 Reference homes survived the initial screening process. Fiqure 2 demonstrates the variability in observed data.

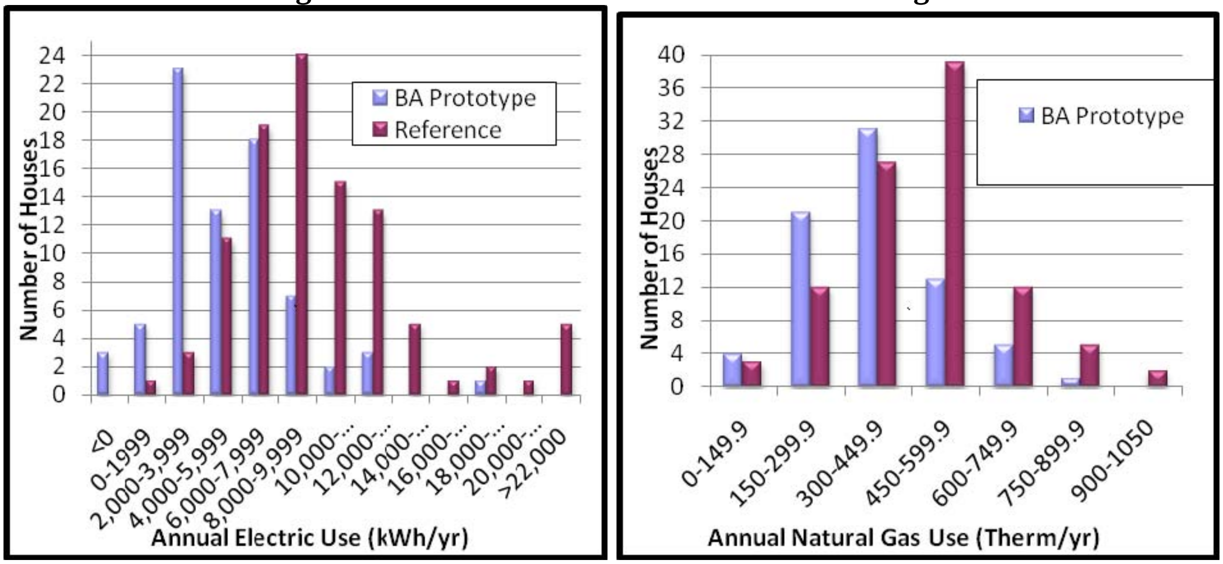
Figure 2. Plot of Monthly Data for Electric Use





The frequency diagrams in Figure 3 demonstrate that the Reference homes tend to use more energy than the BA Prototype homes.

Figure 3. Site Electric & Natural Gas Use Histogram



Statistical analysis was performed on the filtered data to calculate a savings interval based on a 95% confidence interval. A summary of the results are listed in Table 2. Percentage utility costs savings are higher than gas and electric savings due to PG&E tiered rates which penalizes electric above baseline. It was also noted that the observed BA Prototype utility costs were 28% lower than the simulated ($1,400: see Table 1).

Table 2: Observed Energy Usage and Cost Comparison between Communities

	Average Electric Use (kWh/yr)	*Average Natural Gas Use (Therms/yr)*	*Average Source Energy (MBTU/yr)*	**Average Utility Cost ($/yr)**
BA Prototype (w/PV)	5,048	371	92	1,009
Reference Community	10,281	474	159	2,523
Savings 95% Confidence Interval	3,896 to 6,009	63 to 144	51 to 77	1,227 to 1,800
% Savings Interval	38% to 58%	13% to 30%	32% to 49%	49% to 71%

Comparing Actual Savings to Expectations

Figure 4 plots simulated and observed source energy use for the BA Prototype and Reference communities together to illustrate the differences. Although there are significant differences between simulated and observed energy use, the energy savings was relatively close.

Figure 4: Observed Source Energy Savings between Communities

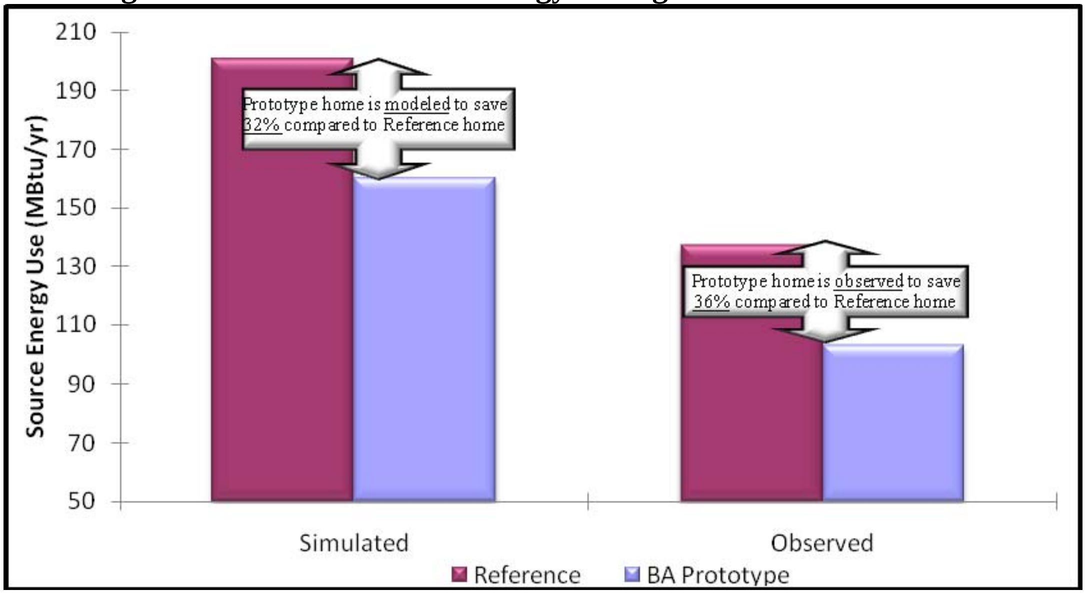


Table 3 further tests the predictive capability of BEOpt by comparing utility bill and simulated gas, electric, and total source energy use data for both the reference community and BA Prototype data sets. BEOpt over predicted energy use for both gas and, electric energy. The resulting overall variance between simulated and observed source energy use is 26% and 33% for the Reference and BA Prototype communities, respectively. This is consistent with a KEMA study that concluded that CA compliance software over predicts heating use for single family homes by 36.6%, water heating by 19% and AC by 25% for homes located in inland California (KEMA et al. 2010).

Table 3. Comparison of Observed Savings to Simulated Savings

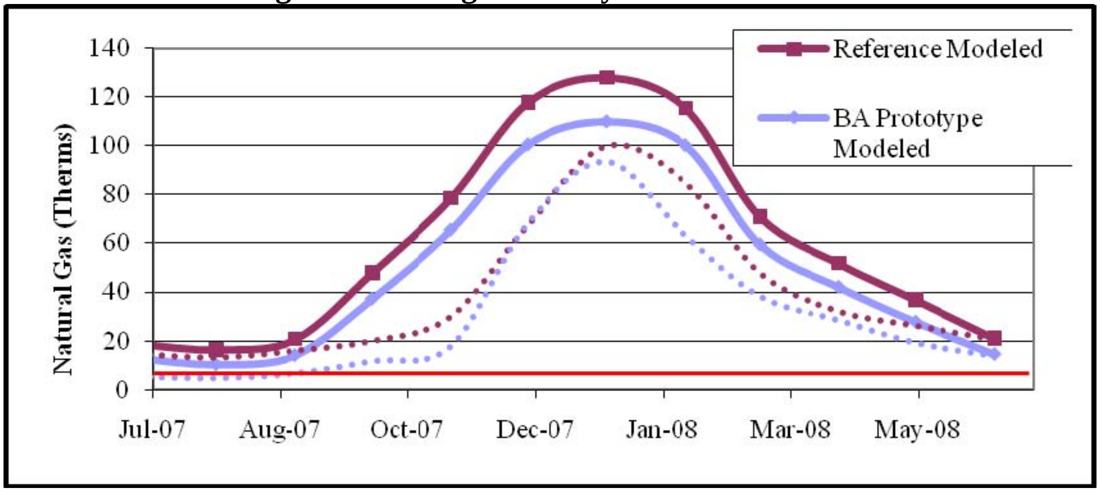
	Reference Community			BA Prototype		
	Electric kWh	**Gas Therms**	**Source MBtu**	**Electric Net kWh**	**Gas Therms**	**Source MBtu**
Utility Bill Usage	10,281	474	160	5,048	371	92
BEOpt Usage	10,552	724	201	6,250	594	137
Usage Variances	3%	35%	26%	20%	37%	33%

Utility Bill Disaggregation

To investigate where the model was breaking down the utility bills were disaggregated to portion the bills into heating, cooling, water heating, and base load energy use.

Natural gas. Natural gas use was portioned into either heating or water heating end uses. The survey conducted concluded that less than half of the homeowners had gas cooking and/or dryer, and so these appliances where assumed electric. Figure 5 demonstrates the average natural gas use throughout the year. Looking at the bell shape of the annual energy use it can be seen how water heating would be the only natural gas use for the months between June and September. Averaging these months gives us the base water heating usage and is represented by the solid red line at the bottom of the graph.

Figure 5. Average Monthly Natural Gas Use



Assuming water heating is relatively consistent throughout the year, annual water heating energy use is observed to be approximately 93 Therm/yr average for BA Prototype and 196 Therm/yr average for the Reference Community. Again, assuming no other natural gas appliances the remaining portion of natural gas use is for heating which were 278 Them/year for Reference homes and 279 Therm/yr for the BA Prototype. It is surprising to not observe heating energy savings between the two communities, however, the discrepancy likely lies in our selection of homes as controls. Information was not available on the average size of the reference homes or on the age and type of existing equipment. It can be inferred that the BA Prototype homes have more efficient equipment and envelope then the Reference community. The heating discrepancy lies in either an inconsistency in housing size between the communities or in differences in occupancy behavior. A multitude of social and economical influences may affect how people use their homes and operate their thermostat set points. While we tried to characterize both communities through homeowner questionnaires, the low responsiveness would not allow us to make definitive conclusions on potential social or economical disparities between the communities. Additional research is needed on how socio-economic status influences energy use behavior.

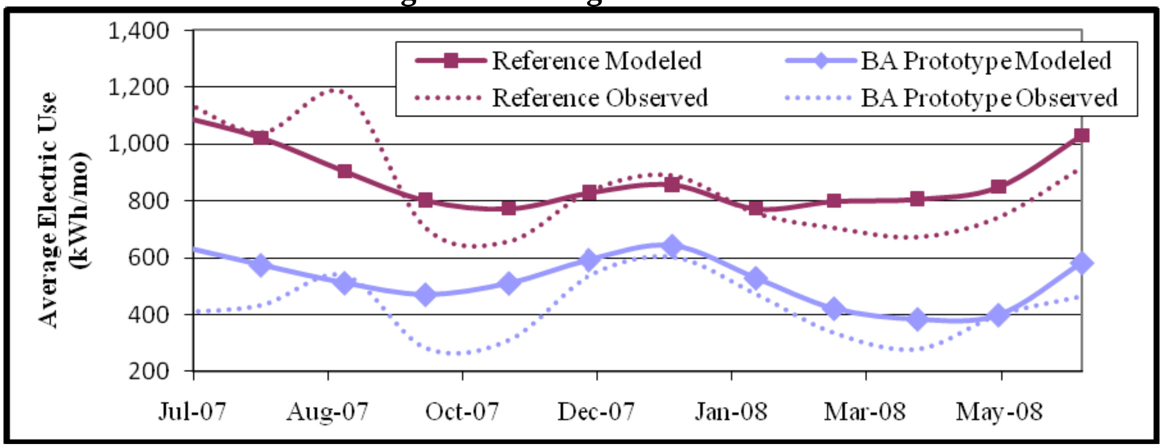
Table 4 below presents the breakdown of natural gas use and the percent the modeled data over predicted the actual use. It was noted that the survey results indicated that some occupants did indeed have other natural gas appliances, e.g. dryers or cook tops. These appliances are used throughout the year and therefore would affect the natural gas base load proportion toward water heating. Accounting for natural gas appliances in the model and in the disaggregation of the utility bills would further magnify the water heating savings

Table 4. Average Natural Gas Energy by End Use

	Reference			**BA Prototype**		
	Observed	**Modeled**	**% Better**	**Observed**	**Modeled**	**% Better**
Gas Heating (Therm/yr)	278	485	43%	279	440	37%
Base Load Gas Use (Therm/yr)	196	228	14%	93	160	42%
Gas Total (Therm/yr)	474	724	35%	372	594	37%

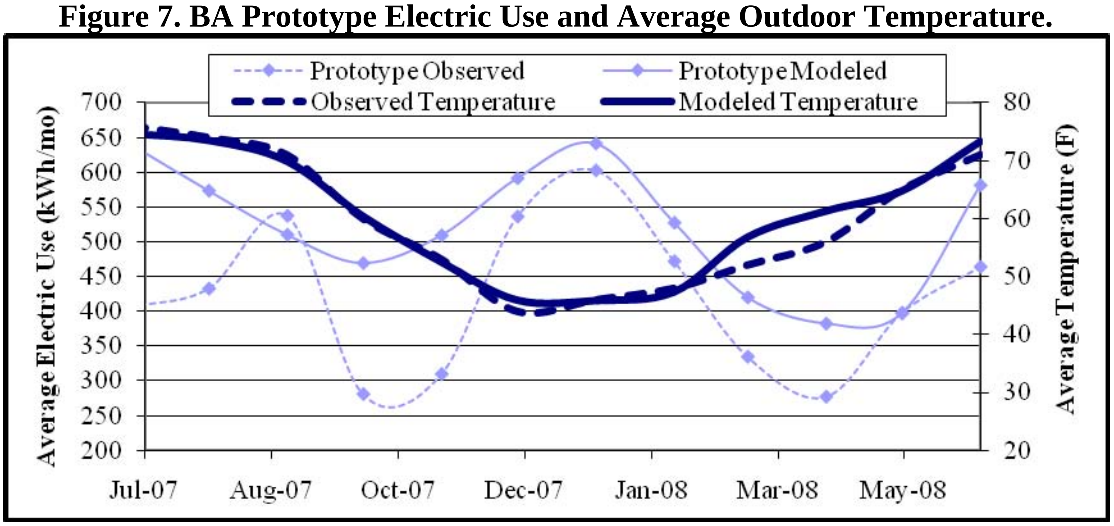
Electric use. Electrical usage patterns were, on average, within 12% of the modeled total electric usage. However, the usage patterns and utility bill disaggregation was not straight forward. Figure 6 below demonstrates the variability in electric use between the model and observed.

Figure 6. Average Electric Use



It can be seen that the model over predicts some times and under predicts at other times. Weather variations are a possible cause. Due to having only one year of data, the effects of unseasonable weather cannot be dampened. Figure 7 graphs the Prototype electrical use against the average monthly outdoor temperature for both modeled and observed.

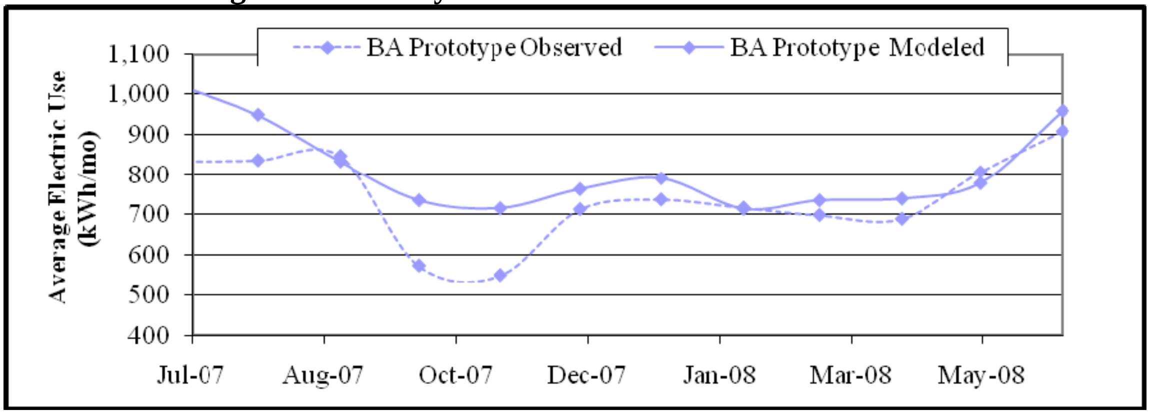
Figure 7. BA Prototype Electric Use and Average Outdoor Temperature.



It was noted that the average observed outdoor temperature was approximately 5°F lower during March and April then the temperature used in the simulation. This could account for additional observed electric use, due to increase heating fan energy and potentially less PV production if there was overcast weather. However, this does not explain what is happening in September in both communities or account for all of the differences between modeled and observed data (see Figure 7).

The first step in disaggregating electric use was to remove the effect of PV production in the Carsten Crossing homes. Monthly average PV production numbers for BA Prototype where obtained from SunPower and added back into the observed monthly electric use and simulated monthly PV numbers from BEopt where added back into the simulated electric use. Figure 8 shows removing PV from the data does not resolve all of the disparities.

Figure 8. Monthly Electric Use without PV Production



After filtering PV generation from the BA Prototype homes, overall observed electric use is within 3% and 9% of modeled data for Reference and BA prototype communities, respectively (see Table 6 below). The data was further evaluated to disaggregate cooling energy use from the electric base loads. The electric base load is the typical average use for lighting, appliances, plug loads and miscellaneous electric loads. The homeowners surveyed did not indicate atypical plug loads, i.e. large aquariums or hot tubs. The only builder provided feature that would affect base load is installed fluorescent lighting. The prototype community installed fluorescent lighting beyond California code, and encouraged the use of fluorescent lighting with its buyers.

Generally, in the Sacramento area, October, November, March, and April have little heating or cooling use and so it can be derived that the average electric use for these months can characterize the base load. Cooling energy use was determined by subtracting the monthly base load from the electric use for the months of May through September. The resulting cooling estimate for the observed data is 1,611 kWh for the Reference community and 1,086 kWh/yr for the BA Prototype community. A summary of electric use by end use is located in Table 5 below.

Table 5. Average Electric Use by End Use

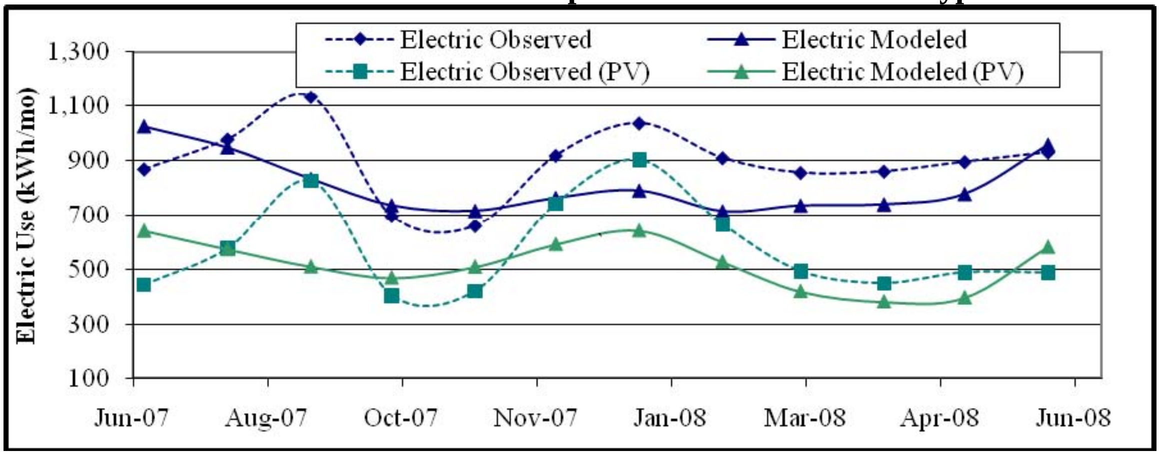
	Reference Community			BA Prototype (w/out PV)		
	Observed	**Modeled**	**% Better**	**Observed**	**Modeled**	**% Better**
Base load (kWh/yr)	8,246	8,537	3.4 %	7,537	7,969	5.4 %
Cooling+Fan (kWh/yr)	1,611	1,439	-12 %	1,086	1,195	9.1%
Total Electric (kWh/yr)[1]	10,281	10,552	2.6%	8,906	9,743	8.6%

While there is relatively good agreement on overall electrical consumption between modeled and observed data the difference between the two are more significant in cooling energy use. To eliminate error introduced by broad modeling assumptions the data was filtered to include only Plan 3 homes. Since only Plan 3 was modeled the utility bill data was reduced to

[1] Total electric use includes heating fan energy use.

only include Plan 3. Furthermore, the data was filtered to only include Plan 3 with PV systems mounted on the Southern exposure. The filtering reduced our sample size to 5 homes, and the results are graphed in Figure 9.

Figure 9. Filtered Data with and without PV production for 5 BA Prototype Plan 3 Homes



Filtering the data resulted in the model under predicting electric use in the winter, and in September. It was noted that the model uses constant lighting values throughout the year. One thought is that increased holiday lighting could account for additional December electric rate.

The filtered data also has the high-peak in September. A multiple year analysis would be required to determine if this is atypical. Disaggregation of the annual data without PV is summarized in Table 6 below.

Table 6. Annual Average Electric Use for 5 Plan 3 Homes

	BA Prototype (w/out PV)		
	Observed	**Modeled**	**% Better**
Base load (kWh/yr)	9,238	7,445	-24.1%
Cooling+Fan (kWh/yr)	963	1,195	19.4%
Total Electric (kWh/yr)[2]	10,760	9,743	-10.4%

The results show that actual cooling energy is over predicted by 19% and electric base load is under predicted by 24 %, resulting in total energy use to be within 10% of the model. Since these results only represent 5 homes of the same size, it is difficult to definitively state that the observed base load energy use is typical of the average use in the community. In fact the base load electrical usage is much higher than the average reported in Table 5. It would also be valuable in future studies to increase the sample size of homes by region, home size and building characteristics. In this climate lighting, miscellaneous, and appliances have a substantial affect on energy use. Base load electric use in on average 81% of the total electric energy use (Table 6) and so it is vital to properly characterize this load. Additional analysis would be required to determine if these results are conclusive. Ideally, a multiple year study would minimize the effects of weather and vacancy of the buildings.

[2] Total electric use also includes heating fan energy use.

Conclusions

A Prototype community in Rocklin, CA was characterized and tested in order to develop a BEopt energy model for Building America. Reconciling the differences between actual energy consumption and simulated energy use was challenging, even in a situation that home energy features were well characterized and verified through inspections.

BEopt over predicted natural gas use by approximately 36% compared to observed data. The results of utility bill disaggregation estimate water heating and natural gas is over predicted by the model by 28% and 40%, respectively. This is further supported by a KEMA study, which saw similar natural gas over prediction with California code compliance software (KEMA et al. 2010).

Electric use comparison was less consistent. Depending on how the data was filtered total electric use is between 9% over predicted and 10% under predicted. The utility bill disaggregation was inconsistent and would require additional data to be conclusive.

Proper characterization of home energy use is essential as energy conservation becomes more main stream. Proper credit and penalty for energy decisions will help to shape the future of residential construction. However, we first have to define the baseline energy use in order to determine the effects of energy decisions. To help define what is typical energy use, a multiple year study and utility bill analysis is required. A single year of data does not have the capability to dampen the affects of unseasonable weather, extended vacancy, or other atypical usage patterns. Results of such a study will help set goals and standards for the future.

It is also important to try to better characterize baseload energy use assumptions used in the models. As homes are built more efficiently, the non-HVAC energy uses become more important. In this study these end uses contribute to over 80% of the annual electric use. Studies that utilize sophisticated utility bill disaggregation technologies will allow models to become more accurate and useful.

References

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