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BUILDING TECHNOLOGIES OFFICE

Energy Evaluation of a New Construction Pilot Community: Fresno, California

A. Burdick, A. Poerschke, A. Rapport, and M. Wayne
IBACOS, Inc.

June 2014

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Definitions

ACH50	air changes per hour at 50 Pascals
AFUE	annual fuel utilization efficiency
AMY	Actual Meteorological Year
BEopt™	Building Energy Optimization (software)
CAHP	California Advanced Homes Program
CEC	California Energy Commission
CFM	cubic feet per minute
HSP	House Simulation Protocols
IMT	ASHRAE Inverse Modeling Toolkit
JR/JC	job ready/job complete
kWh	kilowatt hours
SEER	seasonal energy efficiency ratio
SIMP	systems integrated measures package
TMY	Typical Meteorological Year
WCHH	Wathen Castanos Hybrid Homes, Inc.

Executive Summary

To evaluate the success of implementing energy efficiency upgrades at the community scale using a whole-house systems integrated measures package (SIMP), IBACOS developed a field test plan for a new construction pilot community located in Fresno, California (mixed-dry climate). This pilot community project followed research conducted at the single occupied test house level with builder Wathen Castanos Hybrid Homes, Inc. (WCHH) to meet a 30% energy savings level with respect to Building America House Simulation Protocols (Hendron and Engebrecht 2010). The research was designed to evaluate and document the success of WCHH in applying the SIMP established in the single occupied test house to the production scale.

Following the research results from the individual test house, the project evaluated the success of applying an energy-efficient SIMP at the community scale by addressing factors of implementation and scalability at the community scale. This evaluation included validation of modeled energy performance using collected utility bills for five actual houses, as well as short-term performance testing (whole-house infiltration testing and duct leakage testing) and self-reported assessments from the builder and trade partners regarding implementation challenges and successes. The team implemented a low-cost data logger solution that was capable of being installed by the builder's staff adjacent to each house's thermostat. Using these data, the team was able to improve the accuracy of the models by up to 21% by creating set point schedules, which accounted for any anomalous occupant control behavior. The team performed a regression analysis on the utility bills to disaggregate heating and cooling energy usage from base load and compared the results to modeled heating and cooling energy consumption.

Fresno, California, is a competitive market, and builders are seeking ways to differentiate themselves. The builder acknowledges that state and utility incentives continue to help pay for additional features in the test house, allowing the builder to add more energy-efficient features than it typically would include in its houses. This builder has demonstrated commitment to building high-quality, energy-efficient houses and has become a leader in its local market. However, without the available financial incentives, the builder would be unable to build to as high of a standard of energy efficiency as it currently builds.

Results of monitoring and analysis efforts showed that, in general, the actual gas and electric usage was close to the predicted usage. A gap still existed between the Typical Meteorological Year and Actual Meteorological Year models for gas usage in the winter months. This gap is largely due to a 15% decrease in heating degree days for the actual weather year.

1 Introduction and Background

Builders face several key problems when implementing a whole-house systems integrated measures package (SIMP) from a single test house into multiple houses. Although a technical solution already may have been evaluated and validated in an individual test house, the potential exists for constructability failures at the community scale. Constructability failures can lead to performance issues such as higher energy use in the houses, durability issues such as moisture intrusion and building failure, and cost overruns.

The intent of this research was to analyze the effectiveness of the SIMP to achieve the target energy savings predicted using Building Energy Optimization (BEopt™) software, version 1.2. Key research for this project evaluated the consistency of executed construction specifications, pricing, and efficiencies of scale. Research focused on the builder and trade implementation of a SIMP and the actual utility usage in the houses at the community scale of production. The following research questions target the anticipated discrepancy between the predicted and actual energy consumption of the test houses:

- How do the actual utility bill readings compare to projected energy consumption using BEopt when actual weather and thermostat set points are normalized? What factors account for any significant differences?
- How closely does the normalized predicted heating and cooling energy usage align with actual usage when base load energy usage (water heating, lighting, appliances, and miscellaneous loads) is not included?

With any predictive energy modeling, there will always be gaps between the modeled inputs and the actual conditions of the house or houses that are being modeled. To produce the model, assumptions are made about actual weather conditions and operating conditions (i.e., occupant behavior) of the house. All predictive modeling seeks to accurately represent the actual energy usage of the house, and more accurate inputs should result in more accurate outputs. In this study, physical inspections of the houses and short-term performance testing (enclosure air leakage and duct air leakage tests) have validated many of the modeled inputs. The occupants completed evaluation forms to provide information on occupancy, lighting, and plug loads. For this current research, additional measurements on indoor and outdoor weather conditions will be monitored and will provide additional opportunities to adjust the model inputs and to normalize the outputs to actual weather conditions.

This report addresses factors of implementation and scalability at the community scale and proposes methodologies by which community-scale energy evaluations can be performed based on results at the occupied test house level. Short-term testing results (duct air leakage testing, air infiltration testing) at the community scale are compared with specified targets. The construction efficiencies realized by trade partners that lead to reduced production costs at a community scale are discussed, along with other system trade-offs that can be implemented to capture additional energy savings at no extra upfront cost to the builder.

Actual utility bill readings for five occupied houses are compared to projected energy consumption from models created using the BEopt software to quantify gaps in energy performance between the models and the actual houses. Monthly energy use profiles compare predicted to actual heating, cooling, and base load (water heating and lighting, appliances, and miscellaneous loads) energy use.

This new construction pilot community was constructed by builder-partner Wathen Castanos Hybrid Homes, Inc. (WCHH). In 2009 and 2010, IBACOS supported WCHH (Wathen-Castanos Homebuilders at the time) in the design and construction of an occupied test house that was to achieve greater than 30% energy savings with respect to the Building America House Simulation Protocols (HSP) (Hendron and Engebrecht 2010). The success of this single test house project was measured through an in-house data acquisition system and the results of a study presented in an earlier report published through Building America (IBACOS 2010).

Nine occupied houses, comprising seven floor plans, initially were identified to be evaluated for this community-scale effort. Through foreclosure, vacancy, and other instances of attrition, the final house count for evaluation ended up at five houses comprising five floor plans. This evaluation included validation of modeled energy performance using collected utility bills for five occupied houses, as well as short-term performance testing (whole-house infiltration testing and duct leakage testing) and self-reported assessments from the builder and trade partners regarding implementation challenges and successes.

Five occupants participated in this community-scale research by providing utility bills and information on occupancy and miscellaneous gas and electric appliance use for their houses. IBACOS used these utility data, measured thermostat temperature data, and background house information to analyze the actual energy performance of the houses and to help improve the accuracy of the original predictive modeling for these houses.

Verification with measured data is an important component in predictive energy modeling. The utility bill data confirmed that the as-built and as-occupied houses typically met the predicted energy savings.

To keep the scope of the project to something that could be implemented on a community scale, house electric and gas consumption was not submetered. To separate the base load from heating and cooling energy consumption, the team used the ASHRAE Inverse Modeling Toolkit (IMT), version 1.9 (Kissock 2002).

1.1 House Characterization

Table 1 provides basic information to characterize each of the five test houses.

Table 1. Plan Types

House Number	House Model Number	Number of Stories	Size (ft^2)	Number of Bedrooms	Number of Bathrooms	Reported Number of Occupants	Date Construction Completed
1	202	1	2,028	4	2	2	12/16/2011
2	161	1	1,613	3	2	2	12/12/2011
3	178	1	1,788	4	2	2	8/26/2011
5	220	2	2,202	5	3	2	9/30/2011
6	220	1	1,435	3	2	2	10/27/2011

The standard SIMP for all five houses includes the following specifications:

- Foundation is uninsulated concrete slab on grade.
- Stucco-clad exterior walls consist of 2 × 4 wooden framing with studs at 16 in. on center, insulated with R-13 fiberglass batts inside the wall cavities and 1-in. expanded polystyrene foam sheathing (R-4) on the exterior face, resulting in R-17 nominal thermal performance. Band joists are insulated with R-13 unfaced fiberglass batts.
- Knee walls are 2 × 4 wooden framing with studs at 24 in. on center, with R-13 fiberglass batt insulation inside the wall cavities and housewrap air barrier.
- The attic is insulated at the ceiling plane with loose-fill fiberglass to provide R-38 nominal thermal performance. A radiant barrier is installed on the underside of the roof deck.
- Windows are vinyl-framed, double-paned units with low-emissivity coatings and are argon filled, providing an overall heat transfer coefficient of U-0.34 and solar heat gain coefficient of 0.25.
- The space conditioning system consists of a 94% annual fuel utilization efficiency (AFUE) natural gas furnace and a 16 seasonal energy efficiency ratio (SEER) air-conditioning unit.
- Domestic water heating is provided via a natural-gas-fired tankless unit with an energy factor of 0.82. Low-flow faucet aerators and showerheads are installed on all units.
- Ductwork is insulated to R-8 and is located in the unconditioned, vented attic along with the furnace. The total duct leakage to outdoors target is less than 5% of the system airflow.
- The target building enclosure airtightness level is 2.5 air changes per hour at 50 Pascal (ACH50) test pressure.
- Mechanical ventilation consists of timed exhaust fans with pressure relief.
- All lighting (100%) installed at the interior and exterior of the house, including the garage, is high efficacy—using either light-emitting diodes or compact fluorescent lamps.
- Major appliances (dishwasher, clothes washer, and refrigerator) are ENERGY STAR® compliant.

1.2 Variations From the Systems Integrated Measures Package

All houses included in this study were constructed to the same standard SIMP; however, some of the units included options that were installed during or after construction. Table 2 highlights the significant options to the standard SIMP that were installed in each of the five test houses.

Table 2. Installed Options for Each Test House

House Number	Thermal Enclosure	Space Conditioning	Appliances
1	R-49 attic insulation; R-13 Johns Manville Spider insulation in walls; U-0.33 windows		Electric dryer
2	R-49 attic insulation; R-13 Johns Manville Spider insulation in walls; U-0.33 windows		Electric dryer
3	R-49 attic insulation; R-13 Johns Manville Spider insulation in walls; U-0.33 windows		Gas dryer
5	R-49 attic insulation; R-13 Johns Manville Spider insulation in walls; U-0.33 windows	19 SEER air conditioner	Electric dryer
6	R-49 attic insulation; U-0.33 windows		Electric dryer

Table 3 summarizes the catalog of miscellaneous electric loads provided by the occupants for the five test houses. This information was useful in performing the analysis on the data collected for this project.

Table 3. Summary of Occupant Self-Reported Occupancy and Miscellaneous Loads

House Number	Occupancy	TVs	Computers	Refrigerators
1	2 adults	4 flat screen	3	2
2	2 adults	3 liquid crystal display/flat screen	1	1
3	2 adults	1 flat screen, 1 tube type	1 laptop, 1 desktop	1
5	2 adults	1 flat screen (3D)	3	3 refrigerators, 1 freezer
6	2 adults	1 liquid crystal display, 1 plasma	1 laptop	1

Finally, whole-house infiltration and duct leakage test results were collected from the local Home Energy Rating System Rater who previously conducted these tests for the builder.

Table 4 lists the results of the whole-house infiltration and duct leakage tests for the five test houses.

Table 4. Duct Leakage to Outdoors and Whole-House Infiltration Rates

House Number	Year Constructed	Duct Leakage to Outdoors (% of Total System Airflow)	Whole-House Infiltration (ACH50)
Target	–	5%	2.50
1	2011	4%	3.04
2	2011	6%	3.49
3	2011	5%	3.04
5	2011	4%	2.35
6	2011	5%	2.95

2 Modeling Methods

The builder was largely interested in the salability of the SIMP included in the original occupied test house that was constructed in 2009–2010 by the builder. Fresno, California, is a competitive housing market, and builders are seeking ways to differentiate themselves from their competitors. This builder acknowledged that state and utility financial incentives helped to pay for some of the additional energy-efficient features in the test house, allowing the builder to add more energy-efficient features than would typically be included.

Optimization of the building enclosure and mechanical systems was performed using BEopt version 2.0.0.4 and resulted in a least-cost curve highlighting several key upgrades to the builder's standard specification package. Figure 1 shows the least-cost curve with one of the optimized specification packages selected.

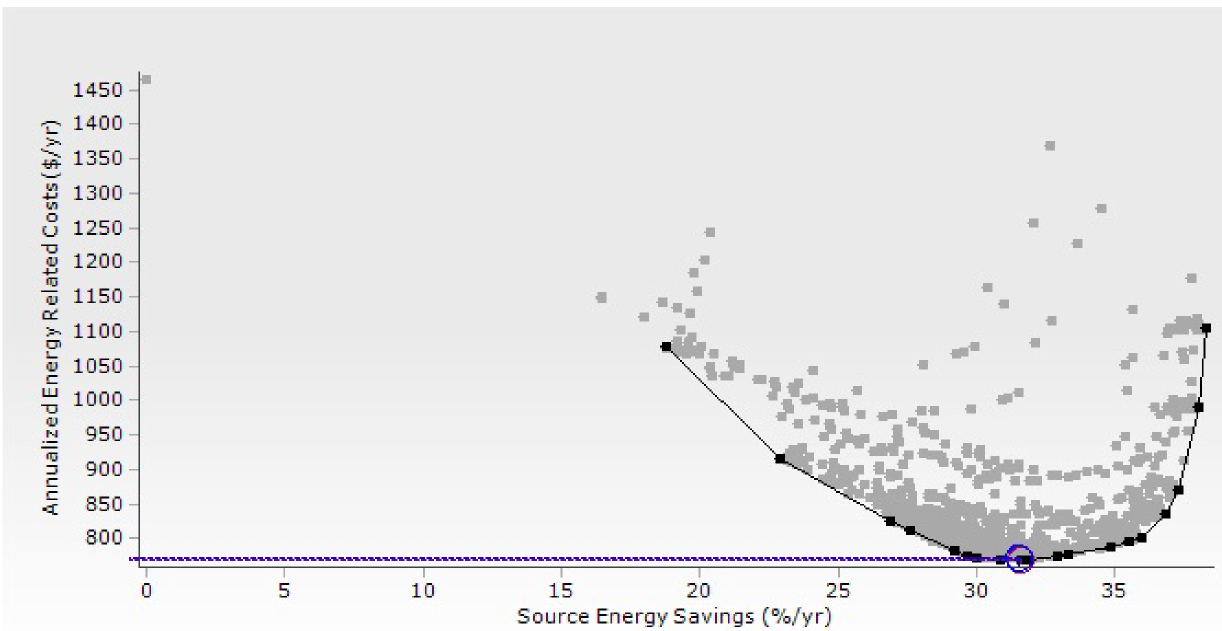

Figure 1. Least-cost curve

Many of the optimized specifications identified by BEopt were selected by the builder, with the following exceptions: R-19 insulated wall with 2 × 6, 24-in. on center framing, SEER 15 air conditioner, 98% AFUE natural gas furnace, and ducts in finished space. These specifications were replaced with other specifications based on availability, available incentives, appeal to customers, and local building practices.

The original test house SIMP was selected to be cost neutral to the *consumer* over an amortized 30-year mortgage at 7% interest; however, the original test house project did not have a cost-neutral first cost to the builder, resulting in an increased sale price to the consumer for that house. To lower the sale price for future houses, the builder adopted a newer baseline measures package that included most of the specifications from the 2009–2010 test house plus a few lower-tier modifications such as a reduced SEER rating on air-conditioning equipment, a reduced energy factor water heater, and reduced R-value of attic insulation from R-44 to R-38.

IBACOS conducted extensive modeling on the original 2010 test house design by using EnergyGauge USA (EnergyGauge 2012) to zero in on a specification package that met the target performance level, fit the builder's marketing agenda, and addressed limited product availability or trade experience. IBACOS recommended that the new design incorporate a "ducts inside conditioned space" strategy to improve the performance of the space conditioning system. However, the builder felt that its signature 10-ft ceilings were an essential part of its successful marketing program and did not want any dropped soffits or bulkheads to interfere with the ceiling plane. The builder also considered a cathedralized attic strategy, but the pricing did not fit the budget. Ultimately, the builder achieved greater than 50% source energy savings by enhancing the thermal enclosure and installing the highest performance gas-fired heating equipment and cooling equipment it could acquire through its preferred supplier.

The final specification package for the initial occupied test house included energy features that achieved Title 24 (2008 Standards) of the California Energy Commission (CEC 2008), met the California Advanced Homes Program (CAHP) Tier II qualifications (2010–2012 Program) (CAHP 2012), and reached 52% whole-house energy savings compared to the 2009 Building America Benchmark (Hendron and Engebrecht 2009).

The most significant upgrades that contributed to this level of savings included a 94.7% AFUE furnace, 19 SEER air conditioner, and 0.98 energy factor tankless water heater. The total duct leakage was measured at 5% of total fan flow. Total building leakage was measured at 2.7 ACH50. Reduced air leakage to the building enclosure was achieved by employing an airtight drywall strategy, including gluing the drywall to the wood framing around the perimeter of each drywall panel. Whole-house ventilation was provided using two Broan SmartSense fans, each rated to 80 CFM, working intermittently and in unison to provide the equivalent of 58 CFM of continuous exhaust from two bathroom locations. Ventilation exhaust rates were set to comply with ASHRAE Standard 62.2 (ASHRAE 2010). Elevated insulation levels in the walls (R-19) were achieved using Johns Manville Spider blown-in fiberglass cavity fill combined with R-4 expanded polystyrene continuous foam sheathing on the exterior. The ceiling was insulated with blown-in fiberglass that achieved R-49.

The builder met the cost-neutrality goal for the original, single test house. IBACOS used BEopt to calculate the annual cost savings for this house plan. The annual cost savings due to energy efficiency improvements (without photovoltaics) were predicted to be $1,612, and the annual increase in mortgage payments (30-year term, 5% annual interest rate[1]) to finance the improvements was predicted to be $112, leading to a net annual cost savings to the occupant of $1,500/year. The 2010 utility rates for Clovis, California, where the community is located, were $0.13/kWh and $1.80/therm.

Table 5 shows the annual source energy consumption and savings and the annual utility bill reduction of the 2009 Building America Benchmark (Hendron and Engebrecht 2009) compared to the test house. Incremental costs (total and amortized annual) also are shown for the test house compared to the builder's standard house at the time (circa 2009–2010).

[1] U.S. Department of Energy, "Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes." http://www.energycodes.gov/sites/default/files/documents/residential_methodology.pdf.

Table 5. Annual Source Energy Savings for the Test House

Description of End Use	Annual Source Energy		Estimated Source Energy		Annual Utility Bill Reduction Test House with Respect to Benchmark	Incremental Costs Test House with Respect to Builder's Standard	
	Benchmark (MBtu/yr)	Test House (MBtu/yr)	Percent of End Use Versus Benchmark	Percent of Total Versus Benchmark		Total Builder Cost + 10% Markup	Amortized Annual Cost 30-Year Mortgage, 7% Interest
Space Heating	64	30	54%	14%	$553	$1,364 $864 thermal enclosure + $500 space conditioning	$88 $56 thermal enclosure + $32 space conditioning
Space Cooling	69	21	70%	19%	$553		
Domestic Water Heating	22	12	44%	4%	$160	$350	$23
Lighting	29	13	54%	6%	$174	$20	$1
Appliances and Miscellaneous Electric Loads	57	43	24%	6%	$158	$0	$0
Outdoor Air Ventilation	3	2	40%	1%	$15	$0	$0
Subtotal	252	121	52%	52%	$1,612	$1,734	$112
Photovoltaic Panel Generation	0	–41	NA	17%	$464	$29, 358	$1,891
Total	252	121	52%	52%	$2,076	$31,092	$2,003

2.1 Energy Modeling

The time frame of this project from individual test house to community-scale evaluation occurred over a 3½-year period from 2009 to 2013. During this period, changes to the Building America benchmark and energy modeling applications resulted in a number of revisions to the analysis. Initial target energy savings were measured against the earlier version of the Building America Benchmark house (Hendron and Engebrecht 2009). Under that 2009 Building America Benchmark, the test house was projected to achieve a minimum source energy savings of 50% over that target. As the project moved into the community scale, energy savings were predicted using BEopt version 1.0.1 against the HSP (Hendron and Engebrecht 2010), with the original SIMP projected to achieve a minimum source energy savings of 30% over the target. This latest community-scale effort builds off the measured energy savings of the single test house, with projected energy savings of 30% relative to the HSP using BEopt E+ version 1.2 (BEopt E+). In addition, all test houses in this community were constructed in accordance with Pacific Gas & Electric's CAHP, which pays incentives to builders based on the level of energy efficiency that they achieve. WCHH is participating at the Tier II level (30% better than California Code of Regulations, Title 24) (CEC 2008).

3 Research and Experimental Methods

To properly characterize the five test houses included in this community-scale study, IBACOS collected data from the builder on the "as-built" conditions of the houses and used that data to inform the predictive energy models that were created using BEopt version 2.0.0.4. The research team then compared the energy usage produced from the models to that collected from the utility bills of the houses, enabling the team to identify the possible causes of any differences in consumption. IBACOS also compared the modeled energy use and usage based on the utility bills with the predicted energy use of the Building America Benchmark (Hendron and Engebrecht 2009) and the original test house SIMP.

3.1 Utility Data Collection

IBACOS collected data on whole-house energy consumption by obtaining occupant utility bills for both electricity and natural gas use for each test house. In addition, indoor temperature measurements were taken in each test house at the site of the thermostat using a single Onset HOBO[2] at each location. Due to the fragmented nature of the utility bills, whenever a full month's worth of data was unavailable, the team extrapolated those data to fit the entire month.

Additionally, a weather station was installed in a central location among the test houses to collect data on outdoor temperature, wind speed, and solar irradiance via a single HOBO data logger. Because this station did not have a remote connection, a failure in the logger that stopped data collection after several days was not discovered until the logger was retrieved at the end of the analysis period. As a surrogate for measured data, historical weather data were purchased as an Actual Meteorological Year (AMY) data file from Weather Analytics LLC.[3] To maximize accuracy, data from the nearest station, Fresno Air Terminal, was chosen. Weather Analytics uses a set of algorithms to fill and smooth missing data, allowing a continuous EnergyPlus weather file to be generated for the period of monitoring (EnergyPlus 2012). The team then ran a BEopt model for each house using the AMY file to normalize for weather conditions.

3.2 Analysis Methodology

Traditionally, linear regression is used to create a model of a building's energy consumption as it responds to outdoor temperature changes. Utility bills are then normalized to the Typical Meteorological Year 3 (TMY3) outdoor temperature data used in an energy model for comparison. Instead, the team chose to use an AMY weather file to normalize modeled energy consumption to utility bills so that additional errors would not be introduced from the process of linear regression and to allow monthly energy consumption to be compared. Additionally, using an AMY file allows all meteorological variables, beyond dry bulb temperature, to be normalized in a robust fashion.

Set point and set back parameters were determined by visually inspecting the HOBO thermostat measurements. The team determined set back schedules by selecting days that best matched typical behavior. If no regular set back schedule was observed, the team assumed a constant set point value representative of average behavior.

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[2] Onset Computer Corporation. http://www.onsetcomp.com/products/data-loggers.
[3] Weather Analytics LLC. http://www.weatheranalytics.com/.

Inputs to the BEopt energy models included the standard specifications (Hendron and Engebrecht 2009) from the original SIMP along with the installed options for each house using both the standard temperature set points and the actual set points measured by the HOBOs, and the measured test results for whole-house infiltration and duct leakage.

4 Results

This section provides details about the annual and monthly profiles of the actual (utility bills) and modeled energy consumption for the five test houses.

4.1 Annual Energy Use

Figure 2 summarizes the modeled energy use compared to the actual 12-month utility bill data for each of the five test houses. It shows that the actual energy use generally was less than the modeled energy use for each test house, with the exception of House 5. The differences among the various models and actual usage varied for the different houses. However, because few changes were made to the as-built houses from the SIMP, the energy use for those two modeled scenarios remained fairly close.

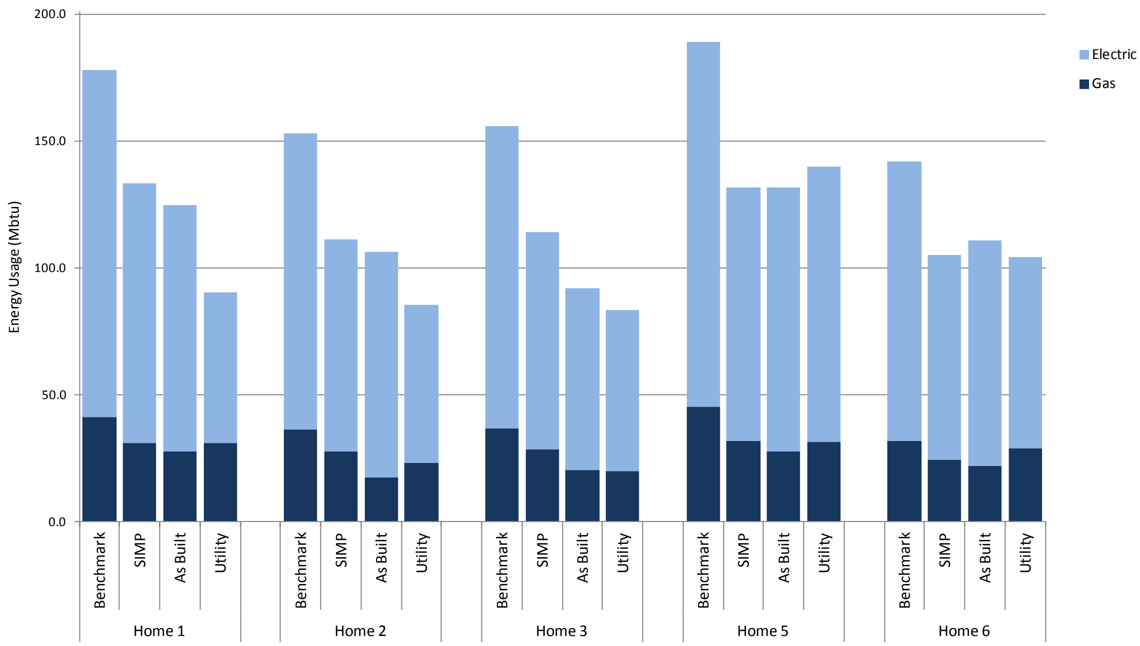

Figure 2. Annual energy use comparison of utility bills and models

Using temperature measurements taken at the thermostat over the course of one year, the team was able to determine an adjusted set point and set back schedule, as shown in Table 6. Using this information, the team adjusted the BEopt models to reflect occupant behavior. Table 7 summarizes the results from this modification.

Table 6. Adjusted Set Point Parameters

		House 1	House 2	House 3	House 5	House 6
Heating	Set Point	74° F	73° F	68° F	71° F	70° F
	Set Back	70° F	70° F	64° F	68° F	–
	Schedule	00:00 to 10:00	00:00 to 17:00	00:00 to 10:00	05:00 to 18:00	–
Cooling	Set Point	80° F	75° F	80° F	79° F	70° F
	Set Back	–	–	–	–	75° F
	Schedule	–	–	–	–	08:00 to 22:00

Table 7. Change in Model Accuracy Due to Adjusted Set Points

		House 1	House 2	House 3	House 5	House 6
Annual Energy Consumption (MMBtu/Yr)	Standard set points*	134	112	110	142	107
	Adjusted set points	125	106	92	132	111
	Utility bill	90	85	83	140	104
	Percent change	**7.4%**	**5.8%**	**19.4%**	**7.6%**	**–3.8%**

A standard set back schedule was observed: the team assumed a constant set point value representative of average behavior.

*Standard set points: 71°F heating, 76°F cooling (Hendron and Engebrecht 2010).

4.2 House 1 Utility Usage

Figure 3 and Figure 4 show gas and electricity usage per month for House 1, respectively, from June 2012 through May 2013. The graphs, which have been wrapped to show a normal calendar year, include energy usage data gathered from the TMY model, AMY model, and utility bills. There were a few gaps in the utility bill data for May, June, and December because of collection difficulties. This was accounted for in these graphs using the days of that month with data to average a monthly energy usage value. As the two figures show, the gas usage was relatively close among the two models and actual data, but a significant difference occurred with electricity usage. The actual usage was much lower than that predicted by the model, which is most likely because of occupant behavior.

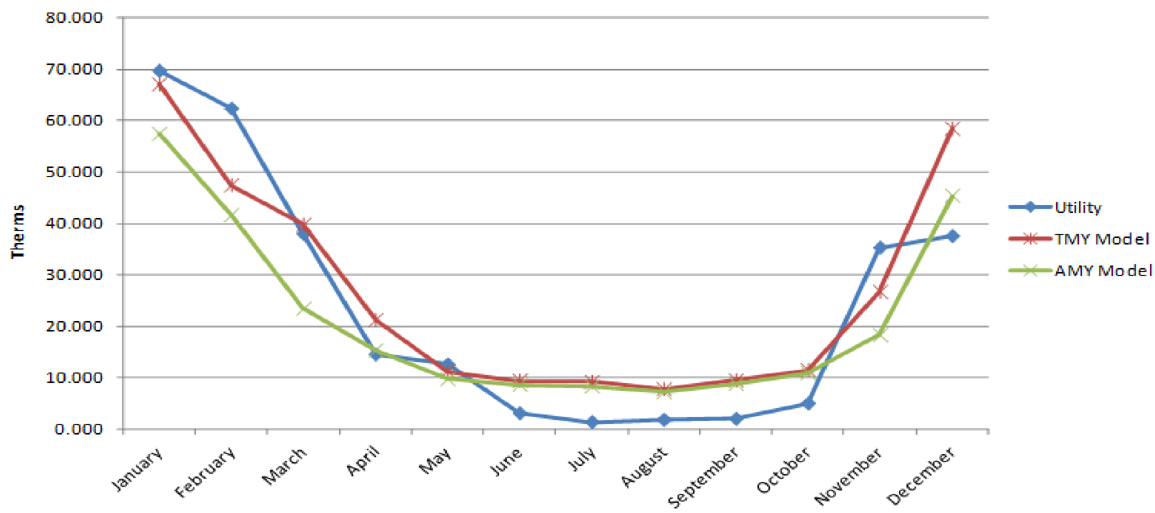

Figure 3. House 1 gas usage

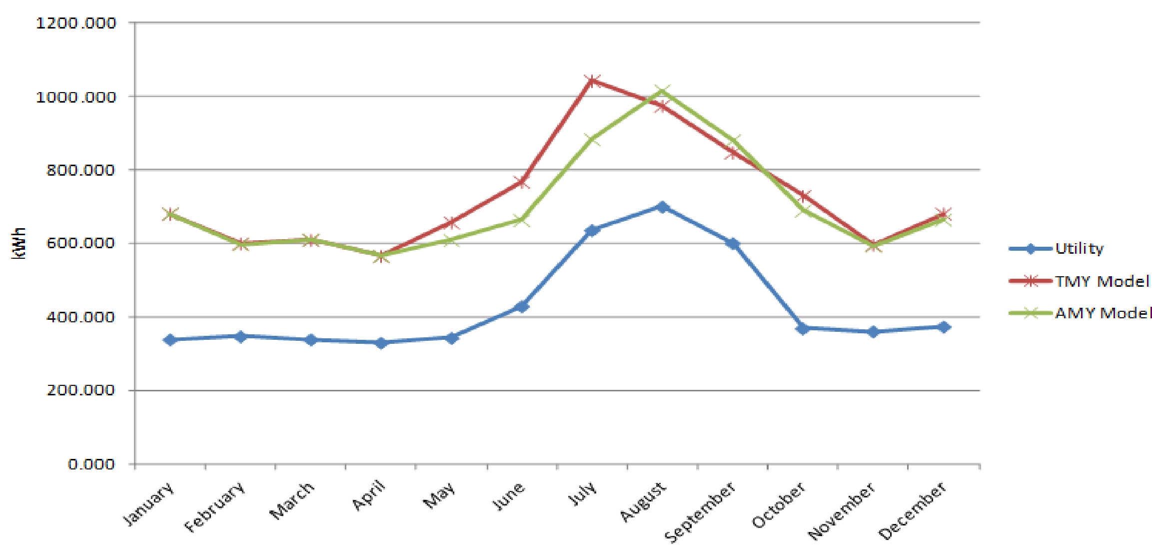

Figure 4. House 1 electricity usage

4.3 House 2 Utility Usage

Similarly, Figure 5 and Figure 6 show the gas and electricity usage per month, respectively, for House 2 from January 2012 through December 2012. The graphs include energy usage data gathered from the TMY model, AMY model, and utility bills. Partially missing utility data in January, March, and April were accounted for as previously stated. The results for House 2 are similar to those for House 1; the gas usage was fairly close, but a gap exists between modeled and actual electricity usage. Also, a clear difference between the TMY and AMY models exists for gas usage in the winter months, which can be attributed to 15% fewer heating degree days for the actual weather year.

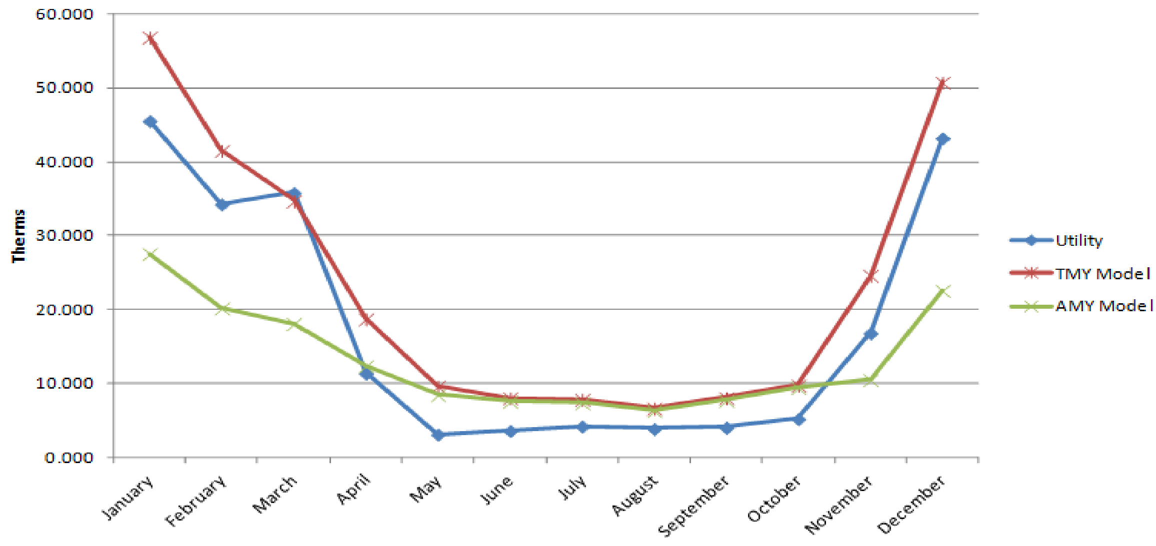

Figure 5. House 2 gas usage

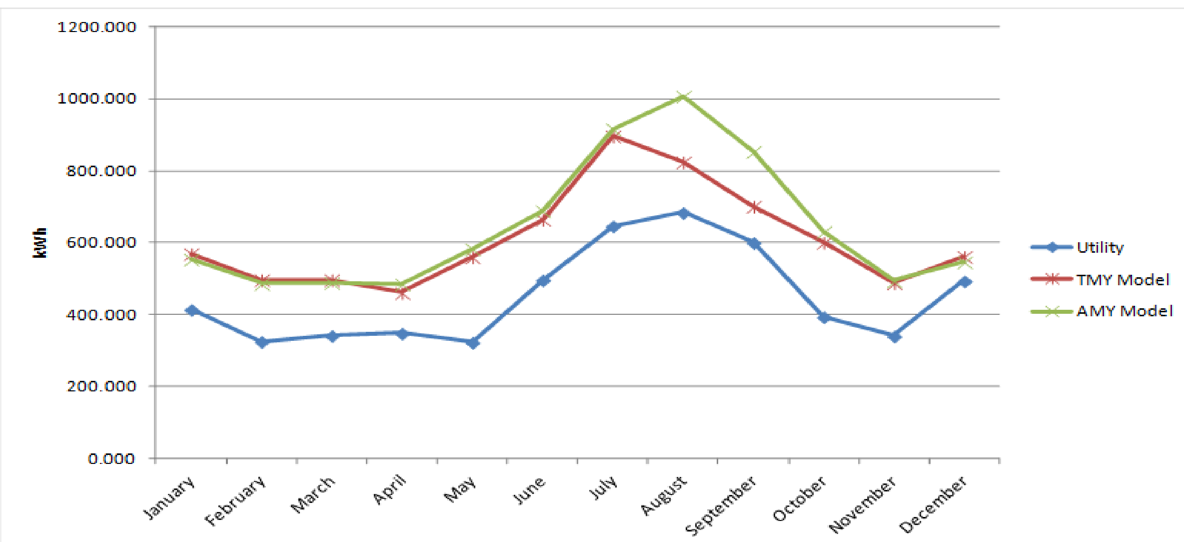

Figure 6. House 2 electricity usage

4.4 House 3 Utility Usage

The gas and electricity usage per month from the TMY model, AMY model, and utility bill data for House 3 are shown in Figure 7 and Figure 8, respectively, from January 2012 through December 2012. No gaps in the utility data existed for this house, making the data as accurate as possible. In general, the actual gas and electricity usage was close to the predicted usage. A gap still existed between the TMY and AMY models for gas usage in the winter months. This gap is largely due to a 15% decrease in heating degree days for the actual weather year.

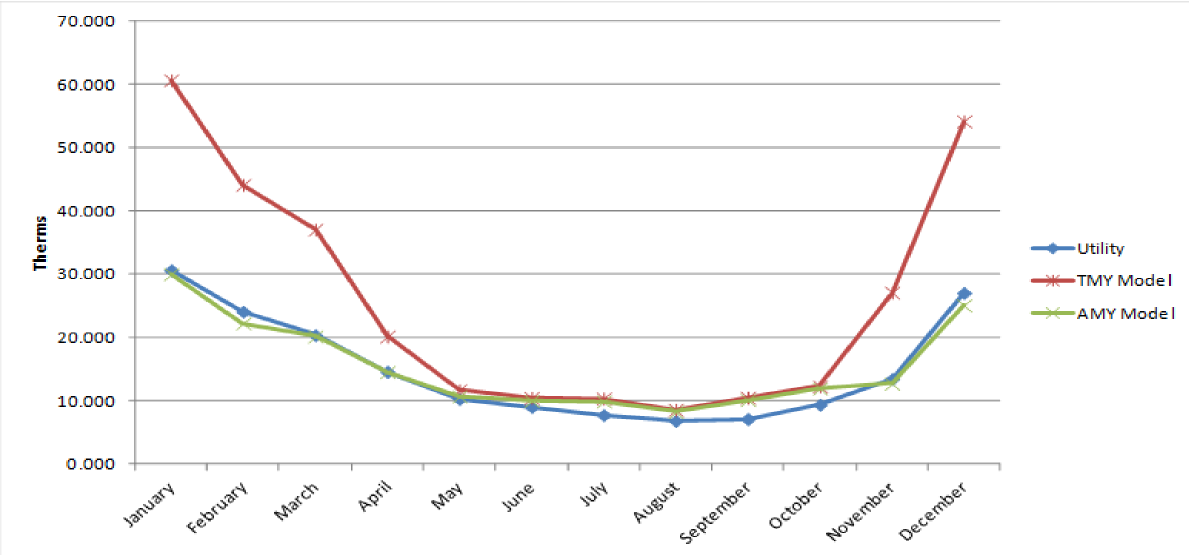

Figure 7. House 3 gas usage

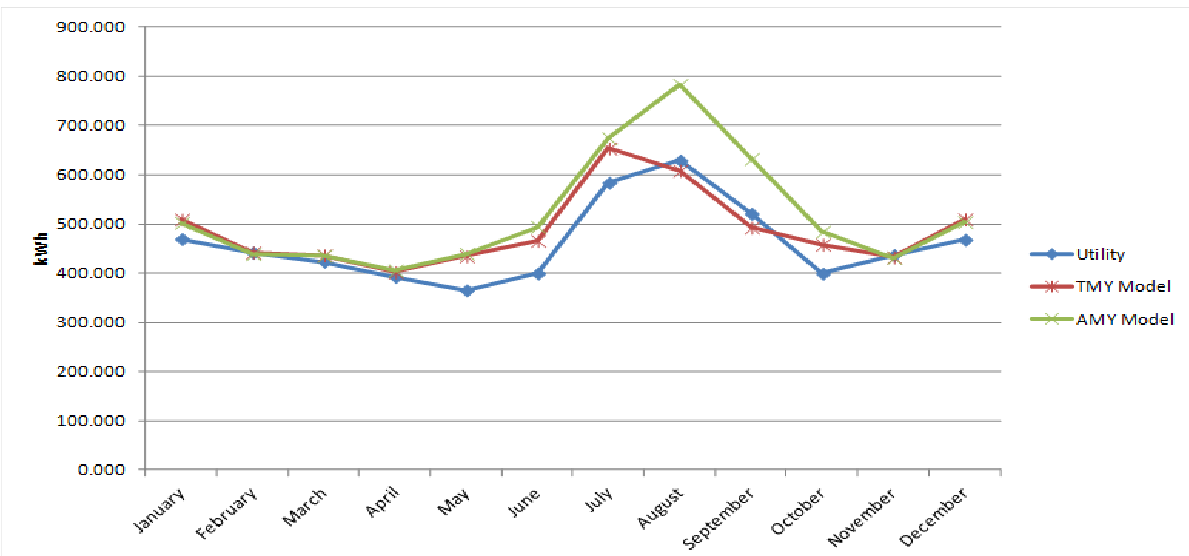

Figure 8. House 3 electricity usage

4.5 House 5 Utility Usage

The projected and actual gas and electricity usage for House 5 is represented in Figure 9 and Figure 10, respectively, from February 2012 through January 2013. Graphs have been wrapped to show a normal calendar year. Partially missing utility bill data in February, June, and July were accounted for by the same method previously mentioned. Both models and the actual utility data were very similar over the year for gas and electricity usage, showing accurate prediction from the models.

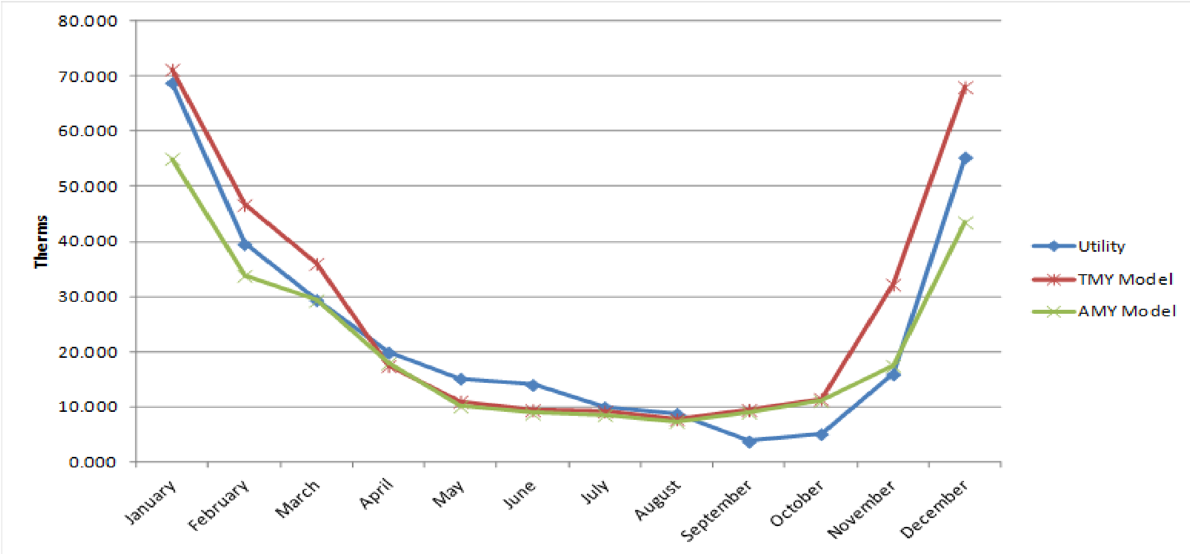

Figure 9. House 5 gas usage

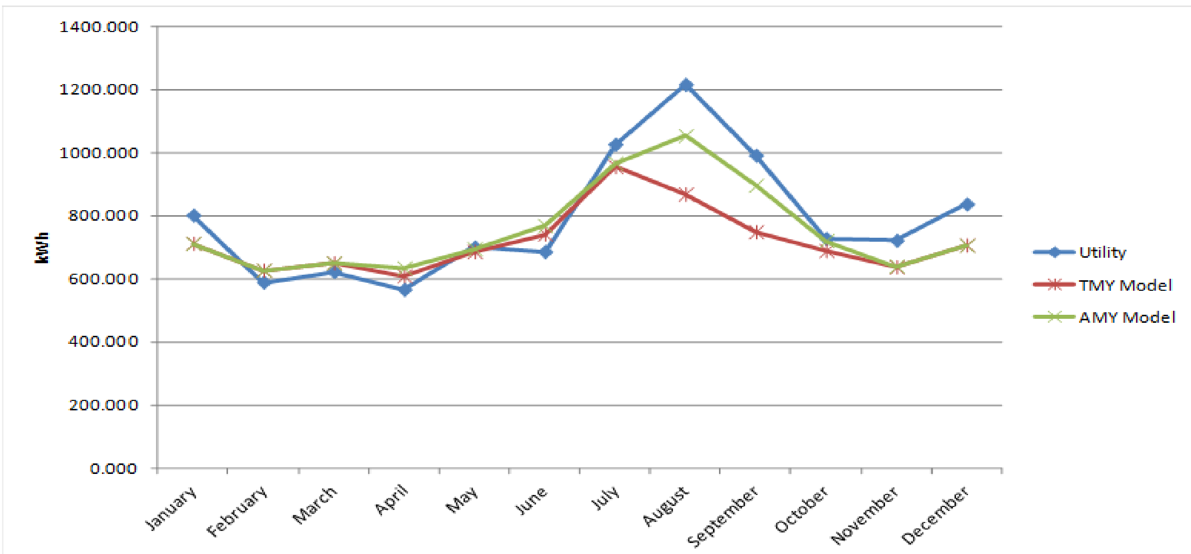

Figure 10. House 5 electricity usage

4.6 House 6 Utility Usage

Figure 11 and Figure 12 show gas and electricity usage per month for House 6, respectively, from February 2012 through January 2013. Graphs have been wrapped to show a normal calendar year. The included energy usage data were gathered from the TMY model, AMY model, and utility bills. Utility bill data partially missing in July and August were accounted for by the same method previously described. The gas usage is fairly similar among the two models and actual data, but a slight difference existed between the models and the actual data for electricity usage.

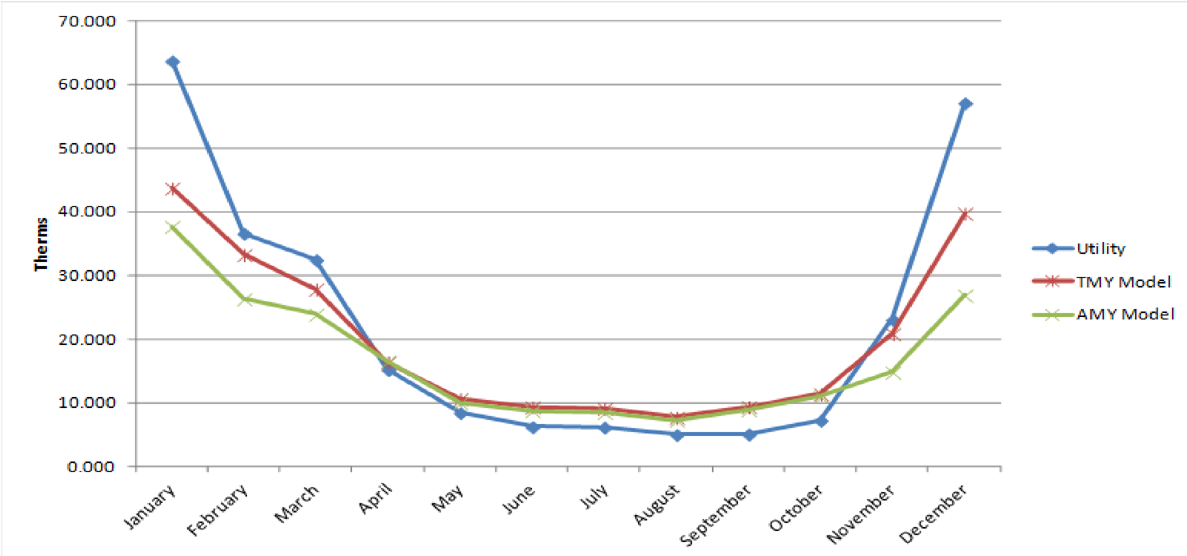

Figure 11. House 6 gas usage

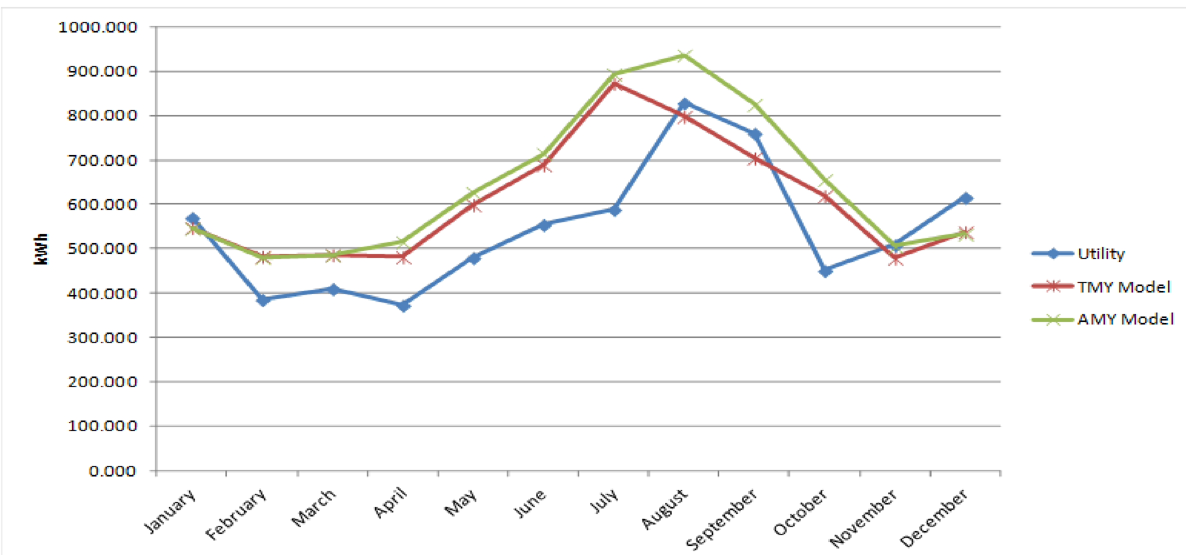

Figure 12. House 6 electricity usage

4.7 Inverse Modeling and Utility Bill Disaggregation

One of the additional research questions the team considered was how well the predicted heating and cooling energy usage aligned with actual usage. Heating and cooling energy usage was not submetered as part of this project; therefore, regression analysis was necessary to estimate the base load. To perform this analysis, the team used the ASHRAE IMT, version 1.9 (Kissock 2002). This tool takes utility bills or energy consumption measurements and performs a linear regression against weather data, typically outdoor temperature. The team decided to use a three-parameter regression on the monthly utility bills and hourly weather data, treating the gas and electric data separately to improve accuracy. The result of this regression is a heating change-point, a cooling change-point, and the slope of the heating and cooling lines, indicating how the house responds to colder or warmer outdoor temperatures.

Table 8 summarizes the results of this regression. Total error of the regression model as indicated by the R^2 value was minimal for all but one of the houses considered in the analysis. Despite the low error in the regression model, the disaggregated cooling and heating energy usage does not align well with BEopt predictions. The heating energy usage predicted from the IMT does not take into account fan energy; therefore, this was not summed from the BEopt output. A result of this is that the electrical base load also includes the heating fan energy, raising the apparent base load.

Table 8. Disaggregated Energy Consumption from Inverse Modeling Compared to BEopt

	Cooling Energy Usage (kWh)				Heating Energy Usage (Therms)			
House Number	BEopt	Utility – IMT	Percent Difference*	R^2	BEopt	Utility – IMT	Percent Difference*	R^2
1	970	1,549	–37%	0.97	233	126	85%	0.89
2	925	2,097	–56%	0.88	164	47	250%	0.97
3	442	1,200	–63%	0.80	81	46	75%	0.95
5	1,137	1,596	–29%	0.84	153	121	27%	0.95
6	846	2,096	–60%	0.63	192	71	171%	0.98

* Percent difference of BEopt results compared to the inverse model.

5 Discussion

This section presents the analysis of the measured and modeled data. As shown in Table 1, through occupant surveys, the team determined that each of the five test houses was under-occupied relative to the HSP (Hendron and Engebrecht 2010). As a result, the utility bill data showed less consumption than predicted.

5.1 Verification of Predicted Energy Savings

Verification with measured data is an important component of predictive energy models, specifically when there is a target energy savings. Incorrectly installed or malfunctioning heating, ventilation, and air conditioning equipment can be problematic in the residential building industry. Additionally, many simplifications and assumptions must be made regarding the as-built and as-occupied house.

To identify any inaccuracies in the modeling processes, the team implemented an inexpensive monitoring program through which the test house occupants submitted utility bills, and a HOBO data logger was installed next to the thermostat in each test house. This method allowed for the installation of hardware by an untrained layperson representing the builder.

For all houses presented in this report, the team was able to estimate seasonal set points and set back schedules, as well as to analyze any aberrant occupant thermostat control behavior. Reliance on the occupants' diligence in submitting monthly utility bills increased the risk of inconsistencies or missing values in the data. Despite this deficiency, the utility bill data confirmed the as-built and as-occupied houses typically met the predicted energy savings.

This method of verification proved useful and cost effective at the community scale. A more expensive monitoring system (more than $5,000) using a traditional data logger, sensors, and telemetry is an effective approach for a single house but is impractical for the community scale. Based on measurements taken at the thermostat, the team was able to improve the accuracy of the simulations by 7% to 21% in four of the five houses, with the accuracy of the fifth house reduced by 4%. Although this may not influence the design stage of the house construction, these data provide an indication that standard set point and occupancy schedules might not be appropriate to be uniformly applied during the decision-making process. A stochastic method of predicting occupant behavior would provide a range of possible energy savings.

5.2 Disaggregated Load Analysis

Disaggregated heating and cooling energy consumption from the IMT aligned poorly with the values predicted by BEopt in this project. This is largely due to the way the IMT estimates coefficients during regression analysis. The tool attempts to minimize the error in total energy consumption, while not giving weight to how well base load is separated from cooling and heating energy. Low load homes exacerbate the discrepancy because of greater influence of base load relative to heating and cooling loads. Lower magnitude numbers also are more susceptible to noise. Using monthly utility bills alone is not a reliable means to estimate disaggregated heating and cooling energy usage. To determine how well BEopt predicts heating and cooling energy usage, it is necessary to submeter the equipment separately.

5.3 Construction Best Practices

The builder uses a third-party inspection provider for high-level liability issues such as framing and water intrusion issues. The third-party program inspection occurs at the rough stages in every house after windows are installed. Quality assurance inspections of these key areas in every house are a big part of the builder's ability to deliver consistent quality to the occupants. Random inspections of other structure areas, such as foundations, add to the overall quality assurance/quality control process. Defects are red tagged and are given a tracking number for reporting purposes. A lot-specific report then is sent to the site contact for resolution. The site contact manages resolution through the trade, and then both the trade and the site contact sign off that the repairs have been made properly. The third-party inspector then sends an aging report of open items to the builder's office for follow-up and, ultimately, resolution.

The builder also uses an in-house program tied to first-time quality, which it learned from its work with the National Housing Quality Award program. A series of checklists from first-time quality has been developed by the builder specifically for the builder's practices. As of the time of completion of construction of the community, these checklists had been in place less than a year, and a few trades have adopted the practice while others have not. This is a "ground-up" or grass-roots effort to identify areas for quality inspection, and checklists are generated for each trade with the trade's input. Each phase of work has a checklist for each associated trade. The trade foreman walks the house and rates the job on a job ready/job complete (JR/JC) form for the previous trade. The JR/JC forms are submitted to both the trade's offices and the builder's offices. The builder site superintendent also back checks the trade foreman with its own JR/JC form. The builder management analyzes the JR/JC forms for trends to identify hot spots and works with trades to address issues.

Performance testing occurs on a sample of houses with blower door, duct tightness, refrigerant, maximum cooling, and soon to be required low-leakage tests. Infiltration testing results are consistently within the program limits, with only one in every 25 to 30 houses having an issue. A final duct blaster test is performed after carpets are installed in the house. The site superintendent is present in the house during the testing to strengthen all parties' understanding of what is being tested.

5.4 Additional System Trade-offs

Relocating the tankless water heater to the attic to reduce the amount of wasted water is one system trade-off under consideration. The relocation of the tankless water heater to the attic also reduces the risk of theft from the house during construction, thereby reducing the builder's risk. The builder would like to take advantage of the low-leakage air handler credit from the CEC when the equipment becomes available through its preferred manufacturer. The builder also is looking forward to the CEC certifying low-leakage air handlers for its current manufacturer, reducing the Title 24 duct leakage requirements (CEC 2008).

5.5 Construction Efficiencies Realized by Trade Partners

One critical success factor identified by the builder was finding the right trade partner that was willing to work with and deal with the changes the SIMP involved. The tricky details of air sealing and installing insulation around pipes or the Title 24 caulking details were identified as challenging for trade partners to achieve.

IBACOS conducted a phone interview with the insulators to discuss the implementation of the SIMP at a community scale (Cooper 2012; Ewing 2012). The insulators perform the insulation and air sealing scope. To reduce their production costs and to minimize the costs associated with training new crews, the insulators try to keep the same crews going to the builder's houses when possible. To bring a new crew member up to speed requires one week of on-the-job training by a production manager before the new crew member can be fully utilized. The insulators estimated a 15% administrative cost increase over their typical work associated with the additional labor and paperwork required for the builder's work.

The insulators viewed the builder's quality assurance/quality control program as being similar to their own internal quality checks. They clearly saw the value in the process and indicated its connection to the Title 24 requirements.

Although the insulation and air sealing scope are directly related to the performance of the house, there is not much interaction between the installer and tester except when a solution to a problem is needed. Sealing of outlet plates was given as an example of cooperative work between the two.

The insulators worked with the builder to achieve the desired results in the fireplace air barrier details and are working to address a question on the use of raised heel trusses. Air sealing around fire sprinkler heads and the best attic insulation material for the money are other issues they are working together to solve.

The insulators reaffirmed that this builder is one step ahead of other builders in the area in utilizing heating, ventilation, and air conditioning supplies sealed to surfaces, caulking plates, and interior wall sealing. They see other builders following this builder's lead. Most of this builder's practices are the insulators' standard practices, although the insulators did not indicate whose practices came first.

6 Conclusions

The following research questions target the anticipated discrepancy between the predicted and actual energy consumption of the test houses:

- How do the actual utility bill readings compare to projected energy consumption using BEopt?
- How closely does the normalized predicted heating and cooling energy usage align with actual usage when base load energy usage (water heating, lighting, appliances, and miscellaneous loads) is not included?

Nine occupied houses, comprising seven floor plans, initially were identified to be evaluated for this community-scale effort. Through foreclosure, vacancy, and other instances of attrition, the final house count for evaluation ended up at five houses comprising five floor plans.

Verification with measured data is an important component of predictive energy models. As shown in Section 5.1, the utility bill data confirmed that the as-built and as-occupied houses typically met the predicted energy savings.

By measuring the temperature at the thermostat and estimating set points, the team was able to account for occupant behavior. The modified set points improved the accuracy of the simulations by 7% to 21% in four of the five houses, with the accuracy of the fifth house reduced by 4%.

Using the IMT and monthly utility bills is not a reliable means to estimate disaggregated heating and cooling energy usage. To determine how well BEopt predicts heating and cooling energy usage, it would be necessary to submeter the equipment separately.

With continued implementation of quality assurance/quality control measures that were previously developed and executed by the builder, the results of performance testing in future houses in this community are likely to continue meeting the targeted levels of performance.

With feedback from the trades and the builder regarding efficiencies gained through consistent execution of the SIMP and discussions around other possible measures, additional opportunities were identified for further improving the levels of energy efficiency that will bring the incremental cost of upgrades closer to being first-cost neutral to the builder.

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