U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Measured Performance of Occupied, Side-by-Side, South Texas Homes

Dave Chasar and Valerie vonSchramm
Building America Partnership for Improved Residential Construction

September 2012

Building America
U.S. Department of Energy

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, subcontractors, or affiliated partners makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Measured Performance of Occupied, Side-by-Side, South Texas Homes

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

Dave Chasar and Valerie vonSchramm

Building America Partnership for Improved Residential Construction

Florida Solar Energy Center

1679 Clearlake Rd

Cocoa, Florida, 32922

NREL Technical Monitor: Stacey Rothgeb

Prepared under Subcontract No. KNDJ-0-40339-00

September 2012

Acknowledgments

The authors wish to acknowledge the assistance of Lake Flato Architects, Inc., Woodside Homes of South Texas, and Builder's Energy Rater. Staff at Lake Flato Architects performed the preconstruction modeling and developed the residential construction specifications to reduce the home's energy consumption by 50%. Staff at Woodside Homes worked diligently to ensure the proper adoption of these modified building techniques. Thank you also to the staff at Builder's Energy Rater for the extra assistance in photo documentation of the homes and assisting with the adoption of new construction practices.

Contents

Acknowledgments iv
Contents v
List of Figures vi
List of Tables vi
Definitions vii
Executive Summary viii
1 Introduction 1
2 Home Comparison 2
2.1 Envelope Features 3
2.2 Envelope Air Sealing 3
2.3 Duct Tightness and Location 4
3 Building America Benchmark Energy Analysis 5
4 Electricity Demand 7
5 Cooling Energy 10
6 Photovoltaic Performance 15
7 Results and Conclusions 17
References 18

List of Figures

Figure 1. Front view of control, high performance, and PV homes ... 2
Figure 2. Infrared and visible images of high performance home (above) and PV home (below) ... 4
Figure 3. Hub and branch ducts (left) and tapered ducts (right) ... 4
Figure 4. BEopt source energy by end use ... 6
Figure 5. Measured electric load on the hottest summer day (July 8, 2009) ... 8
Figure 6. Measured control home electric loads ... 9
Figure 7. Cooling energy versus outdoor-indoor temperature difference ... 11
Figure 8. Average daily ambient and indoor temperatures (°F) ... 13
Figure 9. Monthly electricity use in the PV home from July 2009 through March 2011 ... 15
Figure 10. Comparison of measured and estimated monthly PV production ... 16

Unless otherwise noted, all figures were created by the Building America Partnership for Improved Residential Construction.

List of Tables

Table 1. Home Features Comparison ... 2
Table 2. BEopt Analysis Results ... 5
Table 3. Projected “Non-PV” Site Energy Savings Versus BA 2010 Benchmark ... 6
Table 4. Sensors and Datalogger ... 10

Unless otherwise noted, all tables were created by the Building America Partnership for Improved Residential Construction.

Definitions

A/C	Air conditioning
ACH50	Air changes per hour at 50 Pascals pressure differential
AFUE	Annual fuel utilization efficiency
BA	Building America
BEopt	Building Energy Optimization
CFM25	Cubic feet per minute at 25 Pascals pressure differential
HVAC	Heating, ventilation, and air conditioning
PV	Photovoltaic
Qn,out	Normalized duct leakage to the outside calculated by dividing the measured duct leakage to the outside at a test pressure of 25 pascals (CFM25,out) by the conditioned area of the home. For example, Qn,out of 0.03 represents a leakage of 3 CFM for every 100 ft^2 of conditioned space.
RH	Relative humidity
SEER	Seasonal energy efficiency ratio (for the efficiency of air conditioners and heat pump cooling)
SHGC	Solar heat gain coefficient

Executive Summary

The performance of three occupied homes built in 2009 in San Antonio, Texas with identical floor plans and orientation were evaluated through a partnership between the Florida Solar Energy Center, CPS Energy, and Woodside Homes of South Texas. Measurements included whole-house gas and electricity use as well as heating, cooling, hot water, major appliances, and indoor and outdoor conditions. One home built to the builder's standard practice served as the control; the other homes demonstrated high performance features.

The goals of this research were to: (1) learn how energy systems affect peak load profiles during the hottest weather conditions; (2) inform the development of builder and homeowner incentive programs that manage demand and energy consumption; and (3) measure cooling energy use to determine savings from envelope and equipment improvements.

Data collection began in July 2009, which was at about the time of first occupancy, and continued through April 2011. One home (CP3) was unoccupied for the first two months of data collection. Energy ratings for the homes yielded E-Scales (aka Home Energy Rating System Indices) of 86 for the control home (CP1), 54 for one improved home (CP2) and 37 for the other improved home (CP3), which has a 2.4-kW photovoltaic array. Envelope improvements included:

- Sealed attic with R-28 open cell spray polyurethane foam at the roof deck
- Frame walls insulated to R-15 and R-3 rigid insulating sheathing
- ENERGY STAR® windows with a U-value of 0.34 and a solar heat gain coefficient (SHGC) of 0.33
- Enhanced air sealing

Equipment improvements include right-sized (per Air Conditioning Contractors of America Manual J) tankless gas water heaters (versus gas tank), two-stage air conditioning with a Seasonal Energy Efficiency Ratio (SEER) of 18 (versus right-sized SEER 14), ENERGY STAR appliances (versus standard appliances), and 100% fluorescent lighting (versus 5% fluorescent).

The improved homes overall saved 55% –77% in cooling energy and, on the hottest day, a utility peak demand reduction of 6–8 kW (62%–83%). A 2.4-kW grid-tied photovoltaic array successfully offset total monthly heating, ventilation, and air conditioning electric energy and 80% of the time on a daily basis during the summer months. Because the homes were occupied, the impact of occupant behavior on the results is unclear.

1 Introduction

The Florida Solar Energy Center supports many Building America (BA) projects with long-term monitoring of building energy use and environmental conditions. Homes are typically monitored using 15–50 channels of data to measure indoor and outdoor environmental conditions and energy use of heating, cooling, water heating, whole-house, and other points (e.g., solar photovoltaic [PV] or solar domestic hot water) as needed. CPS Energy is the nation's largest municipally owned energy company providing both natural gas and electric service. Acquired by the City of San Antonio in 1942, the company serves approximately 700,000 electricity customers and more than 320,000 natural gas customers in and around America's seventh largest city. Thirty-year weather averages for this location include 1,573 heating degree days and 3,038 cooling degree days.

Research on these homes focused primarily on comparisons of peak electric load profiles and cooling energy performance. Several electric demand reduction strategies were used to limit demand, especially during utility peak periods. These included high efficiency electric equipment and replacement of electric appliances with gas and PV panels.

2 Home Comparison

Construction of the three homes began in late 2008 and was completed in early 2009 (see Figure 1). Each residence was built on the same street running north-northwest to south-southeast within 300 ft of each other. All homes have identical 1,979 ft^2 floor plans and orientation. There are differences in attic construction and wall insulation (as seen in Table 1), but otherwise the homes are similar. Gas appliances were used in the improved homes with the exception of a high-efficiency, electric heat pump in the high performance home (CP2). The control home (CP1) had mainly electric appliances except for a gas water heater and furnace, all of standard efficiency. Standard appliances and lighting were used in the control home to represent higher internal cooling loads than found in the improved homes. (See Table 1 for details.)

Figure 1. Front view of control, high performance, and PV homes

Table 1. Home Features Comparison

	Control CP1	Hi-Performance CP2	PV CP3
Foundation	Uninsulated slab on grade (1,979 ft^2)	Uninsulated slab on grade (1,979 ft^2)	Uninsulated slab on grade (1,979 ft^2)
Roof Cladding	Brown asphalt shingle	Brown concrete tile	Brown concrete tile
Attic Type	Vented	Sealed	Sealed
Attic Insulation	R-30 blown fiberglass in ceiling plane, roof deck radiant barrier	R-28 open cell spray foam under roof deck	R-28 open cell spray foam under roof deck
Wall Type	2 × 4 frame/brick veneer	2 × 4 frame/brick veneer	2 × 4 frame/brick veneer
Wall Insulation	R-13 fiberglass batts	R-15 blown-in fiberglass +R-3 insulated sheathing	R-12 open cell spray foam +R-4 insulated sheathing
Windows	SHGC: 0.37 U-value: 0.53	SHGC: 0.33, U-value: 0.34 +1 ft roof line extension	SHGC: 0.33, U-value: 0.34 +1 ft roof line extension
Heating	80% AFUE* gas furnace	9.5 HSPF** heat pump + 5kW b/u strip heat	94% AFUE gas furnace
Cooling	SEER 14	SEER 17.8	SEER 17.7
Water Heating	40-gal Gas, EF = 0.59	Tankless gas, EF = 0.82	Tankless gas, EF = 0 .82
Ventilation	None	Passive runtime	Passive runtime
Lighting	Incandescent +5% fluorescent	100% fluorescent, timers and occupancy sensors	100% fluorescent, timers and occupancy sensors
Cooktop	Electric	Natural gas	Natural gas

	Control CP1	Hi-Performance CP2	PV CP3
Refrigerator	775 kWh***/yr	ENERGY STAR, 505 kWh/yr	ENERGY STAR, 505 kWh/yr
Washer	Standard top-loader	ENERGY STAR Tier 3	ENERGY STAR Tier 3
Dishwasher	EF = 0.46	ENERGY STAR, EF = 0.66	ENERGY STAR, EF = 0.66
Dryer	Electric	Natural gas	Natural gas
Thermostat	Nonprogrammable	Programmable	Programmable
PV	None	None	2.4-kW roof tiles
Home Energy Rating System Index	86	54	37
Envelope Leakage	5.84 ACH50****	3.64 ACH50	1.95 ACH50
Duct Leakage	70 CFM*****25, Qn = 0.035	47 CFM25, Qn = 0.024	65 CFM25, Qn = 0.033

*Annual fuel utilization efficiency
**Heating seasonal performance factor
***Kilowatt hour
****Air changes per hour at 50 Pascals
*****Cubic feet per minute

2.1 Envelope Features

All homes were built on uninsulated, slab-on-grade foundations with 2 × 4 frame walls and brick veneer. Wall insulation varied, with standard R-13 batts used in the control home, R-15 blown fiberglass plus R-3 foam sheathing in the high performance home, and R-12 spray foam as well as R-4 foam sheathing in the PV home. The window-to-wall ratio of 16% was identical in each home with double-pane low-emissivity used throughout, although those in the improved homes were of higher performance. An additional 12 in. of roof overhang is built into the improved homes over that of the control. The control home had a vented attic with R-30 blown fiberglass insulation on the ceiling and a radiant barrier roof deck. The improved homes had identical sealed attics with R-28 open cell foam sprayed on the roof deck and at the garage-home attic interface. Reflectance of the roof materials was similar, (medium to dark in color); the control home had asphalt shingles and the improved homes had concrete tile.

2.2 Envelope Air Sealing

All three homes have air-sealed envelopes, as reflected in the envelope leakage numbers, due to a concerted effort by the builder. Slab-to-wall connections were caulked in all homes, as were wall, window, and ceiling penetrations. Insulated sheathing in the improved homes was taped, and all three homes received a taped house wrap. Access to the vented attic in the control home was outside the conditioned space (garage). The control home envelope is reasonably airtight at 5.84 air changes per hour at 50 Pascals pressure differential (ACH50), below the ENERGY STAR V3 requirement of 6 ACH50 for climate zones one and two. The improved homes are considerably tighter but with noticeable variation. The PV home was fairly well sealed at 1.95 ACH50, while the high performance home measured in at nearly twice that number. All the homes had a sealed roof-wall interface; however, infrared images of the improved homes on a cold December day indicated more leakage at this location in the high performance home than in the PV home (similar wall locations in CP2 and CP3 are illustrated in Figure 2). The roof-wall interface of the high performance home was at approximately 45°F, while the roof-wall interface of the PV home was at approximately 51°F. This is thought to be the main contributor to higher envelope leakage in the high performance home.

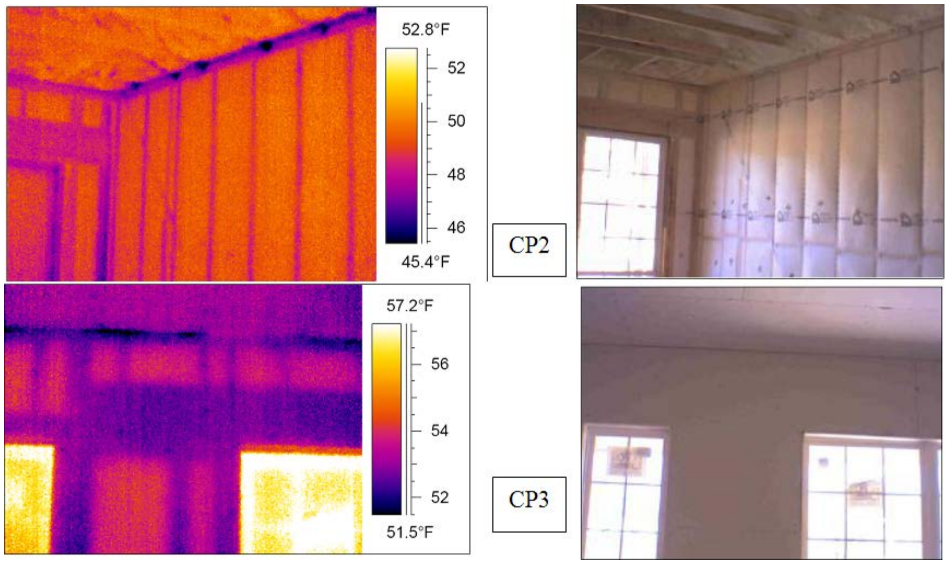


Figure 2. Infrared and visible images of high performance home (above) and PV home (below)

2.3 Duct Tightness and Location

Air distribution systems consisted of R-6 flex duct in the attic of each home. All ducts were sealed with mastic, which resulted in test numbers of no more than 0.035 CFM25/ft^2 of conditioned floor area. Measured attic conditions during the summer reflect one difference between the homes. Results show an average temperature of 95°F for the control home and 79°F for the two improved homes, which had similar attic conditions. This illustrates the effect of the sealed and insulated attics in the improved homes during the hottest months of the year—June through August—in both 2009 and 2010. Maximum attic temperatures reached 129°F and 85°F in the respective homes during these months. Another difference was that the improved homes had the ducts engineered for optimum distribution efficiency with tapered duct transition pieces; whereas the control home had a standard hub and branch design (Figure 3).

Figure 3. Hub and branch ducts (left) and tapered ducts (right)

3 Building America Benchmark Energy Analysis

Analysis was performed using Building Energy Optimization (BEopt) version E+ 1.1 software (NREL 2011) and local typical meteorological year weather data following the Building America House Simulation Protocols (Hendron and Engebrecht 2010). Table 2 shows predicted source energy savings for each home over the reference benchmark. The analysis showed construction of the control home to be 14% better than the reference benchmark. Source energy savings, without considering PV, totaled 45% for the high performance and PV homes. Inclusion of the 2.4-kW array in the PV home increased its total source energy savings to 64%. The table also includes annual source energy use and savings based on measured data from September 2009 to August 2010, although these are not expected to correlate well with simulation results because of differences in occupant behavior. CP2 housed only one occupant during this period; the other homes housed three. A home-based business accounted for larger than typical miscellaneous electric loads in CP3.

Table 2. BEopt Analysis Results

Annual Source Energy (MBtu*)	Control (CP1)	Hi-Performance (CP2)	PV (CP3)	PV (Building Only)** (CP3)
Benchmark	205	198	202	202
As-Built (Simulated)	175	109	72	108
Savings (Simulated)	14%	45%	64%	46%
As-Built (Measured)	151	94	127	164
Savings (Measured)	26%	52%	37%	19%

*Million British thermal units
**PV excluded from analysis

Figure 4 shows the BEopt end-use energy breakdown for each mixed-fuel home. Miscellaneous energy use was a significant component in each home except in CP1, where the cooling energy of the control home, with a seasonal energy efficiency ratio (SEER) of 14, is roughly equivalent to annual miscellaneous energy use. The dark horizontal line in the CP3 bar represents the level of energy contribution from the PV system amounting to 36 MBtu/yr.

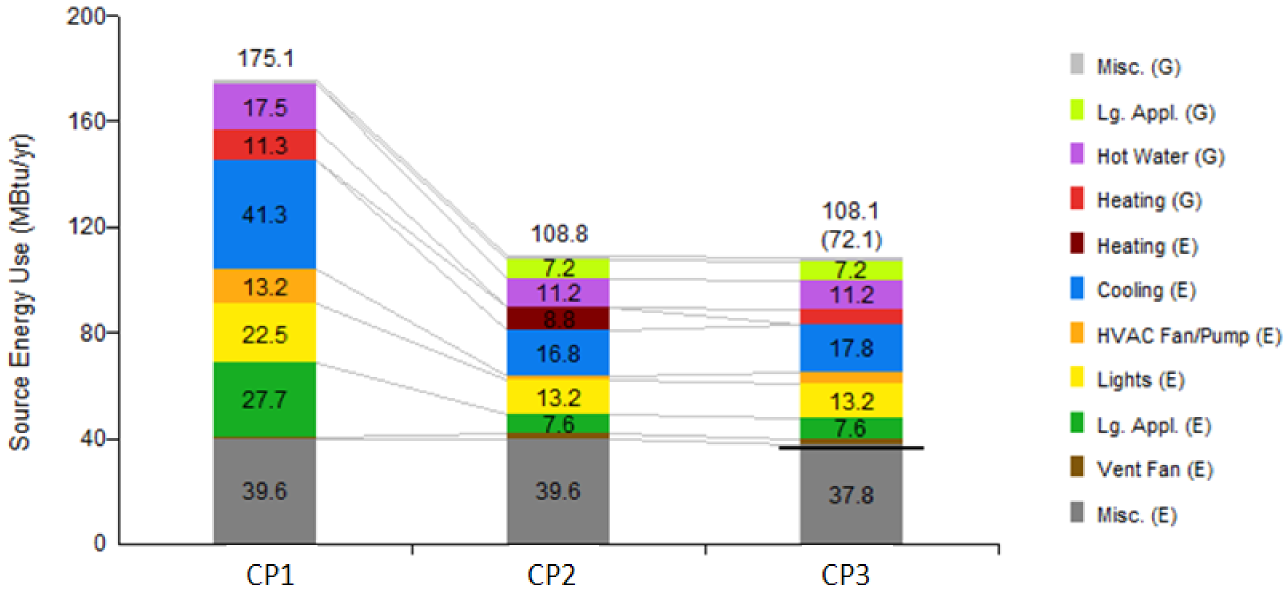


Figure 4. BEopt source energy by end use

Estimated costs for energy measures were derived from a mix of construction costs reported by the builder at the trade-level (plumbing, insulation, framing, etc) and BA database estimates. Construction and equipment specifications for the PV home (not including PV) were used to arrive at an amortized annual package cost of $1,019 and energy savings of $614, leaving a $405 annual shortfall. The very low utility rates in San Antonio compared to other regions contribute to the negative cash flow situation.

Table 3. Projected "Non-PV" Site Energy Savings Versus BA 2010 Benchmark

	PV Home* (CP3)
Insulation	$4,537
Windows	$1,399
HVAC	$6,000
Appliances	$2,832
Water Heating	$800
Lighting	$250
Total Package Cost	$15,818
Amortized Annual Package Cost (30 yr, 5%)	$1,019
As-Built Annual Site Energy Savings Over Benchmark	$614**
Net Annual Cash Flow	-$405

*Incremental cost relative to CP1, Does not include PV costs or production
**CPS 2010/2011 utility costs: $0.08/kWh and $0.80/Therm

4 Electricity Demand

One goal of the research partnership with CPS Energy was to learn how the energy systems in the three South Texas homes affect their peak load profiles during the hottest weather conditions. That information can be used to help design incentive programs for builders and homeowners to help manage demand and energy consumption, where demand is defined as the peak load (in kilowatts) on any given day. Demand is important to energy-efficient operation of generating resources in the same manner as peak heating/cooling load is to a heating, ventilation, and air conditioning (HVAC) system designer. Both result in oversized equipment running inefficiently when the peak load is considerably larger than the average load. Although this is beyond the scope of the present study, the results from this work and similar studies could be used to develop tools to estimate source energy savings from more efficient power plant deployment and operation.

In San Antonio, the highest system-wide loads are encountered in the summer months. CPS Energy's current demand management program runs from May through September between the hours of 3:00 p.m. and 7:00 p.m. Central Daylight Time.

Many strategies can be used to reduce demand, but the strategies of most interest of study to CPS Energy were:

- High efficiency air conditioning (A/C) paired with envelope upgrades
- PV panels
- Electric versus gas cooking
- Electric versus gas clothes drying

Figure 5 is a side-by side comparison of the electric load profiles on the hottest summer day (July 8, 2009) for the control home, the home with the upgraded envelope and SEER 18 heat pump, and the solar home with the upgraded envelope, SEER 18 A/C unit, and 2.4-kW solar array. Total energy (in kilowatt-hours) provides a relative measure of energy consumption or production for the components of each graph. Measured indoor temperatures averaged 76.7°F, 75.5°F, and 76.0°F during this day in CP1, CP2, and CP3, respectively. The graphs show that the envelope and HVAC equipment upgrades effectively reduced the peak A/C loads by 1.17 kW, or 28%, during the utility peak hours in the heat pump home and 2.88 kW, or 68%, in the solar home. Because only the control home and the high performance home were occupied during the entire time of these measurements, it is unclear what portion of differences results from occupant behavior and what portion results from the energy efficiency features of the homes. The graph for the solar home also shows that the southwest-facing panels effectively remove the entire household electric load off the grid during the utility peak hours. They even export excess power to the grid to help reduce grid loads from other homes. Although these results vary from day to day depending on solar insolation conditions, the greatest system-wide utility peaks occur on hot and sunny days.

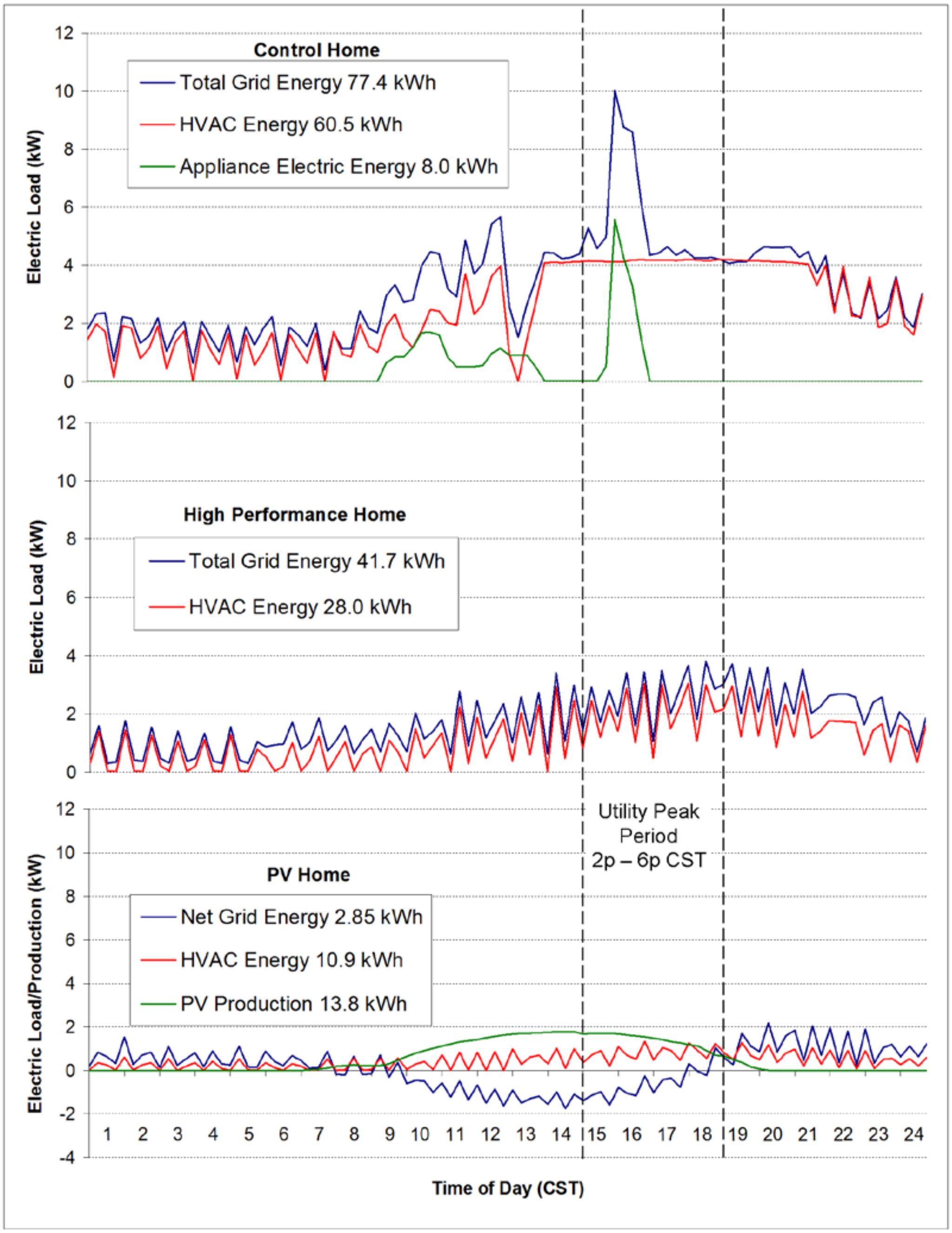


Figure 5. Measured electric load on the hottest summer day (July 8, 2009)

A/C loads contribute greatly to the system utility peak in San Antonio, but other intermittent loads such as large and small appliances and miscellaneous end uses contribute as well. Data on these intermittent loads are limited for a variety of reasons, including lack of widespread in-home monitoring systems, variable household behavior patterns, and differences among household miscellaneous load selections. The electric utility community currently responds to these challenges with data gathering efforts to estimate the system-wide demand contributions from these miscellaneous loads and consumer willingness to time-shift use of these loads. Additional efforts include the development of a smart grid infrastructure that can either directly control the miscellaneous loads or send price signals to consumers to alter their behavior.

The research team studied demand contributions from electric cooking and clothes drying in detail, because the associated appliances use large amounts of electricity when they are on, and they have the potential to significantly increase the utility peak load. In addition, fuel switching (e.g., electricity to natural gas) could control demand, and fuel switching to gas cooking and clothes drying is much less common in San Antonio than gas water heating.

Figure 6 shows the electric monitoring data from the control home on a day when cooking, baking, and laundry occurred during the utility peak hours on a hot day. Above the 4-kW A/C load, cooking and baking added another 1 to 2.5 kW of load to the total. This day may not be typical, but it conveys the significance of the miscellaneous loads toward the utility peak. For example, an examination of the demand reductions on the hottest day (Figure 5) shows that peak electricity use was reduced by more than 6 kW for the high performance home and more than 8 kW for the PV home during the utility peak period. Fortunately, the system-wide utility peak benefits from averaging the differing behaviors among many homes. Incorporating gas cooking and gas clothes drying in the high performance homes greatly reduced these spikes in electricity grid use and had a relatively small impact on the natural gas infrastructure. This also accounts for most demand reduction.

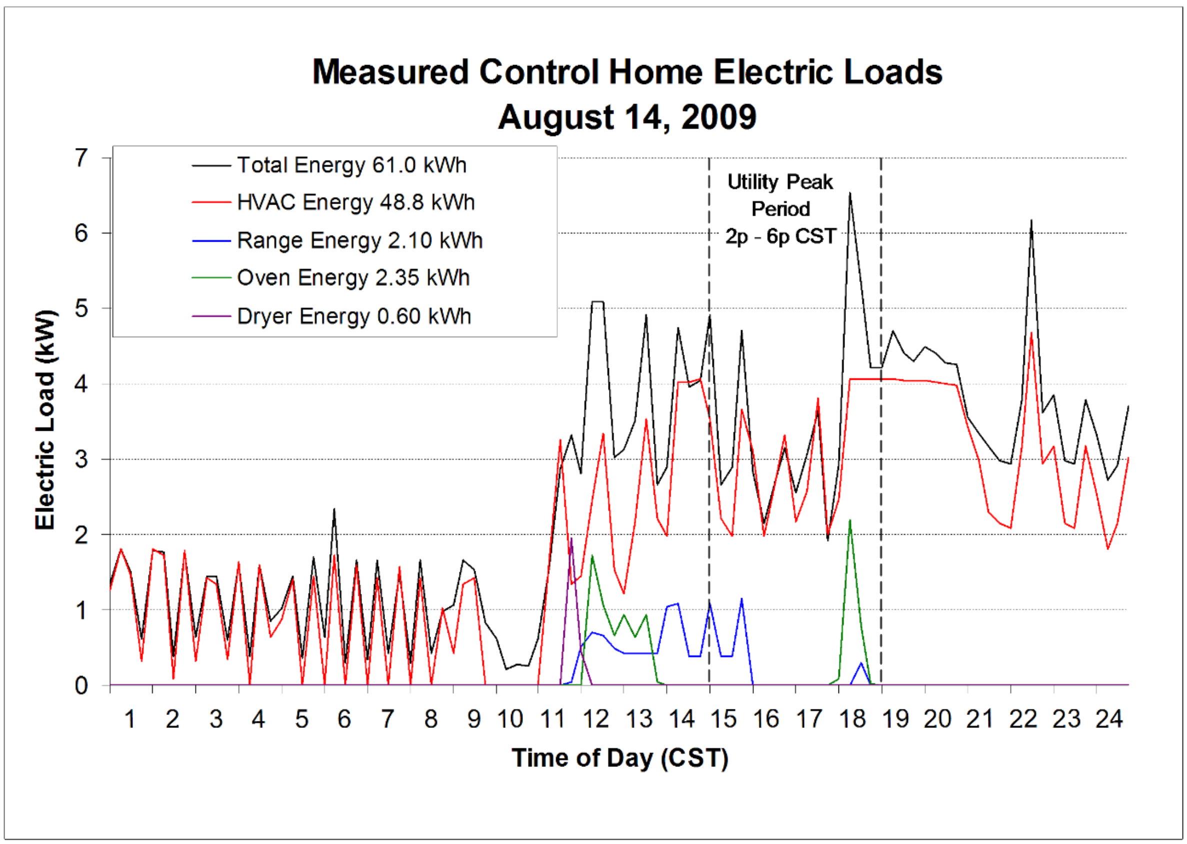


Figure 6. Measured control home electric loads

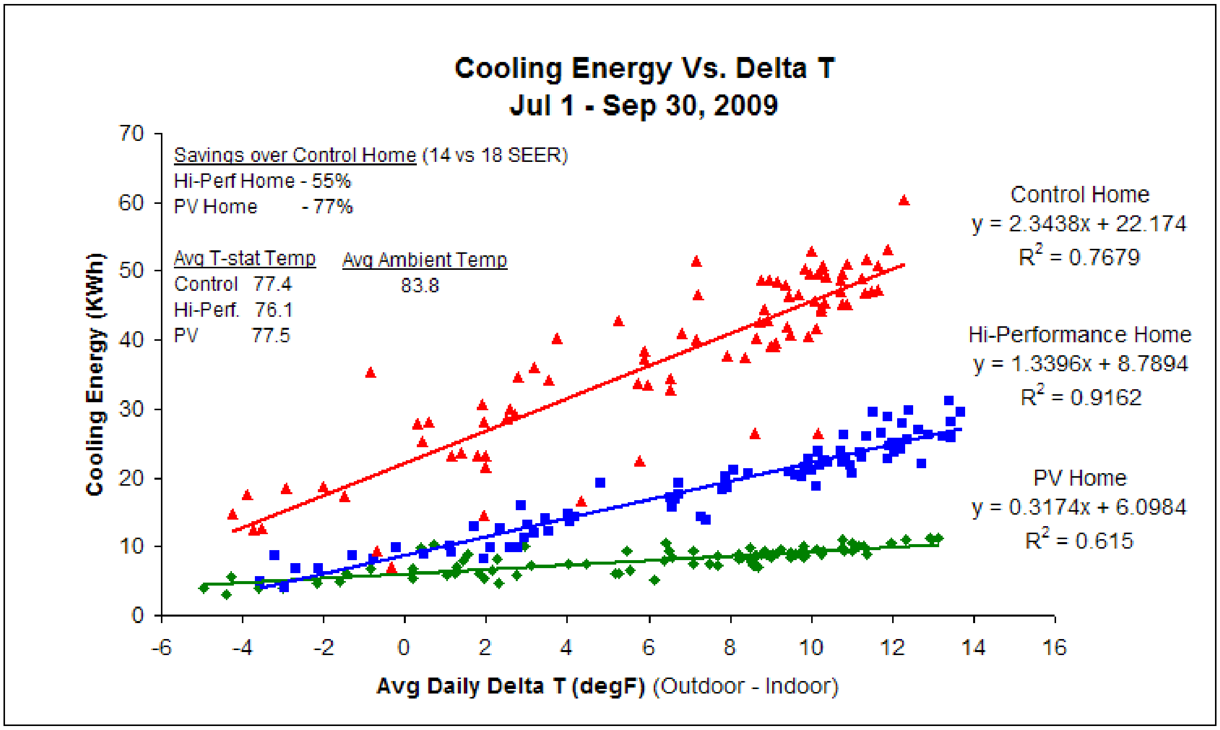
5 Cooling Energy

Summer 2009 was one of the hottest on record in San Antonio, Texas. On-site instruments showed 34 days at 100°F or higher for July and August of that year, with an average daily temperature during those months of 86.3°F compared to 76.6°F for September. The second summer of data collection (2010) had a more typical weather profile. Data collection for all homes was established in late June 2009, so cooling season analysis began in July of that year. Initial occupancy in the newly constructed homes was somewhat staggered, with the control home first occupied in early May, the high performance home first occupied July 1, and the PV home first occupied on September 1. All three homes were fully occupied during summer 2010.

Cooling equipment consisted of split systems with ducted central air handlers. Submetered energy consumption data from the condenser and air handler were stored at 15-min intervals and subsequently combined and totaled on a daily basis. Energy generated by the PV home is not factored into its cooling energy total; it consisted solely of equipment energy use. Daily cooling energy totals (Figure 7) were plotted against the average daily temperature difference between outdoors and indoors for the 24-h period starting at midnight. Weather measurements were collected at one of the homes and consisted of dry bulb temperature, relative humidity (RH), and solar radiation. Indoor temperatures were taken very close to the thermostat. The use of temperature difference is intended to account for indoor temperature variations caused by occupant-determined thermostat settings. Table 4 shows the sensors and datalogger used.

Table 4. Sensors and Datalogger

Measurement	Equipment Used
Indoor and attic T/RH	Vaisala resistance temperature detector/thin-film probe
Outdoor T/RH	Vaisala resistance temperature detector/thin-film probe
Whole-House and HVAC Energy Use	WattNode electric energy meters
Data Collection and Storage	Campbell scientific datalogger



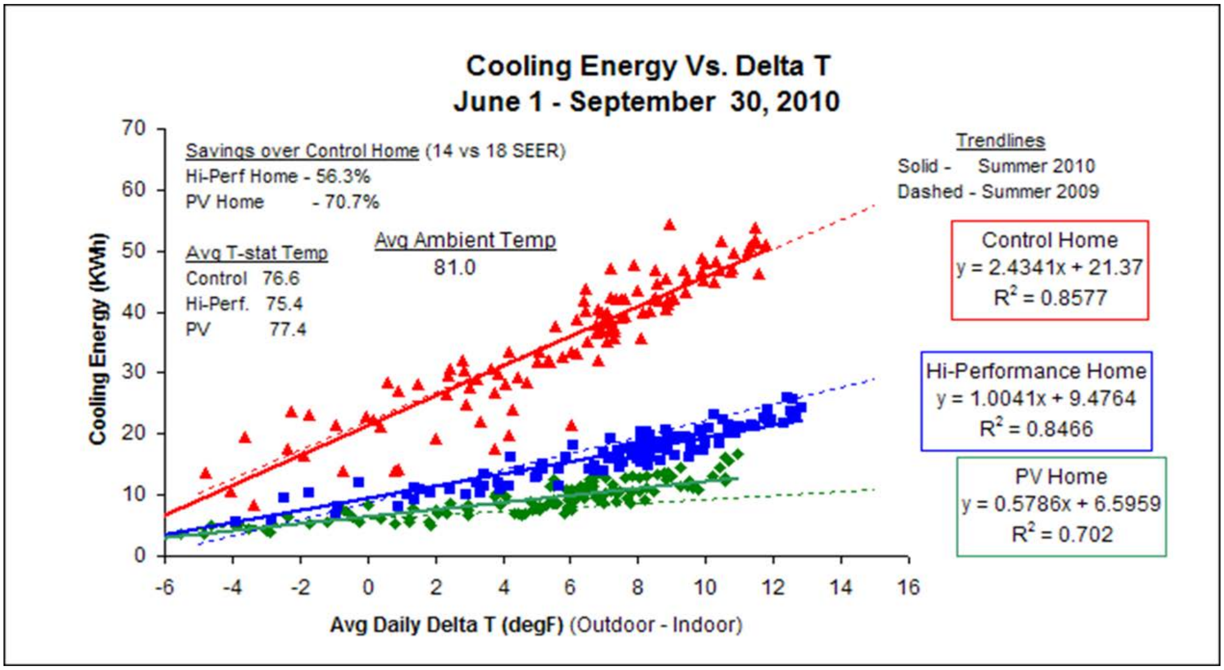


Figure 7. Cooling energy versus outdoor-indoor temperature difference

The cooling performance levels shown in Figure 7 were determined by comparing the areas under the least-squares line. This assumes that the areas are directly proportional to energy use and are affected by the length chosen to make up the bottom edge of the area along the x-axis (–5 to 14 for this analysis). Figure 7 also shows the coefficient of determination (R^2) for each regression line. This measure of "goodness of fit" of the line to its associated data points ranged from 0.62 to 0.92. For the 92-day period in 2009, a total of 4 days were removed from each home's dataset, three of which resulted from a temporary cold front and the other because of datalogger collection errors. Two additional days in 2009 and 2010 were removed from only the high performance home data set due to collection errors. Five days of data were lost to datalogger downtime from August 27 to August 31, 2010 but all collected measurements were otherwise included through the two summer periods. Also during 2009, only two of the homes (control and high performance) were occupied during the entire three-month period. For 2009, the PV home was occupied only during September. All three homes were fully occupied during summer 2010, making it the preferred comparison over 2009. A cooling energy analysis similar to this was performed on eight high performance homes in a previous publication (Chasar 2006)

Cooling savings over the control home were considerable, with the high performance home saving 55%–56% and the PV home saving 71%–77% for the two summer periods. These savings numbers were derived solely from cooling equipment energy use with no impact from the PV system in the PV home.

There was an unexpected difference in cooling energy savings between the two improved homes compared to the control, especially in summer 2009 (55% versus 77%). Each improved home had cooling systems with nearly identical SEER 18 ratings, although the PV home had a straight-cool system with gas heat and the high performance home had a heat pump. Diagnostics performed in November 2009 showed the heat pump to be operating within specifications, which alleviated concerns that the heat pump system was underperforming. Some of the savings discrepancy in 2009 can be attributed to occupancy and occupant behavior, as the PV home was unoccupied during the hottest months (July and August). The cooling energy discrepancy between the improved homes was somewhat less during 2010 when all homes were fully occupied (56% versus 71%). The 2010 graph shows Regression line comparisons for 2009 (dashed) and 2010 (solid).

Figure 8 shows the average daily indoor and outdoor temperatures for each home. The hot weather in June and July of 2009 changes to much cooler temperatures in September, where results show the difference between outdoors and indoors as negative for several days. The coolest weather near the end of the data period is removed from analysis, but all other September data in both years is used and contributed to the points making up the far left portion of the trend lines in Figure 6. Figure 6 most clearly shows the unusually hot weather pattern in 2009, with many more data points visible between 10°F and 14°F on the x-axis during 2009 versus 2010.

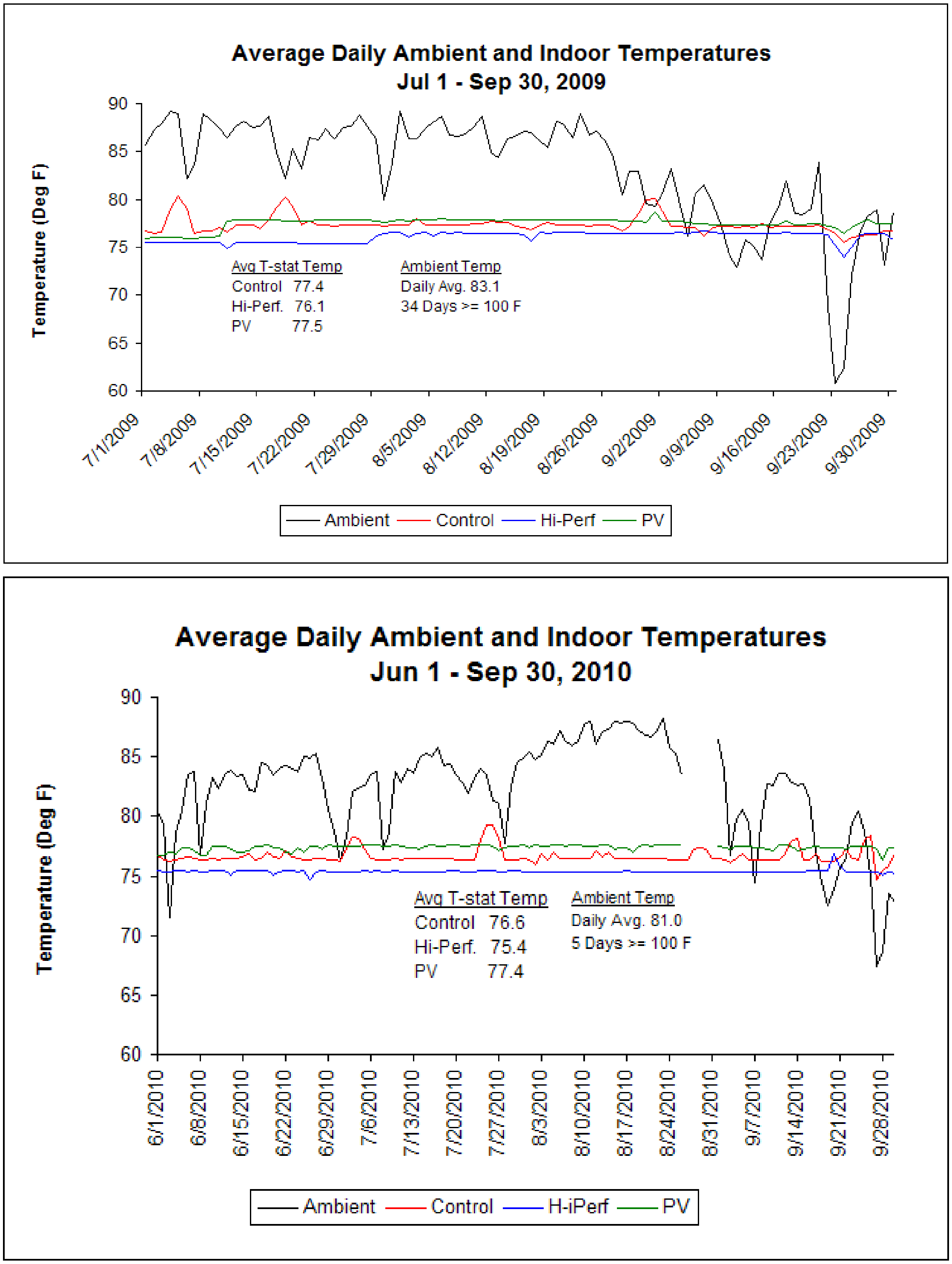


Figure 8. Average daily ambient and indoor temperatures (°F)

The thermostats in all three homes were kept at relatively stable set point temperatures throughout the summer. It appears none of the occupants used programmable functions but there are a few notable days where the control home set point was raised considerably, possibly because of a period of vacancy. These periods of high indoor temperature settings are consistent with reduced energy use as illustrated in Figure 7 by a spread of seven days in the control home data set (red triangles) with low energy use relative to the other days. The days on which these data points fell were sometimes followed by days with relatively high energy use. While these outliers, both above and below the trend line, caused a reduced coefficient of determination for the control home, they effectively offset one another in terms of their impact on final savings calculations. Removing these outliers changed the improved home’s savings values by only one percentage point for the 2009 season.

6 Photovoltaic Performance

The 2.4-kW grid-tied PV array was activated in mid-June 2009, providing energy for the PV home and feeding unused energy back to the utility. Twenty-one months of data were analyzed from July 2009 through March 2011. The home was unoccupied during the first two months of this period, during which the air conditioner was set to maintain an interior temperature of approximately 77°F, similar to that of the occupied control home. The PV home was otherwise continuously occupied from September 2009 to March 2011.

Each stacked bar in Figure 9 represents the total monthly electric energy used by the PV home and the percentage offset by the grid-tied system. The components of each bar are composed of the net-grid energy used by the home, the PV-generated energy used directly by the home, and the portion fed to the utility grid.

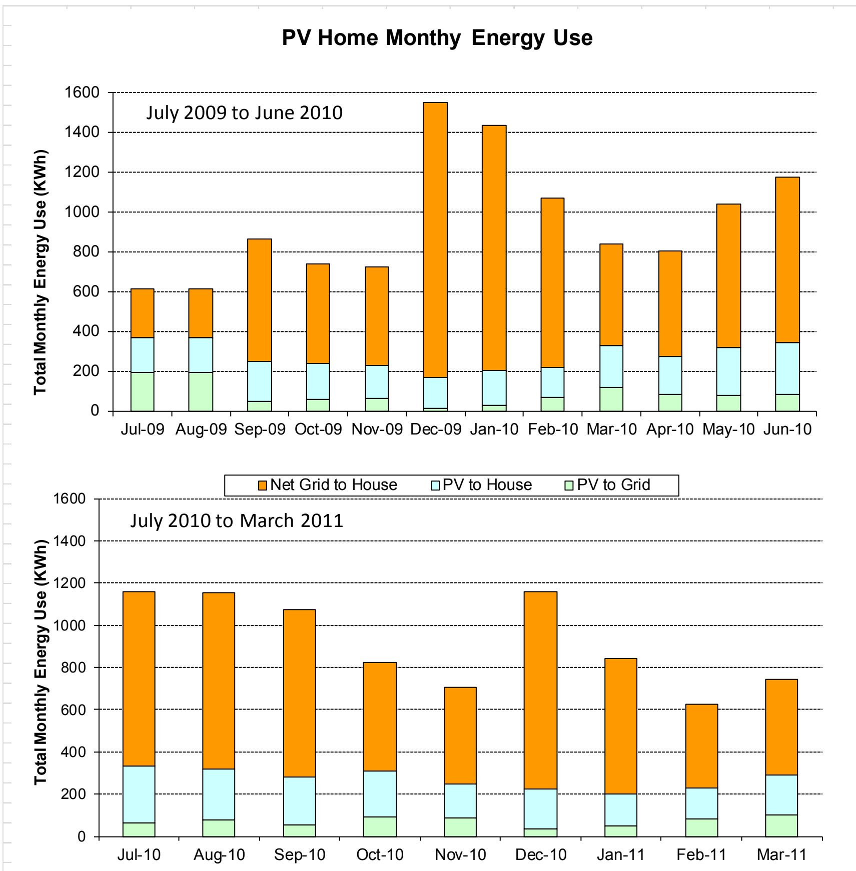


Figure 9. Monthly electricity use in the PV home from July 2009 through March 2011

Total electricity use in the PV home increased once occupancy began on September 1. The noticeable spike in December 2009 was attributed to extensive holiday lighting and the addition of a 1-kW kiln and electric resistance space heating for a garage-based glass-making operation. The extreme electric energy use continued in January and February 2009, presumably due primarily to the glass-making business; however, subsequent months showed more moderate use.

On average, PV energy production made up 29% of total electric energy use; about two-thirds of the energy was used directly by the home and the remaining one-third fed back to the utility.

The 2.4-kW array, with its roughly southwest azimuth, was well suited to offsetting the total monthly HVAC electric load. During the 21-month data collection period, PV production completely offset monthly HVAC electric energy except for August 2010, when it made up 97% of the HVAC load. On a daily basis, PV production offset HVAC energy 80% of the time for the 210 days recorded between June 1 and September 30 in 2009 and 2010.

Figure 10 provides a comparison of measured PV energy production to estimated performance as stated by the manufacturer on an equivalent 2.4 kW system with an azimuth of 230 degrees and a 6:12 roof pitch in San Antonio, Texas. Overall, for the 21-month period of measured data, the system shows 4.6% less energy production than the manufacturer's predictions. Generally, variations associated with weather data can cause measured and modeled PV performance to vary by as much as ±40% for individual months and ±20% for individual years (NREL 2006).

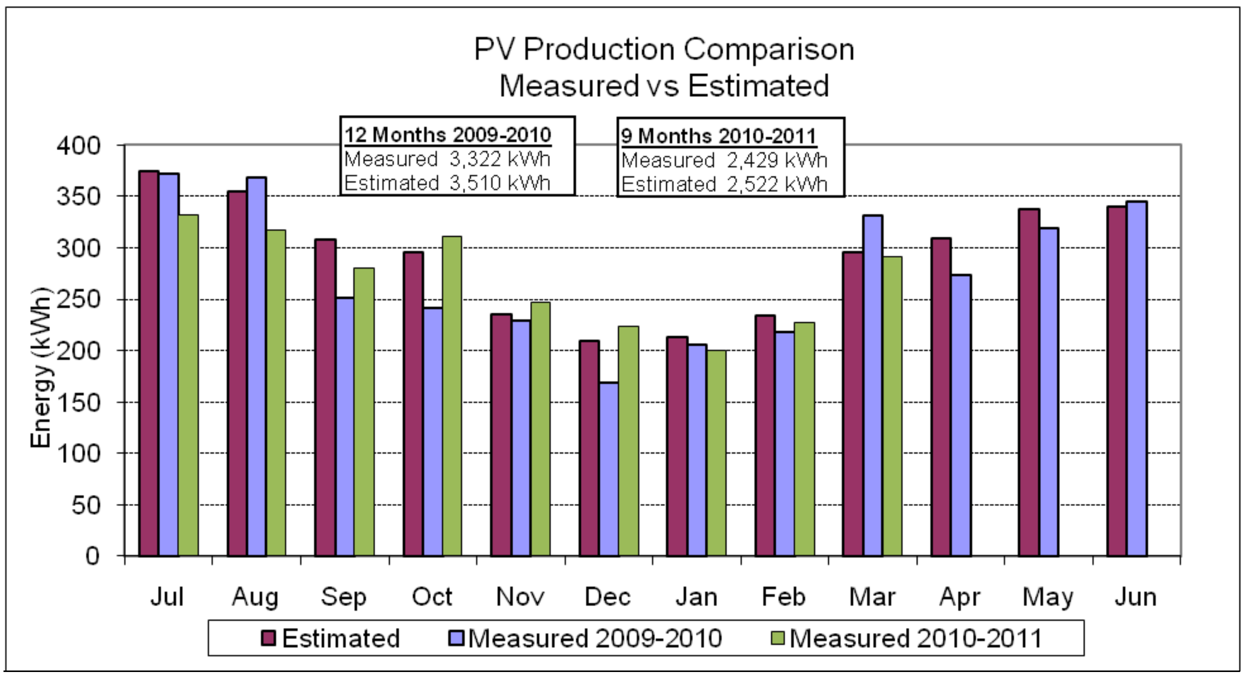


Figure 10. Comparison of measured and estimated monthly PV production

7 Results and Conclusions

Three occupied homes with identical floor plans and orientation in San Antonio, Texas demonstrated reduced energy use and electricity demand by comparing high performance construction with standard building practices. Because the homes were occupied, the impacts of occupant behavior on the results are unclear. Results show that cooling energy savings were 55%–77% in two improved homes over the control home. Total demand reductions between the control and improved homes were 6–8 kW (62%–83%) on the hottest day during the utility peak period. Peak A/C loads in the improved homes on the same day were reduced by 1.2–2.9 kW (28%–68%) over the control. A 2.4-kW grid-tied PV array on the PV home provided 29% of total electric energy needs on average, with about two-thirds of the energy used directly by the home and the remaining one-third fed back to the utility. The southwest-facing array was well suited for offsetting total HVAC electric energy, which was regularly accomplished on a monthly basis and 80% of the time on a daily basis during summer months.

The results of this research provided new knowledge of peak load profiles during the hottest weather conditions in new homes with various energy measures, and in those built according to standard practice for the local area. The study also provides important feedback for builder and homeowner utility incentive programs that manage demand and energy consumption.

References

Chasar, D.; Chandra, S., Parker, D.; Sherwin, J.; Beal, D.; Hoak, D.; Moyer, N.; McIlvaine, J. (2006). *Cooling Performance Assessment of Building America Homes. Proceedings of the Fifteenth Symposium on Improving Building Systems in Hot Humid Climates*. FSEC-CR-1673-06. Cocoa, FL: Florida Solar Energy Center.

NREL. (2006). *PVWATTS: Cautions for Interpreting the Results*. Golden, CO: National Renewable Energy Laboratory. http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/interp.html. Accessed January 2011.

Hendron, R.; Engebrecht, C. (2010). *Building America House Simulation Protocols*. Golden, CO: National Renewable Energy Laboratory.

NREL. *BEOpt Software*. Golden, CO: National Renewable Energy Laboratory. http://beopt.nrel.gov. Accessed July 2011.

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102012-3577 ▪ September 2012

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.