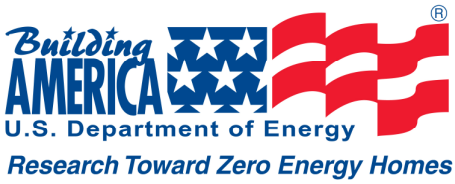

MULTI-YEAR ADVANCED RESIDENTIAL BUILDING SYSTEMS RESEARCH

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Final Project Closeout Evaluations: *John Wesley Miller Companies' Armory Park del Sol*

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Prepared For:
Midwest Research Institute,
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393

Prepared By:
NAHB Research Center
400 Prince George's Boulevard
Upper Marlboro, MD 20774

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Overview

The purpose of this report is to present the final project closeout for the Armory Park del Sol community in the hot/mixed dry climate of Southern Arizona. The homes in the Armory Park del Sol neighborhood of downtown Tucson, Arizona, were built by long-time builder of solar and energy-efficient homes, John Wesley Miller Companies. The community will be evaluated using the Project Closeout "Must Meet" and "Should Meet" criteria from Guidance for Final Evaluation of Building America Communities[1].

Introduction

Armory Park del Sol (APdS) is a development of new homes in downtown Tucson's historic neighborhood of Armory Park. The 14-acre redevelopment project fulfills the vision of developer John Wesley Miller to create a sustainable and livable urban in-fill community. The NAHB Research Center worked with John Wesley Miller Companies through the Building America Program on prototype net-zero energy homes as well as on the community as a whole. Presented here is the analysis of this community of high performance homes built in the hot/mixed dry climate.

Homes in Armory Park del Sol (APdS) honor the historic architecture of the area, yet are constructed to Miller's exacting specifications for durability, energy efficiency, accessibility, and technological innovation. Each home includes solar hot water and solar electric systems to harvest the ample desert sunshine. Water-conserving measures respect the importance of water as a critical resource in the arid climate. Front porches, sidewalks, rear-loading garages, and public spaces facilitate community while electric bills, guaranteed through a partnership with Tucson Electric Power, enhance economic security among the homeowners. Universal design ensures that every home is "visitable" regardless of disability. Residents can further reduce their overall energy consumption by walking to local businesses and venues, which are accessible from Armory Park's downtown location.

The community demonstrates that very high levels of energy efficiency are possible in the hot/mixed dry climate and that these high levels of efficiency—as well as zero energy homes—are, indeed, achievable at a cost that the market is willing to bear. In addition, the community meets the Project Closeout Criteria. Challenges that will need to be addressed include the cost of very high performance homes, the cost of solar technologies, and the consistent quality of installation in lieu of local utility programs such as that provided by Tucson Electric Power. The builder worked in close partnership with the local utility, Tucson Electric Power, under its Guarantee Home program, to inspect and test the newly constructed homes, to meet strict energy performance requirements, and to offer customers discounted electricity prices in exchange for including specific features such as high efficiency heat pumps and solar energy systems.

APdS Community Characterization

The Armory Park del Sol (APdS) home designs meet the Tucson Sustainable Energy Standard. The all-electric homes in APdS, which range in size from 977 to 2,317 square feet (sqft), combine state-of-the-art energy efficiency with on-site solar energy production. APdS is comprised of 99 lots with a total of 92 homes that will be constructed as some of the homes are on multiple lots. As of this study, 87 homes are completed in APdS with five homes remaining. Table 1 below summarizes the models and square footages of the homes at Armory Park del Sol.

Table 1. Summary of APdS Community & Models

APdS Model	Sqft	# at APdS
961	977	9
1100	1,100	6
1344	1,344	13
1468	1,468	18
1638	1,638	6

[1] P. Norton, J. Burch, B. Hendron, *Project Closeout: Guidance for Final Evaluation of Building America Communities* (NREL/TP-550-42448), NREL , March 2008

APdS Model	Sqft	# at APdS
1760	1,760	1
1930	1,930	1
2026	2,026	7
2059	1,996	22
Custom	1,718 - 2,317	4
Not Built		5
Total		**92**

All homes at Armory Park del Sol (APdS) are built with solid-core masonry walls and a float-slab foundation, rigid foam exterior insulation for the walls and slab edge, and skim-coat plaster interior walls. In addition, each home in APdS has a tightly sealed building envelope, includes low solar heat gain windows, has efficient mechanical equipment and advanced duct design, and has solar hot water and photovoltaic (PV) systems. The subdivision consists entirely of energy efficient houses. Energy efficiency features of typical APdS homes are described below.

APdS Foundation

Foundations of all Armory Park del Sol homes are a float-slab design that is poured directly on the ground surface. Each slab is engineered and is 10- to 12-inches thick. The float slab design eliminates the need for cutting footers in the hard desert soil and allows for full insulation depth around the slab edge without burying the insulation. In addition, having the slab extend above the ground allows for drainage to the street level.

APdS Walls

All of the homes in this development are designed in the style of the regional architecture of the Southwest. Unlike most new light wood frame construction in the area, Armory Park del Sol homes are constructed with solid-filled masonry block walls. The masonry block construction provides a high level of thermal mass to help stabilize cooling and heating loads that vary widely both annually and diurnally in this hot/mixed dry climate. Thermal mass interaction with the indoor environment can reduce peak energy use as well as total energy use for heating and cooling. Thermal mass construction has been part of Southwestern building designs for centuries, but has not been common in residential single family home construction for many years in Tucson.

A typical APdS home is insulated with 1½ inches of polyisocyanurate insulation (R-10) attached with Z-strips to the exterior of the block walls. A standard 3-coat stucco finish is applied to the exterior of the insulation. Interior block walls are skim coated plaster rather than drywall to enhance heat transfer between the indoor air and the thermal mass wall. The wall system is not only energy efficient, but also extremely durable, disaster resistant, more soundproof than typical frame construction, and aids to moderate peak cooling loads. The solid-core masonry construction with exterior foam insulation featured in all the APdS homes is shown in Figure 1. The interior walls at Armory Park Del Sol use light gauge steel and are covered with standard sheetrock.

Figure 1. Solid-core Masonry Construction with Exterior Foam Rigid Insulation.

APdS Windows

The primary goal of most windows is to extend the exterior view indoors adding natural light to the interior space. However, windows can also allow a great deal of solar radiation, which increases cooling loads. Although this can be a benefit in the heating periods, in a hot climate such as Tucson, reducing solar gains through windows is very beneficial to comfort during the summer as well as energy savings. The windows incorporate spectrally selective coatings resulting in a U-value of 0.35 and solar heat gain coefficient (SHGC) of 0.29. To reduce the solar gains through the windows, homes in APdS make extensive use of overhangs and porches. Porches, common to all the homes at Armory Park del Sol, also invite community interaction.

APdS Ceiling/Attic and Roof

Most of the homes in the development incorporate a low-slope roof design. The roof surfaces are covered with a highly reflective solar coating and most are white. The flat roofs maximize available area for renewable energy systems while keeping the systems virtually hidden from view from the ground level. A typical APdS home uses I-joists for roof framing members with R-38 insulation between the joists. A few of the homes have sloped roofs with a shingle or tile covering. Roofs are framed with either I-joists or are truss framed.

APdS Garage Design

All of the homes at Armory Park del Sol have pseudo-attached garages. While the garage shares a block wall with the home (a few homes are built with detached garages), there is no direct door entry to the home from the garage. All penetrations for electric and plumbing from the garage to the house are foam sealed. The entrance to the house from the garage is an exterior covered walkway. The exterior garage walls are framed with 2x6 dimensional lumber and are insulated, as is the ceiling. The garage is not conditioned.

APdS HVAC Systems

Standard HVAC equipment at Armory Park del Sol (APdS) is a heat pump. An interior, centrally located mechanical room also reduces losses by keeping critical equipment in the conditioned space.

All the homes in Armory Park del Sol include an efficiently designed heating and cooling duct system with all of the ducts located in conditioned space or, where sloped roofs are used, below the attic insulation. The mechanical designer recognized the unique advantage of combining high performance windows with thermal mass walls to deliver air from the duct system to interior spaces, thereby eliminating long duct runs to exterior walls. Cross-over or jump ducts, located between rooms and the main living area (where the central return duct is located), provide a return air path to the air handler from all rooms. The return duct system to the air handler is very short in all cases and it draws air from the main living area, which is open to all of the main rooms of the homes. Locating ducts in conditioned space and utilizing short runs of ducting reduce distribution losses in the HVAC system. The duct system is tested for air-tightness and leakage does not exceed 5% of air handler fan flow. Mechanical ventilation is provided by a central exhaust fan with ports located in the baths and kitchen, plus a fresh air inlet to the return side of the air handler. When the air handler is operating, fresh air is intentionally introduced within the home.

APdS Air Infiltration

All of the homes in Armory Park del Sol are carefully sealed to limit uncontrolled infiltration from the outdoors. The block wall construction minimizes leakage paths simply by the construction technique. Where wood members meet the masonry walls, air sealing is achieved using spray foam sealants and caulking. Interior penetrations to the attic or roof joist space are limited and, if necessary, are sealed.

APdS Plumbing Systems

Standard plumbing systems in APdS homes incorporate a central manifold to reduce the size of pipe to the hot water outlets. Smaller pipe diameter reduces delivery time for hot water to the outlets thereby reducing water as well as energy consumption and increasing convenience. Water heating in the homes at Armory Park del Sol is provided through use of an Integrated Collector Storage (ICS)[2] solar hot water system feeding to an electric demand water heater. The electric demand heater will activate only as needed to heat the water to its delivery set point and only at the power level necessary. Since the electric demand heater input can vary from zero to full power, only the required energy to boost the hot water temperature to its final set point is used, minimizing losses and utility-supplied energy to heat water. This system has been used successfully in all of the homes at Armory Park del Sol and compliments the often higher ground water temperature in this climate. As interior floor space is extremely valuable in this climate and locating water heaters in the garage would add large runs to the piping system, the combination of a roof mounted solar storage unit in conjunction with a small, wall mounted back-up heater adds large value to the home layout in addition to the enhanced performance.

APdS Lighting and Appliances

Over several years during the construction of the development, a gradual shift to high efficiency lighting for the hard-wired fixtures has been made. About two-thirds of the permanent light fixtures are ENERGY STAR labeled.

APdS Solar Systems

Photovoltaic and solar thermal systems are standard equipment for all Armory Park del Sol homes. Typically, 1.5 kWdc PV systems are mounted on the flat roofs and oriented due South at a 32 degree angle. This angle is mandated by the local utility to maximize annual solar electric production. Solar thermal collectors are generally tilted at a slightly steeper angle (40 degrees) to maximize winter hot water production. Since the homes have parapets that visually obscure the collectors, the historical architectural details are not compromised by the use of roof-mounted solar technologies. Figure 2 shows PV and solar thermal panels on typical homes in APdS.

[2] ICS solar thermal collectors passively heat (and store) the solar heated water that is then used as a preheat to a back-up water heater. ICS collectors are pressurized using potable water that is used directly for domestic hot water.

Figure 2. APdS PV Systems

Construction Features

Although most construction features did not change substantially over time since construction began in August 2000, the first homes tended to be smaller than later models and included slightly different energy features. All homes are built with solid-core masonry walls and a floating slab floor, rigid foam exterior insulation, and skim-coat plaster interior walls. This thermally massive wall system tends to dampen outdoor temperature extremes and shift power demand to off-peak times, which can allow homeowners to reduce their electricity costs when choosing time-of-use electricity rates.

First Models

The first model homes, at 977 and 1,100 sqft included:

- Masonry construction with R-12 exterior rigid foam board insulation
- Engineered slab with R-12 slab edge insulation
- Raised-heel trusses with R-38 fiberglass batt attic insulation
- Window U-value of 0.35
- 12 SEER/7.5 HSPF heat pump
- Ducts sealed with mastic to below 33 cfm_{25}, not in conditioned space
- Air leakage below 0.35 ACHnat
- Integrated Collector Storage ("batch-type") solar water heater with electric tankless auxiliary heater
- 1.44 kW (dc) PV system

The early stages of the APdS subdivision are shown in Figure 3, including the first homes with solar panels on all rooftops and their close proximity to the downtown.

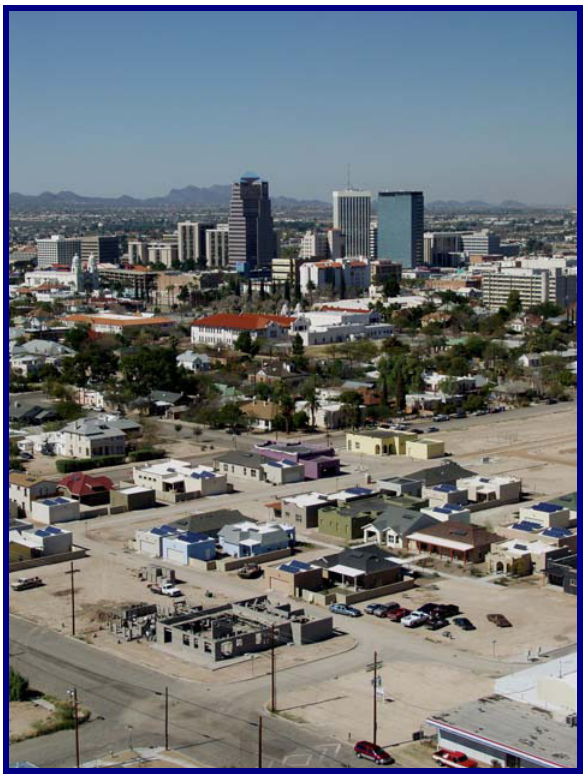


Figure 3. APdS in Early Stages of Development

Current Standard APdS Construction

Currently, homes in the neighborhood are built with essentially the same building envelope as were the first homes. However, the newer homes tend to be more spacious and also include design modifications including:

- 16 SEER high efficiency heat pump
- Programmable thermostat
- All ducts in conditioned space
- Duct leakage below 5% conditioned space
- Average blower door test: 2.9 ACH50
- Insulated hot water lines
- ENERGY STAR appliances
- Ceiling fans
- 1.5 KW (dc) PV systems

Zero Energy Homes

In addition to the typical energy efficient homes in the APdS subdivision, there are two net-zero energy homes (ZEHs). The first ZEH (ZEH1) shown in Figure 4 was completed in April 2003. ZEH1 is a 1,718 sqft, three-bedroom home with the following energy features:

- Passive solar design details including covered porches
- Two inches (R-14) exterior foam insulation over solid-core masonry walls
- R-41 blown cellulose insulation in flat ceiling cavity
- Reflective roof coating
- Radiant barrier roof decking
- U-0.30, SHGC-0.32 low-e, gas-filled windows

- 19-SEER 2-stage air conditioner
- Ducts in conditioned space
- Passive ventilation system
- PEX hot water distribution
- ENERGY STAR appliances and bathroom ventilation fans
- Permanent fluorescent lighting fixtures
- Ceiling fans
- Integrated solar space and water heating system consisting of four, 4x8 active solar water heating panels, a 210-gallon hot water storage tank, a tankless auxiliary water heater, and a hydronic heating coil serving the air handler.
- 4.2 kW (dc) solar photovoltaic system

Figure 4. The neighborhood's first Zero Energy Home completed in 2003.

A second generation Zero Energy Home (ZEH2) was completed in May 2007 and sold in November 2008. At 2,168 sqft, ZEH2 is one of the largest homes in the neighborhood and features:

- Passive solar design details including covered porches
- Two inches (R-13) exterior foil-faced foam insulation over solid-core masonry walls
- R-38 blown fiberglass batt plus R-6.6 foil faced foam roof insulation
- U-0.30, SHGC-0.32 low-e, gas-filled windows
- 17.9 SEER/9.0 HSPF 2-stage heat pump
- Ducts in conditioned space
- Passive ventilation
- PEX hot water distribution
- ENERGY STAR appliances and bathroom ventilation fans
- Permanent fluorescent lighting fixtures
- Ceiling fans throughout
- Active closed-loop solar hot water system with 80-gallon storage and electric tankless auxiliary heater
- 6.93 kW (dc) solar photovoltaic system
- Low water use landscaping
- Rainwater harvesting system

Figure 5. Second generation Zero Energy Home

Construction Practices over Time

Over time, the average size of the homes and the energy features fluctuated somewhat, reflecting the changes in the marketplace and the builder's adoption of practices tried in the ZEH prototype homes. Overarching construction methods, such as the concrete masonry walls and engineered floating slab foundation, remained unchanged. A summary of the homes, organized by date of final inspection, is found in Table 2. The changes made to the homes were, for the most part, slight, owning to the builder's previously established high standard of energy efficiency and inclusion of solar water heating and PV systems as standard on every home.

Table 2. Summary of APdS Homes

Year	# Homes	Average sqft	Insulation	Plumbing	AC efficiency	Light	Water Heating	PV	Notes
2001	5	1100	1.5" polyiso wall; R-38 fiberglass ceiling	Uninsulated in slab	12 SEER	100% incandescent	40 gal ICS with tankless aux	1 kW ac min	
2002	8	1344	1.5" polyiso wall; R-38 fiberglass ceiling	Uninsulated in slab	12 SEER	100% incandescent	40 gal ICS with tankless aux	1 kW ac min	
2003 ZEH	1	1718	2" polyiso R-42 cellulose ceiling	PEX in conditioned space	18 SEER	100% fluorescent	120 sqft active space and water heating	4.2 kW dc	
2003	17	1687	1.5" polyiso wall; R-38 fiberglass ceiling	Switch to insulated in slab	Mid-year switch to 13 SEER**	Mid-year switch to 50% fluorescent	40 gal ICS with tankless aux	1 kW ac min	
2004	15	1774	1.5" polyiso wall; R-38 fiberglass ceiling	Insulated in slab	13 SEER	50% fluorescent	40 gal ICS with tankless aux	Switch to 1.5 kW ac min	
2005	13	1503	1.5" polyiso wall; R-38 fiberglass ceiling	Insulated in slab	13 SEER	50% fluorescent	40 gal ICS with tankless aux	1.5 kW ac min	
2006	22	1632	1.5" polyiso wall; R-38 fiberglass ceiling	Insulated in slab	Switch to 14 SEER	50% fluorescent	40 gal ICS with tankless aux	1.5 kW ac min	13 SEER min efficiency goes into effect
2007 ZEH	1	2168	2" polyiso R-38 fiberglass + R-6.5 rigid foam	PEX in conditioned space	18 SEER	100% fluorescent	64 sqft active SWH with 80-gallon storage	6.93 kW dc	
2007	2	2011	1.5" polyiso wall; R-38 fiberglass ceiling	Insulated in slab	14 SEER	50% fluorescent	40 gal ICS with tankless aux	1.5 kW ac min	13 SEER min efficiency goes into effect
2008	2	1503	1.5" polyiso wall; R-38 fiberglass ceiling	Insulated in slab	Switch to 14 SEER	Switch to 100% fluorescent	40 gal ICS with tankless aux	Switch to 1.6 kW ac	Slightly larger PV system likely reflects manufacturer change rather than purposeful system capacity change
2009	1	1468	1.5" polyiso wall; R-38 fiberglass ceiling	Insulated in slab	Switch to 16 SEER	100% fluorescent	40 gal ICS with tankless aux	1.6 kW ac	

**13 SEER federal minimum efficiency went into effect January 2006

Building America Community Scale Project Closeout

The Armory Park del Sol community is located in a downtown area in a popular city in Arizona. Due to the project location and the unique construction practices, this site is a valuable example added to the Building America projects. In addition, the energy features of the Armory Park del Sol (APdS) community meet the Building America Program Project Closeout Criteria. The "must meet" criteria include source energy savings, neutral cost target, and quality control integration. The "should meet" criteria consist of marketability, builder commitment, homeowner satisfaction, and gaps analysis. The following sections detail the criteria and summarize how this community scale project addresses each one.

Source Energy Savings ("must meet")

Energy Simulation Inputs

EnergyGauge, a residential energy simulation software, was used to estimate the annual energy consumption of Armory Park del Sol compared with the Building America Benchmark. The software calculates loads on an hourly basis. In order to compare the energy use of the APdS homes, two different simulations were performed for each home. The first was the benchmark or base case simulation as defined by the National Renewable Energy Laboratory (NREL) Building America Research Benchmark procedures. EnergyGauge currently has a BA Benchmark option that calculates the energy use and cost for the benchmark by end use. The benchmark home provides a consistent reference from which to compare energy savings nationally. The second simulation was that of an Armory Park del Sol (APdS) house including the APdS energy features used in the home.

As a representative sample of homes, the models simulated include model 961, 1100, 1344, 1468, 1638, 2026, and 2059. These homes represent the homes built at Armory Park del Sol. In addition, all of the homes have many similar features, including block walls and slab floors. If the specific model on a lot was not simulated the home closest to it in both layout and square footage was used to represent that house. In addition, each of the net-zero energy homes, ZEH1 and ZEH2 were simulated individually.

Benchmark Simulation Input

Per BA Benchmark[3] procedures, the benchmark simulation is developed using the specific APdS layout and dimensions. A benchmark was simulated for each of the models listed above. The benchmark includes the same square footage and orientation as the specific model APdS home and the standard features such as a slab foundation, 11-foot ceiling height, and flat roof design. Specific energy features such as wall and roof insulation levels and window ratings are specified using NREL's Building America Research Benchmark Definition. However, unlike the APdS house design, the window area for the benchmark house is a standard 18% of the floor area. The benchmark window ratings, U-value, and Solar Heat Gain Coefficient (SHGC), are specified for the climate in the benchmark procedures. In addition, the benchmark simulation does not include any overhangs for the windows and the wall construction is modeled as wood framing. The benchmark design also includes a 10 SEER/6.8 HSPF heat pump, hard-wired lighting estimated at 14% fluorescent (86% incandescent) of total fixtures, and standard efficiency appliances. There are no renewable energy systems simulated in the benchmark. The BA Benchmark is meant to be representative of home construction in the mid 1990's in the particular region. Using this reference point as the base for comparison assures stable and progressive comparisons against which energy savings may be determined.

APdS House Simulation Input (by model)

Each of the APdS house models was input into EnergyGauge as a template. Next, each home at APdS was simulated with the specific model (or the one closest in square footage) and updated to accurately simulate the orientation and features of the APdS home on that specific lot. The energy features, window features, wall construction, HVAC system, hard-wired fluorescent lighting, appliance efficiency, solar hot water system, and solar electric PV system were specified by the standard construction practices at Armory Park del Sol and the specific features of the home on that specific lot. The comparison of each of the APdS home simulations by lot listed in order of the home's start date are detailed in Table 3 below.

[3] *Building America Research Benchmark Definition*, National Renewable Energy Laboratory, Updated December 29, 2004

Table 3. APdS Lot Features (listed by construction start date)

Lot #	Model	Sqft	Start Date	Front Orientation	Insulation	HVAC	Plumbing	Lighting	Solar Thermal	PV
					(exterior/attic)					(min)
26	800E	1000	8/28/00	South	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
22	1100F	1100	10/13/00	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
25	1344F	1344	10/19/00	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
24	961C	977	03/29/01	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
27	1470A	1470	07/19/01	South	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
39	1100E	1100	07/19/01	North	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
54	961C	977	07/19/01	North	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
23	1671	1671	7/26/01	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
50	1344F	1344	8/20/01	North	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
45	1344F	1344	09/04/01	South	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
37	1470B	1470	10/17/01	North	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
46	961B	977	10/17/01	South	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
44	1100A	1100	01/10/02	South	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
40	1344E	1344	03/05/02	North	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
48	2059A	1996	06/04/02	South	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
21	2059A	1996	09/03/02	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
56	1100A	1100	09/03/02	North	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
19	1344E	1344	09/11/02	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
17	1488	1488	11/11/02	West	1.5" polyiso / R38 ceiling	12 SEER	uninsulated hw in slab		40 Gal ICS w/ demand backup	1.0 kWAC
18	1638	1638	11/11/02	West	1.5" polyiso /	12 SEER	uninsulated		40 Gal ICS w/	1.0 kWAC

Lot #	Model	Sqft	Start Date	Front Orientation	Insulation	HVAC	Plumbing	Lighting	Solar Thermal	PV
					(exterior/attic)					(min)
					R38 ceiling		hw in slab		demand backup	
47	1717ZEH	1718	11/11/02	South	2.0" polyiso / R42 ceiling	18 SEER	PEX manifold	100%	120 sqft flat plate 210 gal storage w/ demand backup	4.2 kWDC
43	2059A	1996	12/15/02	South	1.5" polyiso / R38 ceiling	12 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
57	1344E	1344	12/15/02	North	1.5" polyiso / R38 ceiling	12 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
31	1100A	1100	2/11/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
51	1344F	1344	2/11/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
32/33	Custom	2177	2/14/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
52	1760	1760	3/11/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
85	1638AT	1638	3/30/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
86	2059AT	1996	3/30/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
87	2059AT	1996	3/30/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
35	1470M	1470	4/8/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
28	2012	2012	5/12/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
11	2059A/B	1996	5/21/03	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
30	1930	1930	6/10/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
65	2059A	1996	6/16/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
61	2059A	1996	7/1/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
20	2026A	2026	8/12/03	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
9	2059C	1996	8/13/03	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
70	2059A	1996	8/15/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC

Lot #	Model	Sqft	Start Date	Front Orientation	Insulation	HVAC	Plumbing	Lighting	Solar Thermal	PV
					(exterior/attic)					(min)
38	1468V	1468	10/27/03	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
29	961D	977	12/1/03	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.0 kWAC
8	1100A	1100	1/19/04	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
74	1344E	1344	3/31/04	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
1	2059M	1996	4/16/04	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
82/83	2059M	2317	4/16/04	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
4	2059A	1996	5/24/04	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
49	961D	977	5/24/04	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
76	1638	1638	5/27/04	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
93	1468M	1468	7/1/04	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
41	1468M	1468	7/2/04	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
5	2059E	1996	9/30/04	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
12	961D	977	9/30/04	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
81	1344M2	1344	9/30/04	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
3	1468V	1468	11/30/04	West	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
36	2026A	2026	11/30/04	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
67	2059B	1996	11/30/04	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
58	961D	977	3/31/05	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
97	1468B	1468	3/31/05	South	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
92	1344E2	1344	4/15/05	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC

Lot #	Model	Sqft	Start Date	Front Orientation	Insulation	HVAC	Plumbing	Lighting	Solar Thermal	PV
					(exterior/attic)					(min)
98	1638-98	1638	4/18/05	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
91	1468B	1468	5/12/05	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
99	2059A	1996	5/12/05	North	1.5" polyiso / R38 ceiling	13 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
53	2026A	2026	6/3/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
62/63	2059E	1996	6/23/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
63/64	1638	1638	6/23/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
90	1468T	1468	7/5/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
96	1468T	1468	7/5/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
95	1468M	1468	7/18/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
71/72	2059A	1996	8/15/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
72/73	2059M	1996	8/15/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
94	1468B	1468	9/12/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
66	1468M2	1468	9/13/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
89	1468V	1468	9/15/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
55	2026A	2026	10/17/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
88	2026A	2026	10/17/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
75	961C	977	10/24/05	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
84	1344M2	1344	11/8/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
77	1344M2	1344	12/12/05	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
15	2059AT	1996	1/9/06	West	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC

Lot #	Model	Sqft	Start Date	Front Orientation	Insulation	HVAC	Plumbing	Lighting	Solar Thermal	PV
					(exterior/attic)					(min)
16	1468AT	1468	1/9/06	West	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
79/80	2059E	1996	2/14/06	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
68	1344E2	1344	3/20/06	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
13/14	ZEH2	2168	4/3/06	West	2.0" polyiso, R38 ceiling + R6.5	18 SEER	PEX manifold	100%	64 sqft flat plate 80 gal storage w/ demand backup	6.93 kWDC
69	2026M	2026	5/23/06	North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
78/79	2059A	1996	8/30/06	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	50%	40 Gal ICS w/ demand backup	1.5 kWAC
2	2026M	2026	1/1/08	West	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC
6	1468	1468	4/1/09	West	1.5" polyiso / R38 ceiling	16 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC
42	961T	977	4/1/09	South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC
34	961T	977		North	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC
7				West	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC
10				West	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC
59/60				South	1.5" polyiso / R38 ceiling	14 SEER	insulated hw in slab	100%	40 Gal ICS w/ demand backup	1.6 kWAC

Energy Simulation Results

Once all of the simulation inputs were defined and the data entered into the software, the simulations were performed. The simulation software processes the input data using an engine based on DOE2, a detailed heat transfer model, and an historical weather file to compute the annual energy use and cost. The software first calculates the energy use for all loads and then determines the energy costs from user-input utility rates. For the simulations, the utility rates were assumed to be the electric rates from the Tucson Electric Power Company, $0.10/kWh.

The data in Table 4 compares the energy use and costs for the benchmark and Armory Park del Sol home designs. Each home was calculated using heating and cooling set points of 71°F and 76°F, respectively. Table 4 also shows the energy reduction relative to the 2003 IECC and the BA Benchmark for each Lot. The savings detailed include both efficiency features only as well as efficiency features with PV included. It is worth noting that extensive modeling was performed under another project for the ZEH1 and that the solar thermal hot water and heating system estimate for this report is conservative. The Research Center has data from monitoring to confirm that the home is a net-Zero Energy Home. The savings are shown graphically for APdS in Figure 7.

Table 4. APdS Lot Savings (listed by construction start date)

Lot #	Model	Sqft	Start Date	Efficiency Features		Efficiency Features Including PV	
				% Savings over IECC2003	% Savings over Benchmark	% Savings over IECC2003	% Savings over Benchmark
26	800E	1000	8/28/00	25.4%	41.4%	37%	50.5%
22	1100F	1100	10/13/00	21.6%	39.6%	33%	48.1%
25	1344F	1344	10/19/00	23.8%	41.3%	33%	48.7%
24	961C	977	03/29/01	25.5%	41.4%	37%	50.6%
27	1470A	1470	07/19/01	23.5%	41.6%	33%	48.6%
39	1100E	1100	07/19/01	23.5%	40.7%	35%	49.7%
54	961C	977	07/19/01	23.3%	39.7%	35%	48.9%
23	1671	1671	7/26/01	25.9%	44.9%	35%	51.8%
50	1344F	1344	8/20/01	25.1%	42.4%	35%	49.8%
45	1344F	1344	09/04/01	26.0%	43.0%	36%	50.5%
37	1470B	1470	10/17/01	22.5%	40.8%	32%	47.9%
46	961B	977	10/17/01	25.4%	41.4%	37%	50.5%
44	1100A	1100	01/10/02	20.5%	38.8%	32%	47.3%
40	1344E	1344	03/05/02	25.1%	42.4%	35%	49.8%
48	2059A	1996	06/04/02	26.9%	45.7%	36%	52.1%
21	2059A	1996	09/03/02	26.9%	45.7%	35%	52.1%
56	1100A	1100	09/03/02	23.5%	40.7%	35%	49.7%
19	1344E	1344	09/11/02	23.8%	41.3%	33%	48.7%
17	1488	1488	11/11/02	24.7%	42.5%	34%	49.6%
18	1638	1638	11/11/02	25.9%	44.9%	35%	51.8%
47	1717ZEH	1718	11/11/02	46.9%	60.5%	84.9%	88.8%
43	2059A	1996	12/15/02	31.3%	49.0%	40%	55.4%
57	1344E	1344	12/15/02	29.1%	45.4%	39%	52.8%
31	1100A	1100	2/11/03	26.2%	43.2%	37%	51.6%
51	1344F	1344	2/11/03	30.0%	46.1%	40%	53.6%
32/33	Custom	2177	2/14/03	23.8%	38.5%	33%	46.3%
52	1760	1760	3/11/03	31.5%	49.1%	41%	56.0%
85	1638AT	1638	3/30/03	31.5%	49.1%	41%	56.0%

Lot #	Model	Sqft	Start Date	Efficiency Features		Efficiency Features Including PV	
				% Savings over IECC2003	% Savings over Benchmark	% Savings over IECC2003	% Savings over Benchmark
86	2059AT	1996	3/30/03	31.8%	49.3%	41%	56.3%
87	2059AT	1996	3/30/03	31.8%	49.3%	41%	56.3%
35	1470M	1470	4/8/03	29.7%	46.3%	39%	53.4%
28	2012	2012	5/12/03	32.4%	48.6%	40%	54.4%
11	2059A/B	1996	5/21/03	32.6%	49.9%	41%	56.3%
30	1930	1930	6/10/03	32.5%	49.9%	41%	56.3%
65	2059A	1996	6/16/03	32.5%	49.9%	41%	56.3%
61	2059A	1996	7/1/03	32.5%	49.9%	41%	56.3%
20	2026A	2026	8/12/03	36.5%	51.7%	44%	57.6%
9	2059C	1996	8/13/03	32.6%	49.9%	41%	56.3%
70	2059A	1996	8/15/03	31.8%	49.3%	41%	56.3%
38	1468V	1468	10/27/03	28.3%	45.3%	38%	52.3%
29	961D	977	12/1/03	28.4%	43.8%	40%	52.9%
8	1100A	1100	1/19/04	26.2%	43.2%	37%	51.6%
74	1344E	1344	3/31/04	29.2%	45.1%	44%	56.2%
1	2059M	1996	4/16/04	32.6%	49.9%	45%	59.5%
82/83	2059M	2317	4/16/04	32.5%	49.9%	45%	59.4%
4	2059A	1996	5/24/04	32.6%	49.9%	45%	59.5%
49	961D	977	5/24/04	28.4%	43.8%	46%	57.4%
76	1638	1638	5/27/04	31.2%	48.8%	45%	59.2%
93	1468M	1468	7/1/04	29.3%	46.0%	43%	56.6%
41	1468M	1468	7/2/04	28.3%	45.3%	42%	55.9%
5	2059E	1996	9/30/04	32.6%	49.9%	45%	59.5%
12	961D	977	9/30/04	28.8%	44.1%	46%	57.7%
81	1344M2	1344	9/30/04	29.8%	45.6%	44%	56.7%
3	1468V	1468	11/30/04	30.3%	46.8%	44%	57.4%
36	2026A	2026	11/30/04	33.1%	49.1%	45%	57.9%
67	2059B	1996	11/30/04	31.8%	49.3%	45%	58.9%
58	961D	977	3/31/05	28.3%	43.7%	46%	57.3%
97	1468B	1468	3/31/05	29.3%	46.0%	43%	56.6%
92	1344E2	1344	4/15/05	29.2%	45.1%	44%	56.2%
98	1638-98	1638	4/18/05	31.5%	49.1%	45%	59.4%
91	1468B	1468	5/12/05	28.3%	45.3%	42%	55.9%
99	2059A	1996	5/12/05	31.8%	49.3%	45%	58.9%
53	2026A	2026	6/3/05	32.2%	48.4%	44%	57.1%
62/63	2059E	1996	6/23/05	32.5%	49.9%	45%	59.4%
63/64	1638	1638	6/23/05	33.2%	50.3%	47%	60.7%
90	1468T	1468	7/5/05	30.2%	46.7%	44%	57.4%
96	1468T	1468	7/5/05	31.2%	47.5%	45%	58.1%
95	1468M	1468	7/18/05	31.2%	47.5%	45%	58.1%
71/72	2059A	1996	8/15/05	31.8%	49.3%	45%	58.9%
72/73	2059M	1996	8/15/05	31.8%	49.3%	45%	58.9%
94	1468B	1468	9/12/05	31.2%	47.5%	45%	58.1%
66	1468M2	1468	9/13/05	31.2%	47.5%	45%	58.1%

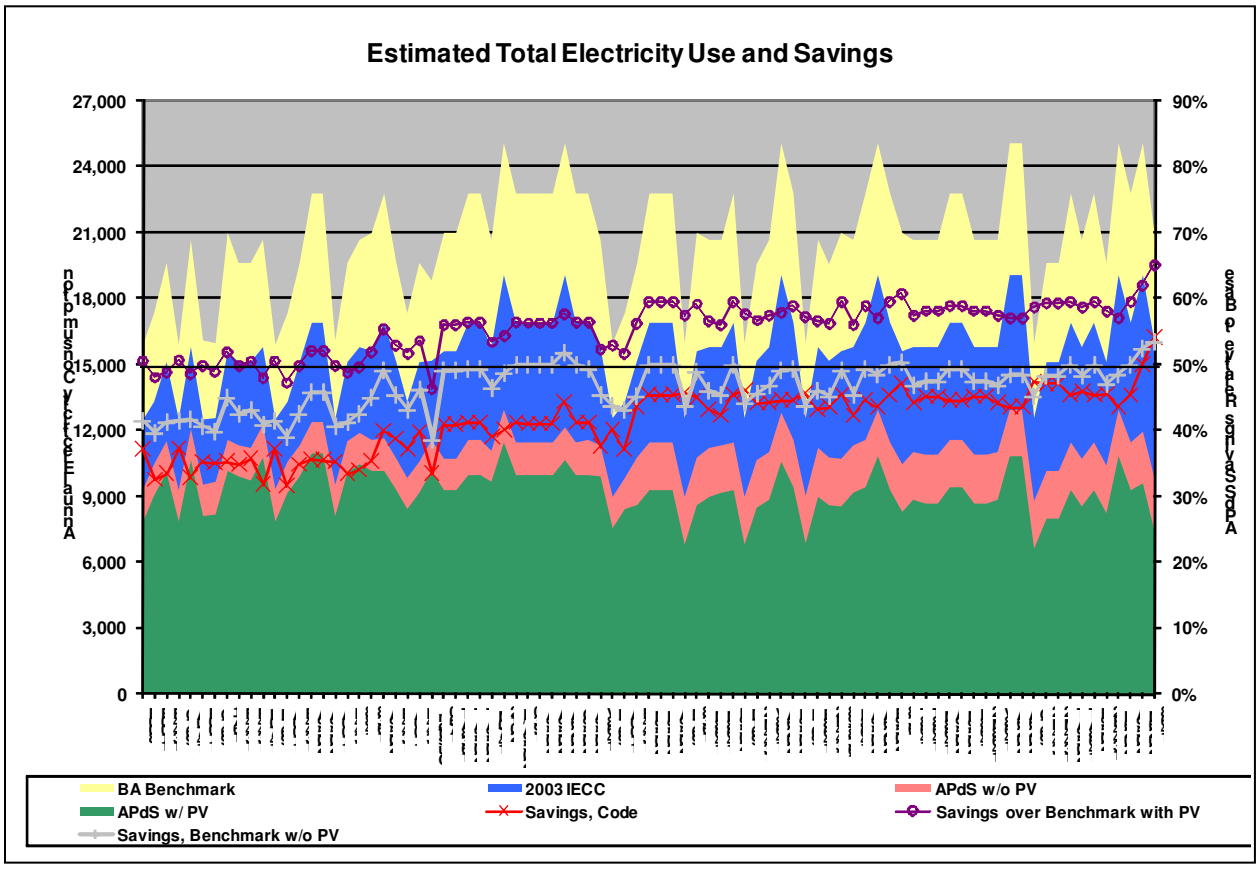
Lot #	Model	Sqft	Start Date	Efficiency Features		Efficiency Features Including PV	
				% Savings over IECC2003	% Savings over Benchmark	% Savings over IECC2003	% Savings over Benchmark
89	1468V	1468	9/15/05	30.2%	46.7%	44%	57.4%
55	2026A	2026	10/17/05	32.2%	48.4%	44%	57.1%
88	2026A	2026	10/17/05	32.2%	48.4%	44%	57.1%
75	961C	977	10/24/05	30.0%	45.0%	47%	58.6%
84	1344M2	1344	11/8/05	32.8%	48.2%	47%	59.3%
77	1344M2	1344	12/12/05	32.8%	48.2%	47%	59.3%
15	2059AT	1996	1/9/06	32.6%	49.9%	45%	59.5%
16	1468AT	1468	1/9/06	32.1%	48.2%	46%	58.7%
79/80	2059E	1996	2/14/06	32.5%	49.9%	45%	59.4%
68	1344E2	1344	3/20/06	31.2%	47.0%	46%	58.1%
13/14	ZEH2	2168	4/3/06	42.4%	55.5%	56%	100.0%
69	2026M	2026	5/23/06	32.2%	48.4%	44%	57.1%
78/79	2059A	1996	8/30/06	32.5%	49.9%	45%	59.4%
2	2026M	2026	1/1/08	37.4%	52.4%	50%	62.0%
6	1468	1468	4/1/09	38.9%	53.4%	54%	65.0%
42	961T	977					
34	961T	977					
7							
10							
59/60							

Source and Site Energy Savings of APdS Standard Homes

Based on the energy simulations, the Armory Park del Sol (APdS) plans offered in this community consume from 39% to 56% less energy compared to the Building America benchmark. With PV, the homes consume 46% to 100% better than the Building America Benchmark. Site energy consumption and savings for APdS Standard homes, IECC 2003 code-compliant homes, and Benchmark homes are reflected in Table 5 and Figure 6. Because the homes are all-electric, site and source energy savings are identical. On average, the energy savings over the Benchmark of Armory Park del Sol is 47% due to energy efficiency measures alone (not including PV). When on-site PV electricity supply is factored into whole-house energy savings, APdS homes are predicted to use, on average, 56% less energy than a Building America Benchmark home and 42% less energy than an IECC 2003 code-compliant home. On a community-scale, aggregate source energy savings of 7,781 MBtu per year would result compared to an identical community of BA Benchmark homes.

Table 5. Average Source Energy Savings Comparison.

	Estimated Annual Source Energy			Source Energy Savings for Community			
				Percent of End-Use		Percent of Total	
End Use	Benchmark (MBtu/yr)	Typ Regional (IECC 2003) (MBtu/yr)	APdS (average) (MBtu/yr)	BA BM Base	IECC 2003 Base	BA BM Base	IECC 2003 Base
Space Heating	34.6	20.3	10.2	71%	50%	10%	6%
Space Cooling	90.3	50.7	30.5	66%	40%	25%	11%
DHW	29.6	25.0	8.0	73%	68%	9%	9%
Lighting	23.3	26.1	17.6	25%	33%	2%	5%
Appliances & MELs	58.0	58.0	58.6	-1%	-1%	0%	0%
OA Ventilation	1.9	0.3	1.8	7%	-577%	0%	-1%
Total Usage	237.7	180.3	126.6			47%	30%
Site Generation			-22.5			9%	12%
Net Energy Use	237.7	180.3	104.1			56%	42%



NOTE: IECC 2003 code-compliant homes, and Benchmark homes. Energy savings of APdS homes over Benchmark and IECC 2003 homes are indicated by lines. X-axis model numbers are displayed chronologically (by closing date) from left to right, which highlights the energy improvements that were made over time.

Figure 6. Site energy consumption and savings for APdS homes

These average energy savings numbers encompass all 87 homes currently built at Armory Park del Sol from 2000 to present. As of this study, there are five remaining homes to construct. During build-out, the builder, John Wesley Miller Companies, did not change their basic thermal enclosure construction methods in which the company president firmly believes (e.g., masonry wall construction). However, several practices were adopted and technologies were tested as prototypes during the research project. In addition, with information provided by repeated inspection and testing, the company was able to reduce the building envelope infiltration rate dramatically. As the construction details such as the HVAC system efficiencies and the lighting were improved at the site as detailed in Table 6, the resulting savings improved as well as shown in Figure 7.

Table 6. Progression of APdS Construction Features

Feature	First Models	Current Construction
Heat Pump Efficiency	12 SEER	16 SEER
Duct Location	Unconditioned	Conditioned
Ducts Leakage (max)	33 cfm25	5% conditioned space
Air Leakage (max)	0.35 ACHnat	0.15 ACHnat, 2.90 ACH50
PV System	1.20 kW (dc)	1.50 kW (dc)
Programmable Thermostat	No	Yes
Insulated Hot Water Lines	No	Yes
ENERGY STAR Appliances	No	Yes
Ceiling Fans	No	Yes

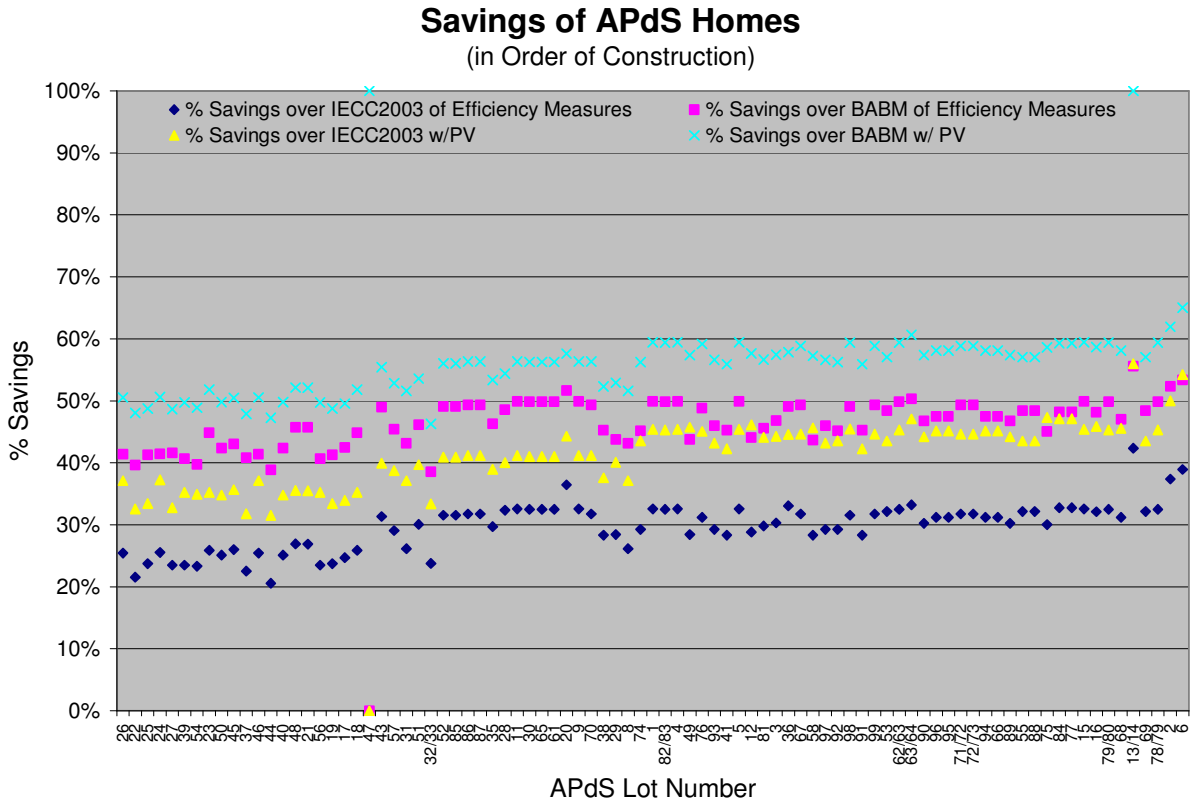


Figure 7. APdS Site Energy Savings

As shown in Figure 7, many of the homes at Armory Park del Sol meet the 2011 Joule target of 50% energy savings over the BA Benchmark for the Hot/Dry Climate (efficiency features only), and the first homes were started in 2000. There are currently a total of 19 homes at Armory Park del Sol (APdS) with efficiency savings of 50% or more including two net-zero energy homes. There are an additional 14 homes with 49% savings and 11 homes with 48% savings over the BA Benchmark respectively. A histogram of energy savings at APdS is shown in Figure 8.

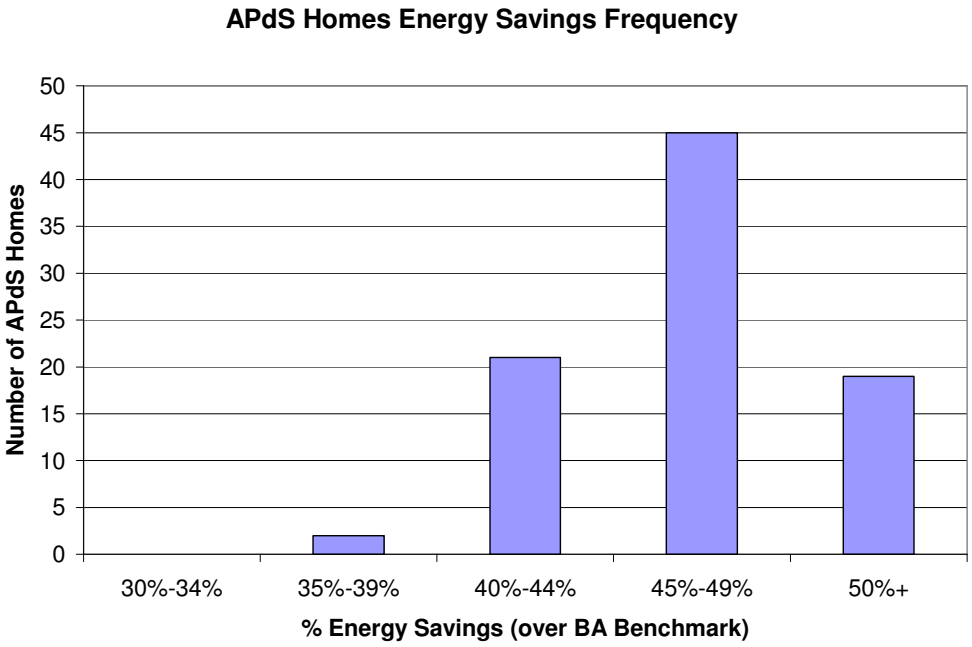


Figure 8. APdS Histogram of Energy Savings

The most recently constructed homes at Armory Park del Sol include 10 homes with an average energy savings over 50% as shown below in Table 7. These are the homes that comprise the 50%+ Hot/Mixed Dry Stage Gate 3 Community Case Study detailed in NAHBRC 2009 Deliverable 4.3.1.6 - Case Study Hot-Mixed Dry 50% Community.

Table 7. APdS Homes with 50%+ Savings over the BA Benchmark

Lot #	Model	Sqft	Start Date	Efficiency Features
				% Savings over Benchmark
6	1468	1468	4/1/2009	53.40%
2	2026M	2026	1/1/2008	52.40%
78/79	2059A	1996	8/30/2006	49.90%
69	2026M	2026	5/23/2006	48.40%
13/14	ZEH2	2168	4/3/2006	55.50%
68	1.34E+05	1344	3/20/2006	47.00%
79/80	2059E	1996	2/14/2006	49.90%
16	1468AT	1468	1/9/2006	48.20%
15	2059AT	1996	1/9/2006	49.90%
77	1344M2	1344	12/12/2005	48.20%
			Average	*50.28%*

Short Term Testing & Performance Analysis

Short-term tests provide insight into the performance of the home and identify construction and installation issues. John Wesley Miller Companies partners with Tucson Electric Power's (TEP) Guarantee Home Program in which homes are inspected and tested at several points during the

construction process. Specifically, TEP performs air sealing and duct testing on each home under the Guarantee Home Program. Additional information on the program is located in the Quality Control Integration section.

Air Sealing Test Results

One of the major areas of improvement during the course of build-out of the APdS community was in building shell air tightness. Third party inspections by Tucson Electric Power reveal a distinct trend toward tighter homes over time, with the earliest homes hovering around 5 or 6 ACH50 and the later homes testing between 1 and 3 ACH50 (with one exception in 2006). Blower door test results from TEP are displayed in Figure 9.

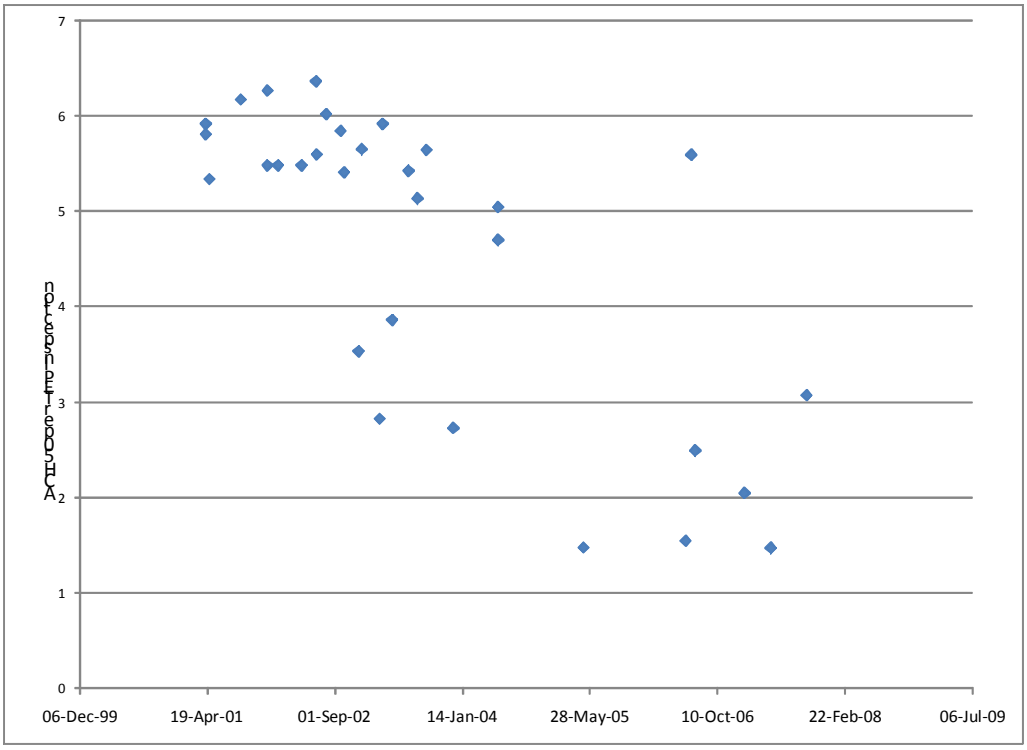


Figure 9. Blower door test results for TEP-tested homes

Duct Test Results

Duct losses, already very low, remained at a consistent level of installation quality, with an average of 0.73% per CFA (maximum of 2.81% and all but two data points below 1.5% per CFA). As with the blow door tests, TEP performs both tests on each house in their Guarantee Home Program.

Neutral Cost Target at Armory Park del Sol ("must meet")

Homes in Armory Park del Sol (APdS) come at a premium cost, not simply due to the energy efficiency and solar energy upgrades, but also due to John Wesley Miller Companies' uncompromising quality standards. For example, light-framed homes would be substantially less expensive to build, but the builder refuses to build any wall system other than the solid-filled concrete masonry wall. Company president John Miller likes the quality of the wall system and, according to him, so do his customers.

Even considering the premium costs, the energy cost savings associated with improvements to homes in this community result in a positive annual cash flow when compared to the annual incremental cost of the improvements financed as part of a 30 year mortgage, in other words, the homes are cost neutral. However, several economic incentives are available to APdS customers, which help reduce the added initial expense of a high performance home. In addition, although homes are not cost neutral when

considering site generation, which is standard on all Armory Park del Sol homes, homes with site generation are cost neutral when considering the local, state, and federal incentives.

Neutral Cost Worksheet for APdS Standard/Prototype Home

The cost neutral analysis was calculated twice. The first analysis shown in Table 8 took the average end use cost for the entire 87 homes currently built using the average APdS estimated energy savings for the site of 47% with energy efficiency measures alone and 56% including PV production over the Building America Benchmark. The second cost neutral analysis shown in Table 9 considered only the most recently built 10 homes as specified in the case study for the Hot/Mixed Dry 50% + energy saving community. The analysis used the estimated energy savings for these 10 homes of 50% for the efficiency features only and 64% when including PV production in the analysis.

Table 8. Neutral Cost Worksheet for Average APdS Homes (all 87 homes currently constructed)

	Annual Electric Energy (Site)					
	Benchmark	Builder Standard Practice (Optional)	Prototype House	Annual Utility Bill Reduction vs Benchmark	Local Marginal Electricity Price	Local Marginal Gas Price
End Use	**(kWh/yr)**	**(kWh/yr)**	**(kWh/yr)**	**($/yr)**	**($/kWh)**	**($/therm)**
Space Heating	3,010	884	884	$213	$0.10	$1.20
Space Cooling	7,867	2,655	2,655	$521	TEP, Flat	
DHW	2,579	695	695	$188		
Lighting	2,029	1,530	1,530	$50		
Appliances and MELs	5,051	5,106	5,106	($5)		
Ventilation	168	157	157	$1		
Total Usage	**20,705**	**11,027**	**11,027**	**$968**		
Site Generation	0	1,844	1,844	$184		
Net Energy Use	**20,705**	**9,183**	**9,183**	**$1,152**		
Added Annual Mortgage Cost w/o Site Gen.				**$955**		
Net Cash Flow to Consumer w/o Site Gen.				**$13**	**Neutral Cost Criteria Met?**	**Yes**
Added Annual Mortgage Cost with Site Gen.				**$2,068**		
Net Cash Flow to Consumer with Site Gen. w/o Incentives				**($916)**	**Neutral Cost Criteria Met?**	**No**
Added Annual Mortgage Cost with Site Gen. & Incentives				**$629**		
Net Cash Flow to Consumer with Site Gen. & Incentives				**$523**	**Neutral Cost Criteria Met?**	**Yes**

Table 9. Neutral Cost Worksheet for Case Study APdS Homes (most recent 10 homes constructed)

	Annual Electric Energy (Site)				Local Marginal Electricity Price	Local Marginal Gas Price
	Benchmark	Builder Standard Practice (Optional)	Prototype House	Annual Utility Bill Reduction vs Benchmark		
End Use	**(kWh/yr)**	**(kWh/yr)**	**(kWh/yr)**	**($/yr)**	**($/kWh)**	**($/therm)**
Space Heating	3,574	1,081	1,081	$249	$0.10	$1.20
Space Cooling	8,924	2,687	2,687	$624	TEP, Flat	
DHW	2,685	749	749	$194		
Lighting	2,261	1,358	1,358	$90		
Appliances and MELs	5,347	5,347	5,347	$0		
Ventilation	175	175	175	$0		
Total Usage	**22,966**	**11,397**	**11,397**	**$1,157**		
Site Generation	0	1,844	1,844	$184		
Net Energy Use	**22,966**	**9,553**	**9,553**	**$1,341**		
Added Annual Mortgage Cost w/o Site Gen.				**$955**		
Net Cash Flow to Consumer w/o Site Gen.				**$202**	**Neutral Cost Criteria Met?**	**Yes**
Added Annual Mortgage Cost with Site Gen.				**$2,068**		
Net Cash Flow to Consumer with Site Gen. w/o Incentives				**($727)**	**Neutral Cost Criteria Met?**	**No**
Added Annual Mortgage Cost with Site Gen. & Incentives				**$629**		
Net Cash Flow to Consumer with Site Gen. & Incentives				**$712**	**Neutral Cost Criteria Met?**	**Yes**

The numbers detailed in the tables above are averages of the homes used in the analysis. Therefore, they are slightly different. However, the cost neutral result is the same. APdS homes are cost neutral when considering the efficiency measures only. An APdS home with site generation, however, is not cost neutral, when the full cost of the photovoltaic system is considered. In fact, any homeowner in this area, purchasing a similar PV system outright would have an additional annual cost of $629, based on the energy cost savings from the PV system. If the site generation was optional and a homeowner is solely driven by cost, they would not add the system to their home at the current cost of a PV system installation. The story at Armory Park is different, however, because there are many incentives for site generation and other efficiency measures. When including the incentives, the homeowner's net cash flow for efficiency features with site generation is cost positive.

The incentives included in the cost neutral analysis include local, state, and federal incentives. In addition, because the homes within Armory Park del Sol are all-electric and are part of Tucson Electric Power's (TEP's) Guarantee Home program, and because they include solar thermal systems they are also eligible for preferential electric rates. The incentives are further detailed below.

Tucson Electric Power Guarantee Home Incentives

APdS customers can choose time-of-use rates (under TEP's PowerShift program), which further delineate electric rates into time of use and includes rates as low as $0.038 per kWh for off-peak, wintertime use. TOU rates are often a cost-effective option for APdS customers for which peak solar power production coincides with the most expensive utility power and which, due to the high thermal mass construction, have peak energy demand that is shifted towards off-peak times.

TEP PV Capacity Incentives

For installing residential, grid-tied solar electric generating capacity of at least 1,200-watt (dc), homeowners are eligible for an up-front payment of $3.00 per watt (dc). Customers can then choose either their preferred electric rate including the reduced time-of-use rate. Customers benefit economically from reduced electric bills from electricity generated and used at the house.

TEP Solar Water Heating Incentives

In addition to financial incentives for solar PV systems, each home in the APdS neighborhood qualifies for a solar water heating system financial incentive of $750 plus $0.25 for each kWh the system is predicted to offset annually (based on OG-300 ratings) up to a maximum of $1,750.

Other Financial Incentives
In addition to utility rebates, APdS homes qualify for a state income tax deduction equal to 5% of the sales price and a property tax exemption for the solar systems.

As part of the cost neutral analysis, the upgrade costs of a typical regional code minimum home to the typical APdS home were determined. The detailed costs used in the cost neutral analysis for upgrading from a code minimum house to the APdS standard home are shown in Table 10. The costs used for the Code Minimum home were based on a "calibrated" RSMeans 2009[4] and the NAHB and ASHRAE RP-1481[5] costs. The costs for the typical APdS home were based on the builder's actual costs.

[4] Reed Construction Data, RSMeans 2009. rsmeans.reedconstructiondata.com.
[5] ASHRAE RP-1481, Economic Database in Support of ASHRAE 90.2 (Energy-Efficient Design of Low-Rise Residential Buildings) 2009. eweb.ashrae.org/eweb

Table 10. Detailed Cost for Cost Neutral Analysis

Measure	Builder Standard Practice (Optional)	Code Minimum House*	Prototype House*	Total Incremental Cost + 10% markup)	Amortized Annual Cost (30 year mortgage, 7% interest)
Thermal Enclosure:	**$0**	**$17,202**	**$24,145**	**$7,637**	**$610**
Roof / Attic	$0	$0	$0	**$0**	**$0**
Wall	$0	$17,202	$24,045	**$7,527**	**$601**
Cavity Insulation		$901		**-$991**	**-$79**
Insulating Sheathing			$6,074	**$6,681**	**$533**
Other Wall Measure		$16,301	$17,971	**$1,837**	**$147**
Foundation	$0	$0	$0	**$0**	**$0**
Air Infiltration Reduction			$100	**$110**	**$9**
Other Enclosure Measures				**$0**	**$0**
Windows:	**$0**	**$0**	**$0**	**$0**	**$0**
HVAC System:	**$0**	**$4,250**	**$4,420**	**$187**	**$15**
Furnace: AFUE				**$0**	**$0**
A/C: SEER				**$0**	**$0**
Ducts				**$0**	**$0**
Ventilation				**$0**	**$0**
Other HVAC Measures		$4,250	$4,420	**$187**	**$15**
Water Heating:	**$0**	**$499**	**$4,255**	**$4,132**	**$330**
Other Water Heating		$499	$4,255	**$4,132**	**$330**
Lighting:	**$0**	**$0**	**$0**	**$0**	**$0**
Appliances:	**$0**	**$0**	**$0**	**$0**	**$0**
Misc Electric Loads:	**$0**	**$0**	**$0**	**$0**	**$0**
Other Measures				**$0**	**$0**
3rd Party Inspections and QA Testing				**$0**	**$0**
Total Energy Efficiency Investment	**$0**	**$21,951**	**$32,820**	**$11,956**	**$955**
Site Generation			**$12,683**	**$13,951**	**$1,114**
Total with Site Generation	**$0**	**$21,951**	**$45,503**	**$25,907**	**$2,068**
REBATES / INCENTIVES	**$0**	**$0**	**-$18,026**	**-$19,829**	**-$1,583**
Builder Tax Credit			-$2,000	**-$2,200**	**-$176**
Tucson Solar Tax Credits			-$7,000	**-$7,700**	**-$615**
TEP Solar Buydown			-$5,750	**-$6,325**	**-$505**
Federal Solar Tax Credit			-$3,276	**-$3,604**	**-$288**
Total Incremental Cost to Buyer Including Incentives	**$0**	**$21,951**	**$27,477**	**$7,881**	**$629**

The results show that the typical Armory Park del Sol home is cost neutral for the efficiency features. In addition, the typical Armory Park del Sol home with efficiency features, site generation, and including incentives is also cost neutral. It is also worth noting that many of the energy upgrades in the home were not only selected for their contribution to energy efficiency but for other properties as well. As an example, the builder uses a solid-core masonry wall system not just for its energy benefits, but even more so for its durability, local material availability and labor familiarity, moisture resistance, fire resistance and other subjective features such as sound insulation and overall comfort.

Quality Control Integration ("must meet")

JWM maintains strict control over the construction process by consistently using the same subcontractors, with which the company holds long-term relationships. In addition, the company relies on a dedicated and trusted construction supervisor who is entrenched in the energy-saving philosophy held

by the company president. Pre-construction meetings to coordinate trade contractors and to ensure buy-in by the site superintendent are essential components of the company's adherence to quality standards.

In addition to including details on plans, quality control is facilitated onsite through a partnership with Tucson Electric Power's (TEP) Guarantee Home Program in which homes are inspected and tested at several points during the construction process. Once homes pass the TEP inspection and testing criteria, they receive a 5-year guarantee on heating and cooling bills and preferential electric utility rates. During the construction process, TEP's inspections and performance testing ensures conformance to Guarantee Home Program specifications. Based on the inspection and testing, TEP simulates energy use for each home and writes a guarantee on heating and cooling costs. The average APdS homeowner pays just over $300 for heating and cooling annually.

In addition to the Guarantee Program, Tucson Electric Power inspects solar electric systems annually and offers financial incentives for onsite solar energy production. A partial listing of the testing and inspection provided by TEP's Guarantee Home Program is found in Table 11. TEP's testing includes blower door and duct blaster testing. The results of these tests are outlined above in the Short Term Testing & Performance Analysis section.

Table 11. TEP third-party inspection and mandatory items

System	Inspection Protocol
Framing	Onsite inspection with multiple checkpoints beyond EPA thermal bypass checklist
Insulation	Onsite inspection with multiple checkpoints for quality insulation installation
Air Sealing	Blower door test results must be less than 0.35 CFM per square foot of leakage area
Windows	NFRC rating required, Max SHGC and U-value requirements Low-e coating not allowed on tinted glass
Ductwork	ACCA Manual D sizing required Completely hard-ducted system required Return air per ACCA Manual T Return air pathways across bedrooms required Pressure balance testing conducted Airflow delivery measured Leakage below 3% conditioned floor area
Heating and Cooling Equipment	Minimum SEER requirements TEP performs room-by-room Manual J load calculations Mechanical ventilation required
Lighting	IC-rated housings for recessed fixtures

Marketability ("should meet")

In addition to the fact that the APdS homes achieve cost neutrality at today's electric utility rates, the neighborhood is very popular and the homes have sold well. Homeowners appear willing to spend more money for homes in APdS, whether their motivation is to reduce their reliance on fossil fuel energy consumption and have the security of guaranteed energy bills or if they simply like the look and feel of the homes and the neighborhood.

Sales and Marketing Materials

John Wesley Miller Companies marketed Armory Park del Sol in a variety of ways. Armory Park del Sol has been featured on HGTV's "Dream Builders" television series, The Wall Street Journal, Arizona Daily Star newspaper, Discover Magazine, Tucson Home Magazine, Professional Builder Magazine, Tucson Lifestyle Magazine, and many others. A more comprehensive list is included in Appendix A as well as on John Wesley Miller Companies website at http://www.johnwesleymillercompanies.com/inthepress.html.

Another method of marketing is the variety of awards that John Wesley Miller Companies and company president John Wesley Miller has received. These include the US Department of Energy's Builders Challenge, Southern Arizona Home Builders Association's 2007 Builder of the Year, 2008 EnergyValue Housing Award Recipient, Governor Janet Napolitano's Arizona Innovation Award, and many others.

Finally, John Wesley Miller Companies also produced handouts and specific marketing materials including presentations, reports, handouts, and customer testimonials such as those available at http://www.johnwesleymillercompanies.com/benefits.html. Even more important are the satisfied homeowners and word of mouth that is a result of all of these sales and marketing materials.

Sales and Home Value Data Analysis

As part of the Project Closeout, Building America is interested in the sales of the community. Armory Park del Sol began in 2000 and the first home sales were in 2001. Figure 10 depicts the home sales per year at APdS. There are currently five homes remaining of the 92 total homes.

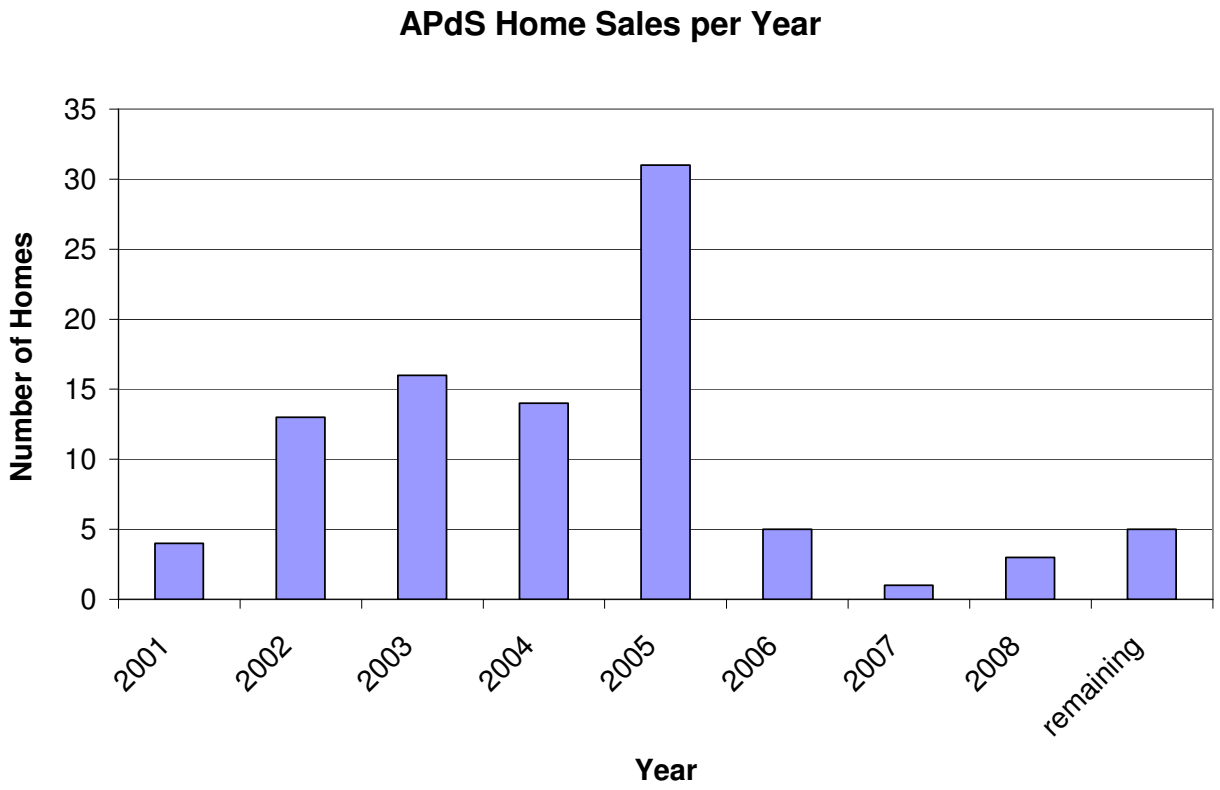


Figure 10. APdS Home Sales per Year

In addition, some of the homes at Armory Park del Sol have been resold. Out of the total 92 homes, 5 have not yet been built and/or sold, 61 homes have their original owners, 16 have been resold, and data was not available for 10 homes. Even considering only that 61 homeowners are in their homes of the 87 homes included in this study, 70% of the homeowners are the original owner.

The final metric considered in the Project Closeout is the sales price of the homes in the community. At Armory Park del Sol, the prices of the homes ranged from $186,500 to $568,000. Note that all of the homes at Armory Park del Sol include solar thermal and electric systems. In addition, the price of the second net-zero energy home, ZEH2, is not included because it is the largest home at Armory Park del Sol in conjunction with the largest PV system at Armory Park. The specific analysis of the costs for the

ZEH2 is detailed in the Building America Prototype Home report from the NAHB Research Center. The sales prices of Armory Park del Sol by model number are further summarized in Table 12 below.

Table 12. APdS Sales Prices by Model

Model	Sqft	Min*	Max*	Average*
961	977	$263,000	$328,000	$291,688
1100	1100	$186,500	$363,000	$292,600
1344	1344	$215,000	$435,000	$307,544
1468	1468	$249,500	$445,000	$339,278
1638	1638	$279,000	$480,406	$347,999
1760	1760	$333,000	$333,000	$333,000
1930	1930	$390,000	$390,000	$390,000
2026	2026	$343,900	$503,135	$418,674
2059	1996	$306,000	$568,000	$410,634
Total*		**$186,500**	**$568,000**	**$359,153**

* includes sales price data for 74 of the 87 homes built

It is important to note that the sales prices for the homes are for downtown lots in a city undergoing revitalization, which can add significantly to the cost of the home. In addition, because Armory Park del Sol is a redeveloped site, the cost of infrastructure changes and additions added cost to each lot.

Builder Commitment ("should meet")

John Miller the owner of John Wesley Miller Companies is dedicated to both energy efficiency and green building. He is a national leader in energy conservation and green building practices and has received numerous industry honors and awards for energy conservation and building quality in his over 50 years as a builder. In 2002, the National Association of Home Builders' National Green Builders' Conference named Miller the year's Outstanding Green Advocate. John Wesley Miller has consulted with Pima County to promote a program for energy efficient homes and the use of solar energy, and with the University of Arizona's Environmental Research Laboratory in developing new energy saving products and technologies.

In addition to Armory Park del Sol (APdS), John Miller also has expertise in energy efficient green remodeling and has completed a retrofit at the Hawthorne House. This renovation is currently being developed as a Building America (BA) deep energy retrofit case study. The energy features used in the home are similar to those at Armory Park del Sol. Miller continues to work with the Research Center on energy efficiency projects including a thermal mass analysis of one of his homes at APdS as a Stage Gate 1 BA project.

Homeowner Satisfaction ("should meet")

Based on the sales of the community and the retention of the original homeowners, there is anecdotal data supporting that the homeowners are satisfied. In addition, there are testimonials on John Wesley Miller's website at http://www.johnwesleymillercompanies.com/benefits.html stating that the homes they live in are comfortable as well as energy efficient.

In addition, while obtaining releases for utility bill data, Global Professional Services, Inc also gathered preliminary anecdotal data about customer satisfaction. When queried about general features of their home at Armory Park del Sol, the homeowners note that the thing they like most about their home is:

- The energy efficiency and emissions reductions;
- Urban neighborhood and lowered transportation costs and times;
- Universal layout of the home for wheelchair accessibility;
- The architectural features; and
- The interior quiet—no mean feat since the APdS neighborhood is close to functioning railway.

Gaps Analysis ("should meet")

Through the build-out of the community, the builder identified areas for improving the air tightness of homes, and implemented other energy savings measures such as bringing ducts into conditioned space, using fluorescent lighting, and insulating hot water piping that were successful in early prototypes. In terms of future construction efforts, there are few, if any, obvious gap or barriers to achieving high performance homes at the 40%+ level.

One area that is in need of continued research is the impact—both energy and economic—of the thermal mass wall construction employed at APdS. Because the wall system is more expensive than conventional light-frame construction, John Wesley Miller Companies' use of concrete block walls is unique in the market. However, if there is significant potential for peak demand shifting and for energy savings, it is a construction method that may be worthwhile promoting to other builders in the region.

The high initial cost of solar photovoltaic and active solar water heating systems becomes a barrier when pushing the energy savings beyond existing levels. A continued relationship with TEP and financial incentives for solar and energy efficient homes in the hot/mixed dry climate will propel the construction of similar homes in this climate in the future.

When extending the lessons learned at APdS to other hot/mixed dry regions, it is necessary to develop systematic testing and inspections such that installation of energy features can continue in a manner that produces consistently excellent efficiency in the absence of a program such as TEP's Guarantee Home program described under the Quality Control section.

Lessons Learned

Although construction did not change dramatically over time, the builder implemented incremental changes to improve energy efficiency and the overall performance of homes. The most significant efficiency changes included insulating hot water distribution lines, shifting to higher SEER air conditioning equipment and upgrading to fluorescent lighting fixtures, increasing the minimum PV system size, and gaining better control over air infiltration. Many of the changes can be directly attributed to the builder's work with the Building America program as a partner with the NAHB Research Center. The BA program provided not only the engineering and analysis but also the feedback provided by short- and long-term testing. For example, through the process of building the first ZEH, the builder learned about the benefits of fluorescent lighting in the cooling-dominated climate and how to select aesthetically pleasing fluorescent fixtures and lamps. Blower door test results identified areas of building shell leakage, and improvements were made over time to cut the average whole-house air infiltration in half.

Lessons learned during the process of building the first ZEH home, in turn, were applied to the design and construction of the second ZEH. For example, the active flat plate solar space and water heating system of the first home was considered too bulky and complicated and was nixed for a smaller active solar water heating system. Instead, a larger PV system was used in ZEH2 to increase generating capacity. The abundant financial incentives for PV systems in Tucson and the climate's relatively small heating load, combined with technical difficulties experienced with the space and water heating system in ZEH1, the need for interior space occupied for the large hot water storage tank and the added cooling load from the tank factored into the decision to invest in a larger PV system rather than a solar space heating system in attaining zero energy home performance.

One unresolved lesson is in the identification and documentation of the benefits of the thermal mass construction. While the added expense of constructing of solid-grout CMU walls has been embraced by the builder, the energy and cost savings have not been fully documented. In addition, the cost savings associated with both the energy efficiency features as well as the advantage of the time-of-use utility rates available to this development, may well understate the economic advantages and hence the cost neutrality analysis. Work is underway to evaluate the house design and performance of thermal mass.

One significant lesson learned from this development and the construction methods and technologies of the builder is that the net-zero energy home design is achievable in this region of the country. The

estimated reduction in energy consumption, the operation of efficient heating and cooling equipment, solar pre-heated water and efficient appliances is sufficient to match the roof area needed to offset the purchased utility supply on an annual basis. The annual solar resource is significant to provide about five sun-hours per day of actual PV supply to the house/utility. With this resource and the efficient design as well as the homeowner understanding of their role in energy consumption, the goal of a ZEH home has been successfully achieved – enough so that the builder can offer this as an option – along with granite counter tops.

Utility Bill Analysis

Beyond the Project Closeout criteria, one additional analysis of the Project Closeout is an optional utility bill analysis. In 2004, John Wesley Miller Companies began work with Global Professional Services, Inc to analyze the energy use at Armory Park del Sol on an annual basis. In 2006, John Wesley Miller Companies expanded the analysis to include community water use. From the electric and water analysis results, conclusions have been disseminated in reports and presentations since 2005 with results available from as early as August 2003[6]. This analysis was sponsored by John Wesley Miller Companies, as were all reports of this period. Appendix C has additional detail on the previous energy and water studies by Global Professional Services.

Utility Bill Data and Calculations

Because of this prior utility data analysis, the NAHB Research Center collaborated with Global Professional Services (GPS), Inc. to continue the utility data collection and analysis. Homeowner participation in the John Wesley Miller Companies energy and water analysis has been via voluntary releases by homeowners to GPS, Inc. (and previously Al Nichols Engineering, Inc.) for a period of five years. The current period required time investment to renew releases that were expired. GPS then contacted the electric utility Tucson Electric Power (TEP) to collect and enter data into a database for the NAHB Research Center. The electric data includes monthly electric use, time-of-use data (as available) and current TEP rate plans to identify potential time-of-use data. Appendix C has additional information on the energy and water data collection as well as the previous energy and water studies by Global Professional Services.

The releases gathered for Armory Park del Sol included a total of 55 of the Armory Park del Sol homes with data ranging from 2003 to 2009. Due to the past studies by Global Professional Services, Inc, 11 of the homes have had releases and include complete years of data beginning in January 2004 through December 2008. The data from Tucson Electric Power (TEP), the local utility, included monthly utility electric use and electric cost data for each home. All of the raw data is shown in Figure 11. Note that this electric use data is the utility electric use purchased by the homeowner—meaning that it is the homeowner usage minus the PV production from the solar electric systems that is standard on each of the Armory Park del Sol homes. TEP offers homeowners a time-of-use rate or a flat utility rate with or without net-metering. A time-of-use rate with net-metering is not currently offered by the utility. Therefore, for homeowners on the time-of-use rate, some of the PV is not accounted for on their utility bill when the PV production is more than the house consumption.

[6] Al Nichols Engineering & Global Professional Services, Inc., *Energy Performance of Armory Park del Sol Homes by John Wesley Miller Companies February 2004-January 2005*, 2005

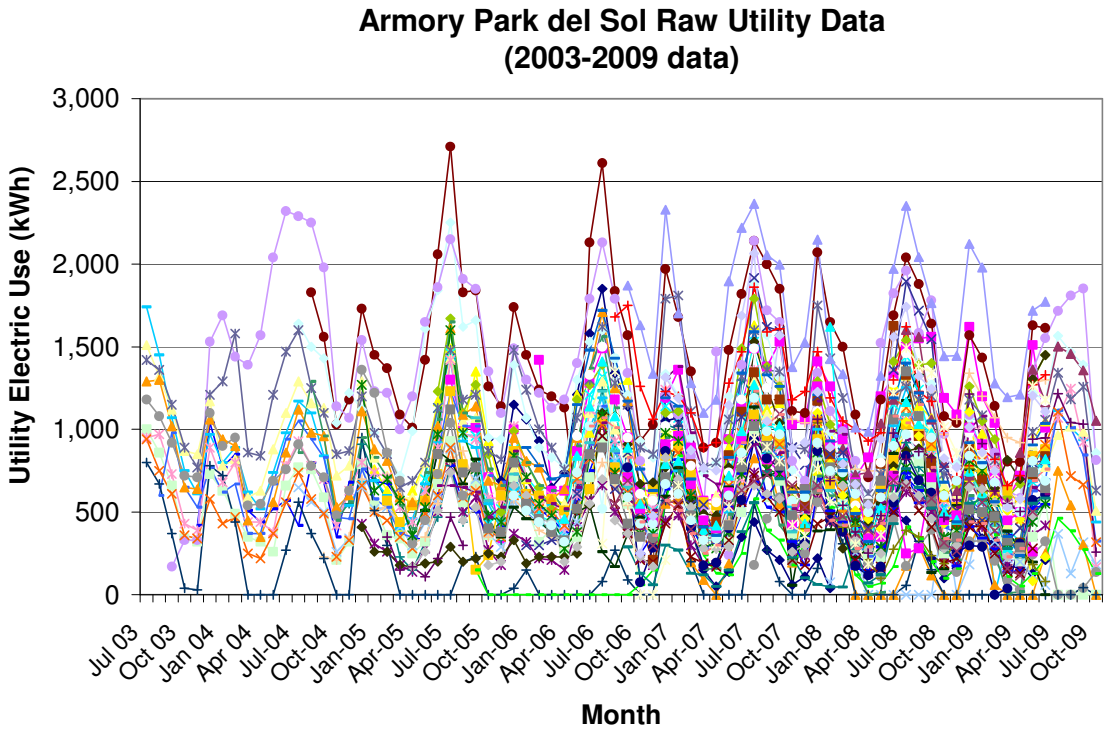


Figure 11. APdS Raw Electric Data

This utility bill analysis is focused on data for the two-year period from January 2007 through December 2008. While there are currently 87 homes built, there were only 83 homes built as of January 2007. Of the 55 homes, 7 houses were excluded from the data due to intermittent use and/or incomplete data from January 2007 through December 2008 for a total of 48 homes. The data points rejected are outlined below in Table 13.

Table 13. House Rejections by Cause for Rejection

Reason for Data Rejection	Number of Houses Rejected
	APdS
Mild Outliers – high users	0
Mild Outliers – low users	0
Intermittent Users	7
Homes with Pools	0
Homes with Spas	0
Homes with both a Pool & a Spa	0

The next step of the analysis is to characterize the site by graphing the annual utility electric energy use depicting the ranges of energy consumption at Armory Park del Sol. Since the Tucson Electric Power (TEP) electric bills do not report the PV production separately, the graph in Figure 12 shows the utility electric use. The x-axis is an assigned house number from highest electric use to lowest electric use in 2008. In addition to the annual total electric energy use, another way to look at the utility data is the frequency of the electrical energy use. Looking at the most recent data in 2008, Figure 13 shows the frequency distribution of the number of homes in bins of Electric Use for the utility electric use of the house.

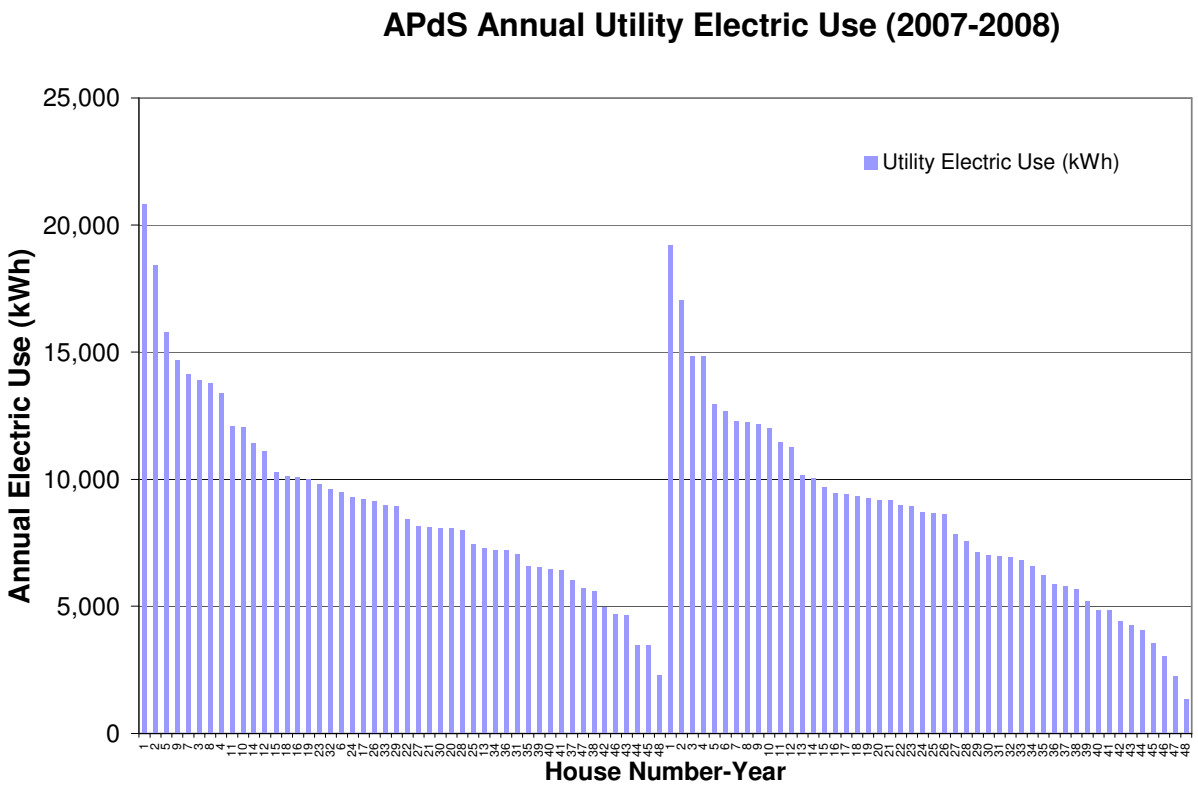


Figure 12. APdS Annual Utility Electric Use (2007-2008)

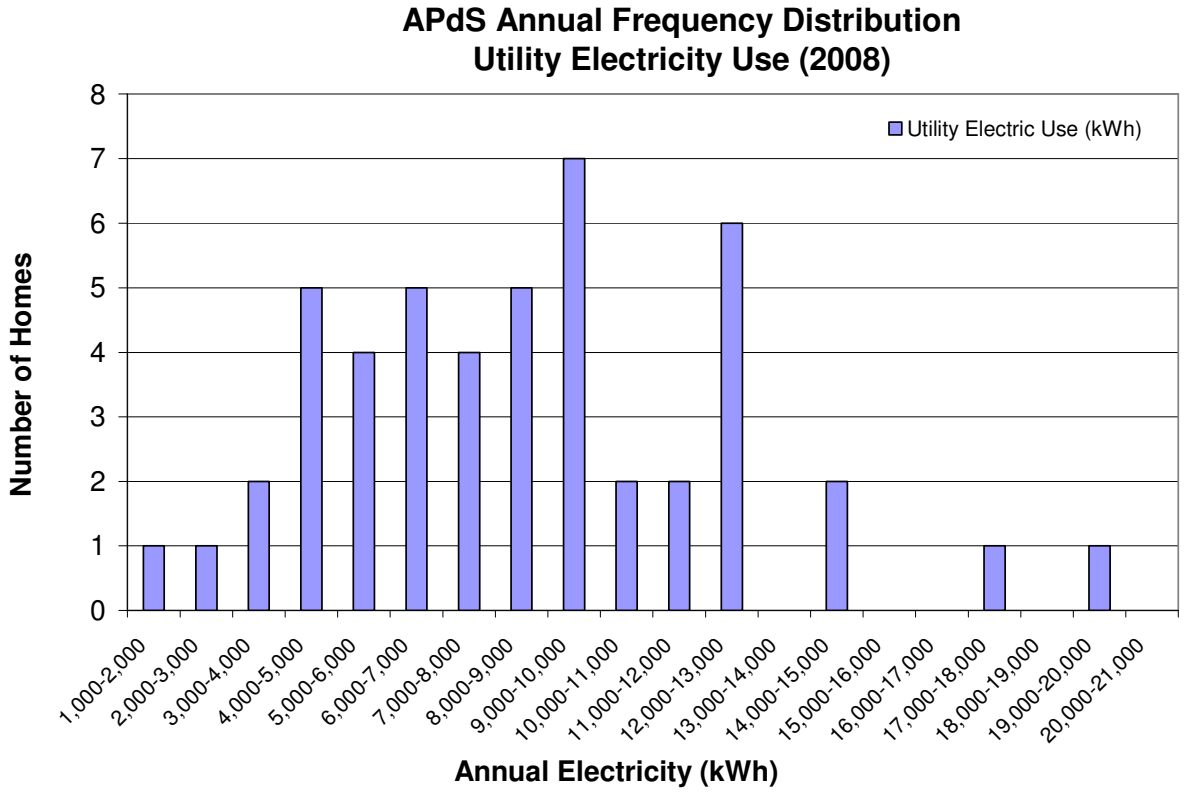


Figure 13. APdS Annual Utility Electrical Use Frequency Distribution (2008)

The sample size for the annual utility electric use of the homes at Armory Park del Sol addresses the required minimum sample size at a 90% confidence level. Based on the Building America Project Closeout specifications, a community with 50% expected energy savings must have a coefficient of variance higher than 40%. As shown in Table 14 and Table 15, the coefficient of variance exceeds this criterion making it a valid utility data analysis.

Table 14. Averages & Statistics for APdS Annual Site Utility Electric Use

	Annual Site Utility Electric Use (kWh)
Minimum	1,372
Mean	8,853
Median	8,690
Maximum	20,843
Standard Deviation	3,762
Coefficient of Variance	42%
Standard Deviation of Mean	3.3

Table 15. Averages & Statistics for APdS Annual Source Utility Electric Use

	Annual Source Utility Electric Use (MBtu)
Minimum	15.8
Mean	101.6
Median	99.8
Maximum	239.3
Standard Deviation	43.2
Coefficient of Variance	42%
Standard Deviation of Mean	0.04

Source Energy Savings

Following these initial analyses, the next step is to look at the Armory Park del Sol (APdS) community as a whole and to look at the energy savings compared with a base community as well as to the energy simulations. The first step is to look at the data for the whole site for the final data set of 48 homes from January 2007 through December 2008 as shown in Figure 14.

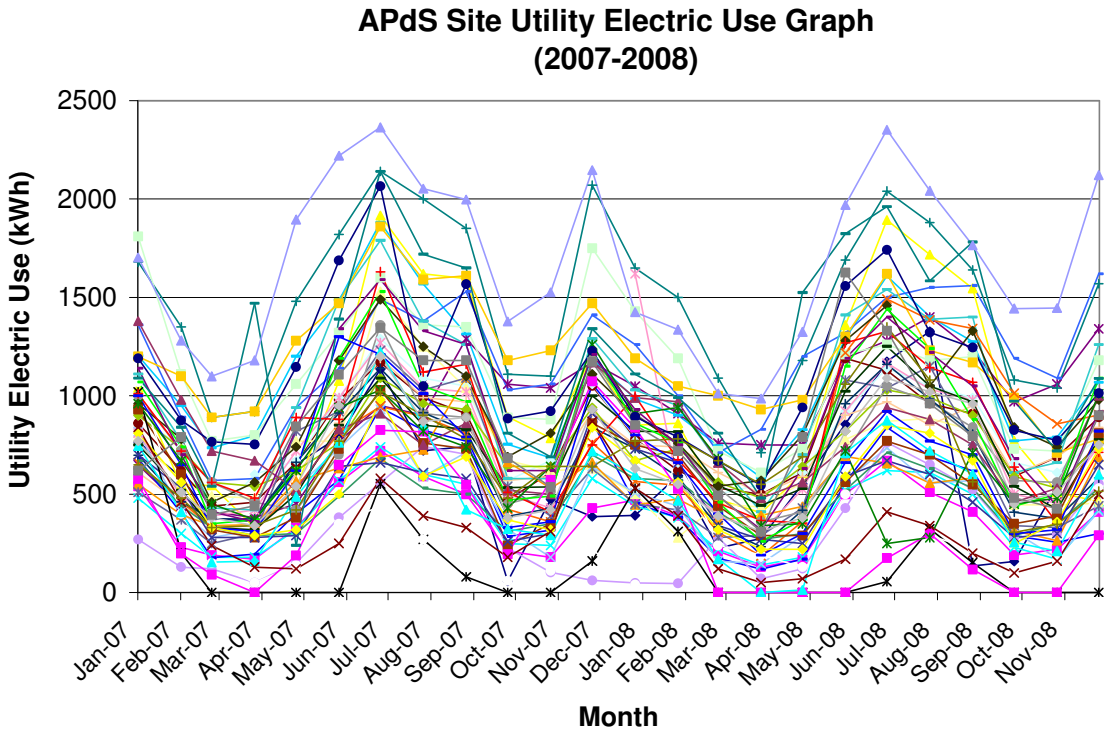


Figure 14. Monthly APdS Utility Data (2007-2008)

As previously noted, homeowners at APdS can choose from a time-of-use rate or from a flat utility rate with or without net-metering. For homeowners on the time-of-use rate, some of the PV is not accounted for on their utility bill if PV production exceeds the house consumption. However, given the smaller average size of the installed PV systems and that the thermal mass construction tends to shift the time of energy use, the time-of-use rate tends to be the lowest cost option for most homeowners at Armory Park del Sol. The flat utility rate with net-metering, however, should account for all of the PV produced as the homeowner is credited at the meter for the excess electricity produced. Net-metering is the lowest cost option for the ZEH home designs, which will see large monthly credits during parts of the year. In addition, monthly credits can be carried over from month to month with the net-metered flat rate. Of the 48 homes included in this utility bill analysis, Table 16 shows the number of homes currently enrolled in each utility rate.

Table 16. APdS TEP Utility Rate Choices

Description	APdS Homes (number)
Time-of-Use	33
Flat Rate w/ Net-Metering	12
Flat Rate (no net-metering)	3
Total	**48**

While looking at all of the monthly electric use data gives a picture of the range of data, another way to view similar information is by graphing the utility bill electricity use along with the home with the minimum annual energy use and the home with the maximum annual energy use. Note that the minimum and maximum were the homes with the minimum and maximum average annual use and is the same house for all months not the minimum and maximum across all homes for each month. Because of the first net-zero energy home onsite, ZEH1, the average minimum utility energy use at Armory Park del Sol is only

305 kWh per month as detailed in Table 17 and Figure 15. Looking at the site energy use is similar to that of the source energy use at Armory Park del Sol because the site is all-electric as shown in Figure 15 and Figure 16. As a result, the source energy savings and the site energy savings are the same at APdS.

Table 17. APdS Monthly Utility Electric Use Summary (48 Homes)

	Minimum House Utility Electric Use	Average APdS Utility Electric Use	Maximum House Utility Electric Use
	(kWh)	(kWh)	(kWh)
Jan-07	1,020	907	1,703
Feb-07	200	616	1,281
Mar-07	0	417	1,099
Apr-07	0	427	1,180
May-07	0	624	1,896
Jun-07	0	927	2,220
Jul-07	552	1,232	2,364
Aug-07	270	994	2,053
Sep-07	80	964	1,997
Oct-07	0	529	1,377
Nov-07	0	549	1,526
Dec-07	160	974	2,147
Jan-08	530	794	1,425
Feb-08	310	694	1,336
Mar-08	0	471	1,012
Apr-08	0	370	986
May-08	0	518	1,325
Jun-08	0	936	1,970
Jul-08	56	1,105	2,352
Aug-08	324	985	2,043
Sep-08	152	870	1,765
Oct-08	0	522	1,443
Nov-08	0	500	1,446
Dec-08	0	803	2,122
2 Year Total	**3,654**	**17,727**	**40,068**
2007 Total	**2,282**	**9,160**	**20,843**
2008Total	**1,372**	**8,567**	**19,225**
Average/month	**152**	**739**	**1670**

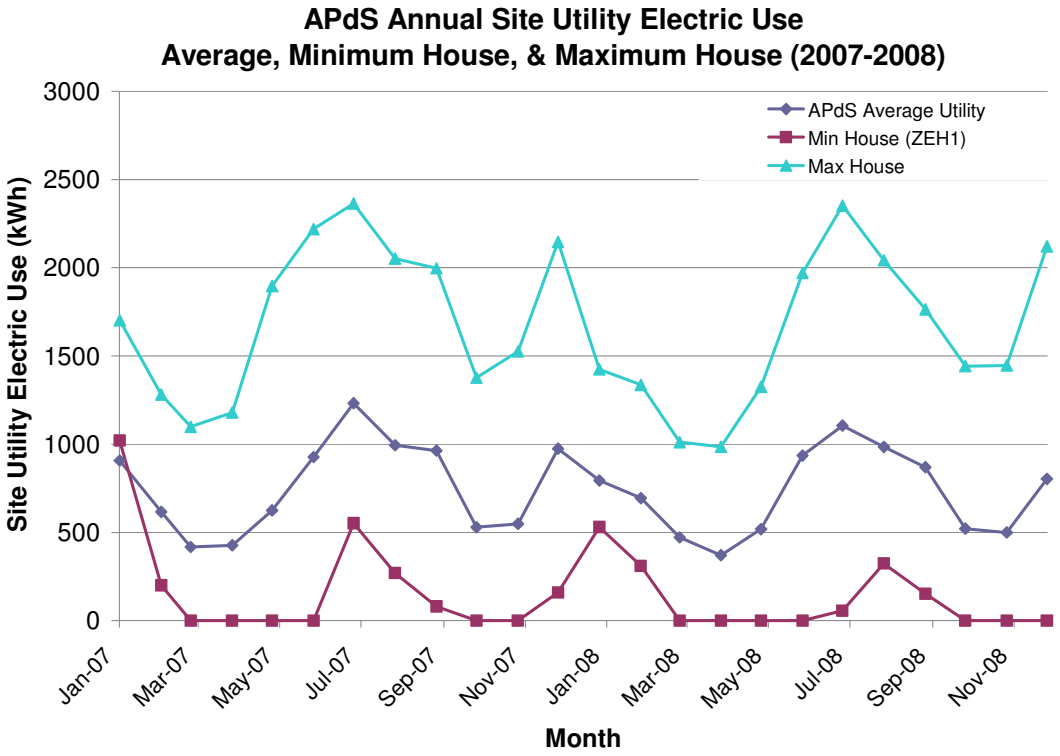


Figure 15. APdS Site Utility Electric Use Summary

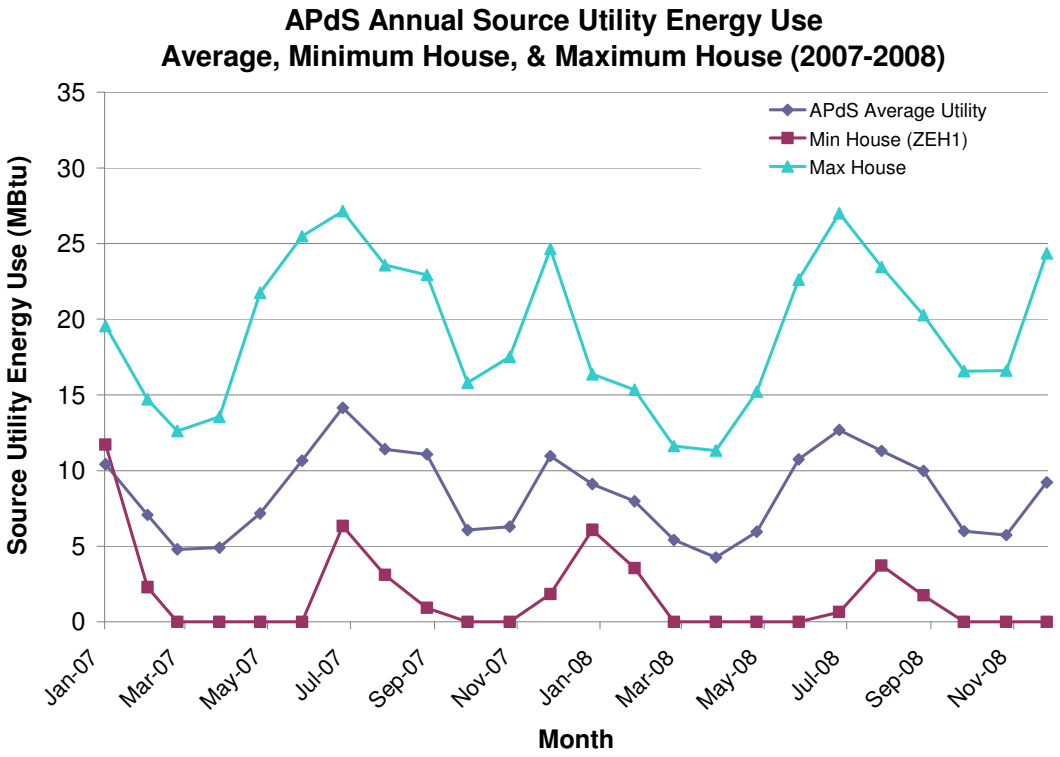
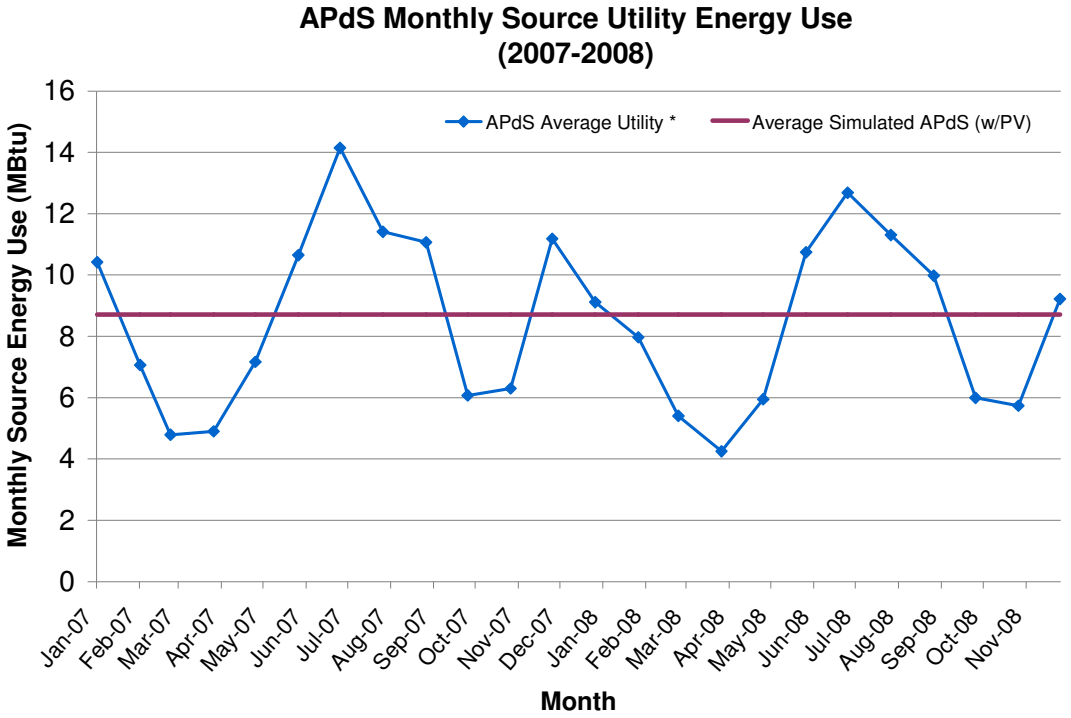


Figure 16. APdS Source Utility Energy Use Summary

Following the site and source utility energy comparison, the next step is to look at the APdS source energy use compared to the estimated average APdS source energy use from energy simulations with PV production as detailed in Table 18 and Figure 17. Both detail the source utility energy use data compared with the energy simulations including PV production. Note that the average monthly source energy from the utility bill data is 8.47 MBtu/month and the average source energy use estimate from energy simulations is 8.71 MBtu/month. Also, note that the electric use data from the utility bills is the homeowner usage minus any PV production supplied to the house that is standard on each of the Armory Park del Sol homes. For homeowners on the time-of-use rate (instead of the flat utility rate with net-metering), some of the PV is not accounted for on their utility bill when they produce more than they consume.

Table 18. APdS Average Energy Use Comparison of Utility Bills and Energy Simulation Results

	Average APdS Utility Energy Use	Estimated Average APdS Utility Energy Use (w/PV)
	(MBtu)	(MBtu)
Jan-07	10.42	8.71
Feb-07	7.07	8.71
Mar-07	4.79	8.71
Apr-07	4.90	8.71
May-07	7.17	8.71
Jun-07	10.65	8.71
Jul-07	14.15	8.71
Aug-07	11.41	8.71
Sep-07	11.07	8.71
Oct-07	6.07	8.71
Nov-07	6.30	8.71
Dec-07	11.19	8.71
Jan-08	9.11	8.71
Feb-08	7.97	8.71
Mar-08	5.41	8.71
Apr-08	4.25	8.71
May-08	5.95	8.71
Jun-08	10.74	8.71
Jul-08	12.68	8.71
Aug-08	11.31	8.71
Sep-08	9.98	8.71
Oct-08	5.99	8.71
Nov-08	5.74	8.71
Dec-08	9.22	8.71
2 Year Total	**204**	**209**
2007 Total	**105**	**104**
2008Total	**98**	**104**
Average/month	**8.48**	**8.71**

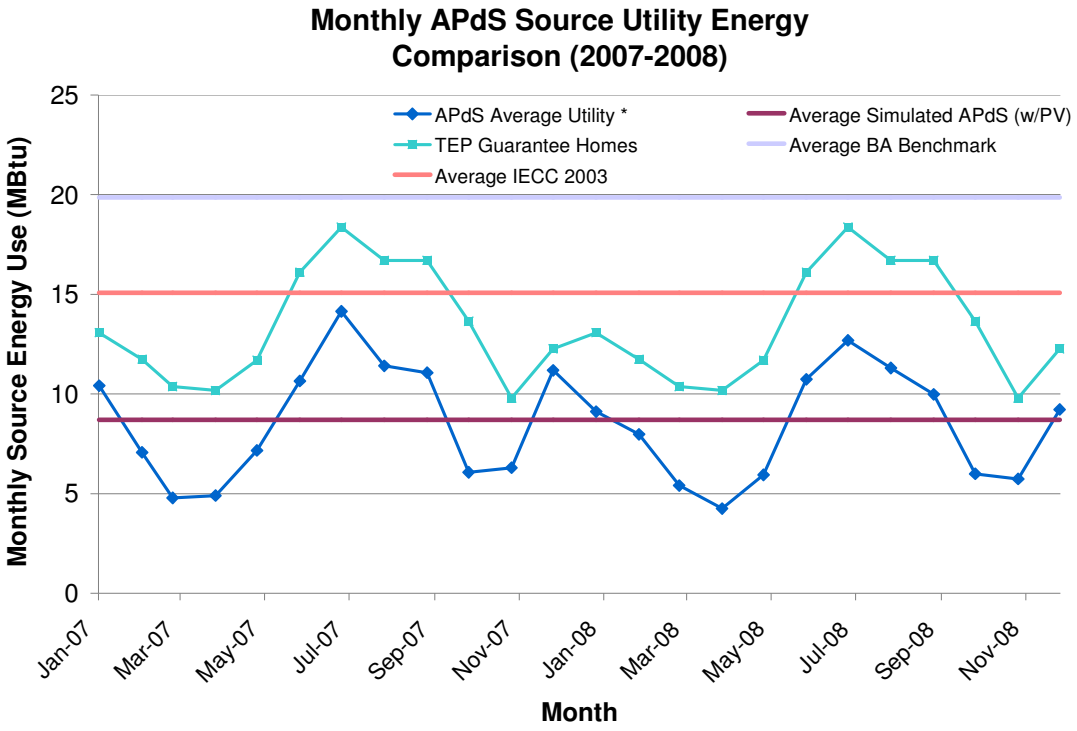


** APdS source energy is the utility electrical use from utility bills including the reduction from PV production*

Figure 17. APdS Monthly Source Energy Use

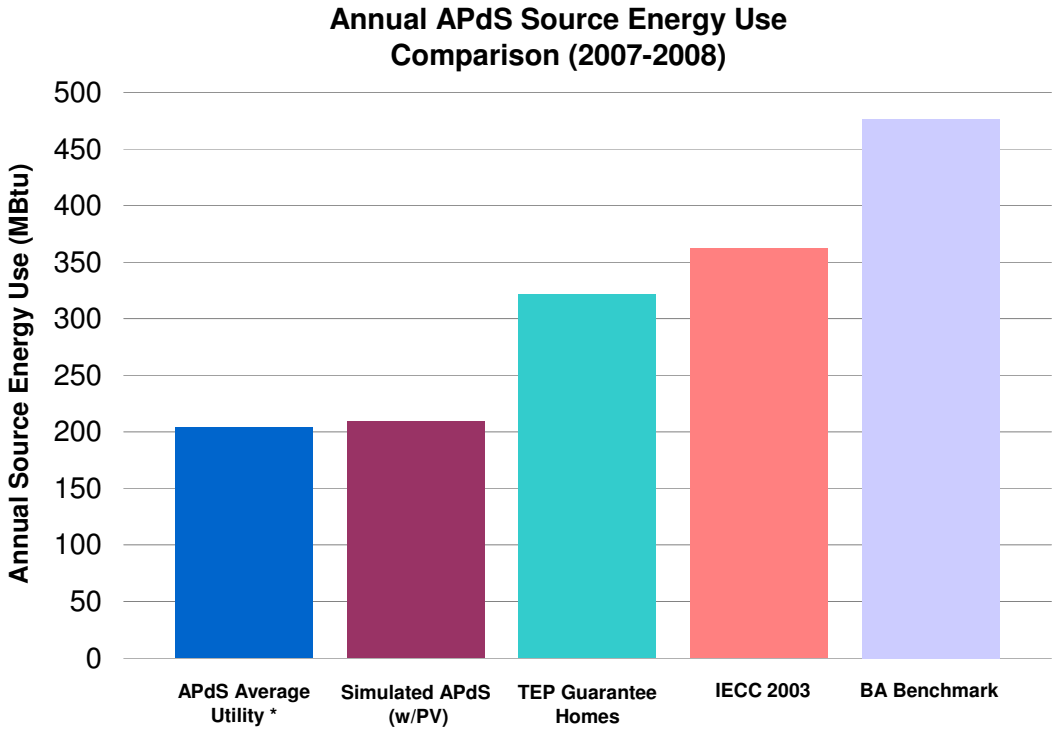
Another monthly source energy comparison includes the source utility energy savings as shown in Figure 18 and Figure 19. This comparison includes the source utility energy use from the utility bills and the average monthly estimated utility energy use from energy simulations included in Figure 17. For comparison, the graphs include the Building America Benchmark and the 2003 IECC average monthly source energy from energy simulations. In addition, another point of reference locally in Tucson, AZ is the Tucson Electric Power (TEP) Guarantee Home Program energy use. As part of a broader study, TEP performed a utility bill analysis across all of their homes in Tucson for one year[7]. Including this data gives an idea of the average utility energy use of a typical TEP Guarantee Home as a basis for looking at the utility energy use of the average Armory Park del Sol (APdS) home. Note that the APdS utility energy use and the simulated APdS home both include reductions in the energy use from PV production. However, the simulated APdS (w/PV) credits all of the PV production to the home as if net-metered, which is not the case with time-of-use rate homes. Figure 18 and Figure 19 depict these comparisons via a line graph comparison and a bar chart comparison.

[7] Enovity, Inc., *Residential Home Standards: Energy Analysis and DOE-2 Simulation Final Report.* Prepared for Tucson Electric Power Company. February 14th 2007.



** APdS source energy is the utility electrical use from utility bills including the reduction from PV production*

Figure 18. Monthly APdS Source Energy Use Comparison



** APdS source energy is the utility electrical use from utility bills including the reduction from PV production*

Figure 19. Annual APdS Source Energy Use Comparison

The final source energy comparison depicts the annual source energy savings. As detailed in the Source Energy Savings section and shown in Figure 20, the site source energy savings with reductions from PV production is 56% over the Building America Benchmark. The savings of the typical Tucson, AZ TEP Guarantee Home over the Building America Benchmark is 33%. The energy savings of the annual average utility bill energy use over the BA Benchmark is conservative as there is some PV production not accounted for in the utility bills for homes on a time-of-use rate when they produce more PV than they consume.

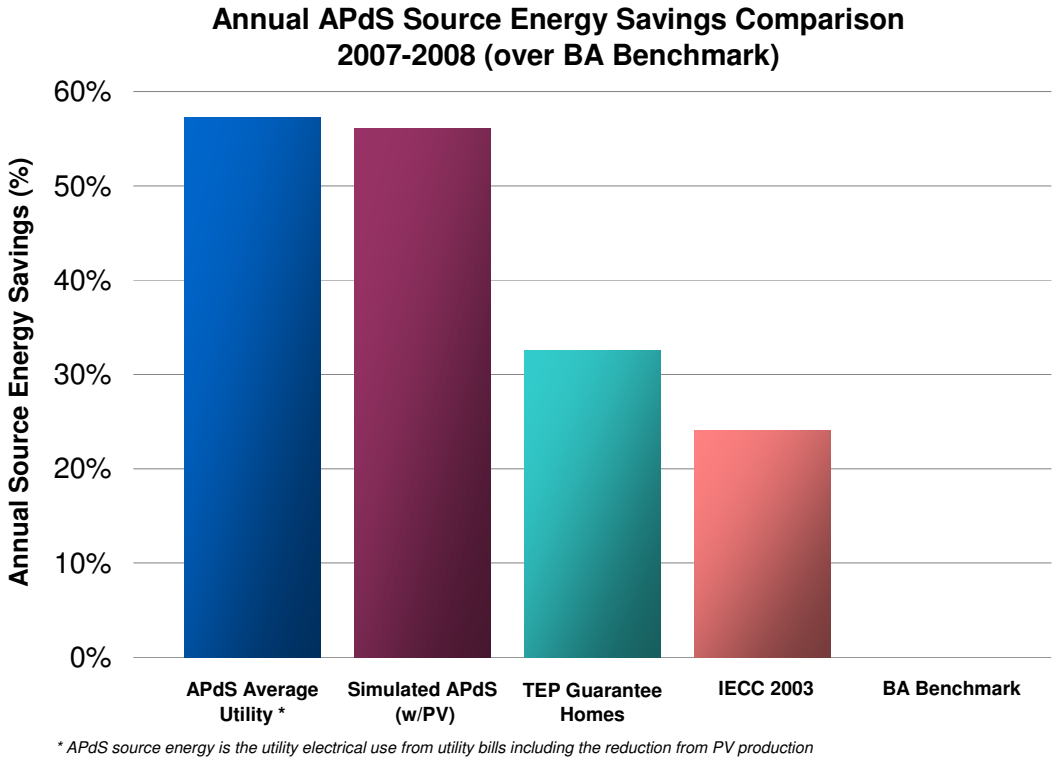


Figure 20. APdS Total Source Energy Savings

Energy Costs Savings

A parallel analysis to the site use and source energy utility bill analysis of APdS is the energy cost analysis. The analysis for the energy cost savings results was similar to the energy analysis. The data was processed the same and there were the same number of homes, 48. To ensure a 90% confidence level, the coefficient of variance was calculated for the energy costs and per the Building America Project Closeout specifications; a community with 50% expected energy savings must have a Coefficient of Variance (CV) higher than 40%. For the cost savings, the CV is 39% as shown in Table 19. While this is below the 40% threshold, the utility source and site energy use CVs are both above 40 as detailed in Table 14 and Table 15.

Table 19. Averages & Statistics for APdS Energy Costs

	Annual Energy Costs ($)
Minimum	$199
Mean	$750

	Annual Energy Costs
	($)
Median	$705
Maximum	$1,815
Standard Deviation	294
Coefficient of Variance	39%
Standard Deviation of Mean	0.26

In addition, the minimum house, average APdS energy costs, and maximum utility energy costs from the collected Tucson Electric Power bills are shown in Table 20. Note that the minimum and maximum were the homes with the minimum and maximum average and is the same house for all months not the minimum and maximum across all homes for each month. Because of the first net-zero energy home onsite, ZEH1, the average minimum utility energy use at Armory Park del Sol is only $20 per month as shown in Table 20 and Figure 21.

Table 20. APdS Community Utility Electric Cost Summary

	Minimum House Utility Energy Cost	Average APdS Utility Energy Cost	Maximum House Utility Energy Cost
	($)	($)	($)
Jan-07	$95.26	$63.12	$127.95
Feb-07	$23.06	$44.56	$97.65
Mar-07	$5.30	$31.68	$84.57
Apr-07	$5.30	$33.97	$90.39
May-07	$5.30	$52.51	$161.85
Jun-07	$5.30	$94.99	$227.36
Jul-07	$61.31	$121.92	$243.22
Aug-07	$32.77	$101.32	$211.97
Sep-07	$13.43	$79.73	$173.75
Oct-07	$5.30	$45.72	$119.06
Nov-07	$5.30	$39.84	$117.58
Dec-07	$19.51	$63.36	$159.81
Jan-08	$52.22	$53.56	$107.97
Feb-08	$32.81	$48.73	$101.58
Mar-08	$5.30	$34.58	$78.32
Apr-08	$5.30	$28.72	$76.45
May-08	$5.30	$43.27	$114.33
Jun-08	$5.30	$95.06	$202.95
Jul-08	$11.26	$111.76	$243.78
Aug-08	$39.71	$101.27	$212.81
Sep-08	$21.45	$72.55	$155.84
Oct-08	$5.30	$46.12	$126.33
Nov-08	$7.59	$38.22	$114.81
Dec-08	$7.59	$55.21	$154.94
2 Year Total	**$476**	**$1,502**	**$3,505**
2007 Total	**$277**	**$773**	**$1,815**
2008Total	**$199**	**$729**	**$1,690**
Average/month	**$19.84**	**$62.57**	**$146.05**

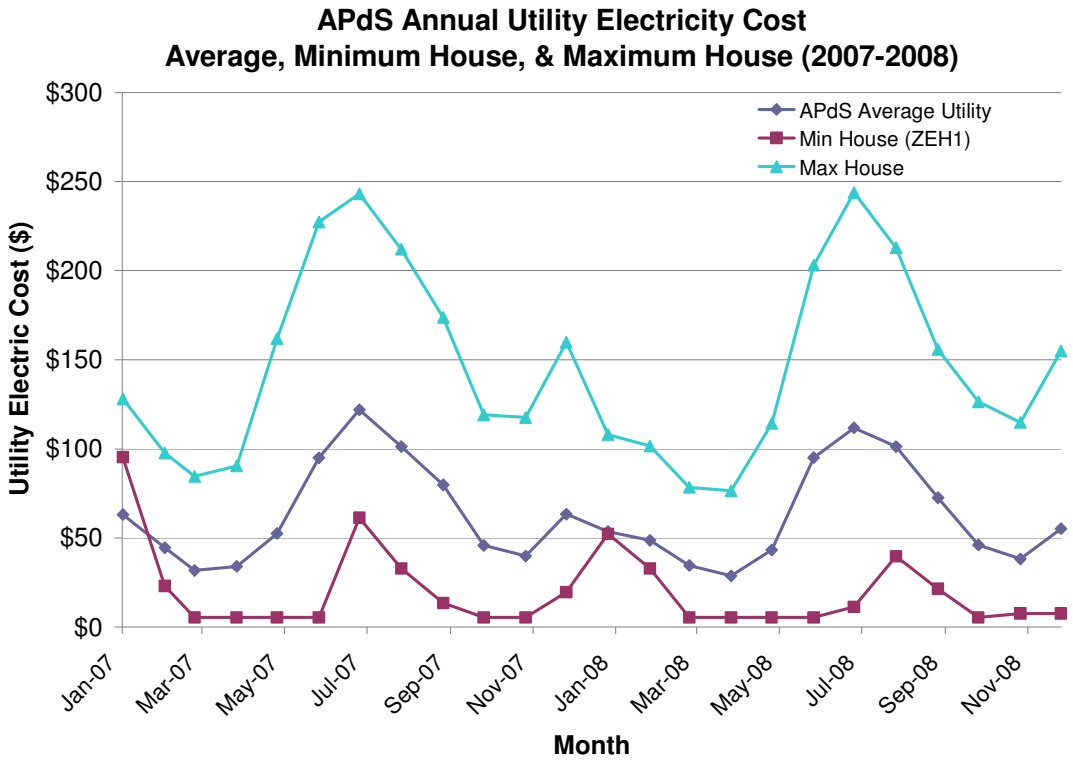
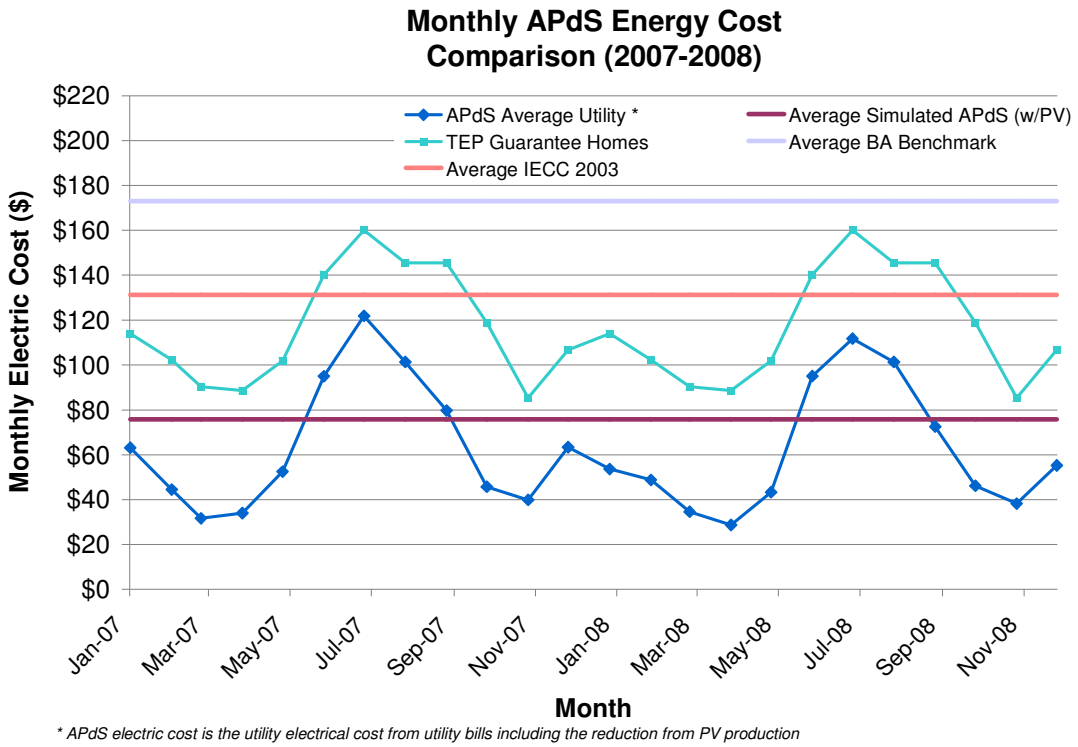


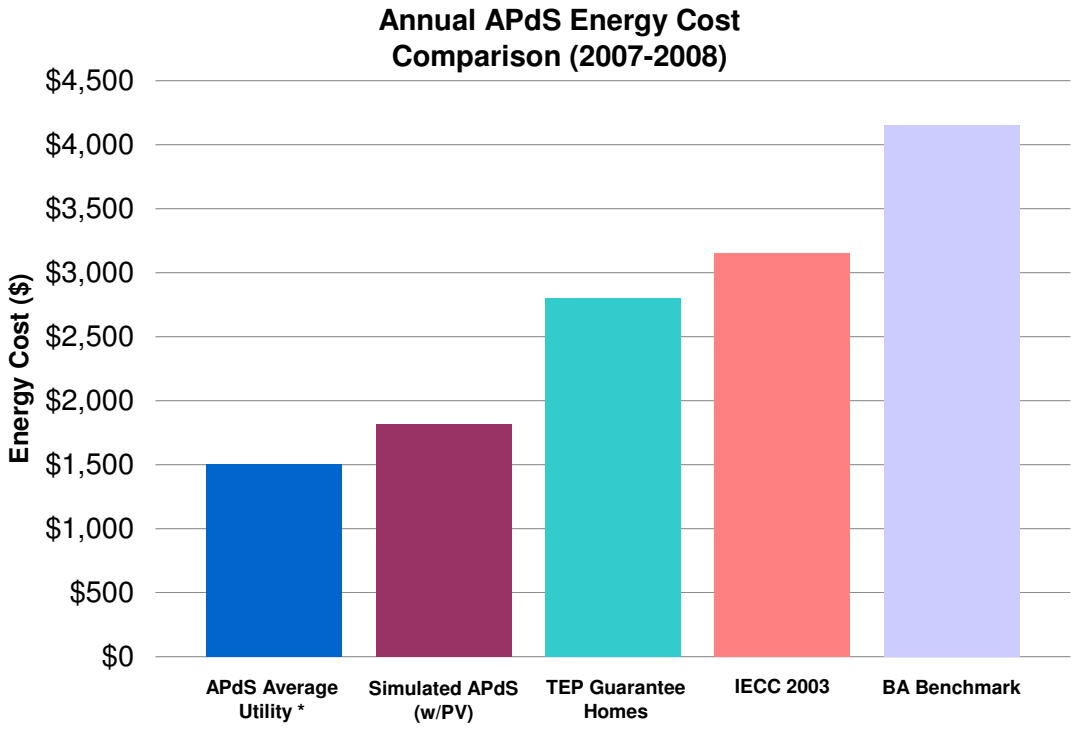
Figure 21. APdS Site Utility Electric Cost Summary

The energy cost analysis included a comparison of the utility electric cost from the utility bill data with the estimated average monthly energy costs using energy simulations including PV. This is also compared with the Tucson, AZ TEP Guarantee Home program average usage. As additional points of reference, the Building America Benchmark and the 2003 IECC average monthly energy cost from energy simulations is included as well. Figure 22 and Figure 23 depict the comparison via a line graph comparison and a bar chart. The results of these comparisons are very similar to that of the source energy analysis. The final energy cost comparison depicts the annual energy cost savings over the BA Benchmark as shown in Figure 24. The energy cost savings of the utility bill energy use over the BA Benchmark is conservative as there is some PV production not accounted for in the utility bills for homes on a time-of-use rate when they produce more PV than they consume.



** APdS electric cost is the utility electrical cost from utility bills including the reduction from PV production*

Figure 22. Monthly APdS Electric Costs



** APdS electric cost is the utility electrical cost from utility bills including the reduction from PV production*

Figure 23. Annual APdS Electric Cost Comparison

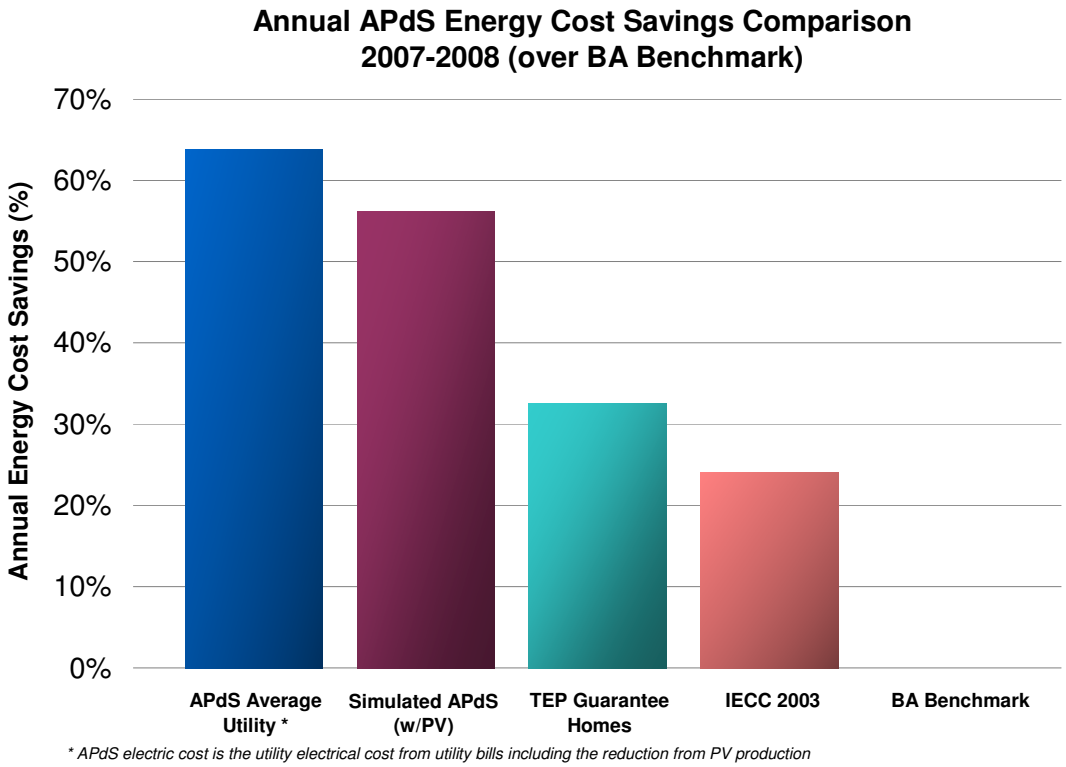


Figure 24. Annual APdS Electric Cost Savings

In addition to simply looking at the costs, one unique aspect of this community is that Tucson Electric Power offers a reduced time-of-use (TOU) rate to the homeowners at Armory Park del Sol (APdS). As detailed in the cost neutral analysis section, because the APdS homes are all-electric and are part of Tucson Electric Power's (TEP's) Guarantee Home program, and because they include solar thermal systems they are eligible for these preferential electric rates. Customers can choose their preferred electric rate including the reduced time-of-use rate. Of the 48 homes used in the utility bill analysis, 33 of these use the preferential TOU rate, 12 use the flat utility rate with net-metering, and 3 use the flat rate with no net-metering as shown above in Table 16. Of the 33 on the time-of-use rate, 19 homes had complete data for 2008.

While the monthly utility energy data included energy use and energy cost, the time-of-use (TOU) data included was the energy use only (kWh) for on-peak, shoulder, and off-peak time periods. Therefore, the first step of the analysis was to estimate the energy costs using TEP's 2007-2008 utility rate structure shown in Table 21 in conjunction with the TOU energy use data. The next step was then to compare the estimated energy cost from the TOU energy data with the actual monthly energy costs from TEP as shown in Figure 25.

Table 21. TEP's R-201C Time-Of-Use (TOU) Rate (2007-2008)

	Mid Summer (Jun-Aug)	Summer (May, Sep-Oct)	Winter (Nov-Apr
Monthly ($/month)	$6.78	$6.78	$6.78
On Peak ($/kWh)	$0.184	$0.137	$0.094
Shoulder ($/kWh)	$0.116	$0.087	$0.000
Off Peak ($/kWh)	$0.058	$0.043	$0.032

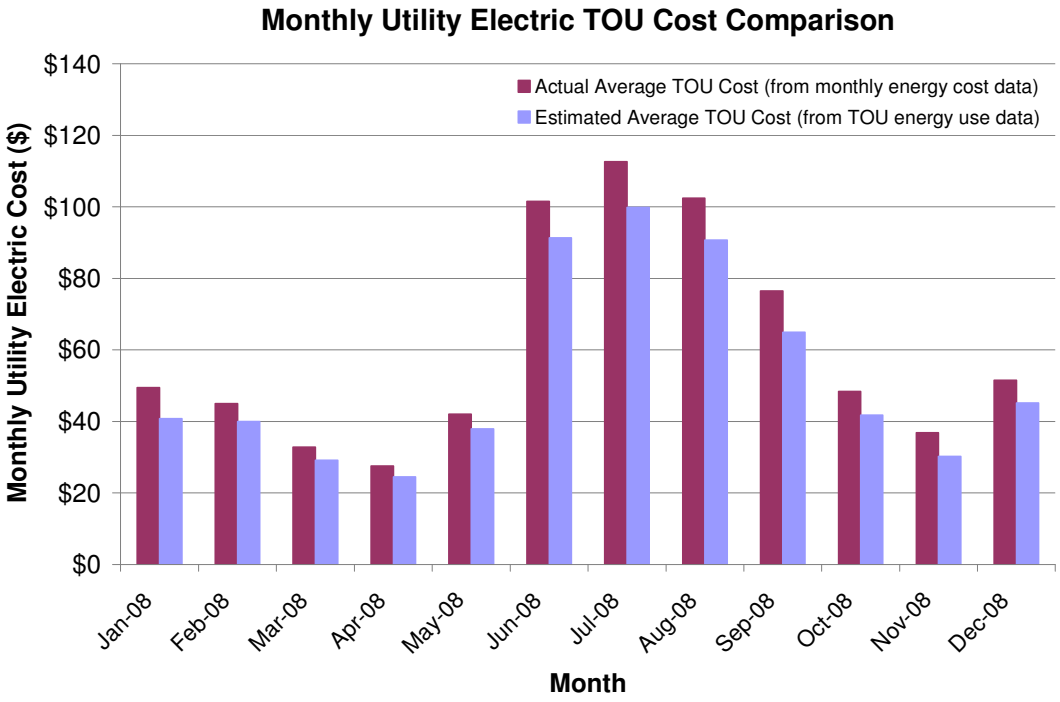


Figure 25. APdS TOU Monthly Utility Electric Cost Comparison

The variation of the estimated average monthly utility bill cost (based on the TOU energy use data) from the actual average utility bill cost (based on the energy cost utility data) shows that the data is not exact. The estimated average monthly utility bill cost varied from $3.08 to $12.75 under the actual average monthly utility bill cost. Because of the variation in the data, the analysis of the TOU data was not extensive.

The other analysis included in this comparison was to take the estimated average monthly utility bill cost based on the TOU energy use data and calculate what the average monthly cost would be using a flat utility rate as detailed in Table 22. The goal of this comparison is to determine, in general, which rate would be more cost effective for an Armory Park del Sol homeowner. The result of the comparison is that when comparing the estimated TOU rate utility electric cost with the estimated flat rate cost, the TOU rate utility electric costs are lower. To demonstrate this result, an example of a typical APdS home comparison is detailed in Figure 26 and Figure 27. It is worth noting that the flat rate with net-metering will be more cost effective for the two net-zero energy homes, however, due to their design with upgraded envelopes, systems, and increased PV production.

Table 22. TEP's R-01 Residential Rate (2007-2008)

	Summer (May-Oct)	Winter (Nov-Apr)
Monthly ($/month)	$4.90	$4.90
Rate ($/kWh)	$0.091	$0.079

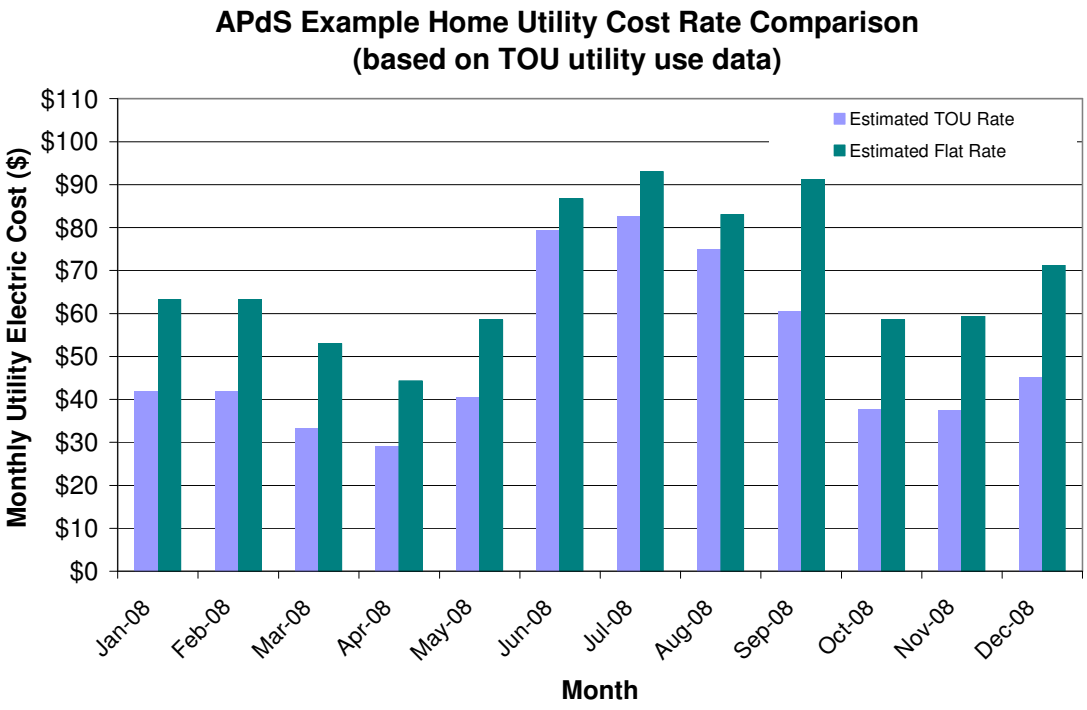


Figure 26. APdS Utility TOU & Flat Rate Energy Cost Comparison (bar chart)

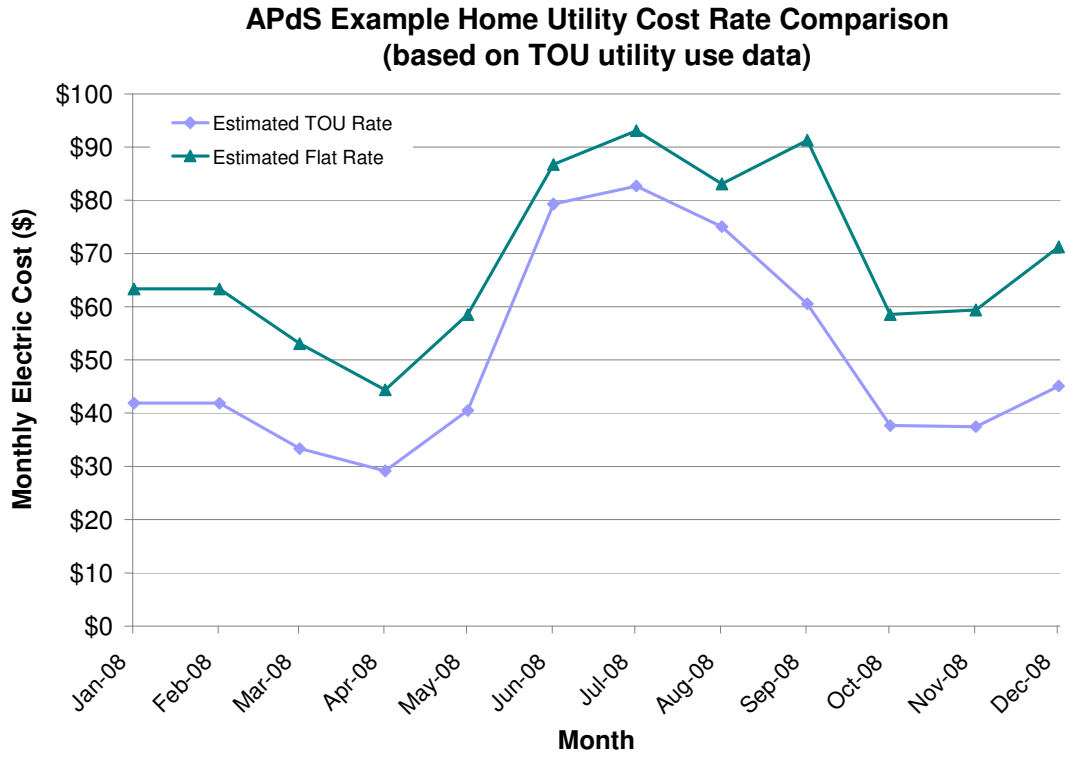


Figure 27. APdS Utility TOU & Flat Rate Energy Cost Comparison (line graph)

Performance Analysis—Water Savings

Water usage at APdS, according to a 2004 study by Global Professional Services, Inc., is reported to be 35% less than the average per-capita residential use in Tucson[8]. This reduced water consumption has a correlated impact on regional energy consumption (as does the reduced energy usage have a correlated impact on reduced water consumption by power plants). A 2005 Al Nichols Engineering, Inc., report further associates the reduced energy consumption of APdS homes (and hence reduced energy production needs of a power plant) with the reduction of 1,860 gallons of water per home per year.

Summary

The Armory Park del Sol development, nearly complete in its build-out, has been modeled to show energy savings of nearly 50% over the Building America Benchmark on average based on the energy efficiency features of the homes. Additional savings of almost 10% is added by the inclusion of the PV system supply to the house. The overall performance reflects a steady increase in efficiency over the past 9 years that the development has been under construction. The original Building America goals have increased from 30% to the current 50% energy savings over the BA benchmark, and the designs of the home in the development have kept pace with the BA joule target goals. Current home designs at build-out show a 50%+ energy savings before the PV systems are estimated, indicating that the development is a good example of the effort to work towards the net-zero energy home (ZEH) goal. To this end, two house designs in the development are full ZEH designs. The first ZEH has achieved about 85% energy savings, monitored over three years. The second ZEH is currently at a net surplus to the utility since it has been occupied in December 2008. In addition, utility bill analysis confirmed that the energy simulation estimations are very similar to the savings seen from the empirical analysis. Further analysis is being performed to better quantify the thermal mass performance of the homes.

[8] Al Nichols Engineering & Global Professional Services, Inc., *Water Use of Armory Park del Sol Homes by John Wesley Miller Companies*, 2004

Appendix A - Armory Park del Sol in the Media

John Wesley Miller Companies was in the press in a variety of ways highlighting Armory Park del Sol. These included the following:

Green Smart Market Report, titled The Green Homeowner: Remodeling and Buying Green Homes by McGraw-Hill Construction Analytics.

Armory Park del Sol has been named one of the country's **Top 10 Cottage Neighborhoods by Cottage Living Magazine**

Armory Park del Sol was named one of **Tucson's Best Places to Live, Arizona Foothills Magazine**.

John Wesley Miller Companies is profiled on Governor Janet Napolitano's **Innovation America Foundation website.**

Local television stations covered the **Grand Opening of our Second Generation Net Zero Energy Home** as well as newspapers such as The Arizona Daily Star, The Daily Territorial and Inside Tucson Business, and more...

On May 5th, Armory Park del Sol was featured in a **cover story in the Arizona Republic** on innovation in green building (please note, the pricing information in the article is incorrect).

Armory Park del Sol and Builder John Wesley Miller were featured in the Wall Street Journal! The original Wall Street Journal article was on the front page of the Marketplace section on Wednesday, February 21st. The story was reprinted on the cover page of the Real Estate section of The Arizona Republic on Saturday, March 24th with an extra side feature on Armory Park del Sol. To read the original Wall Street Journal article, click here.

If you didn't pick up a copy of **Tucson Weekly** (for the week of April 19th) and see the article "Environmental Actions" that featured Armory Park del Sol and John Wesley Miller, you can link to it here.

In April, John Wesley Miller was interviewed about how he utilizes solar power in his projects, including Armory Park del Sol on **KUAT TV's Arizona Illustrated**. See the segment here.

In April, Armory Park del Sol hosted a **Climate Change Round Table Discussion**, which was organized by Congressman Raul Grijalva. The event was covered by various media outlets, including an Arizona Republic article.

John Wesley Miller was interviewed for a **Tucson Weekly article titled, "Environmental Actions"** in April.

KUAT TV's Arizona Illustrated "Sun Power"

Wall Street Journal/Arizona Republic

Tucson Weekly "SOLAR STRIFE- The state is demanding more clean energy - but it will come at a price" By Dave Devine

Tucson Weekly Cover Feature "Residential Revolution"

KOLD Tucson News Channel 13

Solar Supporters Say the Time Is Now to Push for Renewable Energy . . .

Arizona Daily Star Feature "Lots of Positive Energy" By Gillian Drummond

ToolBase News Volume 10, Issue 3

Inside Tucson Business Feature Article

In Business- Cover Feature for the January/February 2005 Issue

Builder Magazine, *October 2003*

Terrain.org - A Journal of the Built and Natural Environments, "Armory Park del Sol", Summer/Fall 2003 (http://www.terrain.org/unsprawl/13/)

Discover Magazine - April 2003 "UNPLUGGED - Self-sustaining homes could mean the end of utility bills or even the end of utilities" By Manny Frishberg (http://discovermagazine.com/2003/apr/featunplug)

National Building News Online, "Tucson Zero Energy Home Sets the Stage for Further Research", July 28th, 2003

National Association of Home Builders, "Zero Energy Home - Tucson ZEH", Summer 2003

Professional Builder Magazine, "The Anatomy of Innovation", June 1, 2003 (http://www.housingzone.com/topics/pb/build/pb03fa022.asp)

Realty Times Financial Wire "Zero Energy Housing on the Horizon" by M. Anthony Carr - August, 2003

Tucson Home Magazine, "The Future Comes Home" Summer 2003, by Christina B. Farnsworth & Michael E. Nicksic

KTVK Channel 3 News AZ, "Zero Energy in Armory Park del Sol", airdate 5/21/02

KUAT Channel 6 News AZ, "Net Zero Energy Home in Armory Park del Sol", airdate 4/22/03

HGTV "Dream Builders" - Episode # 909 - aired March 30. 2003 Click Here...

Environmental Design & Construction, EDC Newsline "Arizona Community Showcases Green Building Concept" 7/08/2002 Learn More...

Juarez, Macario, Jr. "'Green' award goes to builder Miller." November 2002. Arizona Daily Star

"Tucson, Ariz., Selected as Test Site for Solar-Powered Homes", The Arizona Daily Star April 24, 2002

KTVK Channel 3 News AZ, "Zero Energy in Armory Park del Sol", airdate 5/21/02

Environmental Design & Construction, "Designing 21st Century Buildings: Integrating Efficiency and Renewables" By Mark Ginsberg 2/23/2001 (http://www.edcmag.com/Articles/Industry_News/641635f1c9697010VgnVCM100000f932a8c0)

Appendix B - John Wesley Miller Companies' Awards

John Wesley Miller Companies received numerous awards highlighting Armory Park del Sol. These included the following:

John Wesley Miller Companies has received recognition "for demonstrating leadership and commitment to residential energy efficiency" from the **U.S Department of Energy's Builders Challenge.**

John Wesley Miller Companies has been named **Southern Arizona Home Builders Association's 2007 Builder of the Year!**

John Wesley Miller Companies is a **2008 EnergyValue Housing Award** recipient, winning for its Net Zero Energy Home's "consistently good features."

John Wesley Miller Companies has received the 2007 AARP/NAHB Livable Communities Award!

And you may have seen us featured in AARP Magazine or on their website.

City of Tucson Mayor Bob Walkup's Certificate of Appreciation & Recognition was awarded to John Wesley Miller Companies in 2007 for "providing exceptional standard and optional accessible and visitable home construction features, and provisions for individuals with disabilities in our community."

Former Arizona Gov. Janet Napolitano presents John Wesley Miller with the Arizona Innovation Award

John Wesley Miller Companies has been awarded **Governor Janet Napolitano's Arizona Innovation Award**. Napolitano explained, *"This is a perfect example of the type of innovative work going on in Arizona. For years now John Wesley Miller and his company have been ahead of the curve in efforts to build green*"

In May, John Wesley Miller Companies was presented with the **2007 Tucson Pima Arts Award** for its "outstanding support of the arts".

John Wesley Miller named 2005 Faces of Conservation Award Winner for Livable Community by the Sonoran Institute

John Wesley Miller Companies named 2005 Energy Value Housing Award Winner by the Department of Energy, NAHB Research Center, and the National Renewable Energy Laboratory

John Wesley Miller named **"2002 Green Advocate for the Year"**, National Association of Home Builders

Appendix C - Global Professional Services, Inc. Energy & Water Data Summary

Summary Report by Global Professional Services, Inc
NAHB BA Program: Energy and Water Audit for APdS by John Wesley Miller Companies. 2009.
Cari Spring, PhD

Background

In 2004, John Wesley Miller (JWM) began hiring third party verification of energy use in his development by aggressively apportioning resources to contact homeowners to request voluntary participation. Releases were signed for five years, and in 2006 request for use of water data to audit water use was added. In 2007, a simple survey of the impact of urban living was added to the release.

The evolution of the process included the hiring of Global Professional Services (GPS), Inc a company with expertise based in quantitative and qualitative social and behavioral approaches, as the principle researcher and Al Nichols Engineering, the original auditor, came to provide a supporting role. (Al Nichols Engineering and GPS, Inc had collaborated to provide the City of Tucson's mandated energy and water audit of Civano since 2002.) As part of this evolution, GPS was hired to promote behavioral approaches to energy reduction as well as to audit the resource use and in this capacity administered an Energy Education Program to individual residents at the homeowner's request and personalized to their individual needs. This process initiated a face-to-face association with residents that lead to relationships between stakeholders as a benefit to the residents, rather than simply taking data from them.

The audits at this time took account of total energy (and, once added, water) use of the development, and one series studied time-of-use data for one rate plan (Tucson Electric Power's R-201C). At that time, the audit was structured to be evaluated relative to the then-available Sustainable Energy Standard (SES; below) of Tucson, Arizona. The issue involved with all audits through 2008 was that although total use was available through collection of data through the utilities, there was no metric by which to identify hot water use as a separate load taken from the results of total electrical use. Hot water use was mandated in the SES to achieve 50% reductions over base-case assumptions on hot water use in Tucson. Heating and cooling energy were assumed through examination of seasonal variation of use above the plug load, with the actual evaluation metric following the local utility's (Tucson Electric Power, TEP's) algorithm: the base case was assumed to be the mean of the lowest two consecutive months of energy use for any calendar year (March/April or October/November) with heating and cooling energy subtracted from base use.

Source energy in British Thermal Units (Btu) for electrical energy used in the home was computed as utility kilowatt-hours (kWh), multiplied by 3.4 (kBtu) per kWh , multiplied by 3.1 transmission and other production, conversion and transportation costs to result in a source energy use per square foot of housing. Multipliers used to determine source kBtu from point-of-use kWh were as prescribed in Tucson's Sustainable Energy Standard. That multiplier is 3.1.

The 1995 Tucson *Model Energy Code* (*MEC*) specified that the cooling and heating of homes would use approximately 36-54 kBtu/sq ft/year source energy (range depending on home square footage). The 1998 Sustainable Energy Standard (SES) proposed that heating, cooling and hot water energy use for homes built to its standard be half that of the MEC i.e. that the heating (space and water) and cooling of SES Compliant Homes would use 50% that of homes built to the MEC.

Table 1. Sustainable Energy Standard: Prescriptive Compliance Summary

Building	kBtu/sq. ft./year/home as source consumption in kBtu		
Sq. Ft. Range	Heating	Cooling	Total
<1000	5	22	27
1000-1399	4	18	22
1400-1799	4	16	20
1800-2199	4	15	19
>2199	4	14	18

The methods of analysis also did not allow for evaluation of the solar contribution so TEP's estimate for the production of a one-kilowatt (AC) PV system (as installed on houses at APdS) was used: 2,000 kWh's of electrical energy per year in Tucson is estimated to be provided by such systems. Of that total, TEP estimates the following percentages contributed by month:

Month	Percentage	
Jan	6.06	=121 kWh
Feb	8.19	=164 kWh
Mar	8.51	=170 kWh
Apr	8.86	=177 kWh
May	9.40	=188 kWh
Jun	8.61	=172 kWh
Jul	7.92	=158 kWh
Aug	8.86	=177 kWh
Sep	9.44	=189 kWh
Oct	9.13	=183 kWh
Nov	7.16	=143 kWh
Dec	7.43	=149 kWh
	100%	~2,000 kWh

Energy use evaluations for this period are available through John Wesley Miller Company's website, with all assumptions about demographics and data-use and elimination also available. This research was funded by John Wesley Miller Companies but was contracted to be independent third party evaluation. In sum, using the metric available, the development met the SES for all use within 10%. Hot water use was not evaluated separately but the solar thermal systems installed on all houses were taken as proof that substantial reductions in hot water use occurred.

To evaluate water use, no high performance standard of comparison was available so evaluation compared the local utility's assumptions about base use in Tucson. At this time, a problem with the utility's basis of comparison was identified: while residential water use was assumed from the direct residential use by the utility, Tucson Water Company, the problem was that their evaluation was dependent upon their own billing methods, which delineate residential water use as that from residences and commercial use allocated to non-residential use. Since Tucson's development pattern had shifted over the last decade to one in which most new homes were now located in developments AND many were multi-family developments, much of actual residential use was classified as commercial—since laundry, common area use, etc. could be allocated to the HOA of the unit—a commercial entity. The environmental advantage to this shift was that commercial water was code-compliant to use xeriscape and lower water-use landscaping.

Therefore, water use at APdS included evaluation of the HOA portion of the whole development to account for water billed commercially but used residentially. Results for these audits are also available through the website of the developer, John Wesley Miller Companies. Through-out, results were evaluated for reduced water, energy and coal use across the community and across multiple years to show the impact of collective action based in individual reductions. Emissions reductions were also scaled to the results of the collective across multiple years. During this time, 15 residents at APdS availed themselves of the individual Energy Education Program. During this time, exploratory evaluation of homes with an east-west axis, favoring a passive solar effect, were also evaluated and results disseminated.

All data collected and analyses made keep individuals confidential, and results have been supplied in public forums to inform multiple stakeholders in the Tucson community.

- Homeowners have been provided with a profile of their personal energy use, as compared to the mean of the group (provided in source kBtu/sqft) and have been consulted and advised on energy and water issues and strategies for reduced use while maintaining personal values and comfort.

- The builder/developer has been provided third-party evaluation of his intended results by comparing real energy and water use in his homes with the outcomes he sought; this process has continually informed the evolution of the development.
- The local electrical utility's (TEP's) Guarantee program for heating and cooling has been audited, and where applicable, problems reported.
- City of Tucson (CoT) Water Company has been informed of problems in their evaluation metrics on which year to year "residential" water use is reported by viewing the way their information and technology and billing practices categorize use that does not completely correspond to categories understood by the public.
- GPS Inc. has been privileged through the sponsorship of this work to be involved in the research of complex questions of local and national energy use and target reductions long before the market's inclusion of the early majority in what is emerging in the "going green" nomenclature.
- Overall, the case study of APdS has been effectively underwritten and supported by all stakeholders so its results can inform the future of an effective built-environment to meet the needs of a complicated network of intended outcomes requiring behavioral and technological change in the current resource, political, social, and environmental climate that is fast-changing.

It is because of the previous studies and prior involvement with APdS that GPS, Inc. was contracted by NAHB Research Center in mid-2009 to assist with the current APdS project. The overarching goal of this phase of the project has been to quantitatively test the energy simulations modeled by the Research Center in its September, 2009 report through real energy use in the homes. Some homes have now been participants in the series of audits with energy use data available from as early as 2003, providing for long-term data by which to measure energy use over time at APdS.

GPS, Inc. contributed on- and off-site data collection, recording, and collaboration with the NAHB Research Center BA team for the current study. GPS, Inc. was tasked generally to collect and record data for energy and water audit on APdS homes by supplementing past data with updated data (up to 10/2009). This work specifically involved:

- Collecting releases through face-to-face petition for permission from homeowners to use their energy/water data from Tucson Utilities;
- Updating demographic data for residents and residences as available;
- Updating Tucson Electric Power (TEP) utility rate plans for participants in the study;
- Liaison with Tucson Electric Power Company to receive monthly electrical use and billing data for APdS releases 1/2008-Present (6/2009) then time-of-use data for R-201C plans 1/2008 to present (10/2009);
- Liaison with City of Tucson Water Company to provide residential data for 1/2008-present (6/2009) and data for common meters of the HOA from 1/2008 to 10/2009;
- Entry of all data into Excel spreadsheet provided to the NAHB Research Center;
- Collaboration on evolving goals and methods throughout project;
- Collection of two general opinions about the housing/development, what owners like or don't like through door to door visits with APdS residents;
- Identification of APdS residents who will participate in a qualitative study in the future;
- Collection of contacts via electronic communications data (email and telephone) for APdS residents to streamline future studies;
- Face-to-fact communications with APdS residents to encourage stakeholder participation;
- Advise the Research Center on trends and patterns of possible interest in the data analysis and past analysis details; and
- Final report of results and process.

The overall goal of these tasks was to verify simulations modeled for the APdS development by earlier NAHB Research Center BA simulations on the models at APdS. The results also serve to verify from this current study whether earlier results reported accurately reflected real source and resource use and emissions.