Energy Use at Armory Park del Sol by John Wesley Miller Companies

In collaboration with Cari Spring, Ph.D. and Al Nichols, P.E.

Sustainability is our work in progress as building science matches high-efficiency homes with solar energy systems and with the use patterns of people living in these homes.

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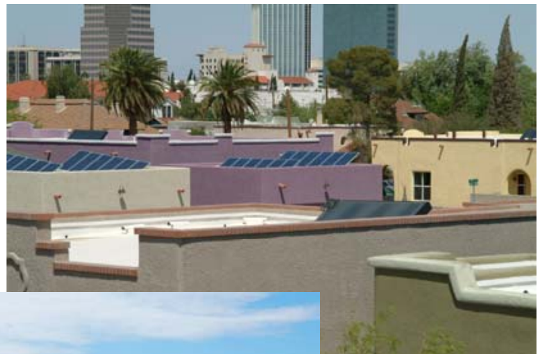


Contents

1. *Communicate, Collaborate, Cooperate = Creativity: The APdS Success*

The Armory Park del Sol process rests in a commitment to outstanding building design and construction through collaborative partnership and information sharing to achieve innovation and excellence. Evaluating outcomes through extensive communication between team members and stakeholders maximizes quality relations and evolves building science. Creativity, the ability to 'build outside the box', results from communication, collaboration and cooperation. This report documents the elements of energy efficiency and quality of life at Armory Park del Sol homes by John Wesley Miller Companies ("APdS" homes), showing benefits to residents, utility companies and environment. Its goal is to inform the Building and Construction Industry of the results: **$734**/yr total energy cost (**8,856** kWh total average energy use/year) and **$301**/yr for heating and cooling. Economic advantages, environmental gains and equity (culture) are thereby promoted. Analysis of energy performance of standard APdS homes is reported here based on three studies of utility data (July 2003-September 2006). Energy use by the first Zero Energy Home ("ZEH") is shown (**$10**/mo), with goals achieved from engineering with solar electric and solar thermal technologies.

Energy efficiency begins with site selection: The APdS Development utilizes a whole systems approach through development as urban in-fill, with its use of pre-existing energy and water-delivery infrastructure. Large-scale storm-water management reduces erosion to and pollution of local desert water ways. High-density, pedestrian-friendly development is placed in existing neighborhoods adjacent to Tucson's old downtown and its cultural attractions. Light-impact transportation is available and used: walking, biking and mass transit, with their economic and social advantages, come with this territory. (Transportation energy is Tucson's largest energy chunk, consuming 45% of Tucson's gross energy use.) The result? Energy, cost and time savings, and comfort and health.

Partnership between the APdS team and associates emphasizes knowledgeable people aware of interconnected issues and evolving outcomes. APdS partnerships engage in national collaboration for the best in Building Science: effective design and construction. APdS associates with HUD—Partnership for Advancing Technology in Housing (PATH); US Department of Energy (DOE), Building America Program; and the National Association of Home Builders—National Research Center. Information gathering and sharing is continuous, as is the evolving state of Building Science itself. In partnership with Tucson Electric Power ("TEP"), a time-of-use electric rate with a heating and cooling guarantee lowers both individual and collective energy use. Solar technologies used with superior building materials and methods save fossil-fuel energy and reduce emissions. Since water is needed to make electrical energy on the utility grid, water-use is lowered with energy use. The result is a lower cost—for residents and utility alike—to operate the home's energy systems. Impacts on environmental sources—land, water and air—are reduced with the energy bill, creating win situations all around. The result is increased standard of living for individuals in the company of sustaining community.

APdS stakeholder education is intensive and voluntary through literature, staff outreach and availability, and through an energy education program developed by APdS. **Information and evaluation** operates through vigorous data collection. Active APdS team and homeowner collaboration provides the energy use data to check results and change building methods when appropriate. Key fields of research have focused on energy, water and transportation. This report presents results of energy use.

But within this whole, Armory Park del Sol Homes by John Wesley Miller Companies provides high quality homes as the starting point.

2. Standard Features of Armory Park del Sol Homes by John Wesley Miller Companies

Standard Features of APdS Homes include

- **Wall construction:** Solid-core filled masonry units with exterior insulation;
- **Insulation: Wall** is R-12 rigid foam insulation; **Ceiling** is R-38 Fiberglass batt; **Foundation** is engineered slab with R-12 edge insulation;
- **Solar Energy Contribution:** Water Heating batch-type solar water heater with electric tank-less back-up and 1 kW AC (~1500 watts installed) photovoltaic ("PV") electric system with programmable thermostat. TEP estimates that a one kW AC PV system provides ~2,000 kWh of electrical energy per year in Tucson (167 kWh/month);
- **Windows:** Low-e, gas-filled windows, U-0.32, SHGO 0.30;
- **HVAC:**SEER 14 heat pump;
- **Ductwork:** All ducts sealed with mastic; 100% in conditioned space (pursuant to TEP rules, ducts in attics are not sealed);
- **Blower door test**: 2.9 ACH50; HERS Rating: 91.

3. Data, Energy Use and Energy Standards, Conversions and Resource Costs, Assumptions

Data. APdS homeowners provide residential energy use data through voluntary participation by giving written permission to collect data and analyze their energy use from utility data. At present, 62 homes have provided releases, with generally more data available as more homes are occupied for successive years. Since data collection began in July of 2003, some homes have sold with new occupants dropping out of the study, while other have joined; sample size across the years varies. As of September, 2006, 37 homes provided one year or more of energy data for the study. Data from approximately 50 homes will be available next year (the APdS development will have 93 homes at project build-out). The release provided by owners collects demographic data, including number of residents, house square footage, move-in date and utility rate selected. TEP records for the current study provide total kilowatt hours used, time-of-use data (On-peak, Off-peak and Shoulder) for the R201C rate plan—a time-of-use plan rewarding energy use at non-peak times—and billed amounts to residents. TEP standard rate structure provides cost/kilowatt hour. **All data here report on utility energy use and do not include contributions of solar electric/solar thermal in results reported.**

Energy Use and Standards. While a *sustainable* level of energy use is a moving target—controversial to standardize and difficult to evaluate—comparisons can be made on the basis of average energy use (by home, region, sector, etc.) and on the basis of target declines. Such comparisons hold in common that decreased energy use—across time period, home, sector, region—attains a more sustainable use level than energy use at the current or climbing levels. Technologies (e.g., Energy Star) and programs (e.g., the USGBC's Leadership in Energy and Environmental Design—"LEED") aim to attain set reductions. Tucson's 1995 *Model Energy Code* ("*MEC";* now adopted into the *IECC*) prescribed cooling/heating of homes in Tucson at 36-54 kBtu/sq ft/year 'source' (below) energy. The 1998 Sustainable Energy Standard ("SES") for Tucson proposed that heating, cooling and hot water energy use for homes built to a 'sustainable' standard be half the MEC, as shown in Table 1.

Building	kBtu/sq. ft./year/home as source consumption in kBtu		
Sq. Ft. Range	Heating	Cooling	Total
<1000	5	22	27 (MEC:54)
1000-1399	4	18	22 (MEC:44)
1400-1799	4	16	20 (MEC:40)
1800-2199	4	15	19 (MEC:38)
>2199	4	14	18 (MEC:36)

Table 1. Tucson's 1998 Sustainable Energy Standard—Prescriptive Compliance Summary. The SES evaluates *source energy* to determine compliance with target goals, specifying point-of-use electrical energy multiplied by 3.1 (for transmission and other production, conversion and transportation costs) as source electrical energy. **While the SES includes hot water in the calculation, hot water cannot be subtracted based on utility bill data.**

Conversions and Resource Costs: Source energy in British Thermal Units (Btu) for electrical energy use is computed here as utility kilowatt-hours ("kWh") at point of use (i.e., on the TEP bill), multiplied by 3.4 (Btu) multiplied by 3.1 (for source energy). In Tucson, approximately 2.3 pounds of CO_2 are released per kWh of electrical energy (charts appear in *Benchmarking Air Emissions of Electric Utility Generators in the United States*, National Resource Defense Council, 1996), and approximately 1 pound of coal and 0. 65 gallons of water are used per kWh of electricity.

Assumptions. "Plug" or "base" load is the estimated energy use of the home less heating and cooling costs. For the current study, base load was determined by following TEP's practice of taking the lowest average between the sets of months of March/April and October/November as base and subtracting this from all months to approximate the remaining energy as cooling and heating. For studies in previous years, the lowest month energy use was considered to be the base and was subtracted from all months to approximate heating and cooling energy. In fact, both cooling and heating can and does occur in Tucson in margin months like March/April and October/November. Additionally, use of solar hot water and photoelectric ("PV") complicates all assumptions about base energy use. Hot water cannot be isolated from plug loads using utility data to measure house energy performance. **In all, known utility data cannot isolate all factors in this complex of interrelating approximations. The current report supplies what is known based on available data.**

One lot had no reading reported by TEP for Jan 2006. The reading for February of 2006 was divided (both cost and kWh) between Jan/Feb 2006. A second lot had no reading for April 2006; therefore May of 2006 was split between May and April, 2006; this reading affected base use assumption since March/April is the base month for the current study.

Time of use data provided by TEP showed several examples where the On-peak, Off-peak and Shoulder calculations did not match total kWh reported. Typically, when such an error occurred, the data were off by 10 kWh, occasionally 20 kWh. In one case, 310 kWh were not accounted for by time-of-use data due to a broken meter (1,310 total kWh were claimed but 1,000 resulted by addition of On-peak, Shoulder and Off-peak numbers). The result is that time-of-use data do not total exactly with kWh reported.

Cost for cooling and heating energy is approximated by taking the percentage of cooling/heating energy as compared to total energy use and applying that ratio to the total cost of energy. In fact, because most homes in the sample (30/37) utilize the time-of-use plan (201C) and cool and heat at different times with On-peak/Shoulder/Off-peak energy, cost for heating and cooling is an approximation.

4. Three studies of APdS energy use: February 2004- September 2006

Results: Current sample compared with two previous studies

	10/'05-9/'06 homes	9/'04-8/'05 homes	2/'04-1/'05 homes
Sample size	37	23	16
Avg. sq feet	1,576	1,460	1,492
Total kWh/yr	8,856	9,456	9,920
Source kBtu/sf/yr	59	68	70
Total cost (yr/mo)	$734/$61	$777/65	$821/68
Base kWh/yr	5,991	*5,844	*6,132
Base kBtu/sf/yr	40	42	48
Total C/H kWh/yr	2,865	*3,612	*3,788
C/H kBtu/sf/yr	19	26	22
C/H Energy Cost (yr/mo)	$301/$25	*$295/$25	*257/$21

Table 2. The current year (column 2) is based on 37 samples and compares energy use—total, base and cooling and heating ("C/H")—with studies from previous years. Costs for total energy and cooling and heating energy are given, as is energy as source kBtu per square foot per year. 499 was the monthly base point of use kWh (analyzed from March/April 2006 data; compare this to 552 kWh for Oct/Nov 2005). Average number of people/home:1.66.

Discussion: In contrast to the national norm, energy use in the APdS sample is declining from 2004 to 2006. As compared with the Energy Information Administration (EIA) data for West Census Division (including thirteen states in the US west/Alaska/Hawaii; http://www.eia.doe.gov/emeu/reps/maps/us_census.html), the APdS home, with 30,217 kBtu point-of-use energy use, is less than half the regional average at 70,100 kBtu/home (http://www.eia.doe.gov/emeu/recs/recs2001_ce/ce1-12c_westregion2001.html). The APdS home achieved Tucson's 1998 Sustainable Energy Standard—setting sustainable level of energy use at ~20 source kBtu/sf/year for heating and cooling (40 source kBtu/sf/yr for heating and cooling is assumed to be the average; see section 3). Since energy use relies on raw sources, energy use reductions translate as avoided use of earth's water and land and avoided pollution to the air. Heating and cooling the APdS home used about half the coal, half the water to make energy, and produced as emissions just half the CO_2 associated with heating and cooling the average Tucson home. The collective result is big. Assuming that each house of the 93 at APdS saves about 2,865 pounds of coal per year (see section 3 for coal/energy ratio), since APdS uses half of the average Tucson house at 2,865 kilowatts (over homes built to the Tucson Standard MEC/IECC), the collective annual savings is about 133 tons (266,445 pounds) of coal—and the associated costs to mine and transport it—for all homes in the Community. Over a fifty year life, over 13 million pounds of coal will be avoided. Energy also takes water to make: annually some 1,860 gallons of water is saved on energy-production for heating and cooling the average APdS home. For all 93 homes, about 173,000 gallons will be saved annually; over a 50 year life cycle almost 10 million gallons will be avoided. Reduced CO_2 is about 3.3 tons (6,600 pounds) per home per year, collectively totaling more than half a million pounds each year for all homes together. Over 50 years, release of 30.6 million pounds of CO_2 will be avoided.

5. TEP Rate 201C—one year

Results

	TEP 201C Rate 10/’05-9/’06	10/’05-9/’06 homes
Sample Size	30	37
Avg. sq feet	1,544	1,576
Total kWh/yr	8,495	8,856
Source kBtu/sf/yr	58	59
Total cost (yr & mo)	\$685/\$57	\$734/\$61
Base kWh/yr	5,532	5,991
Base kBtu/sf/yr	38	40
Total cool/heat kWh/yr	2,963	2,865
C/H kBtu/sf/yr	20	19
C/H energy cost (yr/mo)	\$303/\$25	\$301/\$25

Table 3. Comparison of use and cost using TEP’s time-of-use rate is provided in column 2 and compared with the larger sample in column 3 (note 30/37 of the larger sample use the 201C rate). Average residents per home is 1.55 (compare 1.66). This sample shows that additional reductions occur beyond the APdS average when the homeowner selects the time-of-use plan. According to TEP data provided for the current study, 30 lots are associated with TEP Rate 201C for the year 10/’05 to 9/’06.

Discussion: The 201C rate uses one kBtu/sf more than the 37 home sample, but total use is down, and as base is computed, lower base energy use is down. Cost of energy is \$49/yr less than the 37 sample average.

6. APdS homes with east-west axis

Results

	Homes with east-west axis	10/05-9/06 homes
Sample Size	5	37
Avg. sq feet	1,389	1,576
Total kWh/yr	6,956	8,856
Source kBtu/sf/yr	53	59
Total cost/ yr & mo	\$599/\$50	\$734/\$61
Base kWh/yr	4,800	5,991
Base kBtu/sf/yr	36	40
Total cool/heat kWh/yr	2,156	2,865
C/H kBtu/sf/yr	16	19
Cooling/heating energy cost (yr/mo)	\$225/\$19	\$301/\$25

Table 4. The APdS house with an east-west axis maximizes cooling and heating efficiency. This small sample is interesting because it indicates a potential for additional energy and cost savings when passive solar orientation is utilized in design and

construction. Since the APdS Development aligns with east-west and north-south streets, few houses at APdS are aligned with passive solar orientation. (One lot had a large impact in a sample size of five because its energy use is exceedingly low while another's was high relative to the others.)

Discussion: This group performs better than the APdS average, saving both base energy (likely saving year-round lighting and base cooling) and space heating and cooling. For the five-home sample, the savings is about 1,900 point-of-use kWh/yr and about $135/yr--**comparable to the output of a one kW AC electrical PV system.** At APdS, two of four passive solar design basics (beyond the house orientation on the east-west axis) are included as standard features: use of thermal mass to store heat and coolth in the house and use of proper insulation to contain interior air temperature.

7. Time of Use Data at APdS

Results

1	2	3	4	5	6	7	8	9
	Avg. total kWh	**Avg. Bill**	**kWh ON-PK 1-6PM ($0.184)**	**kWh SH 6-8PM ($0.116)**	**kWh OFF-PK other times ($0.058)**	**Total cost of kWh only**	**Avg. Cost/ kWh only**	**Avg. kWh solar**
June '06	989	$98.13	156 (15.8%)	84 (8.5%)	749 (75.7%)	$81.87	**$0.0828**	172
July '06	1,165	$110.90	160 (13.7%)	89 (7.7%)	916 (78.6%)	$92.89	**$0.0797**	158
Aug '06	880	$88.16	128 (14.5%)	80 (9.1%)	672 (76.4%)	$71.79	**$0.0816**	177
	Avg. total kWh	**Avg. Bill**	**ON-PK 7-11AM 6-9PM ($0.094)**	**SH none**	**OFF-PK other hours ($0.032)**	**Cost of kWh only**	**Avg. Cost/ kWh**	**Avg. kWh solar**
Dec '05	805	$49.97	189 (23.5%)	0	616 (76.5%)	$37.47	**$0.0466**	149
Jan '06	656	$43.37	173 (26.3%)	0	483 (73.7%)	$31.69	**$0.0483**	121
Feb '06	535	$36.61	138 (25.9%)	0	396 (74.1%)	$25.69	**$0.0480**	164

Table 5. Time-of-use data (TEP Rate 201C, APdS homes with solar electric, solar thermal and TEP Guarantee) with benefits to APdS homes are shown. Summer (rows 3-5) and winter (rows 8-10) use is shown for current year. Average total kWh is in column 2, and average homeowner bill in column 3. On-Peak use (column 4), Shoulder use (column 5), Off-Peak use (column 6) with time period and cost/kWh are shown for summer (row 2) and winter (row 7); data in cells show average kilowatt hours and percent of energy use in parentheses. Average fixed-cost for kWh, i.e., less service charge, taxes and non-fixed charges is given in column 7—column 3 is the bill, column 7 is the fixed energy charge in that bill. Average cost/kilowatt hour in column 8 reflects utility benefit of house construction paired with time-of-use plan and solar technologies. Column 9 shows TEP estimate of average monthly kWh contribution of the approximately 1 kW AC photovoltaic electric system on each APdS home supplementing the utility grid to achieve the win-win–win result for resident, utility company and

environment. According to TEP data provided for the current study, 30 lots are associated with Rate 201C for the year 10/'05 to 9/'06.

Discussion. Quantifying sustainable use of energy solely as a property of individual buildings misses the context of power production and energy use since centralized electrical energy is produced at power plants serving many buildings; periodicity of energy use in the community determines peak and base utility infrastructure and other related costs; and power generated at peak times costs producers more to generate and end-users more to purchase. Sustainable energy standards must capture the fact that reduction of individual kilowatt hours used is only part of the low energy use solution. Time-of-use energy plans take advantage of these facts to produce win-win situations for power-producers and end users.

One benefit of the investment in solar energy is that the solar system generates heat (solar thermal) and electricity (photovoltaics) to power the home during times when the power company would otherwise have to build additional generation capacity. The result is avoided infrastructure and cost to build, maintain and secure it. Since solar systems produce energy during the times of day when the electrical grid as a whole most needs it, solar powered homes can essentially buy down the cost to the power company to produce power. This produces the win-win-win potential to residents, utility and environment, making time-of-use programs with low cost/kWh possible.

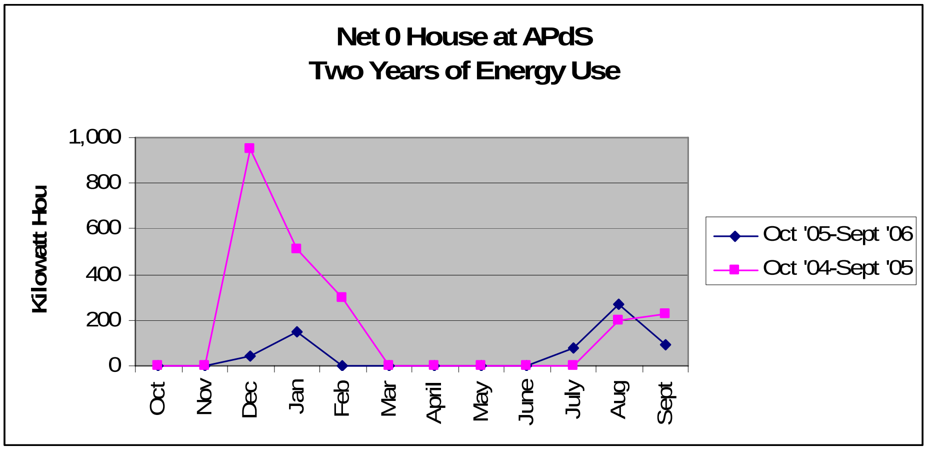
8. Zero Energy Homes

Results

	ZEH 10/'05-9/'06	ZEH 10/'04-9/'05
Sample Size	1	1
Avg. sq feet	1,717	1,717
Total kWh/yr	630	1,956
Source kBtu/sf/yr	4	12
Total cost (yr & mo)	$125/$10	$262/$22
Base kWh/yr	*0	*0
Base kBtu/sf/yr	*0	*0
Total C/H kWh/yr	*630	*1,956
C/H kBtu/sf/yr	4	12
Cooling/heating energy cost (yr/mo))	*$125/$10	$262/$22

Table 6. Based on TEP-provided data, the first ZEH at APdS used 163 kWh/mo average for the year Oct '04-Sept '05, and 53 kWh/mo average for the year Oct '05-Sept '06. Although the residents occupied the ZEH beginning in October, 2004, data from this month were used in order to compare two full years of utility data. In order to participate in TEP's net-metering tariff, the ZEH is billed using a flat rate structure—not the more optimal 201C rate. The flat rate structure includes a monthly cost of $5.28 for the privilege of connecting to the grid (included in the $10/mo average cost shown).

Graph 1 shows that grid energy is used for winter and summer energy demand only, with base loads (and most heating and cooling) supplied entirely by the photovoltaic/solar thermal systems; it also shows an example of the continual technical improvements based on experience—a learning process central to the APdS success.



Graph 1. Two years of energy data show ZEH energy use for the current year at 10/mo, including the monthly service charge.

Discussion. The first ZEH uses solar thermal energy for hot water heating and for space heating. The design goals for the ZEH by NAHB Research Center in conjunction with John Wesley Miller Companies were for 100% of hot water, and 75-90% of the space heating to be provided by solar thermal system, leaving 10-25% of the space heating to be supplied by electricity (the design goal is to use the smallest amount of water storage necessary to not-quite-meet the heating demand and rely on the back-up electric heating for the final 10-25% of space heating needs). The ultimate goal of a ZEH is to use no energy other than that supplied by the solar thermal and solar electric systems of the house, but realistically, because of issues in time of collection of the sun's energy as heat or electricity and its storage together with human use patterns, an annual charge for utility-supplied electrical use is expected: $10-20/mo. The $10/mo goal was achieved for Oct '05-Sept '06, the current year studied.

A major design challenge for the Zero Energy House centers on the question of balancing solar electric and solar thermal to provide for the major heating functions in the house—hot water and space heating. Solar thermal technologies can capture more energy per square foot of collection than solar electric can, but solar thermal costs more to store as compared to the storage capacity of the electrical grid for solar electricity. Use patterns of hot water are frequently when the sun is not shining, or when it has not yet heated the water enough for use. This compares to electrical use, where a grid connected PV system puts the electricity not used at any given time right back into the grid for later use. Solar thermal tends to have a faster payback than solar electric systems due to the lower installation cost. Design choices revolve around the installed costs for solar thermal and solar photovoltaic systems and the energy used for heating and cooling the home and heating hot water.

After the results of winter 2003-2004, problems with the first experimental stages of the first ZEH were identified by NAHB Research Center. However, not until occupancy was established in the winter of 2004-2005 was the interaction of a home-owner—critical to this kind of experimental design—available. During the winter of 2004-2005 the homeowners provided the tank monitoring and interactions required to isolate the problems. By February, 2005, four issues were isolated and addressed: 1) The collection tank for storing solar hot water was not as well insulated as it needed to be. The tank was wrapped with extra insulation; 2) Thermo-siphoning in the hot water piping system required attention; 3) The heating set point for the on-demand water heater (used as a hot water back-up for the house) was optimized to match the ability of the solar collector's tank to transfer heat to the heating coil; and 4) A new solar thermal controller was installed to allow the homeowner to adjust the solar tank temperature based on the season. In sum, the first winter of occupancy showed that fine-tuning needed for this first, ZEH home. The second winter had occupants in the house who were willing and interested to participate in the experiment, an element that was critical to fine tuning the space/water heating system.

ZEH designs are a work in progress as advanced home designs optimally match high efficiency houses with thermal and electric solar technologies and with the use patterns of people living in these houses and using these energy systems. See the technical website at www.toolbase.org/zeh, displaying technical data on Armory Park del Sol's First Generation ZEH.

Appendix: TEP rate structure showing time-of-use (Rate R 201C)

Tucson Electric Power Company literature suggests that an average 22% savings results on a PV powered electric bill when the consumer chooses time-of-use ("TOU") rate plan R201C as compared to a non-time-of-use plan.

			Peak 1-6 pm	**Shoulder 6-8pm**	**Off other**
Summer	Non-TOU	June - Aug	0.091	0.091	0.091
		May, Sept, Oct	0.074	0.074	0.074
	201C	June-Aug	0.184	0.116	0.058
		May, Sept, Oct	0.137	0.087	0.043
			Peak 7-11 am 6-9 pm	**Shoulder none**	**Off other**
Winter	Non-TOU	Nov - April	0.064	0.064	0.064
	201C	Nov - April	0.094	0.032	0.032

Analysis of Armory Park del Sol home energy use by ANE, Inc. for the year Feb. 2004 - Jan. 2005 showed that R201C was the cheapest plan for Armory Park del Sol homes for that year. Comparison of the current sample confirms this finding.