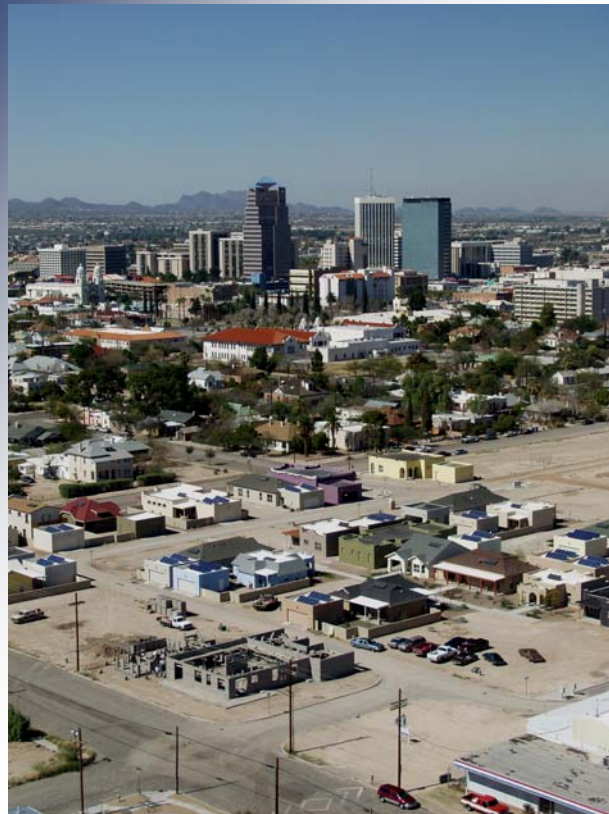


INTERIM REPORT FOR FIELD EVALUATION OF PATH TECHNOLOGIES

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TUCSON, ARIZONA



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field evaluation



PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new and innovative technologies, the goal of PATH is to improve the quality, durability, environmental efficiency, and affordability of tomorrow's homes.

PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, all federal agencies that engage in housing research and technology development are PATH Partners, including the Departments of Energy, Commerce, and Agriculture, as well as the Environmental Protection Agency (EPA), the Federal Emergency Management Agency (FEMA), and State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH Partnership.

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The NAHB Research Center, Inc., under a contract with HUD, is monitoring and evaluating a wide variety of new and innovative technologies incorporated at this Field Evaluation and Demonstration Site in Tucson, Arizona.

DISCLAIMER

The work that provided the basis for this publication was supported by the PATH Program of the U.S. Department of Housing and Urban Development. The substance and findings of the work are dedicated to the public. The author is solely responsible for the accuracy of the statements and interpretations contained in this publication. Such interpretations do not necessarily reflect the views of the Government.

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Interim Report for Field Evaluation of PATH Technologies

John Wesley Miller Companies Armory Park del Sol Tucson, AZ



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The NAHB Research Center, Inc. is a not-for-profit subsidiary of the National Association of Home Builders (NAHB). The NAHB has over 205,000 members who build more than 80 percent of new American homes. NAHB Research Center, Inc. conducts research, analysis, and demonstration programs in all areas related to home building and carries out extensive programs of information dissemination and interchange among members of the industry and between the industry and the public.

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1.0 INTRODUCTION

Armory Park del Sol was created as a sustainable community in the historic Armory Park neighborhood of the inner city of Tucson. Former Mayor George Miller and the City Council endorsed the project, for it met many of their goals to foster a livable inner city. The project incorporates sustainable, high-density urban infill development techniques to preserve open spaces. The community also features extensive walkways to encourage pedestrian traffic and reduce the negative effect of vehicle emissions on the environment.

Using what was a vacant, unused and unattractive lot, Armory Park, when completed, will consist of 99 single-family homes. These homes incorporate many innovative technologies identified by the NAHB Research Center through the PATH program as having the potential to help achieve PATH goals of affordability, durability, and energy efficiency.

This interim report provides a limited analysis of the data collected to date. A more developed analysis will be presented in a final report at the completion of the field evaluation.

2.0 PLANNING AND DESIGN

In partnership with the local utility, Tucson Electric Power (TEP), homes are being constructed with stringent air infiltration, duct loss, and insulation level requirements. High efficiency equipment is being installed and air balancing is performed to provide efficient equipment performance and occupant comfort. Homes are designed using thermal mass walls with exterior insulation, high levels of ceiling insulation, ducts inside conditioned space, and windows that minimize heat loss and gain. Based on these features as well as the use of solar technologies to provide electricity and hot water, electric utility rates are discounted over base residential rates, thereby lowering monthly utility bills.

As a significant commitment to environmental sensitivity, the houses are incorporating solar water heaters, and photovoltaic panels (PV) to produce electricity. These technologies will offer a high value both in reducing costs and in reducing the environmental impact of the homes.

3.0 MONITORING PLAN

3.1 General

A monitoring program was developed and initiated to verify savings and to evaluate performance of the innovative technologies installed under the PATH program. Major energy uses in each of the monitored homes are being evaluated, including consumption levels normalized to square footage, degree-days, and indoor-outdoor temperature differences. System and appliance energy use under analysis includes cooling, heating, water heating, major appliance, and base whole-house energy use on an hourly, monthly, and annual basis. This data is being used to analyze energy performance, and the extent to which air sealing, glazing, efficient equipment, and the operation of the new homes result in energy and cost savings as compared with other recently constructed homes in Tucson. Data may also be used to validate and correct simulation models. In turn, simulation models can be used to provide

information about the energy implications of new construction details for future homes in the Demonstration Site.

The renewable energy systems are being monitored not only for total energy produced but also for time of use (TOU). The timing of energy use and energy production is important for both solar produced electricity and solar hot water. For solar electricity, the time-of-use electric rates (see Table 11) are highest during the daytime when PV production is also highest. Coincident production and use of electric energy at times of peak electric rates means that PV power has a high value because it is displacing expensive electricity. Additionally, with TOU rates, homeowners are not reimbursed for PV energy that is sent back to the utility. Therefore, it is advantageous for the homeowner to use as much of the PV-produced power onsite. The time of use of solar hot water is important because the batch-type water heater that is used provides most hot water in the afternoon. If a household uses most of their hot water in the morning, this type of solar water heater may not be the most advantageous system. Time of use data will be used to perform an economic analysis of the PV and solar hot water systems and to recommend system designs which may incorporate energy controls that are sensitive to energy cost and time of use.

Future testing may include, with the help of the National Renewable Energy Laboratory (NREL), an evaluation of the photovoltaic (PV) and solar hot water systems for overall system efficiency and collector efficiency. Detailed data for the renewable energy systems will provide confidence in the use of the equipment, as well as a clear understanding of the performance of the systems as installed rather than as simulated. However, the detailed measured results can be used to support models that accurately reflect the performance of systems, as designed and as operated under assumed conditions.

3.2 Purpose of the Overall Monitoring Effort

As a PATH Demonstration Site, the project's goals are to obtain verifiable performance data and documentation of progress towards the following:

- Reduce monthly operating costs
- Lessen environmental impact
- Reduce energy use
- Improve durability
- Reduce maintenance costs

NAHB Research Center staff is documenting the level of achievement of the Armory Park project toward these PATH goals, and evaluating cost and performance of various technologies for application by other builders. It is recognized that lessons learned at the beginning of any project may translate into later savings when new technologies or methods are implemented on a regular basis throughout a project.

Two important renewable energy systems are being evaluated in greater detail: the solar hot water systems, and photovoltaic electrical generation systems. These

technologies are part of a PATH Field Evaluation to demonstrate installation and operation of the systems and to analyze energy and economic benefits associated with them.

3.3 Specific Systems for Energy Monitoring

3.3.1 Solar Water Heating

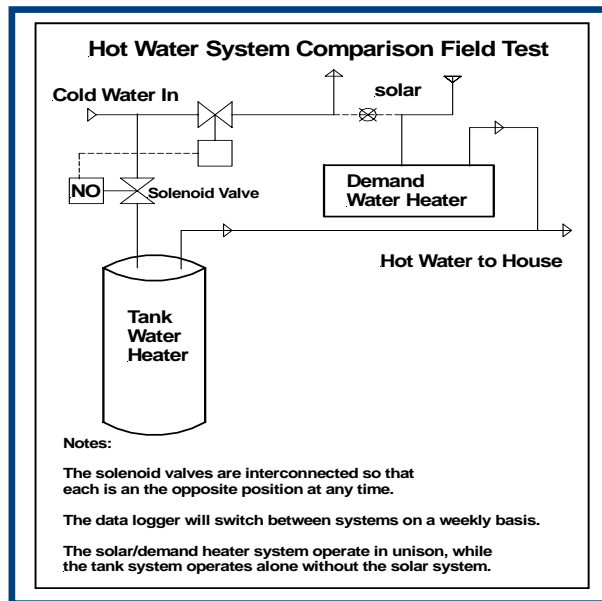
The purpose is to assess the performance and benefits of a solar hot water system used in conjunction with a demand (tankless) water heater. The following tasks were specified:

- (1) Measure water heating energy consumption and hot water use in six homes, with the following monitoring equipment:
 - A flow meter on the cold water side of the hot water system,
 - A power meter on the demand water heater.
- (2) Perform a detailed analysis of long term solar and hot water system performance through a direct comparison with a standard tank system in one of the six homes. The monitoring system will be in place for a minimum of one year, and require the following:
 - Installation of the solar/demand water heating system,
 - Installation of a standard (40-50 gallon) hot water tank,
 - Controls to switch between systems,
 - A data logger and numerous temperature, flow, and power sensors,
 - A separate telephone line connection for remote data retrieval.

A standard tank water heater was added as a second heating unit. The tank water heater or the solar/demand water heater supplies hot water to the home during alternating weeks. In this way, the performance of each system is analyzed under similar conditions of inlet water temperature, draw profile and total consumption.

This special test system includes temperature sensors on the hot water pipe, a flow meter on the cold water inlet, and a power meter on the electrical input to each water heating system. In addition, temperature sensors are placed on the solar system to determine the contribution from the solar system to the demand water heater and the house during weeks where that system is activated. On alternate weeks, the solar/demand system remains idle. Figure 1 provides a schematic diagram of the hot water system test setup, and Figure 2 is a photograph of the installation.

Figure 1: Hot water system test diagram



The water heater system comparison test setup contains an electric tank water heater (foreground), and an electric demand (tankless) heater (background) which is fed from the rooftop solar water heating collector. Solenoid valves alternately operate each system for a one-week period. A flow meter measures cold water supply to the system. Four immersion-type thermocouples measure cold and heated water temperatures. A data logger receives data and transmits it via modem to the NAHB Research Center.

Figure 2: Hot water system comparison at Armory Park



3.3.2 Photovoltaic (PV) Electrical Generation

The field evaluation is designed to assess the performance and benefits of the PV system with respect to the total home electric energy consumption. The procedure is to measure long-term electrical production from the PV system, and compare results to overall house electric energy consumption. On a 15-minute basis, performance is analyzed, including time of energy use and production relative to time-of-use electric rate schedule. The monitoring system will be in place for a minimum of one year, and includes:

- An electric energy meter located in the utility room or near the electric panel,
- A connection to the home's telephone line for remote data transfer.

3.3.3 Time of Electric Energy Use

The research plan is designed to evaluate the time-of-use of electric energy in the home. Time-of-use is important due to graduated electricity rates based on time-of-day that electricity is used (see Table 11 for details). To lower energy costs further, electricity use may potentially be shifted to periods when electricity prices are lower. Additionally, an economic analysis can be conducted regarding coincident house electric use and PV production to determine the effect of utility rate structure on the economic viability of PV power production. Various methods may be used to moderate electric energy consumption based on electricity costs at different times of the day and will be identified in this analysis. The monitoring equipment that is required for this analysis is the same equipment as that used for the PV system analysis above.

3.3.4 Peak Electric Use

House performance relative to peak energy consumption is evaluated and compared with various energy factors, such as outdoor and indoor temperature, thermostat programming, and hot water use. This analysis may include suggestions to the homeowner to incorporate various heating and cooling strategies to minimize the peak demand during periods of peak electricity rates. Monitoring and other equipment necessary for this analysis includes:

- Electric metering as described above,
- Indoor temperature measurements,
- Outdoor temperature measurements.

3.3.5 Overall Home Energy Performance

Overall home performance with respect to energy consumption, indoor temperatures, and hot water energy use is assessed. This detailed assessment evaluates the energy use in the home while monitoring indoor air and surface temperatures, as well as duct delivery temperatures, among others. The analysis provides details on areas where potential energy and/or cost savings may be gleaned, such as in pre-cooling methodologies, or in building shell or HVAC system

modifications. Due to the extensive nature of this analysis, only one home is being monitored.

This detailed analysis requires use of sensors throughout the home, primarily to monitor temperature, but also to record relative humidity, heat flux, equipment run-time, and solar radiation. General monitoring equipment includes:

- Electric metering as described above,
- Indoor temperature measurements located in numerous rooms and surfaces of the home,
- Outdoor temperature measurements,
- Various power and run-time measurements,
- Total power measurements as described above, and
- A data logger system including a phone line for remote data collection.

The energy performance of homes is also being evaluated in comparison to houses constructed in the late 1990s in the same general location. This evaluation will identify the degree to which the PATH energy efficiency goals are achieved. In a previous phase of the study, six base homes were monitored for a period of 13 months, and a determination of base house energy performance will be used for comparison to the Armory Park del Sol project. Energy performance will be measured on a normalized basis (such as by square footage, heating degree-days, or number of bedrooms).

4.0 CONSTRUCTION PHASE

4.1 Start of Construction

Clearing and grading of the site and development of the infrastructure began in August 2000. After several delays in obtaining approvals and permits for the six model homes, construction began on the first model in late August 2000.

4.2 Grand Opening Ceremony

On March 30, 2001, a Grand Opening Ceremony was held on site. It was attended by over 200 people, which included neighborhood residents, local officials, and leaders of private and public organizations. Seven speakers provided testimony to significant advancements in housing construction made by John Wesley Miller and his skilled staff, which included advances in energy efficient construction techniques, renewable energy systems, high tech communication wiring, and an open, accessible community atmosphere. Construction and site advances are incorporated into house designs true to the historic district within which they reside. Speakers included Jim Pignatelli, president and CEO of Unisource, parent company of Tucson Electric Power Co.; Hercules Dellas of the Arizona Corporation Commission; Councilperson Fred Rohnstadt; Mark Ginsberg of the U.S. Department of Energy; Marge Sternberg, president of the Armory Park Neighborhood Association; Liza Bowles, former president of the NAHB Research Center; and John

Wesley Miller, builder. The event marked the official opening of this PATH Demonstration Site, where monitoring continues as construction proceeds.

4.3 Primavera Builders' Groundbreaking Ceremony

On August 29, 2001, Primavera Builders, John Wesley Miller Companies, and Tucson Electric Power (TEP) broke ground on a lot in Armory Park del Sol. Primavera Builders is a non-profit agency that provides job training in construction trades for the homeless, working poor and at-risk youth. The agency completes approximately 30 homes per year, which are sold to low and modest income families in the Tucson area. TEP and John Wesley Miller Co. donated the lot to Primavera for construction of an affordable, energy-efficient, three-bedroom, two-bath, and 1,300 square-foot (sf) home.

Approximately 85% of Primavera's at-risk high school students receive their diplomas. Persons who earn between 30 and 80 percent of the community's average median income are eligible to purchase a Primavera home. All qualified applicants receive credit counseling, down payment assistance, and homeownership education.

Primavera trainees learn how to apply advanced construction technologies, such as photovoltaics, which will give them a competitive edge in today's labor market. John Wesley Miller said, "I partnered with Primavera because I want to teach people how to fish, not just give them a fish."

4.4 Construction Progress

At the time of this report, over 40 homes had been completed at Armory Park del Sol, with others in the planning stage. With completion of the infrastructure on the 14-acre inner city tract, the development has clearly matured. Several houses have been sold, and one house has even been resold. The average price for the homes, however, has increased to over \$200,000, due to the rapidly increasing value of land in the immediate neighborhood.

Monitoring equipment, sensors, and energy meters were installed, and will continue, as more homes are constructed and photovoltaic (PV) systems are installed. Whole house energy monitoring is currently being performed at two homes. One of these, a north-facing, 961 square-foot house (House A) has been monitored since late November 2001. The other, a south-facing, 1100-square-foot home (House B) has been monitored since late June 2002. Energy generated by the PV systems is also being monitored at both homes, beginning in February 2002 for House A, and in late June 2002 for House B.

Equipment for the solar hot water test system, as well as for the energy performance assessment, was also installed in House B. The solar hot water system was installed side-by-side with a standard electric tank water heater, and operation of each system alternates weekly. Hot water system usage and

temperatures are recorded, and energy consumption is monitored in 15-minute intervals.

Future status reports and results of monitoring will be submitted to HUD and will be posted on the ToolBase website, as construction and monitoring progresses.



Figure 3: Newly completed homes in Armory Park del Sol



Figure 4: Homes under construction at Armory Park del Sol (model homes in background)

Figure 5: Example of wall insulation



Figure 6: House A with solar PV and hot water systems

5.0 HEATING AND COOLING ENERGY ANALYSIS

Homes at Armory Park del Sol are designed to satisfy requirements of the Tucson Sustainable Energy Standard (TSES). These voluntary requirements are intended to reduce the heating, cooling and water heating energy of buildings by 50% from that which would be required by the Model Energy Code (MEC) or International Energy Conservation Code (IECC). Other applicable requirements include:

- Maximum air leakage of 0.35 air changes per hour (ACH), at natural conditions,
- Specifications for glazing solar heat gain coefficients (SHGC),
- Minimum air conditioner efficiency of 12 SEER (seasonal energy efficiency ratio), and heat pump efficiency of 7 HSPF (heating seasonal performance factor), and
- Mastic sealing of all ducts, and maximum measured duct leakage rate of 33 cfm at a pressure of 25 pascals.

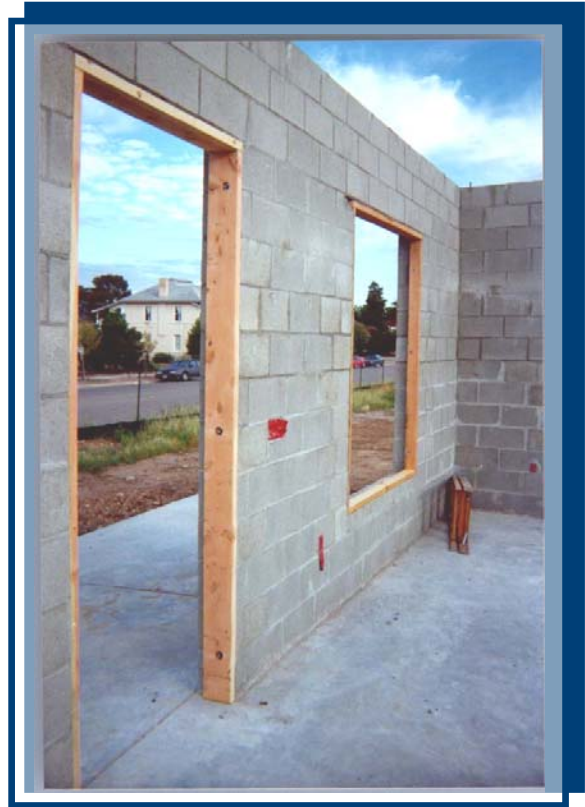


Figure 7: Concrete block wall construction

An energy analysis of the first model home constructed showed compliance with the TSES. The following building features were included in this model home:

- Raised-heel trusses and R-38 attic insulation,
- Masonry construction with R-12 rigid foam board insulation attached to exterior,
- Window U-value of 0.32,
- Slab edge insulation to full depth of slab, and
- Minimum equipment efficiencies of 12 SEER and 7.5 HSPF.

With these construction specifications, the basic energy analysis results and code comparisons are shown in Table 1:

Table 1 Energy code comparison

Energy Code or Standard ¹	Maximum UA Allowed ²	UA of Building Design ³
TSES	251	245
1995 MEC	483	246
2000 IECC	483	246

¹ Use of software analysis based on SEScheck Version 1.0 and MECcheck Version 3.0.

² Maximum UA, modified by equipment efficiency for each code analysis.

³ UA - Overall component heat loss (U-value) weighted for area of particular component, such as wall or ceiling.

The house design met the TSES energy requirements based on equipment efficiency, and substantially exceeded the 1995 MEC requirements for Tucson. In addition, all homes will utilize

solar energy systems for both hot water and electrical production, which will further reduce the overall energy consumption of the homes.

A computer energy analysis was also performed on the designed home to provide a more detailed estimate of energy consumption. This energy consumption was compared with a baseline home to estimate energy savings, including a credit for energy production, over “typical” construction practices. Analysis was performed on hourly data, and incorporated details such as building orientation, thermal mass, and internal heat gains. Based on this analysis, the homes are estimated to use 45% less heating and cooling energy than the modeled baseline home.

Heating and cooling energy data has been collected since December 1, 2001 for two subject homes in Armory Park. Data from November 1, 2002 through October 31, 2003 includes a complete single heating season and cooling season, and is compiled in Table 2.

Table 2 Annual summary of heating and cooling energy use

November 1, 2002 – October 31, 2003 Energy Consumption	House A (961 sq. ft. area)	House B (1100 sq. ft. area)
Heating Energy (kWh)	366	302
Cooling Energy (kWh)	1448	1492
Blower Energy (kWh)	included	included
Energy Use – Heating	0.38 kWh/square foot	0.27 kWh/square foot
Energy Use – Cooling	1.51 kWh/square foot	1.36 kWh/square foot
Total Energy – Home (kWh)	8291	7132
Percentage of Total Home Energy Consumed by Heat Pump	22%	25%

6.0 COMPARISON OF TANK AND SOLAR-ASSISTED DEMAND WATER HEATING SYSTEMS

A PATH Field Evaluation to compare the energy use of a standard tank water heating system with a solar-assisted demand (tankless) water heating system was initiated in Spring 2002. The purpose of the evaluation was to produce empirical results of energy savings and to identify any performance issues with the solar-assisted demand system. Tank systems are installed in most new homes in Tucson, with or without a solar preheat system. In Armory Park del Sol, the builder, through the assistance of the PATH program, elected to forego the use of tank water heaters altogether in favor of an electric demand water heater. Originally, the system design was to use a solar batch water heater on the roof to feed a storage tank, which then, if required, would raise water temperature to the delivery set point (about 130°F). However, after becoming familiar with the design of the water heating system using the demand heater, the builder switched to a solar-assisted demand system for all homes.

The PATH Field Evaluation was developed to provide a good estimate of expected savings of a solar-assisted demand design over a typical tank system. A test was designed to supply hot water, alternating weekly between the tank system and a solar-assisted demand heater system. Monitoring equipment was installed at House B, in Spring 2002, while the home was under construction. A flow meter, multiple temperature sensors on the piping lines, and a power meter on the demand water heater and tank water heaters was installed. Solenoid valves were

controlled remotely and alternated hot water systems weekly. A data logging system recorded performance data for more than a year. A direct comparison between the two water heating systems was performed over a sufficient time period to average out weekly anomalies of water use and cold water temperatures. Figures 1 and 2 in Section 3.3.1 provide a schematic diagram and a photograph of the test setup.

Water temperature is measured at the cold water inlet, on the piping which returns from the solar heating panel, at a location just past the solar heating system mixing valve (the mixing valve blends cold water with the solar-heated water to deliver a specified maximum temperature into the demand heater), and then finally at the hot water supply into the home.

The home was occupied in late June 2002, and the water heating comparison setup was tested and calibrated at that time. The system was allowed to operate until late September 2003. Periodic checks with the homeowner were made to assess any problems with either system operation.

The batch-type solar water heating collector shown in Figure 8 is mounted on the roof of the homes. This unit feeds solar-heated water to the demand (tankless) water heater. When the water temperature leaving this unit is above the demand heater set point (~ 125°F - 135°F), it passes through without demand heater operation. When the temperature is below the set point, the demand heater boosts the water temperature to the desired setting.



Figure 8: Solar water heating collector

Data was collected on both hot water systems for a period of thirteen months from July 2002 through August 2003. Tables 3 and 4 summarize the performance of the two systems.

Table 3 Summary of hot water system performance comparison over 13 months of operation

Measured or Calculated Parameter	Tank System	Solar/Demand System
Total Energy Supplied	2,439,054 Btu	2,238,793 Btu
Energy Supplied- Electricity	2,439,054 Btu (100%)	894,178 Btu (40%)
Energy Supplied-Solar	0 Btu (0%)	1,344,615 Btu (60%)
Water Use (Gallons)	5,541 gallons	5,429 gallons
Duration of System Operation (Days)	211 days	216 days
Average Daily Hot Water Use (Gallons/Day)	26.3 gallons/day	25.1 gallons/day
Average Energy Usage per Gallon	0.15 kWh/gallon	0.05 kWh/gallon

Based on the measured data, and the weekly alternating use of each water heating system, the solar-assisted demand water heating system averaged two-thirds less energy than the tank system. Each system performed for a nearly equal time and supplied a similar amount of hot water. The delivery temperature from each system was also nearly identical. The average water use of about 25 gallons per day is well below that of the average for households in the U.S., but consistent with what would be expected of a single occupant.

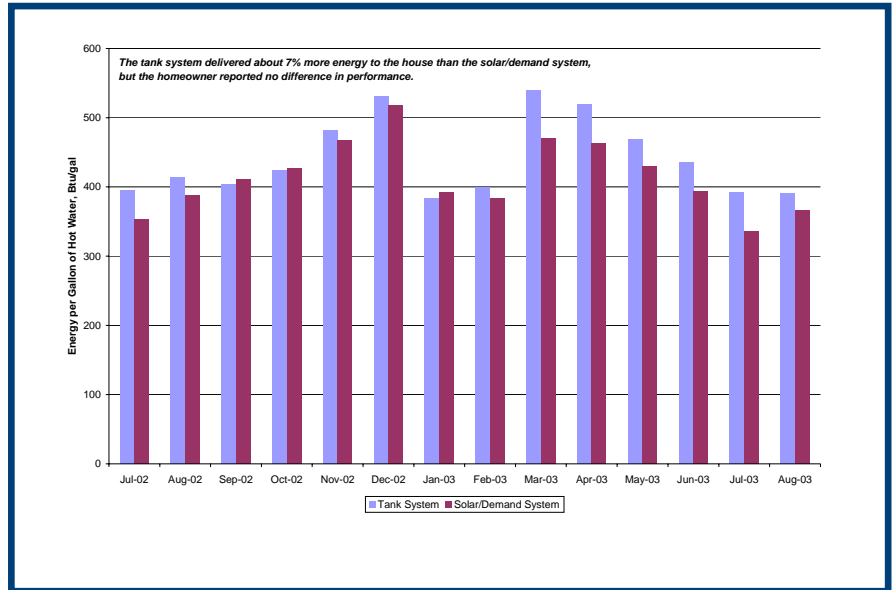


Figure 9. Energy supplied to hot water by system

The solar collector has a storage volume of 40 gallons, indicating that the available solar heated water is significantly higher than was actually used in the house. Therefore, for a household using double the amount of hot water, savings would be expected to be proportionately higher.

Although the energy delivered to the hot water was about 7% more with the tank system than the solar/demand system, the homeowner reported no difference in system performance. More energy was likely delivered in the tank system because a tank system always delivers hot water, while a demand system may not activate for very low flow rates. Figure 9 shows the energy delivered per gallon of hot water for each system, by month.

Table 4 Monthly summary of system performance

Month	Average Daily Water Use-Tank System (gallons)	Average Daily Water Use-Solar/Demand System (gallons)	Normalized Energy Use-Tank System (kWh/Gallon)	Normalized Energy Use-Solar/Demand System (kWh/Gallon)
Jul-02	16.1	18.6	0.193	0.041
Aug-02	12.9	18.1	0.215	0.042
Sep-02	15.1	18.9	0.197	0.036
Oct-02	17.0	20.3	0.185	0.060
Nov-02	19.8	18.5	0.193	0.088
Dec-02	17.8	12.9	0.217	0.118
Jan-03	71.7	52.0	0.068	0.041
Feb-03	59.8	51.3	0.077	0.047
Mar-03	32.7	29.2	0.173	0.076
Apr-03	29.0	29.2	0.172	0.055
May-03	37.2	34.2	0.149	0.042
Jun-03	14.9	25.7	0.203	0.035
Jul-03	13.8	12.2	0.202	0.027
Aug-03	13.6	13.7	0.200	0.015
Average	26.3	25.1	0.147	0.050

A closer examination of the monthly data in Table 4 reveals the difference in performance of each system based on months of high demand and low demand. Clearly, the tank system performs more efficiently when a higher level of water is used. Also, the solar contribution is evident in the monthly variation of normalized energy, ranging from a high of 0.118 kWh/gallon in December to a low of 0.015 kWh/gallon in August. The solar contribution is dependent on the time-of-use of the hot water, since with a batch-type solar water heater, the hot water is stored in solar collector itself. At night the heated water cools due to losses to the nighttime air. Use of hot water in late morning and early afternoon would generally result in the highest proportion of solar-heated water. Early morning use of solar-heated water would provide the lowest solar contribution since the water in the collector has had all night to cool.

Figure 10 shows the hourly hot water use profiled based on daily averages for the 13-month period. The largest use is in the morning; however, a significant amount of hot water is used in the later morning as well.

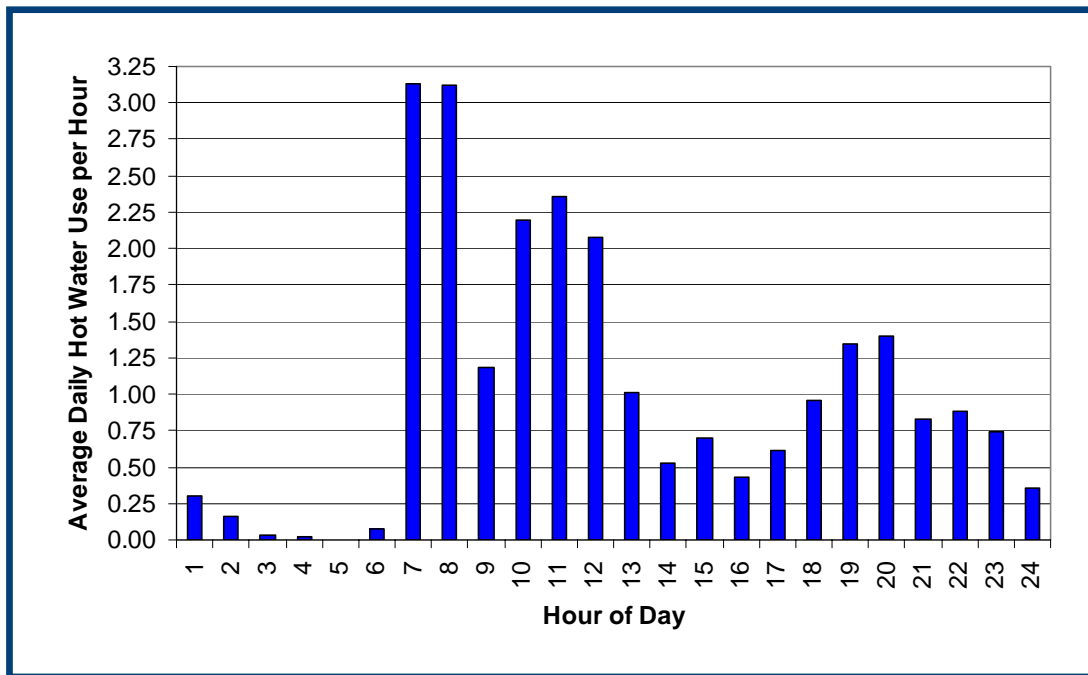


Figure 10: Hourly water use profile (all days)

Figures 11 and 12 show the monthly variation in hot water use by system and the energy required to meet the demand. The variation in the electric energy required to meet the load is due to a combination of factors including the incoming cold water temperature, the standby losses as a proportion of the hot water use, and the quantity of solar pre-heated water available each day.

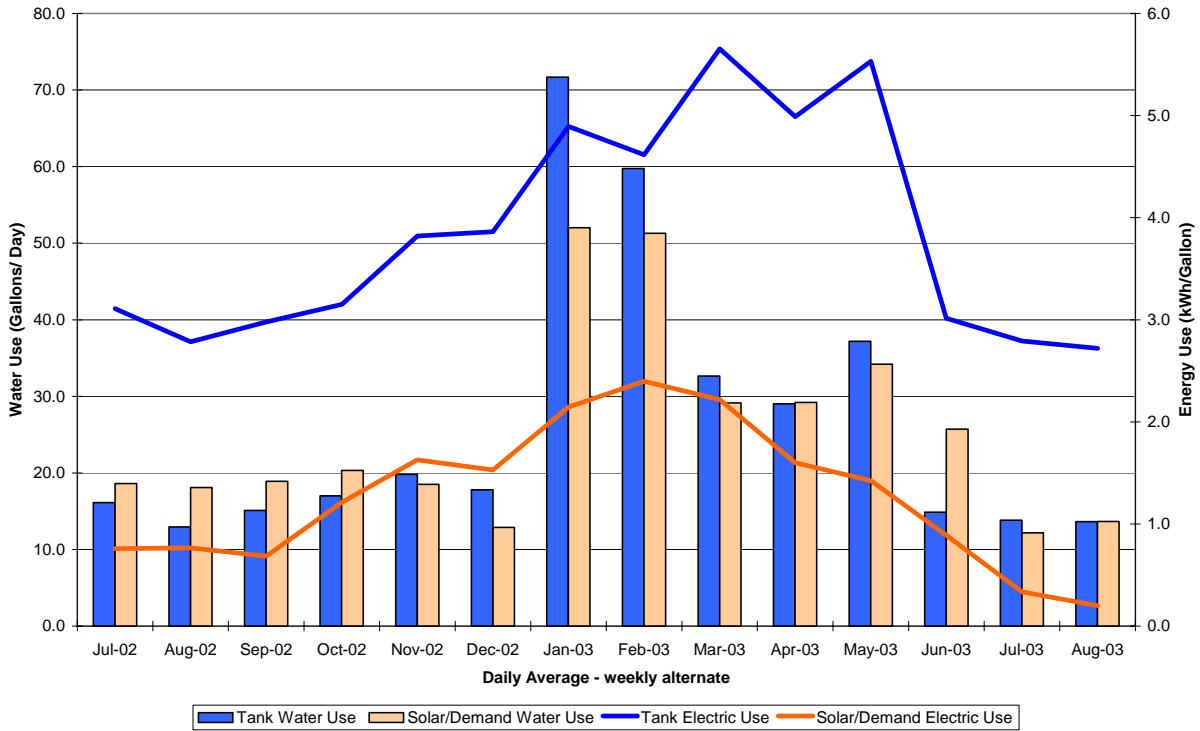


Figure 11: Average daily water and energy consumption by system

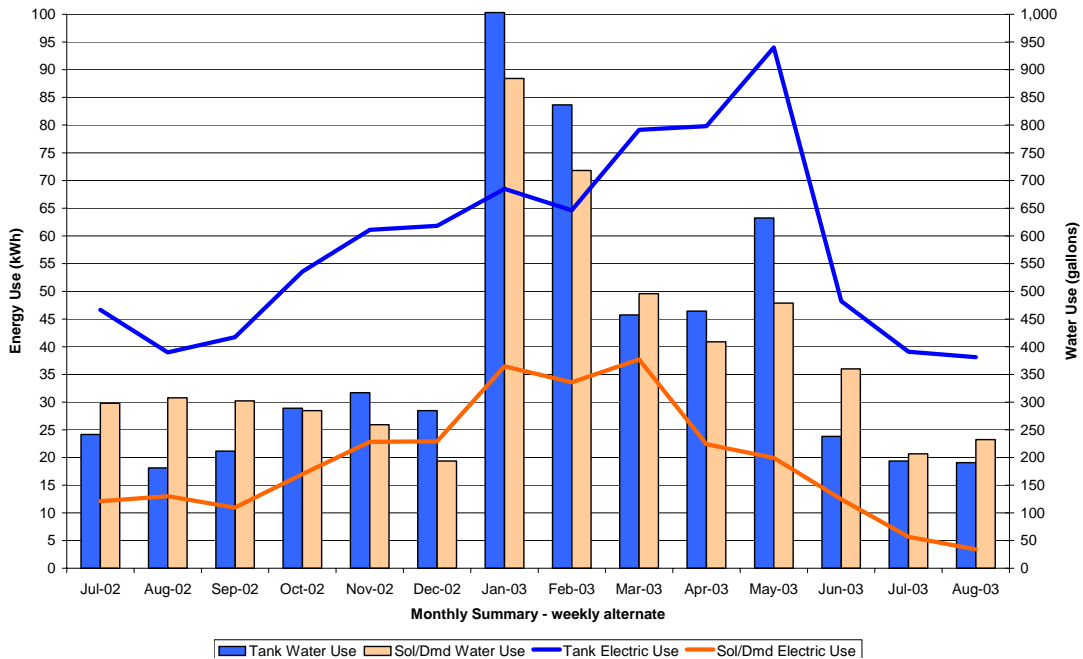


Figure 12: Monthly water and energy consumption by system

For the solar-assisted demand system, the hot water energy supplied to the home is supplied by the combination of solar and electric energy. Throughout the year, the proportion supplied by the solar varies as is shown in Figure 13.

Another performance difference exists between the systems that is much less measurable but plays a role in energy efficiency of hot water systems – unintended hot water use. Some of the hot water use, especially those very low flows that result from short use at a sink or from operation of a single-lever faucet valve, never results in hot water delivered to the outlet. During these specific types of hot water use, tank systems will always deliver hot water to the piping system. Demand heaters however have a minimum flow rate required for activation of the heaters, albeit very low. For very short or very low flow rate hot water draws, the demand heater will not activate, simply passing through the solar preheated water to the piping system. This resultant energy savings is difficult to measure; however, it is evident in the total energy delivered to the piping system.

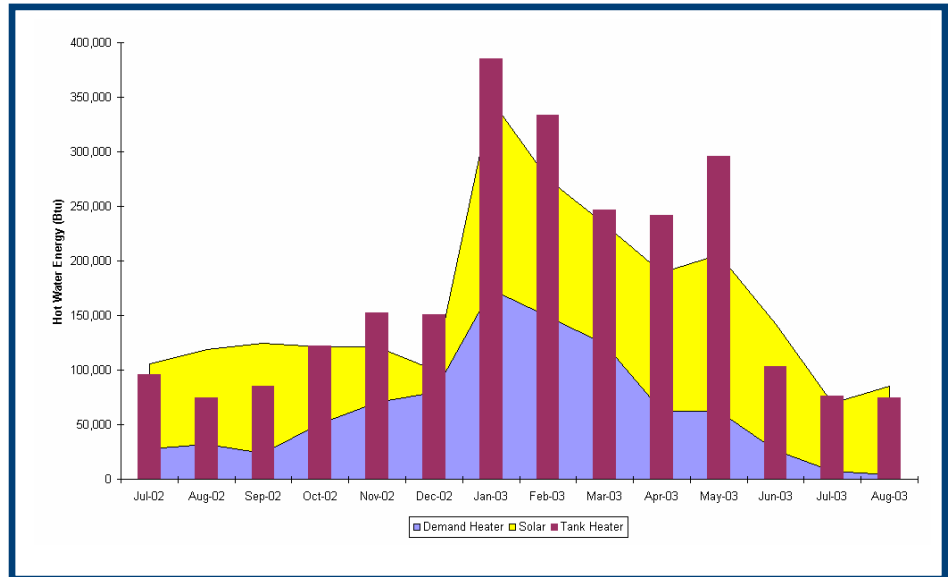


Figure 13: Total hot water energy supplied to home by system

Table 5 Summary of energy use and savings over a 14-month period

Electricity Required for Tank System	1,614 kWh
Electricity Required for Solar/Demand System	546 kWh
Energy Savings	1068 kWh
Savings of Solar-Assisted Demand Heater over Tank	66%

Furthermore, in a home where more hot water is used (up to double the hot water demand), energy savings would be expected to be in the same proportion – as shown in Table 6.

Table 6 Estimated energy use and savings for 14-month period by system at twice actual usage

Electricity Required for Tank System	3285.3 kWh
Electricity Required for Solar/Demand System	1078.5 kWh
Energy Savings	2,207 kWh
Savings of Solar-Assisted Demand Heater over Tank	66%

Another way to analyze the hot water test data is to estimate the energy use if each of the systems would have supplied the entire hot water load over the 14-month period. Figure 14

provides the monthly results and the estimated savings of the solar-assisted demand system over the tank system.

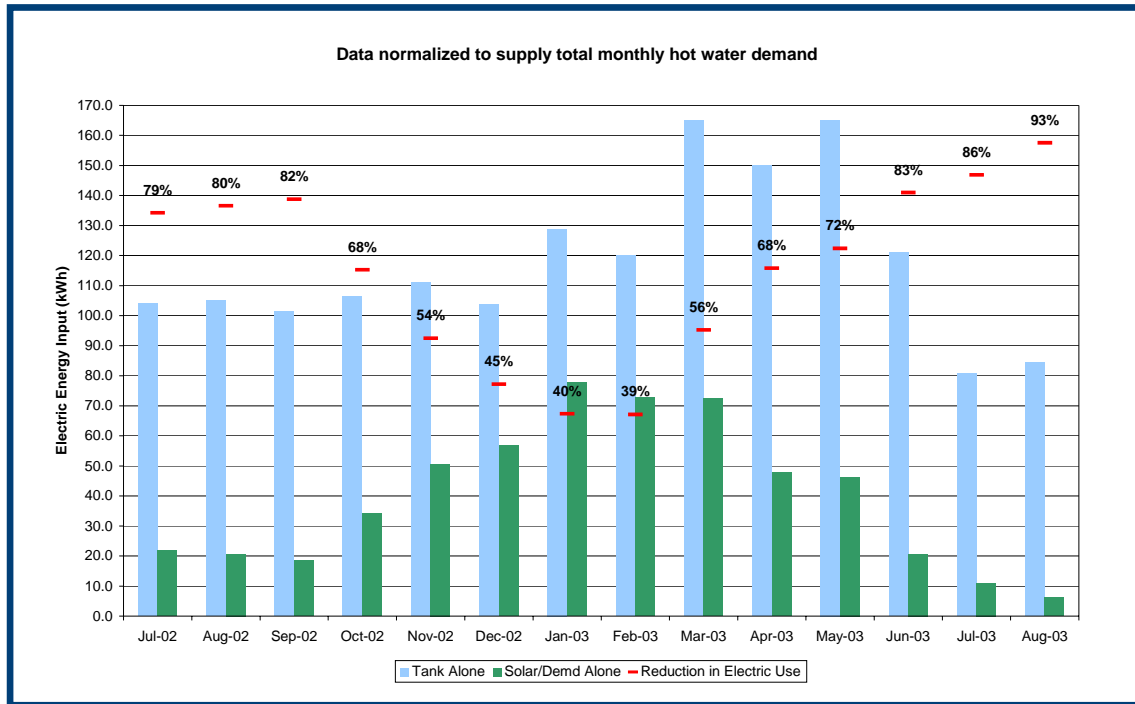


Figure 14: Energy required by system to meet total hot water use

The energy savings may be translated directly to economic savings in the cost of electricity. Table 7 provides a summary of the economic analysis considered for this hot water system test.

Table 7 Economic analysis of hot water test systems over a 14-month period

Low Hot Water Use (~25 gallons/day)	Tank System	Solar/Demand System
Installed Cost (estimate)	\$450.00	\$3,300.00
Annual Electricity Used	1614 kWh	546 kWh
Annual Electricity Cost (@\$.10/kWh)	\$161.40	\$54.60
Annual Savings	\$0.00	\$106.80
Simple payback		26.7 years
Higher Hot Water Use (~50 gallons/day)	Tank System	Solar/Demand System
Installed Cost (est.)	\$450.00	\$3,300.00
Est. Annual Electricity Used	3285 kWh	1079 kWh
Est. Annual Electricity Cost (@\$.10/kWh)	\$328.50	\$107.90
Est. Annual Savings	\$0.00	\$220.60
Simple payback		12.9 years

Another method to evaluate the economics is to assume the systems are financed in the mortgage. A brief analysis shows that, with 7% financing over 30 years and electricity cost of \$.10/kWh, the solar-assisted demand heater system costs less per month than the tank system when the average water use is about 50 gallons per day. Certainly, if utility costs increase, or if there are incentives for solar installation, the payback is much faster, which is true if the equipment cost of the solar thermal and demand heater continue to decrease.

7.0 PHOTOVOLTAIC SYSTEM PERFORMANCE

Each home at Armory Park del Sol is equipped with a nominal one kilowatt photovoltaic (PV) system, which consists of an array of PV modules (commonly referred to as solar collectors or panels) mounted on the garage rooftop, and a DC to AC inverter which provides conditioned power to the home. The arrays are installed at an angle of 32° from horizontal. The electrical output of PV systems varies greatly based on seasonal and local weather conditions. Daily PV output is affected by:

- Horizontal position of the sun,
- Ambient temperature (solar cell efficiency is reduced at higher outdoor temperatures),
- Duration of sunshine, and
- Clearness of the sky.

Maximum PV energy production occurs in the spring and fall seasons, when the horizontal position of the sun is near perpendicular to the solar array, and when cooler temperatures provide higher PV efficiency. While the summer months have longer hours of sunshine, higher temperatures reduce the total output. Additionally, cloud cover is more frequent in summer and fall in Tucson.

The PV systems produce electricity that is fed directly into the homeowner's utility panel. The electricity is used first in the home, and if the PV electricity produced is in excess of that needed in the home, it is fed back to the utility. In a TOU rate structure (in effect at House A and House B); the homeowner does not receive financial credit for this electricity. In TEP's flat rate structure, the homeowner would receive full retail rate credit for any power that is fed back to the utility.

The PV systems for the subject homes were installed in 2002 and have been monitored continuously for electrical power generation. These PV systems can produce about 1100 watts of AC power at their peak output. The homes in this study drew less than about 100 watts at their minimum power consumption to over 6,000 watts at their maximum. Tables 9 and 10 summarize the results of the PV system's performance and the homes' consumption over a twelve-month period. Since these systems are net-metered, all excess PV production sent back to the utility is termed "PV Feedback," all consumption above the daily PV



Figure 15: PV Array at House A

production is termed “Net-Utility Consumption,” and power that would need to be purchased from the utility in a TOU rate structure is termed “TOU-Utility.”

The PV system at House A, initially installed in February 2002, consisted of ten Solarex MSX-120 solar modules and an Advanced Energy GC1000-SA inverter. On July 16, 2002, the inverter was replaced with a Trace Sun Tie XR1500 model. While no problems were apparent with the Advanced Energy inverter, the builder decided to standardize all inverters on the Armory Park site to the Trace XR models.

A PV system for House B was installed in late June 2002. This system was initially equipped with a Trace Sun Tie 1500 inverter and four ASE-300-DGF/50 PV modules. The inverter did not perform well at the high ambient temperatures typical of Tucson in the summer, and it was replaced in mid-July with a Trace Sun Tie XR1500 inverter, whose higher temperature performance is improved. All inverters were replaced with model XR1500 in July, 2002. The four original ASE modules were replaced with twelve BP-Solar 120 Watt modules in late October 2002. This increased the overall rated capacity of the home’s PV system from the original 1.2 kW to 1.44 kW. Table 8 lists the final specifications for the two homes.

Total electrical production of the system from October 1, 2002 to September 30, 2003 was 1,801 kWhrs (AC) with daily electrical output of the PV system averaging 4.9 kWh per day. The peak power output of 1,064 W (AC) occurred on March 29, 2003 at 12:15 PM. Peak daily production also occurred on this day and totaled 7.37 kWh

Table 8 PV specifications at standard test conditions

Module	House A	House B
Module Name	Solarex (BP) MSX-120	BP-Solar SX-120
Cell Type	Multicrystalline silicon	Multicrystalline silicon
Maximum Power Rating	120 watts	120 watts
Voltage at Max-Power Point	17.1 volts	33.7 volts
Current at Max-Power Point	7.0 amps	3.56 amps
Open Circuit Voltage	21.3 volts	42.1 volts
Short-Circuit Current	7.6 amps	3.87 amps
Total Array		
Number of Modules in Array	10	12
Maximum Array Power	1440 watts	1440 watts
Number of Modules in Series	Four	Two
Voltage at Max-Power Point	68.4 volts	67.4 volts

A total of 2,262 kWh was produced by the PV system at this home from December 1, 2002 to November 30, 2003, for an average production of 6.2 kWh per day. Maximum daily electrical generation occurred in the months of March through May, with the maximum daily PV system output totaling 8.72 kWh on March 30. The peak value of power production was 1,224 watts (AC) and occurred on March 29. The decrease in daily output during the summer months, originally seen in 2002, was not as dramatic during 2003. Much of this may be attributed to the improved thermal performance of the new inverter.

Table 9 One-year summary of electric energy supply and use (House A)

Period	PV Production		Total House Use		PV Feedback	Net-Utility*	TOU-Utility**
	kWh	kWh/day	kWh	kWh/day	KWh	kWh	kWh
Dec-02	150	4.9	744	24.0	78	594	672
Jan-03	187	6.0	560	18.1	102	372	474
Feb-03	129	4.6	527	18.8	60	398	457
Mar-03	191	6.2	524	16.9	109	333	441
Apr-03	225	7.5	351	11.7	144	126	271
May-03	216	7.0	568	18.3	77	352	429
Jun-03	208	6.9	852	28.4	9	644	653
Jul-03	194	6.3	1,148	37.0	6	954	960
Aug-03	191	6.2	1,026	33.1	11	835	846
Sep-03	198	6.6	925	30.8	12	728	740
Oct-03	204	6.6	576	18.6	67	372	438
Nov-03	168	5.6	490	16.3	101	322	423
Totals	2,262	6.2	8,291	22.71	775	6,028	6,804

* "Net-Utility" credits the PV to the homeowner by turning the meter backwards (net-metering)

** "TOU-Utility" does not receive credit for the PV power fed back to the utility

Table 10 One-year summary of electric energy supply and use (House B)

Period	PV Production		Total House Use		PV Feedback	Net-Utility*	TOU-Utility**
	kWh	kWh/day	kWh	kWh/day	kWh	kWh	kWh
Oct-02	141	4.5	454	14.6	79	313	392
Nov-02	135	4.5	433	14.4	84	298	383
Dec-02	115	3.7	584	18.8	58	469	528
Jan-03	147	4.7	552	17.8	85	405	490
Feb-03	101	3.6	521	18.6	50	420	470
Mar-03	161	5.2	533	17.2	94	372	466
Apr-03	187	6.2	406	13.5	110	218	328
May-03	170	5.5	748	24.1	70	578	647
Jun-03	165	5.5	874	29.1	28	709	737
Jul-03	155	5.0	1,001	32.3	7	846	854
Aug-03	161	5.2	873	28.2	13	712	725
Sep-03	164	5.5	758	25.3	47	594	641
Totals	1,801	4.9	7,737	21.2	725	5,936	6,661

* "Net-Utility" credits the PV to the homeowner by turning the meter backwards (net-metering)

** "TOU-Utility" does not credit the PV fed back to the utility

A number of details are of particular interest in this performance summary:

- The PV output is very consistent from month to month indicating good solar resource and reliable operation of the PV-related equipment.
- The house energy use is driven by cooling system operation.
- The PV system feedback to the utility is minimal during the summer months and very high during the swing seasons, matching the utility rate structure.
- Net-metering saves about 11% of the total home's energy usage, compared to non-net metering options specific to these PV systems.

Figures 16 through 19 graphically represent the proportion of electricity produced by the PV system relative to the utility produced portion, by month and annually over a one-year period.

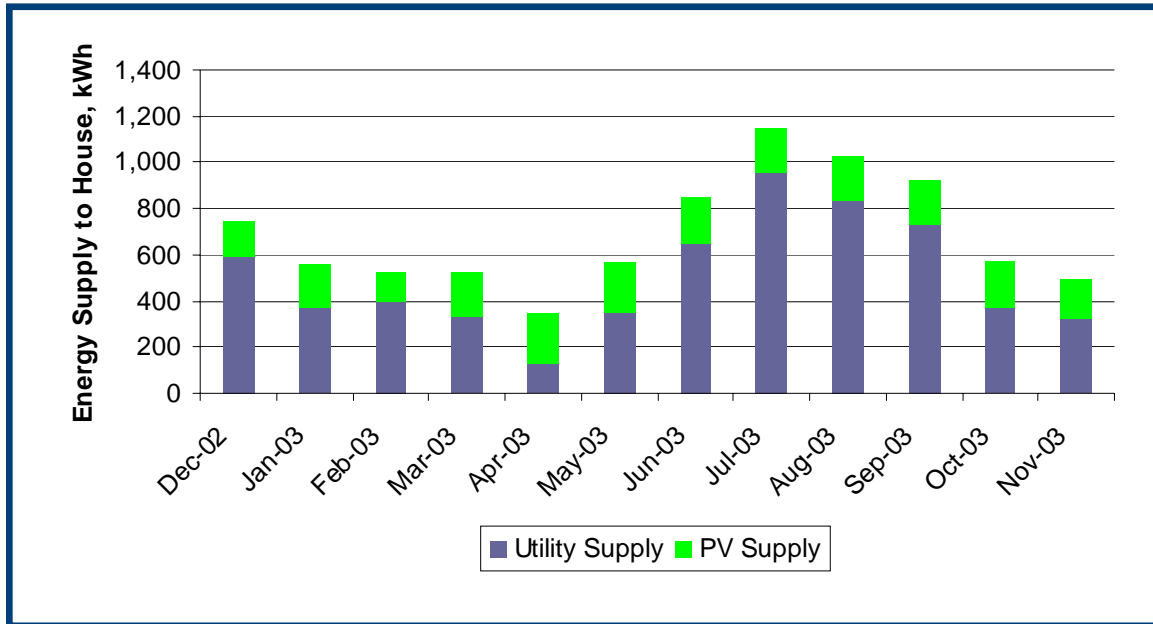


Figure 16: Graphical Summary of Electric Supply to House A

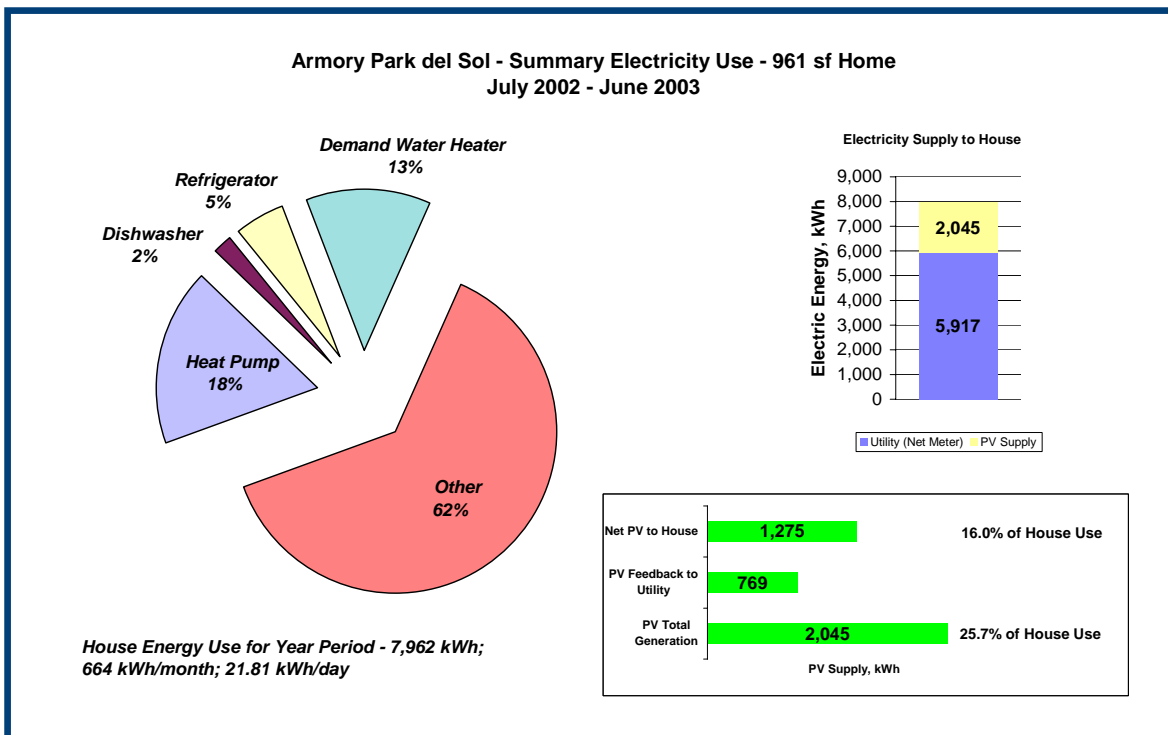


Figure 17: Summary of Electric Loads and Supply for House A

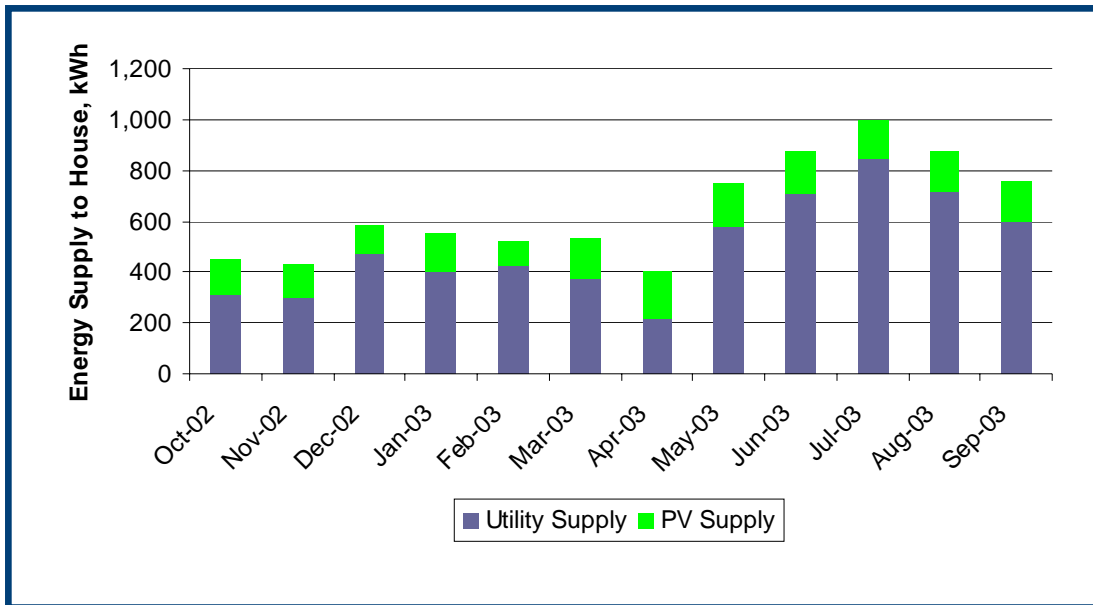


Figure 18: Graphical Summary of Electric Supply to House B

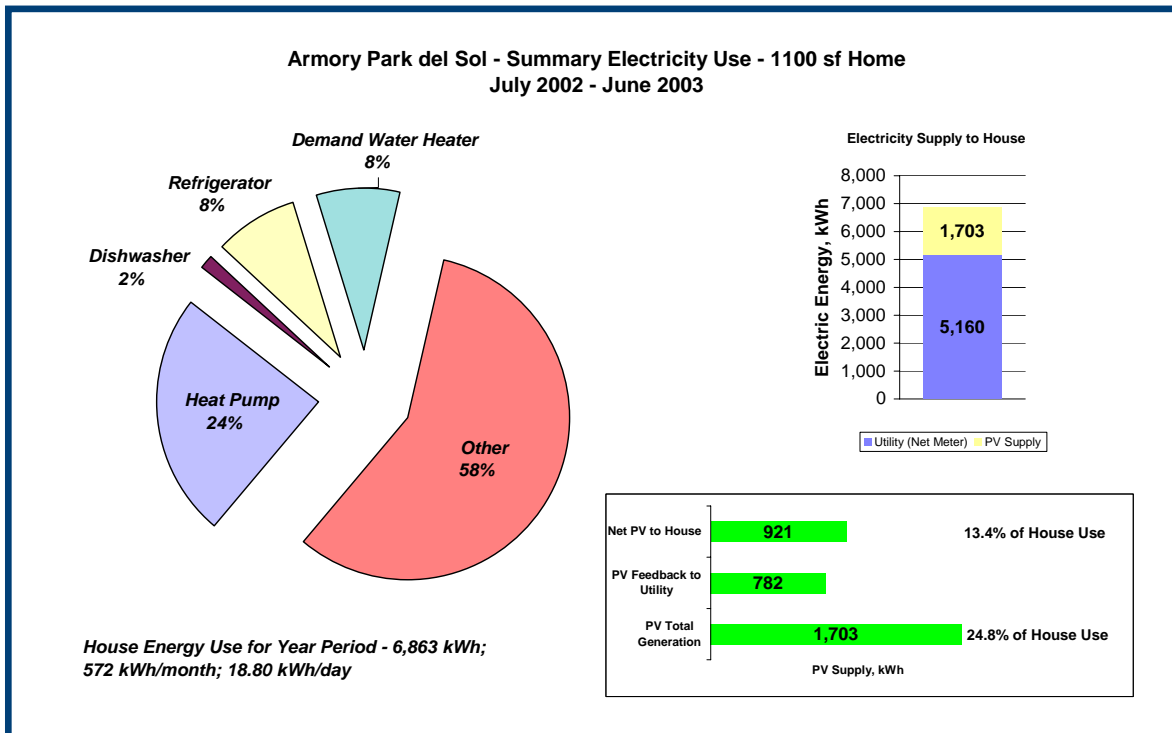


Figure 19: Summary of Electric Loads and Supply for House B

8.0 TIME-OF-USE ENERGY AND UTILITY RATE ANALYSIS

An analysis of photovoltaic (PV) system performance and household energy consumption can provide a number of informative results, including the percent of home electrical consumption provided by a PV system, the amount of electricity produced by a PV system which is fed back to the utility grid, and the seasonal variation of PV system electrical generation actually used at the home instead of being contributed to the utility grid for use by other electric customers. Also of importance is the issue of PV system cost-effectiveness to the homeowner, and correspondingly which type of electric rate schedule is most beneficial to a homeowner with a PV system.

Tucson Electric Power Company offers a time-of-use (TOU) electric rate to qualified residential customers who have solar photovoltaic and/or solar hot water systems installed at their homes. The Special Residential Schedule No. 201c has on-peak, shoulder, and off-peak electricity costs for three different seasons, "Mid-Summer," "Winter," and "Remaining Months". Net metering is not available under this rate (*i.e.*, customers are not compensated for any electricity sent back to the utility grid from their PV systems). All electricity delivered to the home from the grid is charged at the rate corresponding to the season and time of day. By contrast, Residential Schedule No. 1, the basic flat electric rate for residential customers, does compensate for all PV electricity sent back to the grid. Under this net-metering rate schedule, customers are charged monthly for their net electrical consumption, which is the grid-supplied consumption less the PV feedback to the grid. Charges for the two rate schedules are listed in Table 11.

Table 11 Residential electric rate schedules for Tucson Electric Power Company

Tucson Electric Power Company		<i>Rates Effective as of July, 2000</i>	
Tucson, Arizona			
Residential Schedule No. 1			
	\$4.90	/month	Customer Charge
	\$0.090921	/kWh	May – Oct
	\$0.078970	/kWh	Nov – Apr
Special Residential Schedule 201c			
	\$6.78	/month	Customer Charge
<i>on-peak:</i>	\$0.184171	/kWh	Jun – Aug 1 - 6 pm, Mon - Fri
<i>shoulder:</i>	\$0.116318	/kWh	6 - 8 pm, Mon - Fri
<i>off-peak:</i>	\$0.058160	/kWh	8 pm – 1 pm, Mon - Fri
<i>on-peak:</i>	\$0.137207	/kWh	May, Sep - Oct 1 - 6 pm, Mon - Fri
<i>shoulder:</i>	\$0.086658	/kWh	6 - 8 pm, Mon - Fri
<i>off-peak:</i>	\$0.043328	/kWh	8 pm - 1 pm, Mon - Fri
<i>on-peak:</i>	\$0.093879	/kWh	Nov – Apr 7 - 11am & 6 - 9pm, Mon - Fri
<i>off-peak:</i>	\$0.032491	/kWh	11am - 6pm, 9pm - 7am, Mon – Fri
<i>Note: All hours during weekends and holidays are off-peak.</i>			

Electrical monitoring of the two subject homes at Armory Park provides 15-minute data for both house electrical consumption and PV system power production. An analysis of this data along with the two rate schedules listed above was performed to determine which rate schedule is most cost-effective for the homeowner. The PV systems were installed in 2002 and were changed slightly over the summer of 2002. The period of our analysis for the two homes is slightly different, but is for a total of twelve months each. Both homes have been billed by the utility under the TOU schedule since their construction.

Table 12 summarizes the electrical consumption and PV system production during the subject periods for the two homes, if billed under a standard residential rate with net metering. Under this arrangement, all excess solar generation fed back to the utility is credited at its full value to the customer. At many times of the day, the PV systems at both homes did produce excess electricity that was fed back onto the grid. Under standard billing arrangements, this energy is credited on a continual basis and is balanced against the energy purchased from the utility on a monthly basis.

The total values for the twelve month periods are shown in the table as the kWh credited under net metering. The percentage of this energy to the total produced by the PV systems was between 34% - 40%. Electricity charges for this flat-rate schedule are also shown here, including both energy costs and customer charges and a graphical representation of the data on a monthly basis is shown in Figures 20 and 21.

Table 12 Electric supply and use summary - Utility flat rate, net-meter

Energy Characteristic	Test House A (961 sf)		Test House B (1100 sf)	
Period of Data Monitoring	11/02/02 – 11/01/03		9/24/02 – 9/23/03	
Total Electric Used in the Home	8,291 kWh		7,737 kWh	
Total Electric Produced by PV	2,262 kWh		1,801 kWh	
PV Electric Used Directly in the Home	1,487 kWh		1,076 kWh	
Electricity Purchased from Utility	6,028 kWh		5,936 kWh	
PV electricity credited by Utility (flat rate scenario)	775 kWh		725 kWh	
PV electricity not-credited by Utility (TOU rates)	0 kWh		0 kWh	
PV Portion of House Consumption	27%		23%	
Electricity Cost for Period	\$522.49	\$0.087/kWh	\$513.62	\$0.086/kWh
Customer (Meter) Charge	\$58.80	\$4.90/month	\$58.80	\$4.90/month
Total Utility Cost for Period	\$581.29	\$48.44/month	\$572.42	\$47.70/month

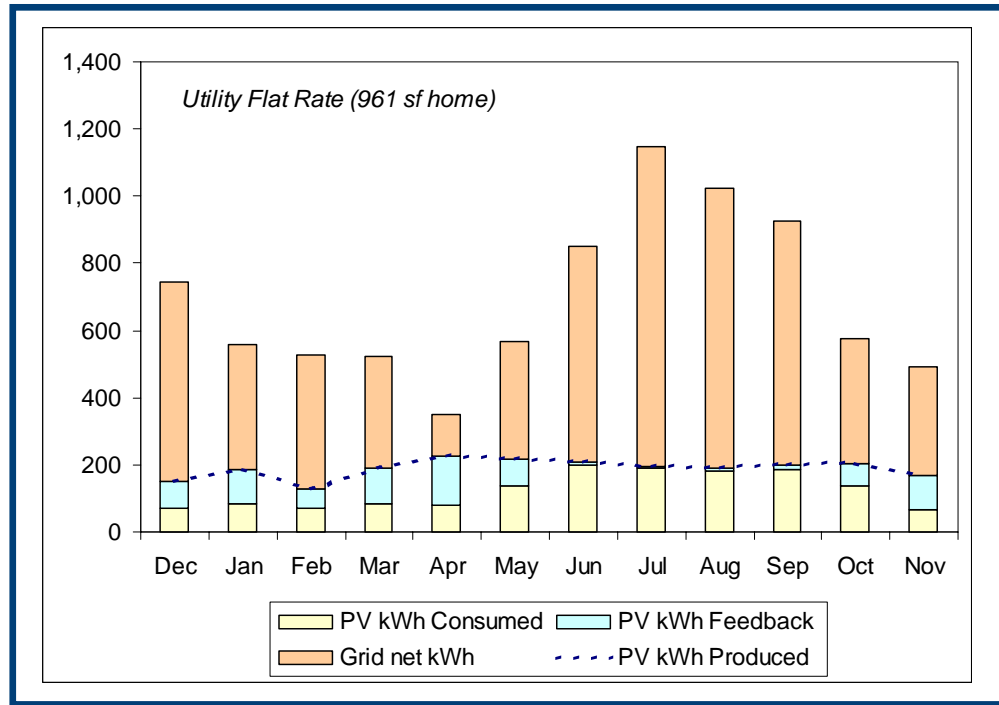


Figure 20: Monthly Electric Supply to House A

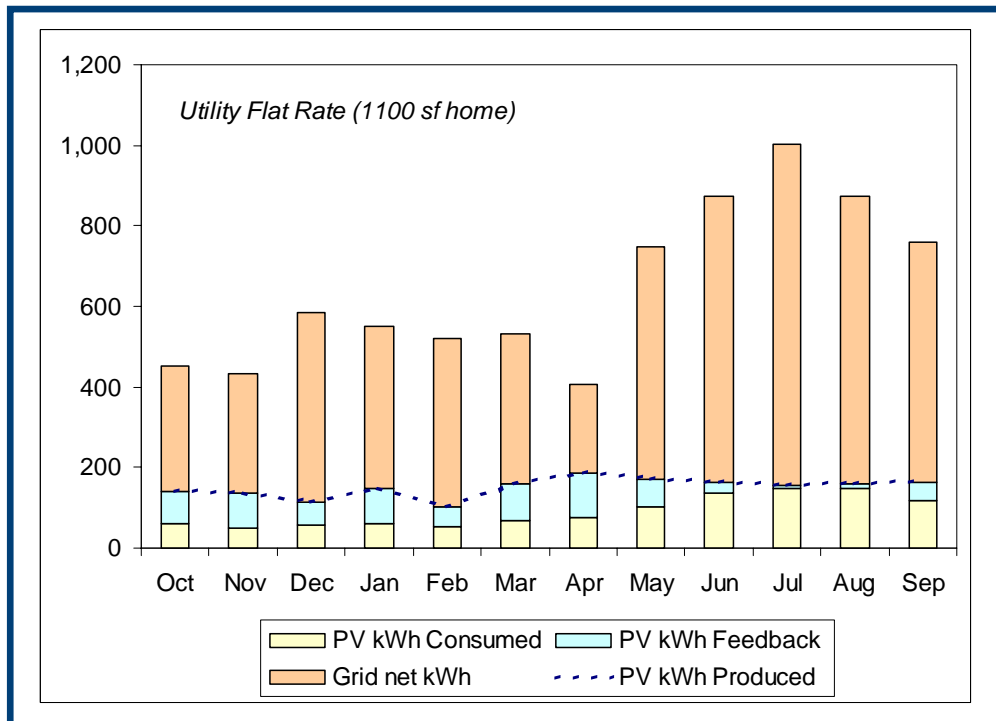


Figure 21: Monthly Electric Supply to House B

An analysis was performed for the same time period using the actual 15-minute data to compare utility billing under the time-of-use schedule. Under this agreement, the excess generation by the PV system is not credited to the customer. The economic value of the energy offset by the PV system (consumed by home) is higher, however, than under the flat-rate schedule, since a large percentage of the PV system's energy production coincides with household energy use and occurs during peak-rate periods. Table 13 shows how the actual consumption of the home and production of the PV system is billed by the utility under a TOU arrangement. A graphical monthly summary of the data can also be seen in Figures 22 and 23.

Table 13 Electric supply and use summary - Utility time-of-use rate, no net-metering

Energy Characteristic	Test House A (961 sf)		Test House B (1100 sf)	
Period of Data Monitoring	11/02/02 – 11/01/03		9/24/02 – 9/23/03	
Total Electric Used in the Home	8,291 kWh		7,737 kWh	
Total Electric Produced by PV	2,262 kWh		1,801 kWh	
PV Electric Used Directly in the Home	1,487 kWh		1,076 kWh	
Electricity Purchased from Utility	6,804 kWh		6,661 kWh	
PV electricity credited by Utility (net meter)	0 kWh		0 kWh	
PV electricity un-credited by Utility (no net meter)	775 kWh		725	
PV Portion of House Consumption	18%		14%	
Electricity Cost for Period (average)	\$456.34	\$0.067/kWh	\$417.33	\$0.063/kWh
Customer (Meter) Charge	\$81.36	\$6.78/month	\$81.36	\$6.78/month
Total Utility Cost for Period	\$537.70	\$44.81/month	\$498.69	\$41.56/month

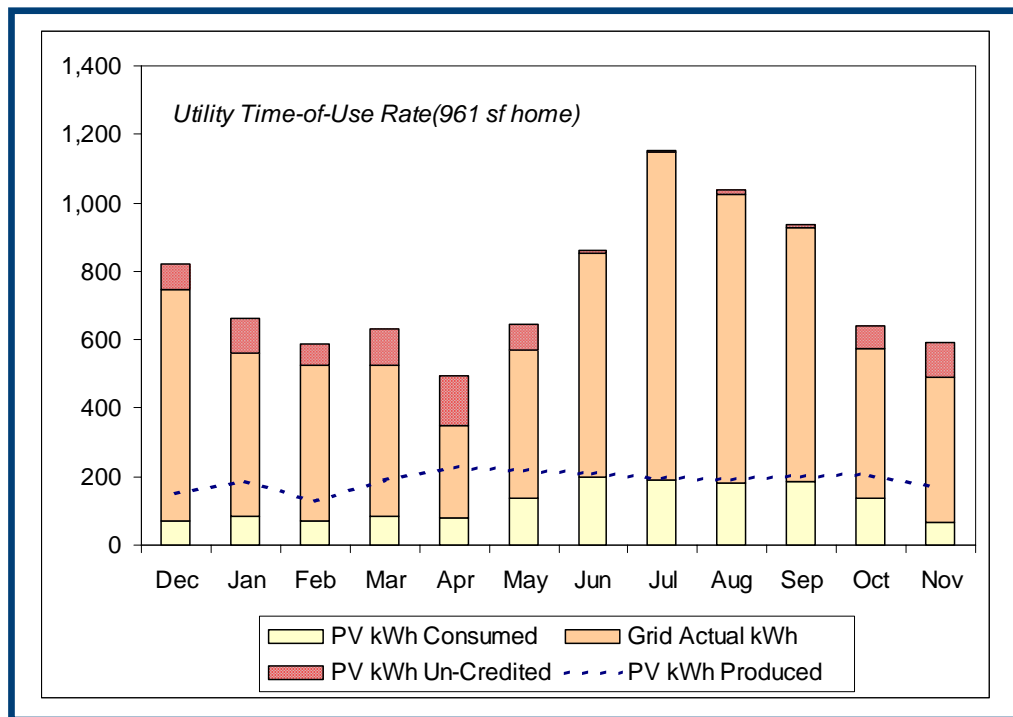


Figure 22: TOU Rate application to monthly electric supply to House A

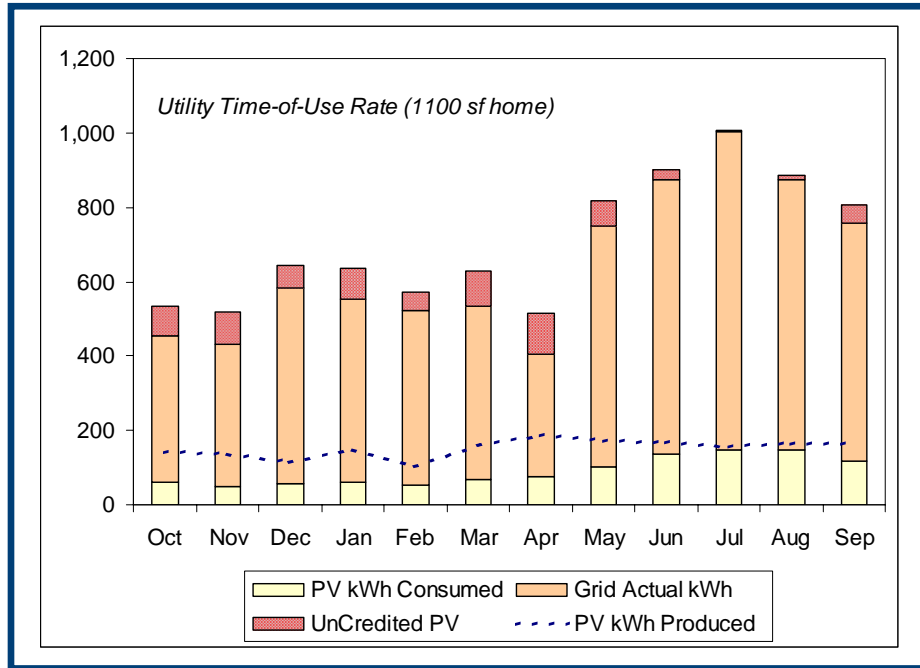


Figure 23: TOU rate application to monthly electric supply to House B

It is interesting to note how, in both homes, the PV systems rarely produced excess generation to the grid during the major cooling months of the year. The PV systems' generation is also fairly consistent throughout the year due to the exceptional solar resources of the Tucson area. It appears that the homeowners would not benefit from a switch to a flat rate net-metered schedule despite the fact that up to 40% of the total PV systems' production currently is uncredited by the utility. This will not be the case for all homes, since it is highly dependent on the pattern of daily demand in the home, the solar resource, and the utility rate schedule. A combination of TOU rates with net metering would certainly be the best option for these homeowners, but is not currently available.

9.0 CONCLUSIONS

A more in-depth analysis of data and conclusions will be provided in the Final Report.