MULTI-YEAR ADVANCED RESIDENTIAL BUILDING SYSTEMS RESEARCH

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Gate 2 - Prototype House Evaluations: *ZEH2 (JWM Companies)*

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STAGE GATE 2—PROTOTYPE HOUSE EVALUATIONS: JOHN WESLEY MILLER COMPANIES ZEH2

INTRODUCTION

Armory Park del Sol (APdS, pictured in Figure 1) is an urban infill project in an historic district in downtown Tucson, Arizona. When completed, the inner city subdivision will include over 92 homes that blend with the historic neighborhood yet include high performance features to dramatically reduce their energy footprint. All of the homes are designed to meet the voluntary Tucson Sustainable Energy Standard by performing 50% better than the Model Energy Code in addition to meeting the 2003 IECC.

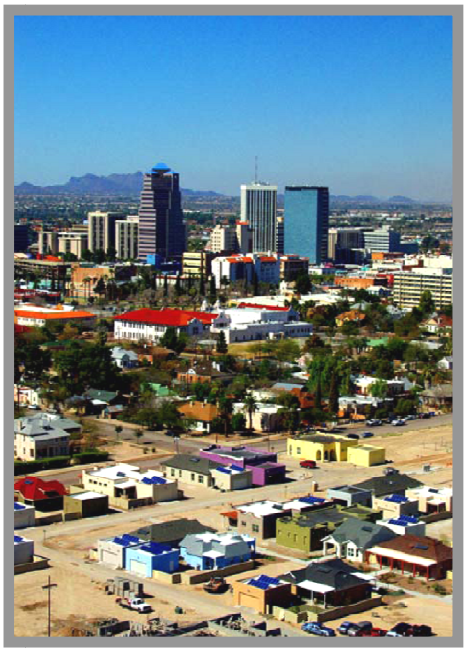

Figure 1 - Armory Park del Sol Development in Tucson, AZ

In addition, all of the homes in the subdivision have solar hot water and photovoltaic (PV) systems. In 2003, the builder completed its first net-Zero Energy Home (ZEH1) that included enhanced efficiency features and larger solar systems than other homes in the neighborhood. ZEH1 has achieved as much as a 90% net reduction in use of utility-supplied energy and is shown in Figure 2. In 2007, a second ZEH (ZEH2) with upgraded energy features was subsequently constructed with the goal of achieving 100% net reduction in the use of utility-supplied energy as shown in Figure 3. In December 2008, homeowners moved into ZEH2.

This report summarizes the design and construction of ZEH2 at Armory Park del Sol. Although this is a community of high performance homes, the ZEH2 serves the Stage Gate 2 process well as it goes beyond the builder's standard home design (40% to 50% savings on the BA Benchmark) to achieve the net-Zero Energy Home designation. This ZEH designation is for 100% of the energy use in the home. The use of the ZEH2 as a prototype home design is meant to be highlighted as a model for a full net-ZEH construction achievable in the Tucson climate.

Figure 2 - ZEH1 at APdS

Figure 3 - ZEH2 at APdS

HOUSE DESCRIPTIONS

Typical Regional Construction

Typical Tucson residential construction methods are similar to those across much of the U.S. Homes in this region are usually built on slab-on-grade foundations with light framed, 2"x4" walls having cavity insulation. Due to the stucco exterior cladding that is common in this region, exterior foam insulation is often applied to house exteriors. Heating and cooling equipment and appliances are typically federal minimum/standard efficiency and solar water heating and photovoltaic systems are not typically included on new homes in Tucson.

Standard Armory Park del Sol (APdS) Homes

Homes in APdS range in size from 977 s.f. to 2,457 s.f. Their construction is unique in that walls are constructed of solid-filled concrete masonry block on an engineered floating slab foundation. All homes in the neighborhood are designed to meet the rigorous efficiency requirements of the Tucson Sustainable Energy Standard. Each home is well insulated (including the slab edge), has a tightly sealed building envelope, includes efficient windows, has efficient mechanical equipment and a well-designed and tightly constructed duct system, uses fluorescent lighting, has a batch-type solar water heater with tankless back-up and insulating water piping, and a moderately sized photovoltaic (PV) system that is designed to produce about 15% to 20% of a home's annual energy consumption.

ZEH2 Home

ZEH2 is a 2,168 square-foot, single-story home having 3-bedrooms, 2½ baths, and an attached heated office area that adds an additional 289-s.f. of independently controlled conditioned space to the single-family house. ZEH2 incorporates all of the standard energy efficient features typical of homes constructed in APdS but includes some modifications and upgrades to enhance performance. A comparison of energy features of the typical regional, standard APdS, and ZEH2 home designs are shown in Table 1.

Table 1 - Comparison of Energy Features and Value

House Feature	Typical Regional Construction	Armory Park del Sol Standard	Armory Park del Sol – ZEH2
Foundation	4" slab	10" float slab	10" float slab
Foundation Insulation	0	R-10	R-10
Wall Construction	2x4 Wood Frame	Concrete Block solid fill	Concrete Block solid fill
Wall Insulation[1]	R-13 + R-3	R-10	R-13
Ceiling Insulation[1]	R-30	R-38	R-38 + R-6.5
Window Ratings[1]	U-0.57/SHGC-0.4	U-0.35/SHGC-0.29	U-0.30/SHGC-0.32
Air Leakage (typical)[2]	0.45 ACH_{nat}	0.20 ACH_{nat}	0.20 ACH_{nat}
Fresh Air Ventilation	None	Yes	Yes
Heating and Cooling Duct Location	Garage and Attic	All within the House	All within the House
Heating Efficiency[1]	7.7 HSPF	8.5 HSPF	9.3 HSPF
Cooling Efficiency[1]	13 SEER	14 SEER	17.6 SEER
Hot Water System	Standard Tank	Passive Solar with Electric Demand	Active Solar with Electric Demand
Lighting	Standard Efficiency	50% High Efficiency	90% High Efficiency
Solar Electric System	0 watts	1,000 Watt – 1,600 Watt	6,930 watts

[1] *Higher values indicate better performance*
[2] *Lower values indicate better performance*

Efficiency features of the ZEH2 are further described below.

Foundation
As with all APdS homes, the ZEH2 foundation is a 10- to 12-inch-thick concrete float slab that includes full-height R-10 slab edge insulation. The slab extends above grade to allow for drainage.

Walls
Like the other homes in the neighborhood, ZEH2 is designed in the Southwestern style and constructed with solid-filled masonry block walls as shown in Figure 4. Exterior wall insulation is upgraded from the typical R-10 foam to two-inch thick (R-13) polyisocyanurate insulation. Like the other homes, a standard 3-coat stucco finish is applied to the exterior of the insulation and interior block walls are skim coated plaster.

As with other APdS homes, the windows of the ZEH2 are carefully located and selected. Most of the glazing faces north and is shaded by a wrap-around porch as shown in Figure 5. The garage/storage area is located to the west of the home so there are no western-facing windows. There are few windows on the south side of the home. Therefore, the selected windows have a higher u-factor than that of typical APdS. The ZEH2 windows have a U-value of 0.30 and a Solar Heat Gain Coefficient of 0.32.

Figure 4 - Typical APdS Block Wall Construction

Figure 5 - Porches Provide Shading at ZEH2

Ceiling/Attic and Roof

As with most of the homes in the development, ZEH2 incorporates a low-slope roof design. ZEH2 uses the standard I-joist and R-38 fiberglass insulation, but includes an additional inch of polyisocyanurate foam (R-6.5) on the roof deck. This system is expected to perform better than the typical APdS system not only because of its higher R-value, but also because the continuous layer of foam reduces thermal shorts through framing members. As with the other homes at Armory Park del Sol, the roof's reflective surface coating reduces summertime solar gains.

HVAC System

Heating and cooling in the ZEH2 is provided by an ultra-efficient heat pump rated at 17.6 SEER (cooling) and 9.3 HSPF (heating). The heat pump has a two-stage compressor and the air handling unit has a variable speed blower for more comfortable and efficient air delivery. Like the standard APdS homes, all equipment and ductwork are located within the conditioned envelope, total duct leakage does not exceed 5% of air handler fan flow, and crossover ducts provide a return air path to the air handler from all rooms for balanced airflow throughout the home.

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 into the home.

Air Infiltration

Careful attention to air sealing detailing was paid during the construction of ZEH2. Air infiltration was minimized by block wall construction, spray foam sealants, and caulking. The ZEH2 air infiltration rate, tested by Tucson Electric Power, was 740 CFM50, or about 2.05 ACH50.

Plumbing System

A manifold plumbing system with small diameter PEX tubing supplies hot water to fixtures through dropped ceilings. This plumbing design deviates from the typical Armory Park del Sol plumbing system in which insulated copper tubing runs below the slab. As noted previously, the manifold system provides both an energy- and water- saving benefits. An active solar water heating system preheats domestic hot water that is stored in an 80-gallon tank. If necessary, water temperature is boosted by an electric demand heater located centrally to the fixtures in the house. A tankless heater not only minimizes standby losses but also provides an excellent complement to solar preheated water because it has infinitely variable power level to attain a preset outlet temperature. With its small size and without a requirement for an automatic Temperature & Pressure valve, the tankless water heater can be easily located in a small utility space in the home or even in an accessible wall cavity section.

Lighting and Appliances

All of the permanent lighting fixtures are fluorescent. Ideally, the additional plug-in fixtures will also be fluorescent, but that depends on the homeowner. In addition, all major appliances (washer, refrigerator, dishwasher) are ENERGY STAR-labeled.

Solar Systems

ZEH2 has an active solar water heating system and a 6.93-kW (dc) photovoltaic system. The solar hot water heating system, depicted in Figure 6, preheats domestic hot water, which is stored in a tank. When domestic hot water is needed, the preheated water flows through the tankless water heater where its temperature is boosted, if necessary. From there, the hot water flows to a central manifold and to the outlets.

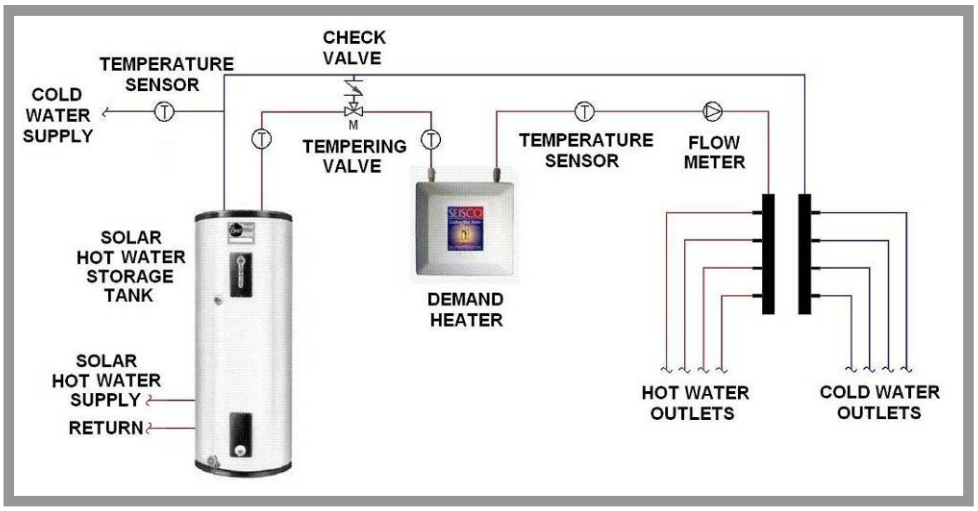

Figure 6 - ZEH2 Domestic Hot Water System Diagram

Solar thermal and electric collector areas for the ZEH2 design are significantly larger than typical APdS systems. Part of the ZEH2 photovoltaic system is shown in Figure 7. Because the system is grid-tied, the electricity produced can be used directly in the house to reduce the electricity purchased from the utility company and excess electricity can be sent back to the utility for credit through a net-metering arrangement.

Figure 7 - ZEH2 PV System

BUILDING AMERICA STAGE GATE PERFORMANCE CRITERIA

The Building America research objective for Stage Gate 2 is to evaluate the cost effective integration of advanced systems with production building practices in prototype homes using results from field tests and energy simulations. This process includes "must meet" criteria including source energy savings (joule targets), prescriptive-based code approval, and quality control requirements. In addition, the process also has recommended "should meet" criteria including neutral cost target, quality control integration, and gaps analysis.

Source Energy Savings ("must meet")

The method of calculating the source energy savings of the ZEH2 was performed by applying the Building America (BA) benchmark procedure to establish a baseline energy performance. The BA benchmark home is modeled as a home of the same size in the same climate region as the prototype home (ZEH2), but that uses construction materials and practices typical of homes built in the mid-1990s. The BA benchmark procedure establishes an estimated energy savings for high performance homes using a whole house approach (e.g., factoring all building materials and methods, systems, lighting, appliances).

Simulations and preliminary monitoring data indicate that the Building America goal of designing and constructing a home that can produce as much energy as it consumes is practical and achievable with current technologies in the hot-mixed dry climate of Tucson. ZEH2 offers a set of construction methods and materials as well as mechanical equipment that, when combined with renewable energy technologies, serves as a standardized design for an actual net-zero energy home in this climate. Now that ZEH2 is occupied (as of December 2008), the energy performance of the house will be monitored for at least one year to verify the degree to which the zero energy goal is achieved. Analysis of the performance of other APdS homes, either through monitoring or through a utility bill analysis, will be used to verify the predicted savings of these homes.

Energy Simulation Inputs

Per the *Building America Performance Analysis Procedures*, three simulations were conducted using EnergyGauge hourly residential energy simulation software to estimate the annual energy consumption of each home. The first was the benchmark or base case simulation as defined by the *Building America Research Benchmark* procedures. The benchmark home provides a consistent reference from which to compare energy savings nationally. The second simulation was the typical regional house, and the third was the ZEH2 including all of the energy efficiency features of the ZEH2 design.

Benchmark Simulation Input

Per *BA Benchmark*[1] procedures, the benchmark simulation was developed using the ZEH2 layout and dimensions. It includes the same square footage and orientation as the ZEH2 and the standard features such as a one-story slab foundation with an 11-foot ceiling height. 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 ZEH2 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- 1990s. Using this reference point as the base for comparison assures stable and progressive comparisons against which energy savings may be determined. For DOE's Building America program, the energy savings is considered on a national scale and can represent fundamental changes in construction practices that

[1] *Building America Research Benchmark Definition*, NREL, Updated December 19, 2008

lead to higher levels of energy savings; hence the importance of having a consistent and stable benchmark that can be universally applied across the country. Per Building America Performance Analysis Procedures, heating and cooling set points of 71°F and 76°F, respectively, were used in all simulations.

Typical Regional Simulation Input

Modeling a typical regional home, in addition to the BA benchmark home, provides a basis for comparison of energy savings with a home that is reflective of the current regional housing market. Especially when evaluating costs, it is important to understand what is available to buyers in the region so that the additional cost of building the prototype home and the associated utility cost savings would be with respect to other new homes on the market. The Typical Regional home simulation has the same square footage, orientation, and window area as the ZEH2. Most of the remaining inputs are the same as the BA Benchmark house with the exception of upgraded insulation (ceiling, wall, R-3 exterior rigid foam), window U-value and solar heat gain properties, federal minimum equipment efficiencies, and duct location.

Prototype ZEH2 Simulation Input

As with the benchmark and regional simulations, the ZEH2 prototype house is modeled with the actual ZEH2 house layout and dimensions including window areas, window type, window overhangs, and wall construction. Energy efficiency features reflect those that were installed in the house, including a cooling system rated at 17.6 SEER, a heating system rated at 9.3 HSPF, and 90% fluorescent lighting (10% incandescent), efficient appliances, an active solar hot water system, and a 6.93-kW (dc) PV system.

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 simulation, electric utility rates were assumed to be $0.10/kWh, which is representative of local Tucson Electric Power residential rates. The NAHB Research Center used the energy simulation software to estimate annual performance of the three homes. Simulated energy use, costs, and estimated annual PV output for ZEH2 are found in Table 2.

Table 2 - Simulation Result Comparison

End-Use	Benchmark		Typical Regional		ZEH2 Prototype	
	Avg. Energy Consumption (kWh)	Average Annual Cost ($)	Energy Consumption (kWh)	Annual Cost ($)	Energy Consumption (kWh)	Annual Cost ($)
Heating	4,043	$405	3,750	$375	1,158	$116
Cooling	9,835	$984	5,396	$540	1,564	$156
Hot Water	2,869	$287	2,876	$288	181	$18
Lighting	2,775	$278	2,773	$277	1,121	$112
Appliances						
Dishwasher	206	$21	206	$21	87	$9
Range	605	$61	604	$60	909	$91
Refrigerator	669	$67	669	$67	580	$58
Clothes Washer	105	$11	105	$11	239	$24
Clothes Dryer	835	$84	835	$84	835	$84
Misc.	3,336	$334	4,130	$413	3,336	$334
OA Ventilation	40	$4	424	$42	198	$20
Annual Sub-Total	*25,318*	*$2,532*	21,768	$2,178	*10,208*	*$1,021*
PV Produced	0	$0	0	$0	-11,840	-$1,184
ANNUAL TOTALS	**25,318**	**$2,532**	**21,768**	**$2,178**	**-1,632**	**-$163***

* Based on current TEP net-metering rules, any credit remaining at the end of the calendar year is zeroed with no cost reimbursement to the PV system owner.

Source Energy Savings

While energy cost savings are one metric of energy efficiency, the BA joule targets are based on source energy savings. Table 3 outlines source energy use for the benchmark, typical regional, and ZEH2 prototype and the source energy savings of ZEH2 with respect to the benchmark and the typical regional homes. For ZEH2, the source energy savings results indicate a 60% reduction in energy use from the BA Benchmark. Since the homes are all electric, the source energy savings and the site energy savings are the same.

Table 3 - Source Energy Savings

	Estimated Annual Source Energy			Source Energy Savings			
				Percent of End-Use		Percent of Total	
End Use	Benchmark (MBtu/yr)	Typical Regional (MBtu/yr)	ZEH2 (MBtu/yr)	BA BM Base	Regional Base	BA BM Base	Regional Base
Space Heating	46.4	43.1	13.3	71%	69%	11%	12%
Space Cooling	112.9	62.0	18.0	84%	71%	33%	18%
DHW	32.9	33.0	2.1	94%	94%	11%	12%
Lighting	31.9	31.8	12.9	60%	59%	7%	8%
Appliances & MELs	66.1	75.2	68.7	-4%	9%	-1%	3%
OA Ventilation	0.46	4.9	2.27	-393%	54%	-1%	1%
Total Usage	290.7	250.0	117.3	60%	53%	60%	53%
Site Generation			-135.9			47%	54%
Net Energy Use	290.7	250.0	-18.6	106%	107%	106%	107%

PV System Sizing

One goal of simulating energy use is to determine the extent to which energy efficiency can reduce whole-house energy consumption towards the goal of net-zero annual energy consumption. Due to the expense of PV-generated electricity and the unobstructed roof area needed for PV panels, energy efficiency is the first priority when designing a net-zero energy home. When increasing efficiency becomes technologically impossible or cost prohibitive, PV capacity is then added to achieve a net-zero annual energy house.

For ZEH2, an energy efficiency package was selected based on economic and practical design decisions. With the energy features only for ZEH2, the simulation estimated annual energy use at 10,208 kWh (without PV). At $0.10/kWh, this corresponds to an annual electric bill of $1,021. To offset this consumption, a 6.93 kW (DC) PV system, which in Tucson is estimated to produce 11,840 kWh of electricity per year, was selected.

Table 4 summarizes the estimated annual energy consumption of the BA benchmark, typical regional, and ZEH2 prototype homes and the energy produced by the ZEH2 PV system. Using these estimates, the annual ZEH2 electricity consumption should be less than zero. However, the bill may not be less than zero due to electric utility service charges that are incurred regardless of consumption.

Table 4 - Simulation Summary Results

Simulation	Energy Consumption			PV Energy Production		Annual Total		
	Energy Use (kWh)	Annual Cost ($)	Savings	Energy Use (kWh)	Annual Cost ($)	Energy Use (kWh)	Annual Cost ($)	Savings over Benchmark
Benchmark	25,318	$2,532	-	-	-	25,318	$2,532	-
Regional	21,768	$2,177	-17%	-	-	21,768	$2,177	-17%
ZEH2	10,208	$1,021	-60%	-11,840	-$1,184	-1632	-$163	100%+

Prescriptive-Based Code Approval ("must meet")

The purpose of this stage gate criterion is to meet all prescriptive or performance safety, health, and building code requirements for new homes. The ZEH meets all the local safety, health, and building code requirements for new construction in Tucson, including the 2006 International Building Code and the 2006 International Energy Conservation Code, both with local amendments. In addition to standard local code inspections, the ZEH2 was also inspected and tested by the local utility, Tucson Electric Power (TEP) under its Guarantee Home program. The ZEH2 complies with TEP's Guarantee program requirements for energy efficiency and performance and, hence, qualifies for a five-year heating/cooling and comfort guarantee. In addition, the home meets the voluntary Tucson Sustainable Energy Standard by performing 50% better than the 1995 Model Energy Code. The ZEH2 is also a Builders Challenge house and qualified for the builder federal tax credit when completed in 2007.

Quality Control Requirements ("must meet")

Because the builder did not deviate significantly from its standard construction methods when building the ZEH2, the company's standard quality control procedures were implemented in ZEH2. However, certain unique details and specifications of the ZEH2 were included on the plans and the scope of work to facilitate installation and oversight.

The purpose of quality control requirements as a stage gate criterion is to enable builders and contractors to successfully implement new systems by defining critical design details, construction practices, training, quality assurance, and quality control. The first step was to define the details and specifications of the ZEH2 plan during the design phase as shown in Table 5 and to include them on the ZEH2 plans and/or in scopes of work for the trades.

Table 5 - ZEH2 Design Details

Details for the Plans	Approach Selected for ZEH2	Detail to be Included on Plan	Detail to be Included in Scope of Work
Building Science & Systems Approach	Discussed during builder weekly meeting	n/a	n/a
Site Drainage, Pest Control, Landscaping	Float slab, spray for termites, landscape plan	Yes	Yes
Foundation System Moisture & Soil Gas Control	n/a - because of slab design	n/a	n/a
Structural Moisture Control			
Window/door flashing details	Per stucco installation requirements	No	Yes
Wall/roof flashing details	Metal flashing	Yes	Yes
Vapor retarder	n/a – due to climate & masonry wall construction	n/a	n/a
Structural Air Sealing			

Details for the Plans	Approach Selected for ZEH2	Detail to be Included on Plan	Detail to be Included in Scope of Work
Air Barrier	Via to masonry wall construction	Yes	n/a
Air sealing details	Per builder & TEP program specifications	No	Yes
Structural Thermal Performance			
OVE framing Insulated corners Reduce waste wood Raised heel trusses	Masonry wall construction with roof framed using engineered lumber	Yes	Yes
Foundation Insulation	Slab edge	Yes	Yes
Exterior insulation	2" polyiso rigid foam insulation	Yes	Yes, change only in thickness
Wall Cavity Insulation	n/a	n/a	n/a
Ceiling Insulation	ceiling R-38 cavity w/ R-5 exterior deck	Yes	Yes for cavity, added R-5 to assembly for prototype
Windows	ENERGY STAR	Yes	Yes
Heating, Ventilating, & AC (HVAC)			
Sizing	Per ACCA Manual J	Yes	Yes
Equipment and Installation	Trane 19i heat pump	No	Yes, except equipment upgrade
Centralized mechanical room	In between kitchen & master bedroom	Yes	No, potential for designer priority list in future
IAQ & Ventilation			
Low VOC Interior Coatings			
Low VOC Adhesives			
Low Emission Cabinets			
Whole-house mechanical ventilation	Passive RA duct system, point exhaust from laundry/mechanical room	Yes	Yes
Ducts			
Sealing	Mastic per builder & TEP specifications	No	Yes
Ducts in conditioned space	Yes, compact duct system design	Yes	Yes
Hot Water System			
Distribution	PEX hot water manifold delivery system	Yes	Yes, except piping material change from typical practice
Water Heating	On demand electric	Yes	Yes
Preheat Systems	Solar closed-loop system	Yes	Yes, except system

Details for the Plans	Approach Selected for ZEH2	Detail to be Included on Plan	Detail to be Included in Scope of Work
			upgrade
Centralized water heater	Yes, in between kitchen & master bath	Yes	No, potential for designer priority list in future
Lighting, Appliances, & MELs			
Lighting	Primarily CFL	No	No, handled by builder
Appliances	Energy Star when supplied by builder	No	No, handled by builder
MELs	No control measures employed	No	No
Homeowner Manual	Covers maintenance and energy saving measures	n/a	No, provided by builder

Neutral Cost Target ("should meet")

According to the BA Stage Gate 2 Criteria, the home must demonstrate cost neutrality such that the initial investment in energy upgrades results is offset by the cost savings from reduced utility bills. Therefore the incremental annual cost of the energy improvements, when financed as a 30 year mortgage, should be less than or equal to the annual reduction in utility bill costs relative to the builder's standard home. To calculate cost neutrality, the NAHB Research Center obtained the cost of energy upgrades from the builder. Although the cost upgrades were well defined, there is potential for costs to be affected by market conditions or subject to the influence of the trade contractor based on volume pricing from the manufacturer, familiarity with the technology, regional availability of the technology, and corporate mark-up procedures, among other influences.

In this case, the ZEH2 is not cost neutral as shown in Table 6. The ZEH2 costs are detailed in Table 7. It is worth noting that the goal of the home, however was to achieve a net-zero energy home. While this does come at a premium, the cost neutral analysis does not take into account the advantage of shielding the homeowner from rising utility costs. In addition, at Armory Park del Sol, there are additional benefits to the upgrades from typical regional homes including the wall system. Therefore, homeowners buying any home at Armory Park may have additional benefits and reasons for purchase.

The upgrades of the ZEH2 from the typical Armory Park del Sol (APdS) home include an upgrade of the exterior rigid foam insulation from 1" standard to 2", a more efficient heat pump including an electronic air cleaner, a closed system solar hot water heater, and a larger PV system. To account for this, a second neutral cost analysis was performed to evaluate the cost neutrality using the Builder Standard Practice (standard Armory Park del Sol home) costs as the basis for the upgrade costs instead of code minimum costs. The costs used are shown in Table 7 and the results of the second cost neutral analysis is shown in Table 8. The ZEH2 efficiency features are cost neutral using the upgrade costs from the Builder Standard Practice.

Table 6 - Neutral Cost Worksheet for ZEH2

	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	4,043	884	1,158	$289	$0.10	$1.20
Space Cooling	9,835	2,655	1,564	$827	TEP, Flat	
DHW	2,869	695	181	$269		
Lighting	2,775	1,530	1,121	$165		
Appliances and MELs	5,756	5,106	5,986	($23)		
Ventilation	40	157	198	($16)		
Total Usage	**25,318**	**11,027**	**10,208**	**$1,511**		
Site Generation	0	1,844	11,840	$1,184		
Net Energy Use	**25,318**	**9,183**	**-1,632**	**$2,695**		
Added Annual Mortgage Cost w/o Site Gen.				**$2,321**	**Neutral Cost Criteria Met?**	
Net Cash Flow to Consumer w/o Site Gen.				**($810)**	**No**	
Added Annual Mortgage Cost with Site Gen.				**$6,887**	**Neutral Cost Criteria Met?**	
Net Cash Flow to Consumer with Site Gen. w/o				**($4,192)**	**No**	
Added Annual Mortgage Cost with Site Gen. & Incentives				**$4,082**	**Neutral Cost Criteria Met?**	
Net Cash Flow to Consumer with Site Gen. & Incentives				**($1,387)**	**No**	

Table 7 - 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)	Notes
Thermal Enclosure:	**$32,681**	**$19,019**	**$34,263**	**$16,769**	**$1,339**	
Roof / Attic	$0	$0	$0	**$0**	**$0**	
Wall	$32,581	$19,019	$34,163	**$16,659**	**$1,330**	
Cavity Insulation		$996		**-$1,096**	**-$87**	
Insulating Sheathing	$8,230		$9,812	**$10,793**	**$862**	2" of exterior rigid foam
Other Wall Measure	$24,351	$18,023	$24,351	**$6,961**	**$556**	
Foundation	$0	$0	$0	**$0**	**$0**	
Air Infiltration Reduction	$100		$100	**$110**	**$9**	
Other Enclosure Measures				**$0**	**$0**	
Windows:	**$0**	**$0**	**$0**	**$0**	**$0**	
HVAC System:	**$5,989**	**$4,250**	**$10,132**	**$6,470**	**$517**	18 SEER & electronic air cleaner
Other HVAC Measures	$5,989	$4,250	$10,132	**$6,470**	**$517**	Does not include garage HVAC
Water Heating:	**$4,255**	**$499**	**$5,800**	**$5,831**	**$466**	
Other Water Heating	$4,255	$499	$5,800	**$5,831**	**$466**	Flat plate system
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	**$42,925**	**$23,768**	**$50,195**	**$29,070**	**$2,321**	
Site Generation	**$12,683**		**$52,000**	**$57,200**	**$4,567**	Upgrade to 6.93 kWh
Total with Site Generation	**$55,608**	**$23,768**	**$102,195**	**$86,270**	**$6,887**	
REBATES / INCENTIVES	**-$18,026**	**$0**	**-$35,135**	**-$38,649**	**-$3,086**	
Builder Tax Credit	-$2,000		-$2,000	**-$2,200**	**-$176**	
Tucson Solar Tax Credits	-$7,000		-$7,000	**-$7,700**	**-$615**	
TEP Solar Buydown	-$5,750		-$22,395	**-$24,635**	**-$1,967**	
Federal Solar Tax Credit	-$3,276		-$3,740	**-$4,114**	**-$328**	PV Capped at $2,000
Total Incremental Cost to Buyer Including Incentives	**$37,581**	**$23,768**	**$67,060**	**$51,135**	**$4,082**	

Table 8 - Neutral Cost Worksheet for ZEH2 (APdS base costs)

	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)**
					$0.10	$1.20
					TEP, Flat	
Space Heating	4,043	884	1,158	$289		
Space Cooling	9,835	2,655	1,564	$827		
DHW	2,869	695	181	$269		
Lighting	2,775	1,530	1,121	$165		
Appliances and MELs	5,756	5,106	5,986	($23)		
Ventilation	40	157	198	($16)		
Total Usage	**25,318**	**11,027**	**10,208**	**$1,511**		
Site Generation	0	1,844	11,840	$1,184		
Net Energy Use	**25,318**	**9,183**	**-1,632**	**$2,695**		
Added Annual Mortgage Cost w/o Site Gen.				**$638**	**Neutral Cost Criteria Met?**	
Net Cash Flow to Consumer w/o Site Gen.				**$873**	**Yes**	
Added Annual Mortgage Cost with Site Gen.				**$4,091**	**Neutral Cost Criteria Met?**	
Net Cash Flow to Consumer with Site Gen. w/o Incentives				**($1,396)**	**No**	
Added Annual Mortgage Cost with Site Gen. & Incentives				**$2,869**	**Neutral Cost Criteria Met?**	
Net Cash Flow to Consumer with Site Gen. & Incentives				**($174)**	**No**	

When evaluating the economics of energy efficiency measures, any available financial incentives will play an important role in decision-making process. In Tucson, as well as nationally, there are numerous financial incentives that reduce the cost of energy efficiency and renewable energy systems. The incentives available for ZEH2 are outlined in Table 9.

Table 9 - Cost Incentives Available for ZEH2 – Builder and Homeowner

Incentive	Description	Incentive Available for ZEH2
Federal Tax Credits	Builder credit for 50% reduction in heating/cooling & building envelope improvements	$2,000
Solar Energy Tax Incentives (AZ)	Homeowner credit, 25% of cost up to $1000	$1,000
City Solar Fee Credit Incentive	Builder permit fee reduction for displacing 1500 kWh/yr site energy. Can also be used in retrofits. $1000 maximum.	$1,000
Builder Tax Credit for Solar	Builder tax subtraction for 50% better than 1995 MEC. Credit equal to 5% of sales price up to $5,000	$5,000
TEP - Renewable Energy Credit Purchase Program - PV	$3/watt (dc) for PV systems	$20,820
TEP - Renewable Energy Credit Purchase Program – Solar Thermal	$0.25/kWh for solar thermal + $750, $1,750 maximum, based on SRCC rating	$1,575
Federal Solar PV	30% of system cost ($2000 limit prior to 2009)	$2,000

Incentive	Description	Incentive Available for ZEH2
Federal Solar Thermal	30% of system cost, $2000 limit	$1,740
Total Incentives		**$35,135**
Total Incentive After 2009		**$50,461**

Based on the extensive incentives, the total credit for the energy efficiency modifications and renewable energy systems was $35,135. However, if the home had been completed in 2009 after the Federal Solar PV credit was lifted, the incentives would have gone up to $15,326 for a combined upfront incentive of $50,461. Achieving higher energy efficiency goals that lead to an annual net-zero energy use require additional upfront expenditures. In order for the homebuyer to afford and energy efficient home, some of the incentives can be used as a mortgage buydown to enable a homebuyer to afford the additional energy features. Specifically for the ZEH2 the two incentives from TEP for the PV and the Solar Thermal system incentives directly affect the cash flow of the homebuyer.

Once the costs neutrality analysis was complete, the next step was to calculate the return on investment (ROI) for the ZEH2 using the energy cost savings and upgrade costs compared with the typical regional house. This gives the builder an idea of the homeowner's return on investment for choosing an energy efficient home over a typical regional home. Three analyses were completed for the ROI including the efficiency features only, efficiency features with PV, and the efficiency features with PV including the incentives as detailed in Table 10.

Table 10 - ZEH2 Monthly ROI

Upgrade	Efficiency Features	Efficiency Features & PV (no incentives)	Efficiency Features & PV (w/ incentives)
Energy Upgrade Investment Costs	$29,070	$86,270	$51,135
Additional Monthly Mortgage Payment Cost *	(-$192.28)	(-$570.63)	(-$338.23)
Monthly Mortgage Interest Deduction Savings **	$42.39	$125.81	$74.57
Monthly Utility Savings over Typical Regional	$96.33	$195.00	$195.00
Annual Return on Investment (ROI)			
w/out mortgage interest deduction	*4.0%*	*2.7%*	*4.6%*
w/ mortgage interest deduction	*5.7%*	*4.5%*	*6.3%*

*30 year loan, 7% interest
** 25% tax bracket

Quality Control Integration ("should meet")

JWM Company 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. The level of quality control required to construct exceptionally energy efficient homes is simplified by the relatively small size of the subdivision and its being the primary construction site for the company.

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. Other quality control measures include weekly meetings with the supervisor and the trades, job completion checklists, and continual inspections by the construction supervisor.

Quality control is further 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 insures 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 TEPs Guarantee Home Program is found in Table 11.

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

Although many of the builder's in-house quality control processes are informal, certain details were included on construction drawings and in contractor's Scopes of Work, as described in Table 12.

Table 12 - Formal and informal builder quality control processes

Features	Final ZEH2 Design	Details on Plan or Scope of Work	Notes/Issues
Building Science & Systems Approach	Discussed during Builder weekly meeting with builder and all trades	n/a	
Site Drainage, Pest Control, Landscaping	Float slab	Yes - on plan	
Foundation System Moisture & Soil Gas Control	n/a - because of slab design	n/a	
Structural Moisture Control			
Window/door flashing details	Per stucco installation requirements	No	
Wall/roof flashing details	Metal flashing	Yes – on plan	
Vapor retarder	n/a – due to climate & masonry wall construction	n/a	

Features	Final ZEH2 Design	Details on Plan or Scope of Work	Notes/Issues
Structural Air Sealing			
Air Barrier	Via to masonry wall construction	Intrinsic	Monolithic wall design with integral air barrier
Air sealing details	Per builder & TEP program specifications	No	Builder has established a set of practices for air sealing
Structural Thermal Performance			
OVE framing Insulated corners Reduce waste wood Raised heel trusses	Masonry wall construction with roof framed using engineered lumber	Yes – on plan	
Foundation Insulation	Slab edge	Yes – on plan	
Exterior insulation	2" polyiso rigid foam insulation	No	Field modification from 1 ½" to 2" of polyiso
Wall Cavity Insulation	n/a	n/a	
Ceiling Insulation	ceiling R-38 + R-5 exterior deck	Yes – on plan	
Windows	ENERGY STAR	Yes – on plan	
Heating, Ventilating, & AC (HVAC)			
Sizing	Per ACCA Manual J	Yes – equipment specification on plan	Mechanical designer holds the Manual J design documentation
Equipment	Trane 19i	No	Field modification
Centralized mechanical room	Between kitchen & master bedroom	Yes – on plan	
IAQ & Ventilation			
Low VOC Interior Coatings		No	
Low VOC Adhesives		No	
Low Emission Cabinets		No	
Whole-house mechanical ventilation	Passive RA duct system, point exhaust from laundry/mechanical room	Yes – on plan	
Ducts			
Sealing	Mastic per builder & TEP specifications	Yes – TEP scope of work	
Ducts in conditioned space	Yes, compact duct system design	Yes – on plan	
Hot Water System			
Distribution	PEX hot water manifold delivery system	Yes – on plan	
Water Heating	On demand electric	Yes – on plan	
Preheat Systems	Solar closed-loop system	Yes – on plan	
Centralized water heater	Between kitchen & master bath	Yes – on plan	
Lighting, Appliances, & MELs			
Lighting	Primarily CFL	No	
Appliances	ENERGY STAR when supplied by builder	No	

Features	Final ZEH2 Design	Details on Plan or Scope of Work	Notes/Issues
MELs	No control measures employed	n/a	
Homeowner Manual		Yes – builder documentation	

In addition, the ZEH2 met all of the quality criteria for the Builders Challenge label. The home also had a HERS index of zero for the home (exceeding the required HERS index of 70) as shown in Figure 8. The builder, John Wesley Miller Companies, was highlighted for their Builders Challenge participation with the ZEH2 at the 2008 EEBA conference.

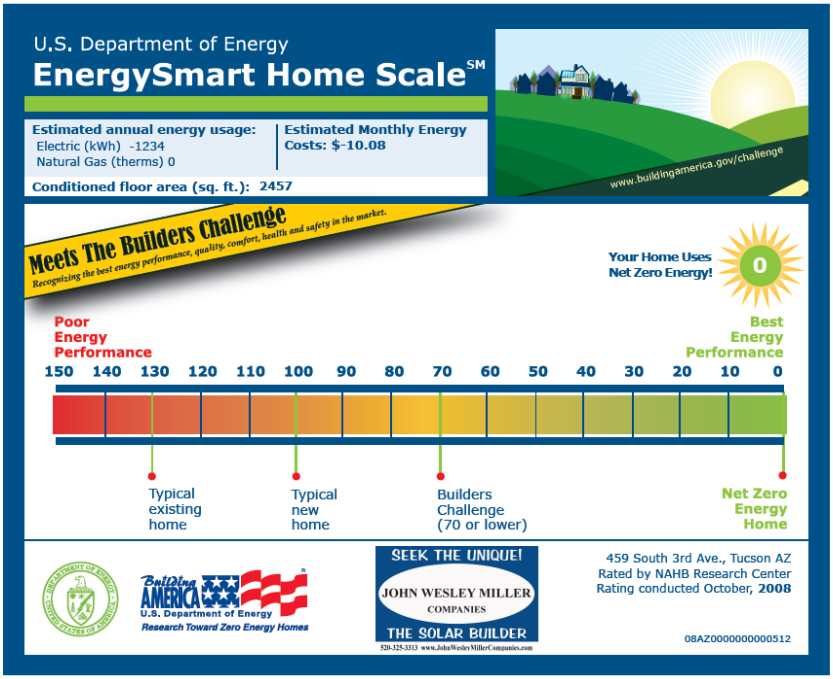

Figure 8 - ZEH2 Builders Challenge Label

Gaps Analysis ("should meet")

The gaps analysis criteria includes gaps in the construction process, lessons learned, as well as technical and market barriers to achieving the targeted performance levels. The biggest market barrier to achieving zero energy homes in the hot dry climate was the high initial cost of solar power. For the builder, for which a standard home achieves the 40%+ energy savings level, the additional energy efficiency features did not add an unreasonable amount to first cost. However, achieving net-zero energy use with PV power offsetting the consumption required a significant cost, even with hefty financial incentives.

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 investigated. In addition, the cost savings associated with both the energy efficiency features as well as the advantage of the special 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 using other tools and analysis methods.

SUMMARY

Armory Park del Sol is an urban infill project in an historic district in downtown Tucson, Arizona in which historic architecture is successfully integrated with advanced energy efficient technologies and renewable energy systems. The current standard home designs are estimated to save over 50% relative to the BA benchmark – including all of the efficiency features, but not including the PV systems. The ZEH2 design is estimated to save over 60% from the BA benchmark home – likewise, including the solar thermal system but not the PV. With the addition of a 1.5 kWdc solar electric (PV) system, the standard Armory Park del Sol homes are estimated to achieve over a 60% reduction in energy use from the BA benchmark. The ZEH2 design is estimated to achieve an annual net-zero utility energy use with the 6.93 kW PV system that is installed.

Substantial energy performance gains can be made in new homes located in the hot-mixed dry climate using currently available technologies and zero energy is possible. Combining high thermal mass structural systems with high levels of insulation and efficient windows that are shaded by architectural features results in excellent energy performance in this climate. This high-mass building method employed in the ZEH2 and all Armory Park del Sol (APdS) homes warrants further research. Renewable energy technologies such as solar thermal and PV can offset remaining energy needs to reach an annual net utility-supplied energy requirement of zero. ZEH2 serves as a successful model of an annual net-zero energy performance home in the hot-dry climate.

In addition, the ZEH2 complies with all of the criteria (including "must meet" and "should meet") for a Building America Stage Gate 2 prototype home and meets all of the local code requirements as well as those of Tucson Electric Power's (TEP's) Guarantee Home Program, the Tucson Sustainable Energy Standard, the Builders Challenge, and the federal tax credit. Source energy savings over the Building America Benchmark are predicted to be 60% without the PV system and 106% (net annual producer of electricity) with the PV system.

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