ZERO ENERGY HOME PROJECT:
2ND GENERATION ZEH AT ARMORY PARK DEL SOL PROJECT AND TECHNICAL SYSTEMS DEVELOPMENT

Prepared By

NAHB Research Center, Inc.
400 Prince George's Boulevard
Upper Marlboro, Md 20774

August 2005

Mission Statement

The NAHB Research Center's mission is to promote innovation in housing technology to improve the quality, durability, affordability, and environmental performance of homes and home building products.

About the NAHB Research Center

Created in 1964 as a separately incorporated, wholly-owned, not-for-profit subsidiary of the National Association of Home Builders (NAHB), the NAHB Research Center has established itself as *the* source for reliable, objective information and research on housing construction and development issues. The Research Center's unique relationship with the housing industry, and breadth of technical expertise, provide an unrivaled depth of the understanding of the housing industry, and access to its business leaders in fulfilling clients' research needs.

This Report was Prepared for The National Renewable Energy Laboratory (NREL)

Disclaimer

ZERO ENERGY HOME PROJECT:
2ND GENERATION ZEH AT ARMORY PARK DEL SOL PROJECT AND TECHNICAL SYSTEMS DEVELOPMENT

ZEH BACKGROUND

The NAHB Research Center is working with U.S. homebuilders to investigate the construction of Zero Energy Homes (ZEH) in current and planned developments. The ZEH concept, as developed through the U.S. Department of Energy (DOE), is comprised of two major aspects. The first aspect seeks to decrease the building energy needs for space heating and cooling, water heating, and appliance and plug energy uses through energy efficiency measures. The second aspect is to utilize renewable energy systems to produce enough energy to offset any utility-supplied energy. A successful ZEH is not independent of the utility, but rather replaces any utility energy used with energy produced from renewable resources, on an annual basis—resulting in net-zero annual energy use.

At this time, the only recognized method to account for net-zero annual energy use is for electrical energy. There is currently no method for accounting for consumption or production of thermal energy produced by other sources such as solar energy, propane, natural gas, or fuel oil, other than reduction in overall energy use (conservation measures).

The NAHB Research Center is working with John Wesley Miller at the Armory Park del Sol development in Tucson Arizona to construct a 2nd generation ZEH to further demonstrate the feasibility of the zero-energy home concept.

WORKING DEFINITION OF A ZERO ENERGY HOME

From the programs inception, and as a basis for every ZEH project, the NAHB Research Center has approached the house design with the intent of achieving an annual net-zero energy use from the utility. To date, the Research Center has focused on increasing the efficiency of all-electric homes to the fullest extent economically possible, offsetting hot water and heating energy consumption with solar thermal systems, and then sizing a PV system to meet the remainder of the electric load. Hence, the ZEH is a true annual net-zero energy use from the electric utility and has no other fuel connections.

However, while the ZEH concept strives to result in annual net-zero energy consumption, the practical ZEH opportunity that can be repeated in large numbers at this time is somewhat less than net-zero energy use. To date, few homes have been designed to achieve a true net-zero energy home status while many others demonstrate the potential to achieve a net-zero energy use through a significant reduction in the energy demand of the home and a significant increase in the use of renewable energy systems. A popular approach to the net-ZEH concept has been to offset most of the electricity used in the home while not accounting for the energy consumption of fuel fired appliances at this time.

Even as there are multiple approaches to the ZEH concept, the approach most often employed at this time is to enhance the building shell and equipment to achieve, at a minimum, the level of an ENERGY STAR® rated home and then to install both solar thermal (hot water) and solar photovoltaic (electric) systems.

THE FIRST ZEH CONCEPT AT ARMORY PARK DEL SOL

In April of 2003, the first ZEH at Armory Park del Sol was opened and sold within a month. The buyer, already purchasing a home at the development, decided to purchase the ZEH instead based primarily on the environmental performance of the home and its unique nature of very low utility bills. While very satisfied with the performance of the ZEH (the homeowner's energy bills average about $30/month for all uses), improvements in the operation of the solar systems are predicted to increase the performance by another 15 to 20% so that the net-energy use will be around 90% instead of the first year 67%.

The Design Approach

The builder, already constructing efficient homes and incorporating solar thermal and electric systems, has been interested in achieving the net-zero energy use goal. His customers in the development have been largely enthused with the level of energy efficiency of their new homes and many have at some level, purchased the home in part due to the efficient performance of the homes.

The ZEH concept at Armory Park del Sol was designed as an enhancement to the builder's own construction standards which already included use of:

- thermally massive wall and floor system,
- low-e and low-SHGC windows,
- reflective roof coating,
- efficient duct design and installation,
- low levels of air infiltration,
- solar preheat for the hot water system,
- instantaneous water heater as back-up, and
- photovoltaic electricity generation.

For the ZEH, the builder extended these standard practices to include:

- Higher levels of wall and roof insulation,
- Redesigned potable and space heating hot water distribution system,
- High efficiency lighting system,
- High efficiency appliances,
- Expanded solar thermal system including storage and space heating, and
- Expanded photovoltaic system.

The additional energy features were selected and designed into the ZEH to achieve a net-zero energy use for the whole house. The only utility cost for the homeowner then would have been the monthly "meter" charge for the utility connection, a $5.28 constant charge for the non-time-of-use (flat rate) meter. These new additional energy efficiency features were added by the builder with the cost passed on to the buyer as with any "optional" features that may be selected

by the homeowner. In this case, the builder chose to incorporate the higher level of energy efficiency prior to sale.

Builder Assessment of the 1st ZEH

While the ZEH was generally acceptable as a house design for the development, the builder indicated a number of efficiency features that proved complicated or simply did not result in acceptable construction outcomes, e.g.:

1. Use of a large solar storage tank – the slab-on-grade homes are slightly smaller than the average new home size while square foot costs are above average. Use of any interior square footage for other than living space is considered to be a shortcoming in the house design. The storage tank, while necessary for annual energy savings, consumed valuable space in the utility room, even though its impact was slightly mitigated by incorporating a stackable laundry center which saved about half of the area which otherwise would have been used by the laundry appliance.

2. Use of plastic plumbing pipe for supply water piping – the parallel piping system which utilized PEX tubing instead of copper pipe, did not fit with the builder's conception of a durable structure. The energy benefit in these homes from using the parallel system was recognized, but the materials were not as acceptable to the builder and would not be incorporated into future projects.

3. Use of a large PV system – was not in of itself a problem, finding the roof area for the panels was difficult. Though used on every home, the solar PV systems installed on flat roof sections designed to minimize visibility. The much larger PV array necessary for the ZEH requires a much larger clear roof area and would not be used on a slopped roof application as the builder has elected to install PV only on flat roof sections.

Other construction issues such as the added time to the construction process, the increased trades involvement in accommodating more plumbing, electrical, and roofing details, and the need to modify permits as necessary added levels of complication that the builder would seek to minimize in future ZEH designs.

Homeowner Assessment of the 1st ZEH

The homeowner has expressed satisfaction with the ZEH design, in large part because the design is visually very typical of other homes in the development. The ZEH features are not as evident except for the solar thermal collectors which are unique for the ZEH and more visible than other solar thermal collectors in the neighborhood.

Some aspects of the ZEH that were particularly important to the homeowners include:

1. The performance of the solar systems – the homeowners were very interested in the concept of the net-zero energy - though realistic about the ambiguous aspects of the concept such as miscellaneous energy use for which they have control or the temperature setting of the thermostat. Achieving the net-zero energy utility cost (except for the base meter charge) is an important performance metric for the homeowners.

2. The reliability of the solar systems – the homeowners are interested in knowing how their solar and other energy efficiency systems function, including the controls that

manipulate the system performance. Similar to the cooling and heating thermostat, other controls for the solar thermal system for example, are of interest to the homeowner. This is especially true if the achievement of the net-ZEH goal is dependent on specific seasonal settings that are manually controlled. In addition, system diagnostics and indicators of system problems are of interest to the homeowner who quickly realized that little information is available if the solar thermal or PV system performance is compromised.

3. The quality of the lighting system – the homeowners recognize the important energy benefit with fluorescent lighting but remain ambivalent of the quality of the light. At times, the fluorescent lighting appears inadequate, according to the homeowner, especially at dusk. However, due to the large energy benefits, the homeowners are not intending to switch to incandescent.

Although these issues play a role in the homeowner's assessment of the ZEH concept, none have yet to dissuade them of the decision to purchase the home. Furthermore, the homeowners would welcome the construction of a second ZEH in the development.

THE SECOND GENERATION ZEH CONCEPT AT ARMORY PARK DEL SOL

The builder has expressed interest in a new second generation ZEH in the development combining the ZEH concept with the "LifeWise" concept of an accessible home to accommodate aging-in-place features. The goals of the second generation ZEH are to lower the cost of the ZEH features and to emphasize the unique opportunity for the home to be fully accessible – providing a unique opportunity for seniors to live in a low-maintenance, accessible home with low monthly variable costs.

With these goals in mind, the builder is planning the 2nd ZEH home as the last model for the development. With this effort, the builder will incorporate the best of the previous ZEH features while modifying the approach based on the assessment outlined above.

Energy Efficiency Features of the Second Generation ZEH at Armory Park del Sol

Heating and Cooling

The heating system of the 1st ZEH used the extensive thermal system to preheat water for space heating and domestic uses while incorporating a demand back-up heater to make up any shortfall. The system required the use of a large storage tank and four solar thermal collectors. While the potential for accommodating the space and water heating loads of the home with the solar thermal system exists, especially in Tucson, the builder does not want to serve the heating load with the solar system. Consequently a much smaller storage tank will be used to preheat the water for the domestic water heating loads. With the smaller tank, less area is needed and potentially the tank can be located in the garage or outside utility space. As with other homes in the development, a high efficiency heat pump system will be used to provide heating and cooling. A two-speed unit will be specified to provide low levels of heating and cooling to extend he benefits of the high thermal mass wall and floor materials (a construction material that does not respond quickly to heating and cooling supply). Since the heating is being supplied by the heat pump, the additional utility energy that will be expended must be made up by the PV system.

The heating system energy in the first ZEH was supplied by the solar thermal system with electric back-up. Switching to a heat pump for the 2nd ZEH increases the electricity use, however not proportionally since the heat pump operates at much higher efficiency levels than the demand heater back-up used in the 1st ZEH design.

Lighting

Based on the first ZEH, the builder has modified the lighting system to eliminate all recessed "can" lights located in ceilings below an attic. Accommodation of the high efficiency can lights resulted in a very high lighting cost in the 1st ZEH along with the typical energy penalties associated with penetrating the ceiling thermal boundary. As shown in the 1st ZEH, the effort to use high efficiency lighting resulted in a large energy savings. This effort will be extended to the next generation ZEH.

Shell Characteristics

Similar to the 1st ZEH, the next ZEH will use a slightly higher level of wall insulation. Increases in the thickness of the wall insulation may affect the performance of the exterior finish and therefore a practical limit is reached fairly quickly. The increase in cost in going from 2" of foam to 2.5" of foam is highly non-linear, far above changing from 1.5" to 2". The estimate to increase the wall insulation from 1.5" to 2" of exterior foam is about $784, whereas the increase in cost to go from 1.5" to 2.5" is about $2188. The markedly high increase in cost is in part due to the decreased spacing of the metal Z-bar (that supports the insulation and stucco finish) from 24" o.c. to 16" o.c. when employing the higher thickness insulation.

For the roof insulation, the 2nd ZEH design will pursue use of rigid foam insulation above the roof rafters rather than filling the rafters with more insulation. This design will avoid the potential increase in rafter costs due to increasing the depth of the rafter to accommodate increased insulation thickness, while obtaining at least a nearly identical performance level.

Plumbing System

Since the builder is comfortable with copper piping, the plumbing system in the 2nd ZEH will forego use of PEX tubing. However, the builder recognizes the benefits of the parallel plumbing system and has worked with the plumber to develop a partial parallel copper piping system. This system simply uses the parallel piping design with ½" copper pipe to all hot water outlets. This system supplants the typical approach of ¾" feeds to bathroom groups resulting in unacceptable wait times for hot water. In addition, the hot water lines are insulated under the slab. The builder has switched to this system design following the experience in the 1st ZEH.

Domestic Hot Water System

The overall system used for domestic water heating is anticipated to remain similar to that of the 1st ZEH, with the major change only in the reduction in the size of the solar thermal pre-heat system. The solar thermal system in the 2nd ZEH will be used only to pre-heat the domestic hot water supply to the house. Serving only the domestic hot water, the solar thermal system is estimated to supply about 90% of the water heating load using at most, 64 square feet of collector area and an 80 gallon storage tank with electric demand back-up. The specific system design is yet to be finalized but will make every effort to utilize standard components. Any system controller will be capable of providing details on the system performance such as tank temperature. Due to the freeze potential, although very slight, the system design will either

include a drainback feature or use antifreeze. In the 1st ZEH, the solar thermal system was designed to handle 100% of the domestic water heating load and nearly 90% of the heating load, and incorporated a large custom tank. Due to its complexity and the modifications that were required later, a simpler solar hot water system will be incorporated.

The builder currently uses a passive solar collector to pre-heat the domestic hot water. While this system is capable especially in the Tucson climate, the potential to reduce hot water energy consumption is limited. The primary value with the passive system for the builder is the elimination of the solar storage tank, primarily due to the space limitations within the home. A smaller solar thermal system will result in a storage tank size that reduces the tank footprint by over two-thirds from the first ZEH design.

PV System

As with any ZEH design, the PV system is theoretically sized to supply all the energy use above the load that is "supplied" by conservation and efficiency strategies. For this 2nd generation ZEH at Armory Park del Sol, the PV system will be required to supply the heating electric load since the solar thermal system is sized smaller to cover only 90% of the domestic water heating load. Based on a simple calculation of the average energy supplied by the solar thermal system compared with the PV system and their respective installation cost, it is less expensive to use the thermal system than using a larger PV system – as long as the thermal load is sufficient. (Using measured data, the thermal system averaged approximately 10 kWh/day of thermal energy collected, the PV system averaged approximately 20 kWh/day of electrical energy; the thermal system cost was about $6000 while the PV system cost was over $33,000.) Even with the utility rebate, the PV system cost remains substantially more expensive than the solar thermal system.

Although the economics favor the thermal system, the complexity of the thermal system and size of the storage tank are such limiting factors that the larger PV system is selected over the larger thermal system for the renewable technology of choice.

MOVING FORWARD WITH THE NEXT GENERATION ZEH (ZEH-2)

Planning for the 2nd generation ZEH at Armory Park del Sol is under way. The house model will be the largest of the single story homes constructed in the development and is the most popular model. With approximately 25% of the development yet to be constructed, the opportunity for other ZEH designs to be constructed and sold remains an option for future construction.

As described in the technologies above, the optimization between energy efficiency costs and PV costs remains, with the balance between each opportunity to save energy residing on the ease of installation and use of new technologies, the cost of PV, and the willingness of the builder to change from standard practices – all very much competing interests in today's residential construction market. The balance is tipped often by non-technical issues such as the space available in the home, the roof area and direction, and the availability of skilled technicians to install and guarantee the operation of new technologies.

Layout

Figure 1 shows the basic floor plan for the ZEH-2. The indicated office area is temporary for the Builder and staff and will be garage space in the final ZEH design.

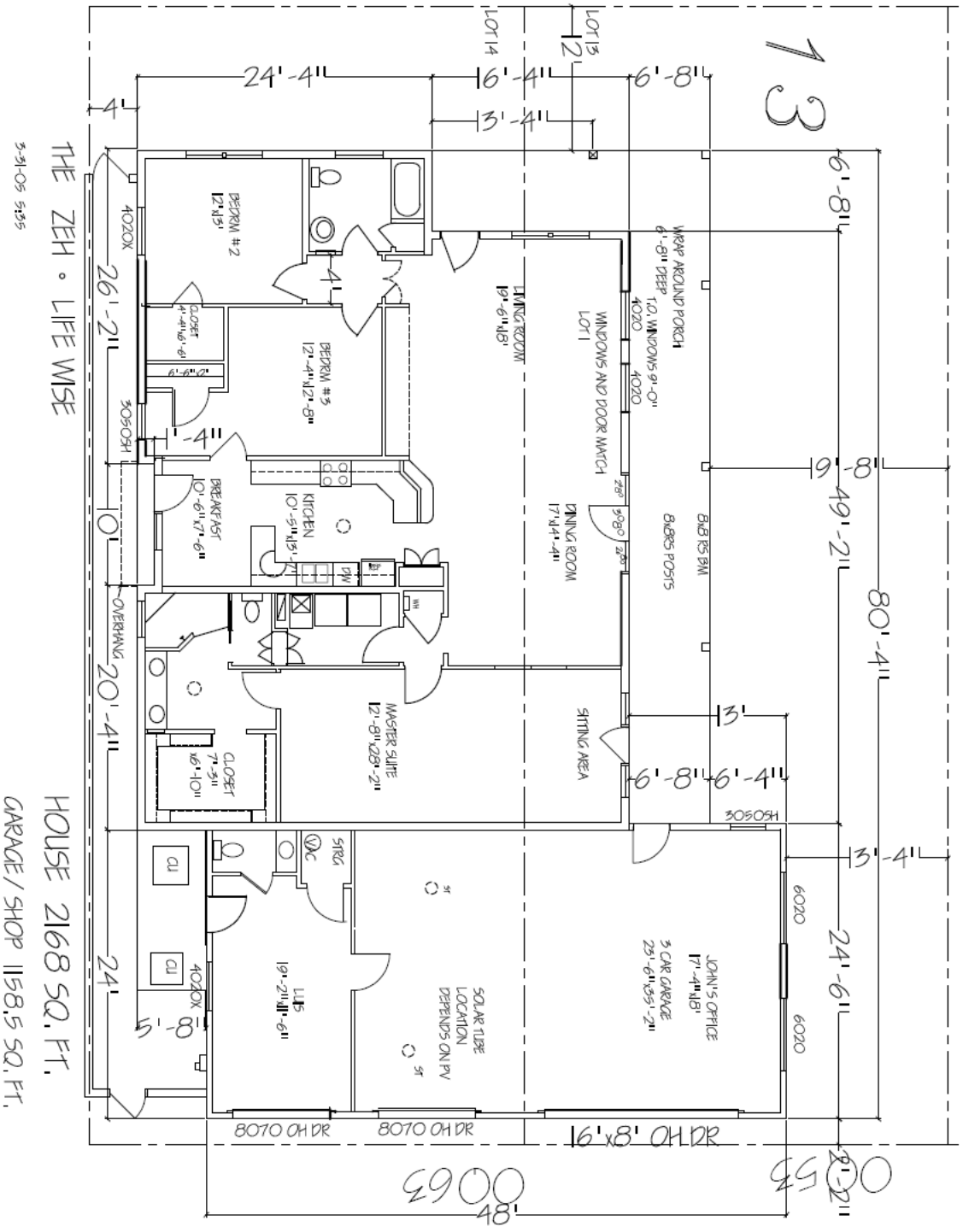

Figure 1 - Proposed ZEH Floor Plan with Temporary Office (for Staff)

The layout is representative of the most popular model sold in the development including wall and window areas. The roof is the typical low-slope design with interior wall heights of approximately 11 feet.

The building shell characteristics are summarized in Table 1:

Table 1 - ZEH-2 Shell Characteristics

House Characteristic*	Value
Conditioned Floor Area (square feet)	2168
Gross Wall Area (square feet)	2138
Total Glazing Area (square feet)	297
Wall to Floor Area	0.99
Window to Floor Area	14%
Window to Wall Area	14%
Bedrooms	3
Baths (not including garage office)	2
Garage	Attached

***Does not include temporary office space in garage

As with all homes in Armory Park del Sol, the garage faces the street while the front of the house faces the common walkway separating homes. As with the detached garages, the attached garages do not have a door entrance directly into conditioned space.

Orientation

A brief analysis was performed to assess the effect of orientation of the home on the predicted energy use for heating and cooling. Figure 2 shows the effect of rotating the house through the compass points with a maximum of 15% of the heating and cooling energy from the highest (front - north) to the lowest (front – east). The effect on overall whole house energy use is about 5% maximum. An additional simulation was also performed with all windows shaded (if not already shaded due to the house design). The resultant energy use indicated no additional energy savings from shading alone.

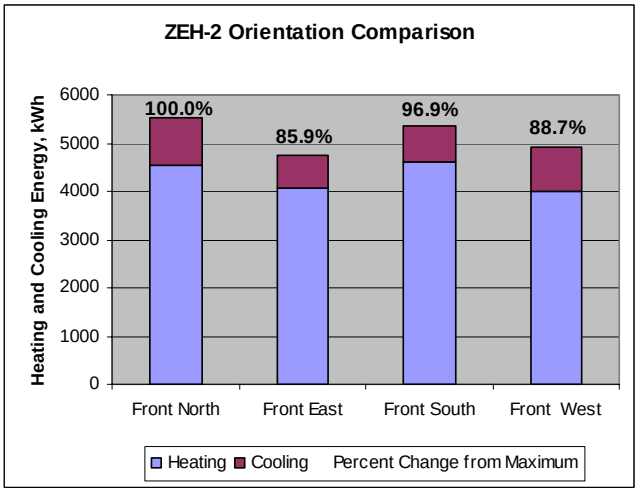

Figure 2 - Effect of Orientation on Heating and Cooling Energy

Efficiency Improvements

Improvements to the building shell and mechanical equipment were selected to highlight both performance and ease of installation and use while keeping increased costs as a low as possible. The features selected for use in the ZEH-2 include:

- 2" of wall insulation (increased from 1.5"),
- 1" of insulation above the roof deck (low-slope roof configuration),
- Reduced infiltration losses,
- Reduced duct losses,
- High efficiency heat pump unit (SEER 16 rated)
- Active solar hot water system,
- Extensive use of high efficiency lighting, and
- Use of high efficiency appliances.

Based on these shell and equipment changes, the energy use estimate results are shown in Table 2.

Table 2 - Energy Use Estimates for ZEH-2 Compared with Base

Energy Estimates	APdS Standard*	ZEH-2	Change
			Difference/Percent
Cooling Use (kWh)	4,538	2,350	2,188 / 48.2%
Heating Use (kWh)	995	503	492 / 49.4%
Water Heating Use (kWh)	1,421	138	1,283 / 90.3%
Other Use (kWh)			
Lighting	2,548	1,274	1,274 / 50%
Refrigeration	669	669	-
Dryer	835	835	-
Range	604	604	-
Ceiling Fans	0	0	-
Miscellaneous	3,932	3,542	390 / 9.9%
Total Energy (kWh)	15,542	9,915	5,672 / 36.2%
Total Energy, Daily (kWh)	42.6	27.2	-
Heat/Cool Cost ($)	504	259	245 / 48.6%
Water Heat Cost ($)	129	32	97 / 75.2%
Total Cost ($)	1,414	921	493 / 34.9%
PV Supply (kWh)	2,263	9,609	7,346 / 325%
PV value (net meter) ($)	206	873	667 / 324%
Utility Cost w/ PV ($)	1,208	48	1,160 / 96.0%
Net Utility (kWh)	13,279	306	12,973 / 97.7%
* The Armory Park del Sol standard construction includes a passive ICS solar thermal system and 1.5 kWdc PV array.			

The preliminary energy use reduction above the Armory Park del Sol standard (which is already approximately 50% more efficient for heating/cooling/water heating than standard local construction) is about 36%, including an estimated 50% reduction in lighting energy.

Solar PV System Requirements

The solar PV system size was selected at 5,760 watts which will provide nearly all of the energy annually to operate the ZEH-2. The array size is approximately one-third larger than the first ZEH. The roof area is sufficient for both the PV and solar thermal systems even accounting for shading from parapet walls and adjacent panels.

Partners

The builder has established relationships with the mechanical installation company, the solar system installation company, the window manufacturer and the insulation company. Based on these relationships, the builder has chosen to utilize these trades contractors and use equipment familiar to them. A primary opportunity with this ZEH-2 design is for a somewhat "standard" package that will be marketed by the builder and familiar enough to the trades so that a large learning curve is avoided.

SUMMARY

The builder has made preparations to construct the next ZEH at the Armory Park del Sol development in Tucson, Arizona. Based on the experience of the first ZEH, a number of design changes have been analyzed to lower the overall cost of the ZEH while still achieving a nearly net-zero energy consumption on an annual basis. The tradeoff is in utilizing a larger PV system while maximizing the efficiency gains from the shell and mechanical equipment. For example, previous experience with the first ZEH has shown that the jump to the highest efficiency A/C system available on the market was very high compared with a relatively modest increase in cost to a high efficiency A/C system (from 18+ down to 16+ SEER).

The second ZEH simplifies the overall design to include an upgraded insulation system, a higher efficiency heat pump, and a higher performing solar thermal system for domestic water heating only, expanded use of high efficiency lighting, and including the standard efficiency upgrades common to all homes in the Armory Park del Sol development.

The builder is working towards construction in late 2005.