Building a Path Towards Zero Energy Homes with Energy Efficiency Upgrades

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ABSTRACT

The ultimate concept in advanced residential home design is to produce affordable and durable homes that consume no more energy than they produce. To achieve this goal, these "low/no energy homes" should combine energy efficiency and passive solar designs, with on-site (renewable) energy sources. With increasing public awareness of the U.S.'s growing dependence on unstable foreign oil supplies, risks of unstable energy prices, advances in photovoltaic technologies, rebate programs, and net-metering policies, it's time to re-consider the design of low / no energy homes. While several demonstration "zero energy homes" have been built in the U.S., little information is available about how to best integrate load and demand reduction technologies with on-site generation equipment. Clearly, with aggressive efforts to reduce heating and cooling energy loads, the cost of on-site generation equipment (i.e., photovoltaic systems) can be substantially reduced.

This paper is an analytical study to assess how and where to most effectively integrate energy efficiency (EE) and passive solar features with on-site generation in new home designs. Structural upgrades, architectural design features, equipment & lighting upgrades, and behavioral modifications were analyzed to accomplish the maximum possible reductions in energy and demand. This information was then coupled with photovoltaic (PV) installation costs, rebates, and electric rates to determine which geographic regions and upgrade combinations work best together. The key finding of this paper is the identification of the "design conditions" where combined EE/PV packages achieved net overall costs that were comparable to the overall costs of standard code built homes.

Introduction

Energy consumed by the residential sector accounts for about 22% of the total U.S. energy consumption (EIA October 2003). This consumption is projected to increase by 25% between 2002 and 2025 (EIA January 2004). This growth is being fueled in part by the 1.5 million new homes constructed each year (USCB 2004).

Renewable energy can certainly play a role in meeting our energy needs. However, renewable energy consumption in the residential sector is only expected to increase from 0.39 quadrillion Btu per year in 2002 to 0.41 quadrillion Btu per year in 2025 (EIA January 2004). One likely reason for the small increase in renewable energy consumption is the high cost of the technologies. However, these expenses can be lessened by combining renewable energy systems with energy efficiency upgrades. The optimal application of this concept is zero energy homes.

While some studies and programs promote the concept of zero energy homes through the use of increased onsite green power generation, the relationship between generation costs and energy efficiency costs have not been well analyzed. This relationship between generation and energy efficiency is made complex by a number of factors including variations in home characteristics (e.g., home size, window area, etc.), the synergistic effect of bundling individual energy efficiency upgrades, weather, and utility rates.

A study (Parker & Dunlop 1994) examined the use of PV to produce the energy required to meet the cooling load of a home in a hot climate. It was found that energy efficiency upgrades could more cost effectively reduce the cooling load than the photovoltaic electric generation. With the use of energy efficiency upgrades, the study showed that the size of the PV array could be reduced by as much as 75%. In addition, a handful of "Zero Energy Homes" (ZEH) have been built and monitored. These studies suggest energy savings of 50% are achievable relative to conventional homes and that 85%-100% of the reduced electric load can be met with PV (NREL 2002). In each of these studies, energy efficiency was an important design feature used to minimize the electric loads.

The purpose of this paper is to improve the understanding of the relationship between the cost of energy efficiency upgrades and the cost of onsite generation to meet the remaining energy needs. This increased understanding will be achieved by considering multiple climates, utility rates, housing configurations, and efficiency upgrade options. The methodology and results of this analysis are presented and conclusions are identified.

Methodology

For this study, a net zero energy house is defined as one that generates the same amount of electricity as it consumes during the course of a year in heating, cooling, water heating, hardwired lighting fixtures, and major consumer appliances. For homes using natural gas, only net zero electrical consumption was targeted.

This analysis was conducted using the DOE2.1E energy modeling program and was limited to three cities: 1) a hot climate with high solar intensity (Phoenix, AZ), 2) a mild climate with moderate solar intensity (Springfield, MO), and 3) a cold climate with low solar intensity (Albany, NY). These cities were selected based on climate and solar intensity information.

Half of the homes modeled in this analysis used natural gas for space and domestic water heating, while the other half used electricity for these end-uses. Nationally, all-electric homes are much less common than mixed-fuel homes, but were included in all three regions of the study. This allowed for the analysis of an all-electric energy budget that could be reduced to zero, which is not possible in mixed-fuel homes. Energy efficiency upgrades were selected from across the following five broad categories: shell upgrades, HVAC & DHW upgrades, architectural design features (including passive solar), hardwired lighting and major consumer appliance upgrades, and behavioral modifications. The analysis of renewable energy systems was limited to photovoltaic systems.

This analysis was divided into four steps. The first step was to develop a base case scenario for each city. The second step was to identify and analyze individual energy efficiency upgrades for the base case scenarios. The third step was to assess the synergistic impact of combining selected upgrades into energy efficiency packages. The fourth step was to compliment the energy efficiency packages with photovoltaic electric generation panels to reduce the annual electric energy consumption to zero. The methodology and results of each of these steps is discussed in more detail below.

Step 1: Develop Base Case Scenarios

The first step in this analysis was to develop a base case for each city. These scenarios provide the basis from which the energy efficiency upgrade impacts could be assessed. Defining the base case characteristics is important because they directly impact the energy savings attributable to the energy efficiency upgrades. For example, a home with many west-facing windows will have a greater cooling load than an identical home with less west-facing glazing. As a result, the energy savings from a window upgrade will not be the same for these two homes.

In order to minimize this dependence on a given set of house characteristics, a number of prototypical base case homes were developed and analyzed. These base case homes were developed through a two-step process. First, variations were identified for some of the key characteristics of a home (e.g., house size, window area, etc.). Only slab on grade foundations were modeled to limit the number of runs required and because it was believed that other foundation types would not significantly impact the results. Next, base case homes that incorporated these variations were designed to meet the 2003 International Energy Conservation Code (IECC). This energy code was chosen for this study since it is the most current model energy code available. Twenty-five states have adopted the 2000 or 2003 IECC for their residential code (BCAP 2004). Table 1 shows the house characteristics and variations that comprise the base case scenarios. A total of 72 base case scenarios were created. The average energy use for the base case scenarios by city and fuel mix is presented in Tables 4 and 5.

Step 2: Identify and Analyze Individual Upgrades

Once the base case scenarios were developed, energy efficiency upgrades were identified that were appropriate for each of the three modeled cities. The upgrades were selected from the following categories. The energy efficiency upgrades that were selected for modeling are presented in Table 1. In all, 40 upgrades were assessed.

Shell, HVAC & DHW upgrades. Commonly found in energy efficiency programs, these upgrades include advanced framing, decreased window area, increased insulation, windows with lower U-values and solar heat gain coefficients, lower solar absorptivity roofs, decreased infiltration, programmable thermostats; increased heating, cooling, and water heating equipment efficiency; and ductwork with reduced leakage.

Architectural design features. Less commonly included in energy efficiency programs, yet highly effective, design strategies include modeling overhangs and porches.

Hardwired lighting & major appliance upgrades. Energy consumption of hardwired lighting and major consumer appliances (i.e., refrigerator, dishwasher, and clothes washer) was also estimated. These components were upgraded by assuming installation of ENERGY STAR products.

Behavioral modifications. Occupant behavior can play a critical role in achieving a zero-energy home. However, estimating the long-term impact and associated cost of attaining these changes is difficult. Therefore, the only upgrade analyzed in this study was an idealized thermostat schedule. This allows for some behavioral modification impact to be assessed, and demonstrates the potential of this upgrade category. It is assumed that such setbacks would be achieved through the use of a programmable thermostat with ramp-up technology, thereby limiting over-sizing and degradation of the HVAC system.

Table 1. House Characteristics For All Base Cases & Upgrade Options

House Characteristic		Base Case (All Climates)	Upgrade Options (Phoenix)	Upgrade Options (Springfield)	Upgrade Options (Albany)
House Characteristics	Area per Floor (sq.ft.)	1000, 1500, 2000	n/a	n/a	n/a
	Number of Stories	single, double	n/a	n/a	n/a
	Foundation Type	slab-on-grade	n/a	n/a	n/a
	Aspect Ratio	2:1	n/a	n/a	n/a
	Window Distribution[1]	50.0% front, 25.0% back or side, 12.5% per other sides	n/a	n/a	n/a
Shell	Framing	2x4, 16" O.C.	**2x6, 24" O.C.**[2]	**2x6, 24" O.C.**	**2x6, 24" O.C.**
	Window Area	18%	15%, **12%**	15%, **12%**	15%, **12%**
	Window U-value	[0.47, 0.40, 0.28] [3]	0.40, **0.30**	**0.30**, 0.28	**0.30**, 0.28
	Window SHGC	[0.40, 0.68, 0.68]	0.50,0.35,**0.30**	**0.35**,0.30	0.60,0.50,**0.35**,0.30
	Attic Insulation	[R-25, R-33, R-41]	R-30, 38, **44**	R-38, **44**	**R-44**
	Wall Insulation	[R-12, R-20, R-24]	R-13, 19, **21**	R-**21**	n/a
	Wall Sheathing	None	R-4, **R-8**	R-4, **R-8**	R-4, **R-8**
	Slab Insulation	[R-0, R-3, R-4]	R-4, R-8	R-4, **R-8**	**R-8**
	Roof Solar Absorption	0.75	**0.35**	**0.35**	**0.35**
	Air Infiltration	[0.39, 0.54, 0.52] nac/h	**0.35 nac/h,** 0.2 +ERV, 0.15 + ERV	0.35 nac/h, 0.2 +ERV, **0.15 + ERV**	0.35 nac/h, 0.2 +HRV, **0.15 + HRV**
HVAC + DHW	Air Conditioner	10 SEER	13, 15, **19** SEER	13, 15, **19** SEER	13, **15**, 19 SEER
	Gas Furnace	78 AFUE	90, 92 AFUE	90, **92** AFUE	90, **92** AFUE
	Heat Pump	6.8 HSPF	7.6, **8.5** HSPF	7.6, **8.5** HSPF	7.6, **8.5** HSPF
	Duct Leakage	15%	6%, **1%**	6%, **1%**	6%, **1%**
	Hot Water	0.54 EF gas, 0.88 EF elec.	0.80 EF gas, 2.0 EF elec., **Solar DHW**	0.80 EF gas, 2.0 EF elec., **Solar DHW**	0.80 EF gas, 2.0 EF elec., **Solar DHW**
Architect. Design	Exterior Shading	None	**6' Deep Porch,** 2' Awnings	6' Deep Porch, 2' Awnings	6' Deep Porch, 2' Awnings
	Window Orientation[4]:	West	**North**	**North**	**South**
Lighting & Appliances	Lighting	Standard	**ENERGY STAR Advanced Lighting Pack.**	**ENERGY STAR Advanced Lighting Pack.**	**ENERGY STAR Advanced Lighting Pack.**
	Appliances	Standard	**ENERGY STAR Appliances**	**ENERGY STAR Appliances**	**ENERGY STAR Appliances**
Behavior Modification	Thermostat	Heat: 6 hr, 6 deg. setback Cool: 6 hr, 6 deg. setup	Setback / Setup night and day	Setback / Setup night and day	Setback / Setup night and day
	Solar Water Utilization	Standard Hot Water Use	Use hot water at peak solar	Use hot water at peak solar	Use hot water at peak solar

[1] The distribution of windows is assumed to be typical to new construction. Other distributions would affect the energy consumption of the base case homes and the impact of the upgrades, particularly changes in orientation.
[2] Bolded specifications were selected for use in the upgraded energy efficiency packages.
[3] Specifications within brackets are base home characteristics for hot, moderate and cold climates, respectively.
[4] Orientation represents direction of the front of the house and was selected to produce the greatest energy consumption and for the upgraded homes was selected to produce the least energy consumption

Step 3: Identify and Analyze Upgrade Packages

Individual upgrades were selected for inclusion in an energy efficiency package based on their energy savings and upgrade costs. Upgrades were ranked by converting the energy reduction and upgrade costs into a monthly cash flow.

To accomplish this, the energy reduction of each upgrade was translated into a monthly reduction in utility bills. For simplicity, two utility rates were selected for this study; the current average national rate and the current 75th percentile national rate. For natural gas the rates used were \$0.89 and \$1.06 per therm. For electricity the rates used were \$0.087 and \$0.113 per kwh.

The upgrade costs (including materials and labor) and expected lifetime of each upgrade were then amortized into a monthly payment assuming a 30 year mortgage and 6% interest rate. Upgrade costs and lifetimes were determined through a variety of sources including RS Means Residential Cost Data, calls to local vendors and online tools. Though not available in all locations, the cost of solar water heaters and PV can be offset by rebates. To capture this potential benefit, rebates of \$750 for solar water heaters and 30% of the installed cost for PV systems were assessed.

Finally, the utility savings and amortized cost were combined into a monthly cash flow for each upgrade. Upgrades with the highest cash flow were selected first for inclusion in the package. Ultimately, all upgrades that were cost competitive with an installed photovoltaic system were selected for inclusion in the packages, with installed unit costs for photovoltaics estimated per kW of rated capacity. To estimate the monthly cash flow of the photovoltaic system, energy production of the photovoltaic system was estimated for each location. This was then converted to a monthly reduction in utility bills. The upgrade costs were amortized into a monthly payment and the two values were then summed to produce a monthly cash flow.

This process is illustrated in Table 2 for the upgrades used in the electric-only energy efficiency package for Phoenix. Monthly savings were generated using current national average utility rates. An identical process was followed to create packages for the remaining two climates. With the energy efficiency package defined, all upgrades were modeled simultaneously to determine the synergistic effects of the package. Using the results, a monthly cash flow was calculated for the package, including cost savings from down-sized equipment.

Step 4: Supplementing the Packages with PV

For the purpose of this study, the photovoltaic panels were sized to meet the annual net electricity required by the home. This approach requires that the home be on the grid and capable of buying and selling electricity with the utility company (i.e., net metering).

The photovoltaic panels were sized using the BP Solar online calculator. The average annual energy generated by a 1 kW PV system in each city is summarized in Table 3. This table also summarizes the approximate average size of the PV systems needed to achieve a net annual energy use of zero.

Costs for solar photovoltaic systems range from \$8,000 to \$12,000 per 1 kW of installed panels. An average cost of \$10,000 per kW (excluding rebates) was used in this study. The cost of panels typically decreases as the number of panels purchased increases. However, the cost savings due to bulk purchases were not accounted for in this study.

Table 2. Net Monthly Cash Flow for Electric-Only Energy Efficiency Packages

		Phoenix					Springfield	Albany
Upgrade Type		Upgrade Cost	Life-time (years)	Monthly Cost	Monthly Savings[5]	Net Monthly Cash Flow	Net Monthly Cash Flow	Net Monthly Cash Flow
Shell	Advanced Framing	Cost with insulation	100	Cost with insulation	Cost with insulation	Cost with insulation	Cost with insulation	Cost with insulation
	Window Area	-$1398	100	$2	$14	$16	$8	$6
	Window U Window SHGC	$4433	50	-$16	$12	-$4	-$3	-$9
	Attic Insulation	$720	100	-$1	$1	$0	$0	-$2
	Wall Insulation	$154	100	$0	$4	$4	$1	-$2
	Wall Sheathing	$627	100	-$1	$5	$4	$3	$3
	Slab Insulation	n/a	n/a	n/a	n/a	n/a	$0	$0
	Roof Solar Absorptivity	$0	20	0	$2	$2	$0	-$1
	Air Infiltration	n/a	n/a	n/a	n/a	n/a	-$18	-$16
HVAC + DHW	Heat Pump - Cooling	$2100	20	-$19	$29	$10	-$14	-$11
	Heat Pump - Heating	$700	20	-$6	$3	-$3	$0	$2
	Duct Leakage	$600	20	-$5	$9	$4	$2	$4
	Hot Water	$1990	20	-$18	$25	$7	$2	$9
Architectural Design	Overhangs	$813	100	-$1	$9	$8	n/a	n/a
	Window Orientation:	$0	100	$0	$11	$11	$6	$7
Lighting & Appliances	Lighting	$540	20	-$5	$8	$3	$3	$3
	Appliances	$371	20	-$3	$3	$0	$0	$0
Behavior Modification	Thermostat	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Solar Water Utilization	n/a	n/a	n/a	n/a	n/a	n/a	n/a

[5] Monthly savings were estimated using current national average utility rates.

Table 3. Photovoltaic Panel Sizing

Location	Annual Energy Generation (per 1 kW)	Approximate Average PV System Size	
		All-Electric	Mixed-Fuel
Phoenix	1773 kWh	2.00 kW	1.75 kW
Springfield	1415 kWh	3.25 kW	1.25 kW
Albany	1252 kWh	3.50 kW	2.75 kW

Results

The methodology described above was used to define and simulate energy efficiency packages supplemented by photovoltaics in three climates for both all-electric and mixed-fuel homes. This resulted in an estimated annual energy use and monthly cash flow for the baseline homes, homes with the optimized package, and homes with both the optimized package and photovoltaics. This information is summarized in a tabular format for all-electric homes in Table 4 and for mixed-fuel homes in Table 5.

Description of Results across the Three Climates

Tables 4 and 5 illustrate that Phoenix represents a climate with high solar insolation, cooling dominated loads, and a high potential for cost effective net zero energy homes. Springfield represents a more moderate climate and Albany represents a climate with low solar insolation, heating dominated loads, and a low potential for cost effective net zero energy homes.

Table 4. All-Electric Homes: Summary of Annual Energy Use & Monthly Cash Flow

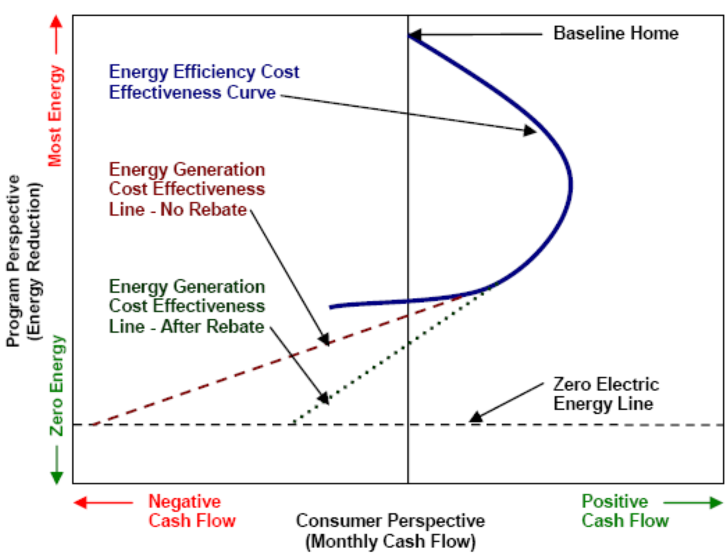
		Phoenix, AZ		Springfield, MO		Albany, NY	
		Average Utility Rate	Higher Utility Rate	Average Utility Rate	Higher Utility Rate	Average Utility Rate	Higher Utility Rate
Baseline	Energy Use (mmbtu)	52.2		37.0		32.3	
	Monthly Cash Flow	$0	$0	$0	$0	$0	$0
	Cash Flow w/ Rebate	$0	$0	$0	$0	$0	$0
Optimized Package	Energy Use (mmbtu)	12.0 (77% savings)		12.1 (67% savings)		14.7 (54% savings)	
	Monthly Cash Flow	$39	$62	-$30	-15	-$3	$14
	Cash Flow w/ Rebate	$46	$69	-$23	-$8	$4	$21
Optimized Package Plus PV	Energy Use (mmbtu)	0.0 (100% savings)		0.0 (100% savings)		0.0 (100% savings)	
	Monthly Cash Flow	-$80	-$57	-$119	-$104	-$138	-$121
	Cash Flow w/ Rebate	-$37	-$15	-$85	-$70	-$91	-$74

Table 5. Mixed-Fuel Homes: Summary of Annual Energy Use & Monthly Cash Flow

		Phoenix, AZ Average Utility Rate	Phoenix, AZ Higher Utility Rate	Springfield, MO Average Utility Rate	Springfield, MO Higher Utility Rate	Albany, NY Average Utility Rate	Albany, NY Higher Utility Rate
Baseline	Energy Use (mmbtu)	66.5		85.5		107.0	
	Monthly Cash Flow	$0	$0	$0	$0	$0	$0
	Cash Flow w/ Rebate	$0	$0	$0	$0	$0	$0
Optimized Package	Energy Use (mmbtu)	17.5 (74% savings)		38.0 (56% savings)		44.1 (59% savings)	
	Monthly Cash Flow	$35	$55	-$10	$5	-$7	$6
	Cash Flow w/ Rebate	$41	$62	-$3	$11	-$1	$13
Optimized Package Plus PV	Energy Use (mmbtu)	7.5 (89% savings)		31.8 (63% savings)		37.2 (65% savings)	
	Monthly Cash Flow	-$65	-$44	-$25	-$28	-$34	-$21
	Cash Flow w/ Rebate	-$28	-$8	-$10	$1	-$27	-$42

Understanding the interaction of the individual upgrades that comprise these results and their relationship on both energy costs and annual energy consumption is difficult to observe in tabular form. To better convey these interactions, each upgrade within the energy efficiency packages was cumulatively modeled for the Phoenix packages to produce an Energy Efficiency Cost Effectiveness Curve. This curve illustrates a pathway from the baseline home to the optimized home and is arranged based on a cost and energy reduction ratio as shown in Figure 1.

Figure 1. Description of Cost Effectiveness Path



As can be seen in Figure 1, the x-axis is a measure of monthly cash flow that incorporates both the amortized cost of upgrades and the energy reduction as measured by reduced utility bills. Higher values along this axis denote increased consumer savings. A home that is minimally compliant with code (i.e., the base line home) will have a cash flow of zero. The y-axis is a measure of annual energy consumption for the heating, cooling, water heating, hardwired lighting fixtures, and major consumer appliances of the home. Each end use was converted from its base units (i.e., therms for natural gas and kWh for electricity) to mmbtu's and summed together for ease of comparison. Lower values along this axis denote reduced energy consumption. A net zero energy home achieves a value of zero on this axis.

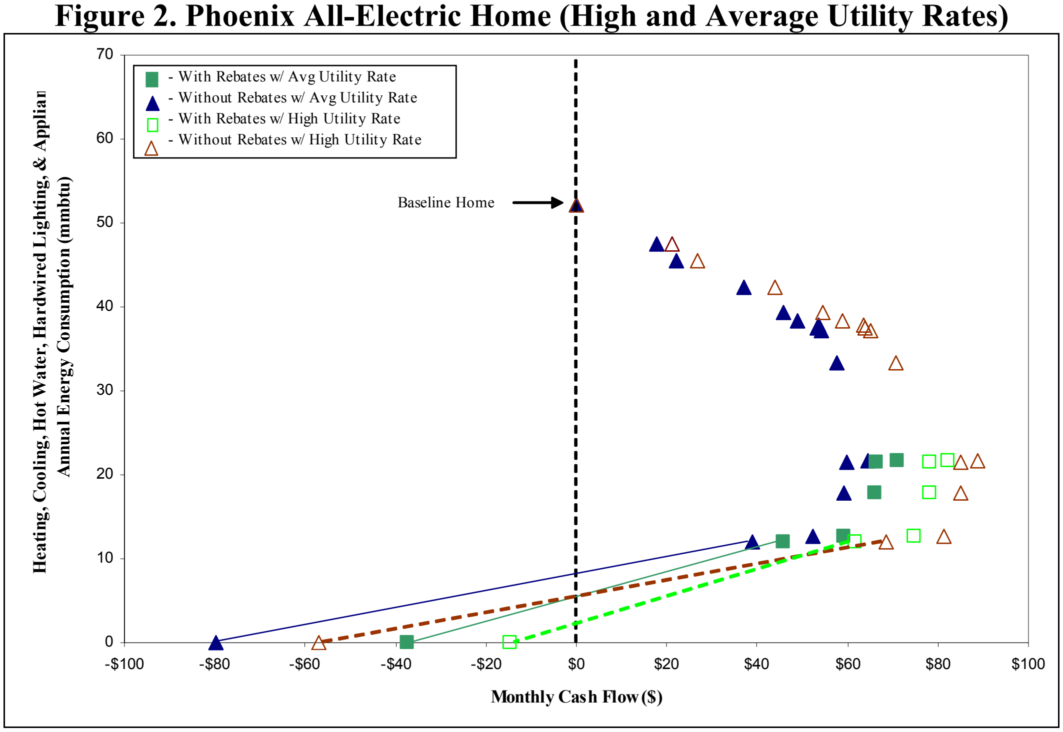
Figure 1 also shows Energy Generation Cost Effectiveness Lines. These lines illustrate the pathway from the optimized energy efficiency package to a zero energy home – through the installation of a PV system. Two lines are shown on the graph – one that includes the rebates for photovoltaic panels and one excluding the rebates.

Additionally, the figure shows the Zero Electric Energy Line, which occurs in mixed-fuel cases. The amount of energy below this line is the energy consumption of natural gas systems, including furnaces and domestic water heaters.

Description of Phoenix Electric-Only Home Results

Table 4 illustrated that the Phoenix baseline all-electric home uses 52.2 mmbtu annually while the optimized home uses only 12.0 mmbtu annually, a savings of over 75%. In addition, the energy savings of the package result in a monthly cash flow between $39 and $69, depending on the utility rate and the use of rebates. Beyond this level of savings, upgrades are no longer competitive with the installed cost of a photovoltaic system. This is visually demonstrated in Figure 2. In other words, additional energy efficiency upgrades would result in a more horizontally sloped line compared to the photovoltaic system. This defines the point at which a photovoltaic system should be installed to bring the net annual electrical energy consumption to zero. Doing so results in an associated monthly cash flow of between -$80 and -$15, depending on the utility rate and the use of rebates. This illustrates that with rebates and a high utility rate, a net zero energy home can be built with costs comparable to a home built to code in Phoenix.

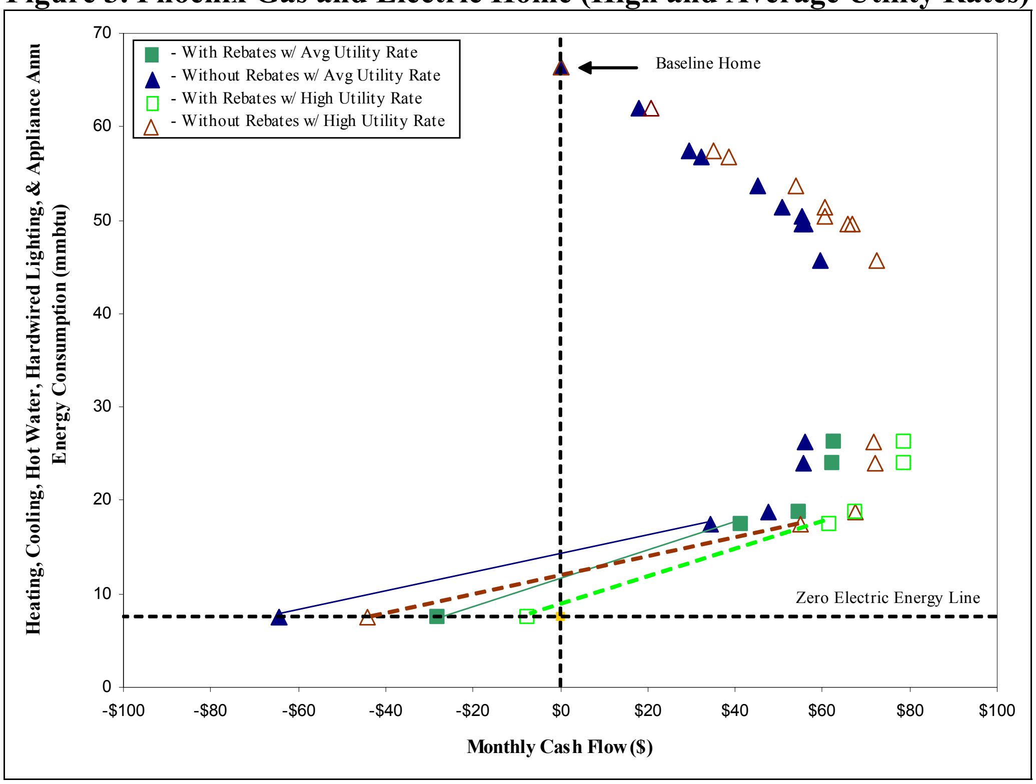
Figure 2. Phoenix All-Electric Home (High and Average Utility Rates)



Description of Phoenix Mixed-Fuel Home Results

Table 5 illustrated that the Phoenix baseline mixed-fuel home uses 66.5 mmbtu annually while the optimized home uses only 17.5 mmbtu annually, a savings of nearly 75%. In addition, the energy savings of the package result in a monthly cash flow between $35 and $62, depending on the utility rate and the use of rebates. By supplementing this package with photovoltaics, the net electrical energy consumption is reduced to zero, with an associated monthly cash flow of between -$65 and -$8, again depending on the utility rate and the use of rebates. While this home will operate with a net electrical consumption of zero, its natural gas energy consumption will remain at 7.5 mmbtu. These results are represented graphically in Figure 3, and this point at which electric consumption is eliminated is represented by the Zero Electric Energy Line.

Figure 3. Phoenix Gas and Electric Home (High and Average Utility Rates)



Life of the System/Home Cost Effectiveness

The results of this study suggest that even in a highly optimized scenario, while a net zero energy home can achieve costs that are comparable to a home built to code, it still does not achieve a positive cash flow. For this scenario to improve, either photovoltaic system costs must decrease or utility rates must increase. While the equipment and materials installed in a new home have a one-time cost over their lifetime, energy costs vary each year over the life of the home based on inflation, supply and demand changes.

To assess the impact of rising utility rates on the cost effectiveness of net zero energy homes, the monthly cash flow was recalculated using projected 30 year average utility rates. These rates were determined by using a linear trend between the current and future utility prices as projected by the Energy Information Administration's predicted trend for electric retail price through the year 2025. The resulting 30 year average projected electric rate is $0.138 for the mid average retail electric price and $0.178 for the high average retail electric price. Based on these increased rates, the monthly cash flow for the all-electric and mixed-fuel homes in the three cities is presented in Table 6.

While the monthly cash flow improves with the projected higher utility bills, it is still negative in Springfield and Albany all-electric cases. Higher rebates and/or a significant drop in upgrade costs (including PV systems) could help increase the monthly cash flow.

Table 6. Monthly Cash Flow

Monthly Cash Flow After Rebate with 30 year Average Electric Rates			
	Phoenix	Springfield	Albany
Mixed-Fuel Low Rate	$15	$19	$6
Mixed-Fuel High Rate	$47	$41	$27
All-Electric Low Rate	$12	-$50	-$47
All-Electric High Rate	$48	-$27	-$20

Conclusion

The purpose of this study was to determine how and where to most effectively integrate energy efficiency upgrades and passive solar features with onsite power generation. Annual energy consumption was estimated from more than 4,000 DOE-2 simulations accounting for six housing types, three distinct climates, two fuel types, two utility rates, and over three dozen upgrades. These simulations were combined with industry cost data to produce monthly cash flow values that easily defined the relative effectiveness of each individual upgrade.

The Energy Efficiency Cost Effectiveness Curve allows industry to evaluate the aggressiveness of program goals relative to consumer benefits in the form of monthly cash flow. Curves can be customized for different climates and desired energy efficiency measures.

It was demonstrated that energy efficiency packages can result in significant energy savings while maintaining positive or nearly positive monthly cash flows. Particularly in hot climates, energy efficiency upgrades can cost-effectively reduce baseline energy consumption of the heating, cooling, and water heating systems; hardwired lighting fixtures; and major consumer appliances by 75%. By coupling aggressive upgrade packages with photovoltaic systems, it is possible to produce net zero energy homes with net overall costs close to that of standard code-built homes.

The use of solar photovoltaic onsite power generation to create a net zero energy home is currently feasible in locations that have high solar loads and low photovoltaic panel costs after rebates. Based on current day pricing of the materials and labor for a new home, and future pricing of energy, the feasibility of zero energy homes will increase. Additionally, if the price of photovoltaic technology and/or energy efficient upgrades decreases there will be a similar increase in feasibility.

By using better information and better design, the concepts in this paper illustrate just a few of the many pathways that can lead to net zero energy homes or homes with significantly reduced energy consumption and positive cash flow. Following these paths can lead to significant energy reduction in the residential sector, along with associated economic, environmental, and security benefits.

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