Utility Benefits of Homes Approaching "Zero Energy"

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ABSTRACT

A tremendous number of energy efficiency measures in homes are cost-effective but don't seem to appeal to builders or homeowners. Solar energy systems, on the other hand, are quite appealing to many but their high costs tend to discourage buyers. Combining both efficiency and renewable energy – moving towards "zero energy" – offers market appeal greater than either separately; and when combined into a single package it can be cost effective.

In 2003, Western Massachusetts Electric Company ("WMECO," a Northeast Utilities System company) and Steven Winter Associates, Inc. (SWA, with funding from U.S. Department of Energy's Building America program) began this research effort consisting of three parts:

- Supporting construction of a home in western Massachusetts by upgrading energy efficiency measures and incorporating active solar thermal and electric systems.
- Detailed monitoring of the home's energy performance.
- Evaluation of the project using the Total Resource benefit-cost test.

The home was completed in Spring of 2004. During 2005 (the first complete calendar year monitored), the solar thermal system provided 62% of energy to heat domestic hot water. The home's electricity consumption was 9.7 kWh/day – approximately 50% of the New England average consumption for all housing (per RECS EIA 2001). The 2.6-kW PV system produced an average of 7.3 kWh/day providing a solar fraction of 76%. More important to the utility: the home was almost always a peak net generator during critical summer peak periods.

Total Resource benefit-cost analysis was performed using very recent avoided cost values (ICF 2005). The analysis showed that life-cycle benefits associated with efficiency and renewable energy were significantly greater than the costs (shown in Table 1).

Table 1. Summary of Cost-Benefit Analysis

Incremental Costs:	$40,101
Total Resource Benefits:	$52,932
Benefit/Cost Ratio:	**1.32**

The authors hope that this study may be a first step toward a utility pilot program providing incentives for homes incorporating efficiency and renewable energy cost effectively. They also hope this study may pave the way for similar analyses across the country.

The House

While the house is much more efficient than the average home, it does not employ uncommon technologies or products. It is a large home; conditioned floor area totals approximately 4,000 ft^2. The main section of the home is approximately 3,200 ft^2 and houses a family of three. There is also an 800-ft^2 in-law apartment with a single occupant; while the apartment has a separate electric service, it shares the main heat and hot water systems. The home is stick-framed with 2x6 walls insulated with dense-blown cellulose. The attic is insulated with R-45 cellulose; vaulted ceilings are insulated with R-30 fiberglass batts. Windows are double-pane, low-e with U-values of 0.32 $Btu/ft^2h°F$ and SHGC of 0.29. The basement is not particularly well-insulated with R-13 batts below the first floor.

Space heating is provided by a Buderus oil boiler with an AFUE of 86% via baseboard convectors and radiant floors (B20 is the fuel – a 20% mix of biodiesel and fuel oil). The boiler also provides heat to an indirect water heater. There is no air conditioning in the home; the homeowners use efficient ceiling fans.

All fixed lighting in the home is fluorescent (the majority compact fluorescent) and appliances are Energy Star® or equivalent. The range and clothes dryer are electric.

A 2.6-kW photovoltaic system and two 32-ft^2 flat-plate solar thermal collectors are mounted on the southern roof. The solar domestic hot water system uses a PV module and DC pump to circulate glycol from the collectors to a heat exchanger in an 80-gallon storage tank. The solar tank serves as preheat for the indirect water heater. The home and solar collectors are shown in Figure 1.

Figure 1. The Home in Western Massachusetts

Energy Analyses and Monitoring Results

As the home was part of WMECO's Energy Star® Homes program, the building was modeled using REM/Rate software and received a HERS score of 90 (not to be confused with the newer HERS Index). To assess the actual energy use of the home and the performance of the energy systems, SWA installed equipment to monitor:

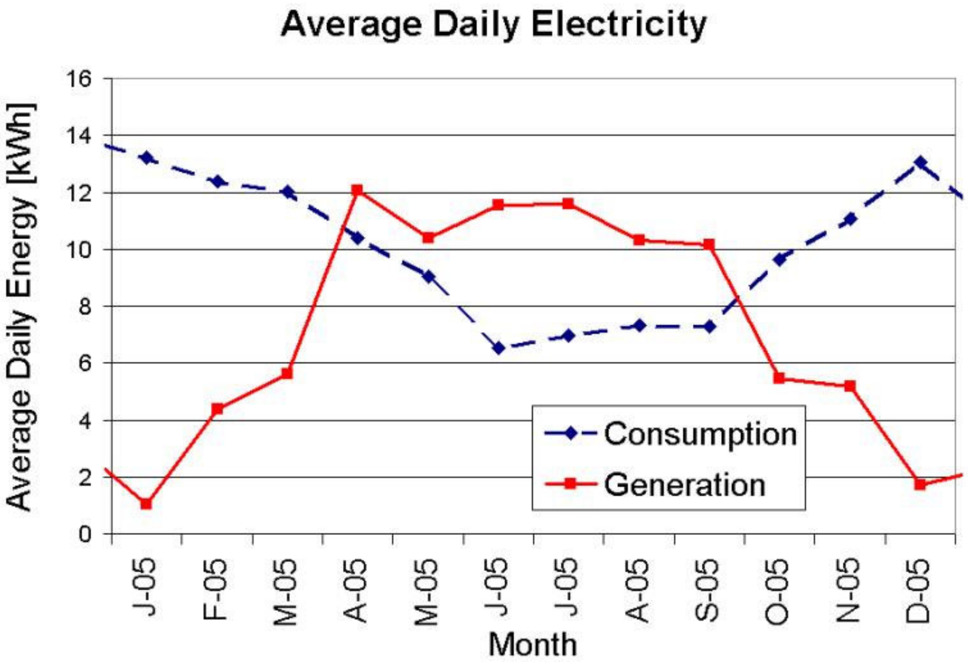
- Indoor and outdoor temperature and humidity;
- Horizontal solar radiation;
- Net electrical energy consumed;
- DC energy from the PV system;
- AC energy from the PV system;
- Solar thermal energy collected;
- Hot water consumption (both water volume and the energy used to heat it); and
- Oil/biodiesel consumption.

Values collected from sensors were averaged or totaled (as appropriate) every 15 minutes and collected remotely via telephone modems.

Electric Energy

The electricity used in the home is very low: an average of 9.7 kWh/day during 2005. The PV system generated an average of 7.3 kWh/day for an annual solar fraction of 76%. The Residential Energy Consumption Survey (EIA 2001) shows average household electricity consumption in New England of 19.8 kWh/day. Overall, residents of this home purchase 88% less electric energy than average residents. While efficient design, lighting, and appliances are responsible for much of these savings, based on interviews with the homeowners, the authors believe that these conscientious residents also play a significant role in reducing electricity consumption.

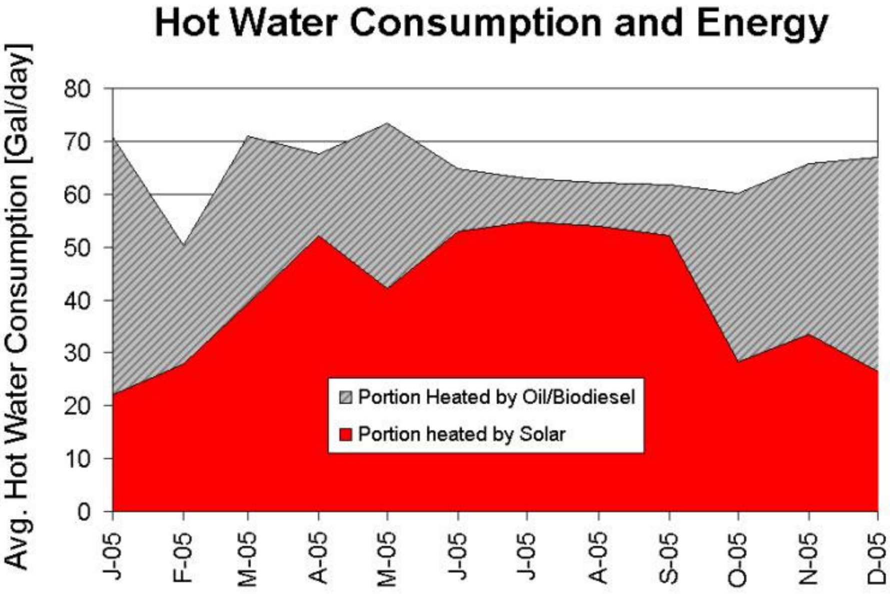
Figure 2. Summary of Daily Electricity Consumption and Generation



Heat and Hot Water

The solar thermal system provided 62% of energy needed to heat domestic hot water (DHW) for the main house and apartment during 2005. Occupants consumed an average of 64 gallons of hot water each day – well within the average range for a family of four. During 2005, total fuel consumed was 1,022 gallons of oil/biodiesel for space heating and auxiliary water heating.

Figure 3. Average Monthly Hot Water Consumption



Note: Shading indicates portions of water heating energy load provided by solar and oil during 2005.

Performance During Peak Periods

For electric utilities, the true appeal of PV's is that their peak generation is coincident with many utilities' peak demand periods. Since many areas of New England do not have sufficient generation to meet peak demands, the idea of having a home be a net generator could appeal to many utilities and could be used as part of a strategy to reduce congestion costs associated with importing electricity during periods of high demand. By combining energy efficiency with renewable energy, SWA and WMECO hoped that this home would serve to demonstrate zero-peaking and perhaps be a peaking net generator through much of the summer.

Peak Demand

Monitoring of the home confirmed that it was often a peak generator. During WMECO's peak demand period, defined as 12:00 pm – 4:00 pm on the hottest day of the year, the average net demand of the home was -1.4 kW; the negative value here indicates net generation (see Table 2 and Figure 4). By contrast, modeling shows that a similar home using "typical" construction would consume an average of 5.1 peak kilowatts. While in most homes, where space cooling is a large driver of peak summer demand, this project demonstrated that not only can peak demand be **minimized**, it can in fact be **reversed**. (The effects of air conditioning are discussed in more detail below.)

Peak Energy

During most of WMECO's peak energy periods – when electric energy is most expensive – the home was also a net generator. Summer peak energy periods are defined as 6:00 am – 10:00 pm weekdays in June, July, August, and September. Table 3 shows that the average net energy consumption at the home during these peak periods in 2005 was -6.2 kWh/day (the negative value indicating net generation). The average 15-minute demand over 24 hours for each summer month (depicted in Figure 5) shows that the home is a peak generator during most summer daylight hours.

Table 2. Electric Performance During WMECO's Peak Demand Period (12 noon – 4 pm On the Hottest Day of the Year)

Average Load:	180 W
Average Generation:	-1600 W
Average Net Load:	**-1420 W**

Figure 4. Electric System Performance at the Hadley Home During Three Days in August (August 2 was the hottest day of 2004)

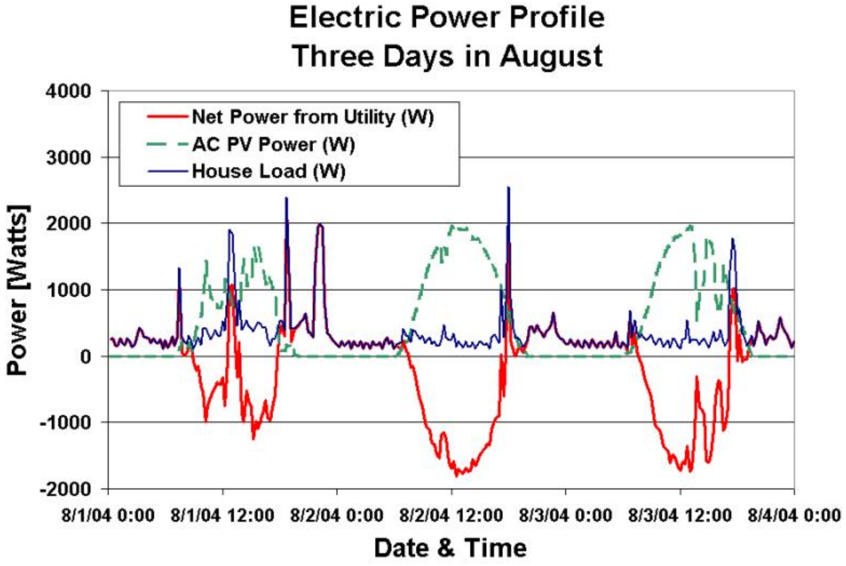
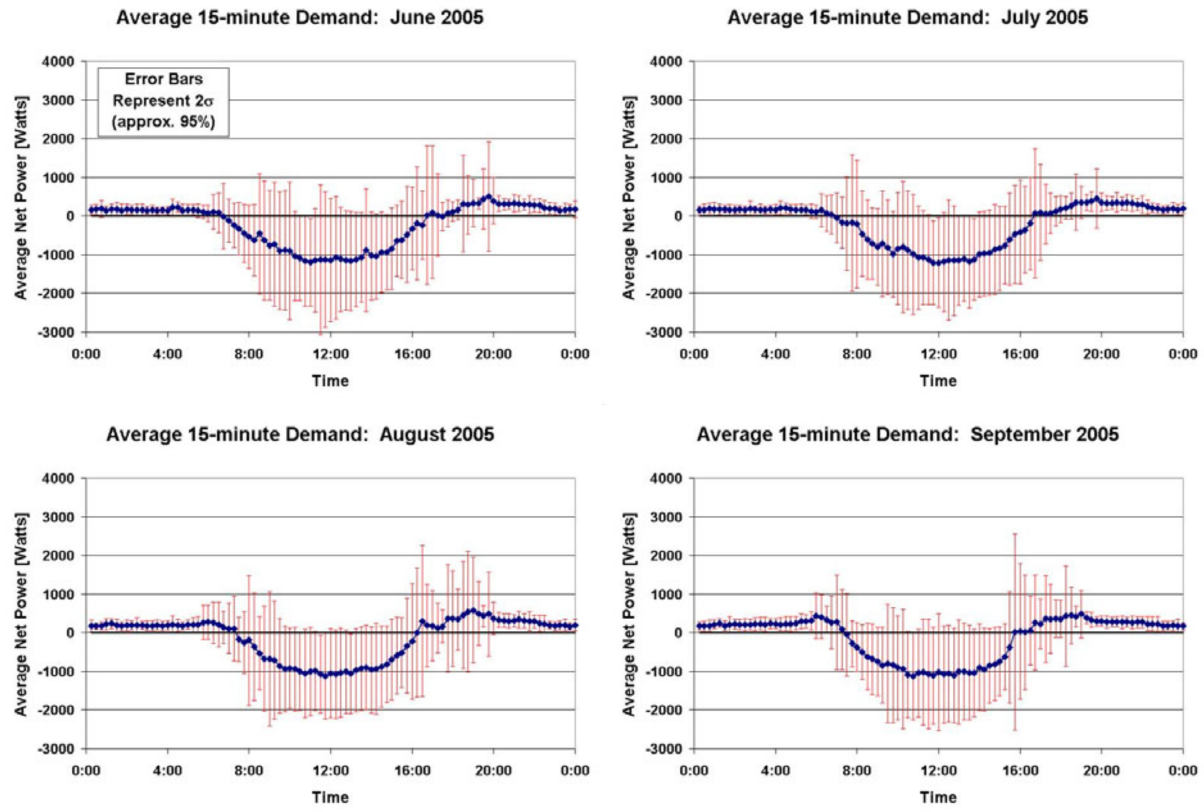


Table 3. Summary of Net Demand and Energy During WMECO Peak Energy Periods (6 am-10 pm Weekdays, June-September)

	Average 15-Minute Demand	Average Daily Net Peak Energy
June	-421 W	-6.7 kWh
July	-432 W	-6.9 kWh
August	-437 W	-5.6 kWh
September	-341 W	-5.5 kWh
Overall	**-408 W**	**-6.2 kWh**

Note: Negative values indicate net generation.

Figure 5. Average 15-Minute Demand During Each Summer Month



Note: Negative values indicate net generation.

Benefit/Cost Analyses

Incremental Costs

As part of the research process, WMECO obtained costs for all major building elements that were improvements over "typical" construction in Massachusetts ("typical construction" in Massachusetts is defined in Xenergy 2001). Incremental improvement costs for home systems, and the life span of the measures used in the analyses, are summarized in Table 4 below.

Utility Benefits and Avoided Costs

To analyze program viability, Massachusetts relies primarily on the "Total Resource Cost" test as defined by the Mass. Department of Telecommunications and Energy (DTE). This test attempts to account for all benefits associated with the house including electric energy and peak savings as well as other non-electric benefits such as fossil fuel savings and water savings. To calculate total resource savings, the authors have used results of energy modeling – not monitored data. Because results will be used to evaluate widespread effects of similar building practices, effects of homeowner behavior need to be eliminated. (In this home, oil consumption agrees quite well with modeling, but residents use less than half the electricity predicted by modeling). A summary of electrical and fossil savings used in the total resource test is shown in Table 5.

Table 4. Summary of Incremental Costs to Improve Energy Performance Above "Typical" Construction in Massachusetts

Home Improvement	Incremental Cost	Measure Life (yrs)
Upgraded cellulose insulation	$1,800	25
High-performance windows	$1,028	25
Efficient oil boiler	$750	25
Indirect water heater	$800	25
100% compact fluorescent lamps	$1,120	6
Energy Star® clothes washer	$250	14
Energy Star® dish washer	-	-
Efficient refrigerator	$100	19
Solar electric system	$26,445	25
Solar thermal system	$7,808	15
Total improvement costs:	**$40,101**	

Table 5. Key Electricity and Fossil Fuel Reductions Used in the Total Resource Test – Values Include Modeled Gains from Efficiency as well as Solar Generation

Annual electric energy reduction	7,345 kWh
Summer peak demand reduction	2.9 kW
Annual site fossil fuel reduction	92 MMBtu

The most recent utility avoided cost values, revised in 2005 (ICF 2005), capture the effects of Hurricane Katrina on fuel prices and the benefits associated with federally mandated congestion charge (FMCC) reductions due to conservation including DRIPE (demand reduction induced price effect). These benefits, calculated over the lifetime of each measure or building system, are summarized in Table 6.

Table 6. Summary of Avoided Costs and Utility Benefits

Measure or Improvement	Electric Benefit	Non-Electric Benefit	Total Benefit
Space cooling	$9,605	$111	$9,716
Lighting	$1,782	$373	$2,156
Refrigerator	$155	$9	$164
Efficient space heating	$129	$15,420	$15,549
Efficient water heating	-	$3,008	$3,008
Clothes washing	$330	$843	$1,173
Photovoltaics	$18,360	$413	$18,773
Solar hot water	-	$2,394	$2,394
Total	**$30,361**	**$22,571**	**$52,932**

A comparison of Table 6 and Table 4 shows that this move towards "zero energy" is cost effective: the ratio of total benefits to total costs is **1.32**. A closer look at the benefits and costs shows which elements are most cost-effective. Cost for improved insulation and heating equipment, for example, results in a space conditioning benefits of seven times the additional cost. Efficient lighting has a benefit-to-cost ratio of nearly 2. When the solar systems are considered separately, however, the benefit-cost ratios are substantially lower than one. As expected, it is the efficiency measures which drive the cost-effectiveness of the "zero energy" approach.

Costs and Benefits to the Homeowner

The added cost for efficiency and renewable energy features in this home was $40,101; this figure can certainly be intimidating for any homebuyer. With current energy prices and available incentives, however, the improvements are cost effective for the homeowners as well as for the utility. With energy savings of $2,587 each year (reductions of 7,345 kWh at retail electricity rates of $0.14/kWh and 663 gallons of oil/biodiesel at prices of $2.35/gallon), Table 7 shows that without any incentives, the simple payback on the $40,101 investment is 16 years. The second row shows the approximate net costs after available state incentives for PV and WMECO incentives for Energy Star® homes and lighting; it also shows that the internal rate of return of the investment after incentives is 7.5% -- above most current mortgage rates.

Table 7. Summary of Homeowner Costs and Benefits

	Net Incremental Cost	Annual Energy Savings	Simple Payback	Rate of Return
No Incentives	$40,101	$2,587	16 years	4.1%
After State and Utility Incentives	$28,731	$2,587	11 years	7.5%

Note: The second row includes incentives for PV, Energy Star® homes, and Energy Star® lighting available to customers in 2006. Federal tax credits are not included. Electricity rates are $0.14/kWh; oil costs are $2.35/gallon.

Current federal tax credits can further improve the cost-effectiveness, and, using results from this study, WMECO hopes to develop a pilot program providing additional incentives for builders reaching even higher levels energy performance.

Broader Applications and Implications of the "Zero Energy" Approach

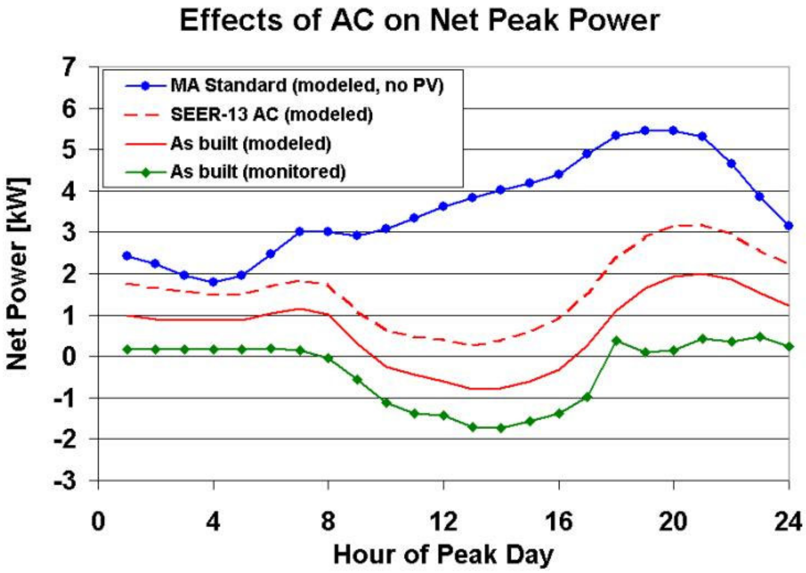
Until now, this paper has veered very little from a focused analysis of a single home. While this focus is useful to highlight the costs and benefits of a real-world example, there are many other areas which have not been considered but are key for more wide-spread analyses.

Air Conditioning

While the residents of this home claim that air conditioning is not necessary, central air conditioning is certainly standard in most new homes in western Massachusetts. In the avoided cost analyses above, a cooling benefit is shown based on envelope improvements only. Because the home did not have any air conditioning, avoided cost modeling assumes an air conditioner of "typical" efficiency (SEER-10.2 in this case). While inclusion of an efficient air conditioner with a tight duct system would have increased the actual electric load in the home, it would have significantly *improved* the benefit-to-cost ratio by showing a greater load reduction when compared to typical construction.

To clarify, the peak summer demand reduction calculated for this home with standard-efficiency AC is 2.9 kW. If the home had an efficient air conditioning system (SEER-13), the total resource analysis would include peak savings of 3.5 – 4 kW. The actual peak savings measured at the home (with no air conditioning) was 5.7 kW, though this includes factors besides the missing air conditioning load. Figure 6 shows modeling results of air conditioning this home during the peak summer day. Energy Gauge software was used to model hourly cooling loads for a home without AC, the home with SEER-13 AC, and the home with typical Massachusetts construction.

Figure 6. Effects of Air Conditioning on Peak Demand



Note: The bottom series shows net power measured at the Hadley home during the hottest summer day. The middle two series show loads predicted by Energy Gauge modeling (with and without air conditioning). The highest line shows modeling results for this home with typical construction and no solar systems.

Renewable Energy Credits (RECs)

Solar electric RECs are currently trading in Massachusetts at approximately $80/MWh. At this rate, the present value of the RECs generated by the PV system over the 25 year analysis period would be $4,583. This is one of the largest direct, monetary benefits not included in the utility's Total Resource test.

Cost of Solar

From the analyses above, it's clear that solar electricity and solar hot water are the most costly and least cost-effective energy improvements to the home. While costs of PV have increased recently because of supply issues, it's hoped that in the long-term prices will continue in their downward trend. If the installed cost of PV was reduced from $26,445 to $21,100 (or from $10/Watt to $8/Watt, a price reported now from builders in many parts of the country) and cost of the solar thermal system could be reduced from $7,800 to $6,000 (such prices are seen now in some regions) the overall benefit-to-cost ratio of the project would increase dramatically from **1.32** to **1.61**.

Increasing Energy Costs

Rising energy costs will continue to make efficiency and renewable energy more and more cost effective. When the authors began analyzing data from this project in mid-2005, the published avoided costs (ICF 2003) only resulted in an overall benefit-to-cost ratio of **0.84**. The increase in the B/C ratio (to **1.32**) is a reflection of the rapidly changing energy markets.

A Utility Pilot Program for Homes Nearing "Zero Energy"

This research effort has already achieved positive results. The home has been featured in several local newspapers and on three local TV news programs. For some residents of the area, it has opened their eyes to the viability of solar energy in Massachusetts and the possibility of approaching "zero energy" (or at least "zero electricity") in homes. Most importantly, it showed that this combination of energy efficiency and renewable energy is cost effective – both for the utility and for homeowners.

WMECO is currently considering the next phase of this project: a pilot program for 6-12 homes in western Massachusetts. In the pilot program, home builders would meet minimum standards for energy efficiency and renewable energy, allow WMECO to monitor the homes' performance, and receive a financial incentive above those already in place for efficiency and solar electricity. While the standards and incentives are far from being finalized, Table 8 outlines the preliminary requirements of homes in such a program.

Table 8. Preliminary Minimum Specifications for Homes Participating in WMECO's Pilot Program Currently Under Development

Heating and Cooling	At least 50% less consumption than a home built to 2004 IECC.
	Central AHUs use brushless permanent magnet (BPM) motors.
	Min. SEER-14 AC (if installed)
Water Heating	Min. 0.61EF for gas or oil
	Min. 0.9 EF for electric
	Integrated or indirect with Energy Star® (or equivalent) boiler
	No immersion/tankless coils in high-mass boilers
	Only manually-controlled DHW recirculation (if any)
Lighting	At least 90% of fixed lighting is Energy Star® (or equivalent)
Appliances	All Energy Star® or equivalent
Ventilation	Exhaust fans Energy Star®
	Central fans use BPM motor
	All ceiling fans Energy Star®
Solar Electric	2 - 3.5 kW of PV
Solar Thermal	At least 40 ft^2 of collector coupled with 80 gallons of storage.

Homes would participate in WMECO's existing Energy Star® program and undergo even more rigorous inspections and testing (including commissioning of solar and other advanced systems). The requirements are designed to leverage several existing utility, state, and federal financial incentives totaling \$8,000 - \$26,000 (outlined in Table 9).

Table 9. Financial Incentives (to Home Builder or Home Owner) Available in 2006-2007

WMECO Energy Star® Home incentive	\$500
WMECO Energy Star® lighting package	\$500-\$1,500
Mass. Technology Collaborative PV Incentive (\$2.50-\$5.25 per Watt):	\$5,000-\$18,375
Federal Tax Credit – 50% over IECC	\$2,000
Federal Tax Credit – PV system	up to \$2,000
Federal Tax Credit – solar DHW	up to \$2,000
Total:	\$8,000-\$26,375

With yet another incentive from WMECO for homes meeting all of the above requirements, almost half of the incremental up-front costs to the builder and/or home buyer will be offset. While costs will range substantially, SWA and WMECO expect that such an investment will result in simple paybacks for the homeowner of 5-10 years with rates of return of 8-15%. For the utility, total resource benefit-to-cost ratios will likely range from 1.3 – 2.

References

[DTE] Massachusetts Department of Telecommunications and Energy. “Investigation by the Department of Telecommunications and Energy On Its Own Motion to Establish Methods and Procedures to Evaluate and Approve Energy Efficiency Programs, pursuant to G.L. c. 25, § 19 and c. 25A, § 11G.” DTE 98-100.

[EIA] Energy Information Administration. 2001. Table CE1-9c. “Total Energy Consumption in U.S. Households by Northeast Census Region.” *2001 Residential Energy Consumption Survey: Household Energy Consumption and Expenditures Tables*.

[ICF] ICF Consulting. *Avoided Energy Supply Costs in New England*. December 2005.

______. *Avoided Energy Supply Costs in New England*. August 2003.

XENERGY, Inc. 2001. *Impact Analysis of the Massachusetts 1998 Residential Energy Code Revisions*. May 14.