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Indirect Solar Water Heating in Single-Family, Zero Energy Ready Homes

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Consortium for Advanced Residential Buildings

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The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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Definitions

CARB	Consortium for Advanced Residential Buildings
DHW	Domestic Hot Water
HPWH	Heat Pump Water Heater
ICS	Integrated Collector and Storage
PV	Photovoltaic (Solar Electric)
SDHW	Solar Domestic Hot Water
WWSV	Wisdom Way Solar Village

Executive Summary

Solar water heaters have been installed on homes for decades, but they have not become prevalent in most of the United States. Most of the country is cold enough that indirect solar thermal systems are required for freeze protection, and their average installed cost is $9,000–$10,000 for typical systems on single-family homes. These costs can vary significantly in different markets and with different contractors; federal and regional incentives can reduce these upfront costs by 50% or more.

In western Massachusetts, an affordable housing developer built a community of 20 homes with the goal of approaching zero energy consumption. In addition to excellent thermal envelopes and photovoltaic systems, the developer installed a solar domestic hot water (SDHW) system on each home. The Consortium for Advanced Residential Buildings (CARB), a U.S. Department of Energy Building America research team, commissioned some of the systems, and CARB was able to monitor detailed performance of one system for 28 months.

Once several problems with the SDHW systems were resolved, the monitored system provided 80% of the water-heating loads during the first 2 years. This translated into natural gas savings of no more than 96 therms/year ($134 at $1.40/therm). The developer received a grant to cover the cost of the SDHW systems; however, without large incentives, the SDWH economics did not look favorable.

Economics are not the only factor in zero energy homes. In this report, CARB explores factors and situations in which indirect SDHW may be a practical method of achieving zero energy consumption. These situations include:

- No natural gas onsite
- High SDHW incentives
- High energy prices and high domestic hot water consumption
- Heat pump water heaters are not practical
- Reliable contractors
- Reliable, low-cost maintenance.

Even when these conditions favor SDHW, CARB believes substantial reductions in indirect SDHW system cost are needed for the systems to be practical in most U.S. zero energy homes.

1 Introduction

This report examines the role of solar domestic hot water (SDHW) systems in very efficient homes such as zero energy ready homes and homes that aim to achieve zero energy consumption. This report focuses specifically on colder climates where indirect SDHW systems are needed for freeze protection.

Section 2 provides a brief background that reviews system types, performance data from a few past studies, and analysis of the costs and savings potential of SDHW systems. Section 3 is a case study of a 20-home community in Western Massachusetts where each home had an SDHW system. The U.S. Department of Energy’s Building America research team Consortium for Advanced Residential Buildings (CARB) worked with the developer to assess the cost, reliability, and performance of the systems. In one home, CARB was able to monitor detailed performance of the water-heating systems for 28 months.

Section 4 examines the effectiveness of SDHW systems from a purely economic perspective (hard costs versus hard benefits) and from a zero energy perspective, i.e., in what situations are SDHW systems a practical choice for achieving zero energy? Section 5 presents concise answers to this question.

2 Background

2.1 Solar Domestic Hot Water in Nonfreezing Climates

In some milder climates (where freezing is a lesser concern than in colder regions), passive systems such as thermosiphon or integrated collector and storage (ICS) systems can be installed for lower costs than more complex, freeze-protected systems. Several Building America partners have successfully incorporated ICS systems into homes (e.g., PNNL 2013, Baechler et al. 2009) and monitored their performance (e.g., Rudd 2008, Rittlemann 2004). These researchers found that properly designed and installed ICS systems could provide 30%–60% of the water-heating load in single-family homes. Rittlemann (2004) shows that improperly designed and installed ICS systems can sometimes dramatically increase water-heating energy use.

Because these systems are quite simple with few active controls or moving parts, costs can be significantly lower than active indirect systems. A solar program evaluation study (Itron 2009) shows typical costs of ICS systems in Hawaii at $5,250 and typical costs of thermosiphon systems in California at $6,518.

2.2 Solar Domestic Hot Water in Colder Climates

In colder climates, potable water cannot remain in rooftop solar collectors. The two main methods of freeze protection (drainback and antifreeze) are indirect; i.e., potable water is not plumbed to the collectors. Both methods are more costly and complex than direct systems (Baechler 2007, DOE 2013, Mehalic 2010). CARB has worked with several utility programs, builders, and homeowners who are interested in incorporating solar water heating in cold-climate homes. Figure 1 and Figure 2 show monitored water-heating energy in a Massachusetts home and a Wisconsin home (Aldrich and Vijayakumar 2006). Both homes had very similar hot water use (64–71 gal/day); solar systems consisted of 64 ft^2 of flat-plate collector and 80 gal of dedicated storage. During the summer months, solar provided 80%–95% of water-heating energy; during the winter months, solar fractions dropped as low as 19%. Overall, both solar systems provided 61%–63% of water-heating energy annually. Both homes also, however, had efficient water heaters that provided auxiliary heat, and savings from the solar systems were estimated at $80–$140/year. From a strict cost standpoint, these savings did not justify the installed costs of $4,000–$6,300 *after* rebates.

In the years since this study, energy prices have risen dramatically and incentives for solar thermal have increased. Maguire, Fang, and Wilson (2013) compared the cost-effectiveness and source energy implications of several water-heating systems, including solar thermal. This modeling study examined different regions with different incentives. Without incentives, solar water heating was never the most cost-effective choice. When financial incentives were included, the authors found that solar thermal was the most cost-effective system in several scenarios. Not surprisingly, the SDHW systems had the lowest source energy consumption in many situations.

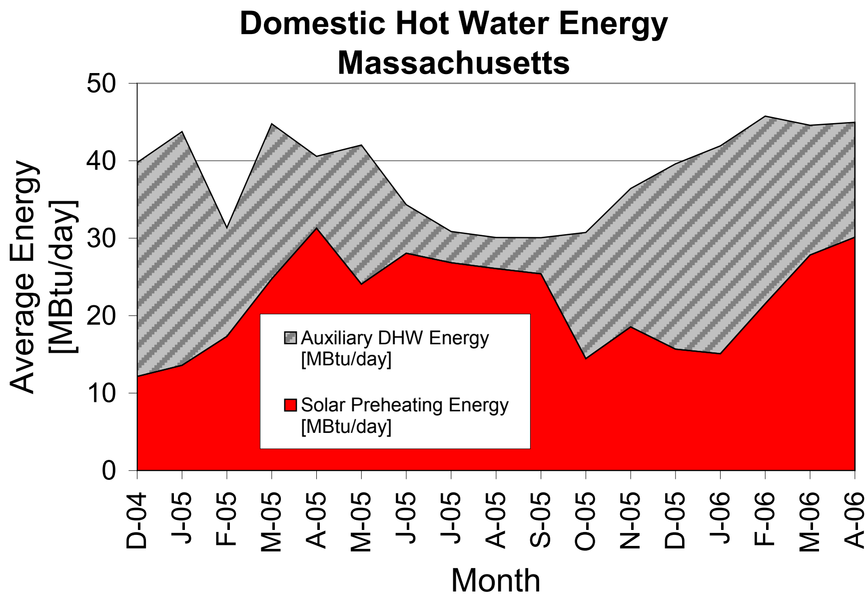

Figure 1. Performance summary of hot water systems in a Massachusetts home

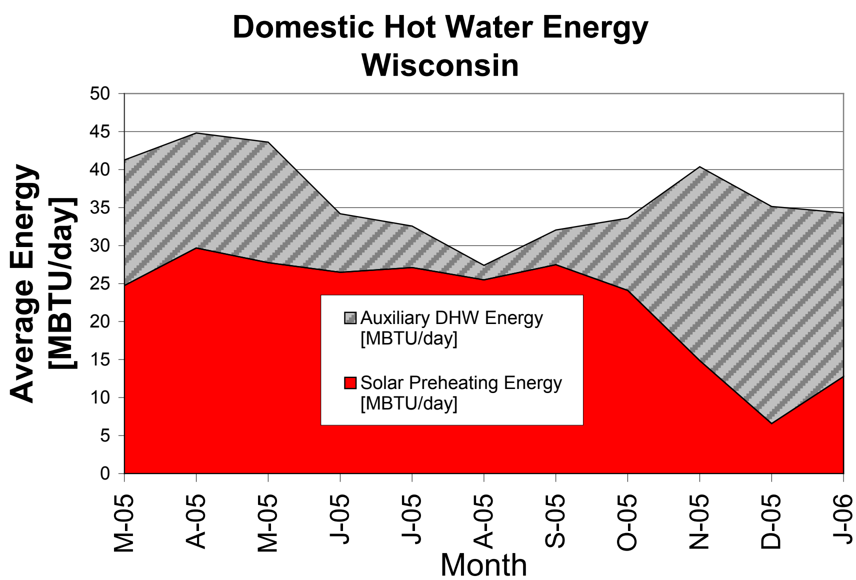

Figure 2. Performance summary of hot water systems in a Wisconsin home

2.3 Indirect Solar Domestic Hot Water System Cost

Solar system costs certainly vary with system type, size, and region. Maguire, Fang, and Wilson (2013) included analyses of installed solar system cost of approximately $7,000–$9,000. (Costs varied with system type and location.) In CARB's experience in the Northeast, installed costs for SDHW systems on single-family homes are typically $8,000–$12,000. A Massachusetts database of solar thermal systems (MCEC 2014) shows average installed cost of $10,200 for water-heating systems on single-family homes (average of 418 systems with two or three collectors, excluding larger systems that are likely used for space heating).

A California incentive program has a similar database of more than 1,000 SDHW systems installed on single-family homes (CSI-Thermal 2015). The average installed cost of all systems was $9,400, but this includes many smaller direct systems (such as ICS systems) that can cost significantly less than indirect systems.

These installed costs do not include state, federal, or utility incentives that can dramatically reduce upfront costs. System cost and the impact of incentives are revisited in Section 4.

2.4 Water-Heating Costs

When assessing the costs and benefits of solar water heating, the costs of heating water with conventional methods should be examined. According to the Residential Energy Consumption Survey (EIA 2009), the average water-heating cost in single-family homes is $304/year. Average costs vary tremendously by region and fuel. In parts of the Northeast, average costs for electric water heating exceed $400/year; in the West, gas water heating costs less than $200/year on average.

Energy prices have risen since these data were published, but two other drivers may counter this trend: more efficient water heaters and lower hot water consumption. In zero energy ready homes, which typically include efficient appliances, low-flow fixtures, and very efficient water heaters, water-heating costs are usually substantially lower than in typical homes.

3 Case Study: Wisdom Way Solar Village

3.1 Community Overview

In 2011, Rural Development Inc. completed construction of Wisdom Way Solar Village (WWSV), a development of 20 very efficient homes in Greenfield, Massachusetts. The homes featured R-40 walls, triple-pane windows, R-50 attic insulation, and airtight construction. All homes also had photovoltaic (PV) systems and SDHW systems; auxiliary water heating was provided by tankless gas water heaters. The homes achieved ENERGY STAR®, Leadership in Energy & Environmental Design (LEED) for Homes Platinum, and Builder's Challenge (the precursor to the U.S. Department of Energy's Zero Energy Ready Home Program) certification.

Figure 3. One of the duplexes at WWSV

3.2 Hot Water System Overview

Each home has its own solar thermal system that consists of Stiebel-Eltron SOL-25 flat-plate collectors coupled with a 110-gal storage tank. Each collector has a total area of 29 ft^2; two-bedroom homes have two collectors, and three- and four-bedroom homes have three collectors. A propylene glycol solution transfers heat from the solar panels to a heat exchanger located in the bottom of the storage tank. A direct-current circulator moves the fluid through this circuit, and the pump is powered by a small, dedicated PV module on the roof. To reduce the risk of overheating, a buried copper coil serves as a heat dump when the storage tank reaches its maximum temperature.

Cold water enters the bottom of the storage tank. From the top of the tank, water heated using solar energy enters the tankless water heater input, where it is heated further when needed. The tankless water heater is a Rinnai R75LSi rated at 180,000 Btu/h peak input capacity and 84%

efficiency. After the tankless water heater, hot water enters a tempering valve before it is distributed throughout the house. Bypass valves were installed so that either the solar system or the tankless water heater could be operated independently; a graphic of this was included in the homeowner's manual (see Figure 4). Homeowners were encouraged to manually bypass (and disconnect power to) the gas water heaters during summer months by opening valve #4 and closing valve #5. Valve labels were installed on each valve in each home (Figure 5).

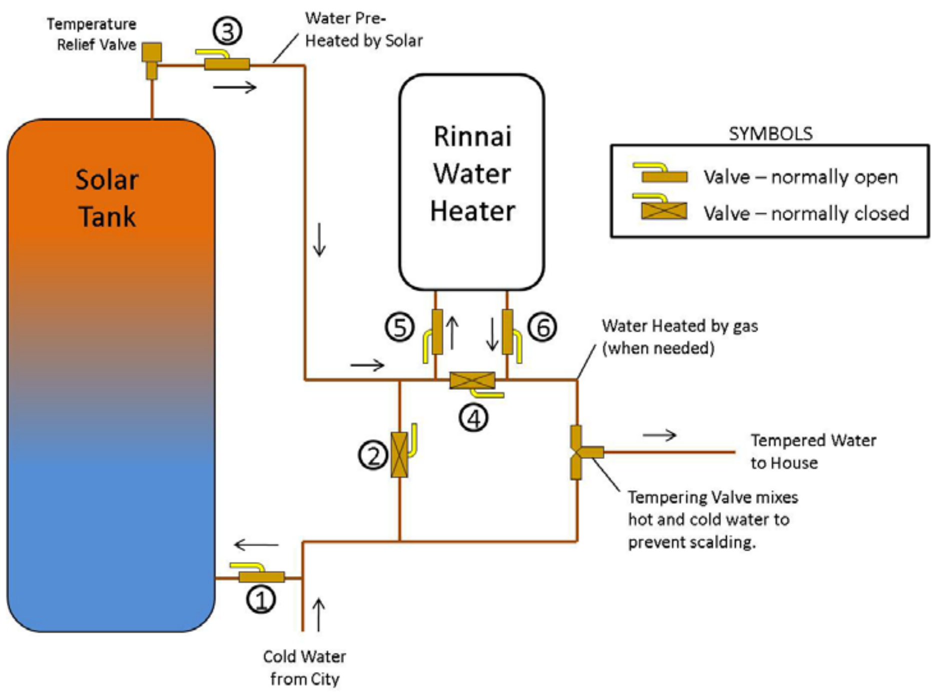

Figure 4. Schematic of water-heating system from homeowner's manual

Figure 5. Solar tank and auxiliary water heater in a WWSV basement

The installed costs of the solar thermal systems (without incentives) were $9,600 for a three-collector system and $8,600 for the two-collector system. Largely because this was a community of affordable homes, the developer was able to obtain a grant that covered the entire cost of the solar thermal systems.

3.3 Performance Problems

Even though the solar thermal systems have provided most of the energy needed to heat water in the homes, several problems occurred during the installation, commissioning, and ongoing operation. Details of these challenges were described in some detail in a previous report (CARB 2010); an overview is provided below:

- The direct-current circulators and PV modules powering them were too small and both needed to be replaced.
- Poor coordination during construction led to the heat dumps being buried beneath the basement slabs rather than underground outside the homes. This results in very warm basements during the summer months.
- Minimum pipe insulation of R-4 $ft^2h°F/Btu$ was specified, but installed insulation was initially half this value. More insulation was added to accessible sections.
- Uncertainties during construction led to relatively long pipe runs between the solar storage tanks and the tankless water heaters in three homes. Solar pipe runs typically varied between 30 feet and 90 feet one way (the monitored home had one-way pipe runs of approximately 50 feet).
- The wrong heat transfer fluid was installed in many systems because the manufacturer mislabeled several batches of its product. Several of the solar systems needed to be drained and reprimed.

- Visual flow meters were installed on the systems, but problems with the threads resulted in leaks. These meters needed to be replaced.
- The heat dumps were plumbed in different configurations. Instead of in series with the collectors and tank, sometimes the heat dump was in parallel with the storage tank, other times the heat dump was in parallel with the solar collectors. Several systems had overheating problems.
- In one home, a few times during the winter preheated water entered the tankless water heater at approximately 100°F. At modest flow rates, preheated water could be too warm for the tankless water heater to fire, but this temperature resulted in lukewarm showers. The showerhead was replaced with a higher-flow model; at higher flow rates, the tankless water heater fired with lukewarm entering water.

3.4 Monitoring Equipment

Toward the end of the project build-out, researchers installed equipment to monitor long-term performance of one of the water-heating systems. Sensors were installed to measure:

- Domestic hot water (DHW) volume (V_{DHW}, gal)
- Cold water inlet temperature (T_{cold}, °F)
- Temperature of water preheated by solar ($T_{preheat}$, °F)
- Temperature of water exiting tankless water heater (T_{hot}, °F)
- Temperature of mixed water running to loads (T_{temp}, °F).

A diaphragm meter with pulse output measured natural gas used by the water heater alone. Sensors were connected to a Campbell Scientific data logger and data were collected using a cellular modem (Table 1). With data from these sensors, CARB was able to calculate energy provided by the solar system, energy provided by the gas water heater, and efficiency of the gas water heater.

Table 1. Sensors Used To Monitor SDHW System

Measurement	Sensor	Listed Accuracy
Water Temperatures	Immersion thermistors, Omega ON-910-44031	±0.1°C (±0.2°F)
Water Flow Rate	Turbine meter Omega FTB4607	±1.5% of rate higher than 1.1 GPM ±2% of rate lower than 1.1 GPM
Natural Gas Consumption	American Meter Company AC-250TC with remote volume pulser	0.5% of reading

Heat delivered by the solar system (Q_{solar}, Btu) and the gas water heater (Q_{gas}, Btu) were calculated as follows.

$$Q_{solar} = V_{DHW} \times \rho_{water} \times c_{p,water} \times (T_{preheat} - T_{cold})$$

$$Q_{gas} = V_{DHW} \times \rho_{water} \times c_{p,water} \times (T_{hot} - T_{preheat})$$

where,

ρ_{water} = density of water (lbm/gal)

$c_{p,water}$ = heat capacity of water (Btu/lbm°F)

Efficiency of the gas water heater was calculated as follows.

$$\eta_{gas} = \frac{Q_{gas}}{V_{gas} \times 1{,}025\ Btu/ft^3}$$

where,

η_{gas} = efficiency of the gas water heater

V_{gas} = volume of natural gas (ft^3)

Sensors were sampled every 10 seconds. Density and heat capacity were quite constant, but they were calculated at the appropriate water temperature for each heating value (Q_{solar} and Q_{gas}) at each 10-second sampling interval. Energy values were calculated every 10 seconds based on instantaneous temperatures and water delivered during each 10-second interval. Energy sums, total water volume, average water temperatures, and maximum and minimum water temperatures were recorded at 15-minute intervals. Uncertainties were calculated using the root sum of the squares of the uncertainties and relative uncertainties using the sensor accuracies shown in Table 1. Relative uncertainties in heat delivered were typically 2%–5%.

3.5 Monitoring Results

During the first 2 years monitored, the solar thermal system provided 82% of the DHW load; average consumption was 40 gal/day for this home with two adults and two young children. As shown in Figure 6, the solar system provided 100% of the load in a few summer months.

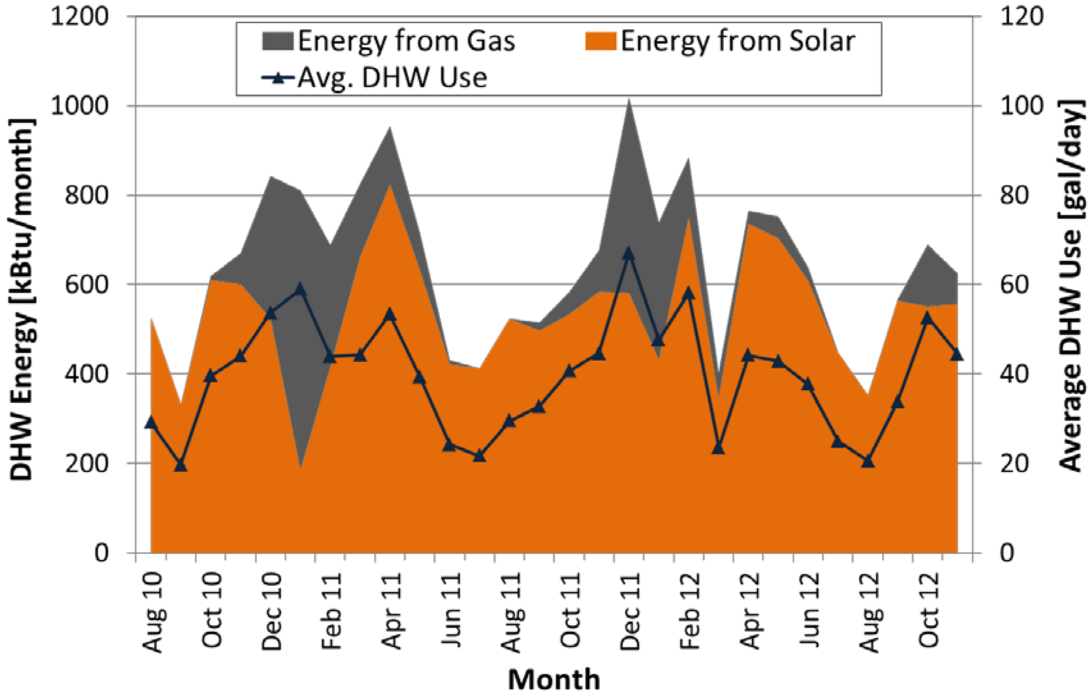

Figure 6. Overview of DHW consumption and water-heating energy

This monitoring effort also allowed an examination of the efficiency of the tankless water heater. During the first two years monitored, the overall efficiency of the tankless water heater was 67%. As Figure 7 shows, the efficiency varied tremendously with the load imposed on the water heater. The water heater was much more efficient during periods of higher load. CARB suspects two reasons for this:

- **Cycling.** This home has 12–15 feet of pipe between the solar tank and the tankless water heater inlet. When this volume of water (approximately 0.3 gal) is allowed to cool, the tankless water heater may still fire at the start of a water draw until the solar-heated water reaches the tankless heater. This short-cycling may lead to very poor efficiency.
- **Preheated water.** The gas water heater may be less efficient when heating preheated water. The water heater may require a higher temperature differential (with colder incoming water) to achieve better efficiencies. Also, with preheated water the water heater operates at lower capacities; whether or how efficiency varies with different loads and firing rates is unclear.

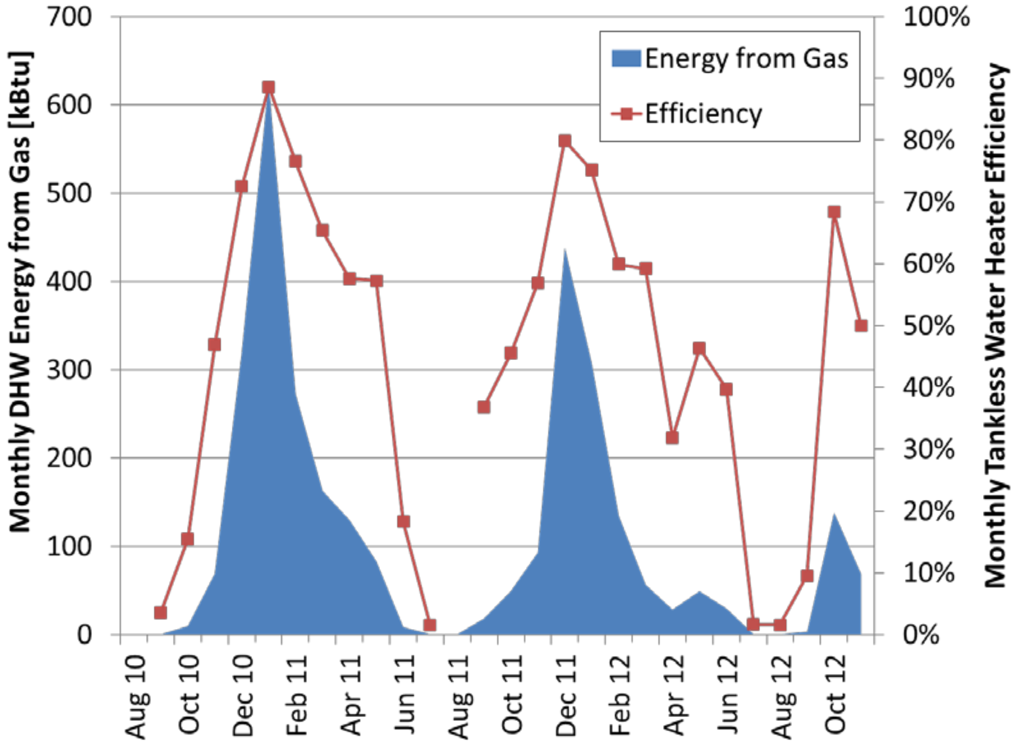

Figure 7. Thermal energy from the gas tankless water heater and water-heater efficiency

The homeowners' manuals include operating instructions that encourage them to turn their water heaters off entirely during summer months (as long as water temperatures are still acceptable). Turning off gas water heaters would eliminate gas use when the solar tank is warm enough. Apparently homeowners adjusted the valves to bypass the gas water heater during the first summer (no gas was used at all in August 2011); during the second summer apparently they did not.

3.6 Overall Assessment

The solar thermal system clearly provides most of the water-heating energy for this home. Providing all this energy with the tankless natural gas water heater—even at the reduced efficiency of 67%—would require an additional 96 therms/year. At a gas price of $1.40/therm, the solar thermal system saves owners $134/year. These cost savings alone do not justify the $9,600 installed cost. Even with the grant that covered the cost of the systems, the developer would be unlikely to install solar thermal systems in homes again. In hindsight, because of the performance problems and modest energy savings, the developer would have liked to use the roof area for additional PV capacity.

4 Discussion

4.1 Gas versus Electricity

One of the main reasons that solar water heating operating cost savings at WWSV were so modest is that the community had access to natural gas and used fairly efficient gas water heaters. If electric resistance water heaters were used in similar homes, apparent savings would be much more substantial: 2,100 kWh/year for annual savings of $437.[1] This may seem to be a somewhat irrelevant hypothetical situation, but CARB has seen a growing trend in zero energy (or zero energy ready) homes that avoid fossil fuels entirely and use electricity to meet all loads. Excellent envelopes enable small space-heating loads to be met with efficient heat pumps. Builders are exploring efficient ways to meet water-heating loads without natural gas to avoid the plumbing costs, infrastructure costs, and ongoing gas utility fees. Avoiding gas also simplifies the zero energy equation when on-site PV can meet all building loads.

Cassard, Denholm, and Ong (2011) identified auxiliary water-heating fuel as one of the most critical factors in determining the breakeven point for solar thermal systems. These authors found that, all else being equal, solar systems that offset electric water heating could cost approximately twice as much as those that offset natural gas to maintain a net-positive cash flow.

4.2 Hot Water Consumption

With lower hot water consumption, energy required to heat this water is lower, and potential savings from SDHW systems will also be lower. Although CARB is not aware of substantial studies on the topic, its monitoring efforts have generally shown a drop in DHW consumption over the past 10–15 years. These evaluations do not yield a statistically significant sample, but CARB believes that efficient appliances and low-flow fixtures have resulted in real DHW reductions in many homes. In the home monitored above, for example (with a family of four), the average daily DHW consumption of 40 gal/day is 30% less than the 57 gal/day estimated for the Building America reference home of comparable size (Wilson et al. 2014). Builders of high-performance homes are especially likely to install efficient appliances and quality, low-flow fixtures. This effect is even more pronounced in warmer climates where higher inlet water temperatures further reduce water-heating loads.

Because solar savings are lower with more modest hot water loads, SDHW systems may be more cost-effective in applications with higher water consumption. Larger homes with high occupancy certainly can be better candidates, and multifamily buildings may have more potential for SDHW systems (Itron 2012, Aldrich and Williamson 2015).

4.3 Solar Domestic Hot Water System Cost and Incentives

The databases cited from Massachusetts and California show average installed cost for indirect SDHW systems near $10,000. These costs vary dramatically, however, and in more mature markets or when a large number of systems are installed (as in a new residential development) costs can be lower. Hudon et al. (2012) recognized that costs must be reduced for SDHW systems to compete more effectively in cold climates. These authors proposed strategies to reduce indirect SDHW system costs to $1,000–$3,000. The strategies include using lightweight

[1] Using the same thermal load, a simple annual efficiency of 90%, and electricity rate of $0.208/kWh (EIA 2015a).

polymer materials, integrating system components to streamline installation, and other methods to improve performance and reliability.

Even with current SDHW costs, however, many incentives are available to reduce upfront costs. Many take advantage of a 30% federal tax credit[2] and a myriad of regional incentives. In Massachusetts, for example, a state program provides incentives based on the rated capacity of the collectors. The solar system in the Massachusetts case study (total installed cost of $9,600) would have qualified for incentives of $2,500 in this program. (The developer obtained a separate grant for these systems and did not participate in the program.) Between local incentives and the federal tax credit, more than 50% of installed system costs are often covered. Such incentives clearly can be major factors in the decision-making process for builders and developers. Refer to www.dsireusa.org for regional programs.

4.4 Proper Design, Installation, Commissioning, Operation, and Maintenance

As the case study described, this development had many problems with SDHW systems. One was undersized circulators. Aldrich and Vijayakumar (2006) found that the electricity needed to operate solar circulators could reduce SDHW savings by 20%–25%. Careful design and installation are critical for proper SDHW system operation.

Once commissioned and repaired, however, the evaluated systems provided most of the water-heating energy to the homes. Several utility evaluation projects have examined how performance matches predictions. Itron (2011) found that measured energy savings matched predicted savings quite closely in a project near San Diego (when predicted hot water consumption also matched).

Few studies, however, have shed light on the persistence of SDHW performance and savings. Consistent performance often requires proper maintenance, and scant literature is available on SDHW maintenance costs. Holladay (2014) laments this fact and refers to estimates from industry experts such as:

- Annual maintenance costs of 2% of installed cost
- A service visit every other year costing $200–$300.

CARB has encountered similar estimates working with builders and contractors in the Northeast, and such maintenance costs can totally eliminate energy savings in some homes. Other contractors and SDHW system owners, however, claim that they have virtually no maintenance costs.

4.5 Water Heater Options in Zero Energy Ready Homes

Condensing natural gas water heaters can be very efficient and are quite common in high-performance homes. Using the water-heating loads from the home monitored in Massachusetts as an example (40 gal/day, annual thermal DHW load of 7,890 kBtu), an efficient natural gas water heater requires 105 therms/year.[3] At the average national gas rate of $0.97/therm (EIA 2015b), this results in annual water-heating costs of $102. Many builders find the installed cost, operating cost, and reliability of these systems very appealing.

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[2] Residential: http://programs.dsireusa.org/system/program/detail/1235.
Corporate: http://programs.dsireusa.org/system/program/detail/658.
[3] Simple calculation with 75% seasonal efficiency.

A growing number of builders of extremely efficient homes (Passive Houses and true zero energy homes) are using no natural gas or any other fossil fuels. Sometimes this decision is based on a simple desire to avoid on-site fossil fuels; other times builders want to avoid the plumbing and infrastructure costs and ongoing utility charges associated with natural gas. Often natural gas is simply inaccessible.

Well-insulated resistance tanks are often used in all-electric homes. These have low initial costs, and using the 40-gal/day draw example they consume 2,570 kWh/year.[4] At electricity rates of $0.121/kWh (the current U.S. average, EIA 2015a) annual water-heating costs are $311.

Since 2000, heat pump water heaters (HPWHs) have become increasingly common in all-electric homes. CARB has monitored several of these products in homes around the Northeast (SWA 2012). HPWHs had seasonal coefficients of performance of 2, especially when properly sized in homes with modest hot water consumption. Using the same 40 gal/day example, an HPWH would consumes 1,160 kWh/year and cost $140.

Table 2. Example DHW Energy Use and Costs with DHW Load of 40 Gal/Day, 7,890 kBtu/Year

	Natural Gas	Resistance	HPWH
Seasonal Efficiency/Coefficient of Performance	75%	90%	2
Annual DHW Energy	105 therms	2,570 kWh	1,160 kWh
Energy Rate (National Average)	$0.97/therm	$0.121/kWh	$0.121/kWh
Annual DHW Cost	$102	$311	$140

Some homes have used PV with resistance water heaters to successfully achieve zero energy consumption (Rosenbaum 2011), but more than 2 kW_{STC} of PV is needed in most of the United States to cover the resistance loads shown in Table 2. Because of their much higher efficiencies, many builders choose HPWHs in all-electric, zero energy homes. In much of the United States, 1 kW_{STC} of PV generates the energy needed to power the HPWH.

Because of this, some have suggested that PV-powered HPWHs are a much more practical solar water-heating strategy than active solar thermal systems (Holladay 2012). With HPWHs carrying a $1,000–$1,500 premium over electric resistance water heaters (Williamson and Puttagunta 2013) and PV costing $3.50–$4/watt (SEIA 2015), installed cost for the PV-HPWH system could be approximately $5,000 before incentives.

HPWHs, however, are not appropriate for all applications. A packaged HPWH requires a substantial free volume of air from which to draw heat (typically 1,000 ft^3), so it cannot be installed in a closet. It also cools the surrounding space when heating the water. If located within conditioned space, an HPWH can decrease cooling loads in the summer and increase heating loads (and possibly cause comfort problems) during the winter. CARB has talked with a few builders and occupants of zero energy homes in cold climates where HPWHs are located in the basements. Some homeowners are very satisfied with systems; others complain about very cold basements in the winter. In extreme cases, some have removed the HPWHs and replaced them

[4] Using 90% seasonal efficiency for calculations.

with electric resistance water heaters because of comfort problems. A few studies have begun to examine such impacts on space conditioning (CHMC 2014; Williamson, Puttagunta, and Aldrich 2015), but they are not yet definitive.

5 Conclusions

Properly designed, installed, and maintained SDHW systems can provide a great deal of the water-heating energy needed in single-family homes. In most of the United States, however, making an economic argument for indirect SDHW systems in many single-family homes is difficult. The relatively high costs are not typically justified by the relatively modest savings.

But simple economics are not the only consideration. SDHW systems certainly do reduce electricity and fossil fuel use. In homes that strive to achieve zero energy consumption, SDHW systems may provide a practical path to the zero energy target. Solar thermal systems may be most practical if many of the following conditions apply.

- **All-electric homes.** Because electric resistance is usually the most costly way to heat water, economic savings are greatest when SDHW systems displace this method.
- **High incentives.** Some federal incentives are available for the entire United States; several states and utilities also have incentive programs that can dramatically reduce the cost of SDHW systems.
- **High energy prices.** The economics of SDHW are more advantageous when conventional energy sources are expensive.
- **High water use.** With larger water-heating loads, SDHW benefits are also higher. Because DHW loads in efficient single-family homes are quite small, SDHW systems may have greater potential in multifamily buildings.
- **HPWHs not practical.** Packaged HPWHs can use less than half the electricity of resistance water heaters; this electricity can often be provided by PV at lower costs than active SDHW systems. HPWHs are not viable in all homes, however. They do not function properly in closets; they can also increase space-heating loads and cause comfort problems.
- **Lower SDHW costs.** In parts of the country with more mature SDHW markets, installed costs of systems may be lower. Economies of scale can also reduce costs (such as installing SDHW systems on many homes in a community or development).
- **Proper design, installation, and commissioning.** These factors are critical for achieving acceptable performance and savings. CARB recommends using reliable, experienced contractors.
- **Proper, affordable maintenance.** As with any mechanical system, proper maintenance is key for long-term performance. CARB recommends that builders and developers address this by exploring extended, full-service warrantees, service contracts, or coordinating maintenance on a community scale (e.g., through homeowner associations or condominium boards). In any event, homeowners should have clear operating instructions and a means to identify system problems.

The high price for indirect SDHW systems ($9,000–$10,000) is still a major barrier. In an efficient home, heating water with electric resistance may require 2,600 kWh/year. In most of the United States, this electricity load can be met with 2–2.5 kW of PV. With PV prices falling lower than $4/watt, the cost of installing the 2–2.5 kW of PV needed to meet this entire water-heating load is $8,000–$10,000. This is on par with costs for indirect SDHW systems that meet approximately 80% of the water-heating load. CARB believes major price reductions are necessary for indirect SDHW systems to be effective on a significant scale.

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