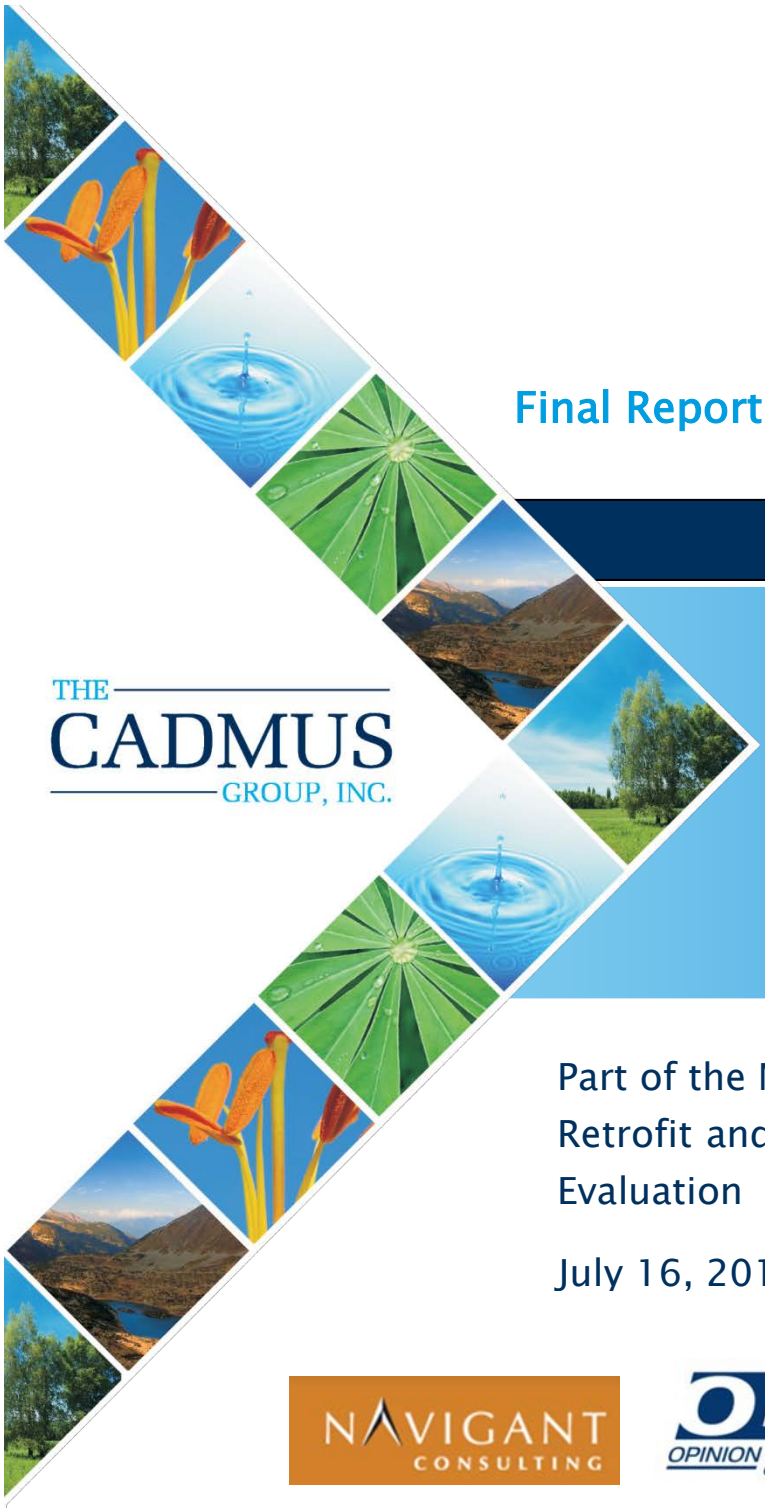

Final Report

Solar Hot Water Pilot Program Evaluation

Part of the Massachusetts 2011 Residential Retrofit and Low Income Program Area Evaluation

July 16, 2012

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Executive Summary

This report summarizes the findings of an evaluation, conducted by the Cadmus Group, Inc. (Cadmus), of National Grid's Solar Hot Water (SHW) Pilot Program. Data for this report were obtained through billing analyses, customer surveys, site visits, and engineering reviews of solar hot water systems installed through this program over the past several years.

Key findings of this evaluation include:

- The SHW pilot program gross gas savings, based on engineering estimates and modeling, is predicted to be approximately 701 MMBTU/yr, with average savings of approximately 14.2 MMBTU/yr per program participant.
- The SHW pilot program net gas savings, based on a billing analysis to account for takeback and other effects, is approximately 512 MMBTU/yr, with average savings of approximately 10.9 MMBtu/yr per program participant.
- Site visits confirmed the quality of SHW installations, with the only consistent problem being the lack of a UV-resistant jacket over the foam insulation on outdoor piping. The most common non-plumbing issue observed was excessive shading of solar collectors.
- The cost-effectiveness of SHW systems installed through this program is low, with simple post-rebate payback periods to customers of 50 years, on average. Some well loaded and well sited systems, however, achieved simple payback periods of 10 years. However, including O&M costs could extend these payback periods to over 100 years and over 20 years, respectively.

Based on these findings, Cadmus recommends that future program iterations be modified to:

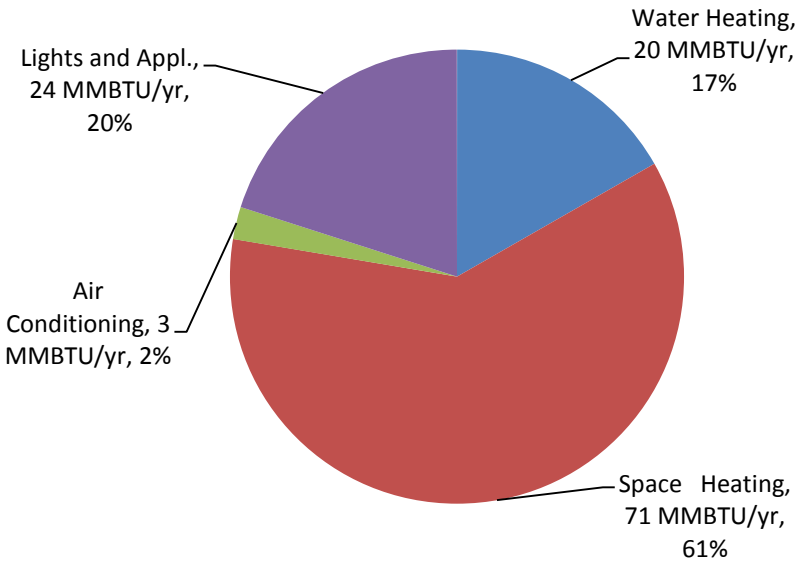
- Require that participants calculate expected energy savings using an industry tool, such as RETScreen, and include relevant inputs and assumptions, such as hot water consumption and shading information, as part of the rebate application. Applications with 25%, or greater, expected shading should receive, at best, a reduced rebate.
- To maintain installation quality and durability, require the use of solar collectors with a Solar Rating Certification Council (SRCC) OG-100 rating and require UV-rated jacketing on all exterior insulation.
- Consider limiting SHW rebate participation to customers with optimal sites and large hot water usage, or more expensive back-up heating fuels (electricity, propane).

1. Introduction

Energy Use for Residential Hot Water Heating

As shown in Figure 1, residential water heating is the second largest single-point load in the average New England household, consuming an average of 20 MMBtu/yr.

Figure 1. New England Household Energy Use (EIA 2001 RECS)



Source: United States Department of Energy's (DOE) Energy Information Agency (EIA).

Water heating energy in the northeastern U.S. is generally derived from natural gas, electricity, and fuel oil. All of the systems examined in this evaluation use natural gas for their domestic hot water heating load.

Background on Solar Hot Water Heating

A solar thermal hot water system collects solar energy to heat water. In most cases, these systems are used to heat domestic hot water, but in some cases they are also used for space heating, supplementing or replacing the use of other fuels. A typical system in a freezing climate consists of one or more solar collectors in a favorable outdoor solar collection location (south facing, inclined to the sun, and un-shaded), a pump with a controller connected to a storage tank and an indoor heat exchanger that circulates a heat transfer fluid through the solar collector(s) when the solar collectors are hotter than the storage tank. The solar storage tank typically is separate from the existing back-up hot water system or a new storage tank with integral heat exchanger and back-up system is installed as part of the solar installation. The outdoor mounted collectors and the storage tank are the main components added to a typical DHW system, since the pump(s), heat exchanger, and controller tend to be small items. The SHW system connects to the existing DHW system by interrupting the cold water inlet to the DHW tank and passing it through the SHW tank, usually with the use of a bypass valve arrangement so that the SHW system can be isolated from the DHW system if necessary.

The performance of SHW systems is primarily a function of the hot water load and the solar aperture (azimuth, tilt and shading), though the aperture has a fairly wide band of conditions that lead to reasonable performance. Collector tilt, azimuth, and shading play a role in SHW system performance, especially the further these siting characteristics stray from the optimum. Tilt and azimuth have a logarithmic impact on performance, where there is a modest adverse impact on performance for minor shifts from optimum values, but as the disparity grows, the degradation grows disproportionately. Shading is an area-based performance degradation – at a specific shading level, collector output will suffer at the direct percentage. Lack of a significant hot water load greatly diminishes the savings of SHW systems, since the energy available at the collector cannot be captured if the water tank is already hot. In this way, SHW systems are similar to off-grid solar electric installations; once the storage media (batteries or storage tank) are full, no more energy can be collected until some is used.

An example of the typical indoor and outdoor components of a residential closed-loop SHW system, with flat-plate solar thermal collectors and a single solar preheat tank, is shown in Figure 2. This system was the most common type observed during Cadmus' site visits; there are many variations on this configuration in use throughout the world.

Figure 2. Typical Installation, Roof and Basement Pictures

Background on the Solar Hot Water Heating Pilot Program

National Grid's SHW pilot program has funded rebates for the installation of 47 SHW systems, to date, at residences in Massachusetts, Rhode Island, New York, and New Hampshire, with most in Massachusetts. The pilot program provides rebates to homeowners interested in installing a SHW system to offset their DHW gas usage. Rebates are awarded based on 15% of total system installation costs, as reported by the project applicant, with a cap of $1,500 per project. It is likely that most program participants also took advantage of the 30% federal tax credit on renewable energy equipment.

Evaluation Activities and Objectives

SHW systems require relatively expensive metering systems or an indirect analysis to determine energy savings, unlike other renewable-energy technologies where direct metering of electricity generation is simple and inexpensive. Cadmus evaluated this pilot program through billing analyses, surveys, on-site validations, and engineering reviews.

The overall plan for the evaluation was to:

- Identify, through a review of billing data, how many and which sites would be best suited for surveys and site visits. Sites with a year of pre- and post- billing data, and an apparently stable summer usage pattern were selected for further study.
- Assess, during site visits, how well systems were situated, designed, and installed.
- Collect survey information to understand what customers thought about their system and if they had had any problems. Thirty-two total sites were sent surveys and 28 returned surveys (24 were visited). One of the visited sites did not return a survey.
- Model SHW system performance using TSOL 5 and RETScreen solar hot water estimation tools.
- Analyze billing data and compare it to SHW system modeling and information collected during the site visits.
- Compare billing and modeling analyses for reasonability and identify any discrepancies.

Cadmus' evaluation answered the following research questions about the SHW pilot program:

- What is the thermal energy contribution of the funded SHW systems, based on billing analysis and engineering estimation?
- What impact has the program had on participant utility bills?
- How do predicted energy contributions compare with changes in customer utility bills?
- Are expectations of program-wide savings likely to be achieved?
- Are there any discernible performance, or cost-effectiveness, trends related to different types of SHW systems funded under this pilot program?
- Are system installations keeping with relevant industry best practices and are they operating as expected?

2. Methodology

Sample Selection

To maximize the possible information collected for this evaluation, Cadmus developed separate samples for each data collection effort: surveys, site visits, engineering analyses, and billing analyses. Before selecting the three samples, Cadmus examined billing data from January 2007 to July 2011 for 47 solar hot water sites in Massachusetts, Rhode Island, New York, and New Hampshire and looked for anomalies in the data for each site. The number of billing data records received at each site varied. Most customers had gas space heating, and since the water-heating load was not easily isolated in the winter months, we focused on summer months (June, July, August, and September) to discern water-heating gas savings. Once all billing data was reduced to the selected water-heating months, complete pre- and post-billing data was available for 32 of the 47 sites. The 15 that did not have complete pre- and post-billing data were excluded from the sample for each evaluation effort. The raw samples for each effort were selected from the pool of 32 valid sites based on having complete data in the evaluation activity being performed.

After site visits and surveys were completed, Cadmus combined information from the participant database with additional information collected through the participant surveys and site visits. This additional data was used to identify sites where pre- and post-billing data could not be readily compared to determine the net savings attributable to the installed SHW system. For example, the site visit data revealed that one customer had a pool and a hot tub, and considering the unusually high yearly and summertime usage, compared with the possible output of the SHW system, this site was excluded from the final sample for engineering and billing analyses.

The proposed solar fraction, provided by the contractor who installed the SHW system, was the only estimate of energy savings that we received prior to beginning the evaluation.[1] In order to convert the reported *ex ante* solar fractions into an energy savings value for comparison, we multiplied each valid site's solar fraction by the calculated pre-installation period DHW energy consumption. This gave a final sample of 23 sites for both the engineering and billing analyses.

The raw and final sample sizes for each activity are summarized in Table 1.

Table 1. Final Sample Size by Evaluation Effort

Evaluation Effort	Raw Sample	Final Sample
Participant Survey	32	28
Site Visit/Engineering Analysis	28	23
Billing Analysis	26	23

Surveys

The energy savings of a SHW system are linked to hot water consumption patterns. Low hot water consumption curtails a solar hot water system's energy output. To gauge trends in hot water consumption, we distributed a written survey with self-addressed stamped return envelopes

[1] The solar fraction is defined as the portion of domestic hot water load met by the SHW system

to program participants with complete billing information. Twenty-eight of 32 surveys were collected.

The survey, which is included in Appendix A, asked for general information in several categories:

- Basic house characteristics and occupancy
- Mechanical system information
- Hot water usage (e.g., showers, laundry, dishes)
- Additional energy efficiency/conservation measures undertaken
- Satisfaction with SHW system and installer
- Respondent free-form comments

Cadmus compared results of the survey to both the engineering and billing analyses to provide context and summarize information about the motivations of early program participants and how they can help the program better understand its target audience.

Billing Analysis

Cadmus compared pre- and post-installation period summer gas consumption data to calculate gas savings resulting from the installation of the SHW system. The difference in gas usage pre-SHW system versus post-SHW system yields the reduction in gas usage due to the installation of the SHW system. We used the months of June, July, August, and September to minimize any impacts from heating system operation, and adjusted the savings by the amount of insolation that occurred during the billing assessment period in relation to the entire year, since SHW systems generally collect more energy during the longer hours of summer than they do in winter. Roughly half of the insolation for the year occurs during the months of June, July, August, and September, with the other half distributed over the rest of the year.

Site Specific Savings Model

Cadmus used a regression model to calculate solar water heater gas savings for each site. The regression model estimates the gas savings, normalized for weather differences in the fall and early spring months between the pre- and post-measure installation periods. The regression equation is shown in Equation 1. We applied this equation twice for each site, for both the pre- and post-measure installation periods.

$$\textit{Equation 1: } ADC_{t,\,pre/post} = \alpha + \beta_1 AVGHDD_t + \beta_2 POST_t + \varepsilon_t$$

Where, for billing month 't':

- $ADC_{t,pre/post}$ is the average daily consumption (therms) during the pre- and post-periods, obtained from provided gas bills.
- α is the base therm usage of the water heater.
- β_1 is the average daily therm consumption per heating degree day.

- $AVGHDD_t$ is the average daily base 65 heating degree days based on site location.
- β_2 is the average site level daily savings from the solar water heaters.
- $POST_t$ is a dummy variable that is '1' in the post-period and '0' otherwise.
- ε_t is the regression model error term.

Seasonal and annual adjustment factors were then applied to the post period average daily gas consumption and the gas savings to account for variability in the solar resource. Since it was necessary to calculate post-period gas consumption based on spring and summer periods when gas bills were unlikely to reflect space-heating loads, simply annualizing the results would over-estimate energy savings. To account for this, we applied a seasonal adjustment factor based on TMY3 solar radiation data, as shown in Equation 2.

$$Equation\ 2: ADC_{post,adj} = ADC_{post} * \left(\frac{f_{yr}}{f_{sol}}\right)$$

Where:

- ADC_{post} is the post-period average daily gas consumption, in therms.
- F_{yr} is the fraction of the year represented by the post-period billing analysis.
- F_{solar} is the fraction of total annual solar irradiance available at the system location in the period corresponding with the post-period billing analysis.

Finally, we adjusted savings to account for annual variability in the solar resource to ensure that reported savings reflect a typical year's savings and are not biased by the solar resource available during the post-installation period. The calculation of this final savings number is shown in Equation 3.

$$Equation\ 3: Sav_{billing} = ADC_{post,adj}\left(\frac{I_{TMY}}{I_{post}}\right) * 365$$

Where:

- I_{TMY} is the insolation for a typical meteorological year, using TMY3 data from the nearest available weather station.
- I_{post} is the measured insolation for the post-installation period (12 months), obtained as daily averages from the Solar Data Warehouse (www.solardatawarehouse.com).

The savings found using Equation 3 are considered to be the net savings for a given site, since they reflect the actual change in gas consumption to the customer.

Site Visits

We attempted to schedule site visits at the 32 locations identified as having sufficient information for a modeling comparison. With the generous cooperation from the SHW pilot program participants, we conducted 24 site visits, two on Long Island, New York, two in Rhode Island, and 20 in Massachusetts. During site visits, we reviewed surveys with participants who

had returned the survey, or completed the survey with those who had not, to ensure their understanding of all questions and the completeness of responses. The following key information was collected during the site visits, most of which was used in the energy savings analyses:

- Collector manufacturer, model, and quantity
- Collector tilt and orientation
- Backup/existing hot water heating system information
- Hot water consumption-related observations
- Shading and orientation losses
- A review of installation quality

Engineering Analysis

We established inputs from site visit data and used the key common assumptions shown in Table 1 to estimate the expected energy output for all sites. These assumptions were based on our experience with other systems and were made for parameters difficult to field verify.

Table 2. Key Assumptions Used in Engineering Analysis

Parameter	Assumption	Basis
Heat transfer fluid composition	40% glycol/60% water	Typical mixture for northeastern climates
Heat transfer fluid flow rate	0.02 gpm per collector ft^2	Average flow rate estimate based on operational systems and SRCC and manufacturers recommended flow rates
Domestic hot water temperature setpoint	120°F	Typical value for residential DHW
Incoming water temperature	Based on ground temperature, sinusoidal between 43-57F	Typical cold water inlet temperature for northeastern US
DHW consumption	Varies between 38 and 87 gal/day based on occupancy	Building America benchmark (see below)

Estimating DHW Consumption

Estimating residential hot water consumption without direct measurements can lead to large uncertainty, as there is significant variability in user behavior, occupancy patterns, and equipment. The best way to understand hot water consumption is to take measurements over a long period of time, at least several weeks. As this was not within the scope of this study, we referenced studies from the U.S. DOE Building America program to estimate hot water consumption for each residence. These empirical consumption equations are summarized in Table 2.

Table 3. Summary of Building America Benchmark DHW Consumption Equations*

End Use	Water Consumption (gal/day) by Number of Bedrooms (Nbr)
Clothes Washer	7.5 + 2.5 x Nbr gal/day (hot only)
Dishwasher	2.5 + 0.833 x Nbr gal/day (hot only)
Shower	(14.0 + 4.67 x Nbr) x 0.75 gal/day (hot only)
Bath	(3.5 + 1.17 x Nbr) x 0.75 gal/day (hot only)
Sinks	(12.5 + 4.16 x Nbr) x 0.75 gal/day (hot only)

*More information on the Building America Benchmark can be found at: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/44816.pdf

Modeling SHW System Energy Output

Cadmus estimated the predicted gross annual energy savings for each SHW system using T*Sol, a SHW system performance modeling tool created by The Solar Design Company. T*Sol is used by SHW system designers, installers, and consultants for system design and performance prediction.[2]

In addition to T*Sol's calculations, we estimated SHW contribution using RETScreen, a free MS Excel-based software package available from Natural Resources Canada for a variety of renewable energy technologies.[3] We compared the results of both models to identify possible model bias and any discernible differences between purchased and free software tools for program implementation and evaluation purposes.

While TSOL requires more detailed information, both models require numerous parameters to produce an estimate of system output. A summary of the key parameters are:

- Collector quantity, type, and tilt / orientation (observed / measured on-site)
- Hot water consumption (estimated from survey results)
- System configuration (observed on-site)
- Shading losses (measured on-site)

Modeling the performance of SHW systems poses a unique set of challenges, regardless of the modeling software. One of the most significant is to accurately estimate on-site hot water heating loads. An inaccurate estimate of hot water load, when designing a SHW system, can lead to an oversized system that wastes energy during the summer months. This difficulty also applies to the post-installation evaluation process.

Other challenges to modeling SHW performance, and how they were addressed, are listed below:

[2] More information about the T*Sol monitoring package is available at: http://www.solardesign.co.uk/tsol-pro.php.

[3] More information about RETScreen is available at: www.retscreen.net

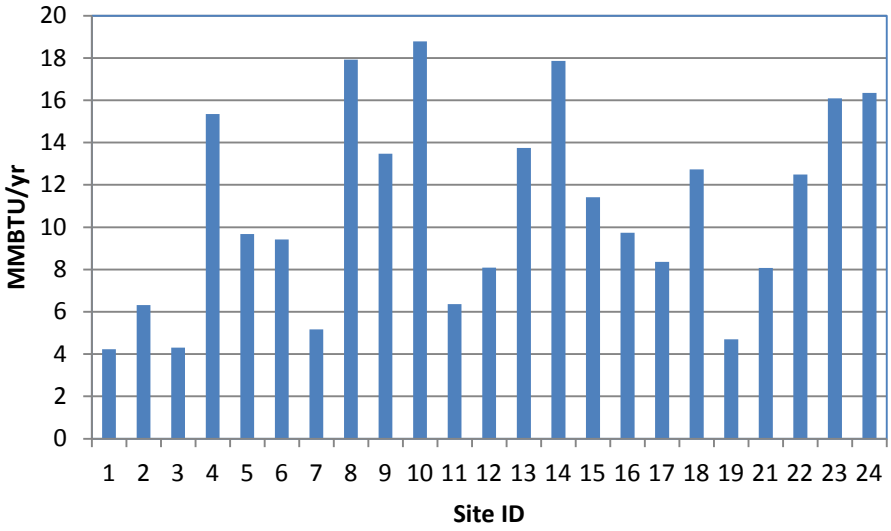
- Challenge: accounting for user interventions in SHW system operation (e.g., manually shutting off backup water heaters, adjusting setpoints)
    - Approach: manual intervention was not addressed
- Challenge: estimating the daily hot water usage profile
    - Approach: a 'morning maximum' profile was assumed, which is a profile of hot water usage with morning showers before work/school and evening chores that use hot water and fits most "typical" households
- Challenge: estimating collector loop flow rate and heat exchanger efficiency
    - Approach: loop flow and heat exchanger efficiency were assumed as previously stated
- Challenge: accurately indicating collector loop fluid composition
    - Approach: assumed value is typical for the northeastern US and energy estimation impacts due to fluid composition are modest
- Challenge: estimating backup water heating *in situ* efficiency
    - Approach: assumed nameplate hot water heater energy factor (EF), or estimated based on back-up heating equipment type

3. Findings

Results of Billing Analysis

Our review of available billing datasets determined the validity of the 23 sites' pre- and post-installation period billing data for analysis. Reduction in gas usage at each viable site due to the SHW system is shown in Figure 3. The overall gas savings of the billing analysis sample was approximately 251 MMBTU, an average of 10.9 MMBTU/yr per site.

Figure 3. Gas Usage Reduction Due to SHW Contribution – Billing Analysis



The billing savings varied widely, partly due to DHW usage and loading, shading, and differences in the efficiency of backup water-heating equipment. Further review of billing savings will be discussed at the end of the Engineering Analysis section.

Results of Survey

Thirty two participants, with valid billing data, received a survey. Of these, Cadmus was able to obtain 28 completed responses, about half returned through the mail and half were collected or filled out during the site visit process. The following is a summary of data gathered from the surveys. Note that some of the 28 respondents left blanks in a few characterizations so totals do not always equal 28.

- Basic house characteristics and occupancy
    - Average of house square footage: 2,160 SF
    - 26 Single-family homes, 2 multi-family homes
    - Average year of construction: 1955

- Average number of bathrooms: 2.4
- Average occupancy: 3.4 people
- Comparable pre- and post-occupancy: 24 out of 28
- No seasonal occupancy changes: 18 out of 24

- Mechanical system information
  - Furnaces: 6 of 28 homes
  - Boilers: 22 of 28 homes
  - Primary home heating fuel: 26 homes used natural gas, two used oil
  - Supplemental heat: half of the homes used some wood heating
  - Median pre-SHW DHW tank capacity: 40 gallons
- Hot water usage (e.g., showers, laundry, dishes)
  - Average of pre-SHW laundry loads/week: 5.8 This is consistent with other laundry studies by Cadmus and others.
  - Reported laundry temperature settings mostly remained the same, though there was a small increase in hot water usage as a result of the SHW system, as shown in Table 4.

Table 4. Changes in Laundry Temperature Settings

	Cold	Mixed	Hot
Pre	6	20	2
Post	4	18	5

  - Twenty-four respondents said they did not change the number of laundry loads as a result of the SHW system. Three respondents left a blank, 1 responded that they had increased laundry by 2 loads/week.
  - Twenty-six respondents said they did not change the number of dishwasher loads as a result of the SHW system. One responded 'yes' while the remaining respondent left a blank
  - All respondents said the number of daily showers did not change as a result of the SHW system, but 3 participating households reported changes in the duration of their showers as a result of the SHW system, by 3, 5 and 10 minutes. The average duration of showers is consistent with a variety of utility hot water calculations from the across the U.S. Most assume shower lengths of 8-9 minutes.
    - Average of number of showers/day per household: 2.8
    - Average length of shower pre-SHW: 8.74 minutes

        - Average length of shower post-SHW: 9.46 minutes

- Additional energy efficiency/conservation measures undertaken
    - Twenty-one respondents strongly agree that they would search out and pay extra for ENERGY STAR® appliances
    - Twenty-one respondents strongly disagree that they purchase used or least-cost appliances and that they do not consider appliance energy ratings
    - Twenty-two respondents strongly agree or agree that the installation of the SHW system has made them more conscious of their home's energy consumption. Based on responses to other questions in this survey, it is likely that the remaining respondents who did not agree with this statement were already very conscious of their home's energy use and the addition of the SHW system provided no new information.
    - Respondents were asked how likely it was that they would install the SHW system without the rebate. Table 5 presents the likelihood of the respondent installing a SHW system without the utility rebate.

Table 5. Likelihood of Installing a SHW System Without a Rebate

Very	Likely	Somewhat	Not
1	5	10	9

    - Tendencies to undertake other household energy-conservation measures are shown in Table 6.

Table 6. Tendencies of Undertaking Other Household Energy-Conservation Measures

Energy Conserving behavior	'Yes' Responses
Turn lights off in unoccupied rooms	27
Heating T-stat low, wear sweater	21
Heating T-stat set-back at night	24
Cooling T-stat set-up during summer	5
Take 5-7 minute showers	16
Shade windows in summer	21
Use extra window coverings in winter	11
Close doors to unused rooms, turn off heat	11
Unplug small appliances when not in use	13

- Twenty-seven respondents expressed being satisfied with how solar installers explained the system to them; an equal number were able to tell when their SHW system was working. The other respondent described that the installer 'sort of' described the SHW system, and they were not able to tell when it was operating.

- Twenty-five respondents considered operation of their SHW system not difficult at all, two not very difficult, and one somewhat difficult.
- Twenty-two respondents had no problems and no downtime with their SHW system since installation. The remaining 6 respondents had various comments relating to their SHW system downtime:
    - Failed Pump
    - Very long delay in getting hot water from tap, but it is not directly related to the solar system
    - Glycol solidified during extreme cold
    - It only holds heat for two days, gas the rest of the time
    - Broken solar tube
    - Plumbers can't figure it out, had to call specialist who built system
- Twenty-five respondents were very satisfied with their SHW system, two were satisfied, and one was somewhat satisfied.
- The following is a summary of comments in the free-form portion of the survey:
    - Respondents were appreciative of the rebates and said they facilitated cost-effectiveness of SHW systems. One found the rebate process complicated and time-consuming and had trouble finding a plumber who understood the rebate process.
    - Some respondents described that they had difficulty with trades-people not understanding the SHW system or getting trades-people to accept responsibility for getting their aspect of the system to work right.
    - Respondents suggested more education and awareness-building for the value of SHW systems, with comments expressing a desire for better energy-collection monitoring and stressing the fact to prospective buyers that low hot-water use reduces the value of a SHW system.
    - Two respondents were unfamiliar with tankless water heaters before installing one as part of their SHW system, and they would have liked more information about them before installation.
    - Two respondents suggested further development of SHW hardware and comparison-testing would facilitate market acceptance.

Site Visit System Installation and Operational Observations

Summary

Improper installation or maintenance of a SHW system can adversely impact the energy benefits of the system. Problems range from minor issues of failed pipe insulation to more serious issues

such as leaks or component failures. Cadmus' inspectors examined each system, to the extent possible, and identified the following performance-affecting issues:

- Fourteen sites lacked sufficient UV protection for outdoor insulation. Exterior insulation that is not protected from UV radiation will break down and fall apart within two to five years, leaving SHW piping uninsulated and reducing efficiency.
- All systems appeared to be operational at time of site visits. One system may require contractor review of sensor functions to ensure system is operating correctly.
- At four sites, collector shading was observed to exceed 25% of available annual solar radiation. Homeowners who had spent a significant percentage of the installed system cost for these systems were still happy with them, though the system economics were less attractive.
- No systems were observed to pose a likely risk to persons or property.

Overall, we found only minor installation issues during its site visits. However, many of these minor issues, if examined two to four years after system installation, will impact SHW system performance. Given that SHW systems are advertised to have a 20-year or longer useful life, even minor issues can have a significant impact on system economics over the life of the system.

General Observations and Sample Characteristics

The majority of observed SHW installations were flush-mounted onto an existing south facing roof, with some amount of exposed piping, and a solar storage tank located in the basement mechanical area. In all cases where nameplate information was viewable, components listed on the application form information provided to Cadmus were observed at site visits.

Most of the collectors faced within 45 degrees of due south and at a tilt angle from 30 to 50 degrees, which is only a small performance difference from the yearly optimum of due south at 35 degrees . Most systems used an indirect-style solar storage tank to transfer solar loop energy to domestic water. Half the solar storage tanks were approximately 80 gallons and the other half approximately 110 gallons. The backup water heating systems were a mix of boilers, second separate gas tanks, and tankless water heaters. One system was designed as a combination heat and hot water system and used much more collector area (256 sq ft) at a steeper collector angle (60 degrees) and with a larger storage tank (600 gallons) than the average. A breakdown of SHW system characteristics is show in Table 7

Table 7. Site Visit SHW System Characteristics

Attribute	Options	QTY	%
Collector Type	Flat Plate	20	83%
	Evac Tube	4	17%
Facing Azimuth	120 degrees	1	4%
	South +/-45d	21	88%
	240, 270d	2	8%

Tilt	20, 27d	2	8%
	30-50d	20	83%
	60, 65d	2	8%
Heat Exchanger Type	SHW Indirect	21	88%
	External HX	2	8%
	Direct Drainback	1	4%
Storage Tank Size	80g +/- Storage	13	54%
	110g +/- storage	10	42%
	500g storage	1	4%
Backup System Type	Gas tank backup	9	38%
	Tankless backup	4	17%
	Boiler backup	11	46%

The following figures present a variety of SWH installations. Figure 4 shows a typical collector installed with exposed piping on the roof.

Figure 4. Typical Collector Installations with Exposed Piping

Four of the 24 sites used evacuated-tube collectors, as shown on the two roofs pictured in Figure 5.

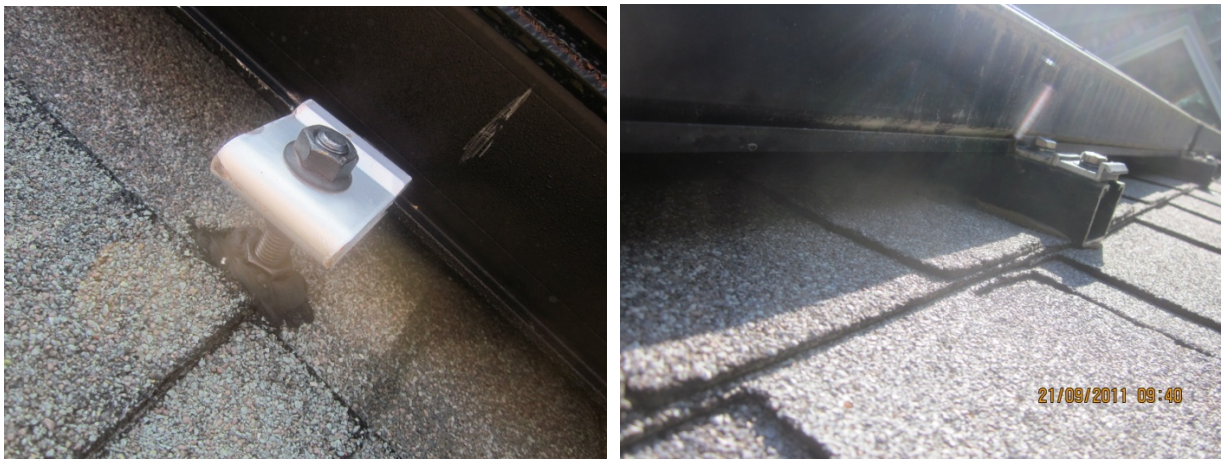
Figure 5. Two Roofs with Evacuated-tube Collectors

All of the collectors with viewable labels carried Solar Rating Certification Council (SRCC) labeling, which is a third party organization tasked with maintaining the quality of SHW equipment and systems. The SRCC rating provides an independent evaluation of the equipment from a performance and durability standpoint, and has been used since the early 1980's as a measure of quality. When providing rebates and incentives for SHW systems, an SRCC label is the best available standard to assure that components will tolerate service conditions for the life of the system.

Figure 6: SRCC Label on SHW collector

The flush-mounted configuration facilitates retrofit installation, but it also results in penetrations through the water-tight layer of the building that need to be durably sealed. Figure 7 shows two different mounting system sealing methods using silicone sealant directly applied to roofing.

Figure 7. Commonly seen Mounting System Sealing Using Silicone Sealant



The design of the roof flashing in Figure 8 is well-designed from a flashing perspective because of the sliding seal at the flashing. However, due to copper's high thermal conductivity and the relatively thick copper pipe fitting that connects from the solar loop piping to the flashing plate, this product is a sizeable thermal bridge from the SHW collector loop to the roofing, which is not a desirable feature in the cold climate of the Northeast.

Figure 8. Thermally Conductive Flashing Design

Arguably the most aesthetically pleasing and simplest to install collector configuration may be the skylight design similar to that used with Velux collectors, which looks like a skylight, has no exposed piping or roof mounts, and need not be removed during re-roofing. Figure 9 shows two photographs with the Velux flush-mount collector design.

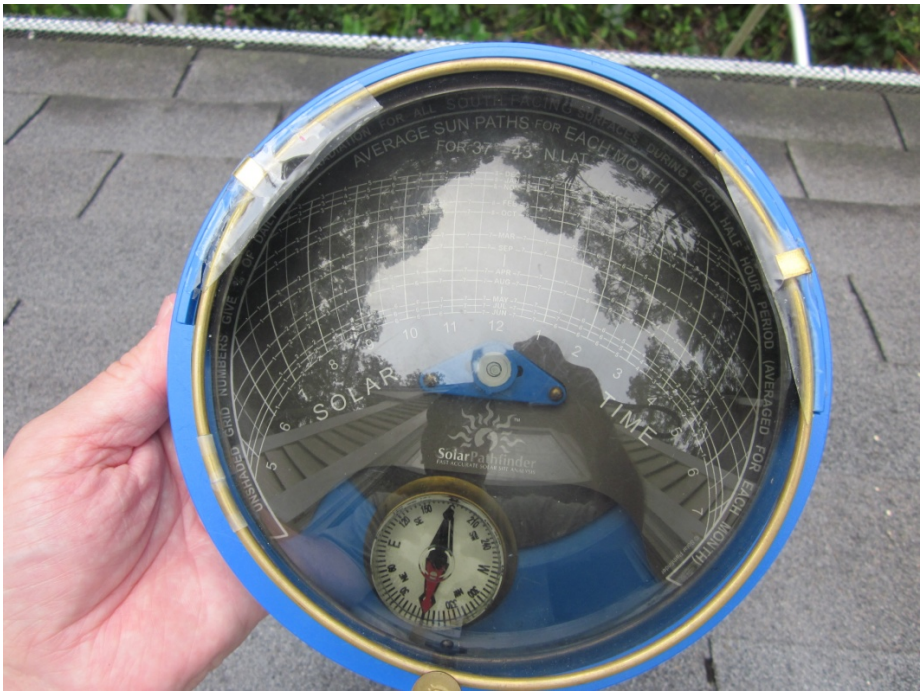
Figure 9. Velux Flush-Mount Collector Design

Many of the collectors with exposed piping had elastomeric pipe insulation to limit outdoor heat loss of SHW energy. This insulation is appropriate for reducing heat loss, but it is not usually rated for long-term exposure to UV rays and breaks down in the sun. Figure 10 shows the beginning of wear after only a couple years of service.

Figure 10. Insulation with No UV Jacketing Degrading in Sunlight

In a few case, there was significant shading (more than 25%) of the collector location, as measured by Cadmus using a solar site assessment tool. One solar site assessment tool to measure the solar fraction is shown in Figure 11. Significant shading adversely impacts system economics, and some threshold might be set for allowing a rebate. In the future, a shading analysis requirement could improve the accuracy of energy savings estimates.

Figure 11. Shading Measurement of 40%



PVC insulation jacketing is commonly used to provide UV resistance in outdoor applications. With the increasing number of mini-split heat pump and air conditioner systems, new products

have come into the market. Figure 12 shows the typical round PVC jacketing (left) and the square jacketing often used to cover insulation on mini-split refrigerant lines(right).

Figure 12. Typical Round PVC Jacketing (left) and Square Jacketing (right)

Pipes were often run on the outside of the house being served, sometimes painted to blend in with the siding, as can be seen in Figure 13.

Figure 13. SHW Piping (center of photo) Painted to Match Siding

Many of the installations incorporated a pre-assembled pump station with one or more pumps; check, fill, drain, and isolation valves; pressure gauge; flow meter; air separator; expansion tank; controller; and an insulated housing to minimize heat loss. In Figure 14, a pump station is shown with and without its cover.

Figure 14. Pump Station, Cover Removed in Right Photo

The pump station facilitates plug and play SHW systems, since the station needs only to be connected to solar collectors on one side, with the means for a heat exchange on the other side (most often an indirect water heater). Factory pre-assembly also reduces the likelihood of leaks and minimizes the amount of design and selection time for pumps and piping specialties associated with the solar loop. Figure 15 shows a solar storage tank with a pre-assembled pump station.

Figure 15. Solar Storage Tank with a Pre-Assembled Pump Station

We observed various backup water heating configurations at the sites visited. In more than half of the installations we visited, the house heating boiler was used as the backup water heating system, most often as a second heat exchanger in the solar storage tank. See Figure 16.

Figure 16. Boiler Backup in Solar Tank Configuration

The other popular option, as shown in Figure 17, was the two-tank system, where the solar storage tank supplies water to the existing gas tank water heater. In this configuration, the gas tank needs DHW water flow to remain warm; otherwise, the gas burner will turn on periodically to offset tank heat losses and to maintain set-point in the gas tank.

Figure 17. Two Tank System: Solar Tank with Gas Tank Backup in Background

As an adaption to the two-tank system configuration, a tankless water heater avoids the stand-by losses associated with tank water heaters and provides unlimited backup water heating, as long as gas is available. In this configuration, selection of the tankless water heater must allow pre-heated water to enter the tankless water heater. Not all tankless heaters maintain the proportion the gas burner flame to measured inlet water temperature, which could result in overheated hot water. An example of a tankless water heater is shown in Figure 18.

Figure 18. Tankless Water Heater Backup
(SHW Tank Output Supplies Tankless Heater)

Perhaps the most-efficient (and most-expensive) approach for backup water heating is the integrated solar storage tank and condensing boiler configuration. A condensing boiler is integrated into the upper section of an indirect water heater tank. Solar energy is input into the same tank; therefore, tank heat losses are only from a single tank and the backup heating efficiency can be as high as 95% from the condensing capability of the burner. Figure 19 shows the heat and hot water system integrated with SHW.

Figure 19. Integrated Heat and Hot Water System with SHW

Results of Engineering Analysis

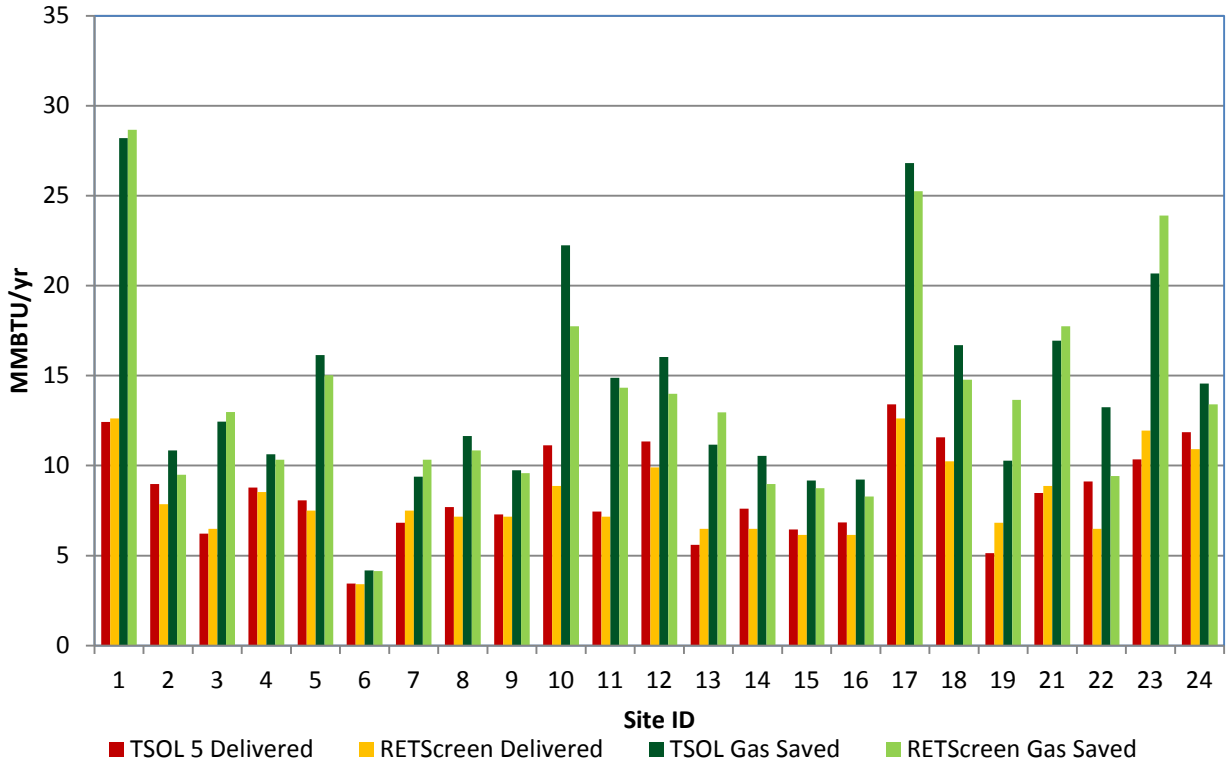
Cadmus collected sufficient information to model SHW system performance at 23 sites, using both T*Sol and RETScreen. Twenty of these sites used flat-plate collectors and three used evacuated-tube collectors.

Comparison of RETScreen and T*Sol Software Packages

As SHW gains more presence in the market, its effectiveness is subject to objective evaluations, such as this one. In order to accurately predict system performance, project proponents must have accurate estimation methods and software. At this stage of early adoption of new SHW systems, however, where many contractors may install only a handful of SHW systems per year,

the cost of such software can be considerable. To understand the value of the software options for SHW modeling, we compared the savings predictions of T*Sol and RETScreen to determine if the free software tool (RETScreen) provided results similar to the more sophisticated and expensive T*Sol software tool. As shown in Figure 20 below, the results for both tools were very similar, with no measureable bias between the two methods. Agreement was good between the two modeling tools (within 5%), therefore further results are reported based on results from T*Sol. Note that the difference between solar output delivered and gas savings shown in Figure 20 is the backup water heating efficiency.

Figure 20. T*SOL and RETScreen
Predicted Solar Energy Delivered (Del) and Gas Savings

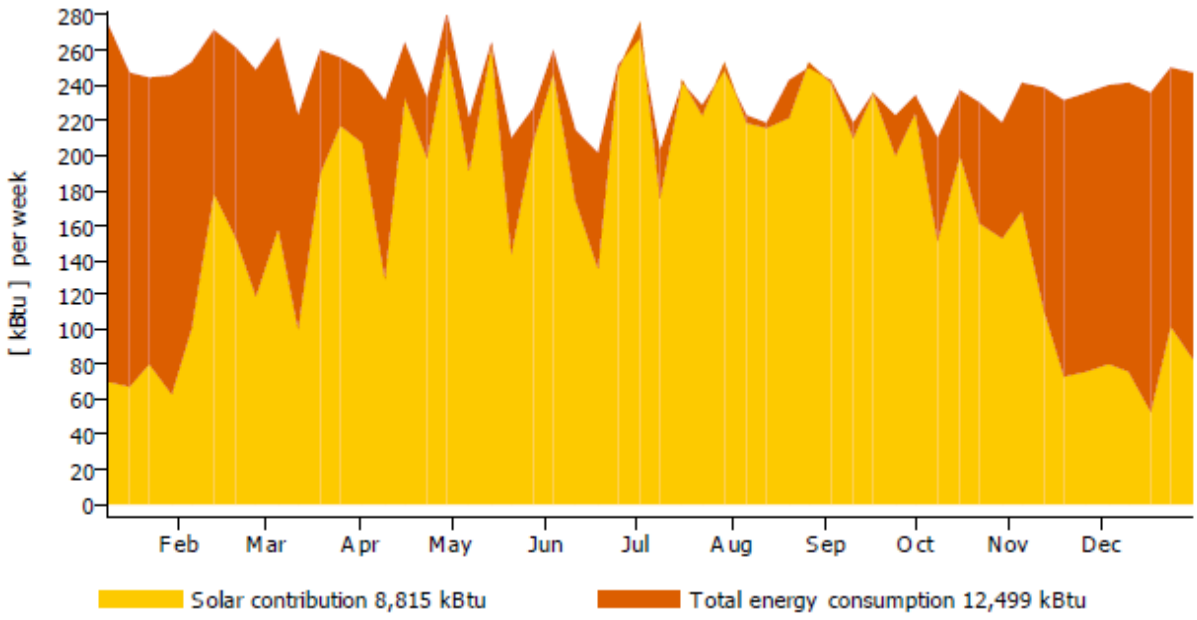


Lessons Learned Through System Modeling

Modeling the performance of SHW systems over the course of a typical year can lead to relevant observations about system sizing, orientation, and other factors on the effectiveness of the SHW system as a whole.

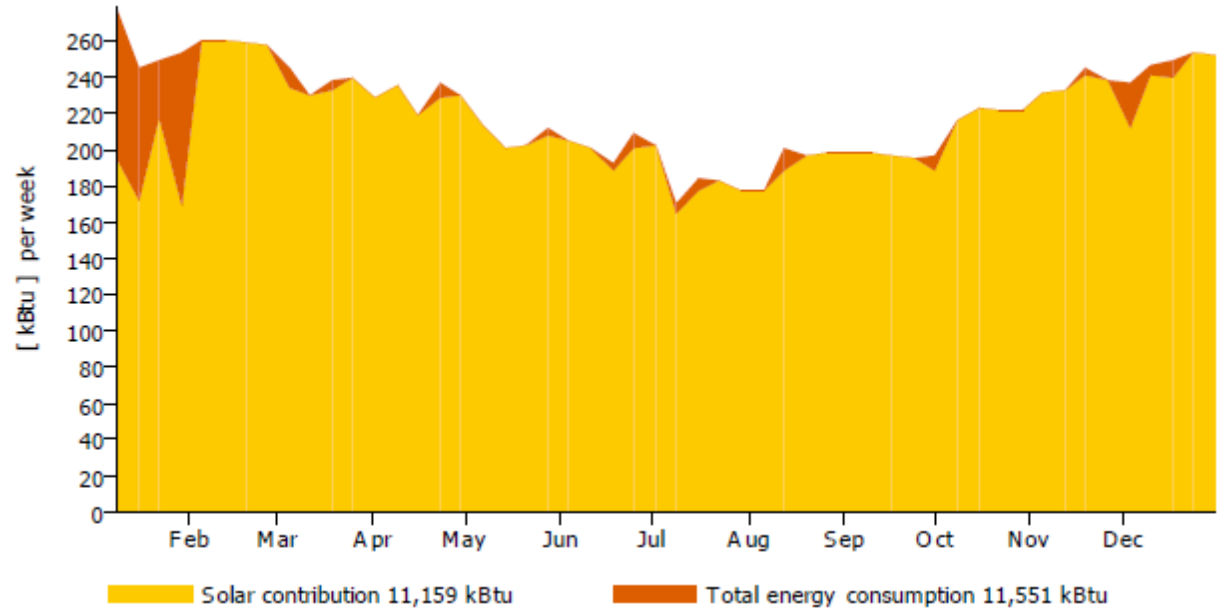
For example, Figure 21 illustrates the energy contribution profile of a well-sited and well-sized SHW system from the sample of 23 sites visited, as generated by T*Sol. During the summer months, when solar radiation is at its peak, the system generates nearly 100% of the hot water heating needed by the site. During the remainder of the year, the portion of the hot water heating load met by the SHW system decreases but there is no significant waste of SHW system energy output during the summer months, so the system generates over 70% of the hot water heating needs of the site on an annual basis.

Figure 21: DHW Energy Profile of a Reasonably Sized and Sited SHW System



Oversizing a SHW system, however, can lead to wasted capacity and a less cost-effective system. For example, as shown in Figure 22, the solar fraction of this site in the sample remains very close to unity for the entire year, which suggests that system energy output is curtailed by insufficient hot water consumption during the sunnier months of the year.

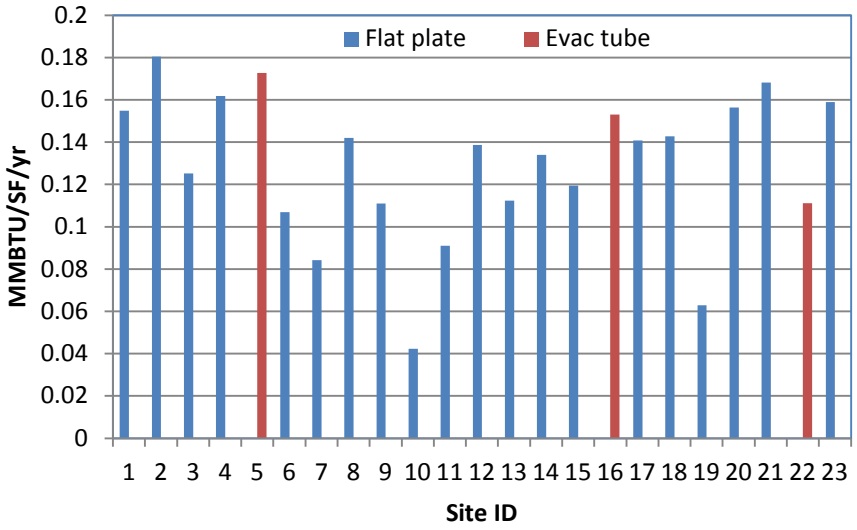
Figure 22. SHW System Sized for Space Heating Shows Oversizing for DHW Water Heating



In Figure 22 available solar energy significantly exceeds DHW usage in summer, which means the SHW system sits idle during the most productive time of the year. The estimated solar fraction of the installation shown in Figure 22 is 97%.

Based on the modeling of the 23 systems, it is possible to compare the engineering estimate and actual energy-collection per-square-foot of collector surface at the different installations. Figure 23 compares predicted output per-square-foot of collector for all 23 of the systems visited.

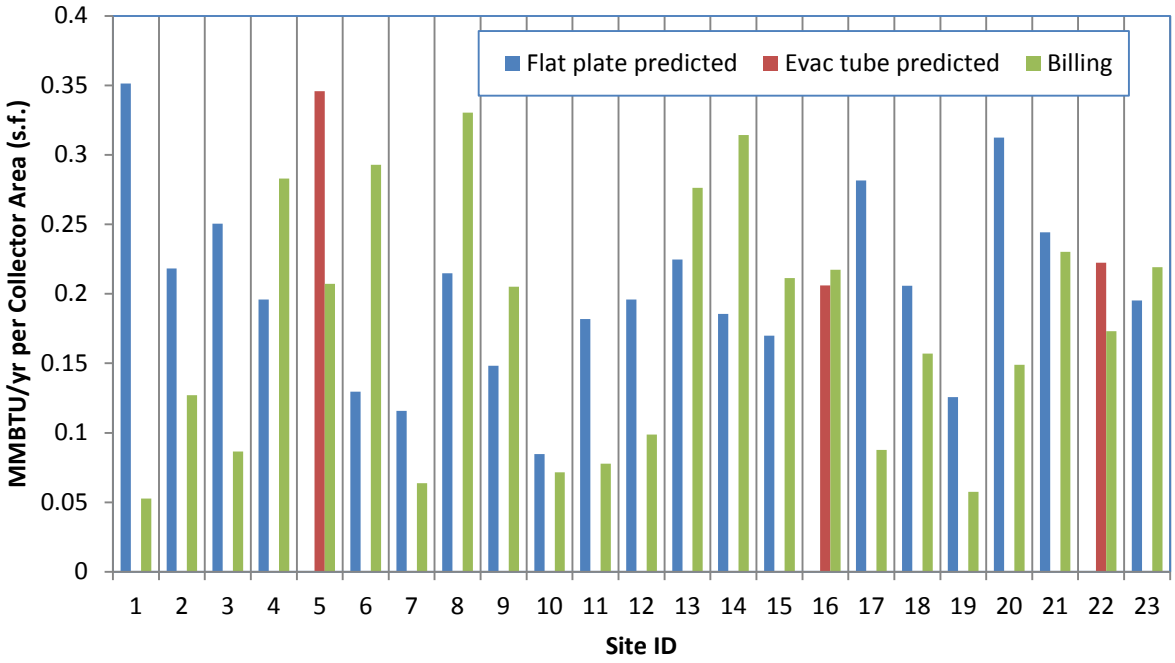
Figure 23. As-built Predicted Collector Output



It was found that the sites with low output had design and siting flaws. The site with 0.04 MMBTU/SF/yr had a SHW system sized for space heating, which results in being oversized for DHW heating, and the site with 0.06 MMBTU/SF/yr is a site with 40% shading. On the other hand, high output locations tend to be well-sized and well-sited systems. On average for the sites modeled, the evacuated-tube collector type has a higher output per-square-foot than flat-plate collectors. However, sizing and siting have more influence on system performance than collector type.

In Figure 24, there is no clear trend in gas savings when applying the billing analysis to the savings by collector type.

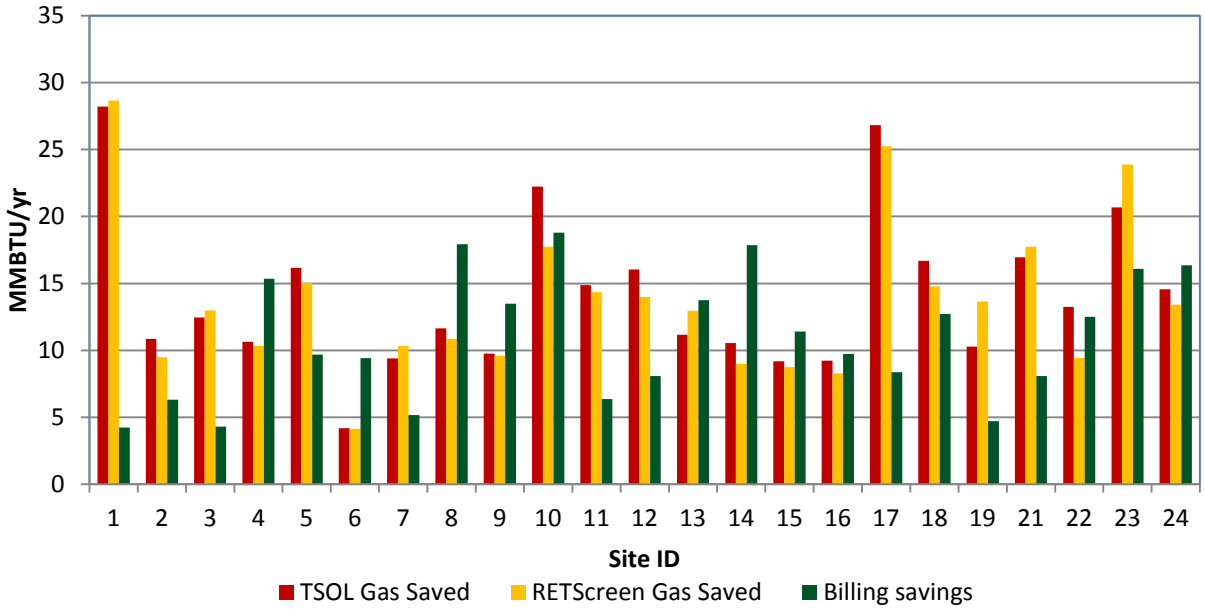
Figure 24. Gas Savings by Site and Collector Type



Comparison of Billing Analysis and Engineering Analysis Results

During this evaluation, deviation was found between observed energy bill reductions in the post-installation period and the predicted SHW system energy savings, as calculated during our engineering analysis. The savings numbers are compared in Figure 25.

Figure 25. Predicted vs. Billing Savings (MMBtu/yr)



There is a large discrepancy for many of the sites between the three savings calculation results, with billing analyses generally providing lower savings estimates. Cadmus attempted to resolve this discrepancy by examining the available survey data to identify possible spillover and takeback effects. For 10 sites, modeled energy savings exceed savings shown in the billing analysis, indicating possible takeback effects. Examples of possible takeback effects that may be influencing the results of the billing analysis, based on the survey data, include:

- Return of college students to home during summer months
- Increasing use of hot water in clothes washing before and after SHW installation
- Longer showers before and after SHW installation

For the remaining sites, there appear to be possible spillover effects. Examples of spillover effects from the survey data include:

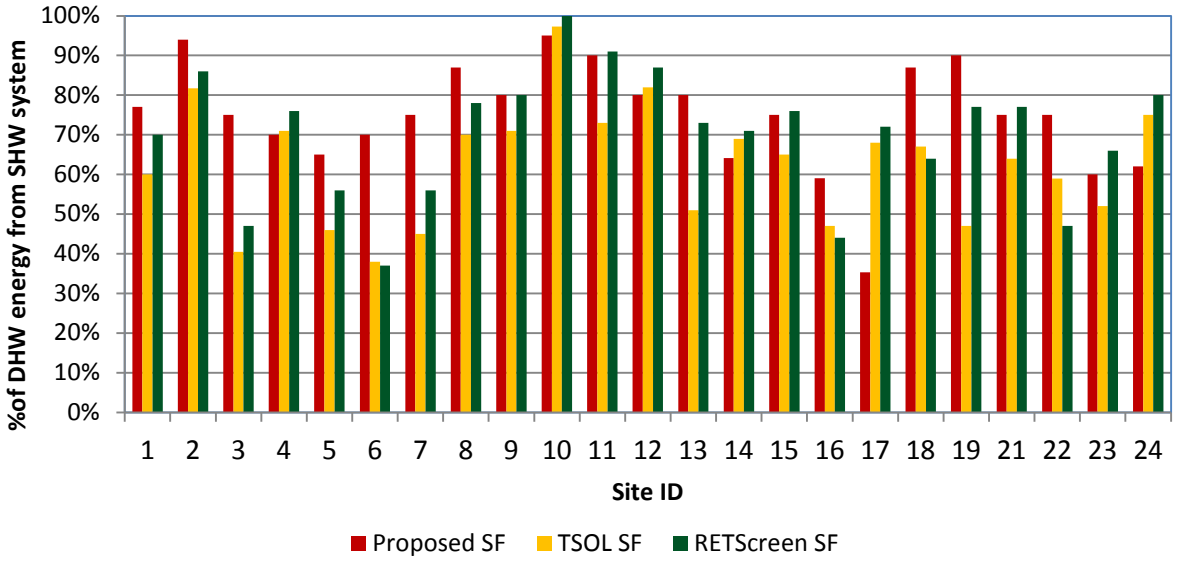
- Installation of additional insulation before and after SHW installation
- Manual shut off of backup hot water heating systems
- Fuel switching of space heating system (e.g., replacing gas heat with wood)
- Installed tankless water heater(s)

Several of the homeowners are operating their homes and hot water systems in ways that confound the billing analysis.

- Several homeowners stated that they shut down their back-up DHW system altogether during summertime, living with whatever temperature water the SHW system can make on its own. (site ID 13, 18, 19, & 22)
- One homeowner was using either the SHW system OR the tankless water heating system, depending on solar availability (site ID 12)
- Two of the homeowners had combined heat and hot water SHW systems, where some amount of space heating was being drawn from the storage tank, in one case the system was designed primarily for space heating, and at least one homeowner installed a new heat and hot water system as part of their SHW installation, making comparison with the previous usage uncertain (site ID 10 & 15)

The proposed solar fraction estimate provided by the installation contractor can be compared with the solar fractions determined by the different models used in this analysis in order to assess the accuracy of the proposed solar fraction estimate. A comparison of the sites' solar fraction is presented in Figure 26.

Figure 26. Solar Fraction Comparison



There is good agreement among the solar fraction calculation and estimation methods for sites that have less than 25% shading. Sites 3, 6, 7, and 19 all have significant shading impacts (30% to 43%), and the proposed solar fraction seems to be overestimated as a result.

Sample and Program-Wide Energy Savings

Using the TSOL modeling software and engineering assumptions, Cadmus calculated an average predicted direct solar energy contribution of 8.5 MMBtu/yr-site, for a total sample solar contribution of 196 MMBTU/yr for the 23 sites. Based on the backup water-heating efficiencies, the predicted total gas contribution offset averages 14.2 MMBTU/yr per site and the total 23 house sample gas offset is 325.7 MMBTU/yr.

Since the program did not collect *ex ante* energy savings estimates, the usual method of calculating a realization rate and applying it to the program population's *ex ante* savings estimate is not feasible. Though a retroactive *ex ante* estimate can be made by multiplying the estimated solar fraction by the pre-period hot water energy consumption, it is not possible to determine what information contractors used in their initial solar fraction estimate.

The energy savings of a SHW system is directly tied to its ability to harvest the solar resource, so Cadmus employed an alternative method to extrapolate sample-level energy savings to the full program population. Overall predicted gas energy savings for the sample of 23 homes (325.7 MMBTU) were normalized to collector area, resulting in a normalized predicted savings of 0.202 MMBTU/sf-yr for the flat-plate collector systems and 0.258 MMBTU/sf-yr for the evacuated-tube systems. As shown in Table 8, across the population-wide collector area of 3,284 square feet, the total predicted gas savings resulting from SHW collection is 701 MMBTU/yr. The billing analysis performed on the 23 site sample calculated an average gas usage savings per site of 10.9 MMBTU/yr, which when multiplied by the 47 sites of the Pilot Program, leads to a total program billing analysis gas savings of 512 MMBTU/yr, or 73% of the predicted total.

Table 8. Total SHW Pilot Program Savings

SHW Savings	Qty	Area (sq ft)	Predicted Average Gas Savings (MMBTU/yr-SF)	Predicted Gas Savings (MMBtu/yr)	Sum Billing Savings (MMBtu/yr)
Flat Plate	37	2,590	0.202	522	
Evacuated Tube	10	694	0.258	179	
Total Program	47	3,284	0.214	701	512
				Billing/prediction:	73%

As discussed previously, comparing the billing analysis to the engineering estimates is complicated, but it appears that approximately 27% of the possible energy savings are subject to takeback effects, such as:

- Longer and/or more frequent showers
- Increase in hot water consumption for laundry
- SHW system operational problems and/or downtime

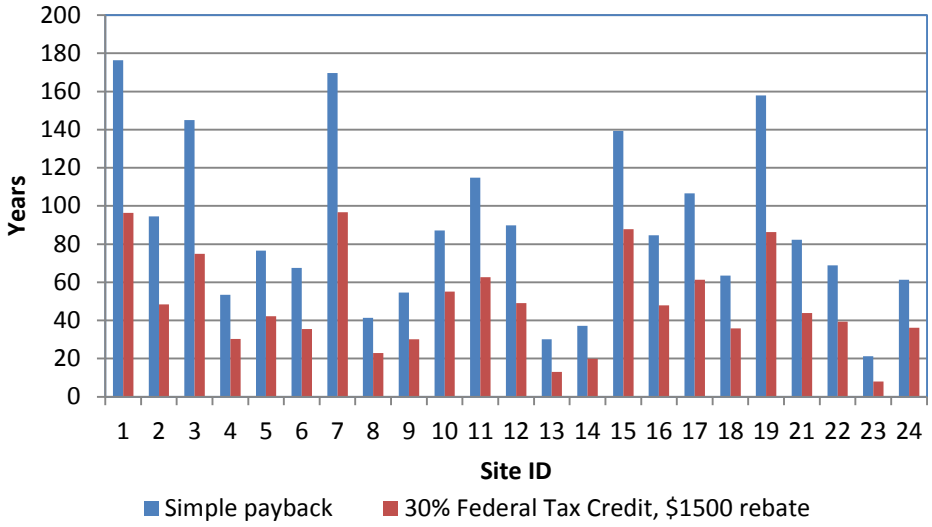
SHW System Cost-Effectiveness Based on Billing Savings

The maximum amount of the rebate is $1,500 and the program is meeting its target of funding approximately 15% of total system costs. For the 47 systems in the pilot program, the average installed system cost was approximately $11,200, excepting systems that involved components beyond typical DHW (i.e. space heating systems). Most systems were installed for around $10,000, with a few systems costing upwards of $20,000, and some as low as $5,000.

Most participants, in addition to the utility rebate, were eligible for a 30% federal tax credit. In most cases, these combined incentives exceeded 40% of system costs.

Based on a current average residential natural gas cost of $13.56/MMBTU, the average annualized simple payback (ASP) period, after rebates and tax credits, was approximately 50 years, before considering operations and maintenance costs, as compared to a typical useful system life of 20 years. With O&M costs included, the ASP increases to over 100 years. However, as can be seen in Figure 27, some well loaded and well sited systems demonstrated ASPs of approximately 10 years (>20 years if O&M costs are included), which is a much more compelling economic case. These more cost-effective systems suggest that SHW systems can be cost-effective in the northeastern U.S., but that it may be worthwhile to focus on ensuring good siting and system sizing practices as part of future programs. Without any incentives, the average ASP for the SHW systems in this study was found to be approximately 90 years.

Figure 27: SHW System Simple Payback (no O&M costs)



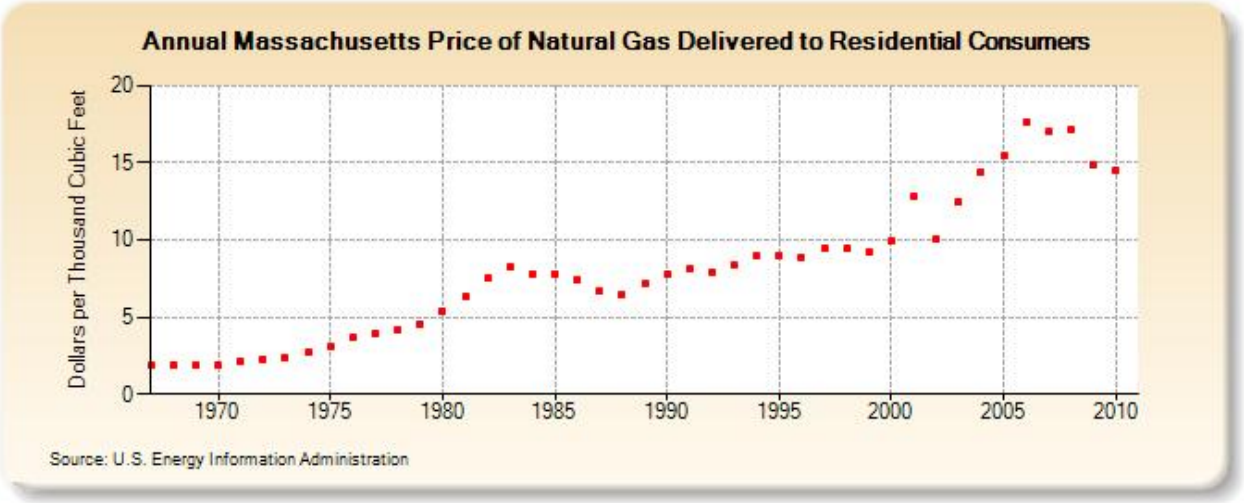
There are several possible contributing factors leading to these low cost-effectiveness results:

- High regional cost of labor
- Minimal contractor experience with SHW systems
- Misrepresentation of installation costs to ensure that maximum rebate is received
- Systems not being correctly sized to match DHW consumption
- Relatively low cost of natural gas

With all mechanical systems, there is also some cost of upkeep for continued operation over a long term. Typical operation and maintenance costs for a residential scale SHW system are about $100/yr, based on budget maintenance information from the National Renewable Energy Lab (NREL) and local long-term SHW owner experience, further reducing their cost effectiveness. Given an average gas savings value of $150, the $100 average maintenance cost significantly diminishes the already lackluster cost effectiveness.

It is important, however, to keep in mind that the cost-effectiveness of SHW systems is highly dependent on the price of the hot water heating fuel being offset. As shown in Error! Reference source not found., the price of natural gas has been steadily increasing for over 30 years, and is subject to market forces. In 2010 residential natural gas prices were approximately 15% below 2006-2008 prices. Had we used these higher prices in our cost-effectiveness analysis, rather than current values, the average simple payback would have decreased from 50 years to approximately 43 years.

Figure 28: Residential Natural Gas Price Trends



While the program evaluated only funded SHW systems supplanting natural gas hot water heating, electricity is also a popular choice for residential hot water heating. According to the U.S. Energy Information Administration (EIA), the average residential electricity price in Massachusetts was $0.1459/kWh. For comparison, this equates to $42.73/MMBTU, or about three times the cost of energy used to calculate the cost-effectiveness of SHW systems funded by the NGRID SHW Pilot Program. Had the customers installing SHW systems under this program been offsetting electricity, instead of natural gas, for hot water heating, the average simple payback period would have decreased from 50 years to approximately 16 years.

4. Conclusions and Recommendations

To date, National Grid has funded approximately $67,000 in rebates for 47 residential solar hot water systems. For this investment, Cadmus found that the predicted displaced gas usage savings were 701 MMBTU/yr and the billing analysis savings were approximately 512 MMBTU/yr. Several participants modified their hot water delivery systems by installing tankless hot water heaters or new higher-efficiency backup boilers and some participants changed their behavior. These interactive effects were not able to be quantified. On the whole, savings calculated by billing analysis were 73% of predicted savings.

Key Findings

- Overall, the billing analysis showed the 47 systems installed as part of the SHW pilot program is reducing gas consumption by 512 MMBTU/yr.
- Sixty-eight percent of participants were somewhat likely or not likely to install a SHW system without the influence of the program. This suggests that there is some element of freeridership but that most participants' decision to install a SHW system is attributable to the program.
- Predicting SHW system energy savings with available software tools tends to overestimate savings compared with an analysis of customer gas consumption. Most of this discrepancy is likely due to takeback effects and uncertainty related to estimating residential hot water consumption.
- All participants were at least somewhat satisfied with their SHW systems, with most being very satisfied.
- Installer education and training was cited as an area needing improvement by several participants.
- Overall installation quality was good, but issues were found with several solar-specific aspects of the installation, suggesting that plumbers installing SHW systems are doing well with typical plumbing work (pipe installation, hot water tank connections, etc.) but may need additional training on other aspects such as:
  - Siting and shading
  - Protection of exterior pipe insulation from weather and UV effects
  - Matching system size to hot water consumption
- The cost-effectiveness of SHW systems remains poor despite the program rebate and available federal tax credits. The median simple payback periods for the systems examined is approximately 50 years. Possible causes for long payback periods include:
  - Lack of experience with SHW system installation
  - Improper siting and system sizing practices
  - Relatively low natural gas prices

Recommendations

To improve program participation and cost-effectiveness, Cadmus recommends that the program:

- Support contractor training and certification efforts by providing preferred status to contractors certified by the National Association of Board Certified Energy Professional (NABCEP) as solar hot water system installers.
- Provide contractors and program participants with access to an accurate modeling tool, such as the free software RETScreen, and a set of region-specific reasonable-input assumptions to facilitate good siting decisions.
- Standardize hot water consumption estimation methods used during the rebate-application process. One possible approach would be to adopt the Building America DHW load calculation algorithms, discussed in this report.
- Require that all applications provide a solar site assessment report, including an estimate of shading at the proposed collector location and deny, or prorate, applications with 25% or greater shading losses.
- Consider providing rebates for more expensive fuel types (electric, propane) to improve cost-effectiveness of the program.
- Require SRCC rated collectors and UV-rated exterior insulation jacketing on all installations to promote long-term system performance.
- Collect additional data from program participants, such as:
    - Actual energy savings (e.g., SHW system monitoring and verification)
    - Estimated energy savings
    - Collector tilt/azimuth

Appendix A. Customer Survey