A COMPREHENSIVE ANALYSIS OF A UTILITY-SPONSORED SOLAR WATER HEATING PROGRAM

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ABSTRACT

This paper summarizes the methodology and results of the evaluation of the "Bright Way to Heat Water"™ solar domestic water heating program in Eugene, Oregon. The research is structured as a comprehensive hybrid evaluation integrating four quite different evaluation methodologies designed to provide comprehensive results that are factored into an ongoing program improvement process. The research incorporates customer and contractor surveys, pre/post billing analysis including a control group, a comprehensive program trends timeline, and solar engineering applied to an aggregate sample.

Program operation evolved from a small rebate to a 100% utility loan that reduced the customer's up front cost of solar water heating to less than $200. The energy savings estimate uses a sample of 293 sites, and employs a multivariable regression technique similar to the PRISM® methodology. Average measured program savings are 1086 kWh/yr., within a 90% confidence limit. The best performing and most popular system in the program shows annual savings of 1600 kWh/yr., which represents current program practice. This analysis uses locally measured solar data to compare the observed savings to commonly used solar performance estimation models, FCHART and QUICK CALC.

Observed savings are lower than the projected savings. Three categories could and did contribute to the difference: (1) incorrect initial expectations; (2) equipment not functioning as expected; (3) people not behaving as expected. Part of this shortfall is due to projections that overestimated hot water usage and to circulation pump over-sizing. The remainder of the shortfall is attributed to system thermal losses and to possible increases of DHW use. An upper bound on behavioral change derived from this data shows increases of about 3.5 gal/day, roughly equivalent to a 2-3 minute increase in total shower time.

We surveyed 21% of the participants by telephone to establish a participant hot-water-use profile, participant satisfaction, and to conduct an analysis of market barriers. Generally, participants were quite satisfied with the program and reported realistic expectations of solar performance. A quarter of the surveyed participants reported problems with the systems, most of which were initial problems repaired under warranty. In spite of initial performance problems, participants reported finding the systems more reliable than they had expected. The surveyed participants requested more information on their systems and their maintenance requirements.

Introduction

The Eugene Water and Electric Board has operated the "Bright Way to Heat Water"™ over the last nine years. The utility provided financial incentives and installation specifications. More than 625 solar domestic hot water heating systems have been installed under this program in the immediate vicinity of Eugene, Oregon. The program currently offers a five-year, zero interest loan that almost entirely removes the up-front cost of the installation.

The purpose of this evaluation was to broadly review the program with the intention of improving the viability of the utility-sponsored program in the current energy-marketing environment. The evaluation focuses on three broad research questions: (1) What market conditions and prices lead to robust participation? (2) What is the levelized cost of the program to the sponsor for each program year? (3) From an engineering standpoint, what avenues of effort will lead to program improvement in participation and cost effectiveness?

A successful solar program requires the concerted action of three parties -- participants, contractors and the program sponsor. All these parties must have sustaining motives for participation. Therefore, the full evaluation examines the perceptions and motives of these parties to formulate program improvement recommendations. A presentation of the complete evaluation results is well beyond the scope of this paper. Therefore, this paper focuses on summarizing the methodology for deriving annual savings for solar water heating from billing records, and on presenting those annual average savings results for the whole program and for the predominant types of solar equipment participating in the program. A brief summary of the interview results is also included because it provides a useful perspective on the concerns and opinions of the participants of this program.

Survey Methodology

Twenty percent of the participants were surveyed by telephone to establish a profile of hot-water-use and household characteristics, and to assess participant satisfaction. The survey included questions structured to support an analysis of market barriers, and was stratified to recognize two principal types of participants: the installing participants and the secondary participants who took over an already installed system. Initially, all participants were original system purchasers, but by the time of analysis, nine years after program inception, approximately 25% of the sites were occupied by secondary owners. In the interviews, different questions were asked of these two types. In the case of original purchasers, there were extra questions dealing with the purchase decision. The contractors accounting for 75% of the installations were also surveyed on marketing and maintenance issues.

The purpose of the analysis of market barriers was to assess which positive and negative expectations dominated the decision making process of the original solar water heater purchasers and then to test which of these were actually experienced. The analysis was fairly simple: direct comparisons of frequencies. The experienced positives and negatives are those that still need to be addressed by solar water heating promoters and the ones expected but not experienced are the unfounded fears - again the market barriers that can in fact be easily addressed by promoters.

Survey Results

Briefly, participant perceptions can be aggregated into seven categories as follows:

1. Expectations – Generally, the story the participant interviews tell is that solar water heating is working in Eugene better than expected. Concern over frequent repairs dropped dramatically after participants gained experience. And, people who expected trouble found systems to be "hassle-free." On the whole, people in Eugene who purchase solar water heating systems have realistic expectations.

2. Concerns – The top concerns experienced by the purchaser are:

- Not work on cloudy days (26%);
- Cost more than the value of the savings (18%);
- Change the way the household uses water (16%);
- Be hard to get someone to repair (10%).

Respondents who were original purchasers reported that the main reason the solar water heaters 'cost more than the value of the savings' is that they are still paying on loans for their system and have yet to experience the savings. Each of the items above should be specifically addressed in the information customers receive when they inquire about the program. The negative expectations and experiences are likely the market barriers slowing adoption.

3. Benefits – The top four benefits experienced by respondents are:

- Help save the environment (89%);
- Reduce reliance on non-renewable energy (87%);
- Set a good example for children (77%);
- Save your household money (62%).

The percentage of people experiencing the expected benefits increased except for one benefit, 'Save your household money.' Like the concern for cost and savings value, respondents who were original purchasers reported that the main reason for this is because they are still paying on loans. In both cases, respondents reported they expected greater savings when the loan is repaid.

4. Expectations of Secondary Purchasers - On the whole, the secondary purchasers expect less from their system and expect more difficulties. Operation and maintenance information is usually not passed from primary to later owners, and was often requested.

5. Maintenance and Repairs - Problems requiring repair were experienced with 26% of the systems, usually within the first two years. While this number seems shockingly high, it should be noted that most problems were minor and were repaired under warranty, with no cash outlay from the participant. The leading problem is tank failure or leaks somewhere in the system. However, these tank failures were an extraordinary situation experienced with only one brand of tank, and clearly a manufacturing or design defect. The tank failures are being remedied in concert with the tank manufacturer. Without the extraordinary tank failures, 16% of the participants still report some need for repair. Most of the system problems occurred quite early in the life of the system and could have been caught with a routine installation follow-up check. Even though maintenance can be minimized, maintenance needs to be a line item in solar program planning.

6. Satisfaction with the Program and with EWEB – Participants, even those who reported problems, are highly satisfied with the program, the system performance, and the contractors. On the whole, they reported experiencing little difficulty with system operation and maintenance. Participants recommend continuing the program, marketing it more aggressively, and retaining the incentives and loan program, as well as funding research and development to improve system performance and efficiency.

7. Participant Perspective on Program Marketing - Participants request information in four areas covering the full time span, from inquiry and purchase to ongoing operation and performance monitoring: (1) contractors, (2) system cost, expected savings and performance, (3) operation and maintenance, and (4) actual performance. Addressing these issues will reduce the negative concerns, and should remove some existing market barriers. Satisfied customers are also an important

component in marketing the program. Note that because of the solar system, more people reported they experienced themselves as a 'leader in the community' than had expected it. These people are the community spokespeople for solar water heating.

Savings Estimate Methodology

The literature documents no other attempt to determine solar water heating savings directly from customer bill data, although the solar engineering literature is rich with savings estimates derived from individual laboratory (which simulate occupant behavior & plumbing situations) or site monitored experiments (capturing actual conditions). Extensive site monitoring of solar DHW was done in the 1980s. This prior work was directed at establishing the solar contribution to the DHW load. In this region of the country, two rigorous studies used BTU meters to measure the DHW load and power meters to measure the DHW electrical input with the difference attributable to solar (Idaho Power 1983, Harris & Dent 1985). Other somewhat less rigorous studies synthesized estimates of the DHW load and solar contribution from monthly end use measurements of DHW water and electrical input along with spot water temperature measurements (Wayne & Laughlin 1985, ODOE 1987). One of these latter studies was structured as a "flip flop"(solar on one month, solar off one month) in order to capture the behavioral impact of solar (Wayne & Laughlin 1985). Rigorous laboratory bench tests of a selection of passive solar DHW systems were also undertaken (Robison 1988). This broad measurement work generally confirmed and refined the solar savings prediction methodologies (Robison 1988).

However, this prior work had an engineering perspective and focussed on the gross savings touching only briefly on the behavioral impacts of having a "free" source of hot water. Interviews with solar system owners in this work suggested that free or "unlimited" hot water was a tangible benefit of having a solar DHW system. Therefore, hot water usage could potentially increase because of the installation of solar. Also the prior work did not rigorously include the effect of nonfunctional systems in the average savings estimates. From a program evaluation perspective, the savings estimate needs to include more real-world effects than did the prior work. The billing-based analysis approach used here is necessary to produce a net savings estimate which includes the effects of any behavioral change caused by the solar system and the effects of system failures within the first two years after installation.

Overall, the program savings estimates are the result of a three-stage process: (1) individual savings are estimated for each site, (2) site savings are aggregated into savings for the whole program, and (3) gross to net corrections are derived from the analysis of a nonparticipant control group. As with all billing analyses, some especially "noisy" data must be removed. This data editing can significantly influence the results, and it expresses the technical judgement of the analyst. Each of these stages is summarized below.

The savings estimate tool developed for this analysis is similar in intent and terminology to the widely used billing analysis tool, PRISM®, developed by Princeton University (Fels et al 1995). PRISM® is most often used to detect winter savings due to weatherization or to detect baseload savings due to lighting improvements. A savings estimate would typically be done by running PRISM® on a year of billing data before and after the installation of the system. But preliminary work on this project showed that solar savings are different. These savings occur principally in the summer and in a conspicuously temperature dependent fashion. Solar savings do not act like the familiar PRISM® baseload savings; they cause PRISM® to absorb these savings into the heating slope and to become unstable with respect to the balance point temperature. In an effort to restore the stability of the regression, the process was modified as described below and more retrofit data (two years pre and post) are used.

Site Savings Analysis

Site solar savings estimates were based on 4 years of billing and temperature data, two years pre-installation and two years post installation. This data requirement restricted the analysis sites to those with installations at least two years prior to the analysis. Eligible sites also needed a constant occupancy (billing identity) during the four-year data interval. Together, these requirements reduced the analysis pool from the 613 sites enrolled at the beginning of the analysis to 422 sites. Sites were further screened manually for participation in other programs and for other occupancy variations leaving 293 sites in the analysis.

The analysis proceeds in a manner similar to the PRISM® technique. This technique uses a regression fit to billing and temperature data to break the consumption bill into a constant baseload (representing appliance usage) and a temperature-dependent portion (representing space heating) that occurs below a "balance temperature." However, this model fails to account for solar savings that are correlated to temperature without a "balance" point. As a result, we modified the procedure to a multivariable regression using a dummy participation variable applied to the pre/post pooled billing data.

Participant interviews suggests that at least 25% of the analysis sites had wood stoves used to supplement winter heating needs on an irregular basis. Instead of removing these entire sites, which could not be positively identified, points for probable wood heat months were individually removed by using a point screen based on the use of average tilted surface solar data, which was fortuitously available for this city. We are concerned about wood heat since our method is based on billing analysis, comparing bills after to bills before. To the extent that wood heating is used, it substitutes for electricity as a source of space heating and has a corresponding impact on bills. If there is a change in the use of wood and we are relying on a change in bills to estimate solar savings, any increase in wood heat will look like solar savings. The process is illustrated below.

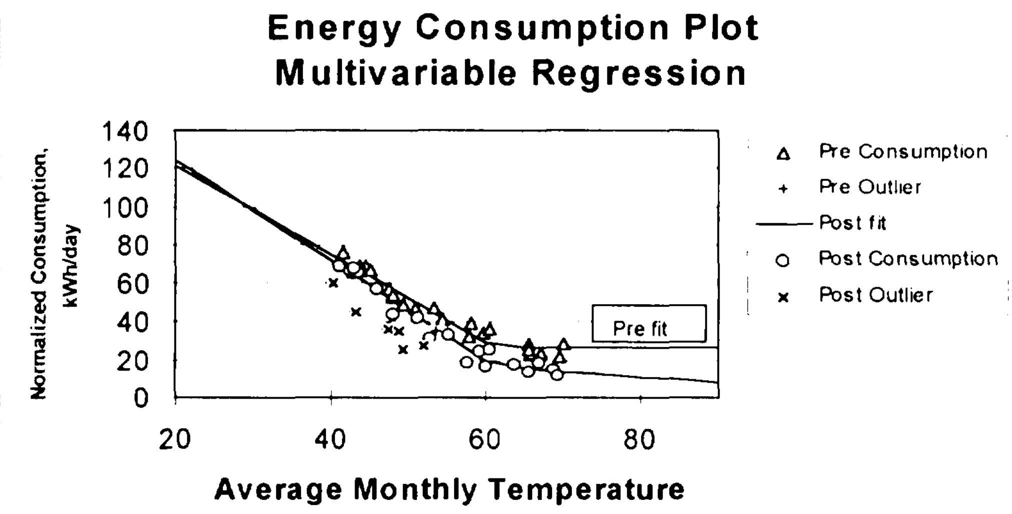

Figure 1. Billing Analysis Example

The methodology is best explained with reference to an example. In Figure 1, the "Energy Consumption Plot" shows the pre-retrofit consumption described by a broken line, similar to that derived from PRISM® analysis. The post-retrofit consumption is another broken line offset below the pre-case. The difference between these lines is attributed to the solar DHW installation. In this figure note the points identified as outliers, probably caused by wood heat, and removed from the data fit.

In Figure 2, the "Solar Residual Plot" shows the individual monthly differences attributed to solar savings. A straight line drawn through the points represents the "best estimate" of the actual solar performance. This linear equation is then evaluated for each month at the long-term average monthly temperatures in order to estimate the annual savings for a normal weather year, commonly referred to as the NAC savings, (Normalized Annual Consumption savings). In principle, an identical solar savings estimate could be made from the difference in annual usage derived by evaluating the pre and post performance functions over the monthly temperatures in the normal weather year. The solar residuals introduced in Figure 2 are intended to display the quality of the regression determined solar savings estimate that is represented by the line in the plot.

Figure 3, the "Solar Yield" plot shows the monthly collected solar versus the incident solar and is used to screen for wood heat and other outliers. The sloping lines in this figure are reference efficiency lines. The upper sloping line is the 80% efficiency line -- any points above this line are probably not solar-caused. For each site the collected solar points for temperatures lower than 50 deg. F. are examined and removed manually if they are larger than 10 kWh/day or larger than the 80% line in the efficiency plot. In this particular example, the solar system appears to be performing well, with an efficiency of about 35%. Clearly, the results of any analysis can be strongly affected by the removal of so called "outlier points." The data editing used here removed points that would otherwise lead to significantly higher estimated solar savings, but the removal criteria will not bias this estimate because they are drawn broadly enough to retain the normally expected noise on the savings measurement. The availability of accurate tilted surface solar measurements from the University of Oregon Solar Measurements Laboratory provides an engineering basis for removing these points by providing an "upper bound" on the "best case" solar savings (Solar Monitoring Lab).

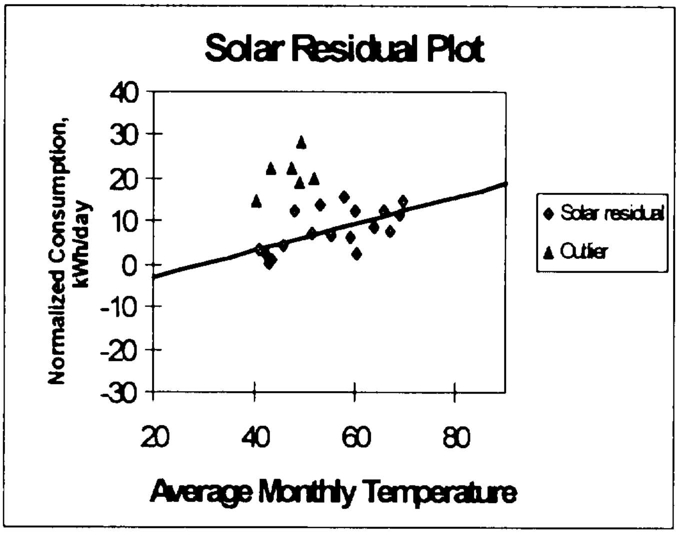

Figure 2. Solar Residual Savings Example

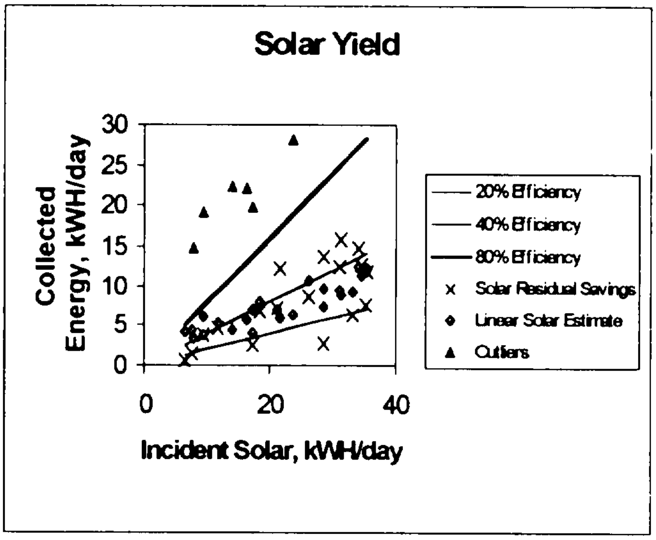

Figure 3. Solar Collector Efficiency Example

Average Measured Savings

The results presented in Table 1 show overall gross mean program savings of 1022 kWh/year and significant differences in savings by system type. This evaluation encountered a high degree of coincident energy savings actions in the form of participation in other programs and the frequent but intermittent winter use of wood heating. These coincident other savings were corrected for by careful editing involving the use of the utility records for participation in all other programs, and by the use of historical solar measurements. Gross savings measurements have been corrected for participation in other programs.

It should also be noted that these average results apply to all the years of program operation from 1990 to 1998. In fact, the mix of systems installed in each program year varied, and therefore the average savings associated with the systems installed in each program year varied significantly. The net average program savings varied from only 667 kWh/year for 1990 to 1600 kWh/year for 1997.

Table 1. Gross Participation Corrected Impact Results

System Type	Number in analysis	Mean Annual Savings, kWh/yr	Standard Deviation, kWh/yr	+&- 90% confidence limit
Drainback	148	1575	1412	191
Geyser pump	106	552	1547	247
Thermosyphon	20	311	1917	705
Other	19	84	2412	910
Total	293	1022	1675	160

Savings Aggregation

The NAC savings for all individual sites are aggregated in two ways:

The cumulative distribution function. The savings distribution shows the fraction of the whole savings sample less than a particular savings value as shown in Figure 4. These plots are algebraically exactly equivalent to the familiar savings histogram but they show differences between populations more clearly. Residential sector consumption is volatile enough to show a natural range of +/- 5,000 kWh/year through natural behavior variations. This figure shows a very clear difference between the participant and non-participant distributions. The net saving is revealed as a shift in the mean of the distributions.

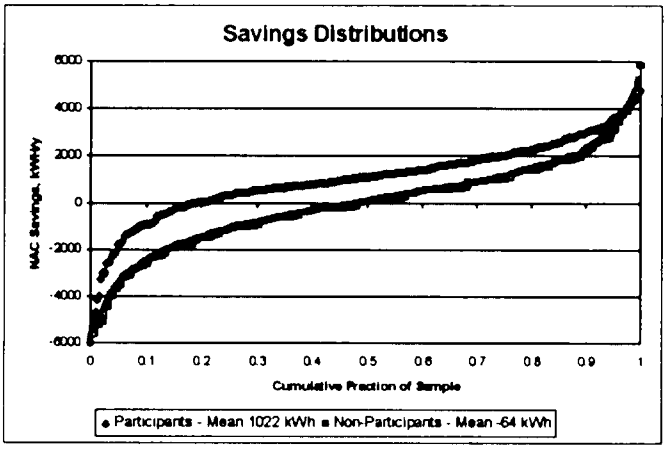

Figure 4. Cumulative Savings Distribution

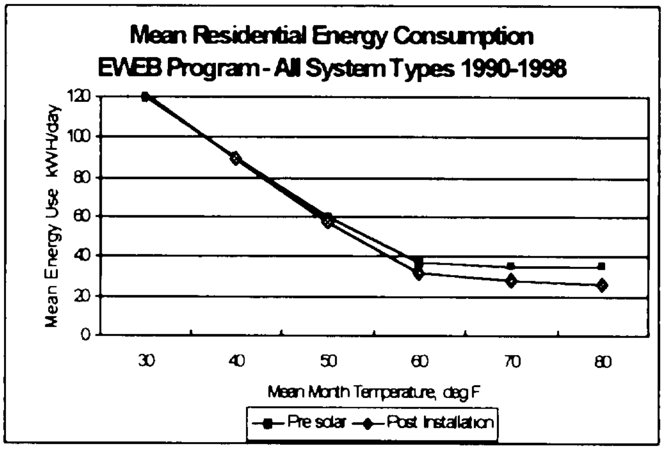

Figure 5. Mean Energy Consumption

Programmatic average consumption function. The individual site models were aggregated into a single mean consumption model with a temperature dependent form as shown in Figure 5.

These aggregate consumption functions permit savings predictions for other locations with different monthly temperatures. However, these functions should be used with care because they strictly apply only on similar systems applied to similar loads and are limited to similar solar regimes.

Gross to Net Savings Correction

The next step in the analysis procedure compensates for methodological biases and for broad non-programmatic or time dependent economic behavioral changes by analyzing a non-participant (control) group. In this study, the non-participant sample consists of 60 constant occupancy sites with occupants who sought program information, but chose not to participate, and 50 constant occupancy sites of participants prior to their participation, for a total of 110 non-participant sites. Given the small sample size, it was not possible to match participant sites on the basis of demographic variables or participation dates. Therefore, each non-participant site was examined longitudinally by executing a savings measurement each year, typically for 6-8 years.

Table 2. Non-Participant Yearly NAC Consumption

Year	Yearly mean NAC	Yearly mean lower 90% confidence limit	Yearly mean upper 90% confidence limit	Mean of full 9 year interval
1989	22,391	21,045	23,736	22,035
1990	22,632	21,255	24,008	22,035
1991	22,095	20,756	23,435	22,035
1992	21,540	20,232	22,848	22,035
1993	22,088	20,714	23,461	22,035
1994	22,062	20,648	23,477	22,035
1995	21,543	19,556	23,530	22,035
1996	21,184	18,792	23,576	22,035
1997	22,778	20,071	25,484	22,035

Overall, the non-participant analysis showed mean savings of –64 kWh/yr. This is interpreted as a very slight yearly increase in the average electrical energy use. This mean was based on 710 savings measurements and has +-90% confidence limit of 121 kWh/yr. While this mean non-participant savings estimate is not significantly different from 0, statistical rigor requires that we use it as the gross to net correction and increase the net savings by 64 kWh/yr. Table 2 shows no significant year-to-year variation in the mean of the control group savings. Table 3 adjusts for control group savings.

Table 3. Net Average Savings

System Type	Percent of Program	Number of Sites Analyzed	Net Savings kWh/yr.
Drainback	56%	148	1639
Geyser Pump	35%	106	616
Thermosyphon	5%	20	375
Other	4%	19	148
All Systems	100%	293	1086

Performance by System Type

Tilted surface solar incidence measurements on a typical solar orientation, 30 deg. S, enabled the calculation of monthly mean solar collection efficiency for the three most prevalent systems. For the system types analyzed, (drainback, geyser pump, and thermosyphon), the observed performance of clearly operating systems and the predicted performance was compared. Then the engineering model was varied to explain the observed performance. In Table 4, the "Program Design Assumptions" refer to expected "basecase" savings. The "Pump & Draw Correction" refers to a recalculated savings prediction with the engineering models adjusted to match observed DHW usage in the region and observed pumping power. The "Adjustment for Possible Thermal Losses" refers to a performance estimate with the hot water usage reduced and additional heat losses assumed for each of the system types. In the case of the drainback system, there is an adjustment (Mitchell et al 1981) for the fact that pumps were sized larger than initially assumed. The engineering models used for reference include FCHART (Duffie & Beckman 1980) and QUICK-CALC (Robison 1988). These models have been discussed and validated in prior large-scale measurement exercises in the northwest region (ODOE 1987, Robison 1988). The annual savings results predicted from each of these three modeling stages are given in Table 4. The basecase estimates are based on State of Oregon tax credit calculations proceeding from SRCC systems test measurements and associated TRYNSYS simulations, and are consistent with the regional measured performance.

The use of the engineering models shows that a small portion of the difference between the observed and expected performance could be explained by a lower than expected DHW usage, 60 vs. 75 gallons/day, and by increased pumping power in the case of the drainback system. The lower than expected DHW usage is supported by recent water end use measurements (non-solar homes) in the EWEB service territory (Mayer et al 1998). The modeling also suggests (but does not confirm experimentally) additional losses affecting solar performance. The problem is most severe for the thermosyphon systems, which appear to lose one third of collected energy in the summer and more than 100% in winter. This type of system needs further in situ monitoring. It has been under represented in prior regional monitoring and the prior laboratory tests (Robison 1988) did not accurately represent the height difference between the backup tank and the system. Modeling also suggests that the geyser pump systems do not pump well below a solar irradiation threshold. Results of the different modeling stages are shown in Table 4.

Table 4. Annual KWh Savings by Engineering Models

System Type	Program Design Assumptions: kWh Savings	Corrected for Pump & Draw	Adjusted for Possible Additional Thermal Losses	Observed
Drainback	2,708	1,952	1,773	1,705
Thermosyphon	2,249	1,922	946	801
Geyser Pump	1,919	1,582	949	907

In Table 4 the performance difference between the draw corrected performance and the observed performance is due to a combination of increased thermal losses and by behavioral change, i.e., increased DHW use in response to "plentiful hot water" reported by survey respondents. However, the data cannot resolve the behavioral portion from the thermal loss portion. An upper bound on the behavioral portion can be inferred from the data in Table 4 for the drainback system. For this system, if all the difference between the draw corrected and observed performance is attributed to behavior, then the difference of 247 kWh/yr. would represent an upper bound on the increased DHW usage due to the installation of a solar DHW system. Assuming that this same upper bound applies to the other system types, suggests the presence of significant thermal losses for the geyser pump and thermosyphon systems.

Table 5. Net Solar Savings and Performance Factor

System Type	Observed "good" system performance, kWh/yr	Net program savings, kWh/yr	Performance factor
Drainback system	1705	1639	.96
Thermosyphon	801	375	.46
Geyser pump	907	616	.68
Other	Varies		

However, Table 4 is based on the analysis of "good" sites, those with obvious evidence in the data that the system was operating. Comparing Table 4 to Table 5 it is apparent that for the drainback system, the full program population of these systems performs as if they were "good" systems. For the other system types the population average in Table 4 is much less than the "good" system average as indicated by the associated performance factors shown in Table 5. This variable is the ratio of the net savings to the savings expected for an operating system. This suggests the presence of nonfunctional systems of those system types. While the existence of these hypothetical nonfunctional systems was not physically verified, it has some anecdotal support from interviews with the participating solar contractors and system owners. To the extent that nonfunctional systems lower the savings effectiveness of the program, they also offer an inexpensive way to improve program performance through repairs.

Program Activity

Program records for nine years of operation were assembled into a comprehensive timeline in order to identify trends. In general, each program year was separately characterized to preserve the effects of differences in program operation from year to year. The mix of system types installed varies significantly from year to year. Since the mean system type changes from year to year, the summary cost data changes also. Note also that the program activity is divided into two primary phases, with the first generation including the years 1990 through 1994, and the second generation including the years 1995 to the present. Changes in program marketing and a change in dominant system type characterize these phases.

During this first generation period the dominant system was the small geyser pumped system and the mean per system observed savings were low, in the range of 700-1000 kWh/yr. The second-generation program was dominated by the drainback system type, which is much larger and with higher annual savings than the geyser pump system. Accordingly, the mean observed system savings for the years 1995 and later are in the range of 1300-1600 kWh/yr.

EWEB's bottom line, the levelized utility cost, did not markedly increase with the second-generation program, even though the EWEB per system contribution almost tripled with the shift from rebates to zero interest loans. This is because the average system yield also increased. The sponsor's levelized cost of savings was of the order of 35-45 mills/kWh nominal, but was contingent on a 20-year system lifetime. Therefore, periodic system maintenance and the identification and restoration of non-functional systems are key to maintaining this levelized cost.

Comparisons of program marketing activity, contractor interviews, and participation levels with classical market transformation curves suggest that most participants to date have been the early adopters. Continuation may require an adaptation of program design that is attractive to the "general consumer" type of participant. Even with a leisurely planned market transformation of one generation, annual participation of the order of 300-500+ per year for several years could be expected by a robust program. At this level of activity, program overhead would be considerably reduced on a per system basis, and the utility value of the saved energy as a "green" resource may have useful value.

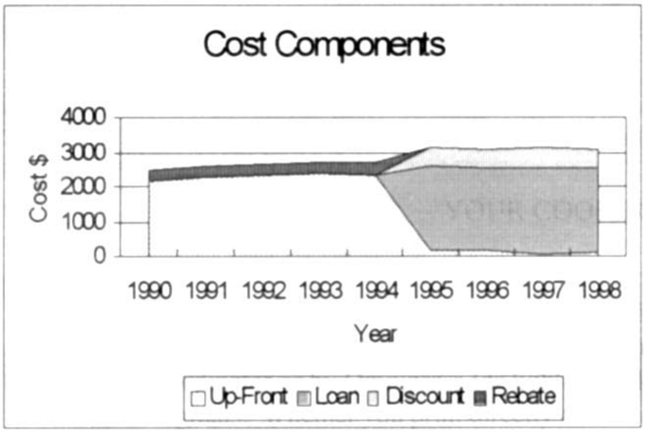

Figure 6. Program Cost Trends

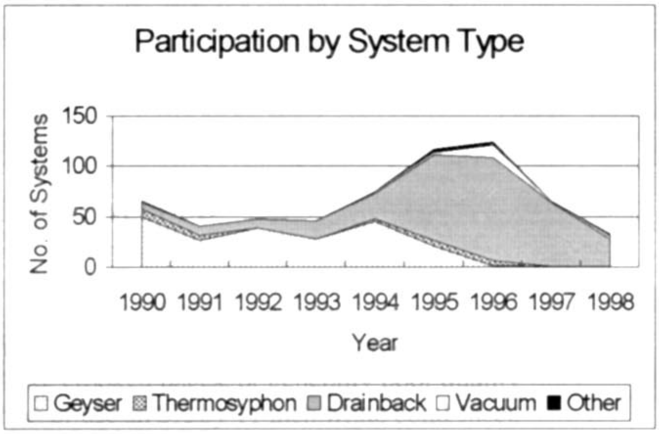

Figure 7. System Trends

Conclusions

1. Participants requested and needed more information on the performance and management of their systems. Participants also perceived the systems to be more reliable than expected. This perception is somewhat paradoxical in light of 26% of participants reporting need for repairs. It appears that after the initial shakedown repairs that the systems performed well for years.

2. Utility (electric) billing data can be used to detect solar DHW savings. A simple billing analysis tool can be used to demonstrate or examine solar savings in individual cases.

3. Observed solar savings were less than expected from draw corrected performance estimates. For the drainback system the performance was approximately as expected from the corrected performance estimate. But for the other system types, the shortfall can be explained by excessive "in situ" thermal losses. Operational monitoring should be used to examine field performance of systems with typical installation details for excess thermal losses or other irregular operation.

4. This analysis cannot distinguish specifically between thermal losses and behavioral changes, but the data can be used to estimate that an upper bound on the behavioral change is 247 kWh/yr., or roughly 3.5 gallons of water. The behavioral response to the "free hot water" did not significantly increase DHW use.

5. Some system types show clear evidence of thermal losses well beyond the upper bound behavioral change. A more aggressive operation and maintenance program can increase the average program annual savings and is the key to ensuring the full cost-effective lifetime of a solar DHW system. Operlations and maintenance should include a component that familiarizes the homeowner with the operation of their system. An operations and maintenance plan sufficient to realize the full potential of the solar DHW system will include: a one year operational check to catch initial problems, attention to tank longevity especially corrosion control, and simple clear operation instructions for the homeowner and their successors.

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