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LIVING WITH SOLAR ENERGY: CHANGING ATTITUDES AND ASSESSMENTS OF SOLAR ADOPTERS

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ABSTRACT

Information is provided on the experiences and current assessments of homeowners who installed active solar energy systems in the middle and late 1970s. These individuals were interviewed in the late 1970s and again in the fall of 1983. Comparison of the results of the original surveys with those in the follow-up survey provides insight in how assessments, satisfaction rates, system reliability, and related factors have varied over time. Our findings show that owner satisfaction levels remain high, estimates of the thermal contributions of the systems are only modestly below original expectations, domestic water designs and newer systems have low repair requirements and costs, and conservation rather than active solar measures are frequently recommended for potential owners. Implications for potential owners, the solar industry, and government policy are provided.

INTRODUCTION

Despite widespread support for solar energy in public opinion polls, the general public has generally held back from purchasing systems despite substantial federal income tax credits and additional tax incentives in most of the states. While the high initial cost is the principal barrier to adoption, lack of information on the systems' performance over the long term also appears to be a significant constraint. The public's desire for such information is legitimate

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since active thermal systems generally require long periods to payback their capital costs. Moreover, the design of the systems makes it impossible for potential consumers to tryout the technology in incremental steps. Finally, the systems' frequent integration into house construction often makes system failure or removal more problematic than the failure of traditional heating equipment.

Important feedback on system performance has been provided by technical review of the systems funded through the Residential Solar Heating and Cooling Demonstration Program [1, 2] and utility examination of their early test installations [3]. However, little information is available on the current attitudes and assessments of the individuals who installed systems in the mid- and late-1970s. This is a serious omission since personal assessments by peers play a central role in convincing (or discouraging) potential adopters.

This article reports the current assessments and recommendations of 171 homeowners: 164 original owners who purchased an active solar energy system between 1973 and 1979 and seven "second owners" of systems installed in this period. The sample is unique because all the original owners participated in two earlier surveys of solar adopters [4, 5]. Comparison of the individuals' responses provides information on how performance expectations, satisfaction levels, and related factors have changed through time. In addition, the follow-up survey asked questions regarding the adopters' current assessments and recommendations for solar energy use and design.

THE SURVEYS AND METHODOLOGY

The study utilizes three surveys. The earliest was conducted in 1977-78 and included 177 homeowners in New England and the Southwest who had installed an active domestic water heating, space heating, or "dual function" solar energy system on a non-subsidized basis between 1973 and 1978. (72% of the systems were installed after 1975.) The survey included premanufactured and site-built systems and asked an extensive array of performance, economic, and barrier and incentive questions. The second survey was conducted in the fall of 1979 and involved 179 randomly selected owners of solar domestic hot water systems in Maryland who received $400 grants from a federal demonstration program implemented through the U.S. Department of Housing and Urban Development. These systems were installed from 1976 through 1979 (with 54% installed in 1979). The Maryland survey repeated many questions asked in the earlier effort. Both surveys were conducted in person and benefited from high response rates, 90 percent and 78 percent, respectively. The individuals represented in these surveys are typical of solar adopters of the period: highly educated, predominantly upper-income homeowners whose adoption was motivated by a blend of economic, environmental, and self-sufficiency interests.

The third effort, the follow-up survey, was conducted in the fall of 1983. Its questions closely replicated those used in the earlier surveys. To facilitate comparison, the respondents were often reminded of their responses in the original survey and asked to compare these with their current assessments. In addition, the follow-up questionnaire contained new questions to obtain the adopters' overall assessment of their solar experience and recommendations to potential buyers. The questionnaires were sent to 171 of the New England-Southwest adopters and 101 of those in Maryland. The overall response rate was 62 percent (58% in the NE-SW survey and 70% in Maryland). When the questionnaires returned as undeliverable are excluded, the response rate increases to 65 percent (62% in the NE-SW survey and 73% in Maryland).

The validity of the follow-up survey results may be challenged on several points. First, individuals who installed a solar system in the 1970s typify innovators and early adopters whose strong emotional and financial commitments to solar energy might bias responses toward more positive assessments.[1] This problem is particularly relevant when dealing with impressionistic rather than monitored data. Second, there is the danger that respondents to the follow-up survey will be a biased subset of the initial survey populations.

Comparison of the satisfaction levels, thermal contributions, and system functions of follow-up respondents' original answers to those of the total population in the initial surveys suggests differences between the two groups are negligible, however. (The satisfaction responses were nearly identical, the average thermal contribution provided by the systems of the responding sample was 47% compared to 42% in the total population and the percentage of domestic hot water systems dropped from 63% to 59%). Similarly, Chi-square tests of independence were unable to identify statistical variations between the samples. (These were not significant for any variable even at the $p < .25$ level.) Nevertheless, participation in the follow-up survey was a self-selection process and it cannot be known whether the responses are skewed toward adopters with negative or positive solar experiences since the original surveys were undertaken.

COMPARISONS OF SYSTEM PERFORMANCE

The follow-up survey collected information on estimated thermal contribution, anticipated payback, resale value, technical problems, and repair costs to compare the owners' current assessments of system performance with those recorded in the original surveys.

[1] Innovation diffusion research has identified a sequence of personality types common in the adoption of innovations. These are, in order: innovators, early adopters, early majority, late majority, and laggards [6].

Thermal Contribution

Each respondent was asked to estimate the percent of the thermal contribution that was provided by their solar system during the previous year to the function it was designed to serve: water heating, space heating, or both of these. The thermal contribution estimates averaged 51 percent, with roughly half the estimates clustered in the 50 to 70 percent range. The mean estimates were highest for the domestic water heating systems (mean 55%) and less for space heating (42%) and dual function systems (49%). When the inoperative systems are excluded, the mean thermal contribution estimate increases to 56 percent. These figures are all lower than those reported by these owners in the initial surveys. (At that time, the mean thermal contribution estimate was 65% for the systems in operation.) As evident in Figure 1, the differences in the two means is largely the result of the decreased number of high estimates in the follow-up survey.

Payback and Resale Value

The time required for the reduced energy expenditures generated by a solar energy system to equal (or "payback") the initial cost of the system is central to the economics of solar energy use. In the follow-up survey, the owners were reminded of the payback estimates they provided in the original surveys and asked how their current estimates varied. Most respondents (59%) thought that their original estimates remained accurate. (These averaged ten years in the

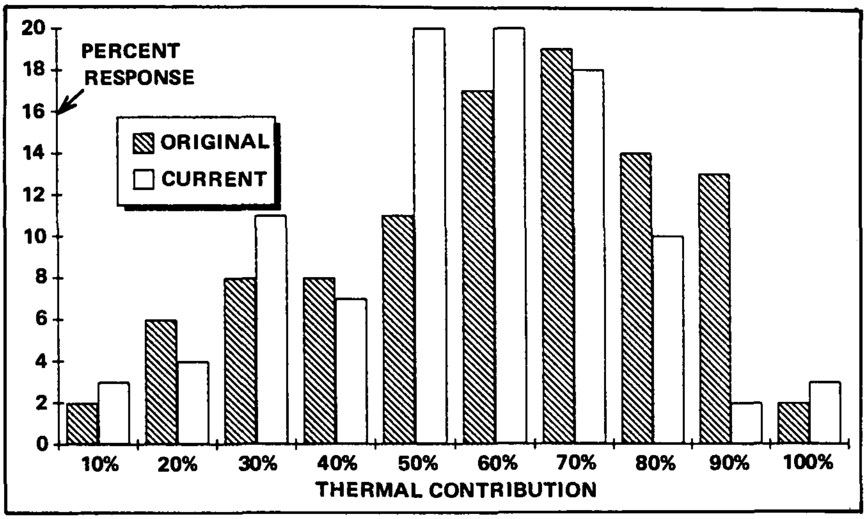

Figure 1. The owners' estimates of their solar systems' thermal contribution.

NE-SW survey and seven years in Maryland.) However, among the changed estimates, the percentage with longer expectations (31%) is three times the percentage of those who anticipated shorter payback periods (10%). There is no way of knowing whether the changed expectations result from changes in system performance or fuel prices. It should also be noted that in all three surveys a large portion of owners chose not to provide any payback estimates. In the follow-up survey, for example, 20 percent did not provide an estimate despite the emphasis on the concept in solar policy and marketing circles.

Resale value is an additional measure of the systems' performance and economic viability. In the follow-up survey, the owners were generally optimistic. Fully 65 percent of the respondents thought their solar installation added to the resale value of their home, while just 2 percent thought they detracted from resale values. (The balance thought the systems would not affect resale price.) The resale value estimates, including zero values for those who thought the systems would be ignored and negative ones for the minority who thought the systems detracted from resale prices, averaged $3,900. Remarkably, this figure is within $30 of these individuals' average purchase price.

The utility of this finding for policy or consumer advising is severely limited, however, by the tremendous range of individual expectations. Among the homeowners who thought the systems would contribute positively to resale values, for example, the estimates ranged from modest figures far below the initial costs to figures that assume sizeable appreciation. Moreover, substantially higher resale values would be needed to equal the original costs in constant dollars because of the four to eight years of inflation that have occurred since the purchases.

System Reliability and Maintenance Costs

Several questions in the surveys investigated the reliability of the systems and the homeowners' assessment of overall system operation and maintenance. These issues are important because high operation and maintenance costs can significantly affect life-cycle cost and payback time.

At the time of the initial surveys, most of the systems had experienced some form of technical problem. In the original NE-SW survey, 73 percent of the systems in service had experienced some form of problem. (This figure declines to 41% when malfunctions encountered in the initial start-up period are excluded.) These homeowners' repair expenditures averaged $156, 3 percent of the average system cost. They estimated that their systems had been malfunctioning "in one way or another" an average of 12 percent of the time since becoming operational. In the Maryland study, the frequency of problems had decreased to 42 percent, with two-thirds of these within three months of installation. Owner repair expenditures averaged just $12, 0.5 percent of average system cost and the average malfunctioning time had decreased to 7 percent.

The repair frequency, cost, and malfunction times reported in the follow-up survey indicate that serious reliability problems persist. Fully 77 percent of the owners reported that their systems had experienced some form of "technical problem" during the previous two years. The frequency of these problems was relatively constant whether the responses are disaggregated according to the type of manufacture (premanufactured 75%, contractor built 77%, homemade 85%) or function (domestic hot water 72%, space heating 78%, dual function 88%). The recent technical problems were very similar to those reported in the earlier surveys. The most frequently mentioned in all three surveys were, in descending order: control systems, water pumps or air handlers, leaks in the pipes to and from the collectors, and leaks in the collectors themselves. (It should be noted that these are also the most readily observed by homeowners. Hidden problems such as tank scaling or insulation decay are less likely to be observed despite their adverse effect on system performance.)

The owners' repair expenditures during the previous two years are the most striking finding of the study. Expenditures for the 171 systems averaged $356 per system. This suggests an average annual maintenance cost of approximately $178, 4.5 percent of the initial cost of the systems represented in the follow-up survey. This is substantially higher than the assumption in most life-cycle cost models that annual maintenance equals just 0.5 to 2 percent of initial purchase price.

Repair expenditures vary noticeably according to system function and manufacture. As evident in Table 1, homemade systems report the lowest costs which would be expected since repairs generally do not include labor and other changes. (Crude repairs may also be more acceptable for these systems.) For both premanufactured and contractor made systems, expenditures tend to increase with initial cost and complexity, with the domestic hot water designs reporting the lowest costs and dual function designs the highest. Indeed, removal of the dual function designs from the sample reduces the overall average repair expenditure for the preceding two years to $103, 1.9 percent of average system cost on an annualized basis. It should also be pointed out that over half of the respondents reported no repair expenditures for these two years and that fully three-quarters of the sample reported expenditures below $130. In short, despite the pattern produced by the average figures, a substantial portion of systems are operating as planned.

A final pattern in the expenditure responses is that, in contrast to the other packaged and contractor built systems, a majority (57%) of the technical problems in premanufactured, domestic water systems were repaired at no cost to the owners. It cannot be determined whether this is the result of ease of repair, warranty coverage, or dealer goodwill.

To better determine system reliability, the follow-up survey also asked the owners to estimate the percentage of the time that their systems had malfunctioned "in one way or another" during the previous two years. The

Table 1. Technical Problem Frequency and Costs in the Two Years Preceding the Follow-Up Survey

Overall			
Number of systems:	171	Average repair cost: $356	
Number with problems:	n = 132 77%	Annualized repair costs as a % of purchase price: = 4.5%	
Premanufactured systems			
Hot water:	n = 86	Space heating:	n = 5
Number with problems:	62 72%	Number with problems:	5 100%
Average repair:	$51	Average repair:	$362
Annualized repair costs % of price:	1.1%	Annualized repair costs % of price:	3.6%
Dual function:	n =17		
Number with problems:	15 88%		
Average repair:	$1182		
Annualized repair costs % of price:	6.2%		
Contractor built			
Hot water:	n = 6	Space heating:	n = 7
Number with problems:	4 67%	Number with problems:	4 57%
Average repair:	$33	Average repair:	$318
Annualized repair costs % of price:	0.9%	Annualized repair costs % of price:	1.9%
Dual function:	n = 17		
Number with problems:	15 88%		
Average repair:	$1474		
Annualized repair costs % of price:	10.2%		
Homemade			
Hot water:	n = 8	Space heating:	n =15
Number with problems:	5 62%	Number with problems:	12 80%
Average repair:	$72	Average repair:	$260
Annualized repair costs % of price:	4.2%	Annualized repair costs % of price:	5.1%

Table 1. (Cont'd.)

Homemade	
Dual function:	$n = 10$
Number with problems:	9
	90%
Average repair:	$273
Annualized repair costs	
% of price:	3.4%

Note: Average repair cost = total repair expenditures/total number of systems in that category.

12 percent average malfunction rate they reported is similar to the rates recorded in the initial surveys. As suggested by the low figure, 79 percent of the owners reported malfunction rates of zero and 5 percent. At the other extreme, 8 percent of the systems had been inoperative 50 percent to 100 percent of the time. When disaggregated according to system function, the owners of the water heating systems reported the best operating record (with malfunctions an average of 7% of the time). In contrast, the owners of space heating and dual function systems reported malfunctions 19 percent of the time on average. Lower malfunction rates were also reported for premanufactured systems (10%) compared to the contractor (18%) and homemade systems (16%).

These perceived reliability figures may be assessed both negatively and positively. On the negative side, they indicate that the solar systems of the late 1970s still do not approach the reliability experienced in traditional heating equipment, even after start-up problems are excluded. Conversely, when put into context—first generation solar equipment, inexperienced installers—the record can be viewed much more positively, particularly for premanufactured domestic water heating designs.

THE OWNERS' CURRENT ASSESSMENTS

A second set of questions investigated the owners' overall satisfaction level and assessment of residential solar energy use.

Level of Satisfaction

Each of the surveys asked the respondents how satisfied they were with their overall experience with solar energy. In common with the findings of other surveys of early solar adopters [7], the respondents in the original surveys expressed very high satisfaction rates, often even when their systems had performed only marginally. In the original surveys, for example, 92 percent of the individuals who responded to the follow-up survey were at least satisfied with their solar experience. (Fifty-nine % said they were "highly pleased.") Conversely, just 8 percent were moderately disappointed and none were very disappointed.

This pattern persists in the follow-up survey with 88 percent still at least satisfied with their experience. (Fifty-one % remained very satisfied.) A modest, but not statistically significant decrease from the initial enthusiasm is suggested in the growth of the dissatisfied percentage (including 5% who were very disappointed). As one would expect, the satisfaction levels are closely related to perceptions of the system performance. Those individuals who reported malfunction rates above 5 percent, thermal contributions of 30 percent or less, or annual repair costs greater than 2 percent of original purchase costs, for example, were far more likely to be disappointed with their solar experience. (Chi-square tests of independence were highly significant, with the probability for all three variables less than .001.) Other factors that might also affect satisfaction levels, e.g., system function, type of manufacture, and regional location, appear to have no significant influence.

Willingness to Repeat Investment

The owners were asked a series of questions to determine their overall assessment of residential active solar energy use. The first of these questions asked each owner whether he would repeat his investment "knowing what you do today." Fully 76 percent of the owners said they would do so. The response was even higher (85%) among owners of domestic water heating systems. (Among owners of space heating and dual function systems, 69 percent and 62 percent, respectively, said they would repeat. (In Chi-square tests, these differences are significant at $p < .01$.) As with the satisfaction levels, willingness to repeat the investment is more common among owners whose systems provide at least 30 percent of the thermal needs ($p < .001$), have malfunction rates 5 percent of the time or less ($p < .06$), or have annual repair expenditures that are less than 2 percent of original system costs ($p < .03$).

Two regional patterns stand out in the repeat investment responses. First, willingness to repeat the investment is greater in Maryland (86%) than in the Northeast and Southwest (71% and 68%). (The difference is significant at $p < .006$.) This pattern is attributed to the greater thermal contributions and lower repair expenditures reported for the Maryland systems. Unfortunately, the analysis could not discern whether the better performance is the result of design improvements initiated after installation of the NE-SW systems, the shorter operation time of the Maryland systems, or the fact that Maryland installations are exclusively water heating systems. The other regional pattern of note is the similar portion of owners in the Northeast and Southwest willing to repeat their investment. One would have expected greater variation from these climatically contrasting areas.

Relative Savings and Recommendations

Despite the willingness to repeat their solar purchases, advocacy of conservation rather than active solar adoption emerges in several questions. The first of these asked what the owners' thought had saved the most energy: their solar system or conservation actions they had undertaken. Only 30 percent of the respondents felt their solar systems had saved more energy than conservation measures. The remaining respondents were evenly divided between those who thought their conservation investments produced greater savings and those who attributed similar saving to each activity. The fact that fewer than one-third of the sample thought their solar activities generated greater savings than conservation is noteable given the magnitude of the average solar investment ($3930). This response pattern leads to two possible conclusions. If the homeowners are correct, it is a vote in favor of energy conservation since it is unlikely the owners spent similar amounts for conservation. Alternately, it is unlikely that the large thermal contributions claimed for the solar systems could be equalled or surpassed by conservation measures, particularly in the homes with solar heating and dual function systems. If this is the case, it indicates that even these highly educated individuals are unable to estimate their comparative savings.

This issue was further explored in a question that asked what the owners would recommend to neighbors willing to spend a similar amount of money to reduce energy bills. This question is perhaps the ultimate evaluation since it builds on the owners' experiences yet is less biased by their personal commitment to active solar use. As shown in Table 2, energy conservation was most frequently recommended. Nearly 50 percent of the owners recommended either this option or the related action of investing in more efficient conventional heating equipment. In contrast, only 28 percent recommended use of active solar energy systems, most commonly domestic heating designs. This question was repeated with the response limited to solar energy alternatives. As shown in Table 3, active solar water heating or passive space heating were recommended by three-quarters of the sample. In contrast, active space heating received fewer than 1 percent of the recommendations.

A more exploratory, open-ended question asked the owners what they perceived to be "the major barriers today to the widespread use of solar energy?" Responses, summarized in Table 4, underscore the constraining effect of high initial costs and, to a lesser degree, lack of information and the systems' unproven reliability. The key barrier effect of high initial cost is also evident in the responses to a separate question that asked the owners to select from a list of six options the "greatest improvements needed on systems like yours." Over half (52%) of the respondents identified cost reduction or efficiency improvements. (To some extent, these are corollaries of one another.) Not surprisingly, the owners also called for greater reliability with the need for improved installation cited by 18 percent as the single-most needed action, improved materials by 13 percent, and general reliability by 9 percent.

Table 2. Recommendations to Homeowners Willing to Spend Similar Amounts of Money

Option	*Frequency of Recommendation*
Conservation measures	37%
Active solar water heating	21%
Passive water heating	16%
More efficient furnace	12%
Passive space heating	7%
Active dual function systems	6%
Active solar space heating	1%

Table 3. Solar Energy Use Recommendations

Option	*Recommendation Frequency*
Active domestic water	43%
Passive space heating	32%
Active dual function	16%
Passive water heating	9%
Active space heating	1%

In the follow-up sample, 58 percent of the systems were domestic water, 16 percent were space heating, and 26 percent were dual function designs.

Table 4. Owners' Assessment of the Barriers to Widespread Solar Use (Barriers mentioned by 5% or more of the sample)

Barriers	*Frequency of Mention*
High initial cost	49%
Public ignorance of solar viability	20%
Unproven reliability	17%
Government changing emphasis/indecision	10%
Poor performance of the systems	8%
Low cost of alternative fuels	7%
Uncertain payback time	7%
Public resistance to change	7%
Lack of qualified installers	6%

CONCLUSION

The follow-up survey contains implications for potential solar consumers, the solar industry, and government policy. For potential consumers, the results provide a series of warnings. First, solar owners tend to provide more positive assessments and satisfaction levels than experience would seem to warrant. This pattern has been revealed in several other studies including a Florida one in which forty of sixty owners reported high satisfaction levels even though inspection of the installations indicated that only six were installed and functioning properly [8].

The owners' overly enthusiastic evaluations may be attributed to lenient expectations and cognitive dissonance. Lower expectations may be assumed because most owners knew they were purchasing a relatively untested product. Cognitive dissonant behavior would be expected where performance does not meet even these lowered standards. In the solar context, this behavior is magnified by the fact that adoption decisions are long-term commitments (in that savings accrue over the life-cycle of the product), discretionary, costly, highly visible, and greatly influenced by noneconomic motivations. The warning to potential owners is that in this case, government reports may be less biased and more accurate than their peers' satisfaction levels. Similarly, if potential adopters seek the advice of current owners, they will obtain more helpful information if they do not challenge the wisdom of the owners' solar adoption decision, but ask what they recommend *now* for *other* individuals.

A second warning is that potential consumers should be particularly concerned with the warranty practices of equipment manufacturers and installers. Investments of the magnitude of solar active systems should not have annual repair costs that equal 4.5 percent of the purchase price, 8 percent of the systems not working half the time, 12 percent malfunction rates, or the reduced thermal contribution expectations reported by the owners. On the positive side, the results suggest that the performance, reliability, and warrantee coverage of newer systems and domestic hot water designs are much better than the overall pattern.

Two final messages for potential owners involve the different approaches to reduce heating bills. Despite their own commitment to solar energy, the owners generally recommended that energy conservation be thoroughly explored before solar energy use. This advice echos the conventional wisdom of energy engineers and architects: insulate first, insolate second. Secondly, when considering solar energy use, the simpler approaches–domestic water heating and passive space heating–were far more frequently favored than more expensive and complex approaches.

Three messages to the solar industry may be drawn from the results. First, although the owners remain remarkably supportive, they are not uncritical of the industry. In particular, these individuals feel the industry must reduce the initial cost and improve reliability. Other accounts indicate the reliability of the systems marketed in the 1980s has greatly improved. However, prices have escalated rather than decreased. (The average price of premanufactured water heating systems, for example, rose from below $2000 in the NE-SW survey to just below $3000 in the Maryland survey and is now over $4000.) Clearly, reducing this cost is essential if the industry is to survive without federal tax credits in the current benign energy environment. (The 40% federal tax credit provided for residential installation expires December 31, 1985.)

Secondly, the industry should expect potential owners to be hypercritical of warranty coverage and performance guarantees. Companies should address these concerns; the experience of past owners indicates they are very legitimate. To improve existing owners' recommendations, they would do well to return to their previous installations and, where inexpensive, correct problems that contribute to the 12 percent malfunction rate. Finally, the results, particularly the repair expenditures and recommendations for passive designs, suggest a new approach is warranted for active solar space heating. Greater attention to simple, lower cost site-constructed designs represent one neglected option.

The federal and most state governments have promoted solar energy use with special tax incentives, research and demonstration efforts, and information programs. Because of this role and the benefits associated with widespread solar use, government has both a special responsibility and interest in addressing the problems identified in the first wave of solar energy use. The states have already risen to the challenge through creation of the Interstate Solar Coordination Council. The ISCC has developed model warranties and standardized procedures to test and rate the efficiency of new collectors. To reduce the problems caused by poor installation, Florida and several other states require special training and licenses for solar installers. The greatest omission in governmental activity is in promoting research and demonstration of low-cost systems. Despite its short history, the active solar industry is remarkably entrenched around relatively expensive copper absorber plates set within carefully machined aluminum collector units. Lower cost, more reliable, and more easily repaired alternatives are clearly needed.

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