THE CONSUMER RESPONSE TO PHOTOVOLTAICS: THE MIT SUN DAY EXPERIENCE

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ABSTRACT

This paper reports on the results of the MIT Energy Laboratory Sun Day PV study. This study continued our assessment of likely market response to photovoltaics. The Sun Day exhibit attracted a high proportion of solar innovators. The study determined that the key issues relating to PV preference are

- economical and ecological soundness
- complexity of the system and
- secondary benefits.

A key result is that this population is much more receptive to PV than were populations previously studied, but we were not able to identify external characteristics associated with that innovativeness.

I. Introduction

A key objective of the Photovoltaics program at the Energy Laboratory at MIT is to assess and monitor emerging and evolving reactions to photovoltaics. The PV diffusion model (see Lilien (2)) requires consumer calibrations as input; even more importantly, we know (see Utterback (3)) that early user input into the R&D process can cut the time to successful marketing of a new product and accelerate the level of that success. This year's Sun Day program in Boston provided an important opportunity to survey solar innovators. This document reports on that experience.

II. Background and Methodology

Wednesday, May 10, 1978 was Sun Day throughout the United States. A major activity in the Boston area was an exhibit by solar manufacturers and other interested parties on the Boston Common. It was a well publicized event in a heavily travelled area, and the weather was good, so thousands of people stopped by.

MIT's Lincoln Laboratory set up a popular exhibit, demonstrating the use of photovoltaics for agricultural pumping and residential power. In conjunction with this exhibit, we had a team of interviewers at the exhibit that day asking the Bostonians passing through the exhibit to participate in a market study. Our objectives were to generate a sample geographically different from our Nebraska results (see Lilien (2)), as well as to gauge the innovativeness of the people attracted to such exhibits. Here, as solar energy was the draw, our sample was self-selected, not random.

The survey was targeted at homeowners. Since an unusually large fraction of the visitors were assumed to be considered solar energy for a new house, we separated current homeowners from prospective homeowners in the initial interview. This allowed us to assess whether retrofit and new construction can be considered a single market, or whether differentiated strategies are required.

The procedure was to ask people if they were willing to participate in a market survey as they passed out of the exhibit. If they agreed, they were asked to identify themselves as either a current or a prospective homeowner, and given a questionnaire containing a concept statement for a Photovoltaic residential power system. At random, half the concept statements described a grid-connected Photovoltaic system, half described a utility-independent system (see Appendix for examples). The final interview was later conducted by telephone. When all the interviews were done, we had 226 cases distributed as in Table 1.

Concept Statement	Homeowner Status		
	Current	Prospective	
Independent	89	30	119
Dependent	77	30	107
	166	60	226

TABLE 1

III. Descriptive Results

The results of the Sun Day survey are contained in the figures on the next few pages. Demographically, our sample was fairly young and well educated. In Figure 1 we see that 50% of the respondents are 25-40 years old. No one had less than a high school education, and 74% had a Bachelors degree or higher (Figure 2). Most of them are well off, with 57% making $20,000 - $40,000 in gross household earnings (Figure 3). The average household has 3.4 residents

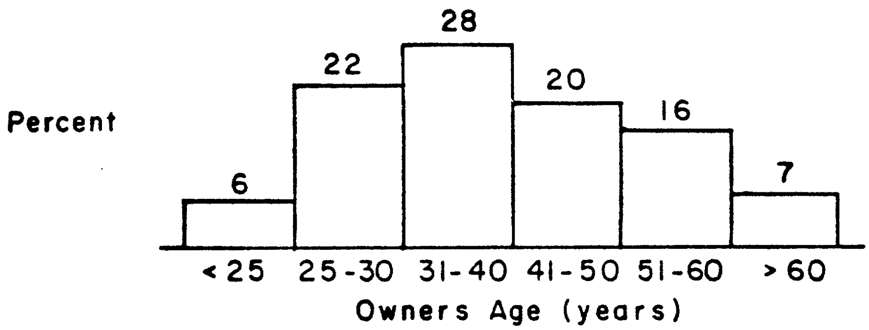


Figure 1

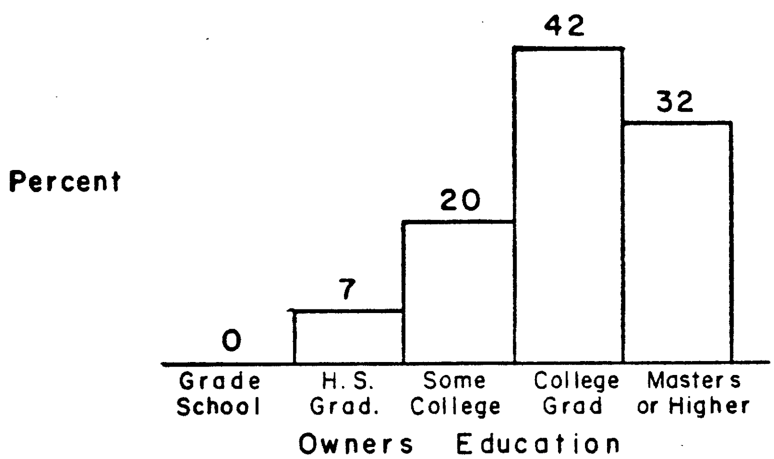


Figure 2

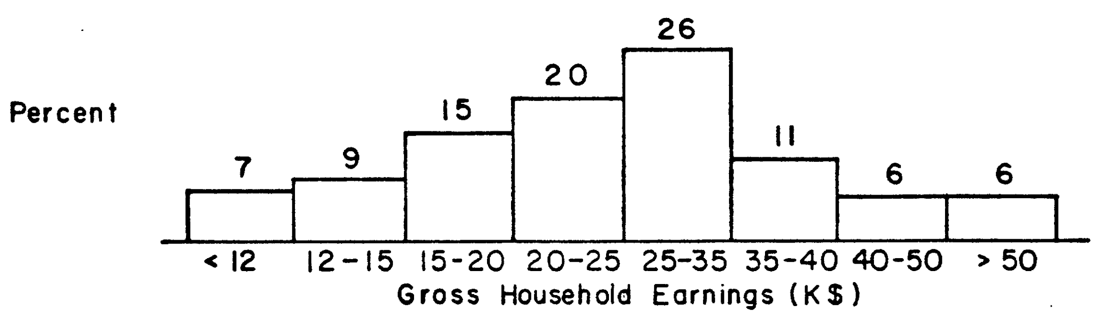


Figure 3

including the owner (Figure 4), and 2.3 of the individuals hold mortgages (Figure 5). Since 23% of the respondents rent (Figure 6), 87% of the true owners hold mortgages. Their houses are moderate in value, with 58% of them having a replacement cost of $40,000 - $75,000 (Figure 7). The expressed probabilities of buying a new home within a year are consistent with the 73%-27% current versus prospective homeowners breakdown (Figure 8).

The dominant heating fuel is oil (Figure 9), and 83% have an average annual heating bill of less than $1000 (Figure 10). A majority of average annual electric bills (excluding heating) are between $200 and $500 (Figure 11).

The attributes that these consumers consider most important when considering power systems are, in order, initial cost, 10 year cost, and number of prior successful installations (Figure 12). The acceptability distributions for first cost, payback period and number of prior installations are shown in Figures 13, 14 and 15 respectively. It is interesting to note that the mean number of prior installations considered necessary in the irrigation survey was 4.5, compared to the Sun Day survey's 1.7; in this respect the Sun Day sample is certainly innovative. Tradeoff or indifference curves for these last three acceptability attributes are plotted in Figures 16, 17 and 18. For this survey they are relatively uninteresting since payback and first cost are nearly independent of number of prior installations. Also, first cost and payback are known to be inversely related, as confirmed in Figure 17, though in fact they are slightly positively correlated in our sample. A principal components factor analysis was performed on these three attributes, which confirmed that they are perceptually independent. This justified the simple multiplication of probabilities that was used to generate Figures 16, 17 and 18.

The innovativeness of the Sun Day population is not clear judging by "technical optimism" questions. Figures 19 and 20 display answers to two

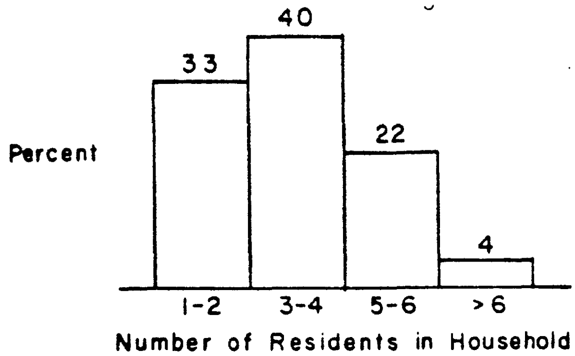


Figure 4

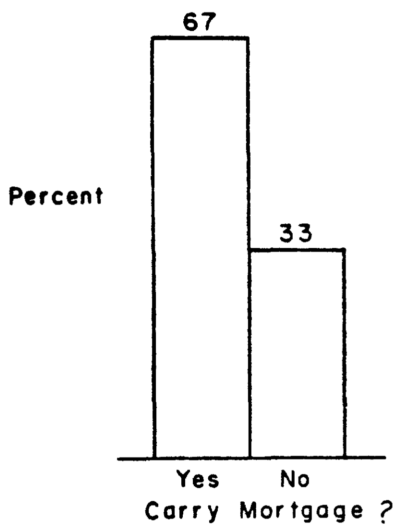


Figure 5

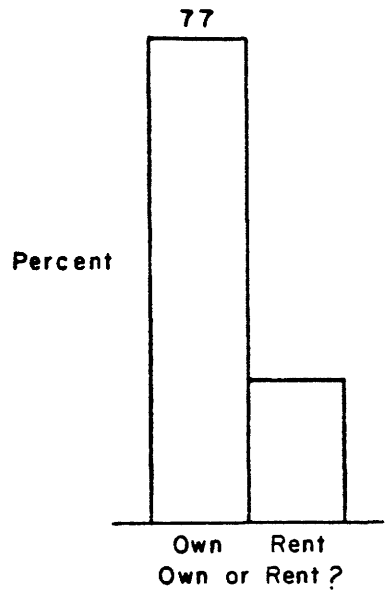


Figure 6

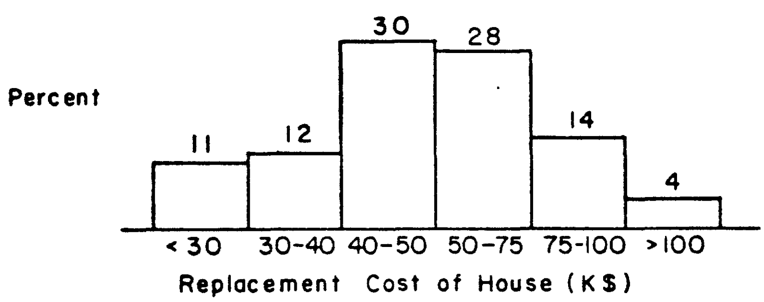


Figure 7

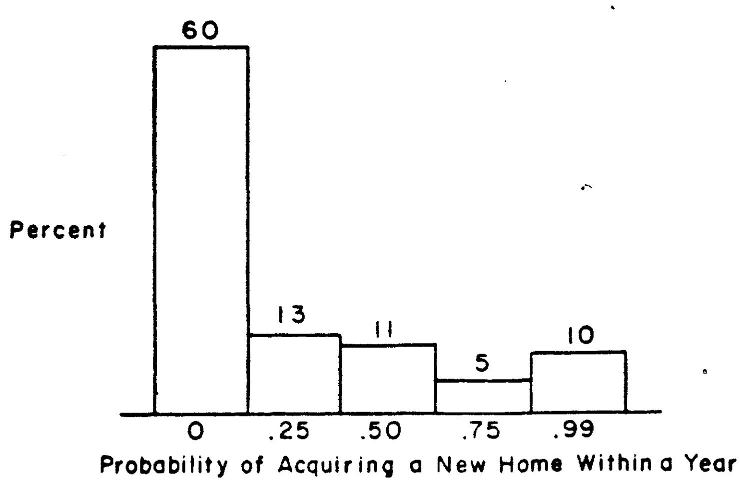
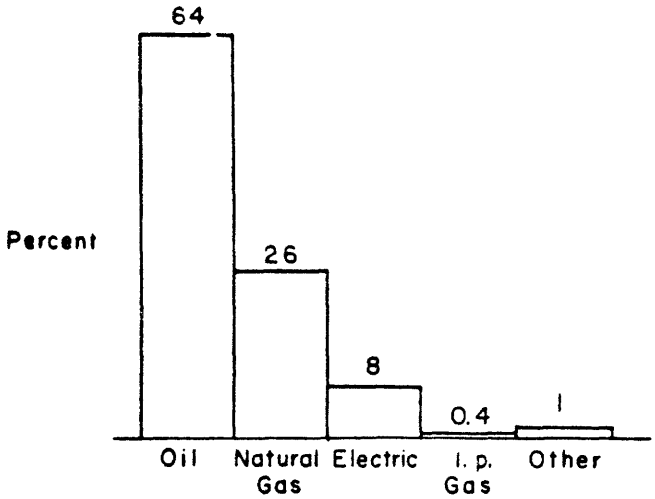
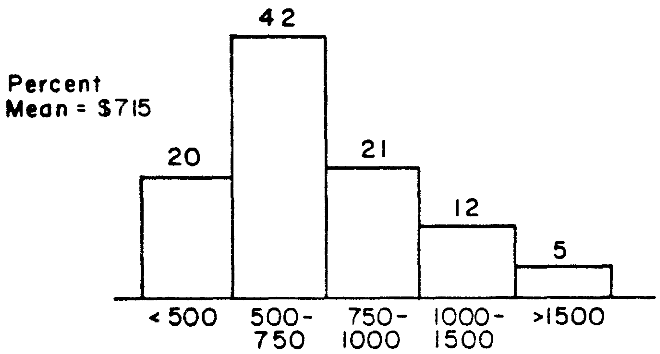


Figure 8



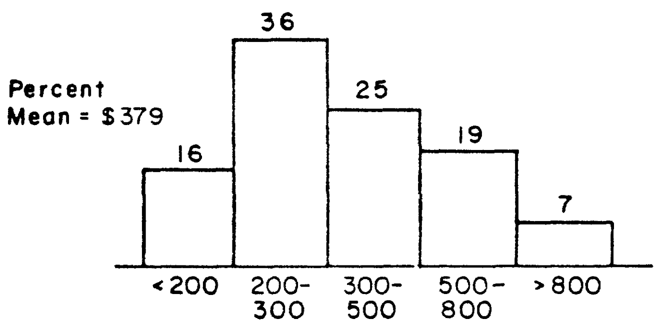
Fuel Used For Heating

Figure 9



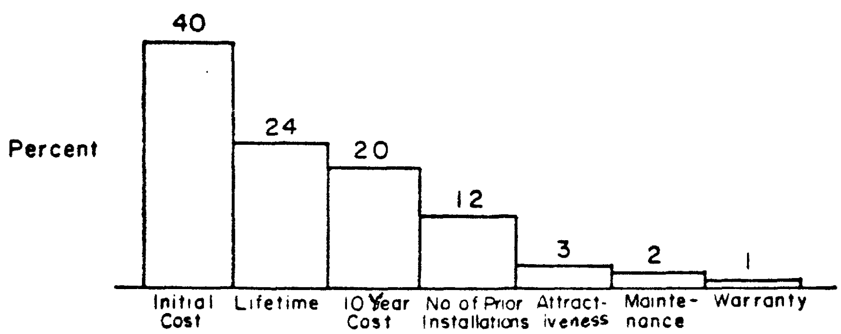
Average Heating Bill Per Year ($)

Figure 10



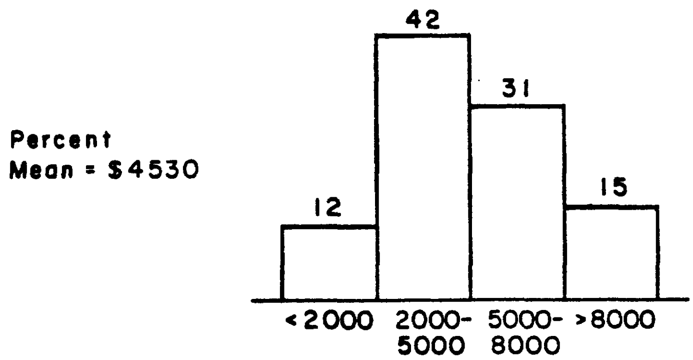
Average Electric Bill Besides Heating Per Year ($)

Figure 11



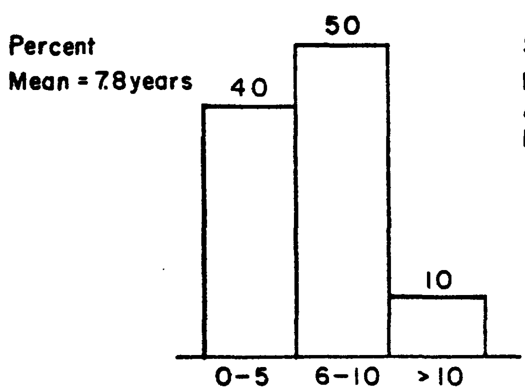
Which System Attribute is Most Important ?

Figure 12



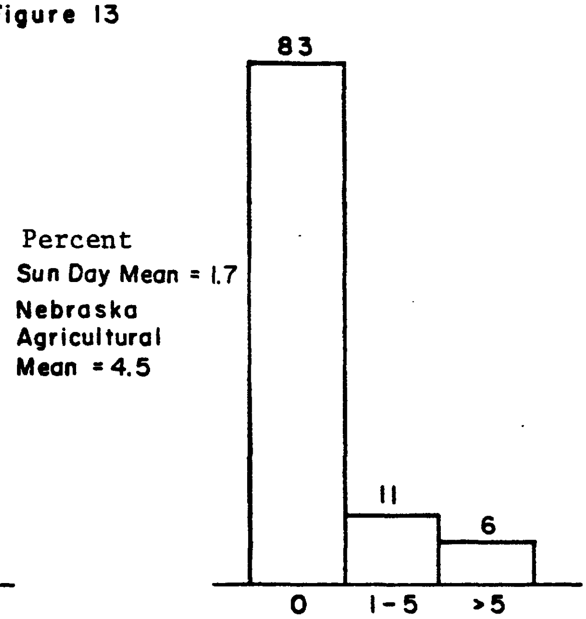
Maximum Acceptable First Cost for an Electricity Generation System ($)

Figure 13



Maximum Acceptable PV System Payback (years)

Figure 14



Minimum Number of Prior Installations Needed to Consider Purchase

Figure 15

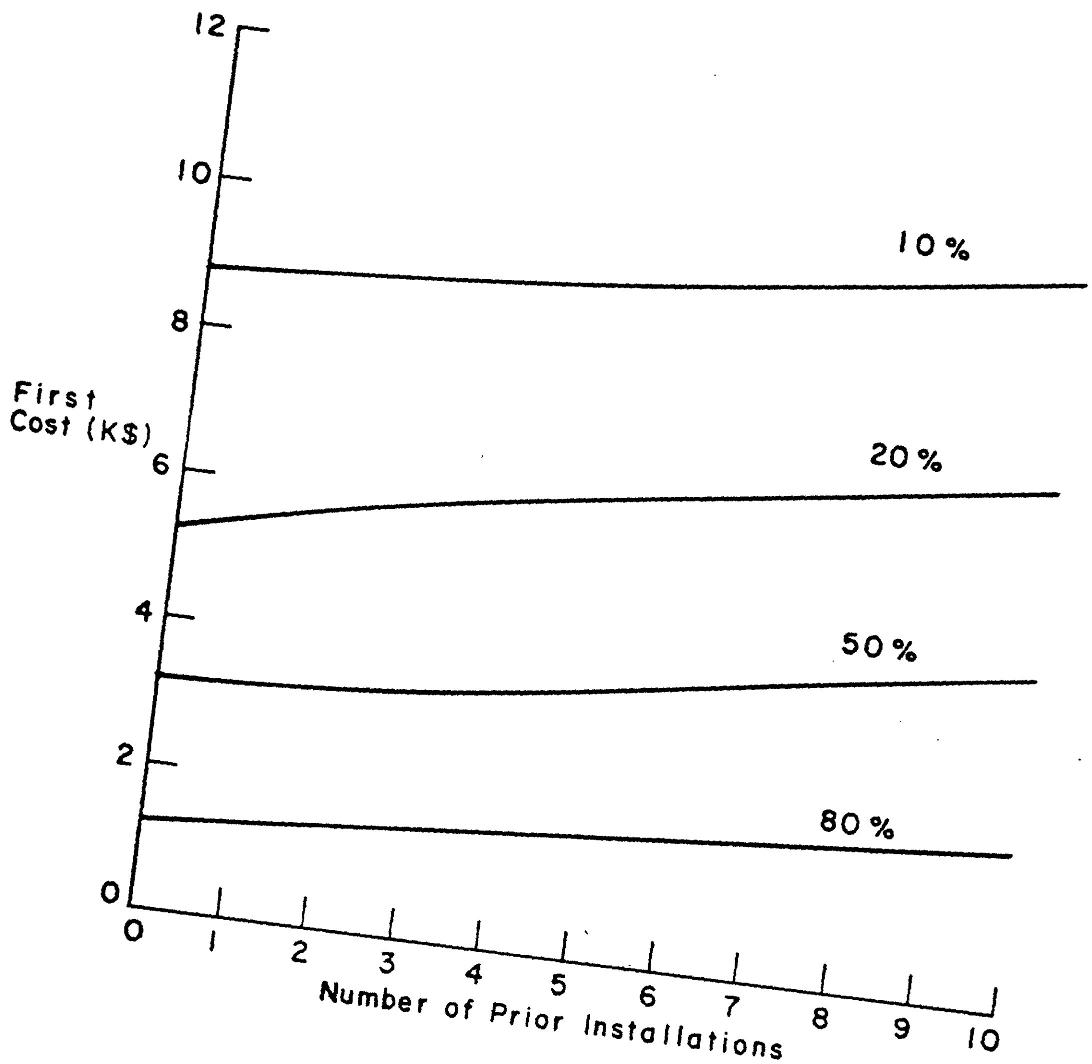

12
10
8
6
4
2
0
First
Cost (K$)
10 %
20 %
50 %
80 %
0
1
2
3
4
5
6
7
8
9
10
Number of Prior Installations

Figure 16

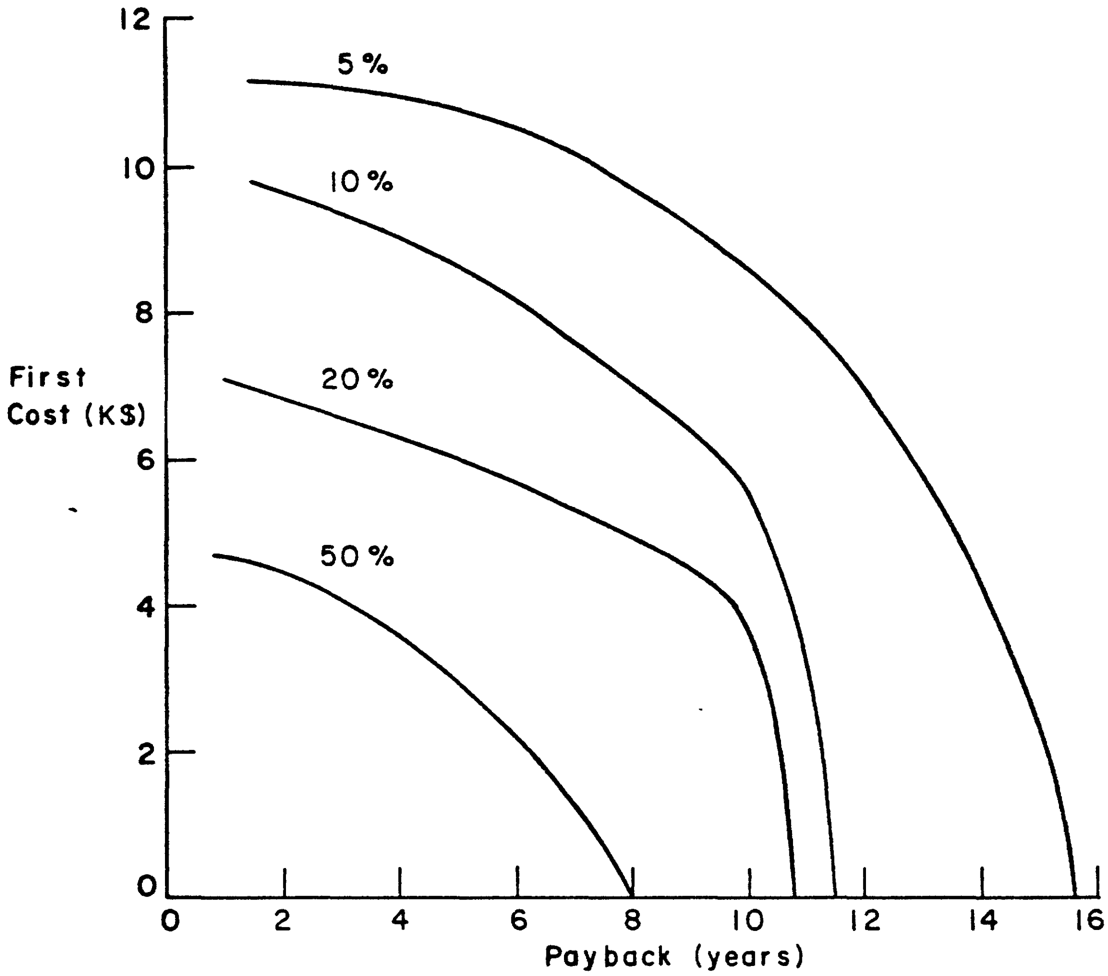

12
10
8
6
4
2
0
First
Cost (K$)
5 %
10 %
20 %
50 %
0
2
4
6
8
10
12
14
16
Payback (years)

Figure 17

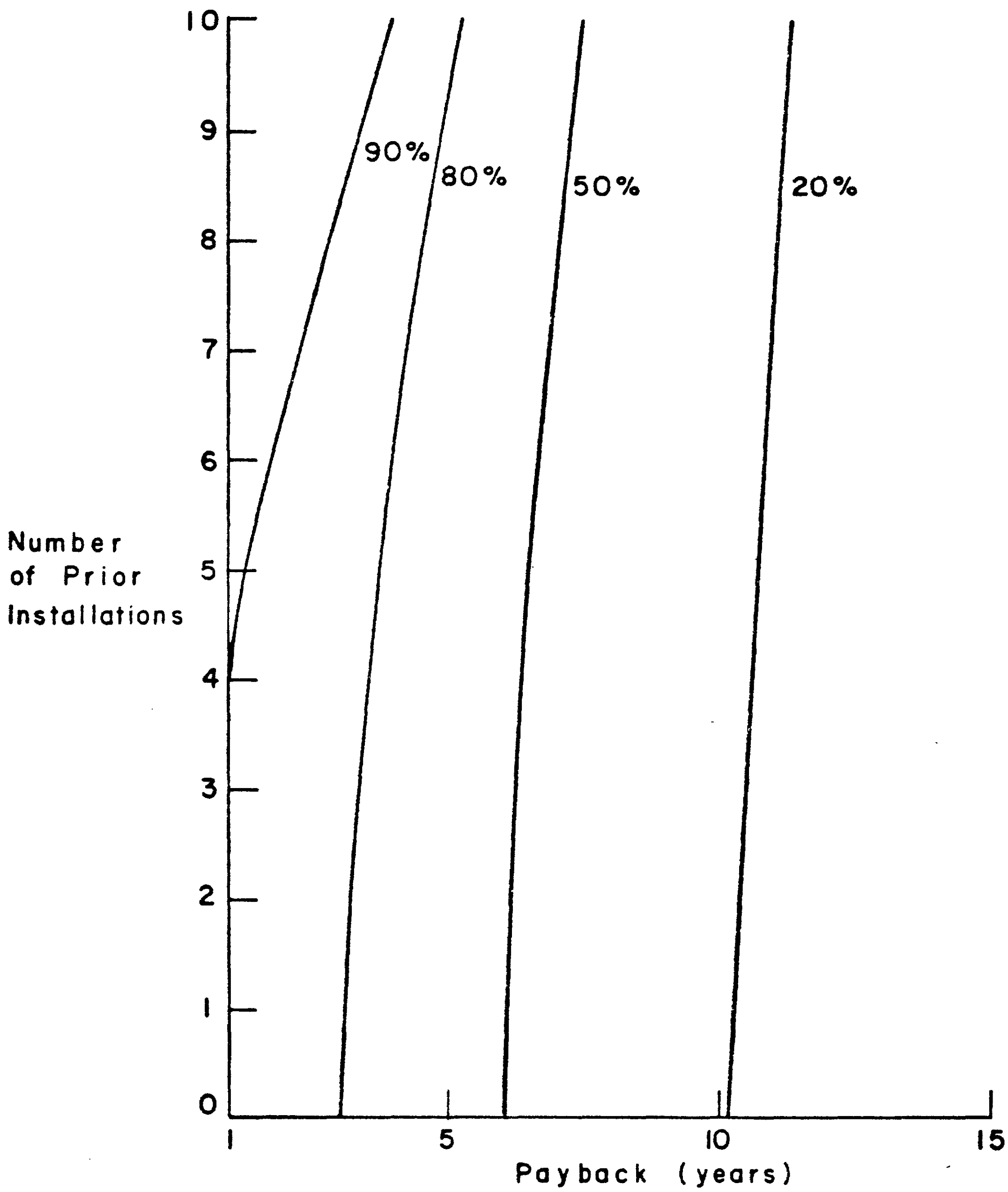

10
9
8
7
6
5
4
3
2
1
0
Number
of Prior
Installations
90%
80%
50%
20%
1
5
10
15
Payback (years)

Figure 18

Sun Day Mean = 2.7
Nebraska Residential Mean = 2.5
Nebraska Agricultural Mean = 2.6

Current Homeowners Mean = 2.7
Prospective Homeowners Mean = 2.6

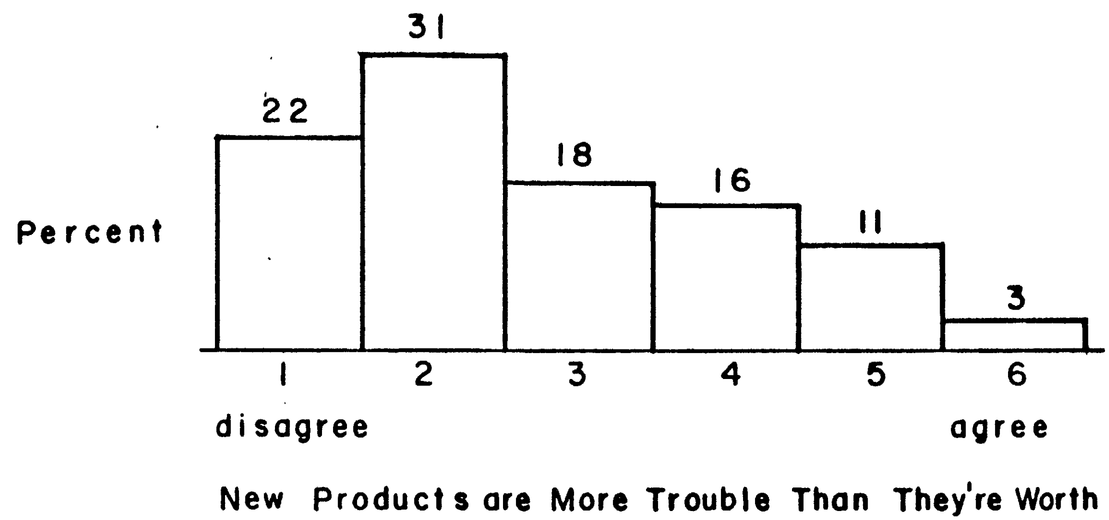


Figure 19

Sun Day Mean = 3.5
Nebraska Residential Mean = 3.5
Nebraska Agricultural Mean = 3.5

Current Homeowners Mean = 3.6
Prospective Homeowners Mean = 3.1

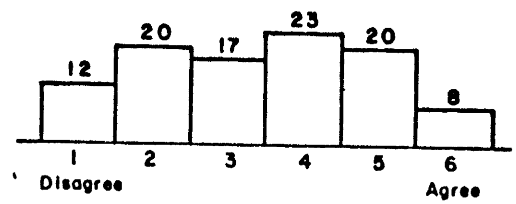


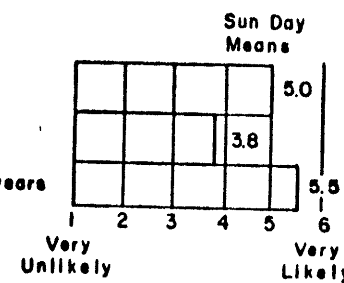
Figure 20

How Likely is it that a Manufacturer:

will produce an economical PV system in 10-15 years

can produce a reliable and dependable PV system now

will produce a reliable and dependable PV system in 10-15 years



Other Means		
Nebraska Residential	Homeowners Current	Homeowners Prospective
5.0	5.0	5.0
3.5	3.8	4.0
5.2	5.5	5.5

Figure 21

Nebraska Residential Means	.37	.23	.12	.07
Current Homeowner Means	.59	.41	.25	.20
Prospective Homeowner Means	.66	.52	.37	.31

Sun Day Mean
Probability of Purchase
at Given Price

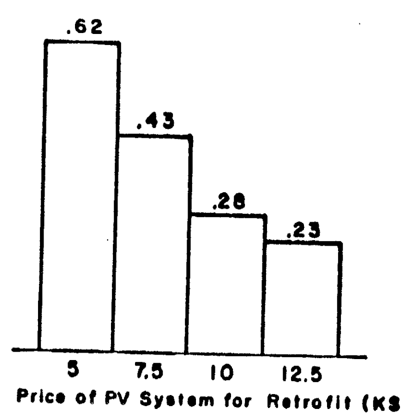


Figure 22

questions about new products in general. Note that the mean answers are essentially the same as in the two Nebraska surveys. Similarly, Figure 21 shows the mean answers on three Photovoltaic-specific questions for the Sun Day and Nebraska residential surveys, again without significant differences.

But when these same two survey groups were asked to rate their probabilities of purchase at various given prices, striking differences appear (Figures 22 and 23). These same questions could also shed light on the relative degree of innovation evoked from current homeowners versus prospective homeowners, but are even more confusing. Figure 20 shows significant differences, with prospective homeowners more optimistic, while Figure 19 shows none. None of the questions in Figure 21 show significant differences. But in Figure 22, prospective homeowners have significantly higher probabilities of purchase at the three higher levels, but passing to the question in Figure 23, which is naturally more relevant to prospective homeowners, they come down to earth and score only insignificantly higher probabilities than current homeowners.

Passing to questions explicitly asking for attitudes about specific questions, we now find interesting differences in innovativeness. Figures 24 and 25 graphically portray the mean answers to the 14 attitudinal questions for Photovoltaics and electrical systems respectively, broken down by current versus prospective homeowner (a similar breakdown by independent versus dependent concept statement showed no significant differences on any question for either systems). The questions do differentiate well between the two systems; only question 3.8 and 3.9 do not show significant differences between Photovoltaic responses and electric responses. Prospective homeowners answer significantly more optimistically about Photovoltaics on 5 out of the 14 questions, and significantly more pessimistically about electric on 3 questions. Comparing these answers with those from the Nebraska residential study (see Lilien (2)), we find that current homeowners respond in essentially the same way as the homeowners in Nebraska,

Nebraska Residential Means	.62	.49	.36	.27
Current Homeowner Means	.80	.65	.48	.39
Prospective Homeowner Means	.81	.63	.56	.44

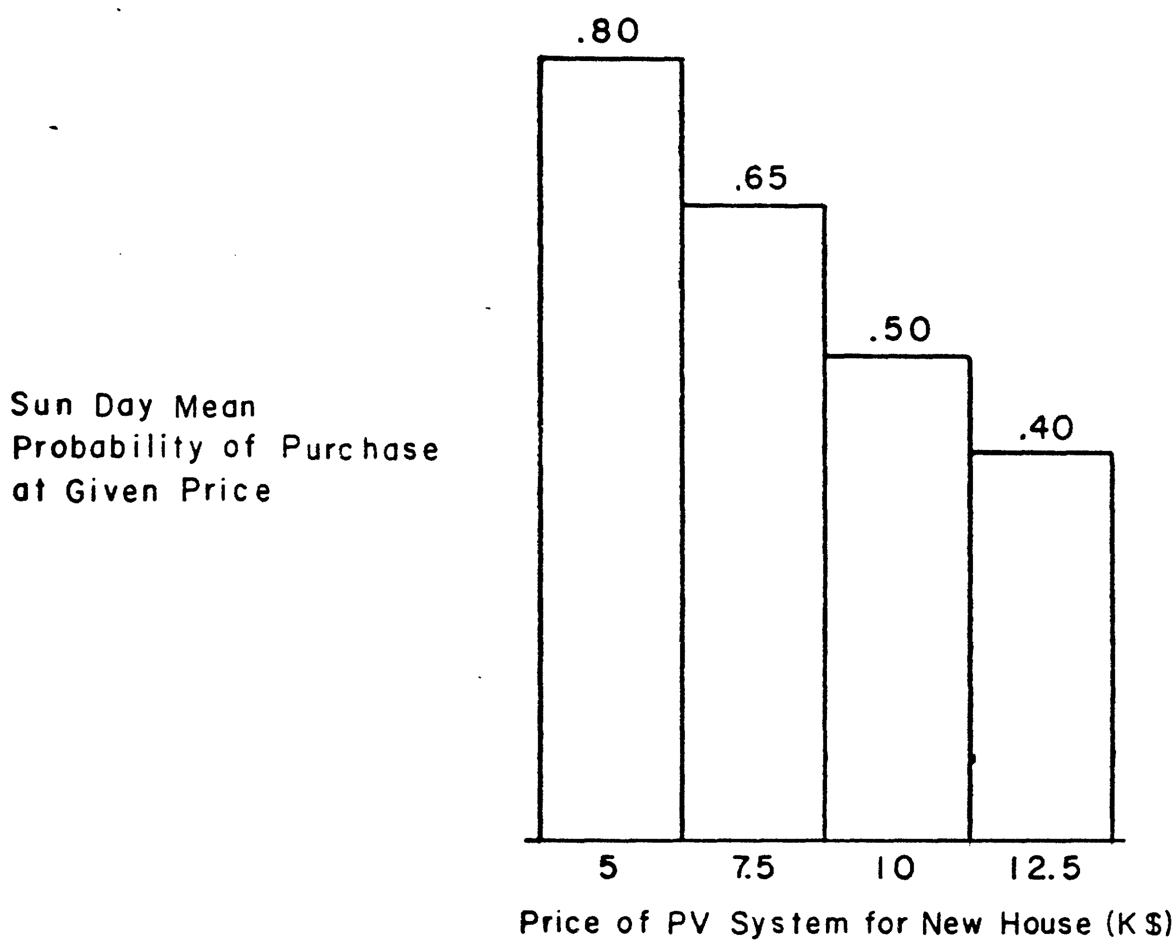
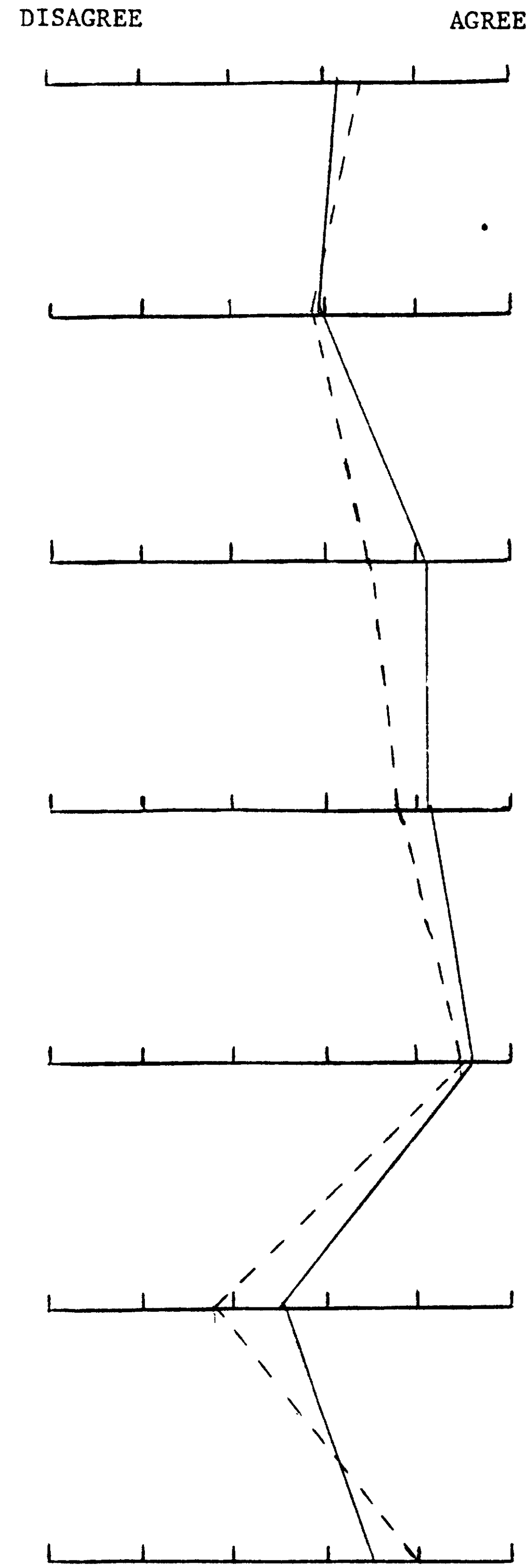


Figure 23

PV Attitudes

Figure 24



3.1 This kind of energy system provides reliable power for home use.

3.2 Adoption of this kind of energy system ensures against power failures in the home.

* 3.3 Performance of this kind of power system is sensitive to weather conditions.

3.4 This kind of power system protects against home energy rationing.

3.5 This kind of power system allows us to do our part in reducing pollution.

* 3.6 This kind of power system uses too many concepts that have not been fully understood.

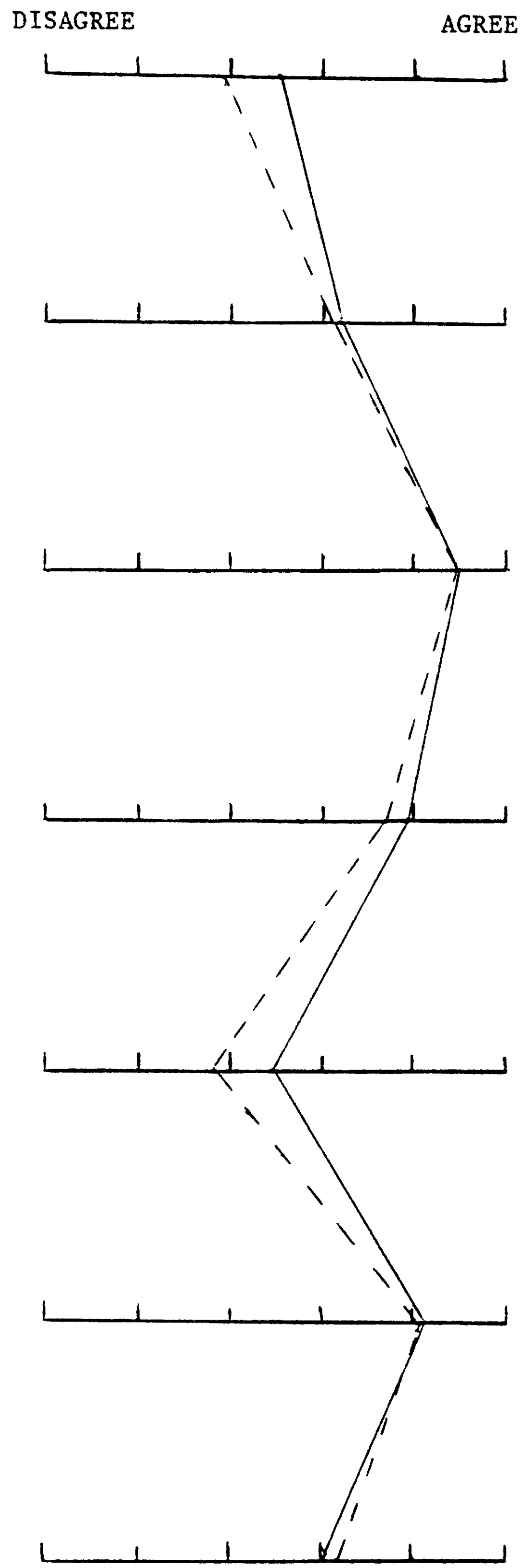
* 3.7 The long term benefits of this kind of power system justify its cost.

* current vs. prospective is significantly different at .05 level

———— current

--------- prospective

Figure 24
(continued)



*3.8 This kind of power system is visually unattractive.

3.9 This kind of power system is subject to weather damage.

3.10 This kind of power source contributes to energy conservation.

3.11 If the experts approved and recommended this kind of power system, I would seriously consider it.

*3.12 This kind of system requires too much space.

3.13 This system seems to be reasonably safe for home installation.

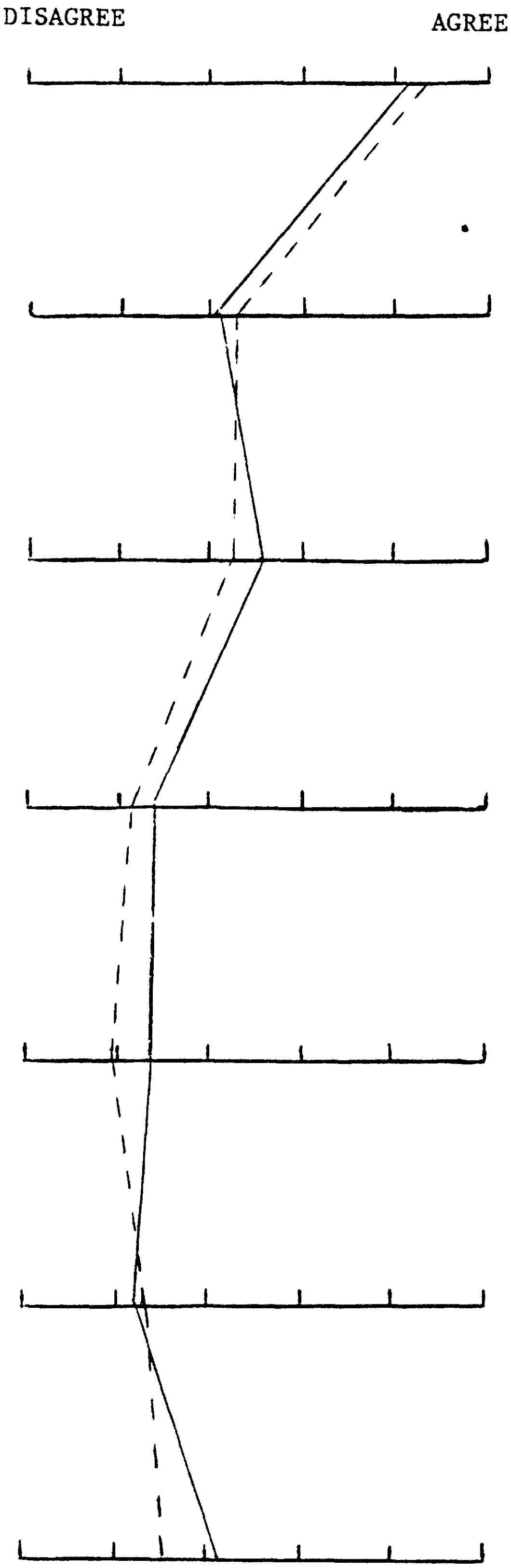
3.14 This system presents problems of repair or maintenance.

* current vs. prospective is significantly different at .05 level

———— current
---------- prospective

Electric Attitudes

Figure 25



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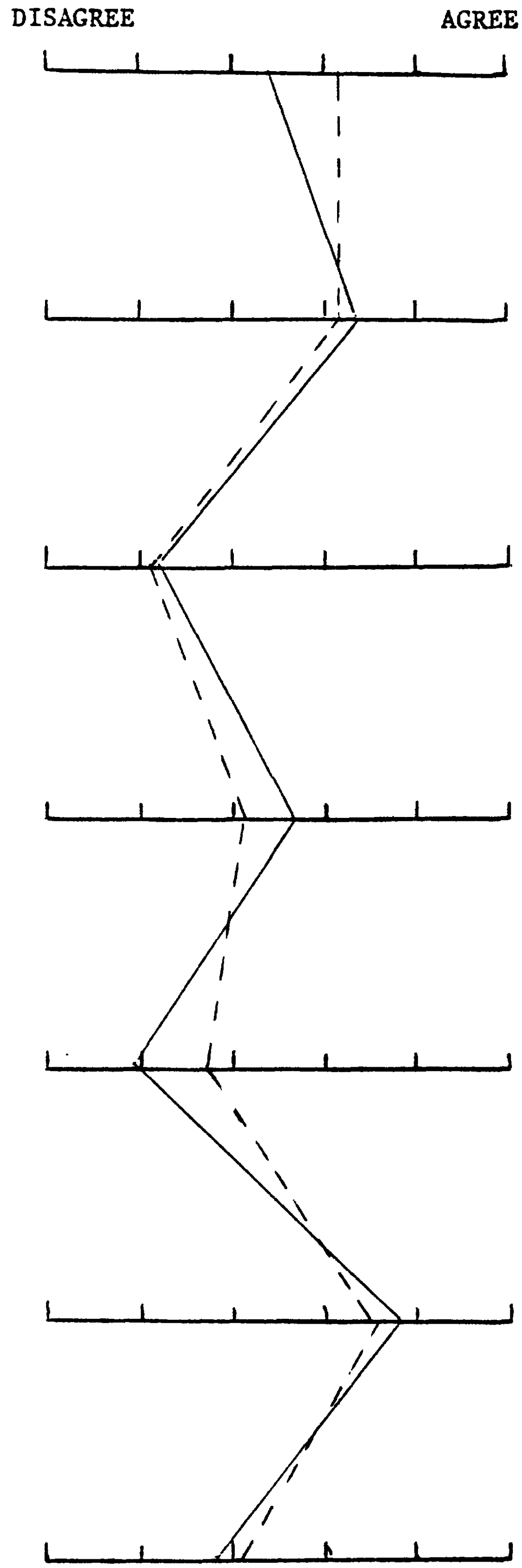
* current vs. prospective is significantly different at .05 level

________ current

-------- prospective

Electric Attitudes

Figure 25
(Continued)



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* current vs. prospective
is significantly different
at .05 level

________ current

-------- prospective

but prospective homeowners are again more optimistic on 4 of the 5 questions in which they outscored the current homeowners in rating Photovoltaic systems (questions 3.6, 3.7, 3.8 and 3.12). For electric, prospective homeowners were more pessimistic than the Nebraskans on the same 3 questions as above, and 3.11 as well. Only in answering question 3.5 for electric were the Bostonians as a group really different than the Nebraskans, seeing electric systems as being more pollution prone.

IV. Perceptual and Preference Analyses

Following the awareness - acceptability - perception - preference paradigm in Lilien (2), the next step was to factor analyze the perceptual space formed by the 14 attitudinal questions. Common iterative factor analysis with varimax rotation was used. A single respondent's dual sets of answers to the 14 questions on a PV system and a conventional electric system were analyzed as two distinct cases, so we can compare perceptions of the systems on a common basis. In addition, to remove a source of extraneous variation, the grand mean of each respondent's 28 answers was subtracted out before the factor analysis was performed.

The four subgroups formed by the independent/dependent concept statement and current/prospective homeowner dichotomies were initially analyzed separately to determine if there are perceptual differences among the groups. First we decide if the four reduced factor spaces have the same dimensionality. All four spaces were found to have a fairly sharp drop-off after the third eigenvalue, which was about 1. Thus we assign 3 dimensions to each of the four factor spaces.

Next we must determine whether the structures of these four spaces are similar enough that we can aggregate them. For this we use a test reported in Choffray and Lilien (1). The results of this computation are that all four factor spaces are significantly different. The four factor matrices are displayed in Figure 26. Not that by eye the four spaces look similar enough that we can describe the four sets of factors with the same three names. It is plausible that with a larger

FINAL VARIMAX ROTATED FACTOR MATRICES

		Independent Concept Statement			Dependent Concept Statement		
		Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Current Homeowners	Q31	0.01433	-0.46232	0.17635	-0.20657	-0.50204	-0.01333
	Q32	0.16546	0.13026	0.71698	-0.06873	0.17791	0.67608
	Q33	0.46878	0.37882	-0.10405	0.52480	0.15557	-0.06684
	Q34	0.69380	0.41331	0.28509	0.69089	0.24250	0.47998
	Q35	0.78074	0.40403	0.26573	0.72031	0.18658	0.44780
	Q36	0.03111	0.53150	0.14807	0.18230	0.40775	0.10054
	Q37	0.71451	-0.06300	0.40798	0.38145	0.07989	0.56917
	Q38	-0.23657	0.14815	0.00526	-0.08424	0.60482	-0.13421
	Q39	-0.06050	0.12067	-0.55760	-0.07130	0.17867	-0.40062
	Q310	0.82035	0.34314	0.22788	0.80446	0.25572	0.40545
	Q311	0.73254	-0.03311	0.01660	0.41705	0.19938	0.52903
	Q312	0.05552	0.75571	0.22779	0.19541	0.77041	0.17912
	Q313	0.37190	-0.26311	-0.19713	0.50069	-0.48470	-0.09679
	Q314	0.15798	0.77375	-0.26139	0.07765	0.61465	-0.11590
Prospective Homeowners	Q31	-0.15781	-0.48633	-0.12758	-0.00232	-0.72077	-0.03029
	Q32	0.49378	0.02228	-0.28867	0.48301	-0.30383	-0.04502
	Q33	0.13727	0.14976	0.25077	0.01149	0.08219	0.68274
	Q34	0.70141	0.11940	0.00118	0.80981	0.29861	0.33442
	Q35	0.86729	0.04424	0.11898	0.81244	0.27203	0.21139
	Q36	0.02333	0.35126	0.29019	0.01251	0.56536	-0.00380
	Q37	0.84393	-0.17878	0.00299	0.85959	-0.04149	0.05036
	Q38	-0.56144	0.23784	0.00198	-0.61517	0.20845	-0.28378
	Q39	-0.20113	0.05405	0.97505	-0.44897	0.24691	-0.03767
	Q310	0.81561	-0.01518	0.29526	0.78719	0.35890	0.25759
	Q311	0.58394	0.07052	0.07031	0.76141	0.19175	-0.27168
	Q312	-0.09714	0.51080	0.22338	-0.37026	0.49526	-0.13782
	Q313	0.29395	-0.70491	0.11450	0.21734	-0.20734	0.35720
	Q314	0.21960	0.27342	0.43006	0.04242	0.65235	0.00821

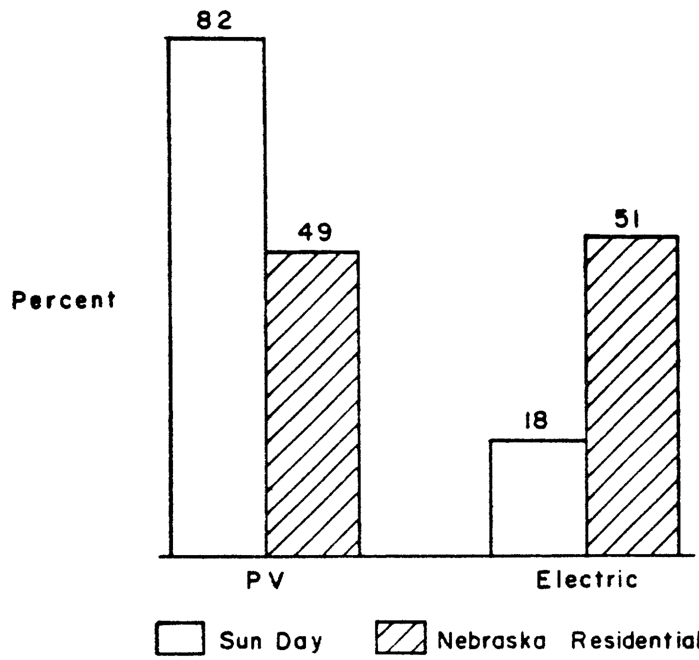
FIGURE 26

sample size, particularly of prospective homeowners, all four groups could be described by a single factor space. The factors that were identified were 1. Economical/Ecological Soundness; 2. Complexity/Untried Concepts; and 3. Secondary Benefits.

Now that the perceptual spaces have been reduced to manageable sizes, we can more easily relate perception to preference through regression. We asked two distinct sets of preference questions on our survey. The first used unrelated 11 point scales for the respective PV and conventional system preferences, the second required a constant-sum allocation of 11 points between the two systems. On this basis we could ascertain if the respondents had consistent system preferences. The inconsistent cases were deleted from the subsequent analysis.

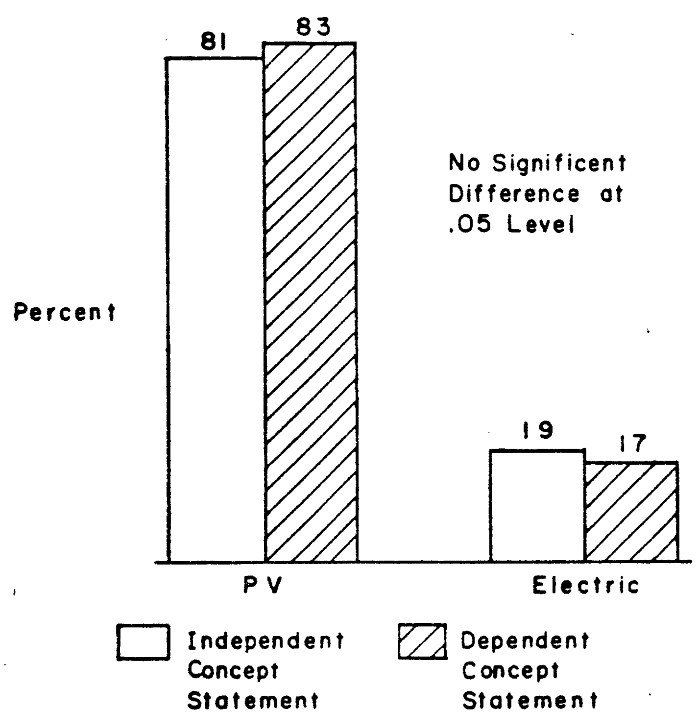
The raw preference results are recorded in Figures 27, 28, and 29. Once again the Sun Day respondents are very enthusiastic about Photovoltaic, with a huge 81% of them rating Photovoltaic higher than electric overall, as compared to only 49% of the Nebraska residential respondents (Figure 27). Surprisingly, very little difference in preference showed up between either of the dichotomies. The different concept statements evoked almost no difference (Figure 28), and the current/prospective homeowner dichotomy produced some differences, but still well within the bounds of chance variation (Figure 29).

Four parallel regression analyses were performed on the four factor spaces. The dependent variable was the constant-sum Photvoltaic system rating. The primary independent variables used were the three differences between the Photovoltaic factor score and the conventional factor score on the three factors. In addition, several other independent variables were tried, including the squares of the factor score differences and several scales derived from the demographic data in the questionnaire. These other variables had no additional consistent explanatory power and were dropped from the analysis.



Which System was Rated Higher ?

Figure 27



Which System was Rated Higher ?

Figure 28

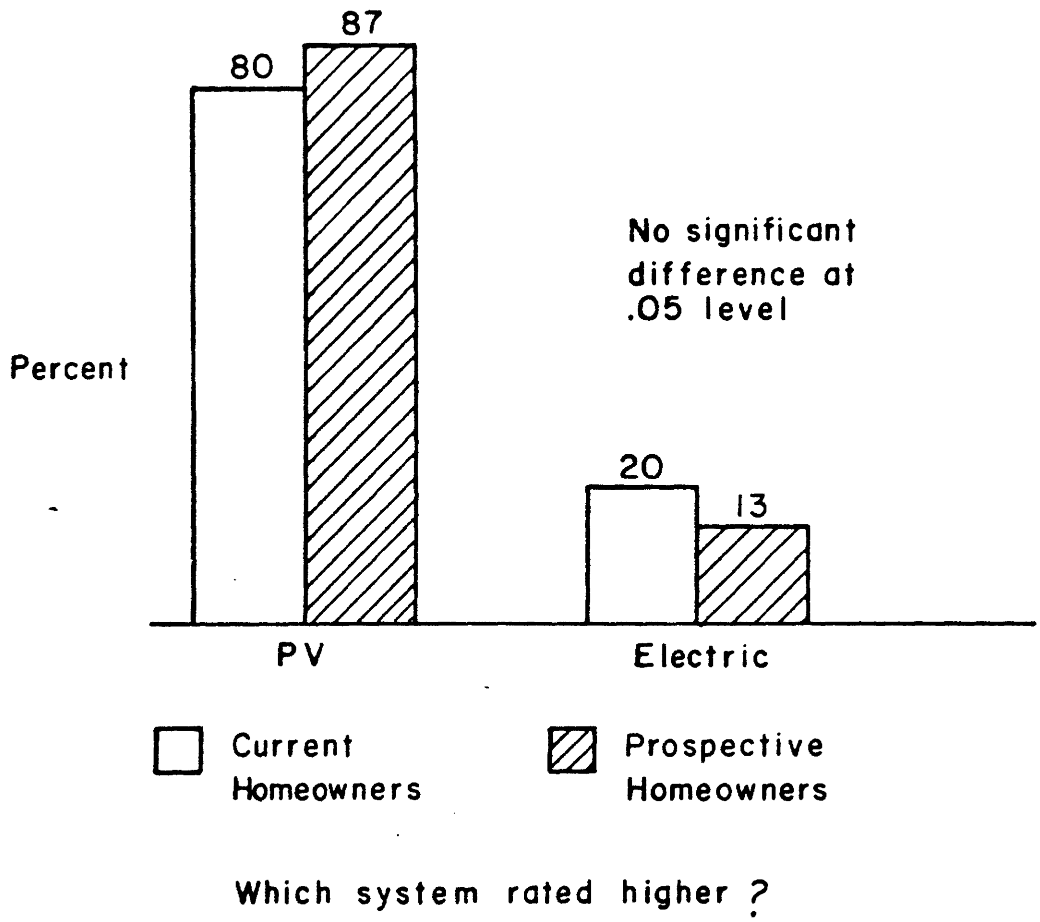

87
80
No significant
difference at
.05 level
Percent
20
13
PV
Electric
Current
Homeowners
Prospective
Homeowners
Which system rated higher ?

FIGURE 29

The final regression equations are displayed in Figure 30. Note that the signs of the coefficients agree with our description of the factors with one exception. Factors 1 and 3 are always positive, and factor 2 is negative, except for the grid-connected prospective group. Closer analysis reveals that this is due to a spuriously high loading of question 3.4 on factor 2. This question is more properly associated with factor 1, which is positive and highly significant, so this stray positive variable overwhelmed the negative ones. Considering the very small valid sample sizes (only 23 for the independent prospectives), the uniformity of the regression equations is good.

We can now use the regression equations together with the factor analyses to go back and see the relative importance of the original 14 questions. The cross product of the factor score coefficients associated with a question with the regression coefficients gives the direction and magnitude of the change in preference caused by a unit change in attitude on that question. Figure 31 shows the 14 questions ranked by their average rank in the four subgroups. Again, the degree of uniformity is clear.

Judging from the signs of the quantities used to determine the rankings, the top five questions capture most of the predictive ability of the regression equations. With the other nine questions, at least one of the four signs is reversed from what it intuitively should be, while the top five are consistently positive. Interestingly, these same five questions are those that consistently load high on factor 1 (check Figure 26 to see).

There is little discernable difference in the rankings across the two dichotomies. People's attitudes on avoiding energy rationing are more important for those who read utility-dependent concept statements, possibly because rationing is still an issue when you're still connected to the grid. And probably the thought of an auxiliary diesel generator made safety a more important issue in the minds of those who read the utility-independent statement.

FINAL REGRESSION EQUATIONS USING FACTOR SCORE DIFFERENCES

		Independent Concept Statement				Dependent Concept Statement			
		Factor 1 Difference	Factor 2 Difference	Factor 3 Difference	Constant	Factor 1 Difference	Factor 2 Difference	Factor 3 Difference	Constant
Current Homeowners	Coefficient	1.45	-2.78	.344	5.46	1.16	-.0648	1.21	4.81
	F-Statistic	(40.96)	(2.64)	(2.88)		(13.82)	(0.13)	(41.34)	
	R^2	.60				.60			
	n	59				52			
Prospective Homeowners	Coefficient	1.15	- .650	.349	6.15	1.99	.784	.268	4.04
	F-Statistic	(10.00)	(7.09)	(2.47)		(25.50)	(1.99)	(0.29)	
	R^2	.54				.59			
	n	23				25			

FIGURE 30

FIGURE 31

Rank				
Independent		Dependent		Question
Prospective	Current	Prospective	Current	
1	1	2	1	3.10 contributes to energy conservation
2	3	7	3	3.5 allows us to do our part in reducing pollution
3	4	4	4	3.11 if experts approve and recommend I would consider it
4	8	1	2	3.4 protects against home energy rationing
9	2	3	5	3.7 long-term benefits justify cost
5	7	9	11	3.12 reasonable safe for home installation
8	6	10	7	3.14 presents problems of repair or maintenance
10	5	8	10	3.12 requires too much space
6	14	11	6	3.2 ensures against power failures in the home
13	10	6	12	3.1 provides reliable power for home use
7	13	14	8	3.9 subject to weather damage
11	12	5	13	3.3 sensitive to weather conditions
12	11	12	9	3.8 visually unattractive
14	9	13	14	3.6 uses too many concepts not fully tested

The rankings are more interesting in understanding the differences between the Sun Day and the Nebraska surveys. The Sun Day people already accept this new technology (untested concepts ranks last) and are much more interested in the positive ecological aspects of the systems. The possible drawbacks of a photovoltaic system rank low for the Sun Day'ers, even "takes up too much space" for the people reacting to independent concept statements, faced with the prospect of batteries and generators in their basements. The nature of these differences suggests that something more than a geographical difference is involved here. Indeed, the rank profile in the Sun Day survey neatly matches the image of the solar innovator - implicit faith in the technology, with high expectations of an almost spiritual benefit from it.

Although innovators can be identified by their attitudes, nothing very different shows up in the demographics. For instance, even though prospective homeowners were specifically solicited on Sun Day, the resulting distribution of ascribed probabilities of new purchase is still similar to what we found in Nebraska. As is historically the case with innovation, there seems no obvious way to pinpoint solar innovators. Innovation is an internal characteristic, not highly related to age, sex, education or wealth.

V. Conclusions

Three perceptual factors were identified in this study, with the first being by far the most important in determining Photovoltaic preference:

- o Economical/Ecological Soundness
- o Complexity/Untried Concepts
- o Secondary Benefits

These factors explain Photovoltaic preference well.

There is very little difference between the subpopulations whether broken down by current/prospective homeowner or by utility-dependent/independent concept statements.

There is a big difference between the Sun Day results and the corresponding Nebraska results. The Sun Day population better accepts the technological feasibility of Photovoltaic and is more concerned with its non-economic benefits. But this difference is not reflected in any of the available demographics.

Once again this study has identified a key set of issues associated with early adoption of solar. But it also points to the need for a more fundamental study of the adoption of solar-type technologies to be able to recognize the needs of the early adopters. Much of the success of solar in general and Photovoltaics in particular in the next few years will be tied to our ability these tasks.

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Appendix: Concept Statements for Photovoltaic Systems

DESCRIPTIVE STATEMENT "A"

PHOTOVOLTAIC ENERGY SOURCE FOR THE HOME

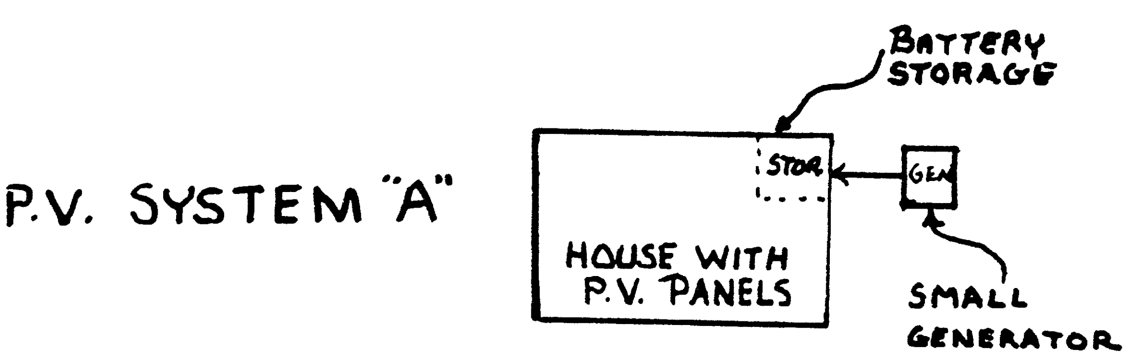
A photovoltaic (PV) system consists of a set of panels covered with interconnected solar cells. Sunlight striking these cells frees electrons in the cells, forming an electric current. A panel 20 feet by 20 feet can be installed on the roof of a house or on a home owner's land and supply all the power needs except for house heating or air conditioning.

Since the sun shines only half the day in good weather and not at all in bad, electricity must be stored for sunless periods. For power grid independence, storage is provided by using lead-acid batteries, similar to those used in automobiles. A day's electricity for an average single family house can be stored in batteries occupying the space of a closet; a row of such closets in the basement or utility room stores power for sunless periods.

A back-up power system could also be used; a small diesel generator similar to those used in hospitals could provide power to charge the batteries during a long, sunless period.

Facts to know about PV:

- $4,000 - $10,000 initial cost for system.
- No more electric bills.
- Panels are strong enough to withstand hail or other extremes of weather.
- System would pay for itself in 12 years or less.
- 20-year system life time.



Appendix

DESCRIPTIVE STATEMENT "B"

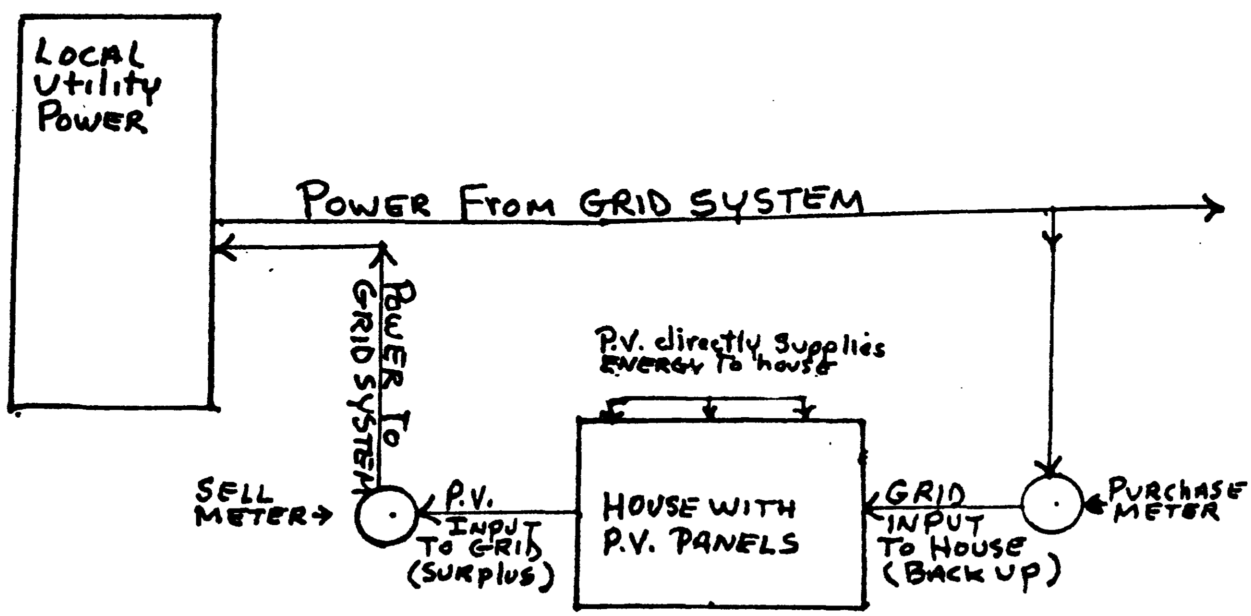
PHOTOVOLTAIC ENERGY SOURCE FOR THE HOME

A photovoltaic (PV) system consists of a set of panels covered with interconnected solar cells. Sunlight striking these cells frees electrons in the cells, forming an electric current. A panel 20 feet by 20 feet can be installed on the roof of a house or on a home owner's land and supply all the power needs except for house heating or air conditioning.

A house would be connected to the local utility company's grid system during sunless periods when PV could not directly supply the household demand, it automatically switches over to the conventional source. Under this arrangement a PV house can feed any surplus power it produces back into the utility company's grid system and receive credit for power sold. This credit would be slightly less than a one for one value.

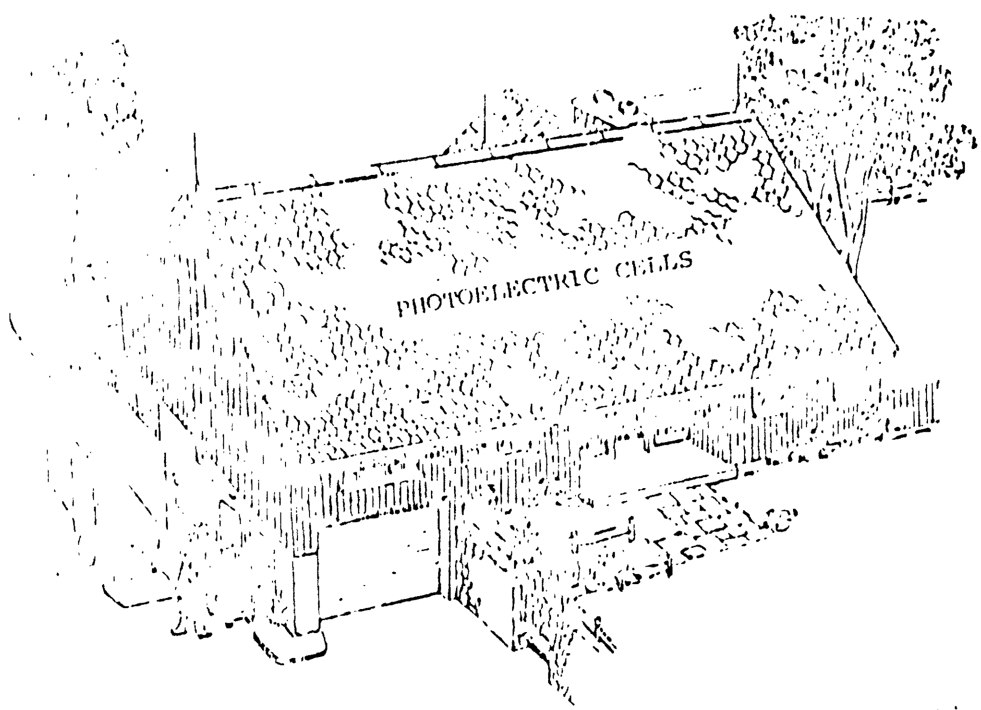
Facts to know about PV:

- $3,000 - $9,500 initial cost for system.
- Extremely small electric bills.
- Panels are strong enough to withstand hail or other extremes of weather.
- The system would pay for itself in 12 years or less.
- 20-year system life.



Appendix

The P.V. energy concept is not new. Cameras, communication systems and space programs have many years experience with P.V. More recently, the University of Nebraska has employed P.V. energy to power an irrigation system and grain drying operation on its experimental farm.



Northern U.S. Location

Photovoltaic Powered Residence