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SOLAR HEATING AND COOLING
OF BUILDINGS - PHASE I
(NON-RESIDENTIAL)

INTERTECHNOLOGY CORPORATION
COST/BENEFIT ANALYSIS REPORT
AND SUPPORTING OPINION SURVEY
COMMERCIAL BUILDINGS
NATIONAL SOLAR DEMONSTRATION PROGRAM

19 January 1976

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Energy Research and Development Administration.

PREPARED FOR
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
DIVISION OF SOLAR ENERGY
WASHINGTON, D. C. 20545
CONTRACT NO. E(11-1) -2688

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INTERTECHNOLOGY CORPORATION

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15 April 1976

Energy Research and Development Administration
Division of Solar Energy
Washington, D. C. 20545

Reference: Contract E(11-1)-2688

Gentlemen:

The National Solar Heating and Cooling Act of 1974 has provided the basic authority and guidance necessary for the creation of a national solar heating and cooling demonstration program. The detailed planning necessary to ensure the efficient use of government funds allocated by this act has been left to ERDA and the private contractors involved. The question, long debated and argued by qualified and informed representatives of Congress, ERDA, and private industry, concerning the number of demonstrations required to meet the overall goals of the program is the subject of this special report prepared under ITC Contract E(11-1)-2688 with the Energy Research and Development Administration. The ITC contract was modified to add a requirement for a parametric study to provide an assessment of the level or number of non-residential solar demonstration projects that will be required to stimulate the participation of commerce and industry in solar equipment manufacturing, marketing, financing, and installation. The "correct" numbers, types, and locations of the demonstrations are, of course, unknown quantities, the values of which will be more clearly perceived 10 years hence.

To fund more demonstrations than that necessary cannot be tolerated for obvious reasons. To fund fewer demonstrations than required to move the program past the point at which the industry and the demand have been sufficiently primed to proceed without government support, would be disastrous to the goal of creating a solar HVAC industry, and totally wasteful.

To provide a quantitative approach to the solution of this basic problem, a techno-economic model of the solar industry, Part I, has been prepared. The detailed results of the trade-off studies and analyses based on the techno-economic model are contained in the enclosed report.

The analytical study based on the techno-economic model suggests that the least-risk minimal demonstrations are 200 (versus electric resistance heating) and 670 (versus the electric heat pump). In both cases the annual savings after a period of twenty years resulting from the solar demonstration program is about 0.2 quads. The detailed matrices of the optimal geography and chronology are found in the attached report.

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In addition to the techno-economic analyses, ITC has conducted an opinion survey (Part II) of key representatives of various sectors of the business economy. The results of each opinion survey conducted are enclosed. In general, the number of demonstrations suggested by the opinion poll ranged from as little as 50 to as many as 240. The general consensus of opinion indicates a number between 150 and 200 is sufficient to meet all the requirements; technical, economic, and institutional. We call particular attention to the survey performed by Mr. Anthony W. Adler, President of Solar Investors Associates (See Part II, Section F). Mr. Adler's survey of 47 different financial institutions resulted in a recommendation of from 120 to 156 demonstrations with from 10 to 13 demonstrations to be installed in each climatic region.

For the benefit of readers outside ERDA, it should be noted that the conclusions and recommendations discussed above and in the enclosed report are based on work performed by ITC and do not necessarily reflect the views of ERDA. Questions and/or comments may be directed to ITC directly or to the ERDA Program Manager, Mr. Eugene R. Doering, Division of Solar Energy, Washington, D.C. 20545.

Sincerely,

G. C. Szego
President

GCS:pg

PREFACE

The InterTechnology Corporation (ITC) was one of two companies who received awards to conduct studies and analyses for the Energy Research and Development Administration (ERDA) in support of the National Solar Heating and Cooling Demonstration Program. The report "InterTechnology Incorporated, Cost/Benefit Analysis Report and Supporting Opinion Survey, Commercial Buildings, National Solar Demonstration Program" was prepared as part of the requirements under contract E(11-1)2688. It is not intended to reflect an ERDA plan or position. It is expected to be used by ERDA in the development of their plans for implementing the Solar Heating and Cooling Demonstration Program.

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I. Cost Benefit Analysis

A. Introduction:

Under the Solar Heating and Cooling Demonstration program, solar heated and cooled commercial buildings are to be constructed throughout the nation to show the technical and economic feasibility of solar energy systems and, most importantly, to establish an economically viable solar industry. The questions arise: How many solar energy systems must be installed and where should they be installed to meet these objectives? This report presents an answer to these questions.

B. Summary and Conclusions:

The approach taken herein was to develop a techno-economic model of the solar industry. The model incorporates the thermodynamic performance of flat plate water cooled collectors as being typical of all collectors. It also incorporates economic features such as economies of scale for production of the solar systems, the effects of learning with regard to production techniques, and a materials substitution factor for cost reduction. The market is predicated on the economical attractiveness of the solar systems, with a factor introduced called the propensity to purchase. Even if the system is economically attractive, the potential user might not want to undertake the project of dealing with a novel system. This effect is incorporated in the model via a risk aversion factor that is related to the cost of removing a solar system along with the amount of experience the particular purchaser might have. His experience via the experience of others who have used solar systems is also taken into consideration.

Many parameters of the model must be estimated based on experience and intuition. Those that could be verified were, but many remain. To offset this weakness in the analysis presented herein, an extensive sensitivity study was undertaken. The results of this study are highly instructive; the reader is urged to review the sections of this report entitled "Implications" to profit from these results.

The results of the sensitivity study were used to devise a nominal case that represents the recommended ERDA program and the answers to the questions posed in the Introduction.

It is recommended that ERDA offer via a solicitation of proposals to pay 75 percent of the first cost of any solar heating and/or cooling system, plus 90 percent of the maintenance costs over the 20-year life of the system in return for data obtained from the system. ERDA should limit its award of contracts to one new building and one old for each of twelve building types in each of twelve regions. It is important to the success of the ERDA program that only those systems be funded that are predicted to be cost effective with the ERDA support. In addition, only reliable, durable systems with a potential installed cost below \$10 per square foot of collector should be funded. Rather than support a few large projects, ERDA should with few exceptions support projects involving less than 5,000 square feet of collector or, alternatively, projects which cost ERDA less than 75 percent of \$200,000 in first cost.

It is important to the success of the demonstration program that a companion program be conducted in support of cost-reducing technology, although this must not be done in such a way that the incentives for manufacturers, in terms of patents or proprietary processes, is adversely affected.

The result of the recommended ERDA offer is predicted by the model to be: 667 demonstration units built in five years in eight regions at a life-cycle cost to ERDA of \$114 million. The regions first to reach a viable, self-supporting market are Phoenix and Boston (1979) with Los Angeles, Washington, D. C., and Madison in the following year. Only Miami, Omaha, Seattle, and Nashville appear unfavorable. The solar industry so established will save 1.53 quadrillion Btu in 20 years, at a rate of 0.22 quads per year in the twentieth year (100,000 barrels per day of oil). The production rate at this time is predicted to be 155 million square feet of collector per year.

Alternative ERDA strategies are suggested and evaluated in the report that reduce the ERDA cost but also the energy saving. The most attractive alternatives involve either limiting the demonstration program to four years or decreasing the ERDA share 30 percent each year.

De-regulation of natural gas and domestic oil and transference of the total cost of the nuclear program to industry would put these alternate energy sources on an equal footing with solar, considerably enhancing the role of solar as an economically attractive, technically feasible energy source.

Other government sponsored programs will also enhance the performance of the ERDA commercial program, and vice-versa, so the overall saving of the solar program could exceed by a considerable amount the above predictions. It is imperative that ERDA coordinate the various demonstration programs to achieve maximum cost effectiveness for the government expenditures.

The potential suppliers of solar-energy systems must have as their target installed system costs between \$10 and \$15 per square foot of collector for their systems to be economically attractive, with long-term goals of \$6.75. If they meet this goal, the predictions of this analysis should be realized and the production rate for the solar industry will reach by 1979 to 1984 one to ten million square feet of collector per year in each of the eight regions solar is cost effective. The last regions to adopt solar systems will be Charleston and Fort Worth in 1981 and Bismarck in 1984.

The potential users can expect to realize a payback period of 10 to 12 years when solar systems first become economically attractive. Users in the favored regions of Phoenix, Boston and Los Angeles will be the first to realize these benefits.

Supporting evidence for the above claims is presented in the report that follows.

C. Model Development

1. Introductory Description of the Model:

The elements of the model are listed on Table 1. The "Supply" part of the model was divided into separate models for the producer, for the designer and for the installer. The cost of a system was then characterized by the unit cost on the basis of collector area, since the collector represents the most costly of the components in the system. In addition, the size of most of the other elements is proportional to the collector area. The unit cost was taken as a function of the number of units produced per year (scale effect), the total number of units produced to date (learning-curve effect), and the year (technological-advancement effect). For year zero, the installed cost of units placed on existing buildings was taken as \$3 per square foot more than for new buildings, on the basis that installation would be more difficult on existing buildings and that a credit must be allowed for omission of some of the roofing materials on new installations.

On the "Demand" side of the model, not only was first cost considered, but also the cost of taxes, insurance, and maintenance as a function of time, with inflation. Until a potential purchaser obtains experience with solar units, he will experience an aversion to the risks of buying a novel device. To include this effect in the model, a risk-aversion cost was introduced that depends on (1) the cost of removal of the system and (2) the number of unit-years of experience the buyer has directly on his type of building and indirectly on buildings of other types and in other regions. It would be desirable to model the "Demand" aspects on the basis of possibly 2,000 companies, some local and some multi-regional, each with its own risk factor. Because data was not available on the total number of buildings each company has at present and expects to have in the next 15 to 20 years, a model of this detail was not undertaken. Instead, the model was devised on the basis

TABLE 1

ELEMENTS OF THE MODEL OF THE SOLAR HEATING AND COOLING INDUSTRY

1. Supply

Producer, Designer and Installer

Effect of

Economies of Scale

Learning Curve

Technology

2. Demand

Retrofit and New (expanding)

Price, Taxes, Insurance, Maintenance

Propensity to buy per life-cycle

cost (must be favorable)

Risk Aversion

12 Regions, 12 Building Types

3. Environment

Available return on investment

General inflation

Fuel-price escalation

4. Government

Cost share of solar for a specified number of years

Limit: x new + y old per type and per region (various x , y)

of twelve building types and twelve climatic regions, each with its own risk aversion factor, for a total of 144 risk factors. Once the solar energy system proved cost-effective, the demand was allowed to expand. The expansion rate was controlled in the model by two factors: (1) the asymptotic market penetration rate of, for example, 15 percent per year of the potential market; and (2) the propensity function, which was taken as a function of the ratio of the life-cycle savings due to the solar-energy system to the cost of fuel for the conventional system.

The economic "Environment" part of the model was described in part by two inflation rates: the general inflation and the fuel-price inflation. In addition, the available return on investment was used as part of the discounting process.

The final part of the industry model was the "Government" activity. The government was assumed to provide a cost-sharing program for a selected number of years. However, not all proposals for cost sharing would be accepted; a limit was set on the number of demonstration buildings per type per region. As will be seen below, there were many cases in which this limit was reached, since the solar-energy system proved so cost effective while the government was contributing to the purchase of the units.

The amount of heating and cooling realized by the solar-energy system was computed on the basis of correlations of the predicted performance of both solar heating and cooling systems as obtained under a separate task associated with this same project.

Before the results of the exercising of the model are discussed, the details of each of the sub-models will be presented.

2. The Supply Sub-model:

The supply sub-model consists of four main aspects: purchase price, installation price, design cost and new/existing construction price differential. The total purchase price includes the cost of the absorption refrigeration system and the cost of controls.

The equation governing the unit purchase price of collector, storage and piping (PC) is as follows (nominal values of the parameters are shown):

$$PC = \underbrace{\frac{PC1}{DA}}_{\text{fixed costs}} + \underbrace{\left[7.5 + 2.5 \left(\frac{5000}{DA} \right)^{1/4} \right]}_{\text{effect of optimal automation}} * \underbrace{[1 - f]}_{\text{effect of the introduction of lower-cost materials}} * \underbrace{\left[1 + \frac{0.8}{1 + (A/50000)} \right]}_{\text{effect of learning curve}}, \$/\text{ft}^2$$

variable costs

where DA = present production rate

$\overline{DA}$ = average production rate

A = accumulative area

$\text{EXP}(X) = e^X$

$$PC1 = 24000 - 22000 * \text{EXP}(-DA/2500)$$

and

$$f = 1/3 [1 - \text{EXP}(-(T/3)^2)]$$

where T = time in years.

The derivation of this equation is given in Appendix B. Typical values are given in Table B-1 of Appendix B.

The equation for the unit installation price is similarly derived to be

$$IC = \frac{IC1}{DA} + [1.50 + 1.61 \left(\frac{5000}{DA}\right)^{1/4}] * \left[1 + \frac{2.5}{1 + (A/50000)}\right], \$/ft^2$$

where

$$IC1 = 15000 - 14000 * \text{EXP}(-DA/2500)$$

There is no material-substitution factor in the installation price. Again typical values are shown on Table B-1. The equation for the unit design price is

$$DC = DC1/DA + 0.25 + 1.5 * 9.75/(1 + A/50000)$$

where

$$DC1 = 200 + 4000/(1 + A/50000)$$

Table B-1 also lists values of DC.

It is evident from Table B-1 that the installed price of a solar heating system is approximately \$33.32 per square foot today and that under long-term, mass-production conditions with low-cost materials, the cost can be expected to drop to \$6.75 per square foot.

Figure 8 and Table B-2 provide additional data on the total installed-system price, as predicted by the models for PC, IC and DC. Table B-2 in particular shows that the learning rate is approximately the same as would be obtained with the more simplified power-law model.

The values for DA, $\overline{DA}$, and A should be for each manufacturer; however, some transfer of technology is inevitable, so to some extent these factors should include part of the production and experience of rival companies. In the beginning, we might expect there to be one or two manufacturers; as the market size increases, we would expect others to enter the field. As these other companies emerge, they will capture only part of the market; the leader's price will prevail. As a consequence, it appears that the most reasonable approach is to use the production rates and experience of the entire region in the equations for the purchase price and the installation price.

The foregoing equations give the prices as installed on new buildings. The prices are assumed to include credit for roofing materials that need not be used under the collector. In retrofit installations no such credit is realized; in addition, installation will be more difficult, so for retrofit cases an additional cost of

$$RC = \$3/\text{ft}^2$$

was used.

The values of PC, DC, IC, and RC were all inflated at an annual rate of IG per year (Inflation, General). The nominal value of IG was taken as eight percent.

Also to be purchased and installed is the absorption refrigeration system (or equivalent). An installed cost of \$720 per ton applies today. This high value is a direct result of the factor of two derating necessary for solar-energy-driven units. The derating is, in turn, a direct result of the reduced heat transfer coefficients under the non-boiling conditions found in the generator. It is possible to oversize the generator without oversizing the other components in the refrigeration system; therefore, we can expect the price of solar-driven units to decrease in the future to be nearly equal to that of the conventional steam-driven unit. As a consequence, the model used for the price of the absorption refrigeration system was

$$CABS = CACFUT + (CACTDY - CACFUT) * EXP(-T/TCONST)$$

where CACFUT = \$360/ton and CACTDY = \$720/ton. The nominal value for TCONST was set at 3.0 years.

Finally a control system must be purchased. Its cost was taken to be

$$\text{Controls cost} = 500. * (1 + EXP(-4000/Ac))$$

where Ac is the collector area for the building being analyzed. This form results in a cost of \$500 for small systems and approximately \$1,000 for systems requiring 40,000 square feet of collector. Part of the controls cost might also be considered as the cost of getting construction equipment to the site, and other related "set-up" costs.

The supply sub-model is summarized on Table 2. Notice that it does not include instrumentation, data collection and information dissemination. It has been assumed that ERDA would pay for these.

3. The Demand Sub-model:

a. Technology

In all, 288 categories of users were considered in the Demand sub-model. Twelve different building types were considered in each of twelve regions*. The users were further subdivided into those with new and those with existing buildings.

Table 3 lists the annual heating loads by building type and by region, due allowance being made for lights and occupant heating. Table 4 presents the cooling loads. On both of these charts, the data has been normalized by the size of the building, measured in square feet of floor space. Tables 5, 6, and 7 list the total floor area for each building category for the years 1975, 1980, and 1990, the last two, of course, being projections. The average building size for each category is shown on Table 8.

*The climatic regions referred to in this report have been designated by a representative city within each region. A map showing the regions and a table for translation into the new designators are found on pages 148 and 149.

TABLE 2
SUMMARY OF THE SUPPLY SUB-MODEL

1. Production Costs: Collector, Storage, Etc.

$$\text{Total Costs} = \text{Fixed Costs} + \text{DA} * \text{Variable Costs}$$

$$\text{Fixed Costs} = 2000 + 22000 * (1 - \text{EXP}(-\text{DA}/2500))$$

(\$/yr)

$$\text{Variable Costs} = \text{Automation} * \text{Materials} * \text{Learning}$$

$$\text{Automation} = \$7.50 * [1 + 1/3 (5000/\overline{\text{DA}})^{1/4}]/\text{ft}^2$$

$$\text{Materials} = 1 - 1/3 [1 - \text{EXP}(-\text{T}/3)^2]$$

$$\text{Learning} = 1 + 0.8/(1 + \text{A}/50000)$$
2. Installation Costs: Collector, Storage, Etc.

$$\text{Total Costs} = \text{Fixed Costs} + \text{DA} * \text{Variable Costs}$$

$$\text{Fixed Costs} = 1000 + 14000 * (1 - \text{EXP}(-\text{DA}/2500))$$

$$\text{Variable Costs} = \text{Automation} * \text{Learning}$$

$$\text{Automation} = \$1.50 * [1 + 1.07(5000/\overline{\text{DA}})^{1/4}]/\text{ft}^2$$

$$\text{Learning} = 1 + 2.5/(1 + \text{A}/50000)$$
3. Design Costs: System

$$\text{Total Costs} = \text{Fixed Costs} + \text{DA} * \text{Variable Costs}$$

$$\text{Fixed Costs} = 200 + 4000/(1 + \text{A}/50000)$$

$$\text{Variable Costs} = 0.25 + 1.5 * 9.75/(1 + \text{A}/50000)$$
4. Retrofit: Add \$3/ft² 1975 dollars
5. Refrigeration System Cost

$$\text{Installed Cost} = \$360. * (1 + \text{EXP}(-\text{T}/3))$$

Due to generator
technology
6. Control-System Cost

$$\text{Installed Cost} = \$500 * (1 + \text{EXP}(-4000/\text{Ac}))$$

Due to expanse
of system

To determine the amount of energy that can be supplied by a solar heating and air-conditioning system, a complete dynamic simulation was performed on a PDP-8 digital computer. The reduction in fuel requirements is shown as a function of collector area of Figure 1a for water-cooled collectors. The coefficients for a parabolic curve fit for these curves are given in Table 9. The optimal storage size is approximately 1.5 gallons of water per square foot of collector for water-cooled collectors. Within the range of collector areas of interest, the cooling supplied by the solar system increases linearly with collector area. The proportionality constant is listed on Table 10, along with the corresponding cooling degree-days. Figure 1a can be viewed as showing a ranking of regions on the basis of heat collected, with Phoenix being the most favorable location for solar and Seattle, the least. This ranking will be shuffled when the cost of fuel is considered. Table 10 can be viewed as a ranking in terms of air-conditioning, with Phoenix being most favorable with a collector area of 6.9 square feet for each million Btu/year needed for cooling. Figure 1b is for air-cooled collectors, the equivalent of Figure 1a for water-cooled collectors. Comparison shows air collectors are always superior. The shortcomings of air collectors do not appear in a global analysis as considered herein. Air systems require a significant but not exorbitant amount of power to circulate the air through the collectors. In addition, large air ducts would be needed in large buildings. However, large buildings usually are divided into zones for heating and air-conditioning, so it is conceivable and probably desirable to have several complete solar/air systems, one per zone, installed on a building. Whether air is better or water is better cannot be decided herein. It is recommended that the demonstration program help decide the proper mix of air and water via evaluation of the proposals submitted to ERDA. In what follows, air and water are considered equivalent; the data for water is used.

TABLE 3
BUILDING HEATING LOADS BY CLIMATIC REGION
WITH CREDIT FOR INTERNAL LOADS
(1000 Btu/ft²-yr)

	Bismarck	Madison	Omaha	Boston	Seattle	Washington, D. C.	Nashville	Los Angeles	Fort Worth	Phoenix	Charleston	Miami
Restaurants (2)	646	573	452	406	368	306	286	197	178	167	134	14
Stores, Service stations	247	220	172	153	136	117	109	70	68	60	50	6
Supermarkets	137	121	92	76	63	64	59	24	28	23	16	0.3
Religious, Social	162	144	113	101	92	77	72	49	46	41	35	3
Office	135	120	93	80	68	64	59	31	33	28	22	1.44
Educational	135	120	93	80	68	64	59	31	33	28	22	1.44
Hospital, Medical (2)	147	131	102	91	81	70	65	41	40	35	29	3
Shopping Centers	90	80	59	46	35	42	38	8	14	10	5	0
Motels, Nursing Homes (2)	121	107	84	74	65	57	53	33	32	28	23	2
Warehouses	103	91	69	57	47	48	44	18	21	18	12	0.2
Libraries, Museums	97	86	66	57	49	46	42	22	23	20	16	1
Hotels (2)	94	83	65	57	20	44	41	23	24	21	17	1

NOTES: (1) This table is for space heating only.

(2) For the buildings marked with (2), domestic hot water could add substantially to the heating loads. This year-long demand would enhance the solar-system performance.

TABLE 4

BUILDING COOLING LOADS BY CLIMATIC REGION

(1000 Btu/ft²-yr)

	Bismarck	Madison	Omaha	Boston	Seattle	Washington, D. C.	Nashville	Los Angeles	Fort Worth	Phoenix	Charleston	Miami
Restaurants	61	64	124	181	37	211	240	101	308	239	350	498
Stores, Service Stations	38	44	79	69	25	111	112	76	156	162	158	276
Supermarkets	29	37	61	56	22	84	88	58	116	112	120	201
Religious, Social	13	14	26	43	8	47	55	23	69	49	80	109
Office	23	27	47	42	16	67	69	46	95	98	96	165
Educational	18	22	37	38	13	54	57	35	75	71	79	128
Hospital, Medical	35	47	69	75	30	101	108	66	132	112	144	226
Shopping Centers	24	29	48	49	18	69	73	46	94	85	100	161
Motels, Nursing Homes	28	36	60	49	22	78	81	57	108	111	109	191
Warehouses	12	13	26	23	8	36	38	24	53	55	54	92
Libraries, Museums	19	24	38	42	14	57	61	36	78	68	84	131
Hotels	17	21	35	33	29	49	51	33	67	64	70	115

TABLE 5

1975 REGIONAL BUILDING INVENTORY
(Million Square Feet)

	Bismarck	Madison	Omaha	Boston	Seattle	Washington, D. C.	Nashville	Los Angeles	Fort Worth	Phoenix	Charleston	Miami
Restaurants	23.7	45.5	20.3	130.3	6.7	58.1	37.0	44.1	22.4	8.4	38.0	8.6
Stores, Service Stations	215.3	412.5	184.4	1182.9	60.8	527.1	335.7	400.6	203.1	76.2	345.4	78.2
Supermarkets	16.5	31.6	14.2	90.7	4.7	40.5	25.8	30.7	15.6	5.8	26.5	6.0
Religious, Social	129.4	247.9	110.9	710.6	36.6	317.1	201.7	240.7	122.1	45.8	207.5	46.9
Office	233.1	446.5	199.6	1280.2	66.0	571.2	363.3	433.5	219.8	82.5	374.0	84.5
Educational	295.9	566.8	253.5	1625.4	83.6	725.1	461.3	550.4	280.3	104.6	474.8	107.3
Hospital, Medical	57.7	110.5	49.4	316.9	16.3	141.4	90.0	107.3	54.4	20.4	92.6	20.9
Shopping Centers	45.1	86.3	38.6	247.5	12.7	110.4	70.2	83.8	42.4	15.9	72.3	16.4
Motels, Nursing Homes	126.8	242.8	108.5	491.0	35.9	310.6	197.5	235.8	119.4	44.8	203.3	46.0
Warehouses	223.5	428.0	191.3	1227.5	63.1	547.6	348.4	415.7	210.7	79.0	358.5	81.1
Libraries, Museums	15.6	29.8	13.3	85.5	4.4	38.1	24.3	29.0	14.7	5.5	25.0	5.7
Hotels	28.2	54.1	24.2	155.1	8.0	69.2	44.0	52.5	26.6	10.0	45.3	10.2

TABLE 6

1980 PROJECTED REGIONAL BUILDING INVENTORY
(Million Square Feet)

	Bismarck	Madison	Omaha	Boston	Seattle	Washington, D. C.	Nashville	Los Angeles	Fort Worth	Phoenix	Charleston	Miami
Restaurants	31.9	60.5	26.8	173.1	9.2	76.3	48.5	62.1	30.4	11.6	51.3	12.2
Stores, Service Stations	289.6	549.1	243.8	1570.3	83.4	692.0	440.1	563.7	275.5	105.3	465.2	110.3
Supermarkets	22.2	42.1	18.7	120.5	6.4	53.1	33.8	43.3	21.1	8.1	35.7	8.5
Religious, Social	153.8	291.5	129.3	833.6	44.3	367.5	233.7	296.3	146.3	55.9	246.9	58.6
Office	303.0	574.4	254.8	1642.5	87.2	724.0	460.4	589.7	288.2	100.1	486.5	115.4
Educational	344.8	653.5	290.0	1868.9	99.1	823.7	523.8	670.9	327.9	125.3	553.6	131.2
Hospital, Medical	68.9	130.6	58.0	373.5	19.8	164.6	104.7	134.1	65.5	25.0	110.6	26.2
Shopping Centers	60.6	114.9	51.0	328.5	17.4	144.8	92.1	117.9	57.6	22.0	97.3	23.1
Motels, Nursing Homes	150.9	286.0	126.9	817.8	43.4	360.4	229.3	293.6	143.4	54.8	242.3	57.4
Warehouses	265.6	503.5	223.5	1440.0	76.4	634.7	403.6	516.9	252.7	96.6	426.6	101.1
Libraries, Museums	18.2	34.3	15.3	98.4	5.2	43.4	27.6	35.3	17.3	6.6	29.1	6.9
Hotels	33.6	63.6	28.2	181.9	9.7	80.2	51.0	65.3	31.9	12.2	53.9	12.8

TABLE 7

1990 PROJECTED REGIONAL BUILDING INVENTORY
(Million Square Feet)

	Bismarck	Madison	Omaha	Boston	Seattle	Washington, D. C.	Nashville	Los Angeles	Fort Worth	Phoenix	Charleston	Miami
Restaurants	54.7	103.8	45.3	295.3	16.3	127.6	80.8	113.9	52.5	20.7	87.7	21.9
Stores, Service Stations	496.9	942.0	411.6	2680.3	147.4	1157.9	733.7	1033.6	475.9	188.6	795.9	199.1
Supermarkets	38.1	72.3	31.6	205.6	11.3	88.8	56.3	79.3	36.5	14.5	61.1	15.3
Religious, Social	181.5	343.8	150.3	978.5	53.9	422.6	267.9	377.3	173.8	68.8	290.6	72.7
Office	491.4	931.5	407.1	2650.8	145.8	1145.2	725.6	1022.2	470.7	186.4	787.1	196.8
Educational	435.4	825.3	360.6	2348.4	129.2	1014.5	642.8	905.6	416.9	163.2	697.4	174.5
Hospital, Medical	91.9	174.2	76.1	495.7	27.3	214.1	135.7	191.1	88.0	34.9	147.2	36.8
Shopping Centers	104.0	197.1	86.1	560.7	30.9	242.2	153.5	216.2	99.6	39.4	166.5	41.6
Motels, Nursing Homes	184.9	350.4	153.2	997.0	54.9	430.7	272.9	384.5	177.0	70.1	296.1	74.0
Warehouses	313.4	594.0	259.5	1690.1	93.0	730.1	462.6	651.7	300.1	118.8	501.8	125.6
Libraries, Museums	22.9	43.4	19.0	123.6	6.8	53.4	33.8	47.7	21.9	8.7	36.7	9.2
Hotels	39.6	75.0	32.8	231.5	11.8	92.2	58.4	82.3	37.9	15.0	63.4	15.9

TABLE 8

AVERAGE BUILDING SIZE FOR VARIOUS BUILDING CATEGORIES

<u>Building Type</u>	<u>Average Size (ft²)</u>
1. Restaurants	1,410
2. Stores, Service stations	4,400
3. Supermarkets	12,500
4. Churches	8,040
5. Offices	11,970
6. Schools	24,720
7. Hospitals	136,000
8. Shopping Centers	63,200
9. Motels	21,850
10. Warehouses	11,100
11. Libraries, Museums	16,300
12. Hotels	40,850

TABLE 9
COEFFICIENTS FOR CURVE FIT OF SOLAR SUPPLIED HEAT

City	Water Collector ⁽¹⁾		Air Collector ⁽¹⁾	
	α_1	α_2	α_1	α_2
1. Bismarck	0.2670	0.7049	0.2190	0.5850
2. Madison	0.3669	1.0349	0.2785	0.7624
3. Omaha	0.3092	0.8041	0.2486	0.6415
4. Boston	0.4737	1.2954	0.3362	0.8892
5. Seattle	0.5502	2.9530	0.3489	1.1746
6. Washington, D. C.	0.3900	1.0241	0.3047	0.7765
7. Nashville	0.4035	1.0914	0.3020	0.8063
8. Los Angeles	0.3108	0.8691	0.2538	0.6753
9. Fort Worth	0.2666	0.6105	0.2328	0.5379
10. Phoenix	0.1899	0.4589	0.1751	0.4257
11. Charleston	0.3175	0.7223	0.2683	0.6120
12. Miami	0.2973	0.7646	0.2586	0.6813

Notes:

(1) $\alpha = \frac{\text{collector area} \times 10^6}{8 \times \text{Bldg. Load, Btu/yr}}$

α_1, α_2 = values of α when the fraction of the load that must be carried by the backup system is 0.65 and 0.30, respectively.

(2) Regression Equation

$$SN = \frac{(0.7\alpha_1^2 - 0.35\alpha_2^2) - (0.7\alpha_1 - 0.35\alpha_2)\alpha}{\alpha_1\alpha_2(\alpha_1 - \alpha_2)} \cdot \alpha$$

TABLE 10

SOLAR-SUPPLIED COOLING

Region	Collector Area/Solar Cooling (Ft ²)/(10 ⁶ Btu/yr)	Cooling Degree- Days Per Year
1. Bismarck	20.1	487
2. Madison	26.4	460
3. Omaha	16.9	1148
4. Boston	27.0	661
5. Seattle	48.0	200
6. Washington, D. C.	18.4	1415
7. Nashville	17.9	1367
8. Los Angeles	10.8	1063
9. Fort Worth	10.4	2250
10. Phoenix	6.9	2888
11. Charleston	11.0	2078
12. Miami	8.2	4038

FIGURE 1a: FRACTION OF HEAT DEMAND SUPPLIED BY SOLAR AS A FUNCTION OF COLLECTOR AREA FOR WATER-COOLED COLLECTORS

FIGURE 1b: FRACTION OF HEAT DEMAND SUPPLIED BY SOLAR AS A FUNCTION OF COLLECTOR AREA FOR AIR-COOLED COLLECTORS

A correlation of air-conditioner size versus annual air-conditioning load revealed that the size can be based on the degree-days from 65°F according to the equation

$$\text{Size (Btu/hr)} = \text{annual cooling load (Btu/yr)} / \text{FLE (hrs/yr)}$$

where the full-load equivalent hours is given by

$$\text{FLE} = 0.8 * \text{cooling degree-days} + 324.$$

The factor "324" arises from the internal heat generation. Although the factor "0.8" was obtained empirically, it is equal to 24 hours/day divided by 30°F, a typical design temperature difference (95-65) for degree-days based on 65°. The coefficient of performance of the conventional air-conditioner was assumed to be 4.0 for cooling loads greater than 100 tons and 2.2 for lesser loads. The former corresponds to a centrifugal compressor; the latter, a reciprocating compressor.

b. Economics

The costs realized by the solar-energy user are four-fold: the installed price of the solar system; the fuel cost; taxes, insurance and maintenance; and a cost saving as realized from the income-tax deduction for inclusion of the solar system. The installed cost was discussed above under the Supply sub-model. The fuel cost was allowed to vary from region to region. The average electricity cost per region was used, as tabulated on Table 11. These 1974 values were multiplied by 1.25 to approximate the year-zero values. Electricity costs would also be comparable to the cost of de-regulated gas. Taxes, insurance, and maintenance were combined into a single factor of, nominally, six percent. The percentage was applied to the inflated value of the solar system. Credit for the income tax deduction was based on the sum-of-the-years-digits method, with depreciation being taken over the same system life as used in the life-cycle cost analysis, which was nominally 20 years. In addition, a seven percent investment tax credit was allowed in the first year.

Even when a solar-energy system proves cost effective, there remains a resistance to purchase of the system due to the hesitancy of the potential purchaser to undertake the risks associated with new devices. This hesitancy, or risk aversion, was factored into the model via a risk-aversion factor that was based on (1) the cost of removal of the solar system and (2) the user's experience with solar systems either directly through his own use or indirectly through the use of others. The risk factor was added to the true installed cost of the system to obtain an effective (and higher) cost. The form of the risk "cost" was

$$\text{Risk Cost} = (\text{Cost of Removal}) * \text{EXP}(- \text{unit yrs}/8)$$

where

$$\text{Cost of Removal} = \text{IC} + \text{RC} - \text{SALVG} * \text{PC} + \text{ACC} + \text{Controls Cost}$$

where ACC is the air conditioning cost. Because the need for refurbishing the building is likely and because the collectors would be removed from the site at additional expense, the nominal value of SALVG was -0.1.

TABLE 11
REGIONAL FUEL COST AND
HEAT-PUMP COEFFICIENT OF PERFORMANCE

Region	1974 Electricity Cost \$ per 10 ⁶ Btu	Heat Pump Average COP
1. Bismarck	5.79	1.46
2. Madison	8.60	1.57
3. Omaha	6.70	1.63
4. Boston	11.09	1.63
5. Seattle	4.10	2.00
6. Washington, D. C.	8.88	1.76
7. Nashville	6.87	1.69
8. Los Angeles	8.09	1.83
9. Fort Worth	6.11	1.83
10. Phoenix	7.10	2.09
11. Charleston	7.26	2.00
12. Miami	8.72	2.20

The argument of the exponential function is the unit-years of experience by the potential user. This is the number of buildings equipped with solar multiplied by the number of years of operation. It was assumed that units installed in existing buildings in 1976, for example, provided 0.5 years of experience in the 1977 computations. Units installed on new buildings in 1976 gave no experience for 1977 or 1978 but a full year of experience for 1979. The potential user also benefits by the experience of others, but not as strongly as by his own use. Weighting factors were introduced to account for this fact, so the following formula was devised:

$$\begin{aligned} \text{Unit yrs} = & 1 * \text{unit-years (same region, same kind)} + \\ & 0.1 * \text{unit-years (same region, all kinds)} + \\ & 0.01 * \text{unit-years (all regions, same kind)} \end{aligned}$$

When all of the above factors are combined, the following equation results for the Demand sub-model as pertaining to the purchase of the solar-energy system:

$$\begin{aligned} \text{Equivalent First Cost} = & \text{Installed price of entire system} * \\ & (1 + \text{TIMN} - \text{GSHARE} - \text{CR}) + \text{Risk Cost} \end{aligned}$$

The factor "TIMN" is the present value of taxes, insurance and maintenance; "GSHARE" is the fraction of the cost of the system that the government is willing to pay; and "CR" is the present before-taxes value of the income-tax deduction. This equivalent first cost was used in selecting the optimum area of collector. The logic of the optimization process is presented in Appendix C. Four possibilities were considered: (1) solar was economical for heating only; (2) solar was economical for cooling only; (3) solar was economical for heating and cooling only; and (4) solar was not economical. The logic is too complicated to repeat here, so the reader is advised to consult Appendix C for both the logic and the relevant equations. The optimal collector area so determined was limited to a fraction of the floor area for the building, on the basis that on a flat roof the collector must be tilted and this tilting results in a collector area equal to approximately one-half of the roof area. The ratios for various types of buildings are listed on Table C-1 of the appendix.

The final aspect of the Demand model is the market growth. Whether the solar-energy market grows was hypothesized to depend on the economical advantage of the solar systems when the government cost-sharing feature is removed. Consequently, at the end of each year a market projection was made for the next year, on the basis of no government cost sharing. If solar was found justifiable without the government participation, government participation was removed for that building type in that region. The judgment of economical justification was based on the life-cycle cost, including the risk cost. In no case was the market allowed to exceed one unit for a given kind of building, region and new/old construction, unless one unit had been built in the previous year. Hence, it was assumed that an experimental unit must be built for each kind, region and new/old construction, whether the unit was government sponsored or not.

Once the governmental support was found unnecessary, the problem still remained to estimate the size of the market in the following year. The number of purchases in the following year was taken to be a function of the degree of economical advantage, in terms of the ratio of the life-cycle cost to the fuel costs without solar. A factor CX was defined according to the equation

$$CX = SN * LOAD/HCOP * PCF - CA * A_c \\ + \delta_c * (SNS * CLOAD/COP * PCF - CABS * PCL * SNS) \\ - CONTROLS$$

SN = Fraction of heating supplied by solar

LOAD = Heating load

HCOP = Heating system coefficient of performance

PCF = Equivalent present fuel cost

CA = Equivalent first cost per unit collector area

A_c = Collector area

δ_c = 0 if no solar air conditioning; $\delta_c = 1$ otherwise

SNS = Fraction of cooling supplied by solar

CLOAD = Cooling Load

COP = Cooling system coefficient of performance

CABS = Cost of absorption cooling per unit cooling load

PCL = Peak cooling load

See also Table 15 for further definition of terms.

In comparing solar with resistance heating, HCOP = 1.0; however, when heat pumps were considered as the competitor, HCOP was used as listed on Table 11 for the various regions.

The terms involving the loads are the terms that indicate the saving in fuel costs by use of the solar-energy system. The negative terms in the equation for CX represent the costs of the components. All terms are on a present-value basis. The propensity to purchase a solar system was given a numerical value by dividing CX by the value of the fuel cost when no solar was used; namely,

$$CO = \text{Load}/\text{HCOP} * CF + \delta_c * \text{CLOAD} * CF/\text{COP}$$

The ratio, CX/CO, was defined as C; it represents the cost saving in terms of the fraction of the present worth of the fuel cost as would be experienced with the conventional system over the same time period as the life of the solar-energy system. The form of the propensity function used was

$$PF = 1 - \text{EXP}(-C/0.3)$$

Note that when $C = 0.3$, the propensity function is at 0.63; that is, when the saving is 30 percent of the conventional fuel cost. The market for the next year was determined by multiplying the propensity function by the total possible market and the maximum anticipated penetration rate. The possible market for existing buildings was equal to 17 percent of the number of buildings of the type under investigation remaining in the region under investigation. The 17 percent is equal to the present fraction of all commercial buildings using electrical heating, including resistance and heat-pump systems. For new construction, the maximum market was 17 percent of the number of buildings being built that year. Note that the number of existing buildings is changed each year by the number of new buildings that are not solar-equipped. The maximum market-penetration rate was assumed to be 15 percent for existing buildings and 70 percent for new buildings.

For existing buildings, the market for the following year is

$$MOLD = 1 + 0.15 * FBLDGS * AS * PF/SZ$$

where FBLDGS is the fraction of all non-solar buildings (characterized by total floor area, AS, divided by floor area per building, SZ) that are electrically heated. For new buildings

$$MNEW = 1 + 0.7 * FBLDGS * GR * PF/SZ$$

where GR is the square-footage of new construction for that year.

Table 12 summarizes the demand sub-model.

TABLE 12

SUMMARY OF DEMAND MODEL

1. Categories of users

12 building types * 12 regions * 2 new and old = 288
Collector-area limits per building type

2. Costs

Installed price of solar - as optimized
Fuel cost - regional average for electricity
Taxes, insurance, maintenance at six percent with inflation
Installed price of absorption refrigeration - as optimized
Income-tax deduction for sum-of-years-digits depreciation

3. Risk-Aversion Cost

Based on cost of removal = $(0.1 * PC + IC + RC + ACC + CONTROLS) * e^{-UY/8}$
Based on unit-years experience = $1 * \text{same region, kind} +$
 $0.1 * \text{same region} +$
 $0.01 * \text{same kind}$

4. Market growth

Number of purchases = $1 + \text{non-solar units} * \% * \text{propensity}$
Asymptotic penetration rate = $\% = 0.15 * 0.17$ for existing
 $= 0.70 * 0.17$ for new

Propensity = $1 - \text{EXP}(-C/0.3)$

$$C = \frac{\text{Life-cycle cost saving}}{\text{Non-solar life-cycle fuel cost}}$$

4. The Economic Environment Sub-model:

The economic-environment sub-model was defined by just three parameters: (1) the general inflation rate; (2) the available interest rate; and (3) the fuel-price escalation rate. It was assumed that the potential purchaser had the choice of investing either in an interest-bearing account or in the general inflation. Consequently all discounting was performed at IX, the maximum of either the general inflation rate or the available interest rate. The nominal value for both was set at eight percent. Fuel inflation was taken at a nominal value of 10.3 percent. As shown in Appendix D, the fuel costs can be converted to an equivalent present value by the introduction of an effective rate of return, RR, where

$$1 + RR = \frac{1 + IX}{1 + IF}$$

where IX represents the maximum of the inflation or interest rate and IF represents the fuel inflation rate.

The economic-environment sub-model is summarized on Table 13.

TABLE 13

SUMMARY OF THE ECONOMIC-ENVIRONMENT SUB-MODEL

1. General Inflation Rate, IG: 8% nominal
2. Available Interest Rate, IN: 8% nominal
3. Return on Investment: MAX (IG, IN)
4. Fuel Escalation Rate, IF: 10.3% nominal

5. The Government Sub-model:

The government participation in the industry model appears in terms of its cost share, GSHARE. The value represents that part of the first cost of the solar-energy system that the government is willing to pay. Nominally GSHARE was set at a constant for the first five years and zero for subsequent years. Other plans were also used as will be discussed in the following sections. The government participation was terminated for any building type and region in which the governmental share was unnecessary to make the system economical. In addition, the government was assumed to limit its participation to a specified number of new and existing buildings for each building type in each region, for a total limit of 288 units per year (12 building types, 12 regions) if the numbers specified were one old and one new.

If, even with governmental cost sharing, the solar-energy system was not economically attractive to the purchaser, the demonstration unit was not installed.

The government sub-model is summarized on Table 14.

TABLE 14

SUMMARY OF THE GOVERNMENT SUB-MODEL

1. Government's part of cost share based on added cost due to solar
150% = nominal GSHARE (first five years only) consisting of
75% initial cost + 90% of maintenance for 20 years.
2. Buildings: Cost-shared
Must be cost effective as cost-shared
Limit: 1 new + 1 old per type per region, per year, nominally

D. Results and Discussion

1. Sensitivity Analysis

The model described in the preceding sections involves many parameters for which intuitive estimates must be made. It is important, therefore, that the sensitivity of the predictions of the model to the values of the parameters be determined. Most of the values used in the nominal case were discussed when the model equations were presented; they are repeated in Table 15 for convenience. Also shown on Table 15 is a list of off-nominal but plausible values that were used to test sensitivity.

The results of the sensitivity study are listed on Table 16. Both Tables 15 and 16 are worthy of careful reading. The model predictions depend on the assumptions to the extent that the number of demonstration systems installed might be anywhere from zero to 1368, with the nominal value being 667. The concern associated with this somewhat alarming range is ameliorated by the data shown on Figure 2; the energy saving resulting from the introduction of solar-energy systems over the next twenty years depends directly on the amount of funds ERDA spends on demonstration units in the next five years. Figure 2 was devised on the basis of all of the results of the sensitivity analysis, so it includes a wide variety of assumptions. The cause for alarm is even further diminished when it is realized that most of the factors involved in the model and its predictions are controllable by ERDA.

The nominal case involves an ERDA cost share of 150 percent. This share should be established as 75 percent of the initial cost at the time of construction and 90 percent of the maintenance costs thereafter. Annual payments for taxes, insurance and maintenance have been assumed to amount to six percent of the initial price. Of this, approximately four percent is estimated for maintenance, so ERDA would be agreeing to pay for an estimated 3.6 percent of the initial price in annual maintenance expenses.* If a lower maintenance cost is

* We have taken 150 percent as equal to 75 percent + 20 years * 3.6 percent, with rounding due to uncertainty in the 3.6 percent value.

experienced, ERDA's expenditures would be reduced. The manner in which ERDA pays for the maintenance should be studied in detail, some possibilities being long-term maintenance contracts, private insurance companies and ERDA-underwritten deductible insurance similar to \$100-deductible homeowner's insurance. ERDA's sponsorship of the maintenance costs could be tied to the data acquisition aspects of each demonstration unit; in fact, the billing of maintenance costs to ERDA would be part of the data collected from the demonstration units and would be invaluable in assisting potential users of solar energy in their economical evaluations.

Although the sensitivity results are listed in Table 16 in the order of decreasing effect on the total energy saved over twenty years, the data shown on Table 16 will be discussed in two categories: (1) factors determined in the market place; and (2) factors controllable by ERDA.

TABLE 15
VALUES USED IN SENSITIVITY ANALYSIS

<u>SYMBOL</u>	<u>DEFINITION</u>	<u>NOMINAL</u>	<u>OFF-NOMINAL</u>
PC2	Fixed cost for large production plant	\$24000/yr	\$12000
PC3	Fixed cost for small production plant	\$2000/yr	\$1000
TCONST	Time factor for introduction of low-cost material and absorption unit	3 years	2
	PRESENT DAY:		
CCTDY	Variable part of collector price	\$14/ft ²	\$10
PRTDY	Production rate	5000 ft ² /yr	50000
PETDY	Production experience	50000 ft ²	5000
CACTDY	Installed cost of air conditioning	\$720/ton	\$800
	LONG-TERM FUTURE:		
CCFUT	Collector cost	\$5/ft ²	\$7
CACFUT	Installed cost of air conditioning	\$360/ton	\$600
IC2	Fixed cost for large installer	\$15000/yr	\$7500
IC3	Fixed cost for small installer	\$1000/yr	\$500
	PRESENT DAY:		
ICTDY	Variable cost of collector installation	\$7.00/ft ²	\$5.00
	LONG-TERM FUTURE:		
ICFUT	Collector-installation cost	\$1.50/ft ²	\$2.00
DC2	Fixed cost for experienced designers	\$200	\$100
DC3	Fixed cost for new designers	\$4000	\$2000
	PRESENT DAY:		
DCTDY	Variable cost of system design	\$10/ft ²	\$20
	LONG-TERM FUTURE:		
DCFUT	Variable cost of system design	\$0.25/ft ²	\$1.00

TABLE 15 (CONT'D)

<u>SYMBOL</u>	<u>DEFINITION</u>	<u>NOMINAL</u>	<u>OFF-NOMINAL</u>
FBLDGS	Fraction of all buildings to which solar might be applicable	0.17	0.57
RC	Cost differential, retrofit - new	\$3.00/ft ²	\$2.00
N	Life of solar-energy system	20 years	15
TIM	Taxes, Insurance and Maintenance, as fraction of installed cost	0.06	0.08
IN	Available interest rate	8%	10%
IF	Annual fuel escalation rate	10.3%	13%
IG	General inflation rate	8%	10%
FUELCF	Amount fuel cost at time zero/1974 fuel cost	1.25	1.50
SHARE	(Life-cycle cost borne by ERDA) (Installed cost of demonstration)	1.50	0 → 2.00
DSDDT	Rate of decrease in "SHARE", as a fraction of SHARE	0	0.2
TSHAR	Number of years of government sharing	5	4, 20
CONTROL	Control-system cost for large systems	\$1000	\$600
RISK	e-fold unit-year factor for risk	8 units	4
SALVG	Salvage factor for collector	-0.1	+0.1
ASYMPTOTIC MARKET PENETRATION RATES:			
EPEN	Existing buildings	0.15	0.10
NPEN	New construction	0.70	0.50
PENMKT	e-fold fractional cost-saving factor for propensity factor	0.30	0.20
BKGRND	Regional production rate for solar systems due to demands of HUD and other solar programs	10000 ft ² /yr	0, 20000
HPYR	Years from today in which heat pumps are the major competition for solar	5	0, 20
IDELAY	Years from contract award that effect of installation on new construction is felt in experience and energy saving	2	1

TABLE 16A
SUMMARY OF SENSITIVITY COMPUTATIONS

Parameter Variation	Demonstrations (units)		20 Year Totals (thousands)		Funding \$ x 10 ⁶ \$ x 10 ⁹		20 Year Savings 10 ¹⁵ Btu 10 ⁹ KWH		Total Collector Area 10 ⁹ ft ²	Number of Successful Regions
	OLD	NEW	OLD	NEW	ERDA	PVT	HEAT	COOL		
FBLDGS = 0.57	304	364	1404	416	113.0	160.0	3.92	240.0	5.26	8
IF = 0.15 IG = 0.10	339	356	830	186	150.0	125.0	2.56	159.0	3.19	11
PENMKT = 0.20	301	365	648	161	113.0	74.0	1.68	103.0	2.34	8
CCTDY = 10.00	337	394	555	138	119.0	62.3	1.55	92.9	2.04	9
SALVG = +0.1	388	420	545	136	142.0	62.6	1.53	89.4	2.00	9
RC = 2.00	330	380	558	127	119.0	59.0	1.50	92.1	2.03	8
ICTDY = 5.00	349	406	545	135	127.0	62.0	1.50	89.3	2.00	9
IC2 = 7500	364	410	534	133	133.0	61.8	1.45	86.3	1.96	9
NKNOLD = 2 NKNNEW = 2	568	732	528	133	215.0	61.1	1.43	86.6	1.94	9
PC2 = 12000	343	391	529	132	123.0	61.3	1.40	84.7	1.93	9
NKNNEW = 2	296	730	508	127	162.0	58.3	1.34	82.6	1.85	8
TCONST = 2	313	372	508	126	115.0	58.3	1.34	82.3	1.85	8
NKNOLD = 2	602	361	505	126	163.0	58.2	1.33	81.8	1.84	8
PRTDY = 50000	438	453	506	127	161.0	61.1	1.33	77.7	1.85	9
TSHAR = 20	623	845	523	132	311.0	61.9	1.32	79.7	1.91	11
CONTRL = 600.	325	389	508	125	118.0	58.1	1.31	80.2	1.84	8
RISK = 4.0	301	374	500	125	117.0	58.0	1.30	79.5	1.82	8

TABLE 16A (Cont'd)
SUMMARY OF SENSITIVITY COMPUTATIONS

Parameter Variation	Demonstrations (units)		20 Year Totals (thousands)		Funding \$ x 10 ⁶ \$ x 10 ⁹		20 Year	Savings	Total	Number of Successful Regions
	OLD	NEW	OLD	NEW	ERDA	PVT	10 ¹⁵ Btu HEAT	10 ⁹ KWH COOL	Collector Area 10 ⁹ ft ²	
IDELAY = 1	304	372	500	124	119.0	57.9	1.29	79.1	1.82	8
DC3 = 2000	307	368	499	124	117.0	57.9	1.29	78.6	1.82	8
PC3 = 1000	300	369	496	123	114.0	57.6	1.27	77.6	1.80	8
IC3 = 500	300	369	496	123	115.0	57.6	1.27	77.6	1.80	8
DC2 = 100	300	369	496	123	114.0	57.6	1.27	77.6	1.80	8
NOMINAL	299	368	496	123	114.0	57.6	1.27	77.6	1.80	8
CACTDY = 800.	294	356	484	121	113.0	56.8	1.22	74.7	1.76	8
NPEN = 0.50	299	372	497	88	114.0	55.5	1.21	73.7	1.71	8
TSHAR = 4	237	300	474	117	86.4	53.9	1.19	75.2	1.70	7
IF = 0.123 IG = 0.10	296	373	445	112	121.0	65.9	1.09	68.5	1.59	7
AFACTR = 0.5	272	340	456	113	96.1	52.8	1.09	67.9	1.64	7
DCFUT = 1.00	297	368	440	111	116.0	53.3	1.08	67.8	1.57	7
CACFUT = 600.	288	361	432	109	113.0	53.0	1.07	65.9	1.55	7
ICFUT = 2.00	271	340	438	111	107.0	52.3	1.05	66.8	1.56	7
IN = 0.10	333	382	410	107	125.0	47.3	0.98	60.5	1.47	7
EPEN = 0.10	304	368	336	123	114.0	42.0	0.92	56.6	1.33	8
PETDY = 5000	152	203	409	108	50.3	48.2	0.90	60.2	1.45	8
CCFUT = 7.00	269	338	378	99	110.0	50.0	0.85	53.7	1.32	7

TABLE 16A (Cont'd)
SUMMARY OF SENSITIVITY COMPUTATIONS

Parameter Variation	Demonstrations (units)		20 Year Totals (thousands)		Funding		20 Year 10 ¹⁵ Btu HEAT	Savings 10 ⁹ KWH COOL	Total Collector Area 10 ⁹ ft ²	Number of Successful Regions
	OLD	NEW	OLD	NEW	\$ x 10 ⁶ ERDA	\$ x 10 ⁹ PVT				
N = 15	269	319	351	90	99.9	43.0	0.85	50.8	1.32	5
DSDDT = 0.1	121	164	275	68	30.6	30.7	0.67	43.2	0.98	3
DSDDT = 0.2	98	147	272	67	20.7	30.5	0.64	41.8	0.96	3
NO COOLING	159	187	254	74	68.3	28.5	0.62	0	0.99	4
DCTDY = 20.00	130	180	85	24	42.9	6.1	0.12	12.2	0.16	2
TIM = 0.08	41	48	13	4	11.0	0.6	0.02	2.4	0.02	1
IG = 0.10	48	60	9	3	13.4	0.5	0.02	1.8	0.01	1
IN = 0.10	49	60	9	3	10.6	0.4	0.02	1.6	0.01	1
IF = 0.10	50	52	8	3	13.4	0.4	0.02	1.5	0.01	1
IG = 0.10	10	16	6	2	1.8	37.9	0.00	0.4	0.01	1
HPYR = 0										

TABLE 16B
SUMMARY OF SENSITIVITY TO FUEL PRICES

Parameter Variation	Demonstrations (units)		20 Year Totals (thousands)		Funding \$ x 10 ⁶ \$ x 10 ⁹		20 Year Savings 10 ¹⁵ Btu 10 ⁹ KWH		Total Collector Area 10 ⁹ ft ²	Number of Successful Regions
	OLD	NEW	OLD	NEW	ERDA	PVT	HEAT	COOL		
IF = 0.13	327	342	851	190	141.0	100.0	2.65	166.0	3.29	11
IF = 0.103	299	368	496	123	114.0	57.6	1.27	77.6	1.80	8
IF = 0.08	44	51	9	3	12.3	0.4	0.02	1.7	0.01	1
FUELCF = 1.50	352	365	696	165	138.0	79.8	2.10	126.0	2.62	11
FUELCF = 1.25	299	368	496	123	114.0	57.6	1.27	77.6	1.80	8
FUELCF = 1.00	58	75	13	4	14.5	0.6	0.03	2.4	0.02	1
HPYR = 20 FUELCF = 0.50	NO UNITS BUILT									

--LEGEND--

SYMBOL	EXPLANATION	NOMINAL VALUE
FBLDGS	Fraction of all buildings to which solar might be applicable.	0.17
TSHAR	Number of years of government cost sharing.	5
PETDY	Present-day production experience.	50,000 ft ²
DSDDT	Annual rate of decrease of government fraction of cost share, as a fraction of government cost share.	0.0

FIGURE 2: RESULTS OF SENSITIVITY STUDY: RELATIONSHIP BETWEEN ERDA COST SHARE AND TOTAL ENERGY SAVING

Primary among the factors that are determined in the market place is the nature of the competition. If solar-energy systems must compete against electrical resistance heaters, the solar systems will capture a greater share of the space-heating market than if they must compete against heat pumps or oil heat. Table 17 lists and Figures 3, 4, and 5 illustrate the effect of the competing systems. (The term "Background Production Rate" represents the amount of collector production in a region over and above the amount sponsored by ERDA under this commercial-building program. The effects of this background production rate are discussed below, with the other factors controllable by ERDA. For now the reader is asked to consider only those curves marked as zero background production rate.) Consider the nominal ERDA cost share of 150 percent of the initial installed price. If the competition is entirely composed of heat pumps, oil, and gas, no solar units will be installed at this cost share level (Figure 3). If, because people are convinced that heat pumps will be as troublesome as they have been in the past, the competition is composed entirely of electrical resistance heat, oil, and gas, solar will not compete successfully against the latter two, but will capture most of the remaining 17 percent of the market that until now has been captured by electrical resistance heat (Figure 4). The nominal scenario used herein involves a competitive market limited to 17 percent of the total space-heating market but consisting of electrical resistance heating for the first five years and of heat pumps thereafter.* In this way, an allowance has been made for the users gaining confidence in heat pump systems. Figure 5 illustrated the nominal scenario. It is on the basis of the results shown thereon that the nominal cost share level was selected. The total energy saving can be increased only a small amount by increasing the cost share level, but, as shown on Table 17, the cost to ERDA increases from \$114 to \$161 million dollars just by increasing the cost share from 150 percent to 160 percent.

*In the Potomac Electric Power Company region of Washington, D. C., 51 percent of the 205 new commercial buildings in 1974 were to be resistance heated and two percent were to be heat pump heated. In 1975, the 418 new commercial buildings were divided into 67 percent resistance and one percent heat pump. This indicates that the 17 percent used in the model is probably low even on a national scale. It also indicates that the current competitor is indeed resistance heat.

TABLE 17

EFFECT OF GOVERNMENT COST SHARE AND COMPETITION

Background Production = 0 ft²/year

Share	Total Demos (Units)	Total Units in 20 Years (Thousands)	Cost to ETDA (\$x10 ⁶)	-----Energy in 20 years 10 ¹⁵ Btu	Saved----- in 20th year 10 ¹⁵ Btu	Cost/Demo (\$x10 ³)
Competition: Resistance Heating						
0.0	0	316	0.00	0.404	0.112	-
0.4	49	327	1.50	0.436	0.116	77
0.8	59	343	3.78	0.482	0.122	80
1.2	119	393	9.33	0.619	0.140	65
1.3	205	559	18.10	1.175	0.209	88
1.4	403	710	57.90	1.803	0.273	102
1.5	667	871	114.00	2.495	0.350	114
1.6	830	964	161.00	2.848	0.389	121
2.0	945	997	325.00	2.998	0.403	172
Competition: Heat Pumps						
0.0	0	0	0.00	0.000	0.000	-
0.4	0	0	0.00	0.000	0.000	-
0.8	0	0	0.00	0.000	0.000	-
1.2	0	0	0.00	0.000	0.000	-
1.6	82	16	7.96	0.027	0.004	61
2.0	1046	611	262.00	1.400	0.218	125
Competition: Mixed Competition						
0.0	0	16	0.00	0.026	0.004	-
0.4	49	18	1.50	0.034	0.005	77
0.8	59	20	3.78	0.044	0.005	80
1.2	119	20	9.33	0.048	0.006	65
1.3	205	105	18.10	0.165	0.026	88
1.4	403	429	57.90	0.914	0.148	102
1.5	667	619	114.00	1.530	0.218	114
1.6	830	680	161.00	1.817	0.245	121
2.0	945	732	325.00	1.989	0.265	172

FIGURE 3: EFFECT OF COST SHARE BORNE BY ERDA
WHEN COMPETITION IS HEAT PUMP

FIGURE 4: EFFECT OF COST SHARE BORNE BY ERDA WHEN COMPETITION IS RESISTANCE HEATING

FIGURE 5: EFFECT OF COST SHARE BORNE BY ERDA WHEN COMPETITION IS RESISTANCE HEATING FOR 5 YEARS AND HEAT PUMPS THEREAFTER

If natural-gas prices are de-regulated, the price of gas could rise to be nearly equal to that for electricity. The market potential would then increase from 17 percent to 57 percent ($FBLDGS = 0.57$); the number of demonstration units would be 668, but 1.82 million units would be in existence in 20 years, saving a total of 4.74×10^{15} Btu over this period, three times the saving if gas regulations were to continue. Inroads made by oil would reduce this impact, but a strong case can be made for deregulating gas as a means for spurring energy conservation once solar heat has been demonstrated as a viable alternative energy source. Although in part a market factor, deregulation is a factor controllable not by ERDA but certainly by the government.

Among the characteristics of the market not controllable by ERDA are the estimates of the inflation rates that must be made by potential solar-energy users in their economical analyses. Figure 6 illustrates the cumulative energy saving, due to the introduction of solar energy, as a function of the anticipated fuel-price escalation rate. If the potential users anticipate a rate five percent above the general inflation rate, they will purchase twice the amount of solar-energy devices as they would if they anticipate a 2.5 percent difference. What industry expects could be determined by a survey, although some allowance must be made for deviations from the survey when the purchasing agent is asked to put his money down and not just fill in the blanks on a survey. Further study is recommended along these lines.

The potential user's estimate is also important in his computations of the cost effectiveness of solar when he considers the maintenance rate for the solar-energy system. In the sensitivity analysis, taxes, insurance and maintenance were combined into a single factor and estimated at six percent of the installed cost for the nominal case; eight percent was considered in the sensitivity study. The resultant range in energy savings and demonstration numbers is large in comparison with the values predicted for the nominal case. It appears that experience is needed with the solar-energy systems so accurate estimates can be made of the maintenance rate. This sensitivity to maintenance cost provides another argument for ERDA to assume part of the maintenance burden.

FIGURE 6: THE EFFECT OF ANTICIPATED INFLATION RATES ON ACTUAL ENERGY SAVINGS

The factor designated FUELCF was also found to be important. The higher value of FUELCF (of 1.50) may yield energy prices valid for certain areas within a region. To include localized effects within the model, such as local fuel prices, would require knowledge not only of the fuel cost but also of the local building inventory at present and in the future. It does not appear that this detail is justifiable in terms of the model, since an extensive survey would be required. Data forthcoming from the responses to the ERDA request for proposals under the Demonstration program may provide some of the needed information. Because energy rates are in fact higher in some subregions, the long-term energy savings predicted for the nominal case are probably underestimated by the model.

The case of FUELCF of 0.50 corresponds to energy prices typical of oil. Consequently, when this case was considered, the heat pump was not considered at any time (HPYR = 20) (the nominal case incorporates heat pumps from the fifth year on). It is evident that solar-energy systems cannot compete with fuel oil within the next twenty years at present prices, even including the allowance for inflation.

Solar cooling has only a minor effect on the energy savings in terms of the actual reduction in the electrical energy required to drive a refrigeration compressor. This phenomenon is a direct result of the low coefficient of performance of absorption refrigeration systems. (The effect is most clearly illustrated on Figure 12 as devised from the data for the nominal case.) Table 16 indicates, however, that if cooling is eliminated from the demonstration program, the cumulative energy saving is decreased considerably, because the use of solar air conditioning does help justify larger collectors and thereby justifies a larger portion of the heating load to be solar supplied. Hence solar cooling should be included in the program from the start, with the economics dictating just when solar cooling should be funded.

The risk factor and the associated anticipated salvage value have a moderate effect on the demonstration program and the long-range energy saving. This is another subjective factor that might be better defined through a survey; however, its influence does not seem to warrant further work at this time.

Fortunately, the available roof area, controlled by AFACTR in the model, has little influence on the outcome of the demonstration program. It appears that ample roof area is available on most buildings. Under nominal conditions we have assumed that 17 percent of all buildings are suitable for solar applications. This percent represents the percent of all commercial buildings that are electrically heated at present, as reported in the Project Independence reports (2). Although it appears that we have assumed that all electrically heated buildings are suitable for solar heating and cooling, in fact we have assumed that the rate of increase in number of electrically heated and cooled buildings is exactly offset by the number that would not be suitable for solar. This assumption may be too harsh on solar systems, since 40 percent of all new homes are being electrically heated. The effect of relaxing this assumption can be estimated by reference to the factor FBLDGS. The amount of energy saved is seen to be approximately proportional to the fraction of the market that is electrically (or equivalently) heated.

The factor PENMKT, which is a measure of the propensity of users to buy solar as based on the economical advantages of solar, is seen to have little effect on the ERDA expenditures but a substantial effect on the energy saving over the 20-year period.

The nominal case uses two years between the time of commitment of ERDA funds and the time when the solar system on new construction begins operation (0.5 years for existing construction). If the new-construction delay is reduced to one year (IDELAY = 1), little difference is experienced.

Table 18 is a summary of the market-determined factors of the sensitivity analysis.

TABLE 18
SENSITIVITY ANALYSIS: FACTORS DETERMINED IN THE MARKET-PLACE

<u>Factor</u>	Sensitivity of	
	<u>ERDA Cost</u>	<u>20-year Energy Saving</u>
1. Escalation Rates: IF, IG, IN Actual values unimportant Potential user's estimate important Survey needed	High	High
2. Taxes, Insurance and Maintenance; Life: TIM, N Potential user's estimate important Data needed from demonstrations	High	High
3. Fuel Coefficient: FUELCF Local variations important Cannot compete with oil	High	High
4. No Solar Cooling: CLINCD	Moderate	High
5. Risk Factor: RISK, SALVG Data needed from demonstrations to provide confidence	Moderate	Moderate
6. Building Suitability: AFACTR	Low	Low
7. Propensity to Buy: PENMKT New buildings less important than old	Low	High
8. Construction Delay: IDELAY One or two years delay on new construction is not important	Low	Low

We can now consider the factors in the sensitivity analysis that can be determined by ERDA. Principal among these is the fraction of the first cost of the solar system that ERDA is willing to purchase. This was discussed in some detail above and the reader is again referred to Figures 3, 4, and 5, and the associated discussion. A different view of the same information is afforded by Figure 7, which shows the relationship between ERDA's expenditures for demonstration systems and the energy saved over the next 20 years. If ERDA's expenditures were recovered through taxation of the energy saved by solar systems, the cost of the solar-supplied energy would increase by 12 cents per million Btu, which is insignificant in comparison with the approximately \$7 per million Btu total that the user is paying for energy. Taxing solar is not the best way of introducing it into the market, but Figure 7 does show that the ERDA expenditure is small relative to the energy saving made possible by the ERDA program.

A second factor of major importance to the results of the commercial demonstration program is the size of related programs that result in the production of solar heating and cooling systems. Table 19, which was devised on the basis that other programs will result in a regional production rate of 20,000 square feet of collector per year, can be compared to Table 17, for which this "background" production rate was assumed zero. Figures 3, 4, and 5 show the same data graphically. The principal effect of this background production is to reduce the cost of solar systems today from approximately \$33 per square foot to approximately \$25 per square foot. As a consequence, solar heating systems for commercial buildings become more economically attractive both initially, under the demonstration program, and ultimately without government sponsorship. Although the solar market is not established until regional production rates are approximately 100,000 square feet per year, the 20,000 square feet rate is a good trigger. This sensitivity indicates the importance of ERDA's coordinating all of the demonstration programs, so the government-supported production rate does not become exorbitant, thereby unnecessarily increasing the government's cost. This sensitivity also indicates the desirability of having regionally managed demonstration programs. As will be shown later when the details of the nominal case are considered, the entire program would probably benefit from staggering the programs in various regions, with Phoenix and Los Angeles being developed

FIGURE 7: ENERGY SAVING FOR VARIOUS LEVELS OF ERDA EXPENDITURES

TABLE 19
EFFECT OF GOVERNMENT COST SHARE AND COMPETITION

Background = 20,000 ft²/yr

Share	Total Demos (Units)	Total Units in 20 Years (Thousands)	Cost to ERDA (\$x10 ⁶)	-----Energy in 20 years 10 ¹⁵ Btu	Saved----- in 20th year 10 ¹⁵ Btu	Cost/Demo (\$x10 ³)
Resistance Heaters						
0.0	0	837	0.00	2.21	0.268	-
0.4	274	854	9.22	2.30	0.341	84
0.8	413	885	30.40	2.45	0.354	92
1.2	674	960	79.00	2.81	0.387	98
1.6	835	1002	171.00	3.06	0.405	128
2.0	928	1003	299.00	3.06	0.405	161
Heat Pumps						
0.0	0	323	0.000	0.413	0.107	-
0.4	9	337	0.094	0.452	0.113	26
0.8	29	348	0.847	0.478	0.116	37
1.2	59	361	3.560	0.512	0.121	50
1.6	524	558	86.100	1.168	0.196	103
2.0	1181	655	279.000	1.512	0.233	236
Mixed Competition						
0.0	0	558	0.00	1.20	0.194	-
0.4	274	578	9.22	1.28	0.201	84
0.8	413	614	30.40	1.45	0.218	92
1.2	674	689	79.00	1.78	0.247	98
1.6	835	738	171.00	2.03	0.267	128
2.0	928	739	299.00	2.03	0.267	161

first, followed by Boston and others. Again, regionally managed programs appear advisable, even in terms of the training of the program managers.

The importance of the duration of the ERDA demonstration program is shown on Table 20. In generating the data reported thereon, we have assumed the ERDA program to continue at the 150 percent cost share level for all of the 20 years considered in this study ($TSHAR = 20$). The only two areas to benefit from extending the program past five years are Omaha and Nashville. The increase in the total number of buildings supplied by solar energy is small, as is the increased energy saving (from 1.53 quads for the nominal case to 1.59 quads for the 20 year program, according to Table 16); however, the cost to ERDA is increased by a factor of three. Although a number of demonstration units would be placed in Miami, the market never takes hold. This result is in part due to the omission of water heating, which would be important in motels, hotels, and hospitals. Further study is needed to determine if these applications would be sufficient to trigger the entire market for Miami. Table 16 also indicates that decreasing $TSHAR$ to four years saves ERDA 25 percent in funds and reduces energy saving only five percent. Whether a four or five year program is more beneficial should be re-examined in the annual program reviews. Although the energy saving over 20 years is reduced from 1.53 to 0.78 quads if ERDA uses a $SHARE$ decreasing from 1.5 to 1.2, 0.9, 0.6 and 0.3 in each succeeding year over the five year period ($DSDDT = 0.2$), the total cost to ERDA is cut to 18 percent of the constant $SHARE$ value, from \$114 to \$20.7 million. As shown on Figure 2, this strategy is the best of the low-cost strategies. In addition, the decreasing cost share would bring pressure on potential users to buy early, thereby providing earlier experience. If a lower cost program is desired, a decreasing cost share is recommended, even though for $DSDDT = 0.2$ the only regions to establish a market would be Boston, Phoenix and Los Angeles. Table 16 and Figure 2 indicate that $DSDDT = 0.10$ (so cost shares of 1.50, 1.35, 1.20, 1.05, and 0.90 are used) also provides an effective strategy. The rate of decrease in cost share could be reviewed annually to give flexibility to the program.

TABLE 20

EFFECT OF CONTINUING DEMONSTRATION PROGRAM INDEFINITELY

Region	Years From Today For Demonstration Program	Market in 20 years (units/yr)	
		20-year Subsidy	5-year Subsidy
Bismarck	4-7	3216	3216
Madison	1-3	6005	6005
Omaha	4-11	2283	-
Boston	0-2	17651	17651
Seattle	-	-	-
Washington, D.C.	0-3	8137	8137
Nashville	7-12	3640	-
Los Angeles	0-3	9107	9107
Fort Worth	0-4	3438	3438
Phoenix	0-2	1506	1506
Charleston	0-4	4847	4847
Miami	0-19	-	-

As indicated on Table 16, increasing the maximum number of demonstration units from one per old and one per new to two per old and two per new buildings per region per building type does little but increase the cost to ERDA. The increased energy savings are due to the earlier introduction of solar that results from the higher production rates associated with the expanded demonstration program. One striking fact does appear from this as well as all of the data on Table 16: development of the retrofit market is more important than development of the new construction market. This is unfortunate for solar, since new construction affords an easier installation, but the new construction does provide needed additional production that keeps costs down for the retrofit market.

The data from Table 16 can be used to compute the average collector size for all the buildings. More detailed computations of the same quantity are given in the following section. In both cases the average sizes are found to be 2000 to 5000 square feet, the larger sizes being typical of regions with high heating loads. Hence, it appears that ERDA would be well advised to fund many small projects, as opposed to several large projects. This stands to reason in terms of the number of small commercial buildings that represent the potential market. It also stands to reason because a complete experience is gained by producer, designer, installer and user even with this smaller unit. Adding collector area does not increase the experience factor.

Taxes, insurance and maintenance also have an important effect on the number of companies willing to install solar energy systems. Tax incentives and limited liability laws could assist, but the most influential action by ERDA is to assume 90 percent of the maintenance costs for the demonstration projects. This fact was discussed above when the nominal case was selected. However, all of this expense and possibly the entire solar heating and cooling program will be in vain if ERDA funds systems requiring high maintenance costs. ERDA should specifically select those projects that hold promise for low maintenance and long life. Manufacturers will thereby be encouraged to devise durable, maintenance free designs.

Some industries thrive on government purchases of high-technology, high-cost products. Such must not be the case in the solar industry, where the objective is to develop a viable commercial industry. The model shows the adoption of solar energy systems hinges understandably on unit prices. ERDA should support only those systems that give promise for low cost in the long run. ERDA can judge proposed designs using rules-of-thumb devised from other industries. For example, automobile frames cost approximately \$1 per pound; steel sheds, 70¢ per pound; and plastic trash cans, \$1.50 per pound. Likewise, long-term installation costs should be low, so hand-crafted systems, constructed on the roof by tradesmen, should be discouraged, even if this is the least expensive way of building solar systems today. Pressure must be maintained by ERDA to make sure that the experience gained by the demonstrations is good experience, leading to systems costs that will be competitive with alternate energy sources.

The installed-cost effects are found in the parameters PC2, IC2, DC2, CCTDY, CCFUT, DCTDY, DCFUT, ICTDY, ICFUT, and RC, especially when taken as a whole. The minor effects of PC3, DC3, and IC3 indicate that the small, low-overhead producer will have only a minor impact on the solar industry. Mass-production techniques will be necessary. The predictions made herein are based on current installed costs for systems with heating and cooling being \$32.70 per square foot of collector for new buildings, but decreasing to \$10 to \$15 per square foot before the market takes hold.

The importance of DCTDY indicates that ERDA would do well to support a few design organizations rather than many, so these can obtain the design experience needed to reduce costs. So what they learn may be transferred to potential competitors, the design charts and specifications developed by these few organizations should become the property of ERDA for its dissemination.

Similarly, ERDA might be well advised to guarantee a market of possibly 120,000 square feet of collector per year for years 1979 to 1983 in each successful demonstration area, so mass-production techniques, with the associated large capital expenditures, will be encouraged. In fact, ERDA would do well to assist the manufacturers in the establishment of their plants either through

such guarantees or equivalent guarantees for reimbursement should solar systems prove marketless in that region. Figure 8 shows that, at constant production, 120,000 ft²/year brings the cost below \$10/ft², a value that will trigger most regions. (See also Table 23.)

The estimated present-day production rate (PRTDY) and production experience (PETDY) give reasonable learning-curve effects, as will be shown in the subsequent sections; however, these are based on catalog information and estimates of costs on the NSF-RANN P.O.C.E.'s. The price histories should be monitored over the first few years to determine if the predictions of the model should be redone.

The cost of controls is significant in small installations. ERDA should support systems using simplified controls for systems using fewer than 3000 ft² of collector.

ERDA could diminish the RISK factor by guaranteeing payment of removal costs, should the systems prove unreliable. It should be sufficient, however, to guarantee re-purchase of the collectors for re-sale, re-use, or research. The cost of re-purchase would be only approximately 30 percent of \$20/ft², or \$6/ft². Re-purchase is not recommended as a matter of policy, because the 75%/90% cost share should be adequate.

Table 21 provides a summary of the ERDA-influenced factors of the sensitivity analysis.

In the following section the predictions for the nominal case, incorporating the recommended policies, is reported in depth. Note that the data reported represents the predicted response of industry to an ERDA offer to pay 75 percent of the initial cost and 90 percent of the maintenance cost for 20 years. The data does not indicate a specific number of demonstration units or funding level. It is recommended that the market response be used to establish these numbers.

FIGURE 8: UNIT COST FOR SOLAR-ENERGY SYSTEMS AT VARIOUS CONSTANT RATES OF PRODUCTION

TABLE 21

SENSITIVITY ANALYSIS: FACTORS DETERMINED BY ERDA

<u>Factor</u>	Sensitivity of	
	<u>ERDA Cost</u>	<u>20-Year Energy Saving</u>
1. ERDA's SHARE of First Cost: SHARE Recommended: 75% of first cost 90% of maintenance Result: $\$114 \times 10^6$ total ERDA cost or $\$0.12/10^6$ Btu saved in 20 years	High, Below 75/90 share	High, Below 75/90 share
2. Other Production in Region: BKGRND For given energy saving, 20000 ft ² /yr cuts needed share to 75%/6%. Recommended: Integrated, Regional Programs	High	High, Below 75/90 share
3. Duration of Demonstration Program: TSHAR Recommended: 5 years, but open to review Sequence regions to reduce cost	Low	Low
4. Size of Demonstration Program: NKNOLD, NKNNEW Recommended: Maximum of one new and one old building per region per type Demo's: 2000 to 5000 ft ² collector/unit Needed: 100,000 ft ² of collectors/yr per region	High	Low
5. Incorporation of Cooling in Demonstration Program Must reduce cost of refrigeration unit Recommended: Let market decide	Moderate	High
6. Taxes, Insurance and Maintenance: TIM Recommended: Support reliable, low- maintenance systems Pay 90% of maintenance	High	High
7. High First Cost: PC, CC, IC, DC, RC, CAC Recommended: Support technology development 1. Technology development for low cost 2. Potentially low-cost systems for demonstrations 3. Mass-producible systems 4. Development of low-cost controls, refrigeration	Moderate	Moderate

TABLE 21 (Cont'd)

<u>Factor</u>	Sensitivity of 20-Year	
	<u>ERDA Cost</u>	<u>Energy Saving</u>
8. Risk Factor: RISK Could guarantee re-purchase of collector Recommended: Guarantee installation rate	Moderate	Moderate
9. Competing Energy Sources: FBLDGS May need oil price support De-regulation of natural gas would be beneficial to solar.	High	High

2. Predicted Response of Commercial Market to Recommended Demonstration Program

The recommended ERDA program consists of ERDA's offering to pay for 75 percent of the first cost of the difference between adding a solar heating and cooling system to a building and using a conventional heating and cooling system. In addition, ERDA would pay for 90 percent of the maintenance costs. Over the 20-year life, this combination of ERDA payments would amount to ERDA's paying approximately 150 percent of the difference in cost between solar and non-solar. In this section of this report we present the response of the commercial sector of the total potential solar market to this offer by ERDA.

First we consider the price history for solar units. Figure 9a shows the installed price of solar systems for new construction in Phoenix. The cost is on a per-unit-collector-area basis in constant 1975 dollars. The actual price in any year is obtained by multiplying the value of the ordinate at any year by 1.08 taken to a power equal to the year. The price history is compared to the more-or-less standard learning-curve predictions on Figure 9a for slopes of 70 percent and 80 percent. Unlike the model, the power-law learning curve is quite sensitive to the value assumed for the present experience. The present model is not so sensitive because learning represents only one portion of the price-determining factors; production rate is considerably more influential, as one would expect on the basis of predictions for mass-produced versus hand-crafted systems. Despite the drastic differences between the model and power-law learning, the two predictions agree quite well if an 80 percent slope is used and current experience is set at 25,000 square feet for each region (300,000 square feet nationally). An 80 percent slope at 50,000 square feet per region yields a significantly slower price decrease than the present model, at least for the first three years. Although the present model uses 50,000 square feet as the base point, there is little reason to expect that both models would use the same base, since the form of the equations and influential factors are so different. For example, much of the decrease in cost in the model is due to material substitution, as would result from direct ERDA support of collector and storage development programs. The power-law model has no such explicit provision.

FIGURE 9a: HISTORY FOR INSTALLED PRICE FOR NEW CONSTRUCTION IN PHOENIX

Figure 9b shows a comparison between price history in Phoenix and price history in Washington, D. C. Similar results are obtained for other regions. Notice that the price decrease in Washington is delayed because the cost shared program is slower in developing, as could be expected for a climate with less insolation. The price history according to the power-law model of the learning curve agrees well with the model predictions for Washington, as well as Phoenix. Figure 10 shows the price histories for all regions, if no inter-regional shipping occurs.

The development of the demonstration program is shown on Table 22, which lists by region the number of demonstration units to be installed in each year. Notice that Phoenix and Los Angeles start strongly and immediately, both having the upper limit on the number of demonstration units. Boston and Washington start more moderately, with only new construction incorporating solar systems. (This latter fact is not evident from the table.) It would appear that little harm would come from delaying demonstration programs in Madison, Charleston and the other remaining regions. In the second year Madison and Charleston would be included. In the third year Fort Worth would be added. Although Miami would also be requesting demonstration units, under the hypotheses used in the model, Miami would never be economically viable for commercial systems. (Those commercial installations in which domestic hot water is needed, such as hotels, motels and restaurants might be viable -- water needs were not analyzed herein.) Hence it would seem that before any projects are funded in Miami, a strong case must be made by the proposer that a commercial market will indeed develop there. The problem is that in Miami heat pumps work so well that solar has difficulty competing.

By the beginning of the fourth year, three years from now, Phoenix and Boston markets can stand on their own, except for some isolated building types. In fact, in scanning Table 22, one can see that in each of the regions where solar does become economically advantageous, a three-year demonstration program is almost all that is needed. Such a staggering of development programs has definite advantages to ERDA, since the experience gained can be transferred by ERDA to the new regions, both in evaluating proposals and in managing the programs. It also serves to reduce the manpower requirements for monitoring the various projects.

NOTES:

1. LINES INDICATE MODEL RESULTS
2. SYMBOLS INDICATE CONSTANT (80%) SLOPE FOR LEARNING CURVE:

$$\text{PRICE} = \text{PRICE}_0 (\text{ft}^2 / \text{ft}_0^2)^{-n}$$

$$n = \tan[(100\% - \frac{90^\circ}{100})]$$

$$= 0.325$$
3. NOMINAL CASE WITH ERDA SHARE = 150%
4. $\text{ft}_0^2 = 25,000$

FIGURE 9b: HISTORY OF INSTALLED PRICE FOR NEW CONSTRUCTION

FIGURE 10: PRICE GOALS FOR VARIOUS REGIONS

TABLE 22

PREDICTED SCHEDULE OF DEMONSTRATION UNITS (150% SHARE)

REGION	YEAR					Totals	ERDA Expend- itures (millions) (at 150% share)	Average Collector Size For all Units Built in First 5 Years (ft ²)	Total Number of Units Built by 1995
	1	2	3	4	5				
Phoenix	24	24	7	4	3	62	10.5	1921	20,000
Boston	11	24	24	6	-	65	16.2	3812	216,000
Los Angeles	23	24	24	14	-	85	12.1	2163	106,000
Washington, D. C.	8	20	24	24	2	78	16.0	3417	96,000
Madison	5	20	24	20	2	71	17.8	4067	70,000
Charleston	2	9	23	24	23	81	10.9	2706	47,000
Fort Worth	2	6	19	24	24	75	11.6	3456	34,000
Bismarck	-	-	-	6	24	30	9.4	4860	24,000
Miami	13	17	18	18	20	86	2.1	386	0
Omaha	-	-	-	2	24	26	6.4	3802	0
Nashville	-	-	-	-	8	8	0.8	1387	0
Seattle	-	-	-	-	-	0	-	-	0
Totals	88	144	163	142	130	667			
ERDA Expenditures (Millions) (at 150% share)	7.5	19.5	28.5	30.8	27.3	114.0			
Average Collector Size for all units built in first 5 years (ft ²)	1568	2965	2348	2695	3446				

TABLE 22 (cont'd)

COST-EFFECTIVE DEMONSTRATION BUILDINGS PREDICTED BY MODEL

	Bismarck	Madison	Omaha	Boston	Seattle	Washington, D.C.	Nashville	Los Angeles	Fort Worth	Phoenix	Charleston	Miami	TOTALS
Restaurants	2	4	2	5	-	5	2	6	5	4	6	9	50
Stores, Service Stations	3	4	2	5	-	7	2	7	6	4	7	10	57
Supermarkets	2	6	2	6	-	7	-	7	7	5	7	2	51
Religious, Social	2	4	2	5	-	7	1	8	7	4	7	10	57
Office	2	5	2	5	-	7	2	7	7	4	7	9	57
Educational	3	7	3	5	-	7	1	7	8	4	9	10	64
Hospital, Medical	3	8	3	6	-	6	-	8	5	8	6	10	63
Shopping Centers	3	7	2	7	-	6	-	7	5	7	5	-	49
Motels, Nursing Homes	3	7	2	5	-	7	-	7	8	4	8	10	61
Warehouses	2	5	2	6	-	7	-	7	5	4	6	-	44
Libraries, Museums	2	6	2	5	-	7	-	8	7	7	7	7	58
Hotels	3	8	2	5	-	5	-	6	5	7	6	9	56
TOTALS	30	71	26	65	-	78	8	85	75	62	81	86	667

If strict three-year programs are not instituted in the various regions, the total number of demonstrations grows from 88 in the first year to 163 in the third, reducing to 130 thereafter. This growth pattern does give ERDA time to reassess its program after the first year. It is recommended that such a re-examination be made and that the model used herein be modified as indicated by the data from the first year to determine if the long-range strategy is still sound.

ERDA's expenditures from year to year are also indicated on Table 22. Note that the demonstration projects involve collectors with areas on the order of 2000 square feet in Phoenix and Los Angeles, so relatively small projects would be undertaken in the first year. For regions such as Boston, where heating demands are high, the collector areas are likewise high, being on the order of 4000 square feet. With many small projects, although the cost per square foot is higher on the whole, the amount of experience gained is greatly increased. Little additional knowledge is acquired by the manufacturer, designer or installer when he installs a 20000 square foot collector, as opposed to a 2000 square foot system. The last part of Table 22 shows the distribution of demonstrations by building type.

Figure 11 illustrates the growth in the number of solar equipped commercial buildings as a function of time on the national scale. The corresponding growth in energy saving per year is shown on Figure 12. It is evident that most of the savings are due to systems installed on existing buildings for use in heating. This does not mean that solar cooling is not useful; as was seen from the sensitivity study, solar cooling permitted the justification of more collector area so more of the heat demand could be economically met by the solar system.

The predicted long-term market is illustrated by region in Figure 13. It is evident that the total market penetration in terms of all buildings, whether oil heated or not, is quite small. By using 17 percent of all remaining non-solar buildings, $FBLDGS = .17$, the market penetration was limited to approximately 17 percent. The bar graph shows that this limit was nearly reached in Los Angeles and Phoenix. The total number of commercial buildings existing in each of the regions is tabulated on Figure 13. One can see from this tabulation that if

FIGURE 11: CUMULATIVE NUMBER OF SOLAR-EQUIPPED BUILDINGS NATIONWIDE

FIGURE 12: NATIONAL ANNUAL ENERGY SAVING DUE TO SOLAR HEATING AND COOLING

solar had been successful in the Omaha, Seattle, and Miami regions, the total number of solar-equipped buildings would have increased only slightly. If Nashville had developed a market for solar, the increase would have been significant. Actually Nashville and Washington, D. C., are nearly the same. Figure 1 shows that the technical performance for these two regions is identical; the difference is that the energy cost in Nashville is considerably less.

When the regional market reaches 10 percent of the long-term (20-year) market, the local market can be considered as established. Table 23 shows the prevailing conditions, region by region, at the time the markets reached 10 percent. Phoenix reaches its 10 percent point in two years (during 1978). By the end of 1977 most of the demonstrations have been built in Phoenix. The production rate for 1977 would be 90,000 square feet; the projected production rate for 1978 would be 500,000 square feet of collector, which would bring the price of solar systems down to \$15.72 per square foot (multiplied by the inflation factor). The installation rate would be 10 percent of 1506, or 151 units for 1978. It is evident from Table 23 that most regions have the market established the year following an ERDA-sponsored year in which the production rate was approximately 100,000 square feet. In the following year the production rate increases by a factor of approximately 10. This phenomenon implies that ERDA must select the demonstration projects to permit such a rapid expansion; therefore, ERDA must select the projects in such a way that the manufacturers will build plants based on mass-production techniques. For example, the Phoenix facilities should be expandable to meet the long-term market of approximately 1500 units per year, with an average size of approximately 1200 square feet of collector. This amounts to a production rate of 1.8 million square feet per year. The market growth rate is illustrated for each of the regions on Figure 14. Most regions experience an anomaly in the growth pattern, that is not shown on Figure 14, in the year heat pumps become competitive. Manufacturers can expect either some cash-flow problems or undersize-plant difficulties around the fifth or sixth year. In Phoenix the anticipated rapid growth in commercial buildings in the next five years might encourage over-expansion of manufacturing facilities to the extent that they will be utilized at 50 percent capacity for years five to ten. A more thorough study of the optimal expansion rate is recommended.

DEMONSTRATIONS

OLD	12	32	12	28	0	33	3	45	31	26	36	41
NEW	18	39	14	37	0	45	5	40	44	36	45	45
TOTAL	30	71	26	65	0	78	8	85	75	62	81	86

20-YEAR TOTALS (THOUSANDS)

OLD	23	57	-	176	-	78	-	83	27	16	37	-
NEW	6	13	-	40	-	18	-	23	7	4	10	-
TOTAL	29	70	-	216	-	96	-	106	34	20	47	-

TOTAL NO. BLDGS	324	616	268	1750	97	751	475	688	312	125	520	132
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NOTES

1. Water Collectors
2. SHARE = 150%

FIGURE 13: GEOGRAPHIC DISTRIBUTION OF DEMONSTRATION PROGRAM AND 1995 SOLAR-ENERGY SYSTEMS

TABLE 23

CONDITIONS WHEN MARKET REACHES 10% of 1995 MARKET

Region	Year	Production Rates (10 ⁶ ft ² /yr)		Price on New Build- ings in Year Shown (1975 \$/ft ²)	Production Rate in 20 Years (Units/yr)
		In Last Year of Major ERDA Support	In Year Shown		
Bismarck	8	0.13	1.99	9.85	3216
Madison	4	0.27	8.51	10.68	6005
Omaha	-	0.09	-	-	-
Boston	3	0.18	6.36	12.31	17651
Seattle	-	-	-	-	-
Washington, D.C.	4	0.18	8.82	11.59	8137
Nashville	-	0.01	-	-	-
Los Angeles	4	0.10	6.74	10.11	9107
Fort Worth	5	0.13	1.39	12.33	3438
Phoenix	2	0.09	0.50	15.72	1506
Charleston	5	0.11	2.10	12.38	4847
Miami	-	0.01	-	-	-

NOTES: 1. Year shown is the beginning of the year in which production exceeds 10 percent of production rate 19 years from today.

2. A "-" indicates that a market did not develop.

The payback period at the 10 percent market point is shown on Table 24 to be between 10 and 14 years. The ratio is expressed in terms of today's dollars, with the fuel prices from Table 11 used with a multiplier of 1.25.

The predicted commercial response to the ERDA program is summarized on Table 25.

The numerical results for this detailed analysis of the nominal case, along with the results of the sensitivity study, can be combined and regrouped so the implications for ERDA, potential manufacturers, potential installers, potential designers and potential users can be more easily grasped.

E. Implications for ERDA

The implications of the foregoing analyses in terms of the ERDA program can be divided conveniently into four categories: (1) the cost-share program; (2) the proposal evaluation procedures; (3) program management; and (4) advising Congress.

1. The Cost-Share Program

ERDA should offer to pay 75 percent of the first cost of the difference between equipping the commercial buildings with solar heating and cooling and equipping the buildings with a conventional system. ERDA should also offer to pay 90 percent of the maintenance costs for the first 20 years of operation. ERDA's payment for maintenance could be in the form of a direct grant or in the form of a maintenance contract. The maintenance support should be tied to the data acquisition program by requiring that all data be made public if maintenance support is given. The data presented in this report is the predicted response to these offerings by ERDA. It is predicted that the solar industry will become self-sustaining in Phoenix in two years and somewhat later in other regions.

ERDA should, with few exceptions, limit its support to systems requiring less than 5000 square feet of collector (if full support is requested in the proposal to ERDA), since the experience gained with larger systems is of no greater value. It is anticipated that in the first year systems involving 5000 square feet will cost approximately \$160,000, so larger systems could be funded if ERDA is asked to pay less than 75 percent of \$160,000.

NOTES:

1. DOT (•) INDICATES YEAR MARKET REACHES 10% OF 20-YEAR MARKET

FIGURE 14: REGIONAL HISTORY OF PRODUCTION RATE REQUIRED TO MEET MARKET

TABLE 24

ECONOMICAL PRICE FOR UNSUBSIDIZED SOLAR-ENERGY SYSTEM

Region	Ratio of (1975 Solar-Energy System Cost) to (Fraction of 1975 Annual Fuel Cost Saved with Solar) at Market Break Point (10% of 1995 Market)
Bismarck	10.10
Madison	10.43
Omaha	-
Boston	10.37
Seattle	-
Washington, D. C.	10.87
Nashville	-
Los Angeles	10.06
Fort Worth	13.54
Phoenix	10.08
Charleston	13.98
Miami	-

NOTES:

- Ratio = $\frac{\text{(Amount paid for all systems/inflation factor)}}{\text{(Amount of fuel saved * 1975 fuel cost)}}$
- 1975 fuel cost = 1.25 * values shown on Table 11.
- A "-" indicates that a market did not develop.

TABLE 25

SUMMARY OF PREDICTIONS AT 75%/90% SHARE

Actions

o Demonstration Projects vs. Year

Retrofit	28	61	77	71	62
New	60	83	86	71	68
Average Size	1600	3000	2500	2500	3500

ad determined by cost effectiveness at 75/90

o ERDA life-cycle cost 7.5 19.5 28.5 30.8 27.3
(millions of \$)

Effects

o First Markets: Phoenix 1978
Boston 1979
Los Angeles 1980

o Units installed in 20 years:

Retrofit: 496,000 units @ 45,000/yr

New: 123,000 units @ 9,000/yr

o Energy Saving

In 10 years: $0.05 * 10^{15}$ Btu/yrIn 20 years: $0.22 * 10^{15}$ Btu/yr $1.53 * 10^{15}$ Btu cumulative

o Regional Distributions:

Phoenix, Los Angeles, Boston, DC, Madison - Favored

Omaha, Seattle, Nashville, Miami - Poor

ERDA should guarantee a five-year market of at least 120,000 square feet per year in each region where success is predicted for the solar industry, so mass-production methods will be developed. ERDA should sponsor a study of the optimal expansion rate for the manufacturer in each region.

2. Proposal Evaluation

ERDA should fund only those proposals that show the solar system to be cost effective as cost shared by ERDA. Maintenance costs must be included in this evaluation; they should be assumed as four percent of the initial cost, unless data is available to the contrary. Only those systems that promise to be reliable, durable and low-cost in the long run should be funded. The proposer should show these merits in his system. It is important to the low-cost feature that the system be mass-producible. Systems with good potential should be funded, even though these systems may be higher in cost under present conditions. In keeping with this concept, manufacturers using mass-production methods should be favored.

To limit the present high costs of system design, ERDA should support only a few, reputable design organizations at first. Design data and specifications developed in these organizations should then be disseminated by ERDA to other design organizations.

Since the most important part of the market lies with existing buildings, proposals involving such buildings should be favored by allowing the proposer to receive a higher payment per unit collector area from ERDA. A differential of \$3 per square foot appears to be a reasonable differential.

The regions of Phoenix, Boston and Los Angeles should be favored in the first year, since these are the most promising areas. Washington, D. C., and Madison should be added to the list of favored regions in the second year and Charleston and Fort Worth, the third year. Miami, Omaha, Nashville and Seattle appear to be so unfavorable that the proposer from these regions should prove that the long-term market really exists within that region.

No favoritism should be offered to competing systems, such as air-cooled versus water-cooled collectors, concentrating collectors versus non-concentrating, or heating only versus heating and cooling. The cost-effectiveness criterion should be used in evaluating these competing systems.

3. Program Management

The single most important aspect of the program management will be the integration of the ERDA commercial program with other government-sponsored solar programs, such as the ERDA/HUD residential program and the ERDA industrial program. The goal of the combined program is to bring the production level up to the point where significant economies of scale can be realized. A production rate of 120,000 square feet per year should be adequate under the combined programs. Because of this interreaction and because of the uncertainties of the model used herein, the program should be reviewed at least annually. The model can be updated and recalibrated so more accurate projections can be made. Although a five-year program should be planned at present, budget permitting, a four-year program might be adequate. The possibility of decreasing the ERDA share in equal steps each year should also be evaluated periodically.

The criterion by which the ERDA program can be evaluated is quite simple: the reduction in the cost of solar-energy systems in the regions where demonstration programs are installed. It is possible, by use of the results shown on Figure 10, to estimate if the price decreases with time will lead to a viable, self-sustaining industry. If so, the ERDA program is being successful; if not, failure is indicated. It will be important to use costs as proposed to ERDA, to avoid estimates that are dreams rather than realities.

The results obtained with the model indicate that regions become economically attractive for the demonstration program sequentially rather than simultaneously. Three-year programs starting in the first year in Boston, Phoenix and Los Angeles only would provide pilot programs for the rest of the nation. These pilot programs, requiring 58 demonstration projects (Table 22), would permit the best three program managers to be selected. These managers would gain the needed experience with these novel systems, each in his own region. This experience

would then be used to train and guide other program managers for the other regions. (It seems advisable to have each program manager live with his region for its entire life, so responsibility is clearly defined.) In essence the ERDA program, and its interacting neighbors, would be administered region by region, an added advantage being that the program manager would be intimately familiar with the systems and manufacturing procedures peculiar to his region.

Finally the program management should be such that companion research and development projects should be funded that will lead to the development of durable, reliable, low-cost systems, including most importantly the collector and its installation, but also the storage, refrigeration and control subsystems.

4. Advising Congress

The price of alternate energy sources has a strong impact on the economical viability of solar-energy systems. ERDA should sponsor a study of the full impact of the de-regulation of natural gas and the institution of oil price supports, so the solar industry can compete in a free market but not one subject to the whims of foreign powers.

Table 26 provides a summary of the foregoing implications and recommendations.

F. Implications for the Manufacturer, Designer and Installer

The importance of the development of the solar industry to the manufacturer, designer and installer can be considered in three categories: (1) price goals; (2) market; and (3) competition. These are outlined on Table 27.

1. Price Goals

The long-range price goals for the manufacturer is \$5.00 per square foot of collector for all of the components in the system, excluding air conditioner and controls. The installer should add no more than \$1.50 per square foot to this. The designer can add no more than \$0.25 per square foot. For a typical 4000

TABLE 26

IMPLICATIONS FOR ERDA

1. Cost Share:

- A. Offer 75% of first cost + 90% of maintenance, tied to data acquisition and reporting.
- B. Market will respond.
- C. Limit to systems with less than 5000 ft² of collector approximately 75% of \$200,000 initial cost today.
- D. Guarantee 5-year market so manufacturers build mass-production facilities.

2. Proposal Evaluation:

- A. Fund only cost-effective projects (as cost-shared).
- B. Fund reliable, durable low-cost systems.
- C. Fund mass-producible designs only, not just lowest cost.
- D. Favor manufacturers with mass-production methods.
- E. Concentrate on a few design organizations at first - then disseminate procedures.
- F. Favor retrofit by allowing higher unit cost.
- G. Favor Phoenix, Boston, Los Angeles at first.
- H. Disfavor Omaha, Miami, Nashville, Seattle.
- I. Allow air systems and air-conditioning systems.
- J. Favor proposals requesting smaller share - to encourage private experimentation.

TABLE 26 (cont'd)

IMPLICATIONS FOR ERDA

3. Program Management:

- A. Integrate with other programs - regional goal 120,000 ft²/yr.
- B. Re-evaluate program annually via model - 5 year program for now, possibly 4 or decreasing share.
- C. Monitor price history to judge effectiveness of program.
- D. Can use 3-year regionally staggered programs - aids management, experience transfer.
- E. Administer by region.
- F. Sponsor companion R & D for reliable, durable low-cost systems, including refrigeration and controls.

4. Advising Congress:

Study implications of natural gas de-regulation and oil price supports.

square foot installation, the manufacturer would receive \$20,000; the installer, \$6,000; and the designer, \$1,000. These are the long-range goals that would involve mass-production techniques and much experience with solar systems. Mass-production to the designer will mean design charts for various regions, standard specifications and the use of packaged components. The market will begin to grow once the price has been brought to the level of \$10 to \$15 per square foot total, although the market will remain small at this price level.

2. Market

If the installed price is brought down to the \$10 to \$15 range, the market will be as shown on Table 26 for each of the regions. It is evident that Phoenix and Boston are the places to start, but most of the other areas are quick to follow. Nashville, Miami, Omaha, and Seattle may never be able to use solar profitably, so producers in these areas should proceed with caution.

Caution is also urged with regard to expansion rate. Figure 14 should be studied for each of the regions and the optimal expansion rate established therefrom. Plant sizes should be based on mass-production techniques, with capabilities between one and ten million square feet per year recommended. Specialized vehicles for installation will probably be required to reduce the price to an acceptable level.

3. Competition

Many of the assumptions made with regard to the model are unfavorable with regard to the expansion of the solar industry. A number of developments could cause a considerably greater demand for solar-energy systems; the producer should become aware of these. If heat pumps are found unacceptable, due, for example, to high maintenance costs, solar systems will compete with electric resistance heaters rather than heat pumps. The long-term market could increase by 50 percent if this were to happen (see Figures 4 and 5). If natural gas is deregulated so its price approaches that of electricity, the market will triple. If oil becomes scarce, the market will also triple, since approximately 40 percent of all commercial buildings are oil heated. If local energy costs are significantly higher than those shown on Table 11 for each of the regions, the solar market could be greatly expanded on a local basis. The Long Island section

has this characteristic. Finally, if fuel costs increase at a rate exceeding 2.3 percent more than the inflation rate, the solar market will increase a like amount, being proportional to the difference in these escalation rates.

At present solar energy systems are not competitive because initial costs are too high, but the ERDA program should put pressure on system costs so a decrease is likely. The decrease should be sufficient for solar to become competitive with electrical resistance heating.

G. Implications for the Potential Users

The discussion of the implications for the manufacturers, designers and installers provides much of the information needed by the potential user, so the reader can apply the summary table to this last category as well.

The payback period for the user when solar energy systems first become economically attractive is approximately 10 to 12 years, so this rule of thumb can aid the user in his evaluation.

No a priori judgments can be made of the systems competing at present. Air heating is just as attractive as water heating, so no guidelines can be offered in this regard. The payback period in 1975 dollars is the best criterion, although reliance must be placed on the truthfulness of the claims of the manufacturer with regard to heat delivery. NASA tests and tests by independent agencies are the only safeguard, unless guarantees by the manufacturer would suffice if honored.

H. Statement of Limitations

A summary of the results and conclusions of this report are given in the introductory Summary section. Some of the limitations of the current analysis will be delineated here, lest the reader be misled.

The primary weakness of the analysis stems from the lack of data to substantiate the parameters used. The sensitivity analysis aids in lessening this effect, but the problem still remains. Of course, the intuitively selected values have

more credence than would similarly intuitive selections of the final results of the study, so this report should represent an improvement over gross guesses as to what constitutes an effective demonstration program.

The omission of the energy demands of water heating could have an important effect of underestimating the solar market. A similar effect is probably present because average energy rates were used, rather than marginal rates such as would be used if the demand for electrical energy were to increase.

Of course, the model lacks the detail of accounting for each potential customer, dealing instead with average building sizes, customers lumped into classes, etc. It also does not consider interaction with other government-sponsored demonstration programs, which could assist substantially in reducing production costs, if the systems are similar.

But the model does have the distinct strength of including the psychological effect of risk aversion, models of the price structure that contain considerable detail and many of the interactions of the techno-economic world that are important to its behavior. The model also has the advantage that it is easily adjustable so what is learned in the first year or so of demonstrations can be used to improve and update the predictions.

TABLE 27

IMPLICATIONS FOR THE MANUFACTURER, DESIGNER AND INSTALLER

1. Price Goals: (1975 Dollars)

A. Long Range

Manufacturer	\$5.00/ft ²
Designer	0.25/ft ²
Installer	<u>1.50/ft²</u>

Total = \$6.75/ft²

B. Acceptable Intermediate: Total = \$10 to \$15/ft²

2. Market:

A. Timing

<u>Region</u>	<u>Year</u>	<u>Size</u>
Phoenix	1978	150 units/yr
Boston	1979	1800
Los Angeles	1980	900
Washington, D. C.	1980	800
Madison	1980	600
Charleston	1981	500
Fort Worth	1981	350
Bismarck	1984	300
Nashville	?	
Miami	?	
Omaha	?	
Seattle	?	

B. Unit Size: 2000 to 5000 ft²/yr

C. Building type: Number of retrofits equals four times new

3. Competition:

A. Greatly increased market if

heat pumps found unacceptable
 natural gas is de-regulated
 oil becomes scarce
 local energy costs are high
 fuel-price escalation > 2.3% + inflation

B. Solar better than resistance heating in many regions.

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APPENDIX A

Sample Computation

A detailed computation will be recorded herein so the reader can gain some confidence in the operation of the model.

The Phoenix region will be examined for the fourth year. The following parameters will be used:

N = 20 years	IC2 = \$15000/yr
TIM = 6%	IC3 = \$1000/yr
IN = 8%	ICTDY = \$7.00/ft ²
IG = 8%	ICFUT = \$1.50/ft ²
IF = 10.3%	RC = \$3.00/ft ²
FUELCF = 1.25	CONTRL = \$1000/system
GSHARE = 1.5 (constant)	RISK = 8 years
TSHAR = 5 years	SALVG = -0.1
TCNST = 3 years	EPEN = 15%
PC2 = \$24000/yr	PENMKT = 0.3
PC3 = \$2000/yr	NPEN = 70%
CCTDY = \$14/ft ²	FBLDGS = 17%
PRTDY = 5000 ft ² /yr	CACTDY = \$720/ton
PETDY = 50,000 ft ²	CACFUT = \$360/ton
CCFUT = \$5/ft ²	COMPETITION = RESISTANCE HEATING
DC2 = \$200	NKNOLD = 1
DC3 = \$4000	NKNNEW = 1
DCTDY = \$10/ft ²	
DCFUT = \$0.25/ft ²	

The "rate of return" for fuel is

$$RR = 1.08/1.103 - 1 = -0.02085$$

so $AC = 25.13766$ years

The tax deduction results in $CR = 0.60606$, with no investment tax credit.

For the 20 year period, TIM accumulates to $20 * 0.06 = 1.20$, which is denoted TIMN.

For Phoenix in the fourth year

$$FACTIG = (1.08)^3 = 1.2597$$

$$CF = 1.25 * 7.10 * (1.103)^3 = \$11.9095/10^6 \text{ Btu}$$

$$EF = (1 - \exp(-(3/3)^2))/3 = 0.21071$$

The experience of the first three years is assumed to be such that

$$DA = 181870 \text{ ft}^2/\text{yr} \text{ (based on projected market)}$$

$$DABAR = 74993 \text{ ft}^2/\text{yr}$$

$$ATOTAL = 299970 \text{ ft}^2$$

Corresponding to these, we have

$$PC1 = 24000 - 22000 * \exp(-181870/2500) = \$24000/\text{yr}$$

$$PC4 = 7.50 + 2.50 * (5000/74993)^{1/4} = \$8.77036/\text{ft}^2$$

$$PC = 24000/181870 + 8.77036 * (1 - EF) * (1 + 0.8/(1 + ATOTAL/50000)) \\ = \$7.8455/\text{ft}^2$$

$$IC1 = \$15000/\text{yr}$$

$$IC4 = 1.50 + 1.61 * (5000/74993)^{1/4} = \$2.31868/\text{ft}^2$$

$$IC = 15000/181870 + 2.31868 * (1 + 2.5/(1 + ATOTAL/50000)) = \$3.2293/\text{ft}^2$$

$$DC1 = 200 + 4000/(1 + 299970/50000) = \$771.48$$

$$DC = 771.48/181870 + 0.25 + 1.5 * 9.75/(1 + ATOTAL/50000) = \$2.3437/\text{ft}^2$$

When combined and corrected for inflation, these give

$$XNEW = (7.8455 + 3.2293 + 2.3437) * 1.2597 = \$16.904/\text{ft}^2$$

$$XOLD = 16.904 + 3 * 1.2597 = \$20.683/\text{ft}^2$$

The corresponding cost of removal is

$$XXXX = (0.1 * 7.8455 + 3.2293 + 3) * 1.2597 = \$8.8355/\text{ft}^2$$

excluding air-conditioning and controls costs.

The air-conditioning costs are

$$\begin{aligned} \text{CSTABS} &= 360 * (1 + \text{EXP}(-1)) * 1.2597 = \$620/\text{ton} \\ &= \$1.9623 * 10^{-5}/(\text{Btu}/\text{yr}) \end{aligned}$$

the latter number being based on 2634.3 full-load-equivalent hours per year.

To continue the example, it is necessary to select the building kind. We choose KIND = 3 (supermarkets). We assume the experience to date to be such that

$$\text{Unit-Years} = 12.3$$

so

$$\text{RFRSK} = 8.8355 * \text{EXP}(-12.3/8) = \$1.8989/\text{ft}^2$$

The equivalent first cost, CA, for new buildings would be

$$\text{CA} = 16.904 * (1 + 1.2 - 1.5 - 0.60606 * 0) + 1.8989 = \$13.731/\text{ft}^2 \text{ (NEW)}$$

and for existing buildings would be

$$CA = \$16.377/\text{ft}^2$$

For this kind of building,

$$\text{Floor area per building} = 12500 \text{ ft}^2$$

$$\text{Maximum collector area} = 0.5 * 12500 = 6250 \text{ ft}^2$$

$$\text{Heat Load} = 23000 * 12500 = 287.5 * 10^6 \text{ Btu/yr}$$

$$\text{Cooling Load} = 112000 * 12500 = 1400.0 * 10^6 \text{ Btu/yr}$$

$$\text{Floor area of buildings being built} = 0.46 * 10^6 \text{ ft}^2/\text{yr}$$

$$\begin{aligned} \text{Floor area of existing buildings} &= 5.8 * 10^6 + 0.46 * 10^6 * 3 - 6 * \\ &\quad 12500 = 7.105 * 10^6 \text{ ft}^2 \end{aligned}$$

$$\text{Peak air-conditioning load} = 1400 * 10^6 / 2634.4 = 531430 \text{ Btu/hr (44 tons)}$$

$$\text{Air-conditioning coefficient of performance} = 2.2$$

In computing the floor area of existing buildings, we have assumed that one new and one existing building was solar equipped in each of the three preceding years. We will assume that the market has not been established.

The cost of supplying the energy for this kind of building by conventional means is

$$\text{CSTHLD} = 287.5 * 10^6 * 11.9095/10^6 * 25.1377 = \$86071$$

$$\text{CSTCLD} = 1400 * 10^6 / 2.2 * 11.9095/10^6 * 25.1377 = \$190512$$

$$\text{CSTLD} = \$276584$$

The criterion function that determines if air-conditioning is justifiable alone is (inequality C-4)

$$\begin{aligned} \text{CRIT4} &\equiv C3 * (AC * CF/\text{COP} - \text{CSTABS} * (1 + 1.2 - 1.5 - 0.0 + 0.215)) - \\ &\quad CA > 0 \end{aligned}$$

the factor 0.215 accounting for the risk associated with solar cooling.

We have, for existing buildings,

$$\begin{aligned}\text{CRIT4} &= 10^6/6.9 * (11.9095 * 25.1377/(2.2 * 10^6) - 1.9623 * 10^{-5} * \\ &\quad 0.915) - 16.377 \\ &= 10^6/6.9 * (136.08 * 10^{-6} - 17.96 * 10^{-6}) - 16.377 \\ &= 17.119 - 16.377 = 0.742\end{aligned}$$

Since CRIT4 is positive, solar cooling alone appears justifiable.

The collector areas would be ($C1 = 2.06735$; $C2 = 1.181$)

Cooling only (SNS = 0.8):	7728 ft	= ARCOOL
Heating only	: 1587 ft	
Heating and Cooling	: 2032 ft	= ARHEAT
Maximum Collector Area	: 6250 ft	= TERM

The curve fit for SN fails for $A > \text{ACRIT}$, corresponding either to $\text{SN} = 1.0$ or the maximum value of SN (if $\text{SN} = 1.0$ is impossible). For Phoenix, SN cannot exceed 0.90473 according to the curve fit. This maximum occurs when

$$\alpha = \alpha_{\text{CRIT}} = \frac{10^6 * \text{ACRIT}}{8 * \text{LOAD}} = 0.87525$$

of $\text{ACRIT} = 2013 \text{ ft}^2$

Since cooling alone is economically justifiable, the optimum A is greater than ACRIT. In fact, 7728 ft^2 can be justified; however, only 6250 ft^2 can fit on the building, so this area must suffice. Corresponding to 6250 ft^2 , we have

$$\text{SN} = 0.90473$$

$$\text{SNS} = 0.647$$

The controls cost is

$$\begin{aligned}\text{CONTRL} &= 500 * 1.2597 * (1. + \text{EXP} (-4000/6250)) \\ &= \$961.97\end{aligned}$$

To determine if this design is profitable, we must compute the total life-cycle cost. The cost saving is

$$\begin{aligned}\text{CX} &= \text{SN} * \text{LOAD} * \text{CF} * \text{AC} + \text{SNS} * \text{CLOAD} * (\text{CF} * \text{AC}/(\text{COP} * 10^6) - \text{CSTABS} * \\ &\quad (1 + 1.2 - 1.5 - 0.0 + 0.215)) - \text{CA} * \text{A} - \text{CONTRL} * 0.915 \\ &= 77871 + 106998 - 102356 - 880 = 81632\end{aligned}$$

The saving is positive, even with the inclusion of the controls cost, so solar is justifiable and the optimum area is 6250 ft².

The life-cycle cost to ERDA for this system would be

$$1.5 * (\text{A} * \text{XOLD} + 962 + 1.9623 * 10^{-5} * 1400 * 10^6 * 0.647)$$

or \$222007, whereas the initial cost to the user would be

$$\frac{222007}{1.5} - 222007 = -\$74001$$

if ERDA paid the full amount immediately.

The energy saving due to this installation would be

$$\begin{aligned}287.5 * 10^6 * 0.90473 &= 260.11 * 10^6 \text{ Btu/yr for heating} \\ 1400.0 * 10^6/2.2 * 0.647/3413 &= 0.12064 * 10^6 \text{ KWH/yr for cooling}\end{aligned}$$

All that remains is to estimate the market for the following year on the basis of no subsidy. A revised CX is computed:

$$\begin{aligned}
 CX &= 77871 + 0.647 * 1400 * 10^6 / 2.2 * (11.9095 * 25.1377 / 10^6) \\
 &\quad - 1.9623 * 10^{-5} (1 + 1.2 - 0.60606) * 0.647 * 1400 * 10^6 \\
 &\quad - 20.683 * 6250 * (1 + 1.2 - 0.60606) \\
 &\quad - 962 * (1 + 1.2 - 0.60606) \\
 &\quad - (8.8355 * 6250 + 17774 + 962) / \text{EXP}((12.3 + 4.0) / 8) \\
 &= 77871 + 123262 - 235912 - 73958 / 7.67 \\
 &= -44421
 \end{aligned}$$

The ratio of CX to the fuel cost without solar is

$$C = \frac{-44421}{276584} = -0.16$$

The negative saving indicates that the market will not grow without government support.

This completes the analysis for buildings of this kind that have already been built. If the foregoing computations are repeated for new construction, CRIT4 is again positive and

$$A = 6250 \text{ ft}^2$$

This time the cost to ERDA is less, due to the absence of RC:

$$\text{ERDA} = 1.5 * (6250 * 16.904 + 962 + 17775) = \$186580$$

The initial cost to the used would be:

$$\text{PVT} = \frac{186580}{1.5} - 186580 = -\$62194$$

C is again negative.

The unit-years associated with this kind of building in this region is, at the end of this year

<u>Year</u>	<u>New</u>	<u>Existing</u>	<u>Unit-Years</u>
0	1	1	$2 + 3.5$
1	1	1	$1 + 2.5$
2	1	1	$0 + 1.5$
3	<u>1</u>	<u>1</u>	<u>$0 + 0.5$</u>
Total	4	4	$3 + 8.0 = 11.0$

In computing the total unit years, the effects of other buildings in this region and of the same building kind in other regions must be added.

The computations recorded above could be repeated for other buildings and for other regions; however, the foregoing should provide an adequate illustration for the reader.

APPENDIX B

DEVELOPMENT OF A MODEL FOR INSTALLED COST

A key element of the solar-business model is the sub-model of the installed cost of the solar-energy system. The sub-model must include effects such as:

1. Improved productivity (learning curve);
2. Introduction of new materials;
3. Introduction of automation into the manufacturing process;
4. Introduction of large-scale installation equipment;
5. Introduction of new technology, such as low-cost concentrating collectors or higher-efficiency collectors.

Many reporters (see, for example, Dean (4)) have indicated that the total cost of the output of a plant is linear in quantity (see Figure B-1)

$$TC = a + bQ \quad (\$/\text{yr})$$

For fixed technology in a mature manufacturing process Dean (Pg 339) modifies this equation when learning effects are significant:

$$TC = a + bQ + \frac{cQ}{1 + dQ}$$

The effects of technology are still to be included.

Improved production technology usually increases capital cost but decreases labor costs. Data from Dean indicates that labor cost is proportional to the cube root of capital cost (Figure B-2). In addition, improved technology may permit the use of low-cost materials. We include the combined effect through the factor "p".

FIGURE B-1: THE LINEAR RELATIONSHIP BETWEEN CAPACITY AND PLANT COST

Ref: Dean, Pg. 302

FIGURE B-2: THE RELATIONSHIP BETWEEN CAPITAL COST AND LABOR COST

The model now takes the form

$$TC = a + bpQ + \frac{cpQ}{1 + dQ}$$

we let

$$p = e(1 - f)(CC)^{-n}$$

where CC represents the capital cost.

The problem now remains to estimate the various parameters. If we take as our base the cost of collectors today, we can use \$25/ft² of collector, with Q = 5000 ft²/yr. The pre-installation cost would be approximately \$18/ft². Therefore

$$5000 * 18 = a + (b + c) * 5000$$

In contrast, the projected cost for the same kinds of units as mass produced is approximately \$10/ft², including the structure for mounting on flat roofs. Therefore, since Q is large, we take

$$10 = b$$

If we assume that high production experience accounts for half of the reduction from \$18 to \$10, we have C = \$4 and a = \$20000/yr. Then, for DA the ft²/yr produced.

$$TPC = 20000 + 10 p(DA) + \frac{4 p(DA)}{1 + dA}$$

Production effects reduce unit costs typically at an 80 percent slope on a log-log graph (Stokes, Ref. 2, Pg 140), where

$$\text{Slope}(\%) = \left[1 + \frac{2}{\pi} \tan^{-1} \left(\frac{DA}{\text{TPC}/DA} * \frac{d(\text{TPC}/DA)}{dDA} \right) \right] * 100$$

This rule-of-thumb does not fit well with the present model, since the slope is not constant; however,

$$\frac{DA}{\text{TPC}/DA} \frac{d(\text{TPC}/DA)}{dA} = \frac{DA^2}{20000 + 10 pDA + 4 pDA/(1 + dA)} * \left[-\frac{20000}{DA^2} \right]$$

For an 80 percent slope, this quantity should be equal to -0.325. If we assume PC/DA = 18, p = 1, DA = 5000 and d = 0, then this quantity is -0.22, corresponding to an 86 percent slope.

We estimate d as 1/50000, so c must be adjusted from 4 to 8 to give

$$\frac{c}{1 + dA} = 4$$

when A = 50000

The terms pDA always appear together. If we take pDA = capital cost + labor cost per ft² * ft², or

$$CCC = pDA = CC + L \cdot DA = CC + h (CC)^{-1/3} DA$$

in accordance with the data shown on Figures B-1 and B-2, the optimum CC is given by

$$0 = 1 - 1/3 h(CC)^{-4/3} DA$$

which yields

$$pDA = \left(\frac{hDA}{3}\right)^{3/4} + 3 \frac{hDA}{3} \left(\frac{hDA}{3}\right)^{-1/4} = 4\left(\frac{hDA}{3}\right)^{3/4}$$

Therefore, we should take

$$p = \text{constant} * DA^{-1/4}$$

We let $p = 1$ when $DA = 5000$. Actually, once the investment is made, it is difficult to divest, so we replace this DA by $\overline{DA}$, the average production rate. Then, at present when $f = 0$,

$$p = e(cc)^{-n} = (5000/\overline{DA})^{1/4}$$

with $\overline{DA} = DA$ at $t = 0$.

Our model now appears as

$$TPC = 20000 + 10\left(\frac{5000}{\overline{DA}}\right)^{1/4} (1 - f) * \left[1 + \frac{0.8}{1 + (A/50000)}\right] * DA$$

The material - substitution factor will be taken as

$$f = 1/3 (1 - e^{-(t/t_0)^2})$$

on the assumption that the material substitution can reduce the cost by 1/3.

We choose $t_0 = 3$.

Under long-time, high-production conditions, the above equation gives

$$TPC = \frac{20}{3} (5000)^{1/4} \frac{DA}{(\overline{DA})^{1/4}}$$

At $DA = 10^7 \text{ ft}^2$ and $\overline{DA} = 10^7$,

$$PC = \frac{TDC}{DA} = \frac{20}{3} \left(\frac{5000}{10^7} \right)^{1/4} = \$1.00/\text{ft}^2$$

To avoid this unrealistically low value, a result of the power-law form, we take (with A as cumulative experience and DA as annual production rate)

$$TCP = 20000 + \left[7.5 + 2.5 \left(\frac{5000}{\overline{DA}} \right)^{1/4} \right] * [1 - f] * \left[1 + \frac{0.8}{1 + (A/50000)} \right] * DA$$

The installation model takes a similar form on the basis of \$7 today and \$1.50 in large quantities:

$$TIC = 12500 + \left[1.5 + 1.61 \left(\frac{5000}{\overline{DA}} \right)^{1/4} \right] * \left[1 + \frac{2.5}{1 + (A/50000)} \right] * DA$$

Note that $A = 50000$ at $t = 0$

Finally, the cost of designing the solar-energy system is similarly modeled as

$$TDC = 200 + \frac{4000}{1 + A/50000} + \left(0.25 + \frac{9.75 * 1.5}{1 + A/50000} \right) * DA$$

No mass-production or materials-substitution effect is present in design, but cumulative experience decreases the fixed part of the cost of design.

One distortion of the foregoing model must still be corrected. The fixed cost is not independent of DA; the minimum fixed production cost would correspond to the mechanic working in his home. This fixed cost might be \$2000. Hence, we replace

For PC: \$20000/yr by $PC1 \equiv PC2 - (PC2 - PC3) * \exp(-DA/2500)$

For IC: \$12500/yr by $IC1 \equiv IC2 - (IC2 - IC3) * \exp(-DA/2500)$

with $PC2 = \$24000/\text{yr}$, $PC3 = \$2000/\text{yr}$, $IC2 = \$15000/\text{yr}$ and $IC3 = \$1000/\text{yr}$.

The final models can be written in a form convenient for sensitivity studies as

$$PC = PC1/DA + PC4 * (1 - EF) * (1 + 0.8/(1 + ATOTAL/PETDY))$$

$$IC = IC1/DA + IC4 * (1 + 2.5/(1 + ATOTAL/PETDY))$$

$$DC = DC1/DA + DC4$$

where

$$DC1 = DC2 + DC3/(1 + ATOTAL/PETDY)$$

$$PC4 = 1.5 * CCFUT + (CCTDY/1.4 - 1.5 * CCFUT) * (PRTDY/DABAR)^{0.25}$$

$$IC4 = ICFUT + (ICTDY/2.25 - ICFUT) * (PRTDY/DABAR)^{0.25}$$

$$DC4 = DCFUT + 1.5 (DCTDY - DCFUT)/(1 + ATOTAL/PETDY)$$

and

$$EF = (1 - \exp(-(T/TCONST)^2))/3.0$$

The nomenclature is such the "FUT" denotes long-range future values and "TDY" denotes today's values. The nominal values are

$$CCTDY = \$14/\text{ft}^2$$

$$DCFUT = \$0.25/\text{ft}^2$$

$$CCFUT = \$5/\text{ft}^2$$

$$TCONST = 3 \text{ years}$$

$$ICTDY = \$7.00/\text{ft}^2$$

$$PETDY = 50000 \text{ ft}^2$$

$$ICFUT = \$1.50/\text{ft}^2$$

$$PRTDY = 5000 \text{ ft}^2/\text{yr}$$

$$DCTDY = \$10.00 \text{ ft}^2$$

$$DC2 = \$200$$

$$DC3 = \$4000$$

The time, T, is measured in years from today. Today, at T = 0, the nominal starting values are

$$ATOTAL = 50000 \text{ ft}^2$$

$$DA = 5000 \text{ ft}^2/\text{yr}$$

$$DABAR = 5000 \text{ ft}^2/\text{yr}$$

Costs for typical cases are listed on Table B-1. The underlined cases might be considered the nominal. At this steady, slow rate of production of approximately ten buildings per year, the price drops at a rate of only \$1 per year. If, however, production increases by a factor of ten, the installed cost drops by a factor of almost 2.

Because the price model is not a simple power law, the slope cannot be determined unambiguously. For fixed materials and production rate, the slope for the nominal case is given by (A = 50000)

$$\frac{A}{(PC + IC)} \cdot \frac{d(PC + IC)}{dA} = \frac{A}{(PC + IC)} * 13 * \frac{-1/5000}{(1 + A/50000)^2} = -0.13$$

which corresponds to a 92 percent slope. The data of Figure 8, generated for the nominal values of the parameters but with constant production rates, is analyzed for slope on Table B-2. The values reported are all reasonable.

The model can also be used to estimate the cost of the Page-Jackson school. As shown in the Results section, the best values for CCTDY and CCFUT are \$14 and \$5. Also ICTDY = 7, ICFUT = 1.50, DCTDY = 10 and DCFUT = 0.25. On the basis of InterTechnology Corporation's experience, ATOTAL = 50000, DA = 1250 and $\overline{DA}$ = 1250, so

$$PC = \$23.97$$

$$IC = 13.71$$

$$DC = \underline{9.32}$$

$$\text{Total} = \$47.00/\text{ft}^2$$

which is quite close to the actual estimate.

TABLE B-1
PRICES FOR TYPICAL CASES

Year	Collector Rate	Production Cumulative	Material Substitution Factor	Purchase Price	Installation Price	Design Price	Installed Cost
T	DA ($=\overline{DA}$)	A	(1 - f)	PC	IC	DC	PC + IC + DC
0	500 ft ² /yr	50000 ft ²	1	\$28.70/ft ²	\$16.90/ft ²	\$11.96	\$57.56/ft ²
	5000	50000	1	<u>18.20</u>	<u>9.62</u>	<u>8.00</u>	<u>35.83</u>
	50000	50000	1	12.95	5.71	7.61	26.27
1	500	50500	0.965	28.09	16.87	11.91	56.87
	5000	55000	0.965	<u>17.53</u>	<u>9.44</u>	<u>7.64</u>	<u>34.60</u>
	50000	100000	0.965	11.37	4.71	5.16	21.23
2	5000	60000	0.880	<u>16.21</u>	<u>9.27</u>	<u>7.30</u>	<u>32.78</u>
10	10 ¹² *	10 ¹² *	0.667	5.00	1.50	0.25	6.75

* As if nearly all national energy needs were solar supplied.

TABLE B-2

INITIAL SLOPE OF UNIT-COST CURVES FOR SOLAR-ENERGY SYSTEMS

Annual Production Rate (ft ² /yr)	----- Initial Slope -----			
	Without Material Substitution ft ₀ ² = 25,000	Without Material Substitution ft ₀ ² = 50,000	With Material Substitution ft ₀ ² = 25,000	With Material Substitution ft ₀ ² = 50,000
7,500	96%	85%	82	70
15,000	91	84	84	74
30,000	90	83	85	77
60,000	89	82	84	78
120,000	87	82	85	80

NOTES:

1. The initial slope was computed over a two-year period for cases with material substitution, since no significant material-substitution effect is felt in the first year.
2. The initial slope as used in power-law models is defined as %, where

$$\text{PRICE}(t) = \text{PRICE}(t = 0) * [\text{ft}^2(t = 0)/\text{ft}^2(t)]^{+n}$$

with $n = \tan ((100 - \%) * 90/100)$

For % = 80, $n = 0.325$. Historically, one would expect the slope to be greater than 80%.

The model can also be used to estimate the effect of plant cost on equipment price. The production part of the price with today's materials is

$$PP = (1 + 0.8/(1 + A/50000)) * PC4 * DA$$

or, in terms of capital, labor and material costs

$$PP = [CC + L * DA + MATL * DA]$$

The optimization yielded

$$L * DA/CC = 3$$

If we take $DA = \overline{DA}$, $A = 50000 + DA$, $CCTDY = 14$, $CCFUT = 5$, $MATL = 7.50$ and $PRTDY = 5000$, the following is obtained.

TABLE B-3
CAPITAL COSTS PREDICTED BY MODEL

<u>DA</u>	<u>Capital Costs (20 * CC/3)</u>	<u>PP/DA</u>
10^4 sq. ft./yr.	$0.13 * 10^6$	15.33
10^5	$0.67 * 10^6$	11.52
10^6	$2.51 * 10^6$	9.00
10^7	$11.69 * 10^6$	8.20
∞	∞	7.50

Material costs are based on 5 lb/sq. ft. * \$0.50/lb * 3 mark-up. The value of $20 * CC/3$ represents the capital investment converted back to manufacturers cost for a plant with a 20-year life. The estimated $20 * CC/3$ is so sensitive to the estimate for MATL, it is doubtful if the results in Table B-3 are worthwhile.

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APPENDIX C

OPTIMAL COLLECTOR AREA FOR HEATING AND COOLING

The total life-cycle cost of a solar-energy system is

$$\begin{aligned}
 \text{TLCC} = & \underbrace{(1 - \text{SN}) * \text{LOAD} * \text{CF}}_{\text{WINTER FUEL COST}} + \underbrace{\text{CA} * \text{A}_c}_{\text{COLLECTOR + STORAGE + ...}} + \\
 & + \underbrace{(1 - \text{SNS}) * \text{CLOAD} * \text{CF}/\text{COP}}_{\text{SUMMER FUEL COST}} + \underbrace{\text{CABS} * \text{PCL} * \text{SNS}}_{\text{COST OF ABSORPTION SYSTEM}} + \\
 & + \text{CONTROLS}
 \end{aligned}
 \tag{C-1}$$

in which the peak cooling load is

$$\text{PCL} = \text{CLOAD}/\text{FLE}$$

Differentiation with respect to A_c , the collector area, leads to

$$\frac{d(\text{TLCC})}{d\text{A}_c} = - \text{SN}' * \text{LOAD} * \text{CF} + \text{CA} - \text{SNS}' * \text{CLOAD} * \text{CF}/\text{COP} + (\text{CABS} * \text{CLOAD}/\text{FLE}) * \text{SNS}'
 \tag{C-2}$$

Since $\text{SNS}' > 0$, solar air conditioning is justifiable only if

$$\text{CF}/\text{COP} - \text{CABS}/\text{FLE} > 0
 \tag{C-3}$$

It is justifiable even without heating if

$$\text{CRIT4} \equiv \text{SNS}' * (\text{CF}/\text{COP} - \text{CABS}/\text{FLE}) - \text{CA} > 0 \quad (\text{C-4})$$

For the cases studied, the cooling load carried by the solar system is a linearly increasing function of A_c ; hence, if (C-4) holds, the collector area should be made large enough to provide all of the cooling.

Since

$$\text{SNS} = \text{C3} * A_c * 10^6 / \text{CLOAD} \quad (\text{C-5})$$

then, if (C-4) holds, we should make $\text{SNS} = 1^*$ and

$$A_c = \text{CLOAD} / (\text{C3} * 10^6) \equiv A_c^* \quad (\text{C-6})$$

unless the collector area required for heating as given by (C-7) is even greater.

If (C-3) is not true, cooling is not justifiable and the collector area is found on the basis of heating only (so $\text{SNS} = 0$ and $\text{CABS} = 0$):

$$\text{SN}' = \text{CA} / (\text{LOAD} * \text{CF}) \quad (\text{C-7})$$

If this equation has no positive solution, the solar-energy system is not justifiable for heating.

*. In the model, SNS was limited to less than 0.8, where linearity prevailed. Correspondingly, equation (C-6) was replaced by $A_c = 0.8 * A_c^*$.

If (C-3) is true but (C-4) is not, then the cooling system is justifiable only if the collector is also used for heating. The optimal collector area is then given by

$$SN' = (CA - SNS' * CLOAD * (CF/COP - CABS/FLE))/(LOAD * CF) - CRIT4/(LOAD * CF) \quad (C-8)$$

Figure C-1 illustrates this case.

In computing the optimal area, a parabolic curve fit was used for SN:

$$SN = \alpha * C1 - \alpha^2 * C2$$

where

$$\alpha = A_c * 10^6 / (8 * LOAD)$$

hence

$$SN' = (C1 - 2 * \alpha * C2) * 10^6 / (8 * LOAD)$$

or

$$\alpha = (C1 - 8 * LOAD * SN' / 10^6) / (2 * C2)$$

If equation (C-7) holds

$$A_c = 8 * LOAD * (C1 - 8 * CA / (CF * 10^6)) / (2 * C2 * 10^6)$$

A similar result is obtained if equation (C-8) holds.

Two complicating factors remain. Because the cost of controls does not depend on A_c (except weakly), the optimal system may still be one with no solar. Hence the A_c as determined from the foregoing must be inserted into equation (C-1) and the TLCC so obtained must be less than the TLCC obtained with no solar, as can be obtained from equation (C-1) with $SN = SNS = CABS = CONTROLS = 0$. Otherwise solar is not justifiable. The second complication is that A_c as determined above may exceed the space available on or near the building; hence, A_c is limited by AMAX, as tabulated below. The values listed are based on AMAX = 0.50 for a one-story, flat-roofed building.

FIGURE C-1: ILLUSTRATION OF OPTIMAL COLLECTOR AREAS FOR VARIOUS CASES

TABLE C-1

MAXIMUM ALLOWABLE COLLECTOR AREAS FOR VARIOUS BUILDING TYPES

<u>Building Type</u>	<u>Maximum A_c/Floor Area</u>
1. Restaurants	0.50
2. Stores, Service Stations	0.50
3. Supermarkets	0.50
4. Churches	0.40
5. Offices	0.25
6. Schools	0.40
7. Hospitals	0.15
8. Shopping Centers	0.50
9. Motels	0.40
10. Warehouses	0.50
11. Libraries, Museums	0.25
12. Hotels	0.10

APPENDIX D

CONVERSION OF FUEL COSTS TO PRESENT VALUES

Summary: If an annual payment of $P_n = P_0 (1 + PI)^n$ and an annual earning of $E_n = E_0 (1 + EI)^n$ are realized in an economy inflating at a general rate of GI and a yield i is realized on investments, then, for P_n and E_n made at the beginning of the year, the net present value in terms of a commodity (such as bars of gold) is

$$NPV_N = NPV_0 + E_0 \frac{1 - (1 + r_e)^{-N}}{r_e} - P_0 \frac{1 - (1 + r_p)^{-N}}{r_p}$$

where $r_e = \frac{1 + i}{1 + EI} - 1$ and $r_p = \frac{1 + i}{1 + PI} - 1$, so GI does not enter the evaluation unless i , the available return on investment is realized via commodities and the general inflation.

Derivation: A sample, year-by-year computation is performed in Appendix DA from which the equations in the Summary are derived. The computations begin with the assumption that \$1000 is borrowed. A commodity such as a bushel of wheat, barrel of oil or bar of gold is used as a standard measure of this \$1000. An ounce of gold is used in the example, the value of the gold being taken as PG_0 , \$200 per ounce, during the first year, rising at the general inflation rate, GI , each year.

Earnings of \$400 are realized the first year. These earnings are used to pay the interest on the loan (\$100) and to reduce the principal by \$300. Hence, the net worth at the end of the first year is \$-700; however, the value of this \$-700 in bars of gold is $-700/(200)(1 + GI)$, since the price of gold has increased.

This computation is repeated for each year; it is systematized in equation (DA-1).

The "value" of a company is measured in terms of the accumulated gold, OG ; however, it is more convenient to express the value of this gold in terms of its value at the end of the first year:

$$\hat{N}_n = OG_n \cdot \underline{PG_0} \cdot (1 + GI)$$

Note that the underlined terms do not vary with n . $\hat{N}$ might be called the "constant-dollar" value of the gold in terms of present dollars. Equation (DA-2) describes the way $\hat{N}$ varies with n .

Equation (DA-2) can be used to compute $\hat{N}_n$, the present-dollar value of the gold accumulated after N years. The derivation is shown in Appendix DB, culminating in Equation (DB-6). Comparison between equations (DA-2) and (DB-1) reveals that

$$1 + \ell = \frac{1 + EI}{1 + GI}$$

$$1 + p = \frac{1 + PI}{1 + GI}$$

$$r = \frac{i - GI}{1 + GI}$$

or

$$1 + r = \frac{1 + i}{1 + GI}$$

These equations can be used in equations (DB-4) and (DB-5) to obtain

$$1 + r_e = \frac{1 + i}{1 + EI}$$

$$1 + r_p = \frac{1 + i}{1 + PI}$$

As described in the last two paragraphs of Appendix DB, if N represents the number of years of the project and if E_n and P_n are paid at the beginning of the year, then equation (DB-6) can be written

$$NPV = NPV_0 + E_0 \frac{1 - (1 + r_e)^{-N}}{r_e} - P_0 \frac{1 - (1 + r_p)^{-N}}{r_p}$$

This equation shows that the NPV is independent of GI, the general inflation rate.

APPENDIX D-1

SAMPLE CASE

Financing the solar system:

Borrow \$1000 (5 oz.) at 10%. General inflation at 7%. Oil inflation at 15%. Earnings inflation at 5%. Gold at \$200/oz (PG_0).

Year (n)	NET WORTH		EARNINGS		FUEL PAYMENTS		INTEREST	
	$(OG)_n$							
	oz Gold	\$	oz Gold	\$	oz Gold	\$	oz Gold	\$
0	-5	-1000	2	400	0	0	-0.50	-100 ^(b)
1	-3.27 ^(a)	-700	1.96	420	0	0	-0.33	-70
2	-1.53	-350	1.93	441	0	0	-0.15	-35
3	0.23	56	1.89	463	0	0	0.02	5.6 ^(c)
4	2.00	525						

Notes: a. $OG = \frac{-700}{200 \times 1.07}$

b. 10% x (-\$1000) with no penalty for rapid repayment.

c. Positive return also based on 10%.

Formula:

$$OG_{n+1} = \frac{1}{PG_0(1+GI)^{n+1}} [E_0(1+EI)^n - P_0(1+PI)^n + iN_n + N_n] \quad (DA-1)$$

where

$$N_{n+1} = OG_{n+1} \cdot PG_0 \cdot (1+GI)^{n+1}$$

so

$$OG_{n+1} = \frac{1}{PG_0(1+GI)} \left[E_0 \left(\frac{1+EI}{1+GI} \right)^n - P_0 \left(\frac{1+PI}{1+GI} \right)^n + \frac{(1+i) OG_n \cdot PG_0 \cdot (1+GI)^n}{(1+GI)^n} \right]$$

or

$$[OG_{n+1} - OG_n] \cdot PG_0 \cdot (1+GI) = E_0 \left(\frac{1+EI}{1+GI}\right)^n - P_0 \left(\frac{1+PI}{1+GI}\right)^n + OG_n \cdot PG_0 (i - GI)$$

If

$$\hat{N}_n = OG_n \cdot PG_0 \cdot (1 + GI)$$

$$\hat{N}_{n+1} - \hat{N}_n = E_0 \left(\frac{1+EI}{1+GI}\right)^n - P_0 \left(\frac{1+PI}{1+GI}\right)^n + \hat{N}_n \left(\frac{i-GI}{1+GI}\right) \quad (DA-2)$$

Equation (DA-2) is amenable to ready interpretation. In the first year $n = 0$, so

$$\hat{N}_1 - \hat{N}_0 = E_0 - P_0 + \hat{N}_0 \frac{i-GI}{1+GI}$$

or

$$\hat{N}_1 = E_0 - P_0 + \hat{N}_0 \frac{1+i}{1+GI}$$

So $\hat{N}_1$ is greater than $\hat{N}_0$ because of earnings E_0 , less payments P_0 . In addition $\hat{N}_0$ was retained along with the interest it gained at rate i ; however, $\hat{N}_0$ and its interest must be devalued by inflation, since it can buy less gold.

In subsequent years, the interpretation of the terms involving $\hat{N}$ is the same. The earning term is seen to increase by the earnings inflation, EI ; however, this earnings inflation is eroded by the general inflation rate. Hence we find the coefficient

$$\frac{1 + EI}{1 + GI}$$

A similar interpretation applies to the coefficient of P_0 .

APPENDIX D-2

DERIVATION OF EQUATION FOR NET PRESENT VALUE

The net value (V) of a company is assumed to increase according to the equation

$$V_{n+1} - V_n = E_n - P_n + rV_n \quad (\text{DB-1})$$

where subscript 'n' refers to the year number; E , the end of year earnings; and P , the end of year payments. If

$$E_n = (1 + \epsilon)^n E_0 \quad (\text{DB-2})$$

$$P_n = (1 + p)^n P_0 \quad (\text{DB-3})$$

then

$$V_{n+1} - V_n = E_0 (1 + \epsilon)^n - P_0 (1 + p)^n + rV_n$$

or

$$V_{n+1} - (1 + r) V_n = E_0 (1 + \epsilon)^n - P_0 (1 + p)^n$$

We multiply this equation by $(1 + r)^{N-n}$ and sum over n to obtain

$$\begin{aligned} \sum_{n=0}^N (1 + r)^{N-n} V_{n+1} - \sum_{n=0}^N (1 + r)^{N-n+1} V_n &= E_0 \sum_{n=0}^N (1 + r)^{N-n} (1 + \epsilon)^n + \\ &\quad - P_0 \sum_{n=0}^N (1 + r)^{N-n} (1 + p)^n \end{aligned}$$

or

$$V_{N+1} + \sum_{n=0}^{N-1} (1+r)^{N-n} V_{n+1} - \sum_{n=0}^{N-1} (1+r)^{N-n} V_{n+1} - (1+r)^{N+1} V_0 =$$

$$E_0 (1+r)^N \sum_{n=0}^N \left(\frac{1+\ell}{1+r}\right)^n - P_0 (1+r)^N \sum_n \left(\frac{1+p}{1+r}\right)^n$$

Since

$$S_N = \sum_{n=0}^N (1+x)^n$$

and

$$(1+x)S_N = \sum_{n=0}^N (1+x)^{n+1}$$

so then subtraction shows that

$$xS_N = (1+x)^{N+1} - 1$$

$$\text{We have for } x = \frac{1+\ell}{1+r} - 1 = \frac{1+\ell - (1+r)}{1+r} = \frac{\ell - r}{1+r},$$

$$\sum_{n=0}^N \left(\frac{1+\ell}{1+r}\right)^n = \frac{\left(\frac{1+\ell}{1+r}\right)^{N+1} - 1}{\frac{(\ell - r)}{(1+r)}}$$

Hence

$$V_{N+1} = V_0 (1+r)^{N+1} + E_0 (1+r)^{N+1} \frac{\left(\frac{1+\ell}{1+r}\right)^{N+1} - 1}{(\ell - r)} +$$

$$- P_0 (1+r)^{N+1} \frac{\left(\frac{1+p}{1+r}\right)^{N+1} - 1}{(p - r)}$$

The net present value of V_{N+1} is $V_{N+1}/(1+r)^{N+1}$, so

$$\text{NPV} = V_0 + E_0 \frac{\left(\frac{1+\ell}{1+r}\right)^{N+1} - 1}{(\ell - r)} - P_0 \frac{\left(\frac{1+p}{1+r}\right)^{N+1} - 1}{(p - r)}$$

This equation can also be written

$$NPV = V_0 + \frac{E_0}{1 + \ell} \frac{1 - \left(\frac{1 + r}{1 + \ell}\right)^{-(N+1)}}{\frac{1 + r}{1 + \ell} - 1} - \frac{P_0}{1 + p} \frac{1 - \left(\frac{1 + r}{1 + p}\right)^{-(N+1)}}{\frac{1 + r}{1 + p} - 1}$$

If we let

$$r_\ell \equiv \frac{1 + r}{1 + \ell} - 1 \quad (\text{DB-4})$$

$$r_p \equiv \frac{1 + r}{1 + p} - 1 \quad (\text{DB-5})$$

then

$$NPV = V_0 + \frac{E_0}{1 + \ell} \frac{1 - (1 + r_\ell)^{-(N+1)}}{r_\ell} - \frac{P_0}{1 + p} \frac{1 - (1 + r_p)^{-(N+1)}}{r_p} \quad (\text{DB-6})$$

Note that $E_0/(1 + \ell)$ and $P_0/(1 + p)$ are the equivalent beginning-of-year values of the end-of-year earnings and payments. The $(1 + \ell)$ and $(1 + p)$ factors appear because E_0 and P_0 are end-of-year and V_0 and NPV are beginning of year values. For beginning-of-year payments, replace $E_0/(1 + \ell)$ and $P_0/(1 + p)$ by E_0 and P_0 , respectively.

Note that $N = 0$ corresponds to a one-year project. To make N be the number of years of the project, $(N + 1)$ should be replaced by (N) in the above formula.

APPENDIX D-3

NUMERICAL EXAMPLE

Tradeoffs might be based on no discounting. If we were to take

$$PI \text{ (oil)} = 13\%$$

$$i \text{ (bank)} = 8\%$$

$$GI = 10\%$$

$$EI = 7\%$$

we would have, assuming investment in GI, since $GI > i$,

$$r_p = \frac{1 + 0.10}{1 + 0.13} - 1 = -0.0266$$

$$\frac{NPV(P_o)}{P_o} = 26.85$$

Rather than the 20.00 for no discounting.

TASK 0 - OPINION SURVEY

II. Opinion Survey, Number of Demonstrations Required to Meet Stated Goals

A. Summary and Conclusions

The enclosed series of reports were prepared by carefully selected representatives of a cross section of the business economy. Each individual selected was asked to prepare a written statement expressing their opinion. In no case was the writers prompted or assisted by ITC personnel. The question concerning the number of non-residential solar demonstrations required to stimulate the market and create an industry was presented in general terms, as clearly as possible, leaving the writers free to make assumptions as required and express their own opinions. In one case, the writer, Mr. Anthony W. Adler, elected to conduct a brief survey of the financial community before preparing his recommendations. In addition to his recommendations concerning the number of demonstrations required, Mr. Adler's survey recommends the following as objectives to be accomplished by the demonstrations:

1. The demonstration projects must prove to be economically viable and offer significant cost savings over existing energy sources. A life cycle basis can be used.
2. The solar systems must demonstrate proven reliability.
3. The solar systems must be installed in buildings which are representative of those in each of the climatological regions and should be both new and retrofit installations. Additionally, there should be a representative cross section of each type of building structure.
4. At least 10 percent of the projects should be for nationally known companies in industries where there exists a potential need for additional installations such as the textile industry. By working with these national corporations there is a high degree of probability that the financial community will receive needed valuable input in terms of user acceptance or reflection of solar systems.

5. The legal question of sun rights must be settled.
6. There should be federal and state tax incentives and/or government guarantees to stimulate user demand.
7. The question of local zoning laws and potential restrictions to solar installations must be investigated and addressed on a national scale.

Mr. Adler's survey of 47 different financial institutions resulted in a recommendation of from 120 to 156 demonstrations with from 10 to 13 demonstrations to be installed in each climatic region.

The individual reports prepared by each of the selected representatives is enclosed. In general, the number of demonstrations suggested by the opinion poll ranges from 50 to 240. The general consensus of opinions received indicates that the number of demonstrations required to meet all of the requirements of the program is a minimum of 150 and a maximum of 200.

Task 0, Opinion Survey
Special Report
Submitted by Mr. John I. Yellott
Visiting Professor in Architecture
Arizona State University

The following is an excerpt from a report prepared for ITC by Mr. Yellott titled, "Analysis of Selection of Building Types and Numbers Required for Adequate Demonstration of Solar Heating in 12 Specified Climatic Regions". The number of demonstrations recommended is based on:

- a. the number of people influenced;
- b. the potential energy saving if demonstrations show that solar heating of space and service hot water can pay investment cost in a reasonably short time.

Assuming on an arbitrary basis that one demonstration should serve an urban population of 50,000 people, the numbers would be as shown in column four of the following table. The total number of demonstrations on this basis would be 382. The number should be adjusted to compensate for population density in New York and Chicago.

If city area were used with one or two demonstrations assumed for each fifty square miles of municipal area, the total number of demonstrations would be eighty four (84) as shown in column five of the table.

A more careful demographic study of SMSA data would provide a refinement of columns four and five and a more logical selection of numbers and types of demonstrations to be recommended.

Summary:

- A. Locate the demonstrations where the people are now and where they will be living in the near future.

B. Install sufficient demonstrations in selected SMSA's to be convincing.

C. Choose climatic regions and conditions where successful demonstrations are reasonably well assured.

TABLE

Demonstration Location and Number

<u>City</u>	<u>Population (1970)</u>	<u>Land Area (Sq. miles)</u>	<u>Population per sq. mi.</u>	<u>Demonstrations</u>	
				<u>Population</u>	<u>Area</u>
Boston	641,000	46.0	13,936	13	2
Washington/New York	8,652,000	341.1	38,664	173	14
Dallas/Fort Worth	844,000	265.6	3,179	17	11
Atlanta	497,000	131.5	3,779	10	5
Madison	173,000	48.5	3,572	3	2
Omaha	347,000	76.6	4,534	7	3
Chicago*	3,367,000	222.6	15,126	67	9
Los Angeles	2,816,000	463.7	6,073	56	18
Phoenix	582,000	247.9	2,346	12	10
Denver	515,000	95.2	5,406	10	4
Pensacola*	(353,000)	-	-	7	3
Charleston	(340,000)	-	-	<u>7</u>	<u>3</u>
				382	84

* Chicago replaces Bismarck and Pensacola replaces Miami.

Ref: Stat. Abs., 1974, pp 23-25.

Task 0, Opinion Survey
Special Report
Submitted by Mr. J. F. Wagner
The Singer Company
New York, New York

Minimum Demonstration Size

This memorandum is intended to answer an ITC request for an estimate of how many sites would be required for an effective national demonstration of the economic viability of Solar Energy for the heating and cooling of buildings. I have estimated that between 200 and 400 sites are required to accomplish this goal.

One basis on which such estimates could be formed is the proper design of the experiment. Using Graeco-Latin Squares, I think about 432 sites would be required. The underlying reasoning is premised on the need to explore three basic factors.

- A. Climatic Zones of which there are twelve.
- B. Building type and usage categories of which there are twelve.
- C. Solar energy application of which there are three (of three possible applications, heating water, heating space and heating and cooling space, two are probably appropriate for most new structures and only one for retrofit applications.)

These three factors give a total of $12 \times 12 \times 3 = 432$ basic cells to be explored. Of the secondary factors, the 12 system options and 12 component options outlined in my memo to Norris Beard, dated July 23, 1975 and titled, "Screening Topics", Attachment I could be laid in the usual Graeco-Latin technique so as to provide linearly independent estimates in an minimal data sense for all of the primary and secondary factors. Thus, for a complete design the experiment should have 432 experiments. However, our analysis in

conjunction with the basic matrix is likely to show that at least half of these are not economically attractive and so the lower limit of 200 sites appears appropriate.

A second basis for estimating the number of desired sites could be found in the public relations end of things. It is clear that ten sites would be too little since we already have at least this number of buildings with little or no effect. It is also clear that within the time frame 1000 or more sites is an unmanageable task. Following the advertising media technique, the top 100 markets form a basis for most TV advertising campaigns and suggest that something of this order is the minimal requirement, if we are to provide the decision makers with a site similar to that he might be contemplating for solar energy.

Then again, we must have something in the order of at least 200 demonstration sites. A more careful analysis by someone skilled in public relations could refine this latter estimate a great deal and I recommend such to your attention.

Task 0, Opinion Survey

Special Report

Submitted by Mr. J. E. Taylor

Solar Corporation of America

Washington, D. C.

I. Introduction

"The principal criterion for recommending the number and type of projects is the ability of those projects to stimulate the participation of commerce and industry in solar equipment manufacturing, marketing, financing, and installation."

With these words, ERDA announced in June 1975 the extensive study phase of the National Plan for Solar Heating and Cooling.

This prime emphasis on enlisting the willing and massive cooperation and investment by all requisite sectors of the private business world is very important for several reasons.

For one, the change over all of our energy consuming activity to the maximum feasible extent must be accomplished in the shortest possible time. This can only be done by achieving the widest acceptance by all business sectors that in this program lies enormous responsibility and opportunity for minimizing damage to the American way of life caused by the impact of escalating fossil fuel costs. Concurrent with the responsibility will go excellent opportunity to apply existing investments and skills to a highest priority national requirement at good profit levels. This will be particularly attractive to businesses who get in early and develop expertise in working in the solar power area.

II. Key General Requirements

The key requirements for approval of any new business activity in the American business community are:

- a. Net profit potential: Is the profit potential large enough to warrant the dedication of assets, both human and material, required to capture and hold for five or more years an attractive share of the market? Is the net profit level expected from solar energy activity competitive with other opportunities available in the specific time frame under study? Is the long-range opportunity interesting? Is the total annual profit large enough to warrant our attention?
- b. Is this business compatible with our skills in marketing, developing and manufacturing? Do we know how to compete in this field?
- c. Capital required: Will the necessary processes and materials require extensive new capital or tie up existing assets to the exclusion of attractive products currently in production? Secondly, is new capital tight or abundantly available? Is the financial climate expansive or restrictive?
- d. Risk factor: It is widely understood that the new product development segment of any business carries high risk. The greater the departure from existing current practice, the more uncertain is the prospect of a successful venture. The failure ratio for new ventures frequently is 8 out of 10. Hence, all companies want to take a long hard look before entering a new area, especially if the work to date has been largely experimental with no demonstrated successful volume production to show the way.

III. Specific Concerns of Business Groups

1. Materials Suppliers

re: glass, plastics, sheet metals, extrusions, fittings, adhesives, elastomers, fasteners, plumbing, tanks, controls, pumps, coatings.

These businesses usually are among the most receptive to supply products to a new venture because they usually can adapt existing technology and plant. They are often highly capital intensive and this tends to make them go slow if a new product requirement "appears" to demand a major change by them. They will want assurance that experimental products will not quickly give way to yet another design change and obsolete the investment. For this reason, solar power will do well to use existing plant and product unless overpowering reasons dictate otherwise.

2. Lending Institutions

re: Banks, Building & Loan Companies, Credit Unions.

These companies are often among the most cautious in the business sector. They fear unknown quantities in new situations which can cause property values to drop below mortgage loans and hence expose them to loss situations. They will, therefore, want to be assured that solar power equipment will remain serviceable long enough for it to pay off its incremental cost over other HVAC equipment. In addition, architect-engineers will do well to make a major effort to produce designs that are aesthetically pleasing and solar equipment makers must produce product which will remain attractive. Low maintenance and insurance costs, as well as low initial prices for the system will, of course, make it possible for greater numbers of user companies to justify the building.

3. Insurance Companies

These companies will want assurance that there are no unusual risks of damage or injuries during severe weather due to such factors as high winds, hail, earthquakes, snow, freezing, falling limbs, and cloud bursts. In addition, designs that are relatively secure from leakage, vandalism, or accidental damage, or which do not use combustion in buildings, will command lower rates and hence be more affordable.

4. Real Estate Sales

These concerns will be primarily interested in impact on their sales. Such factors as reliability, initial cost, operating and maintenance costs, and aesthetics will be of interest.

5. Labor Unions

The building trades are among the most zealous in preserving the status quo in the building industry. For long years they have pressed to maintain local building codes, all too often outmoded. These groups will seek assurance that installation of solar HVAC systems will not reduce jobs or make way for rival unions to enter a new territory. This may slow the desirable trend to integration of collector functions with other functions such as roof or the water storage with a swimming pool.

6. Construction Companies and A & E's

The construction companies are well accustomed to building what the A & E's specify. The A & E's are usually able to accept client demands for a specific type of system, seeking client release only where there is substantial new design practices and costs. It is one of the main objectives of the program to remove all the main areas of doubt, hence it is not anticipated there will be trouble from builders.

IV. Specific Examples

In 1954, TRW, Inc., contracted to construct and operate a \$2.5 million gas turbine components test laboratory of a design advanced beyond those previously built. An ITC consultant was project manager during construction over a two year period and later supervised operation of this facility for several years.

The problem of convincing TRW top management to approve this project took a substantial period because it was difficult to show what products would be developed and hence a profit analyses could not be developed. Further complicating the picture was the fact that limited testing was available at customer and government laboratories at some risk to proprietary position. This reduced TRW incentive to invest. This problem was solved when the United States Navy agreed to provide most of the funding for construction on condition that TRW bear the cost of supervision of construction and later, operation of the laboratory.

This entailed working under the Bureau of Yards and Docks and brought into play the many constraints of such government construction. This caused considerable slow down due to red tape, particularly in forcing award to the low dollar bidder rather than then to the best offer, all things considered.

In some cases this also caused long delay and reduced the quality of the laboratory. For example, Bolt, Beranek, and Newman, a leading acoustics consulting firm, produced an excellent design for the sound treatment which was an absolute necessity to make the facility tolerable to its neighbors.

We have all heard the phrase associated with fouled projects: "It went to the low bidder!" The case at hand was no exception. Out of nine bids, one was much lower than the others. The project manager investigated and recommended it be thrown out. Appeal to the Navy was sustained and the result: the sound treatment didn't pass specified tests. This caused a five month delay and never did work up to specification.

Another problem closely allied with the acoustic problem was the task of getting zoning changed to permit the variance in sound level. Originally, the community was eager to have a job producing facility which would attract well-paid professionals. After a few days of operation at audible noise levels, the annoyance factor went up and the zoning committee was far less accommodating. A small amount of brinkmanship was required to get the use permit.

Problems with the architect/engineer, a leading technical group by reputation, were many. These primarily stemmed from the fact that this was a new technical area that the A & E had not been exposed to previously and the project engineer was not quick to perceive when he was out beyond his experience.

These problems were all eventually solved by patient, firm direction but the price went up and the project time table was violated.

The builder was extremely eager and cooperative and there were no problems beyond routine interpretation of spec problems which were readily solved.

Problems were encountered with subsystem suppliers in several cases because they were breaking new ground. These communication problems were usually caught in project and design reviews before costly hardware mistakes were made. In one case, the supplier of a high temperature spin pit interpreted a specification incorrectly and delivered a \$75,000 sub-system that was not satisfactory. This had to be corrected at substantial loss to the sub-system.

In the case of the solar heat and cooling program, much care should be taken to prevent supplier losses because this could set the advent of solar power back. A similar misapplication happened in the 1960's when heat pumps were

oversold, underdesigned, and poorly understood by the builders. Many of them in the North failed to provide user reliability and comfort control.

As a result some builders who used heat pumps got a black eye and for a decade heat pumps were all but blackballed.

The TRW gas turbine laboratory project experienced no problems with real estate people, insurance, lending institutions or labor unions.

In conclusion, the government red tape problem was the major difficulty. It is possible that ERDA may wish to bypass this problem by selecting a private, professional business firm to manage this program as the Air Force did with its ballistic missile program so successfully.

V. Summary

Integrating these factors with respect to their effect on the National Solar Cooling and Heating Plan, it is seen that a wide variety of building types, solar cooling and heating systems which demonstrate a range of effective designs and techniques, a generous dispersion of building locations, types and use patterns are desirable. A minimum of 50 to 100 buildings is suggested to insure wide participation by a-l segments of the business areas previously discussed as well as a broad cross-section of users in each geographical region.

Task 0, Opinion Survey
Special Report
Submitted by Mr. William Graff, AIA
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Washington, D. C.

The late Walter Gropius told me many years ago that once the proper questions have been asked in outlining a problem, a significant number will suggest their own answers and solutions. This short essay will attempt to pose, therefore, a few pertinent questions in an effort to reach a figure as to the type and number of solar demonstration projects needed to convince the United States public of the feasibility, and even more of the absolute necessity, to utilize solar energy.

1. It is clear that the purpose is to demonstrate that solar energy is not only a readily available but also a plentiful, unending and harnessable source of energy. In fact, it is the original source of all our combined energy sources, such as fossil fuels, wind, hydroelectric, geothermal, nuclear, tide and ocean thermal energy. The fact that minimum skilled labor is required to run a solar energy collecting plant once installed should also be stated and proven. All other known systems require skilled operators, whether to maintain an installation, to deliver a product or even to prevent accidents.
2. Whereas it is obvious that the public at large will have to be awakened to the potentials of this new source of energy, it is those who have a direct bearing on its immediate utilization who will have to be persuaded first. The obvious ones would be the designer, the developer, the financier. However, the stimulus which would be provided at this stage by comprehensive regulations and legislation, whether on a federal or a local level, cannot be underestimated in easing the function of the former. As in most technical developments, so too in solar research an enormous amount of work and information moves in parallel - and therefore duplicate - lines. This diversity of effort, however, has resulted in the present complexity of our technical institutions, particularly in the

variety of construction methods. Therefore, a cross-reference system, such as proposed by the Interim Report published by the Energy Research and Development Administration in March, 1975, should be encouraged not only on a governmental level but also with industry.

Conversations I have had with numerous clients, builders, developers and financiers have further demonstrated just how little is known about these new methods of construction even within the industry. Even more significant is the fact how few are the developers who avail themselves of the architect and engineer in utilizing new developments in building techniques. It should be further pointed out that though a large percentage of the public has become aware of the energy crisis either through the rising cost of fuels or through awareness of imminent shortage, much is blamed on politics and the maneuvering or the part of producing companies and countries. It should be stressed, therefore, that solar energy is truly there for the taking and is immune to any and all monopolies. Only by initiating its utilization shall we learn exactly how this is best done.

3. Now let us ask what impresses the decision makers most? The answer is simply cost efficiency. Questions on initial cost, operating economy, life of the system, maintenance and reliability and overall economic profile as compared to other heating and cooling systems will have to be answered as fully as possible. There are, of course, those who need no conviction, realists who perceive objectively where the present course is leading us, the 'waste not, want not' types, the Sierra Clubs and many others of good common sense. The most eloquent proof to be presented to professional and layman alike in order to win their support would be a real, working demonstration model with a measurable output and cost.

4. How can this be achieved? Any functioning and documented project, whether it be a school, a hospital or an office building would achieve this end. The need of a real, rather than a theoretical model, preferably in the various climatic regions of the United States needs to be stressed here. On the other hand, it would not be necessary to have exclusively solar heating and cooling

in any one structure; as a matter of fact, this is not practical according to studies made up to date. Auxiliary systems would be therefore required.

5. Since conversion to a new energy system would mean financial hardship to many, proper incentives are required. These are a legion and run from tax incentives to subsidies and accelerated depreciation. A most important incentive should be added to these, however; namely, the control which could be imposed by zoning and buildings regulations which would not only encourage, but actually impose energy-saving standards and even award bonuses for such installations. (Please note that the Shah of Iran has commissioned a solar-heated satellite city for Teheran recently, which demonstrates the farsightedness of this ruler.)

6. The distribution of these demonstrator models then should be undertaken with the utmost care since too few will not have the desired impact, and too many may waste or duplicate efforts as well as errors.

Taking the twelve climatic regions of the United States as a base, one demonstration project per million inhabitants would seem a reasonable and feasible number. The resulting 240 pilot projects should be distributed strategically around major demand areas, particularly attractive both for ecological and publicity reasons. Since the energy shortage affects those who can least counteract it on their own, they should be the first to benefit from this new technology: hospitals, schools and public buildings as this would also eventually decrease the expense to the taxpayer. Conversions and retrofitting of suitable structures should be also in the forefront along with new construction, particularly again if they are in the public domain.

In concluding this brief analysis, reference should be made to the many professional studies, as well as reports, written in the recent past, but especially in the last year or two. The potential impact of solar energy is significant. Looking then at the energy problem objectively, let us ask what other choices are open to us? Let us not wait for an energy-generated Pearl Harbor.

The writer is an architect. During his 25-year career, he has taken part in a multitude of projects, large and small, private and public, industrial, institutional and speculative. Some solar designs were also included in his projects.

Task 0, Opinion Survey
Submitted by Mr. Anthony W. Adler, President
Solar Investors Associates
Mamaroneck, New York

SUMMARY AND CONCLUSIONS

This report was undertaken to determine the number of commercial solar demonstration projects (nonfederal nonresidential) necessary to stimulate the interest of the investment community in financing manufacturers of solar heating and cooling systems. To form a basis for the answer to this question, extensive interviews were conducted with key individuals in forty-seven firms in the investing community (venture capitalists, commercial bankers and insurance executives). As expected, these interviews resulted in many faceted responses which were difficult to summarize and required thorough analysis and interpretation.

On the basis of that analysis, it is my opinion that the Demonstration Plan should call for 10-13 commercial solar installations in each of the twelve climatological regions, or a total of 120-156. The installations within each region should be in as many different functional classifications of structures possible.

BACKGROUND

In undertaking this report, it was first necessary to identify those kinds of financial institutions which would most likely be involved in financing a new industry as well as their goals and policies.

The traditional sources of capital in this country can be divided into four classes: venture capitalists, commercial bankers, insurance companies and investment bankers. The basic goals and policies of each of these are as follows:

Venture capitalists seek a high return on their investments as they are usually willing to take calculated risks by financing on an equity basis young unproven companies. They will usually

develop a close working relationship with the management of companies in question to both assist as well as oversee.

Commercial Bankers generally lend either secured or unsecured on a short to intermediate basis (1-7 years). Their main concern is how they will be repaid and therefore make a critical assessment of management and its ability to produce a positive cash flow.

Insurance Companies lend on a long term secured basis with the security usually being capital equipment or real estate. In this instance the quality of the security is every bit as important as the creditworthiness of the borrower.

Investment Bankers perform all of the above functions, e.g., raising venture capital and arranging short or long term credit. Their unique ability is that they underwrite debt or equity securities thereby involving the public market sector.

Since we are dealing with financing a new industry it would be highly unusual to find a willing public market to finance same, especially in light of both current and projected capital shortages. Therefore, it was decided not to include investment bankers in this study.

A representative sample of the remaining three classes of financial institutions was chosen on the basis of their size, generally known or published objectives and their proximity to one or more of the twelve climatological regions (see Table I).

Once it was determined who would be interviewed, it was then necessary to broadly define the various size manufacturers these institutions might well be asked to finance. These were also divided into four classes: major, sub-major, first stage and start up. In the cases of the major manufacturers such as General

Electric and Westinghouse and the sub-majors such as Kalwall Corporation, it was determined that they could obtain financing on the basis of their overall corporate credit and that neither the size nor the scope of a Solar Demonstration Project would have more than tertiary or secondary impact on the financial institution's decision making process. First stage and start-up companies, however, present an entirely different situation. First stage companies are defined as those which have demonstrated solar capability, whose major product base is solar and whose revenue and earnings records are minimal. Two examples are InterTechnology Corporation and Sol-R-Tech. Start-ups are defined as new companies entering the solar field with no demonstrated capability such as Ecotherm Ltd. It is with these latter two classes of solar manufacturers that the Solar Demonstration Plan will have the most significant impact. Any funding source when asked to finance a new or young company in a new industry will be concerned with factors such as market size and potential, market share and potential, product reliability, management expertise and experience, product acceptability, customers' ability to pay and government guarantees, among others.

SIGNIFICANT INTERVIEW RESULTS

In only one instance did an interviewee refuse to participate. Each of the remaining interviewees was extremely cooperative but found it difficult if not impossible to specify an exact number or range regarding the unit size of the Demonstration Plan. However, a thorough analysis of the compiled data indicates that the following points have a significant degree of importance:

1. The demonstration projects must prove to be economically viable and offer significant cost savings over existing energy sources. A life cycle basis can be used.
2. The solar systems must demonstrate proven reliability.
3. The solar systems must be installed in buildings which are representative of those in each of the climatological regions and should be both new and retrofit installations. Additionally, there should be a representative cross section of each type of building structure.

4. At least ten percent of the projects should be for nationally known companies in industries where there exists a potential need for additional installations such as the textile industry. By working with these national corporations there is a high degree of probability that the financial community will receive needed valuable input in terms of user acceptance or rejection of solar systems.

5. The legal question of sun rights must be settled.

6. There should be federal and state tax incentives and or government guarantees to stimulate user demand.

7. The question of local zoning laws and potential restrictions to solar installations must be investigated and addressed on a national scale.

Points 1-4 led to the conclusion expressed in the opening section of this report. It is also concluded that the creditworthiness of the solar manufacturer is of prime importance and in no way can be directly affected by the Demonstration Program.

Finally, it was generally agreed that the market for solar systems will be influenced by strong social support, probable economic savings and lack of political conflict.

<u>State</u>	<u># Banks</u>	<u># Insurance Companies</u>	<u># Venture Capital Co's</u>	<u>Total</u>
Arizona	1	-	1	2
California	2	1	2	5
Colorado	1	-	1	2
Connecticut	1	2	-	3
Dist. of Columbia	1	-	1	2
Florida	1	1	1	3
Georgia	1	1	1	3
Maryland	1	-	1	2
Massachusetts	1	1	1	3
Nebraska	1	1	-	2
New Jersey	-	1	1	2
New Hampshire	1	-	-	1
New York	2	2	4	8
South Carolina	1	-	-	1
Texas	2	1	2	5
Wisconsin	<u>1</u>	<u>1</u>	<u>1</u>	<u>3</u>
Total	18	12	17	47

Geographic Distribution of Financial Institution Sample

CHANGE IN CLIMATIC REGION DESIGNATOR

<u>Zones</u>	<u>City</u>	<u>New Designator</u>
1	Boston	Eastern/Great Lakes
2	Washington, D. C.	Mid Atlantic
3	Madison	Midwest/Down East
4	Los Angeles	Far West
5	Charleston	Southeast
6	Bismarck	Northern Plain
7	Nashville	Central Humid
8	Fort Worth	Southern Plain
9	Omaha	Central Plain
10	Seattle	Pacific N. W.
11	Phoenix	Southwest
12	Miami	Southern Florida