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SOLAR ENERGY SYSTEM ECONOMIC EVALUATION--FINAL REPORT FOR SEMCO-LOXAHATCHEE, LOXAHATCHEE NATIONAL WILDLIFE REFUGE, PALM BEACH COUNTY, FLORIDA

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For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy

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1. FOREWORD

The Solar Energy System Economic Evaluation - Final Report has been developed by the George C. Marshall Space Flight Center as a part of the Solar Heating and Cooling Development Program funded by the Department of Energy. The analysis contained in this document describes the economic performance of an Operational Test Site (OTS). The objective of the analysis is to report the long-term economic performance of the system at its installation site and to extrapolate to four additional locations which have been selected to demonstrate the viability of the design over a broad range of environmental and economic conditions.

The contents of this document are divided into the following topics:

- System Description
- Study Approach
- Economic Analysis and System Optimization
- Results of Analysis: Technical and Economic
- Economic Uncertainty Analysis
- Summary and Conclusions

The data used for the economic analysis have been generated through evaluation of the Operational Test Site described in this document. The data that have been collected, processed, and maintained under the OTS Development Program provide the resource from which inputs to the simulation programs used to perform technical and economic analysis are extracted.

The Final Report document, in conjunction with the Seasonal Report for each Operational Test Site in the Development Program, culminates the technical activities which began with site selection and instrumentation system design in April, 1976. The Seasonal Report emphasizes the technical analysis of solar systems performance. It compares actual performance with predicted performance derived through simulation methods where actual weather and loads defined the inputs. The simulation used for final report analysis is based on the technical results of the seasonal report simulation, with the exception that long-term weather, and derived loads are used as inputs instead of measured weather and loads. This causes the expected value of solar system performance in the Seasonal and Final Reports to differ. In addition, localized and standard economic parameters are used for economic analysis in the final report evaluation. The details of the simulation program are described in Reference [4]* and [5]. Other documents specifically related to the solar energy system analyzed in this report are [1], [2] and [3].

*Numbers in brackets designate references found in Section 8.

2. SYSTEM DESCRIPTION

The Semco Loxahatchee Solar Energy System is located in the home of the refuge manager of the Loxahatchee National Wildlife Refuge in Palm Beach County, Florida. The system is designed to provide domestic hot water (DHW) to the one-story residence. The solar energy system is designed to supply ninety percent of the domestic hot water energy requirements for the residence. The hot water load specified as a design goal for the system is an average load of 1,125,000 Btu/month with a usage rate of 75 gallons per day, at not less than 140°F [2].

The collector array is composed of two Solar Engineering and Manufacturing Co. (SEMCO) Model FP40-7-DG flat plate solar collector panels connected in series. The collector panels are mounted facing south at a tilt angle of 36.7° from the horizontal. Water is utilized as the heat transport medium and is circulated directly from the 120 gallon hot water storage tank through the series-connected panels by a 1/20 HP pump. Gross area of the collectors is 80 square feet* and the collectors are double glazed with tempered glass.

The 120 gallon hot water storage tank is a standard direct feed solar tank and is externally insulated with two-inch thick, high-density fiberglass. Auxiliary energy, as required to maintain a selectable temperature, is provided to the hot water storage tank by a 240 volt, 4500 watt, electric resistance heating element. The system is shown schematically in Figure 2-1. The sensor designations in Figure 2-1 are in accordance with NBSIR-76-1137 (Reference [6]). The measurement symbol prefixes W, T, EP and I represent, respectively: flow rate, temperature, electric power and solar insolation. Figure 2-2 is a pictorial view of the refuge manager's home.

System control is accomplished by a proportional controller designed for application to solar energy systems. The controller operates on

*Some Semco documentation indicates gross array area may be as much as 84.22 ft^2 (i.e. panel is 10' 2-1/2" x 4' 1-1/2" instead of 10' x 4'). With MSFC verbal concurrence, 80 square feet has been used in all site analyses.

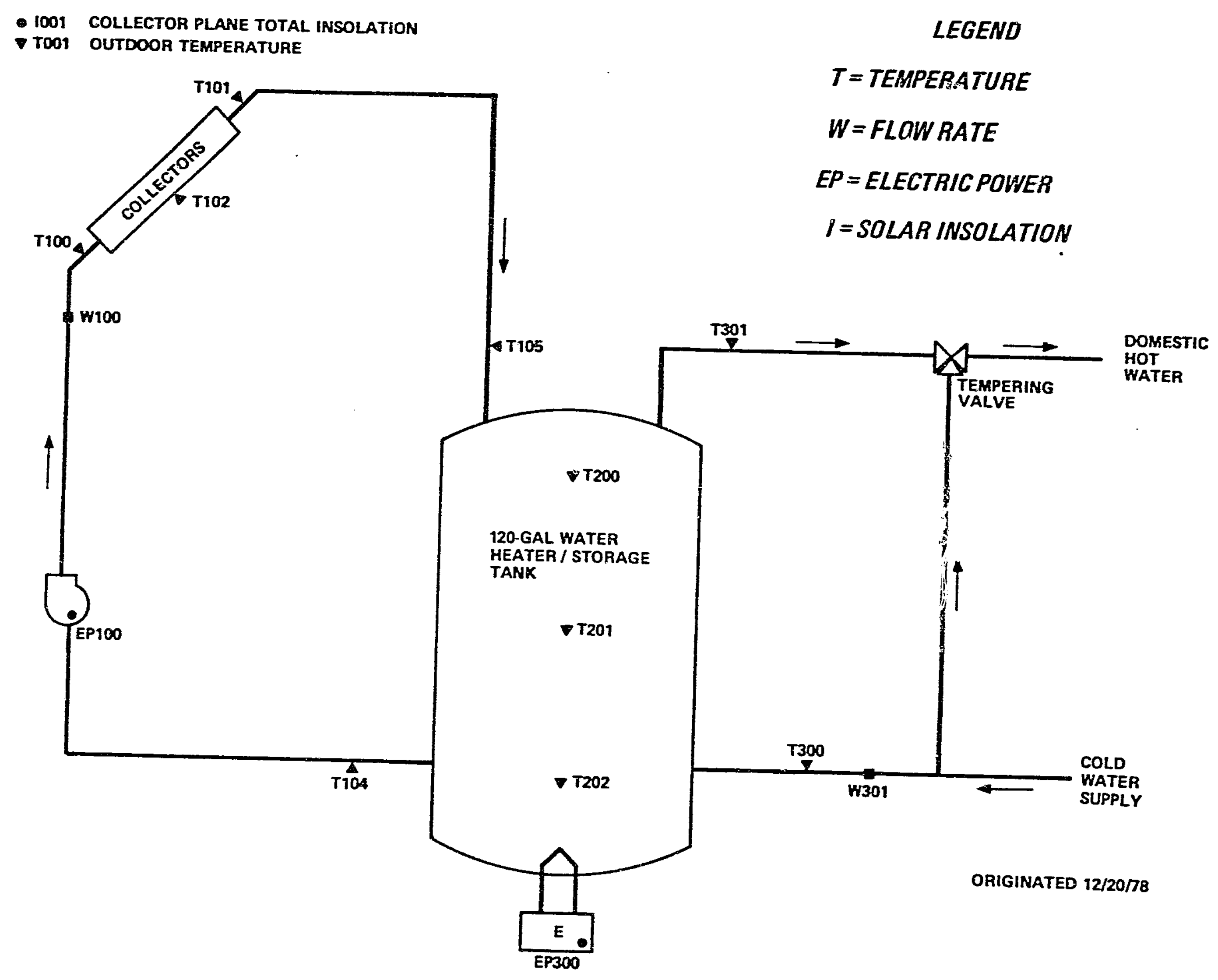
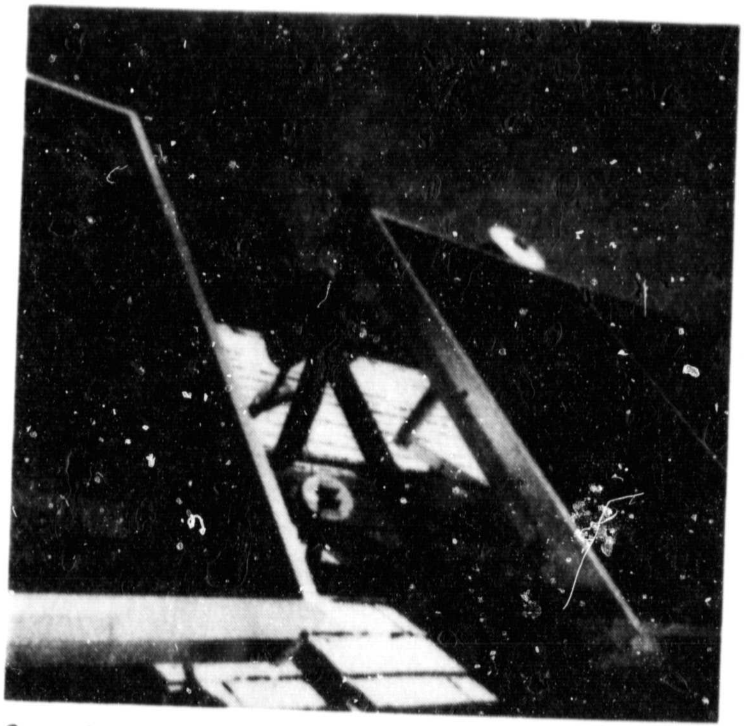
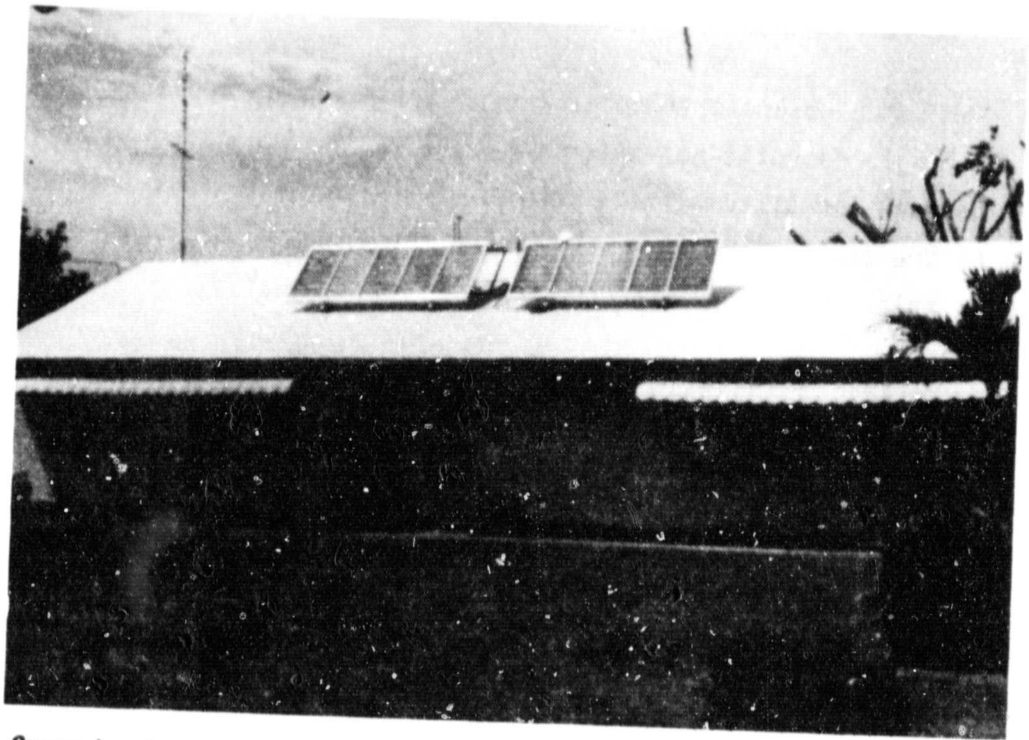


Figure 2-1 . SEMCO-LOXAHATCHEE, FLORIDA, SOLAR ENERGY SYSTEM SCHEMATIC



Samco Loxahatchee– Piping Detail



Samco Loxahatchee–Ranger's Residence

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Figure 2-2. Samco Loxahatchee Pictorial

a sensed difference in temperature between the collector absorber plate and the bottom of storage. The controller provides an output which controls the pump speed to produce a flow which is proportional to the collector-to-storage temperature differential over the range of 3°F to 16°F; a 13°F temperature differential produces maximum pump speed and hence, maximum flow in the system.

The only active solar operational mode for the Semco Loxahatchee System is described as follows:

Mode 1 - Collector-to-Storage: This mode is entered when the differential controller recognizes that the collector absorber plate temperature exceeds the temperature in the bottom of the storage tank by a fixed value (nominally 13°F). The mode is terminated when the measured differential temperature drops below a fixed value (nominally 3°F).

The Semco Loxahatchee Solar Energy System is an application that utilizes a single domestic hot water tank. This is considered an appropriate design feature for systems where nominal daily usage is less than the capacity of the tank. This feature enables the standby losses to be made up directly by solar energy, thereby saving electrical energy.

3. STUDY APPROACH

3.1 Introduction

The Final Report is an economic evaluation of the solar energy system (based on life cycle costs versus energy savings) for five cities which are considered to be representative of a broad range of environmental and economic conditions in the United States. Life cycle costs provide a measure of the total costs of owning and operating a system over the life of the system rather than focusing solely on the initial cost of the system. The life cycle costs used in this evaluation consider hardware, installation, maintenance, and operating costs for the solar-unique components of the total system. Energy savings result from replacement of conventional forms of energy by solar energy after the costs of producing the solar energy are deducted. The total system operates in a scenario that comprises long-term average environmental conditions, loads, fuel costs and other economic factors that are applicable in each of five cities.

The five cities include four standard analysis sites which were selected according to the criteria listed below and the site where the system was, in fact, installed and operated. The selection criteria were based on:

- Availability of long-term weather data
- Heating degree days (load related factor)
- Cold water supply temperature (load related factor)
- Solar insolation
- Utility rates
- Market potential
- Type of solar system

To achieve the range of environmental and economic parameters desired, the four locations listed below, plus the actual installation location, were used. A solar energy system buyer may evaluate his own local environmental and economic conditions relative to those considered in this Final Report by comparing the insolation available, the heating load (applicable only to space heating systems), and the utility rates against the results reported in Section 5.

Albuquerque, New Mexico

1828 Btu/Ft^2/day average insolation*
Medium heating load (4292 HDD)
High utility rates (> 0.06 $/kWh)**

Fort Worth, Texas

1475 Btu/Ft^2/day average insolation*
Light heating load (2382 HDD)
Medium utility rates (0.04 - 0.06 $/kWh)**

Madison, Wisconsin

1191 Btu/Ft^2/day average insolation*
High heating load (7730 HDD)
Medium utility rates (0.04 - 0.06 $/kWh)**

Washington, DC

1208 Btu/Ft^2/day average insolation*
Medium heating load (5010 HDD)
High utility rates (> 0.06 $/kWh)**

Loxachatchee (Palm Beach County), Florida

1438 Btu/Ft^2/day average insolation*
Light heating load (240 HDD)
Medium utility rates (0.04 - 0.06 $/kWh)

The parameters that define the system design were derived from the actual operating conditions of the system at the installation site. Solar energy system design may be economically optimized for the site at which the

*Insolation values are average daily long-term values on a horizontal surface.

**Utility rates are effective yearly average values based on 1000 KWH use for schedules in effect for January, 1980. See Appendix D.

system is installed. The fundamental objective in optimizing the design of a solar energy system on an economic basis is to minimize cost by allocating the required amount of energy between the solar and conventional portions of the system. To attain this objective, each unit of energy should be produced by the portion of the total system which generates the lowest incremental cost in producing that additional unit of energy. This is accomplished in the final report analysis by determining the optional solar energy system size (collector area or equivalently, solar fraction).

In the Operational Test Site (OTS) Development Program there are many solar energy systems designed by many different contractors. Some of the designs were installed in new buildings and some were retrofitted to existing buildings. Consequently, there are a variety of factors which contributed to the design of a system at a given site. In some cases the objective of optimizing the design according to the previously stated criterion could not be met. A method of evaluation which establishes a common basis for evaluation of all these systems was required. The method selected is to optimize the collector size through the f-Chart [5] design procedure. F-Chart is a design program developed by the University of Wisconsin for solar heating and/or domestic hot water systems. The program uses a set of design charts (developed by detailed simulations) which estimate the thermal performance of a solar system based on collector characteristics, storage, energy demands, and regional long-term weather data. Using the results of thermal analysis, an iterative procedure is implemented to select a collector area which minimizes the life cycle costs. Once the optimal collector size has been determined, the resulting thermal and economic performance can be obtained.

The resolution of two interrelated problems was required in order to adapt f-Chart to the evaluation developed in the Final Report. The first was how to use the data and experience gained from the actual operation of the solar energy system; the second was what procedure to follow in view of the fact that all solar energy systems to be analyzed do not have optimal collector area sizing. To resolve the first problem, the characteristics of design and operation of the existing solar energy system were used to develop the input parameters for f-Chart. This procedure, detailed in Appendix A, involved the normalization of collector flow rates and storage capacity to collector area. Collector characteristics developed from field data through a collector analysis program were substituted for the theoretical single panel parameters furnished by the collector manufacturer. To resolve the problem of different collector areas, an optimal collector area was derived for the site. The final adaption of f-Chart includes the inputs derived from operational data and optimal collector area.

As the system application at each of the five analysis sites is studied, the loads are iteratively redefined, the site peculiar parameters are changed as described in Appendix A, and a new optimal collector area is computed. The economic factors are the result of the f-Chart analysis with these inputs.

3.2 Groundrules and Assumptions

The cost differential between solar and the conventional system is significant to the economic evaluation in the Final Report. Cost items which were equal for both alternatives do not contribute to the differential cost. The cost of the conventional system was assumed to be identical with or without the solar alternative. Although a conventional system is usually selected according to the availability and cost of energy in a particular geographic region, this alternative is not permitted in the final report analysis because an existing system is being evaluated. Savings which might be realized by comparing solar against an auxiliary other than the design option were not evaluated. The system configuration, including the conventional auxiliary, is the same for all five analysis sites.

The cost of the solar unique hardware is based on mass production estimates. The total incremental costs for acquisition of a solar alternative are the sum of a cost proportional to collector area and a cost independent of collector area. For economic evaluation, life cycle costs (i.e., costs of acquiring, operating and maintaining the solar systems) were forecast on an annual basis over the design lifetime of the system, then discounted to an equivalent single constant dollar (1980) value as described in Section 4.

Fuel costs are calculated at current (1980) local values for each of the five analysis sites. Other economic parameters are standardized by referencing current national economic conditions. Maintenance, insurance, depreciation, system life, salvage values (for commercial systems) are determined from best experience. Tax credits allowed by the Federal Government for the solar energy systems are credited against the acquisition cost. A combined state and federal income tax rate of 30 percent is assumed for estimating tax savings resulting from the interest paid in financing a solar system. Property taxes arising from the increased value of property with an installed solar system are neglected due to the current trend in many states to forego these taxes to prevent them from being a hindrance to solar energy usage.

The primary measure of cost effectiveness of the solar energy system in the Final Report is:

- Life Cycle Cumulative Savings (LCCS) - The present value of the cumulative energy savings (in dollars) that result from operation of the solar system alternative instead of the conventional backup.

Two secondary measures that depend on the life cycle cumulative savings are:

- Year of Positive Savings - Year in which the solar system first becomes profitable; i.e., the annual conventional fuel bill without solar exceeds the sum of the annual fuel bill with solar and the annual cost for the solar system.

- Year of Payback - Year in which the compounded net savings equals the initial cost for the solar system. Net savings were computed with respect to the fuel cost of the conventional system.

4. ECONOMIC ANALYSIS

4.1 Factors in Life Cycle Costs and Savings

The economic calculations of this study are performed in the f-Chart program and are based on comparisons of life cycle costs of conventional energy systems with those of solar energy systems. The life cycle savings of a solar energy system over a conventional energy system can be expressed as the difference between the total fuel savings that result from operation of the solar energy system and the increased costs that result from the investment in, the operation of, and the maintenance of the solar energy system. The savings can be expressed by the relationship:

$$LCCS = P_1 \, (C_F/\eta)LF - P_2 \, (C_A A + C_E) \qquad (1)$$

where $LCCS$ = Life cycle cost savings of the solar energy system ($) in terms of present worth

P_1 = Factor relating life cycle fuel cost savings to first year cost savings

C_F/η = Fuel cost per unit divided by conventional heating unit efficiency

L = Total load on system computed from long-term average conditions (Btu)

F = Solar fraction

P_2 = Factor relating life cycle investment operation and maintenance expenditures to the initial investment

C_A = Solar energy system costs dependent on the collector area ($/Ft^2)

A = Collector area (Ft^2)

C_E = Solar energy system costs that are independent of collector area ($)

It is assumed that the costs of components which are common to both conventional and solar heating systems (e.g. the furnace, ductwork, blowers, thermostat, etc.), and the maintenance costs of this equipment, were identical. Consequently, all references to solar energy system costs refer to the cost increment above the common costs.

The multiplying factors, P_1 and P_2, facilitate the use of life cycle cost methods in a compact form. Any cost which is proportional to either the first year fuel cost or the initial investment can be included. These factors allow for variation of annual expenses with inflation and they reflect the time value* of money by discounting future expenses to present dollar values.

To illustrate the evaluation of P_1 and P_2, consider a simple economic situation in which the only significant costs are fuel and system equipment costs. The fuel cost is assumed to escalate at a constant annual rate, and the owner pays cash for the system. Here, P_1 accounts for fuel escalation and the discounting of future payments. The factor P_2 accounts for investment related expenses which, in this case, consist only of the investment which is already expressed in current dollars. The factors P_1 and P_2 are then

$$P_1 = PWF(N, e, d)$$

$$P_2 = 1$$

where N = Period of economic analysis (yrs)

e = Escalation rate of fuel price

d = Annual discount rate

*Discounting refers to the fact that an expense that is anticipated to be $1000 in 10 years is equivalent to an investment today of $463 at a discount rate of 8%.

The function PWF(N, e, d) is the present worth factor that accounts for inflating payments in discounted money.

$$PWF(N, e, d) = \frac{1}{d - e}\left[1 - \left(\frac{1 + e}{1 + d}\right)^{N}\right] \tag{3}$$

When multiplied by a first period cost (which is inflated at a rate, e, and discounted at a rate, d, over N years), the resulting value is the present worth life cycle cost.

In the more complex analysis the expenditures incurred by the additional capital investment cause P_1 and P_2 to take the following form:

$$P_1 = (1 - C\overline{t})\, PWF(N, e, d) \tag{4}$$

$$P_2 = P_{21} + P_{22} - P_{23} + P_{24} + P_{25} - P_{26} - P_{27} \tag{5}$$

where P_{21} = Factor representing the down payment

P_{22} = Factor representing the life cycle cost of the mortgage principal and interest

P_{23} = Factor representing income tax deductions for interest payment

P_{24} = Factor representing miscellaneous costs (maintenance, insurance, etc.)

P_{25} = Factor representing net property tax costs

P_{26} = Factor representing straight line depreciation tax deduction for commercial installations

P_{27} = Factor representing salvage (commercial installation) or resale value (residential installation)

The factors P_{21} through P_{27} are defined as follows:

$$P_{21} = D \tag{6}$$

$$P_{22} = (1 - D)\ PWF(N,\ 0,\ d)/PWF(N,\ 0,\ i) \tag{7}$$

$$P_{23} = (1 - D)\ \bar{t} \left\{ PWF(N,\ i,\ e)\ \left[i - 1/PWF(N,\ 0,\ i) \right] + PWF(N,\ 0,\ d)/PWF(N,\ 0,\ i) \right. \tag{8}$$

$$P_{24} = (1 - C\bar{t})\ M\ PWF(N,\ g,\ d) \tag{9}$$

$$P_{25} = t\ (1 - \bar{t})\ V\ PWF(N,\ g,\ d) \tag{10}$$

$$P_{26} = (C\bar{t}/N)\ PWF(N,\ 0,\ d) \tag{11}$$

$$P_{27} = G/(1 + d)^N \tag{12}$$

where D = Ratio of down payment to the initial investment

N = Period of analysis (Note that the period of analysis, the term of the loan, the depreciation lifetime, and the years over which the depreciation deductions contribute to the analysis are arbitrarily set equal in this report).

d = Discount rate (after tax return on the best alternative investment)

i = Annual mortgage interest rate

$\bar{t}$ = Effective income tax rate

C = Commercial or non-commercial flag (1 or 0 respectively)

M = Ratio of first year miscellaneous costs to initial investment

g = General inflation rate

t = Property tax rate based on assessed value

V = Ratio of assessed value in first year to initial investment

G = Ratio of salvage or resale value to initial investment

For a given location, heating load, and economic situation, it is possible to optimize the system design variables to yield the maximum life cycle savings. The main solar energy system design variable is the collector area. The effect of collector area on the life cycle savings is illustrated in Figure 4-1 for the four sets of economic conditions. Curve A corresponds to an economic scenario in which solar energy cannot compete with the conventional system. Curve B exhibits a non-zero optimum area, but the conventional system is still the most economical. Curve C corresponds to the critical condition where solar energy can just compete with the conventional system. Curve D corresponds to an economic scenario in which the solar energy system is the most economical.

Each curve of Figure 4-1 begins with a negative savings for zero collector area. The magnitude of this loss is C_E, and reflects the presence of solar energy system fixed costs in the absence of any fuel savings. As the collector area increases, Curves B, C, and D show increased savings until reaching a maximum at some optimum collector area. As the collector area is further increased, the fuel savings continue to increase, but the excessive system cost forces the life cycle savings of the system to decrease. The collector areas at each of the five analysis sites listed in this report have been optimized by the f-Chart program analysis technique for the long-term average weather conditions and the economic conditions at that site.

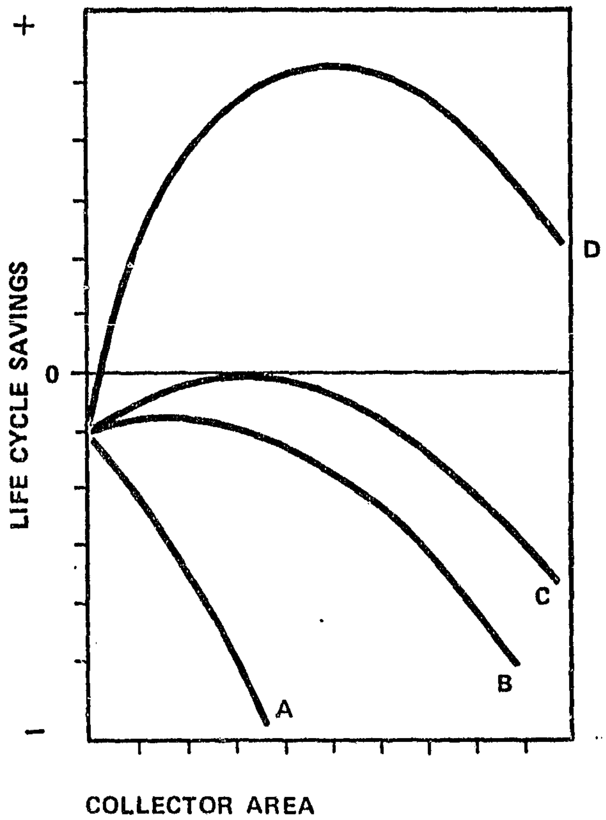

Figure 4-1 Life Cycle Savings versus Collector Area for Four Sets of Economic Conditions

4.2 Federal Tax Credits for Solar Energy Systems

The Federal Government has provided tax incentives that are applicable to solar energy systems.* This credit is 30 percent of the first $2000 plus 20% of the next $8000 spent on solar equipment, or a maximum credit of $2200. The credit is applied in this analysis by reducing both the collector area dependent cost and the cost independent of the collector area, or constant solar cost, by an effective credit factor based on the total cost of the system.

As an example of the tax credit computation, assume the collector area dependent cost is $\$30/ft^2$ based on 100 ft^2 and the constant solar cost is $900 for a total price of $3900. The effective credit factor is:

$$\frac{2000 \times 0.30 + (3900 - 2000) \times 0.20}{3900} = 0.2$$

Therefore the adjusted costs used as f-Chart inputs are:

Collector area dependent cost

$$C_{A'} = \$30 \times (1 - 0.2) = \$24/ft^2$$

Constant solar cost

$$C_{E'} = \$900 \times (1 - 0.2) = \$720$$

The f-Chart econonomic analysis is modified by using these adjusted costs to reflect tax credit effects. Including tax credit in area optimization is an iterative process since the credit is affected by the system size and vice versa. Optimal collector area was modified in this analysis, as were the f-Chart economic parameters, by use of the tax credit. Items 23 and 24 in Table 5.1-2 reflect the solar costs before application of tax credits in terms of collector area dependent cost and constant solar cost. Initial system costs before and after tax credit inclusion are shown in Table 5.2-1 for each site based on optimal collector area.

* The tax credit has been revised after 1979 to 40 percent of the first $10,000 for a maximum credit of $4,000. The new effective credit factor as given in the example above is 0.4 for systems costing less than $10,000 and the ratio of the maximum credit to the total system cost for systems costing more than $10,000.

5. RESULTS OF ANALYSIS

5.1 Technical Results

For each of the five analysis sites an optimal solar system based on the configuration of the actual installation was determined by using the f-Chart design procedure. The environmental parameters and the loads used in this procedure for each of the five sites are shown in Table 5.1-1. In applying the design procedure, a process that iterates on the collector area was used. Figures 5.1-1(a)-(e) show the results of that design procedure in terms of the expected solar fraction versus the collector area for each site. The expected solar fraction is the ratio of the expected solar energy used toward satisfying the load to the total load. The graphs in Figures 5.1-1(a)-(e) show that as the collector area increased, the expected solar fraction increases asymptotically. However, the economically optimal collector area was selected to maximize the economic benefits of the solar energy system, not the expected solar fraction. The optimal collector area is shown by the dotted line for each site. Increasing the collector area beyond the optimal value forces a diminishing return on the investment for the system. The expected solar fraction for the optimal collector area is shown in the last column in Table 5.1-1.

The resulting thermal performance, once the optimal size system is selected, is shown in the graphs of Figures 5.1-2(a)-(e) for each analysis site. The incident solar energy was derived from long-term average insolation at the site. The total load was computed based on design parameters of the actual system as installed and modified by environmental conditions at each site. The load calculations are detailed in Appendix A. The useful solar energy is the product of the system solar fraction and the total load and shows on a month-by-month basis the portion of the total load that is expected to be supplied by solar energy. The shaded portion between the total load curve and the curve of useful solar energy must be supplied by conventional energy.

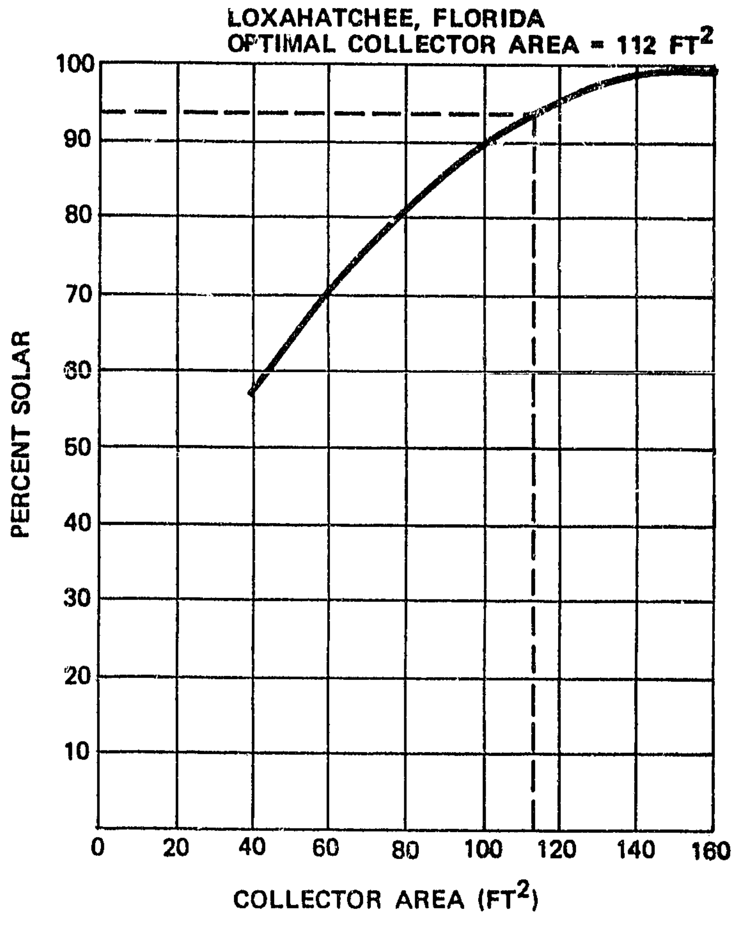

Figure 5.1-1(a). Solar Fraction vs Collector Area for Solar Energy System at Loxahatchee, Florida

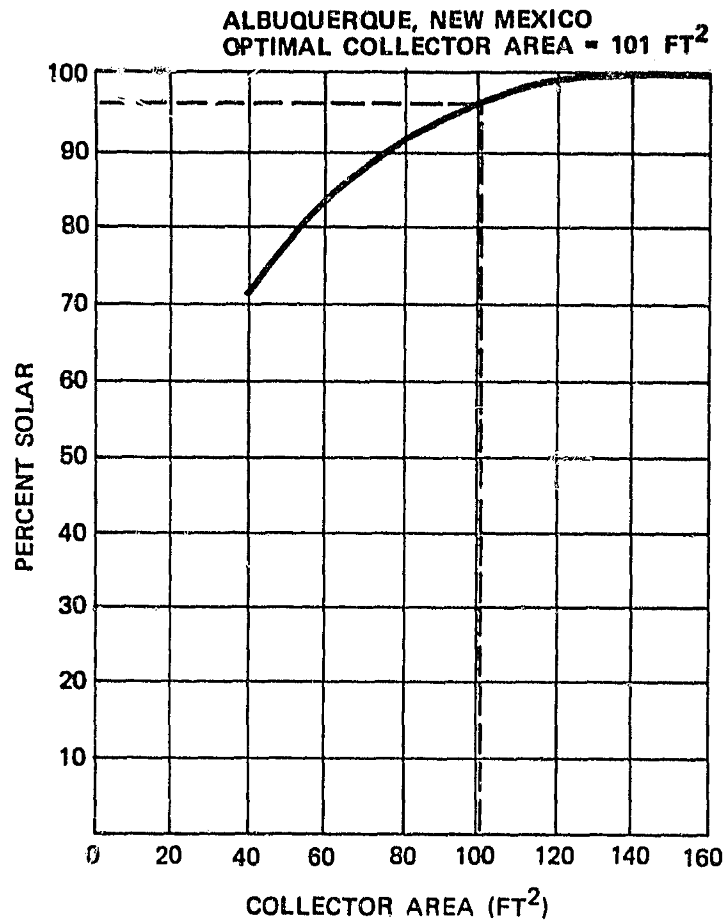

Figure 5.1-1(b). Solar Fraction vs Collector Area for Solar Energy System at Albuquerque, New Mexico

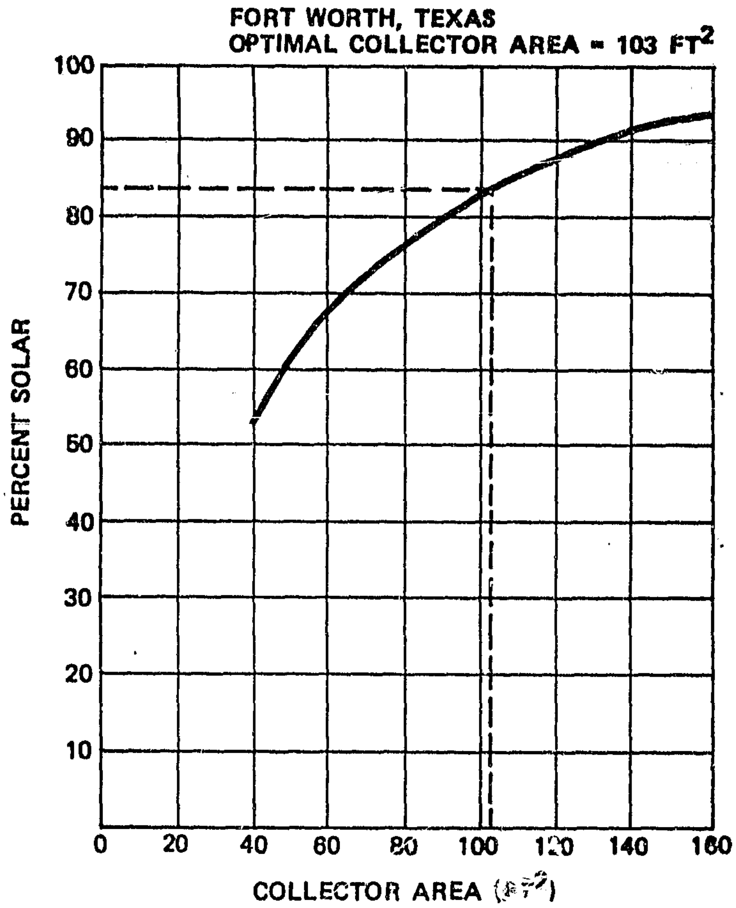

Figure 5.1-1(c). Solar fraction vs Collector Area for Solar Energy System at Fort Worth, Texas

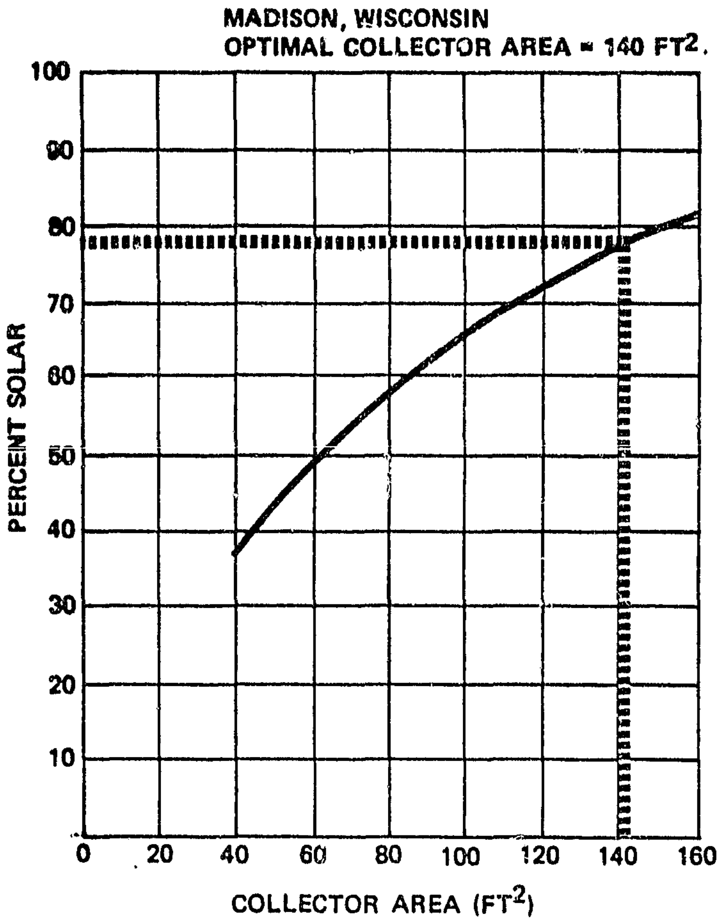

Figure 5.1-1 (d). Solar Fraction vs Collector Area for Solar Energy System at Madison, Wisconsin

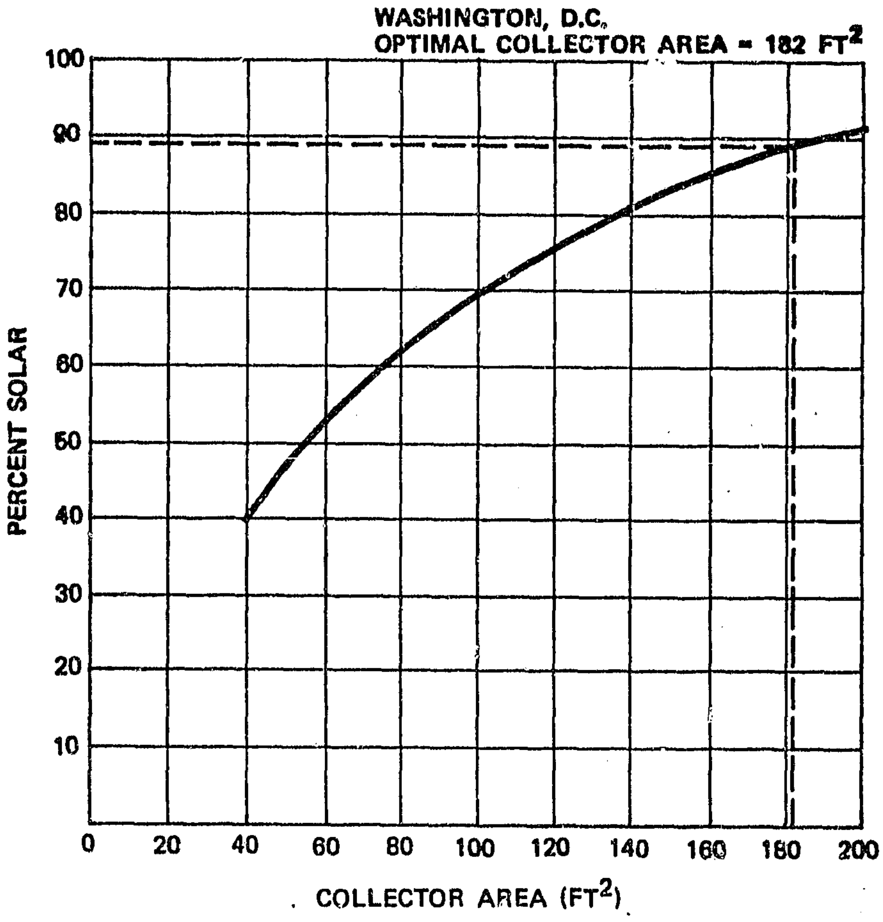

Figure 5.1-1 (a). Solar Fraction vs Collector Area for Solar Energy System at Washington, D.C.

TABLE 5.1-1

SUMMARY TABLE

SOLAR SYSTEM LOAD FACTORS AND ENVIRONMENTAL PARAMETERS

SITE	TOTAL ANNUAL LOAD (MILLION BTU)			ENVIRONMENTAL PARAMETERS - LONG-TERM				EXPECTED SOLAR FRACTION*
	HEATING	COOLING	HOT WATER	AVERAGE INSOLATION, BTU/DAY-FT^2	HEATING DEGREE DAYS	COOLING DEGREE DAYS	SUPPLY WATER TEMP (°F)	
LOXAHATCHEE	N/A	N/A	10.67	1530	240	N/A	82	94.4
ALBUQUERQUE	N/A	N/A	11.60	1828	4292	N/A	73	96.8
FORT WORTH	N/A	N/A	13.05	1475	2382	N/A	65	84.4
MADISON	N/A	N/A	14.93	1191	7730	N/A	54	76.0
WASHINGTON	N/A	N/A	13.96	1208	5010	N/A	60	89.0

*For optimal collector area

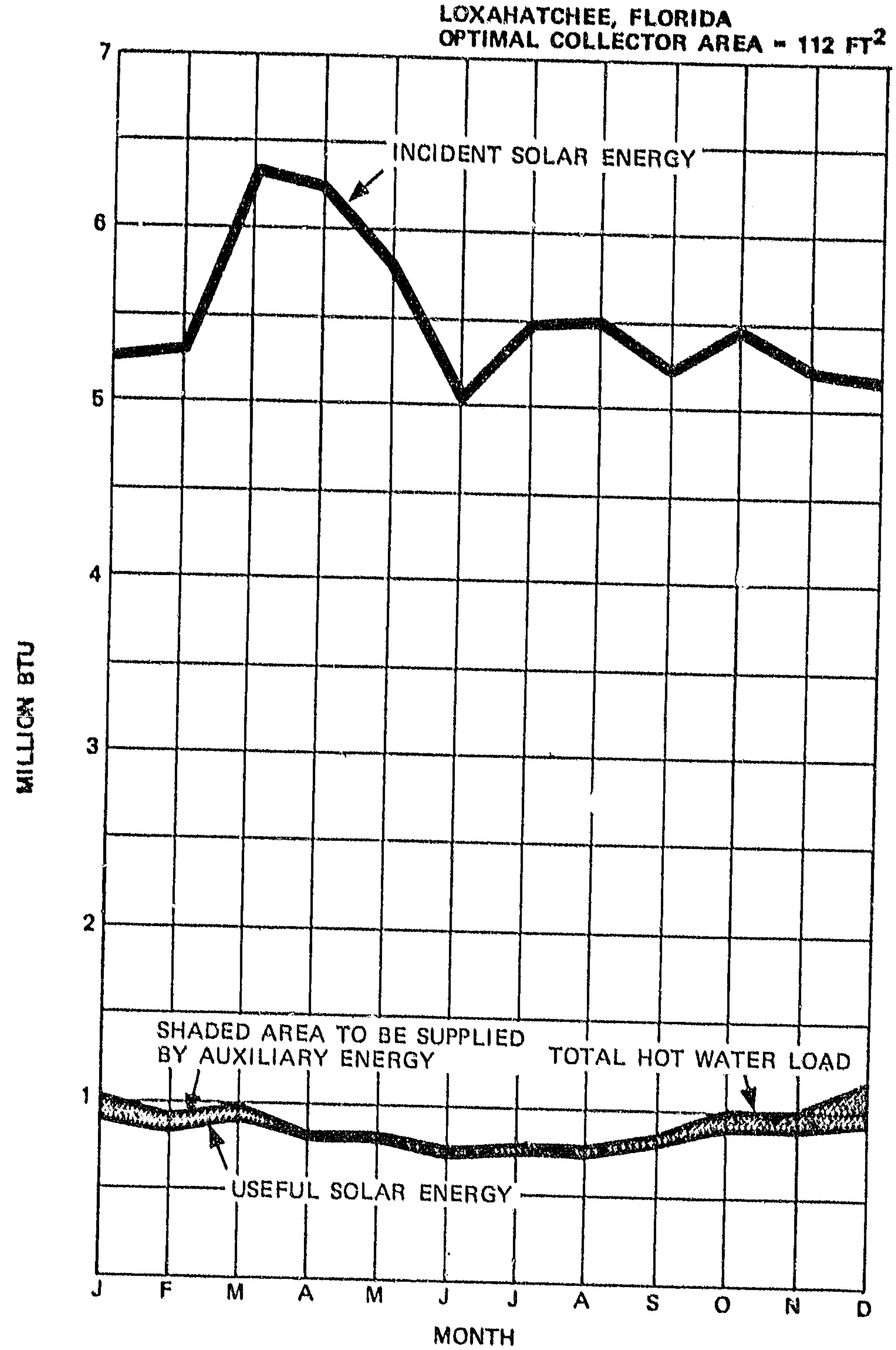

Figure 5.1-2(a). Thermal Performance over Analysis Period with Optimal Collector Area for Loxahatchee, FL

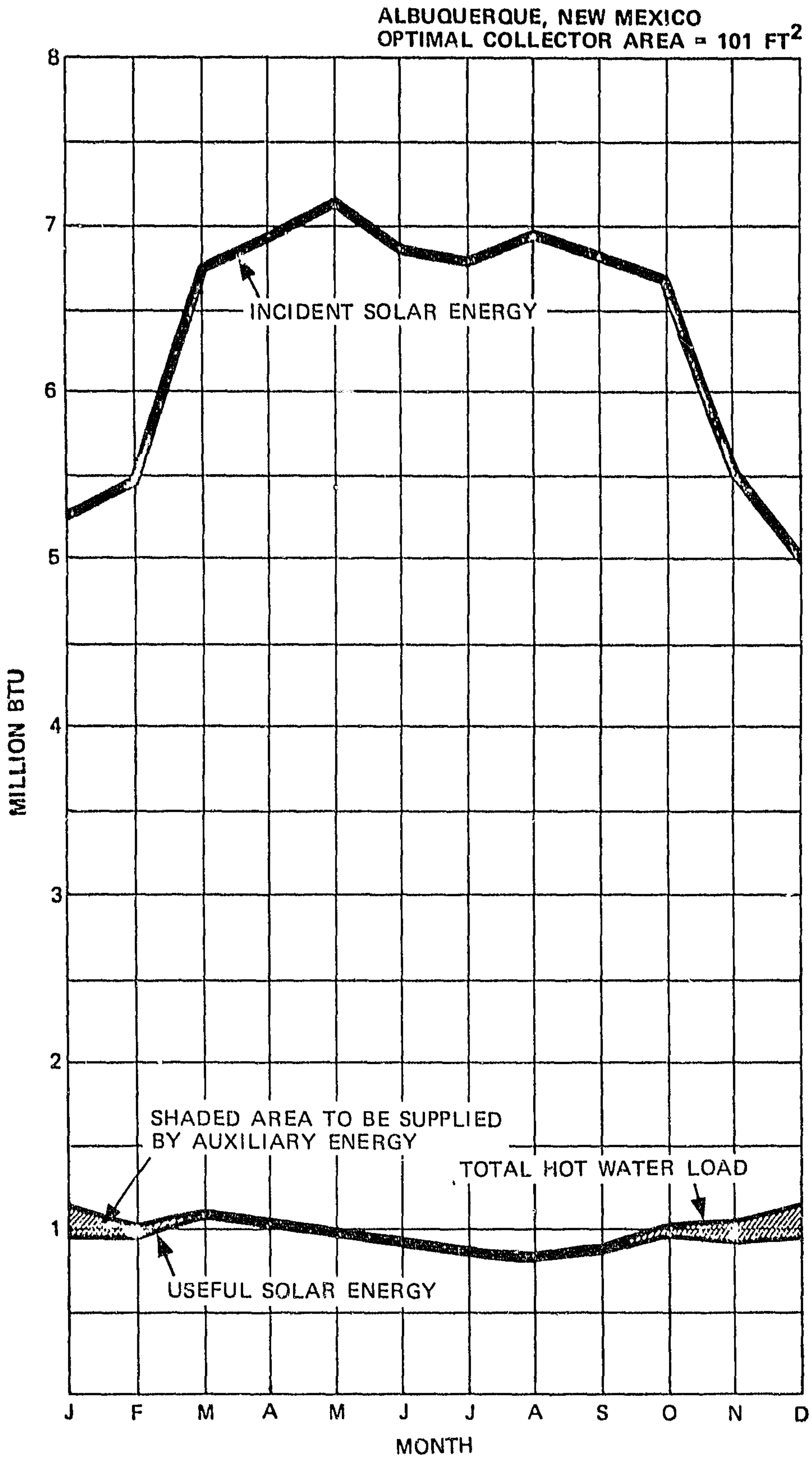

Figure 5.1-2(b). Thermal Performance over Analysis Period with Optimal Collector Area for Albuquerque, NM

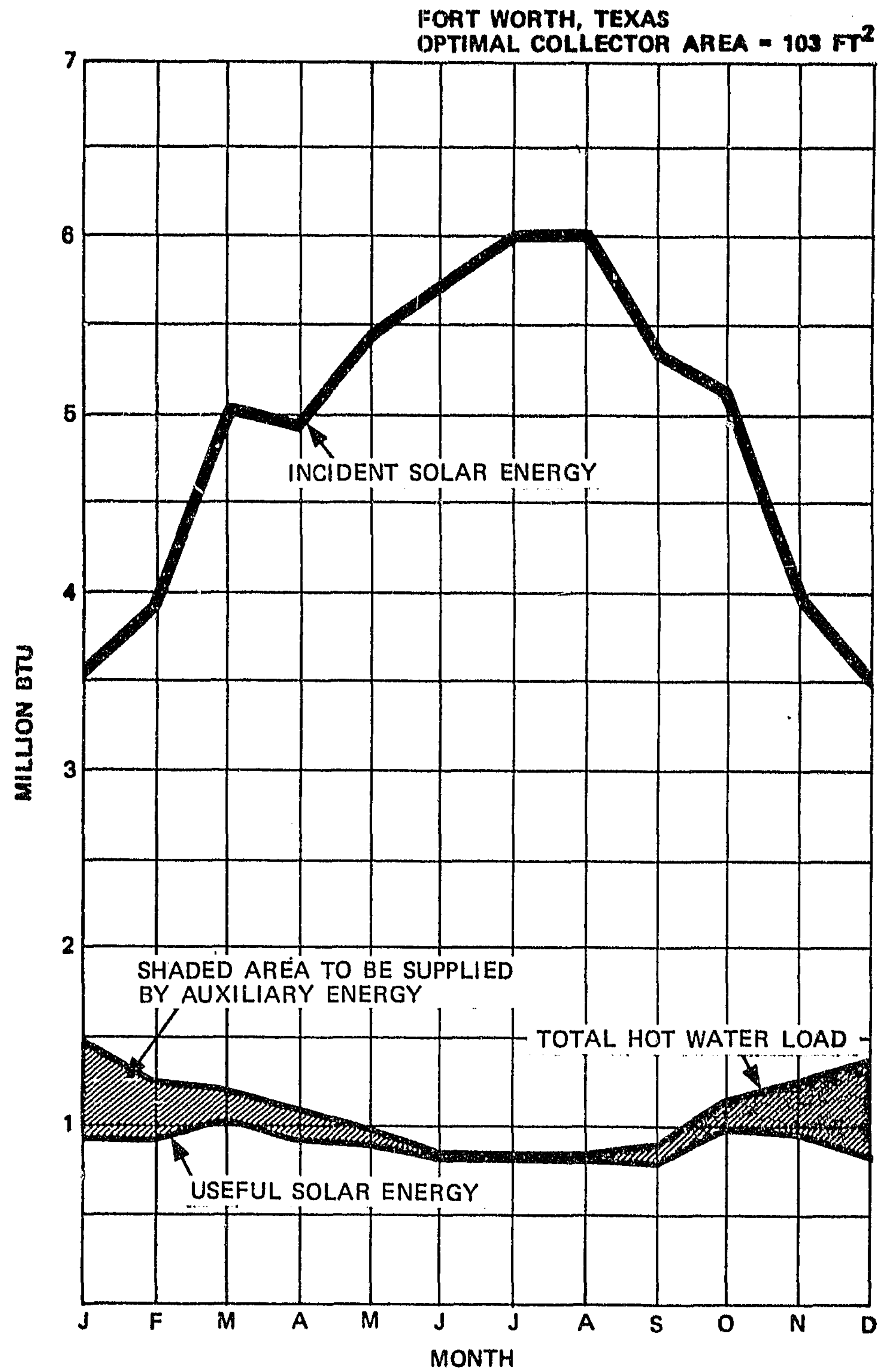

Figure 5.1-2(c). Thermal Performance over Analysis Period with Optimal Collector Area for Fort Worth, TX

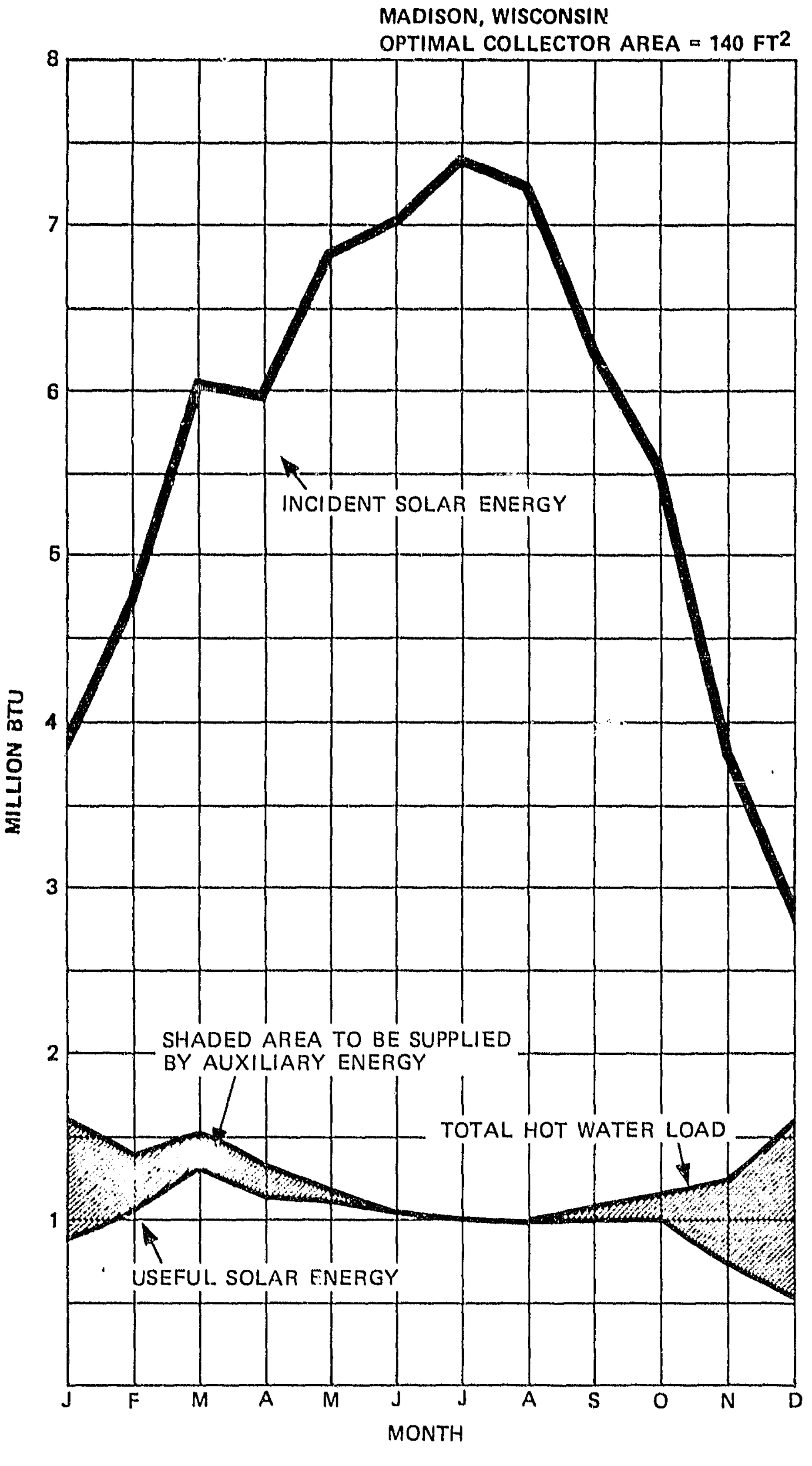

Figure 5.1-2(d). Thermal Performance over Analysis Period with Optimal Collector Area for Madison, WI

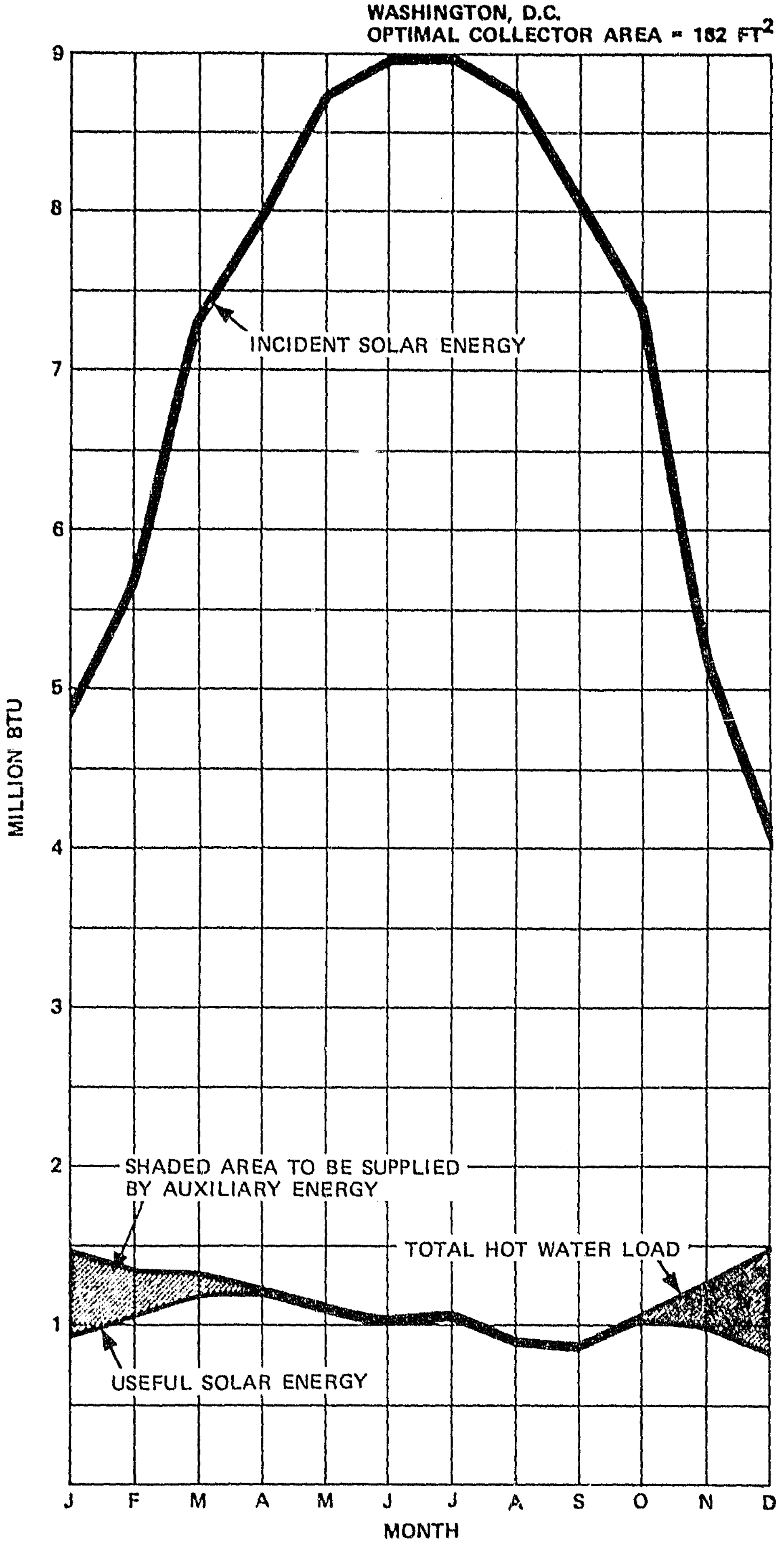

Figure 5.1-2(a). Thermal Performance over Analysis Period with Optimal Collector Area for Washington, DC

As shown in Figures 5.1-1(a) -(e), the optimal collector areas vary from a low of 101 square feet in Albuquerque, New Mexico to a high of 182 square feet in Washington, D.C. Albuquerque also achieves the highest solar fraction (97%), at optimal collector area, because it has the highest annual average daily insolation and next to the lowest hot water load. Conversely, the low solar fraction (76%) at Madison, Wisconsin is attributed to the fact that the site has the lowest average daily insolation and the highest hot water load of any of the analysis sites, due to the low temperature of the supply water in that region. For the five sites, the solar fraction achieved, at optimal collector area, is proportional to the average daily insolation for the year, with the exception of Washington, D.C. and Fort Worth, Texas, which deviate from this order due to the large collector area required in Washington, D.C. to achieve economic optimization.

Figures 5.1-2(a) and 5.1-2(b) show that the solar energy system with optimized collector area is capable of supplying essentially the entire hot water load from March through September for both Loxahatchee, Florida and Albuquerque, New Mexico. In Fort Worth, Texas (Figure 5.1-2(c)), the solar energy system can accommodate the total hot water load only during the summer months and requirements for auxiliary energy are significant in the winter, spring and fall seasons. Madison, Wisconsin (Figure 5.1-2(d)) requires moderate to heavy utilization of auxiliary energy in all months except July and August because of the low temperature of the supply water from the city mains.

Figure 5.1-2(e) shows that Washington, D.C. has significant auxiliary energy requirements only in the coldest winter months due to the large optimal collector area.

The technical parameters that describe the solar energy system are listed in Table 5.1-2 as Items 1 through 21. These parameters are described in detail in Appendix A. Their values are listed by site in Table 5.1-3. The remaining technical parameters are assigned values which are constant for all sites.

TABLE 5.1-2

f-CHART INPUT VARIABLES

ITEMS	VARIABLE DESCRIPTION	VALUE UNITS
1	AIR SH+WH = 1, LIQ SH+WH = 2, AIR OR LIQ WH ONLY = 3 . . .	3.0
2	IF 1, WHAT IS (FLOW RATE/COL. AREA)(SPEC. HEAT)?	N/A
3	IF 2, WHAT IS (EPSILON)(CMIN)/(UA)?	N/A
4	COLLECTOR AREA	TABLE 5.1-3
5	FRPRIME-TAU-ALPHA PRODUCT (NORMAL INCIDENCE)	0.661
6	FRPRIME-UL PRODUCT	0.946 BTU/H-F-FT2
7	INCIDENT ANGLE MODIFIER (ZERO IF NOT AVAIL.)	0.0
8	NUMBER OF TRANSPARENT COVERS	2.00
9	COLLECTOR SLOPE	TABLE 5.1-3
10	AZIMUTH ANGLE (E.G. SOUTH = 0, WEST = 90)	TABLE 5.1-3
11	STORAGE CAPACITY	12.52 BTU/F-FT2
12	EFFECTIVE BUILDING UA	TABLE 5.1-3
13	CONSTANT DAILY BLDG. HEAT GENERATION	TABLE 5.1-3
14	HOT WATER USAGE	60.0 GAL/DAY
15	WATER SET TEMP. (TO VARY BY MONTH, INPUT NEG.#)	136.00 F
16	WATER MAIN TEMP (TO VARY BY MONTH, INPUT NEG. #)	TABLE 5.1-3
17	CITY CALL NUMBER	268.0
18	THERMAL PRINT OUT BY MONTH = 1, BY YEAR = 2	1.00
19	ECONOMIC ANALYSIS ? YES = 1, NO = 2	1.00
20	USE OPTMZD. COLLECTOR AREA = 1, SPECFD. AREA = 2	1.00
21	SOLAR SYSTEM THERMAL PERFORMANCE DEGRADATION	0.0 %/YR
22	PERIOD OF THE ECONOMIC ANALYSIS	20.00 YEARS
23	COLLECTOR AREA DEPENDENT SYSTEM COSTS	9.51 $/FT2 COLL
24	CONSTANT SOLAR COSTS	898.0 $
25	DOWN PAYMENT (% OF ORIGINAL INVESTMENT)	20.00 %
26	ANNUAL INTEREST RATE ON MORTGAGE	13.50 %
27	TERM OF MORTGAGE	20.00 YEARS
28	ANNUAL NOMINAL (MARKET) DISCOUNT RATE	8.50 %
29	EXTRA INSUR./MAINT. IN YEAR 1 (% OF ORIG. INV.)	0.50 %
30	ANNUAL % INCREASE IN ABOVE EXPENSE	10.00 %

TABLE 5.1-2
f-CHART INPUT VARIABLES
(CONTINUED)

ITEMS	VARIABLE DESCRIPTION	VALUE UNITS
31	PRESENT COST OF SOLAR BACKUP FUEL (BF)	TABLE 5.1-3
32	BF RISE: %/YR = 1, SEQUENCE OF VALUES = 2	1.00
33	IF 1, WHAT IS THE ANNUAL RATE OF BF RISE	12.50 %
34	PRESENT COST OF CONVENTIONAL FUEL (CF	SEE NOTE 1
35	CF RISE: %/YR = 1, SEQUENCE OF VALUES = 2	1.00
36	IF 1, WHAT IS THE ANNUAL RATE OF CF RISE	12.50 %
37	ECONOMIC PRINT OUT BY YEAR = 1, CUMULATIVE = 2	1.00
38	EFFECTIVE FEDERAL - STATE INCOME TAX RATE	30.00 %
39	TRUE PROP. TAX RATE PER $ OF ORIGINAL INVEST.	0.0 %
40	ANNUAL % INCREASE IN PROPERTY TAX RATE	6.00 %
41	CAL. RT. OF RETURN ON SOLAR INVTMT? YES = 1, NO = 2	2.00 %
42	RESALE VALUE (% OF ORIGINAL INVESTMENT)	0.0 %
43	INCOME PRODUCING BUILDING? YES = 1, NO = 2	2.00

NOTE: Since the backup for the solar system is assumed to be the same type of system as would conventionally be used without a solar system, backup fuel costs and conventional costs per million Btu are equal.

The economic parameters for the solar energy system are listed in Table 5.1-2 as Items 22 through 43, and are also described in Appendix A with the source for the assigned value designated.

The following items are a function of the analysis site:

- Collector area
- Collector slope
- Azimuth angle
- Effective building UA
- Water main temperature
- Present cost of solar backup fuel
- Present cost of conventional fuel

These are listed by site in Table 5.1-3.

TABLE 5.1-3

SOLAR SYSTEM TECHNICAL PARAMETERS FOR F-CHART PROGRAM

VARIABLE DESCRIPTION	UNITS	LOCATION				
		LOXAHATCHEE	ALBUQUERQUE	FORT WORTH	MADISON	WASHINGTON
COLLECTOR AREA - OPTIMAL	FT^2	112	101	103	130	182
COLLECTOR SLOPE	DEGREES	37	35	33	43	39
AZIMUTH ANGLE	DEGREES	0	0	0	0	0
EFFECTIVE BLDG UA	BTU/°F·DAY	N/A	N/A	N/A	N/A	N/A
CONSTANT DAILY BLDG HEAT GENERATION	BTU/DAY	N/A	N/A	N/A	N/A	N/A
SUPPLY WATER TEMPERATURE	°F	SEE TABLE C-1 FOR MONTHLY VALUES				
SYSTEM THERMAL PERF. DEGRADATION	%/YR	0	0	0	0	0
PRESENT COST OF BACKUP FUEL	$/MMBTU $/KWH*	13.32 0.045	20.39 0.070	13.01 0.044	10.44 0.036	19.78 0.068

*An effective rate is computed for each location based on 1000 KWH per month usage. This effective rate includes all charges specified in the rate schedules in Appendix D.

5.2 Economic Results

An essential factor in maximizing the life cycle savings of a solar energy system, or conversely, of minimizing life cycle costs is the economic optimization of the collector area based on equipment and fuel (conventional energy) costs and the capability of the solar system to replace significant quantities of conventional energy with solar energy. The replacement capability is directly dependent on the environmental conditions at the installation site, i.e. available solar energy.

The graphs of Figures 5.2-1(a)-(e) show the relationship of the factors comprising life cycle costs - equipment costs and fuel costs - as a function of collector area. Both costs are presented in terms of present value, i.e. baselined to today's dollars. It can be readily seen that as collector area increases, solar equipment costs increase proportionately. Also, as collector area increases the fuel costs decrease, although not as a straight line function. At some given collector area, the sum of these two costs is a minimum, as shown by the life cycle cost (LCC) curve. This minimum defines the optimal collector area for the given installation site.

The solar equipment costs discussed in the preceding paragraphs include the principal and interest paid on an assumed 13.5 percent, 20 year mortgage, the income tax deduction for interest for an owner in the 30 percent bracket and the insurance and maintenance costs estimated at 0.5 percent of the initial costs. The fuel cost is that which is required by the conventional backup system and includes the effects of the f-Chart solar system model.

The life cycle costs are not to be confused with life cycle savings. Life cycle savings is the difference between the life cycle cost of fuel for a conventional system and the life cycle cost of owning, operating, and maintaining a solar energy system.

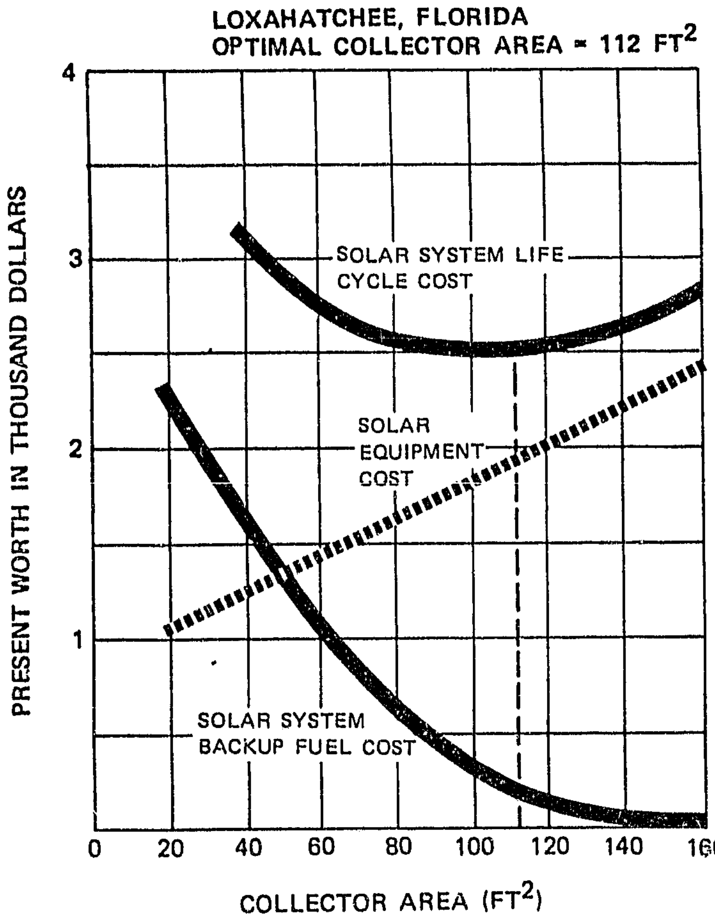

Figure 5.2-1(a). Optimization of Collector Area for Loxahatchee, FL

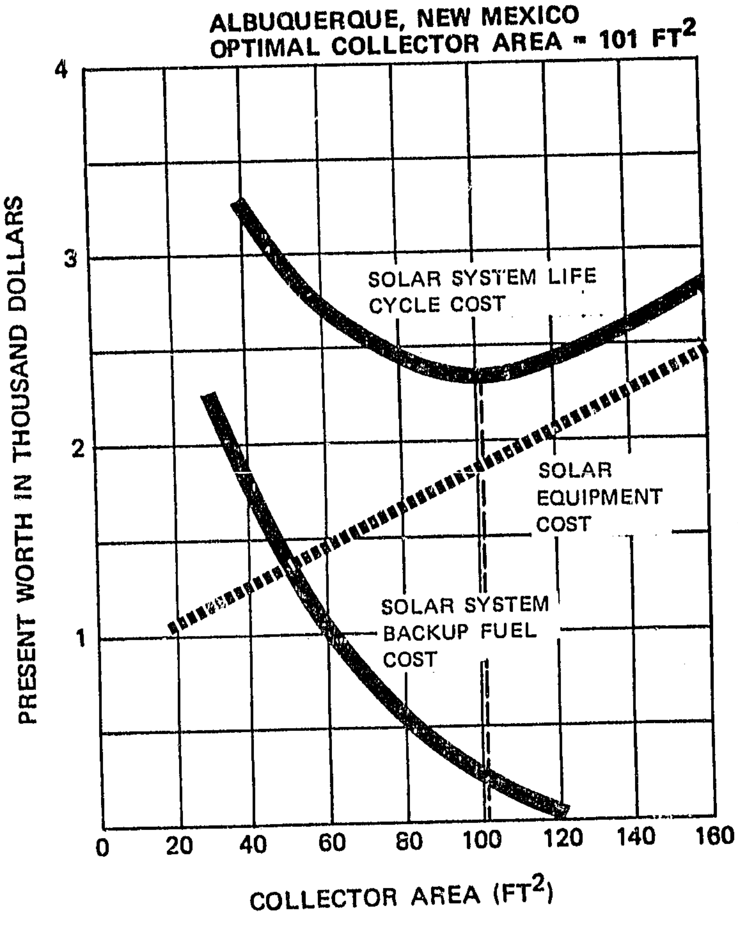

Figure 5.2-1(b). Optimization of Collector Area for Albuquerque, NM

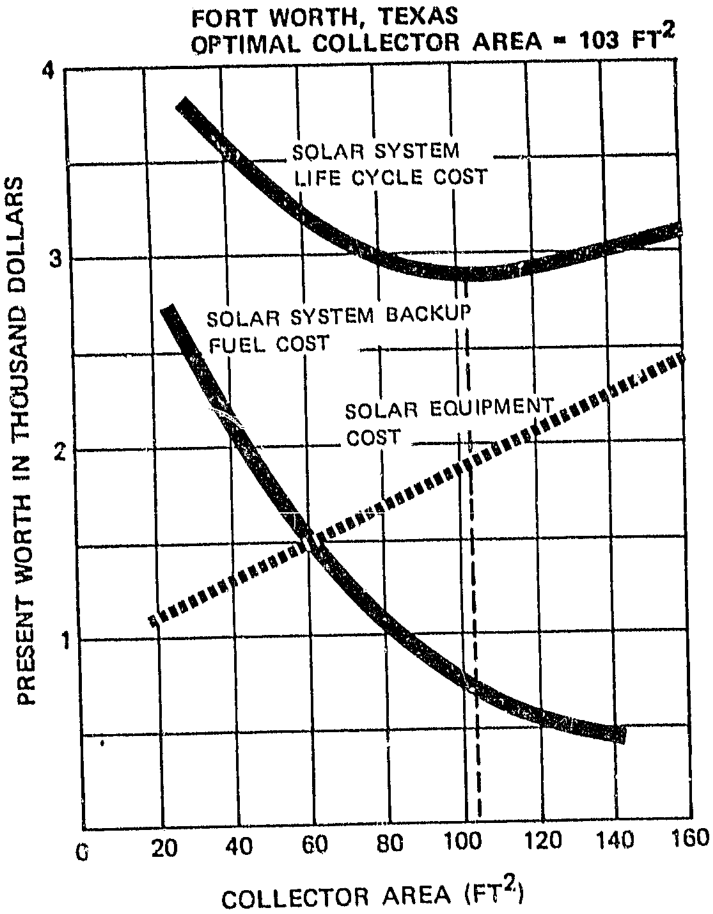

Figure 5.2-1(c). Optimization of Collector Area for Fort Worth, Texas

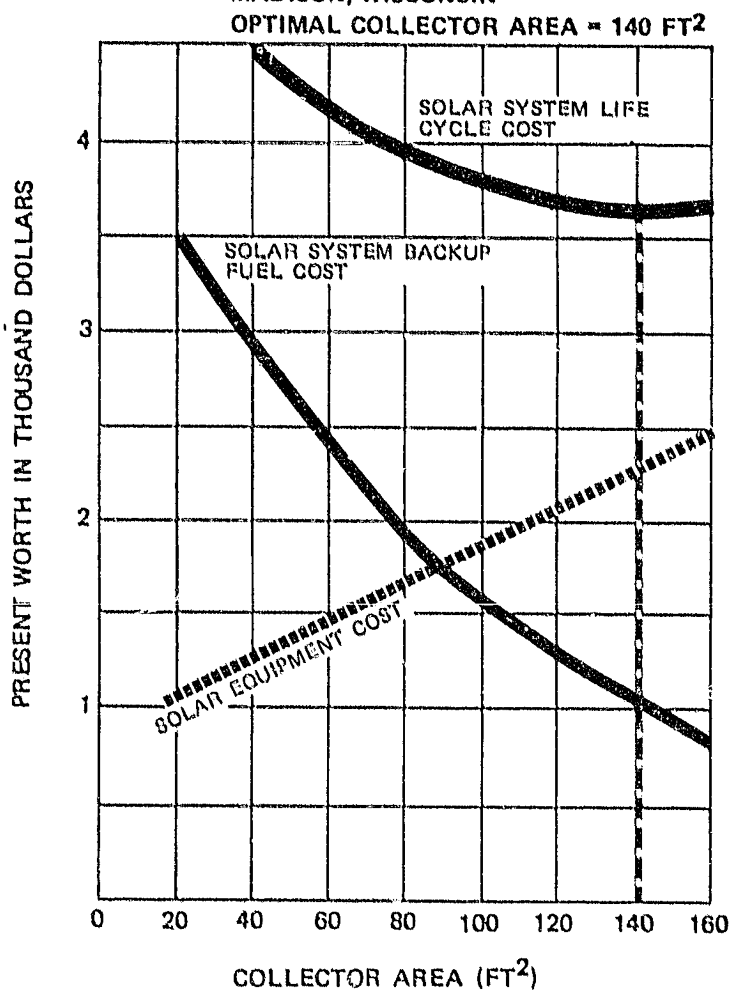

Figure 5.2-1(d). Optimization of Collector Area for Madison, Wisconsin

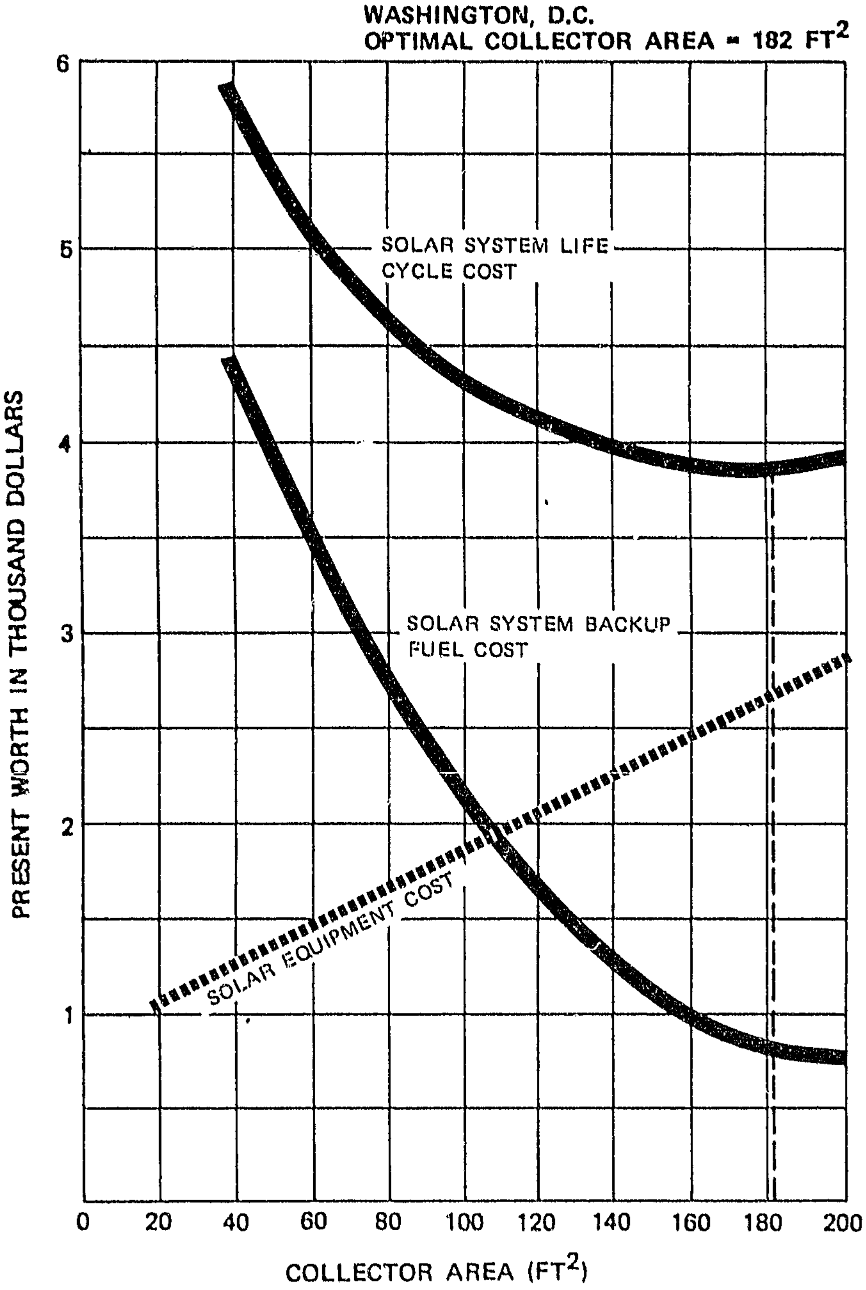

Figure 5.2-1(a). Optimization of Collector Area for Washington, DC

Of the five analysis sites considered in this study, Figure 5.2-1(b) shows that the lowest life cycle cost, for optimized collector area, is achieved at Albuquerque, New Mexico. This is attributed to the combined factors of minimum collector area, maximum backup fuel cost, and maximum solar fraction which yields: (1) lowered solar equipment costs and, (2) a higher dollar value of savings for each unit of conventional energy which is displaced by solar energy. The highest life cycle cost is encountered in Washington, D.C. (Figure 5.2-1(e)) primarily because of the large collector area (182 Ft^2) required for economic optimization. Fuel costs are also high in the Washington area but savings are reduced because of the lower annual insolation value and, hence, reduced solar fraction, with resultant increased expenditure of auxiliary energy. These same factors place Loxahatchee, Florida, Fort Worth, Texas and Madison, Wisconsin in the intermediate range with respect to life cycle costs. (Figures 5.2-1(a), (c), and (d).

A summary of the costs and savings for the conventional system and the solar energy system is shown in Table 5.2-1 in terms of today's dollars expended over the analysis period. It should be recalled that the equipment costs shown do not include the cost of the conventional system since this system must be provided with or without the solar energy system. The equipment costs include only the additional hardware that must be provided for the solar energy system. This includes the following:

- Collectors and mounting hardware
- Piping and duct work (including valves and dampers)
- Heat exchanger(s)
- Storage unit(s)
- Control system

The best estimates of equipment costs for solar energy systems indicate that costs fall into two categories; (1) costs dependent on collector area and, (2) costs independent of collector area (constant). This is the case, especially for residential systems, because regardless of the

TABLE 5.2-1

SUMMARY TABLE

COSTS AND SAVINGS OVER 20 YEAR ANALYSIS PERIOD IN DOLLARS (1980)

SITE	INITIAL COST OF SYSTEM[1]			PRESENT WORTH OF FUEL COSTS		PRESENT WORTH OF OTHER SOLAR COSTS	PRESENT WORTH OF TOTAL SOLAR COSTS	PRESENT WORTH OF TOTAL COST W/O SOLAR	PRESENT WORTH OF CUMULATIVE SAVINGS	YEAR OF POSITIVE SAVINGS	YEAR OF PAYBACK
	CONSTANT	AREA DEPENDENT	TOTAL	WITH SOLAR	W/O SOLAR						
LOXAHATCHEE	1258 (898)	1492 (1065)	2750 (1963)	210	3776	2288	2498	3776	1277	4	16
ALBUQUERQUE	1258 (898	1345 (961)	2604 (1859)	194	6282	2170	2364	6282	3918	1	10
FORT WORTH	1258 (898)	1373 (980)	2631 (1878)	700	4619	2194	2894	4619	1725	3	14
MADISON	1258 (898)	1865 (1331)	3123 (2229)	1036	4842	2609	3645	4842	1197	5	16
WASHINGTON	1258 (898)	2418 (1727)	3676 (2625)	903	7339	3061	3864	7339	3475	1	12

NOTES:

1. Values in parentheses are adjusted for the Federal tax credit by the method detailed in Section 4.2.

exact collector area used, certain items of equipment must be provided and the costs of hardware and labor for installation seem to be relatively constant. However, the cost of collectors, and certain incremental costs, are dependent on the size of the collectors used. These costs are shown in Table 5.2-1 for each of the five analysis sites and the total cost for the system is the sum of the constant cost and the area dependent cost multiplied by the collector area.

The initial cost of the system in this analysis should be adjusted for the federal tax credit (and any other tax credit allowed by the state or local governments) by the methods discussed in Section 4.2. These adjusted costs are shown in parentheses under "Initial Cost of System" in Table 5.2-1 and are used in computing the "Present Worth of Total Solar Costs."

Some conventional energy must be expended with or without the solar energy system because, in most cases, the solar energy system will replace only a portion of the total energy required to support the load. Savings are possible with the solar energy system only because the total costs with the solar energy system are less than the costs of conventional energy. Consequently, the fuel costs over the analysis period (20 years) are shown in Table 5.2-1 with and without the solar energy system.

It is assumed in this analysis that the solar energy system would be financed through a 20 year loan at an interest rate of 13.5 percent. Property taxes are assumed to be zero, but this may not be universally true. Insurance on the value of the solar energy system and maintenance costs are assumed to be 0.5 percent per year of the initial costs. Since interest paid on a loan is tax deductible for federal taxes, and in most cases for state taxes, at different rates according to the income tax bracket of the borrower, a 30 percent combined federal-state tax bracket was assumed. The value of all these costs based on the assumptions of this analysis is shown as the "Present Worth of Other Solar Costs" in Table 5.2-1. Combined with the costs for fuel with the solar energy system, the value is the "Present Worth of Total Solar Costs."

Since only incremental equipment and associated costs are included in the analysis, the present worth of total costs for the conventional system without solar are simply the cost of fuel without solar. Then the "Present Worth of Cumulative Savings" is the difference between the "Present Worth of Total Costs Without Solar" and the "Present Worth of the Total Costs With Solar". These values for each of the five analysis sites are listed in Table 5.2-1.

Finally, two economic performance parameters called "Year of Positive Savings" and the "Year of Payback" are shown in Table 5.2-1. As previously discussed, the year of positive savings is the year after purchase in which the solar system first becomes profitable, i.e., the annual conventional fuel bill without solar exceeds sum of the annual fuel bill with solar and the annual costs for the solar system. The year of payback is the year after purchase when the compounded net savings equals the initial investment for the solar energy system. The factors that determine years until positive savings are shown in Figures 5.2-2(a)-(e) for each analysis site. The factors that determine the years until payback are shown in Figures 5.2-3(a)-(e) for each analysis site.

As Figures 5.2-2(a)-(e) show, a solar energy system of the type installed in the Loxahatchee, Florida site is economically feasible for all five of the analysis sites included in this study. Positive savings would be realized during the first year of operation in Albuquerque, New Mexico and Washington, D.C. (Figures 5.2-2(b) and (e)) because of the high cost of conventional energy in those locations. Fort Worth, Texas and Loxahatchee, Florida would experience savings in the third and fourth years, respectively (Figures 5.2-2(c) and 5.2-2(a)). Madison, Wisconsin, because of the present low cost of conventional fuel, would not produce solar system savings until the sixth year of operation. Solar system costs would be highest in Washington, D.C. and lowest in Albuquerque, New Mexico in proportion to the collector areas required at these two locations.

As shown in Figures 5.2-3(a)-(e), the payback period for the solar energy system ranges from ten years in Albuquerque, New Mexico to sixteen years in Madison, Wisconsin. It is evident from these plots that the payback period varies roughly in inverse proportion to the fuel cost for the site under consideration. For a system of the Loxahatchee design, the solar system payback would occur within the term of the twenty year mortgage period, assumed in this study for all five of the analysis sites.

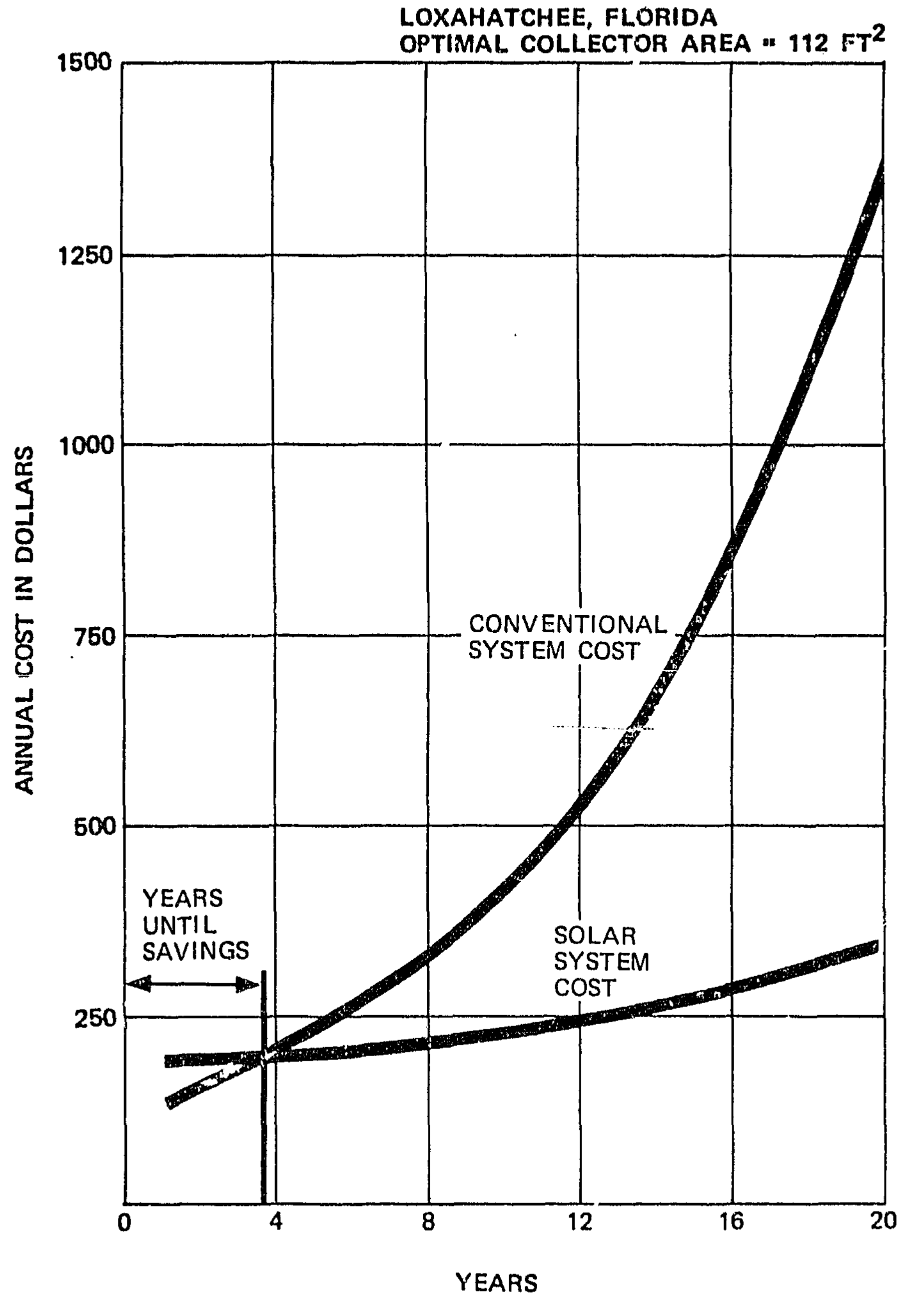

Figure 5.2-2(a). Annual Expenses for Solar and Conventional System at Loxahatchee, FL

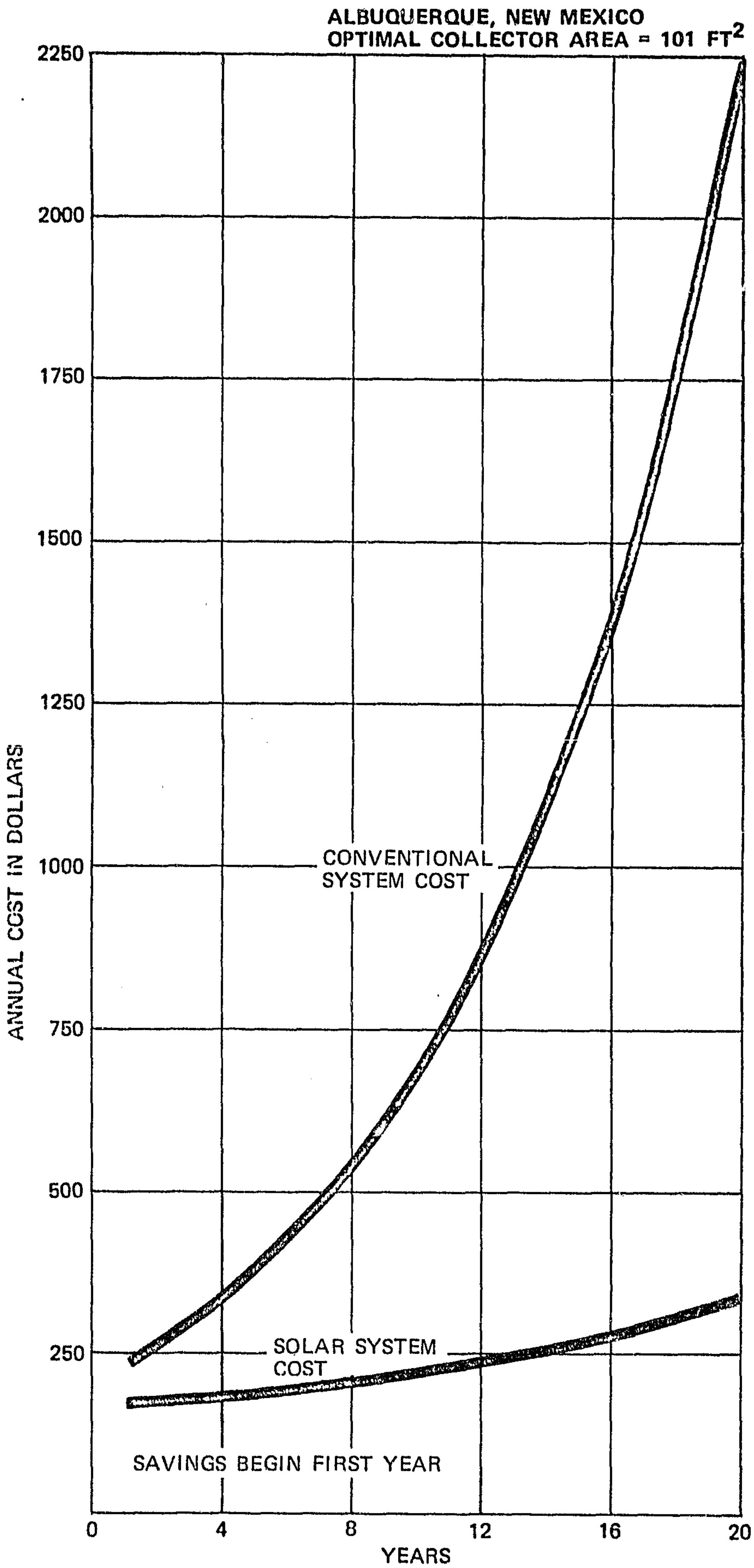

Figure 5.2-2(b). Annual Expenses for Solar and Conventional System at Albuquerque, NM

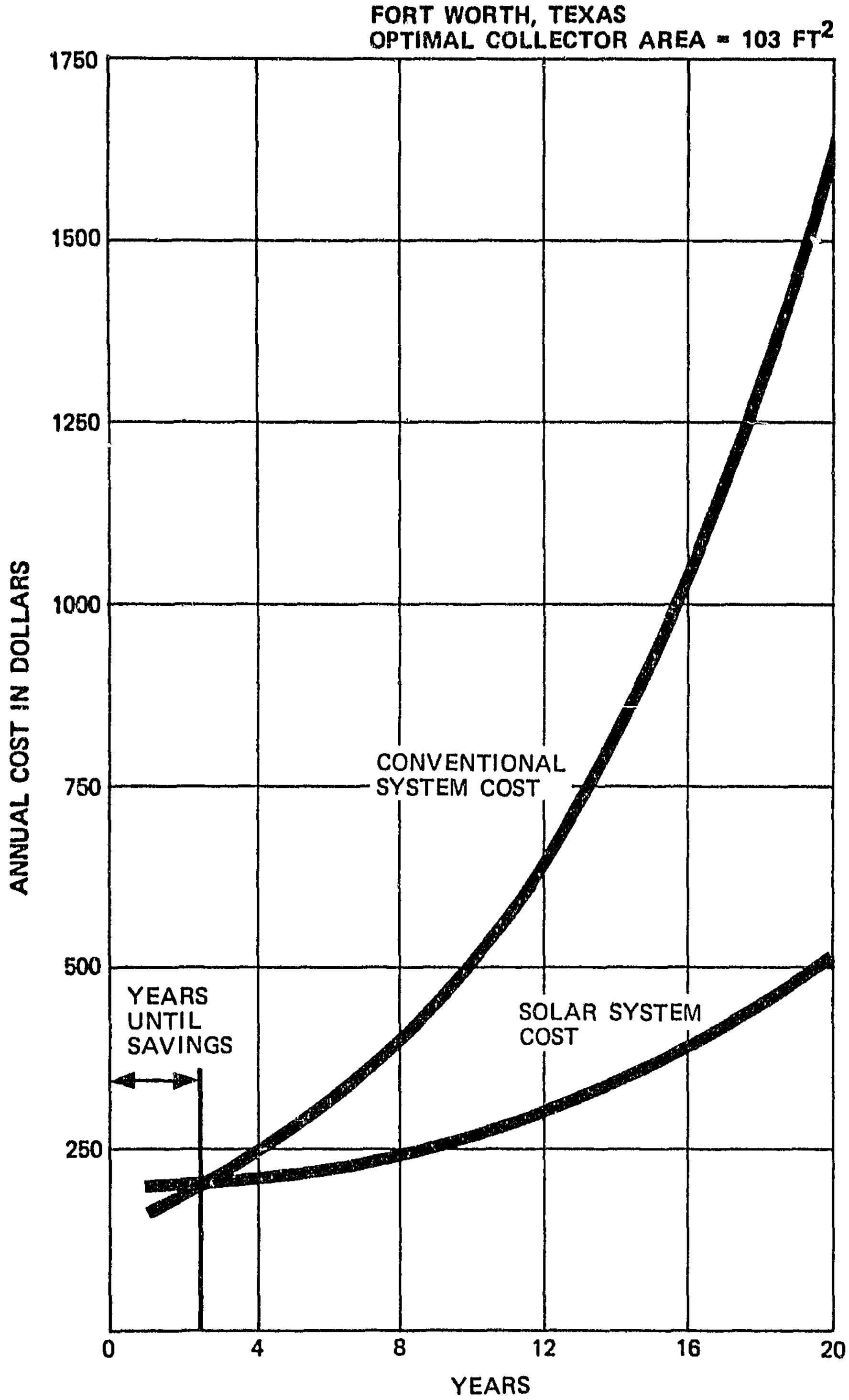

Figure 5.2-2(c). Annual Expenses for Solar and Conventional System at Fort Worth, TX

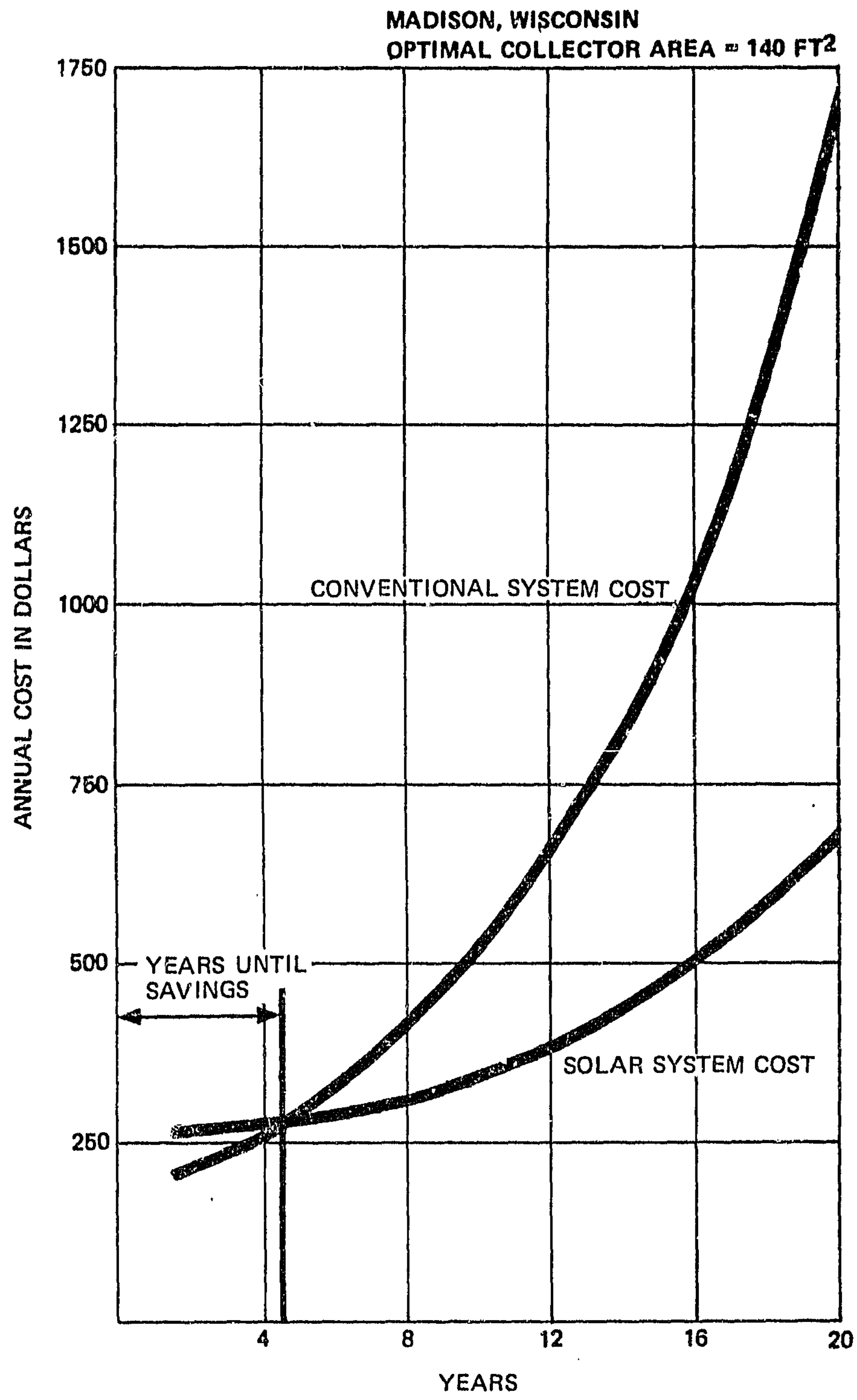

Figure 5.2-2(d). Annual Expenses for Solar and Conventional System at Madison, WI

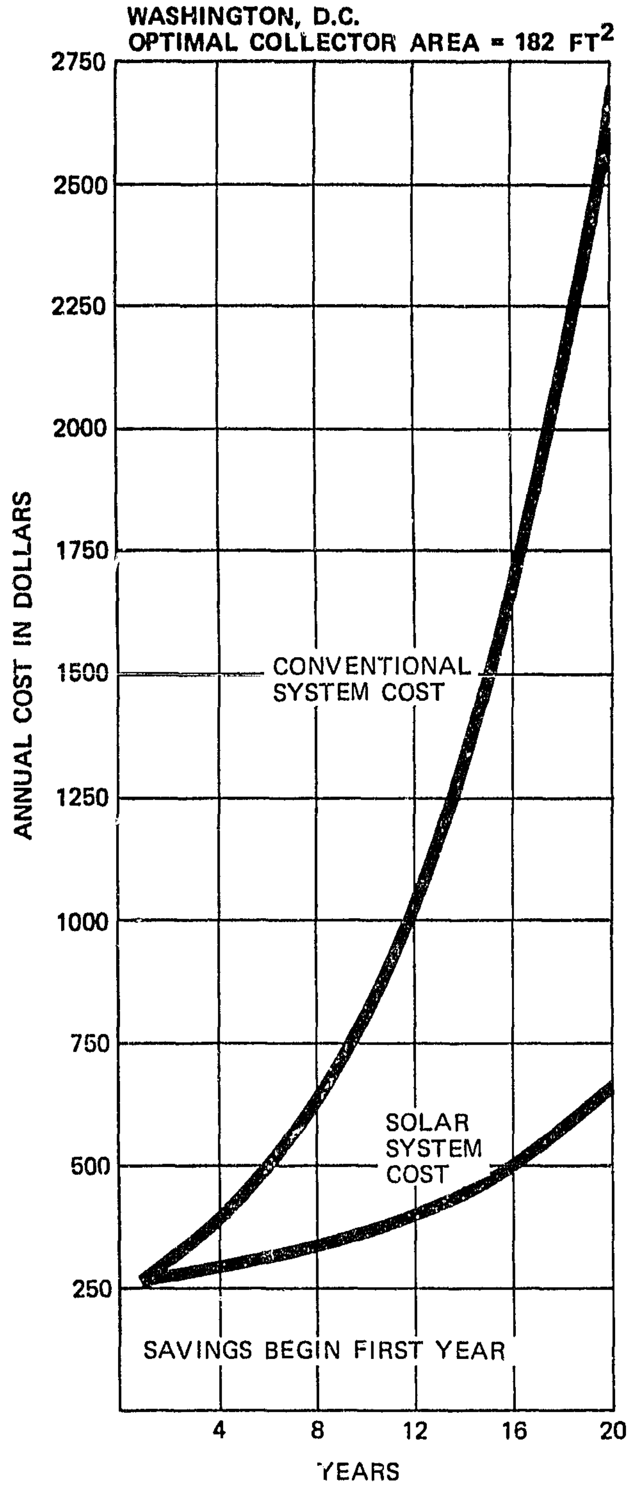

Figure 5.2-2(e). Annual Expenses for Solar and Conventional System at Washington, DC

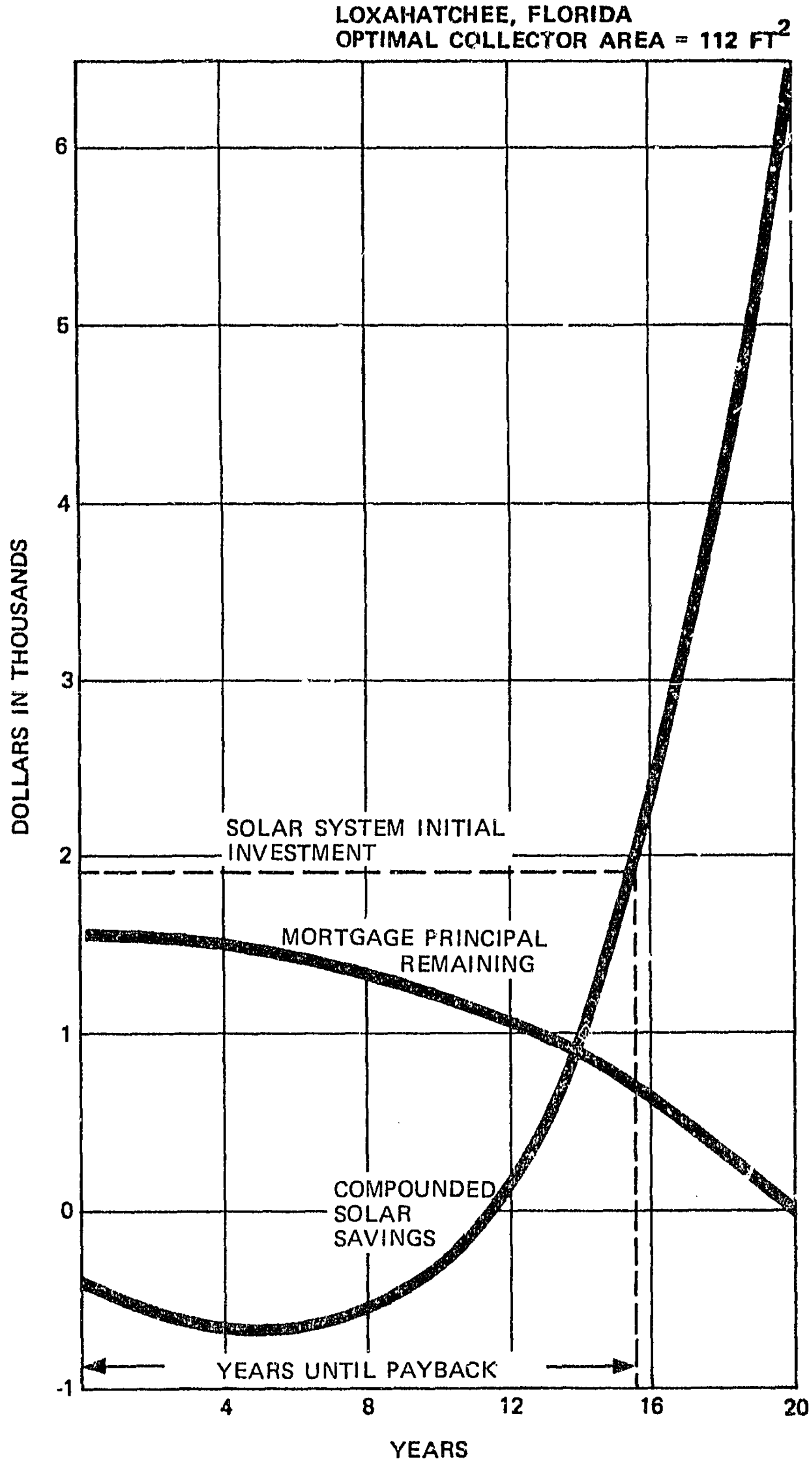

Figure 5.2-3(a). Payback Period for Solar Energy System at Loxahatchee, FL

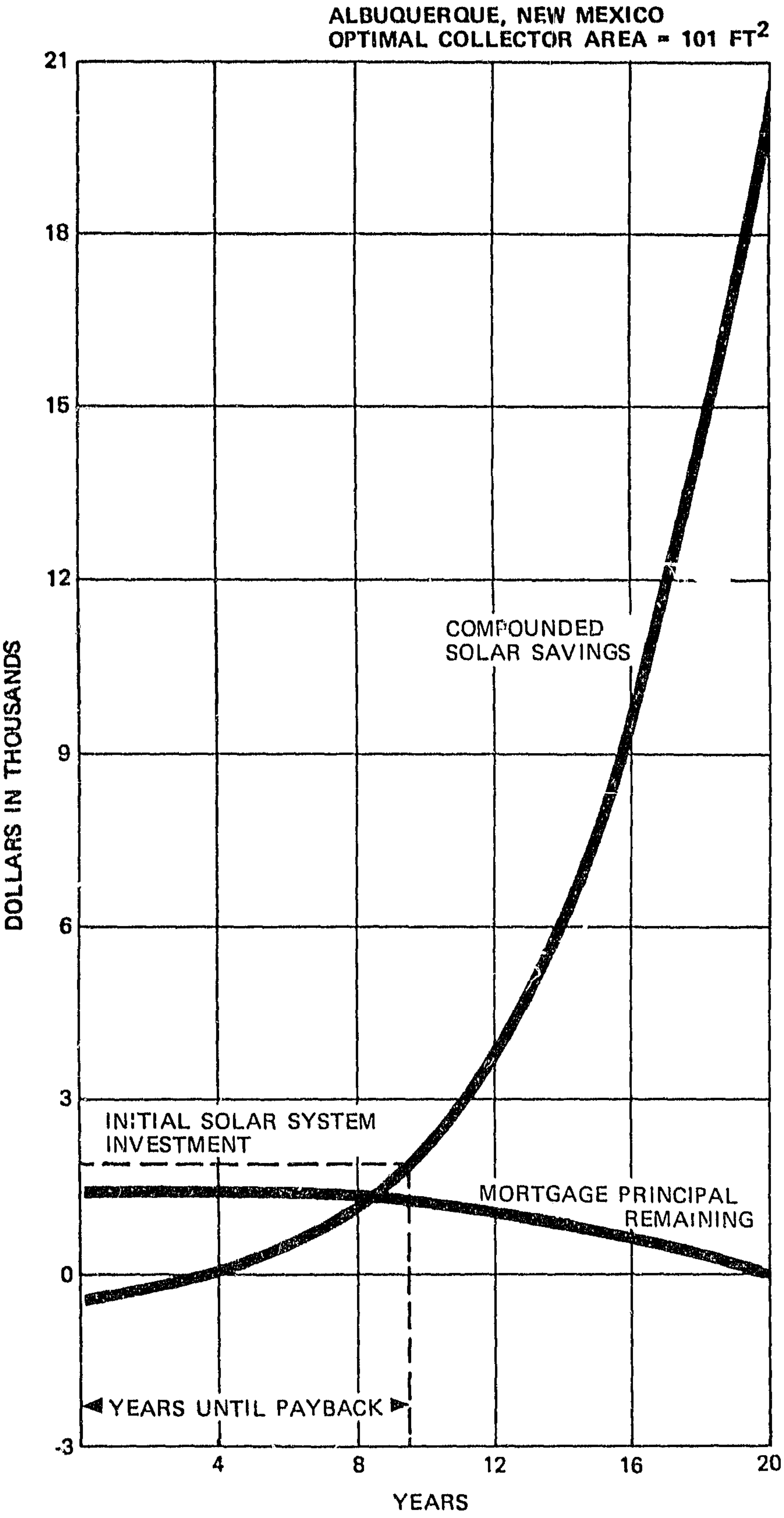

Figure 5.2-3(b). Payback Period for Solar Energy System at Albuquerque, NM

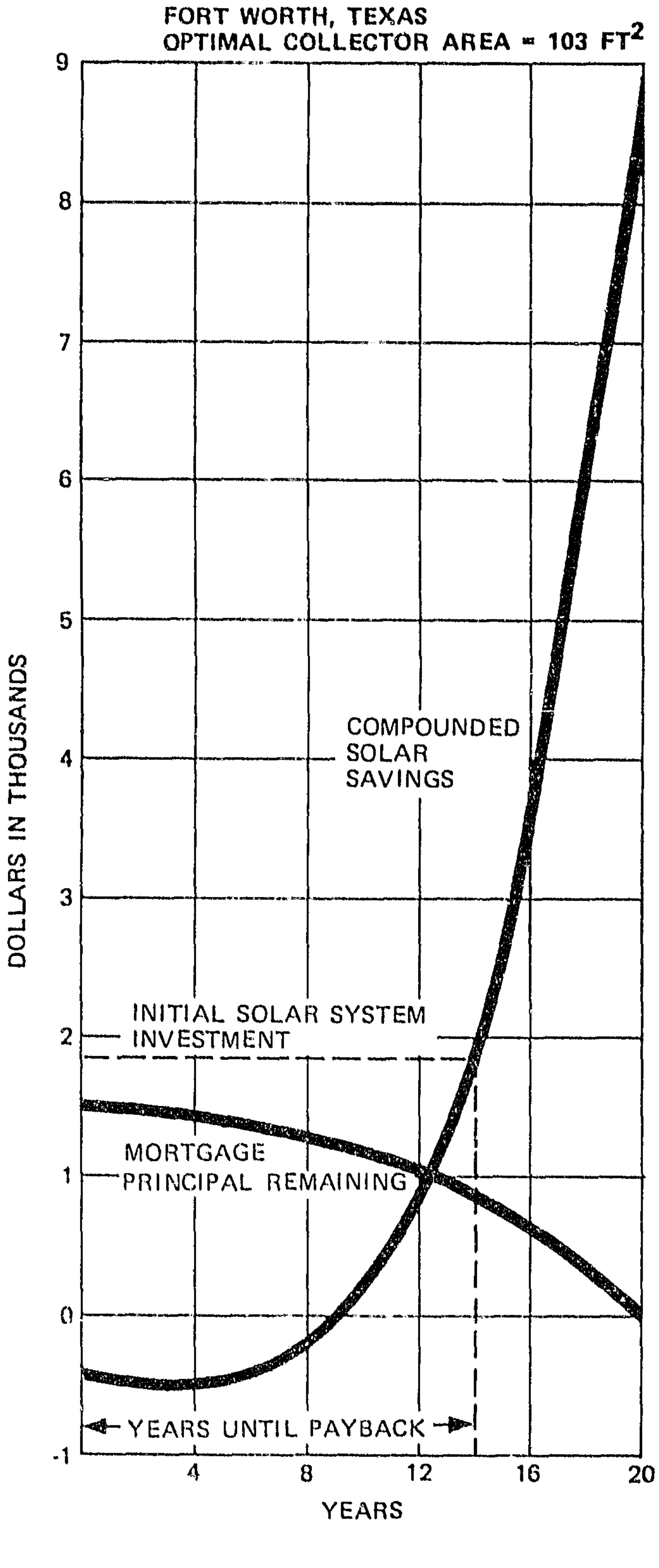

Figure 5.2-3(c). Payback Period for Solar Energy System at Fort Worth, TX

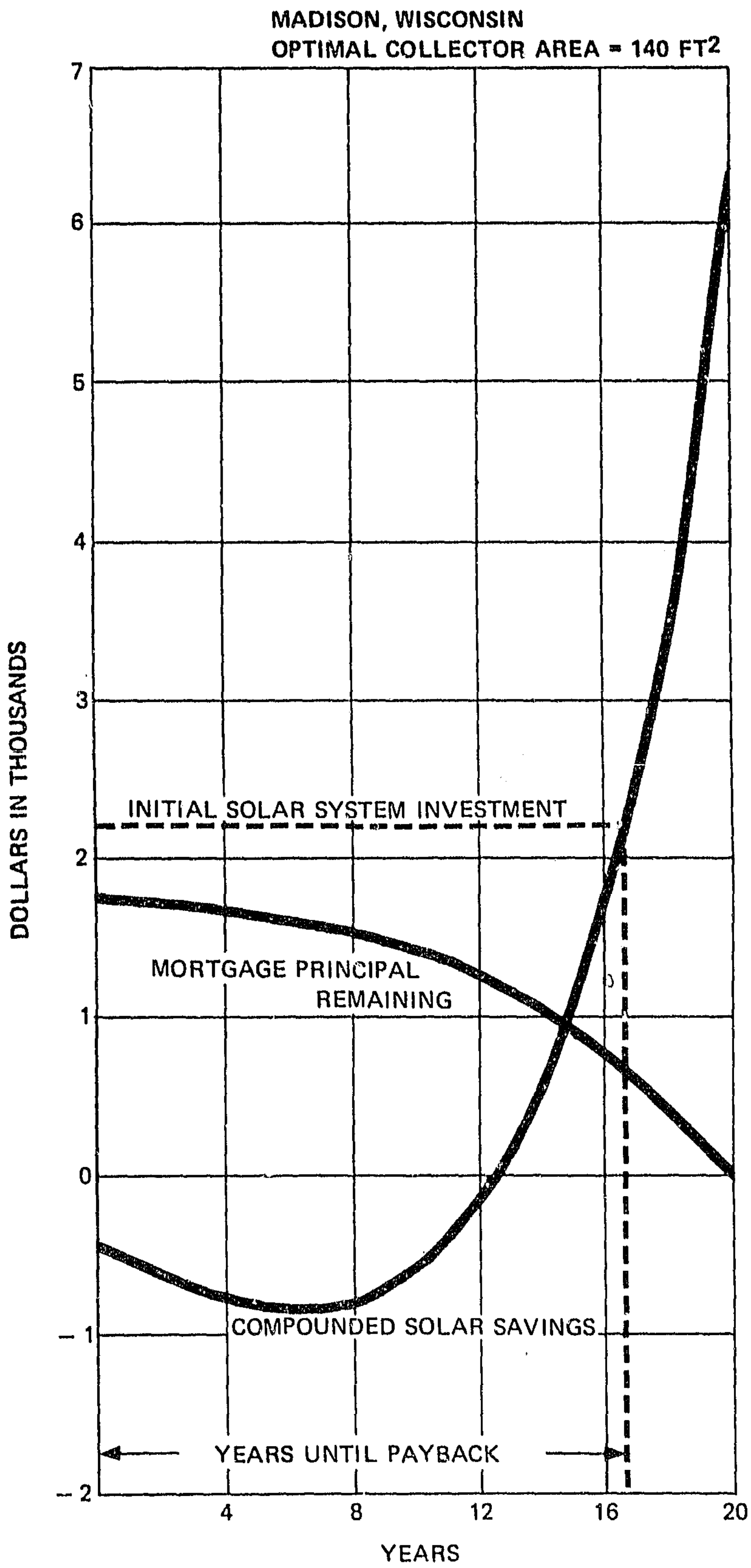

Figure 5.2-3(d). Payback Period for Solar Energy System at Madison, WI

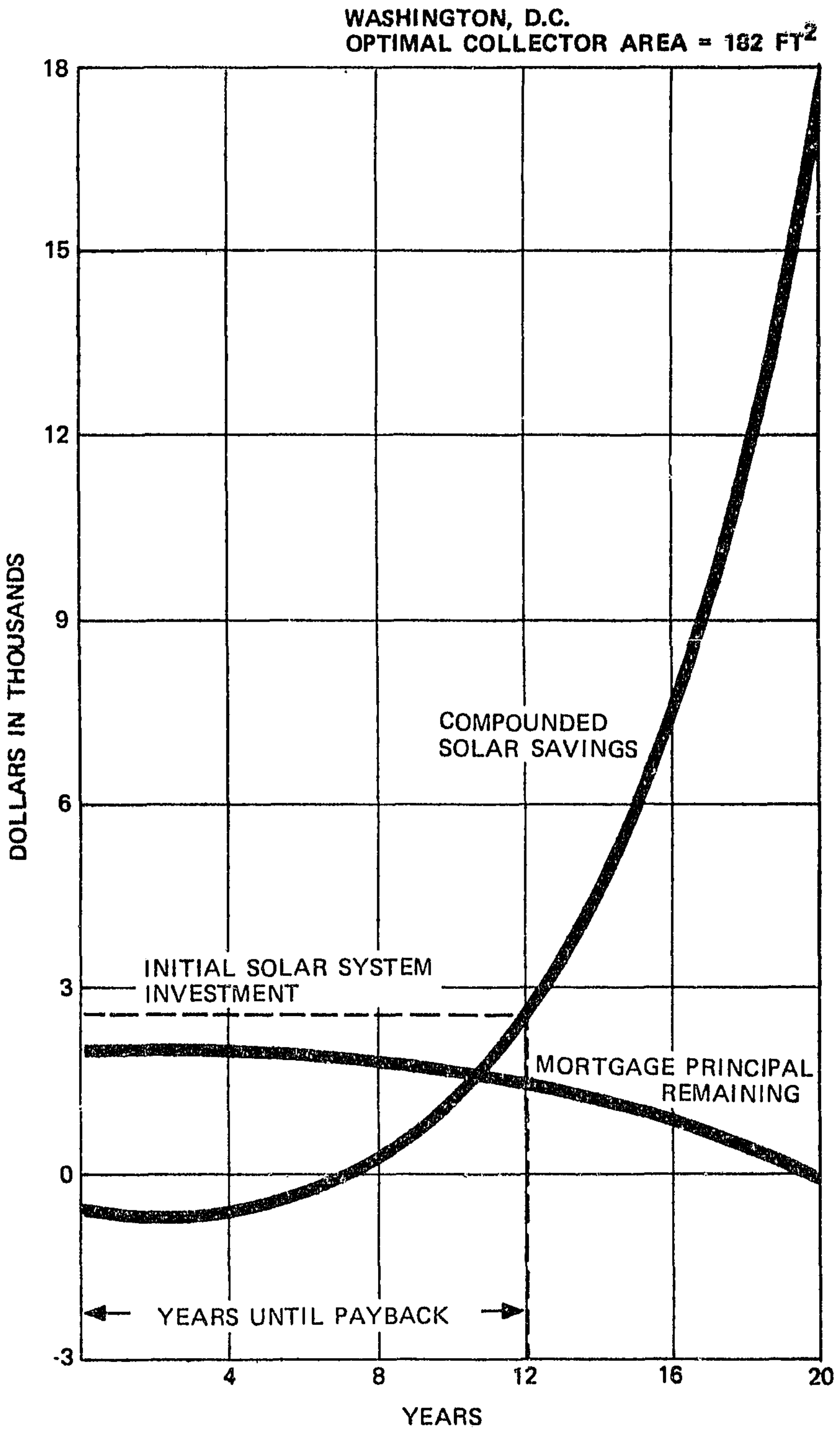

Figure 5.2-3(e). Payback Period for Solar Energy System at Washington, DC

6. ECONOMIC UNCERTAINTY ANALYSIS

The economic evaluation methods presented in this report are based on the assumption that reliable values for economic variables can be assigned. However, there is an inherent uncertainty in predicting future expenses and benefits which is magnified by international economic unstability. As a consequence, the results of both the life cycle cost analysis and the optimization procedures must be accepted with discretion and the effect of uncertainties must be evaluated.

For a given set of conditions, the change in the present worth of life cycle cumulative savings (Table 5.2-1), ΔLCCS, resulting from a change in a particular variable, Δx_j, can be approximated by the following:

$$\Delta LCCS = \frac{\partial LCCS}{\partial x_j} \Delta x_j \qquad (13)$$

The expression for $\partial LCCS/\partial x_j$ can be obtained by direct differentiation of the life cycle savings equation. The life cycle cost model of Equations (1), (4), and (6)-(12) will be used for this analysis. The derivatives of these equations for each variable are given in Appendix B. To illustrate the use of these relationships, Uncertainty Analysis, Tables 6-1 through 6-5, were made up for the installation site. The tables give the change in solar system life cycle cumulative savings, ΔLCCS, caused by a 10 percent relative increase in each of the variables.

Table 6-1 for Loxahatchee, Florida, shows, for example that a 10 percent increase in the discount rate from 8.5 to 9.4 percent yields a decrease in the value of P_1 of approximately 2.434 giving a modified value of P_1 = 24.136 (9.2 percent decrease). The value of P_2 decreases by 0.068 (6.0 percent decrease) giving a modified value of P_2 = 1.077. The value of LCCS decreases by approximately $193 or a relative change of 15 percent in the baseline value of $1277.

The information of Tables 6-1 through 6-5 can also be used to estimate the total uncertainty in life cycle cumulative savings due to uncertainty in different variables. If all the economic parameters are subject to variation, a reasonable estimate of savings uncertainty can be obtained by the following:

$$\Delta LCCS_{prob} = \left[\sum_{j=1}^{N} \left(\frac{\partial LCCS}{\partial x_j} \Delta x_j \right)^2 \right]^{\frac{1}{2}} \qquad (14)$$

As an example, assume uncertainties of ±10 percent in all fifteen of the variables listed in Table 6-1. The probable uncertainity estimate, using the data from the Table is:

Loxahatchee, Florida

$\Delta LCCS_{prob}$ = \$800

Cumulative Savings = \$1277

This value is 37 percent smaller than the present worth of cumulative savings for Loxahatchee, given in Table 5.2-1. Had the probable uncertainity estimate greatly exceeded the cumulative savings, the risk of purchasing the solar system in anticipation of savings would have been greater, in direct proportion to the magnitude of the uncertainty in the individual variables. The results for the other sites are as follows:

Albuquerque, New Mexico

$\Delta LCCS_{prob}$ = \$1362

Cumulative Savings = \$3918

Fort Worth, Texas

$\Delta LCCS_{prob}$ = \$853

Cumulative Savings = \$1725

Madison, Wisconsin

$\Delta LCCS_{prob}$ = \$810

Cumulative Savings = \$1197

Washington, D.C.

$\Delta LCCS_{prob}$ = \$1462

Cumulative Savings = \$3475

TABLE 6-1

UNCERTAINTY ANALYSIS FOR LOXACHATCHEE, FLORIDA

Optimized Collector Area = 112 FT^2

COST PARAMETER (x_j)	NOMINAL VALUES	NOMINAL VALUE DELTA	$\frac{\partial P1}{\partial x_j}$	$\frac{\partial P2}{\partial x_j}$	$\frac{\partial LCCS}{\partial x_j}$	$\Delta LCCS$ ($)
AREA DEPENDENT COST (C_A)	9.51	0.9510	0.0	0.0	-128	-122.
AREA INDEPENDENT COST (C_E)	898.00	89.8000	0.0	0.0	-1.	-103.
FUEL COST (C_F)	13.32	1.3320	0.0	0.0	268.	356.
DOWN PAYMENT/INIT INV (D)	0.20	0.0200	0.0	-0.074	145.	3.
FIRST YR. MISC COST/INIT INV (M)	0.005	0.0005	0.0	21.066	-41355.	-21.
FIRST YR. ASSESSED VAL/INIT INV (V)	0.0	0.0	0.0	0.0	0.0	0
SALVAGE VAL/INIT INV (G)	0.0	0.0	0.0	-0.196	384.	0
ANNUAL MKT DISCOUNT RATE (d)	0.085	0.0085	-286.35	-7.987	-22793.	-193.
ANNUAL MKT RATE OF FUEL COST INC. (e)	0.125	0.0125	252.55	0.0	33883.	424.
ANNUAL INT. RATE ON MORTGAGE (i)	0.135	0.0135	0.0	4.406	-8650.	-117.
ANNUAL RATE OF GENERAL INFLATION (g)	0.100	0.0100	0.0	0.954	-1872.	-19.
PROPERTY TAX RATE (t)	0.0	0.0	0.0	0.0	0.0	0.
EFFECTIVE INCOME TAX RATE ($\bar{t}$)	0.30	0.0300	0.0	-0.838	1644.	49.
ANNUAL HEATING AND HOT WATER LOAD (L)	10.67	1.0670	0.0	0.0	334.	356.
ANNUAL SOLAR FRACTION (F)	0.944	0.0944	0.0	0.0	3776.	356.

TABLE 6-2

UNCERTAINTY ANALYSIS FOR ALBUQUERQUE, NM

Optimized Collector Area = 101 FT^2

COST PARAMETER (x_j)	NOMINAL VALUES	NOMINAL VALUE DELTA	$\frac{\partial P1}{\partial x_j}$	$\frac{\partial P2}{\partial x_j}$	$\frac{\partial LCCS}{\partial x_j}$	$\Delta LCCS$ ($)
AREA DEPENDENT COST (C_A)	9.51	0.9510	0.0	0.0	-116.	-110.
AREA INDEPENDENT COST (C_E)	898.00	89.8000	0.0	0.0	-1.	-103.
FUEL COST (C_F)	20.39	2.0390	0.0	0.0	298.	608.
DOWN PAYMENT/INIT INV (D)	0.20	0.0200	0.0	- 0.074	137.	3.
FIRST YR. MISC COST/INIT INV (M)	0.005	0.0005	0.0	21.066	-39151.	-20.
FIRST YR. ASSESSED VAL/INIT INV (V)	0.0	0.0	0.0	0.0	0.0	0.
SALVAGE VAL/INIT INV (G)	0.0	0.0	0.0	-0.196	364.	0.
ANNUAL MKT DISCOUNT RATE (d)	0.085	0.0085	-286.35	-7.987	-50717.	-431.
ANNUAL MKT RATE OF FUEL COST INC. (e)	0.125	0.0125	252.55	0.0	57822.	723.
ANNUAL INT. RATE ON MORTGAGE (i)	0.135	0.0135	0.0	4.406	-8189.	-111.
ANNUAL RATE OF GENERAL INFLATION (g)	0.100	0.0100	0.0	0.954	-1773.	-18.
PROPERTY TAX RATE (t)	0.0	0.0	0.0	0.0	0.0	0.
EFFECTIVE INCOME TAX RATE ($\bar{t}$)	0.30	0.0300	0.0	-0.838	1557.	47.
ANNUAL HEATING AND HOT WATER LOAD (L)	11.60	1.1600	0.0	0.0	524.	608.
ANNUAL SOLAR FRACTION (F)	0.968	0.0968	0.0	0.0	6285.	608.

TABLE 6-3

UNCERTAINTY ANALYSIS FOR FORT WORTH, TEXAS

Optimized Collector Area = 103 FT^2

COST PARAMETER (x_j)	NOMINAL VALUES	NOMINAL VALUE DELTA	$\frac{\partial P1}{\partial x_j}$	$\frac{\partial P2}{\partial x_j}$	$\frac{\partial LCCS}{\partial x_j}$	$\Delta LCCS$ (\$)
AREA DEPENDENT COST (C_A)	9.51	0.9510	0.0	0.0	-118.	-112.
AREA INDEPENDENT COST (C_E)	898.00	89.8000	0.0	0.0	-1.	-103.
FUEL COST (C_F)	13.01	1.3010	0.0	0.0	293.	381.
DOWN PAYMENT/INIT INV (D)	0.20	0.0200	0.0	-0.074	138.	3.
FIRST YR. MISC COST/INIT INV (M)	0.005	0.0005	0.0	21.066	-39551.	-20.
FIRST YR. ASSESSED VAL/INIT INV (V)	0.0	0.0	0.0	0.0	0.0	0.
SALVAGE VAL/INIT INV (G)	0.0	0.0	0.0	-0.196	367.	0.
ANNUAL MKT DISCOUNT RATE (d)	0.085	0.0085	-286.35	-7.987	-26037.	-221.
ANNUAL MKT RATE OF FUEL COST INC. (e)	0.125	0.0125	252.55	0.0	36189.	452.
ANNUAL INT. RATE ON MORTGAGE (i)	0.135	0.0135	0.0	4.406	-8273.	-112.
ANNUAL RATE OF GENERAL INFLATION (g)	0.100	0.0100	0.0	0.954	-1791.	-18.
PROPERTY TAX RATE (t)	0.0	0.0	0.0	0.0	0.0	0.
EFFECTIVE INCOME TAX RATE ($\bar{t}$)	0.30	0.0300	0.0	-0.838	1573.	47.
ANNUAL HEATING AND HOT WATER LOAD (L)	13.05	1.3050	0.0	0.0	292.	381.
ANNUAL SOLAR FRACTION (F)	0.844	2.0844	0.0	0.0	4511.	381.

TABLE 6-4

UNCERTAINTY ANALYSIS FOR MADISON, WI

Optimized Collector Area = 140 FT^2

COST PARAMETER (x_j)	NOMINAL VALUES	NOMINAL VALUE DELTA	$\frac{\partial P1}{\partial x_j}$	$\frac{\partial P2}{\partial x_j}$	$\frac{\partial LCCS}{\partial x_j}$	$\Delta LCCS$ ($)
AREA DEPENDENT COST (C_A)	9.51	0.9510	0.0	0.0	-160.	-152.
AREA INDEPENDENT COST (C_E)	898.00	89.8000	0.0	0.0	-1.	-103.
FUEL COST (C_F)	12.21	1.2210	0.0	0.0	311.	379.
DOWN PAYMENT/INIT INV (D)	0.20	0.0200	0.0	-0.074	164.	3.
FIRST YR. MISC COST/INIT INV (M)	0.05	0.0005	0.0	21.066	-46964.	-23.
FIRST YR. ASSESSED VAL/INIT INV (V)	0.0	0.0	0.0	0.0	0.	0.
SALVAGE VAL/INIT INV (G)	0.0	0.0	0.0	-0.196	436.	0.
ANNUAL MKT DISCOUNT RATE (d)	0.085	0.0085	-286.35	-7.987	-23067.	-196.
ANNUAL MKT RATE OF FUEL COST INC. (e)	0.125	0.0125	252.55	0.0	36048.	451.
ANNUAL INT. RATE ON MORTGAGE (i)	0.135	0.0135	0.0	4.406	-9823.	-133.
ANNUAL RATE OF GENERAL INFLATION (g)	0.100	0.0100	0.0	0.954	-2126.	-21.
PROPERTY TAX RATE (t)	0.0	0.0	0.0	0.0	0.	0.
EFFECTIVE INCOME TAX RATE ($\bar{t}$)	0.300	0.0300	0.0	-0.838	1867.	56.
ANNUAL HEATING AND HOT WATER LOAD (L)	14.93	1.4930	0.0	0.0	254.	379.
ANNUAL SOLAR FRACTION (F)	0.783	0.0783	0.0	0.0	4844	379.

TABLE 6-5

UNCERTAINTY ANALYSIS FOR WASHINGTON D.C.

Optimized Collector Area = 182 FT^2

COST PARAMETER (x_j)	NOMINAL VALUES	NOMINAL VALUE DELTA	$\frac{\partial P1}{\partial x_j}$	$\frac{\partial P2}{\partial x_j}$	$\frac{\partial LCCS}{\partial x_j}$	$\Delta LCCS$ ($)
AREA DEPENDENT COST (C_A)	9.51	0.9510	0.0	0.0	-208.	-198.
AREA INDEPENDENT COST (C_E)	898.00	89.8000	0.0	0.0	-1.	-103.
FUEL COST (C_F)	19.78	1.9780	0.0	0.0	330.	653.
DOWN PAYMENT/INIT INV (D)	0.20	0.0200	0.0	-0.074	194.	4.
FIRST YR. MISC COST/INIT INV (M)	0.005	0.0005	0.0	21.066	-55378.	-28.
FIRST YR. ASSESSED VAL/INIT INV (V)	0.0	0.0	0.0	0.0	0.0	0.
SALVAGE VAL/INIT INV (G)	0.0	0.0	0.0	-0.196	514.	0.
ANNUAL MKT DISCOUNT RATE (d)	0.085	0.0085	-286.35	-7.987	-49376.	-420.
ANNUAL MKT RATE OF FUEL COST INC. (e)	0.125	0.0125	252.55	0.0	62065.	776.
ANNUAL INT. RATE ON MORTGAGE (i)	0.135	0.0135	0.0	4.406	-11583.	-156.
ANNUAL RATE OF GENERAL INFLATION (g)	0.100	0.0100	0.0	0.954	-2507.	-25.
PROPERTY TAX RATE (t)	0.0	0.0	0.0	0.0	0.0	0.
EFFECTIVE INCOME TAX RATE ($\bar{t}$)	0.30	0.0300	0.0	-0.838	2202.	66.
ANNUAL HEATING AND HOT WATER LOAD (L)	13.96	1.3960	0.0	0.0	468.	653.
ANNUAL SOLAR FRACTION (F)	0.890	0.0890	0.0	0.0	7337.	653.

7. SUMMARY AND CONCLUSIONS

The Semco Solar Energy System is economically beneficial under the assumed economic conditions at Loxahatchee, Florida; Albuquerque, New Mexico; Fort Worth, Texas; Madison, Wisconsin and Washington D.C., as shown in Figure 7-1. Life cycle savings range from a high of $3918 at Albuquerque, New Mexico, where average solar insolation is 1828 Btu/Ft^2/day and conventional energy costs are also high (0.070 $/kWh) to a low of $1197 at Madison, Wisconsin, which is penalized, for solar system application, by a low average value of solar insolation (1191 Btu/Ft^2/day) and low conventional energy costs (0.042 $/ kWh).

Economic benefits from this solar energy system depend primarily on two factors: (1) maintaining or decreasing the initial investment required and (2) the continuing increase in the cost of conventional energy. The capability to maintain or decrease the cost of the system relative to its present level is uncertain. It depends on favorable tax treatment from the various levels of government, local through federal, as well as the continuing development of the solar industry. On the other hand, increases in the cost of conventional energy are virtually assured. From the economic uncertainty analysis in Section 6, where the conventional energy costs are medium to high, the savings with this system are 1.6 to 2.9 times more sensitive to increases in the conventional energy cost than to proportional increases in the solar system cost. This sensitivity serves to somewhat mitigate the risks. If the conventional energy costs are low, system cost increases and proportional increases in the cost of conventional energy equally impact the savings.

The analysis and results given in this report can be used to guide a potential solar energy system buyer in evaluating the purchase of this type of Domestic Hot Water (DHW) system. To do this the solar insolation buyer's geographic area must be known. This data is available from several sources, including Reference [9] and [10]. The cost of conventional energy must also be known. The local utility company can furnish rates from which

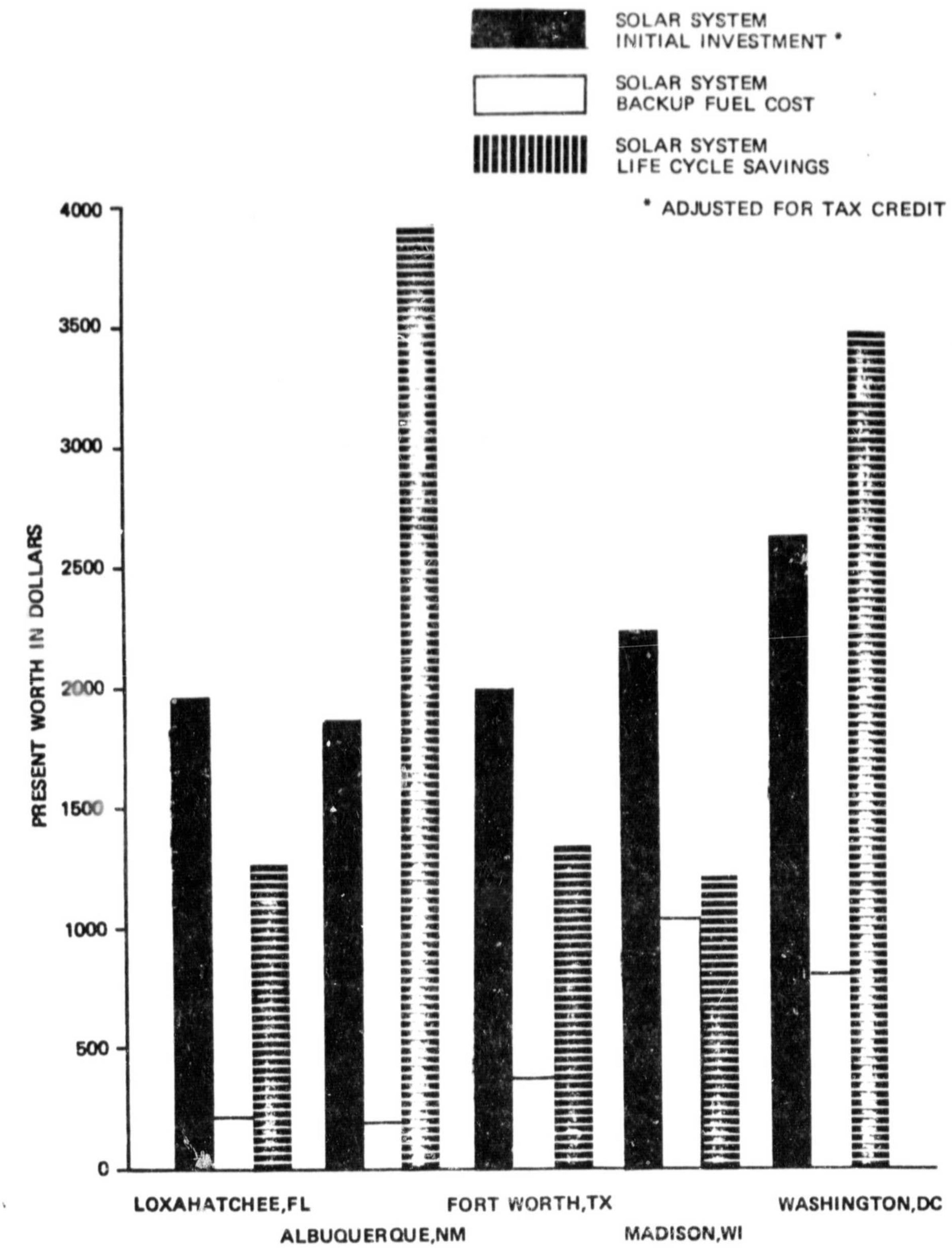

Figure 7-1. Economic Summary Chart for All Anaysis Sites

a comparison cost based on 1000 kWh use can be computed in dollars per kWh. These values can then be compared with the characteristics of the analysis sites given in Section 3.1. The results for that analysis site can be ascertained from Sections 5.1 and 5.2. The primary economic parameters such as solar system cost, mortgage rates, inflation rates, discount rates, etc., are generally known by the buyer for his area. Deviations in these economic parameters from the values assumed in developing the results in this report can be evaluated from the material included in Section 6. The ΔLCCS values given in Tables 6-1 through 6-5 were computed based on a 10 percent increase in the economic parameter in question. A 10 percent decrease simply means changing the sign of the value in the appropriate table. Larger increases or decreases in an economic parameter can also be obtained by multiplying the ΔLCCS value by the ratio of the desired increase to the 10 percent increase used in the original computation.

As an example of the discussion above, assume the buyer has determined that the characteristics of his locale are similar to Fort Worth, Texas and is considering the results reported for this solar energy system in Fort Worth. He notes that the reported savings from Table 5.2-1 is $1725; however, the conventional energy cost of his locale is $0.040/kWh instead of the $0.044/kWh (Table 5.1-3) used in developing the Fort Worth saving. To modify the saving to consider the new rate the change is computed as:

$$\frac{0.040 - 0.044}{0.044} \times 100\% = -9.1\% \text{ (Decrease)}$$

In Table 6-3 for Fort Worth it can be seen that a 10 percent increase in fuel cost yields a value of ΔLCCS of $381. The impact on the Life Cycle Cost Savings of a 9.1 percent decrease in fuel cost can be computed as follows:

$$\Delta LCCS = \frac{-9.1}{10.0} \times 381 = \$-347$$

Therefore, the new savings is:

$1725 -$347 = $1378

The buyer can evaluate the result of a change in any of the economic parameters in the same manner. However, he should be aware that the parameters are sometimes interrelated and a change in one parameter may affect the ΔLCCS for several parameters. Consequently the larger the changes the less the accuracy. However, approximate results may be obtained that prove to be of value in making a final decision.

8. REFERENCES

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APPENDIX A

F-CHART PROCEDURE

APPENDIX A

F-Chart Procedure

Modifications are made to f-Chart to enable the program to be used to perform economic analysis of the following:

1. Systems that use heat pumps and fossil fuel space heating systems, as well as electric resistance heat.

2. Systems that use two different energy sources for domestic hot water heating and space heating.

The problem of analysis of the solar energy system with a conventional backup other than electric resistance heat is resolved by introducing a Coefficient of Performance (COP) whose value is dependent upon the type of backup system. Typical COP's of heat pumps are computed from a heat pump model which uses as inputs the ambient and building temperature. Fossil fuel furnace COP's are assumed to be 0.60 unless different efficiencies, based on manufacturer's or other sources of data, are available.

The problem of analysis with two different energy sources is resolved by adjusting the COP of the space heating system in accordance with the type of fuel used for the DHW system. This is necessary because the structure of f-Chart assumes electric energy to be the source for both space heating and domestic hot water. The adjustment factor is the adjusted ratio of the rates for the two energy sources used. The general expression for this is:

$$\text{SH COP}' = \frac{\text{DHW Auxiliary Fuel Rate (\$/million Btu)}}{\text{SH Auxiliary Fuel Rate (\$/million Btu)}} \times \left(\begin{array}{l}\text{SH COP} \\ \text{ or} \\ \text{SH Efficiency}\end{array}\right)$$

where the DHW Auxiliary Fuel Rate is the effective rate for fuel actually used and is equivalent to the electrical energy rate in a 100 percent efficient electrical hot water heater. The DHW auxiliary Fuel Rate will also be used for the value of Item Number 31 and 34 for systems of this configuration.

The value of SH COP' is input to the modified f-Chart program. This value is used to compute an adjusted total load. The load, in turn, is used to derive the solar fraction which is input to the f-Chart economic analysis subroutine.

Major considerations of the final report analysis procedure are the definitions of the loads that the system supports as it is analyzed in different geographic locations, and the sizing of the system to handle these loads at the various locations. The method it outlined in the following paragraphs.

The monthly long-term heating load at the selected analysis sites is computed from the following equation:

$$HL_{LT} = UA*24*HDD_{LT} - HTGEN$$

where

UA is the modified building energy loss coefficient

HDD_{LT} is the monthly long-term average heating degree days

HTGEN is the internally generated heat computed from measured data.

It is to be noted that UA is a modified parameter. The modification is to compensate for the fact that housing standards differ from location to location, i.e., the construction standards for a Florida house are not suitable for the New York environment. The UA factor used is derived from the ASHRAE 90-75 Standard [8] as a function of long-term heating degree days according to the appropriate U-value. The area, A, is derived from the building where the system is installed.

HTGEN is a factor that accounts for the part of the load which is internally generated. This is assumed to be the heat added which brings the building to the desired (comfortable) temperature when the outside ambient temperature is 65°F and no auxiliary heat is being added to the building. HTGEN, once derived, is assumed to be constant since it is a function of the life style of the occupants. The value of HL_{LT} is the monthly long-term average heat load input to f-Chart.

Additional technical and economic parameters that are input to f-Chart for the final report analysis are listed below with applicable comments.

1. Air SH + WH = 1, Liq SH + WH = 2, Air or Liq WH Only = 3

   Comment: This is a definition of system type. The value is 1, if the system uses air collectors and supplies both space heat and domestic hot water; 2, if the system uses liquid collectors and supplies both space heat and domestic hot water; 3, if the system uses either type of collector and supplies only domestic hot water.

2. (Flow rate/col. area) * (Spec. heat)

   Comment: If the system is an air system, this parameter is applicable. It is the air mass flow rate in lb/min divided by the gross collector area multiplied by the specific heat of air at standard conditions. The value of this parameter is computed for the system at the actual installation site. This value is then maintained constant as the collector size is optimized for all analysis sites.*

*f-Chart uses an optimized value of 2.15 Btu/Hr °F Ft^2 for this parameter In resizing a system, only the collector size is varied. The system is not given the benefit of further optimization.

3. εCmin/UA

Comment: If the system is a liquid system and uses a liquid to air heat exchanger in the space heating loop, this parameter is applicable. It is the manufacturer's heat exchanger effectiveness multiplied by the minimum capacitance rate through the heat exchanger and divided by the building energy loss coefficient. If the heat exchanger effectiveness is unknown, a default value of 0.5 is specified. The capacitance, Cmin, is the minimum product of mass flow rate and specific heat, which usually occurs on the air side. The UA value is the modified parameter applicable to the site. Deriving this value of UA has been previously discussed. The value of εCmin/UA is computed for the system at the actual installation site. This value is then maintained constant as the collector size is optimized for all analysis sites.*

4. Collector Area

Comment: This is the gross collector area which is optimized for all analysis sites. The optimization is extended to the actual installation site if an optimum sizing is not apparent in the original design. The predicted performance with optimal collector sizing is then compared to the predicted performance of the actual design and the actual measured performance.

5. $F_R\ (\tau\alpha)$

Comment: The basic value of $F_R\ (\tau\alpha)$ was derived from the collector analysis program. This value is more consistent with actual operation than the manufacturer's or laboratory single

*f-Chart uses an optimized value of 2.0 (dimensionless) for this parameter
In resizing a system only the collector size is varied.
The system is not given the benefit of further optimization.

panel test values. If the system has a heat exchanger between collectors and storage, the derived value of $F_R (\tau\alpha)$ was modified by the F_R'/F_R factor as outlined in Section 2.4.4 of EES Report 49-3 (f-Chart Users Manual). [4] Note that the values input to f-Chart are assumed to be derived in accordance with ASHRAE specified method.

6. $F_R U_L$

Comment: Same comment as Item 5.

7. Incidence Angle Modifier

Comment: In general, the default value of 0 is used. For evacuated tube collectors modeled as flat plate collectors the collector angle incidence modifier is obtained from the collector manufacturer.

8. Number of Transparent Covers

Comment: This is specified according to the characteristics of the collector.

9. Collector Slope

Comment: Collector Slope is changed according to the latitude of the site and the type of system. When the site analyzed is the existing site, the actual slope value is used. For other analysis sites the slope is computed as follows:

- Latitude +10° if space heat and domestic hot water
- Latitude if domestic hot water only

10. Azimuth Angle

Comment: At sites other than the existing installation site the aximuth angle is 0°. At the existing site azimuth angle used for analysis was actual. However, any resulting performance degradation is noted.

11. Storage Capacity

Comment: This parameter is computed as the product of storage mass and specific heat divided by collector area for the existing site. The same value of storage capacity is used for all sites.

12. Effecting Building UA

Comment: The building UA, if not known, is derived from the measurement data contained in the Seasonal Report [3]. The computed value of UA is compared for reasonableness with a corresponding value of UA derived from ASHRAE Standard 90-75. For other analysis sites the value of UA is derived from ASHRAE Standard 90-75 as a function of building type and heating degree-days for each site.

13. Constant Daily Building Heat Generation

Comment: For residential type buildings, this parameter is derived from the measurement data contained in the Seasonal Report [3]. The derived value is held constant for all analysis sites.

14. Hot Water Usage

Comment: An effective average hot water consumption rate that accounts for actual load plus standby losses was computed from the following equation:

$$HWCSMPEFF = \frac{\frac{HWSE + HWAT}{C_p\left(\frac{TMAIN + TSET}{2}\right) * (TSET - TMAIN) * RHO\left(\frac{TMAIN + TSET}{2}\right)}}{\text{Number of Days in Month}}$$

15. Water Set Temperature

Comment: The actual value of this parameter at the existing site is used for all analysis sites.

16. Water Main Temperature

Comment: The inputs for this parameter are a series of monthly values. The actual monthly value at the existing site is referenced to the average long-term ambient for the month for analysis at that site. For analysis at other sites the monthly value of TMAIN was established by site measurement at a nearby site referenced to the average long-term ambient for the month. (See Appendix C)

17. City Call Number

Comment: If the analysis site is located at a city listed in the November 1978 Input Data For Solar Systems that site is entered into the f-Chart data record. If the analysis site is not a part of the data record, an interpolative routine computes the data for any arbitrary site from nearby sites where data is available.

18. Thermal Print Out by Month

Comment: None

19. Economic Analysis

Comment: In general, all runs made for Final Reports specify print out of economic analysis.

20. Use Optimized Collector Area = 1, Specified Area = 2

Comment: In general the runs made for Final Reports use an optimized collector area.

21. Solar System Thermal Performance Degradation

Comment: A value of zero percent is used.

22.-46. Economic Parameters

Comment: The values of the economic parameter were worked out between MSFC and IBM for the Final Reports. The source of the value is given in the notes on page A-11.

Residential

Item	Variable Description	Value	Units	Source
22	Period of Economic Analysis	20	Yrs.	SAI[1]
23	Collector Area Dependent System Costs			MSFC[2]
24	Constant Solar Costs			MSFC[2]
25	Down Payment (% of Original Investment)	20	%	SAI[1]
26	Annual Interest Rate on Mortgage	13.5	%	MSFC[2]
27	Term of Mortgage	20	Yrs.	SAI[1]
28	Annual Nominal (Market) Discount Rate	8.5	%	SAI[1]
29	Extra Insur., Maint. in Year 1 (% of Orig. Inv.)	0.5	%	MSFC[2]
30	Annual % Increase in Above Expenses	10.0	%	MSFC[2]
31	Present Cost of Solar Backup Fuel (BF)			Actual[3]
32	BF Rise: %/Yr. = 1, Sequence of Values = 2	1		

Residential (Continued)

Item	Variable Description	Value	Units	Source
33	Annual Rate of BF Rise			
	Electricity	12.5	%	MSFC[2]
	Oil	12.5	%	MSFC[2]
	Natural Gas	12.5	%	MSFC[2]
34	Present Cost of Conventional Fuel (CF)			Same as #31[4]
35	CF Rise: %/Yr. = 1, Sequence of Values - 2	1		
36	Annual Rate of CF Rise			
	Electricity	12.5	%	MSFC[2]
	Oil	12.5	%	MSFC[2]
	Natural Gas	12.5	%	MSFC[2]
37	Economic Print Out by Year = 1, Cumulative = 2	2		Analyst Option
38	Effective Federal State Income Tax Rate			
	Residential	30	%	SAI[1]
	Commercial	48	%	MSFC[2]
39	True Property Tax Rate Per $ of Original Investment	0	%	SAI[1]
40	Annual % Increase in Property Tax Rate	NA If #39 is "0"		
41	Calc. Rt. of Return on Solar Investment? Yes = 1, No = 2			Analyst
42	Resale Value (% of Original INvestment)	0		MSFC[2,5]
43	Income Producing Building, Yes = 1, No = 2			Site Dependent
44	Dprc.: Str. In. = 1, Dc. Bal. = 2, Sm-yr.-Dgt. = 3, None = 4	2	%	MSFC[2]
45	If 2, What % of Str. Ln. Dprc. Rt. is Desired	150	%	MSFC[2]
46	Useful LIfe for Deprec. Purposes	20	Yrs.	MSFC[2]

47. Economic COP for Auxiliary System

Comment: This is a new parameter defined for f-Chart to account for economic analysis of solar systems having auxiliary backup other than electric resistance heat. The default values of this parameter are as follows:

Heat Pump Auxiliary	COP = 2
Fossil Fuel Auxiliary	COP = 0.6
Electric Resistance	COP = 1.0

The value of the basic COP is modified, according to the method described on page A-2, to account for differences between the fuel used for the domestic hot water and the fuel used for space heating.

NOTES:

1. Source was Science Applications, Inc. (SAI) Draft Final Report on "Comparison of Solar Heat Pump Systems to Conventional Methods for Residential Heating, Cooling, and Water Heating," April 1979.

2. These items were based on judgment and best experience.

3. The actual current utility rates for the analysis sites selected were obtained. (See Appendix D).

4. The assumption for final report analysis was that the backup system actually used for the installation was the same type of system that would be used if the solar system was not installed.

5. The declining balance technique never permits 100% depreciation of the asset no matter how long the period. The balance remaining at the end of the system lifetime was treated, for accounting purposes, as salvage value. No other salvage value was presumed to exist.

APPENDIX B

ECONOMIC UNCERTAINTY ANALYSIS EQUATIONS

APPENDIX B

ECONOMIC UNCERTAINTY ANALYSIS EQUATIONS

1. Area dependent investment costs (C_A)

$$\Delta LCCS_{CA} = -P_2 A \, (\Delta C_A)$$

2. Area independent investment costs (C_E)

$$\Delta LCCS_{CE} = -P_2 \, (\Delta C_E)$$

3. Ratio of downpayment to initital investment (D)

$$\Delta LCCS_D = -(C_A A + C_E) \left\{ 1 - (1-\bar{t}) \frac{f(N,\ 0,\ d)}{f(N,\ 0,\ i)} + \bar{t} f(N,\ i,\ d) \left[i - \frac{1}{f(N,\ 0,\ i)} \right] \right\} (\Delta D)$$

4. Ratio first year's misc. costs to init. inv. (M)

$$\Delta LCCS_M = -(C_A A + C_E) \left[(1 - C\bar{t}) \, f(N,\ g,\ d) \right] (\Delta M)$$

5. Ratio first year's assessed value to init. inv. (V)

$$\Delta LCCS_V = -(C_A A + C_E) \left[t \, (1 - \bar{t}) \, f(N,\ g,\ d) \right] (\Delta V)$$

6. Ratio salvage or resale value to init. inv. (G)

$$\Delta LCCS_G = -(C_A A + C_E) \left[\frac{-1}{(1 + d)^N} \right] (\Delta G)$$

7. Annual market discount rate (d)

$$\Delta LCCS_d = C_F LF (1 - C\overline{t}) \frac{\partial}{\partial d} f(N, e, d) (\Delta d)$$

$$-(C_A A + C_E) \Big\{ \frac{1-D}{f(N, 0, i)} \frac{\partial}{\partial d} f(N, 0, d) +$$

$$\left[(1 - C\overline{t}) M + t (1 - \overline{t})V\right] \frac{\partial}{\partial d} f(N, g, d) -$$

$$(1 - D) \overline{t} \left[\frac{1}{f(N, 0, i)} \frac{\partial}{\partial d} f(N, 0, d) +\right.$$

$$\left.\left(i - \frac{1}{f(N, 0, i)}\right)\frac{\partial}{\partial d} f(N, i, d)\right] - \frac{NG}{(1 + d)^{N+1}} -$$

$$\frac{C\overline{t}}{N} \frac{\partial}{\partial d} f(N, 0, d) \Big\} (\Delta d)$$

8. Annual market rate of fuel price increase (e)

$$\Delta LCCS_e = C_F LF (1 - C\overline{t}) \frac{\partial}{\partial e} f(N, e, d) (\Delta e)$$

9. Annual interest rate on mortgage (i)

$$\Delta LCCS_i = -(C_A A + C_E) \Big\{ (D - 1) (1 - \overline{t}) \frac{f(N, 0, d)}{f(N, 0, i)}$$

$$\frac{\partial}{\partial i} f(N, 0, i) - \overline{t} (1 - D) \left[i - \frac{1}{f(N, 0, i)}\right]$$

$$\frac{\partial}{\partial i} f(N, i, d) - \overline{t} (1 - D) f(N, i, d)$$

$$\left[1 + \frac{1}{f(N, 0, i)} \frac{\partial}{\partial i} f(N, 0, i)\right] \Big\} \Delta i$$

10. Annaul rate of general inflation (g)

$$\Delta LCCS_g = -(C_A A + C_E)\left[(1 - C\bar{t})\, M + (1 - \bar{t})\, t\, V\right]$$

$$\frac{\partial}{\partial g} f\,(N, g, d) \quad (\Delta g)$$

11. Effective income tax rate ($\bar{t}$)

$$\Delta LCCS_{\bar{t}} = -C_F LFCf(N, e, d)\,(\Delta\bar{t})$$

$$-(C_A A + C_E)\left\{ (D-1)\left[\frac{f(N, 0, d)}{f(N, 0, i)}\right] + (D - 1)\, f(N, i, d)\right.$$

$$\left[i - \frac{1}{f(N, 0, i)}\right] -t\, Vf(N, g, d) - C\left[Mf(N, g, d) + \right.$$

$$\left.\left.\frac{1}{N} f(N, 0, d)\right]\right\}(\Delta\bar{t})$$

12. Property tax rate (t)

$$\Delta LCCS_t = -(C_A A + C_E)\,(1 - \bar{t})\, Vf(N, g, d)\,(\Delta t)$$

13. Cost of conventional fuel in the first year (C_F)

$$\Delta LCCS_{CF} = P_1 LF\,(\Delta C_F)$$

14. Annual heating and hot water load (L)

$$\Delta LCCS_L = P_1 C_F F\,(\Delta L)$$

15. Annual load fraction supplied by solar (F)

$$\Delta LCCS_F = P_1 C_F L(\Delta F)$$

NOTE: Three functions used above required definition

$$f(N, a, b) = \frac{1}{b - a}\left[1 - \left(\frac{1 + a}{1 + d}\right)^N \right]$$

$$\frac{\partial}{\partial a} f(N, a, b) = \frac{1}{b - a}\left[f(N, a, b) - \frac{N}{1 + a}\left(\frac{1 + a}{1 + b}\right)^N \right]$$

$$\frac{\partial}{\partial b} f(N, a, b) = \frac{1}{b - a}\left[\frac{N}{1 + b}\left(\frac{1 + a}{1 + b}\right)^N - f(N, a, b) \right]$$

APPENDIX C

MONTHLY AVERAGE WATER SUPPLY TEMPERATURES

TABLE C-1

MONTHLY AVERAGE WATER SUPPLY TEMPERATURES IN °F

	MONTH												
SITE NAME	J	F	M	A	M	J	J	A	S	O	N	D	AVERAGE
LOXAHATCHEE, FL	73	73	74	82	82	85	85	88	80	72	70	58	78
ALBUQUERQUE, NM	66	66	66	70	74	76	80	83	79	74	71	66	73
FORT WORTH, TX	42	49	58	65	73	80	82	83	78	63	53	49	65
MADISON, WI	34	37	39	50	61	68	70	72	68	63	54	36	54
WASHINGTON, DC	42	42	52	56	63	67	67	78	79	68	55	46	60

APPENDIX D

ENERGY COSTS FOR ANALYSIS SITES

LOXAHATCHEE, FL

ELECTRICITY (RESIDENTIAL)

0 - 750 KWH	$0.0303/kWh
> 750 KWH	$0.03846/kWh

FUEL RATE ADJUSTMENT	$0.00992/kWh
SERVICE (MINIMUM) CHARGE	$3.20/MONTH

TAX - NONE ON RESIDENTIAL RATES

1000 KWH EFFECTIVE RATE ≈ $0.045/kWh

ALBUQUERQUE, NM

GAS (RESIDENTIAL)

0-165 THERMS 0.0803/THERM
165-340 THERMS 0.0826/THERM
340+ THERMS 0.0966/THERM
SERVICE CHARGE $1.25
FUEL ADJUSTMENT $0.2114/THERM
TAX 4%

EXAMPLE
30 THERMS * 0.2114 = $6.34

ELECTRICITY (RESIDENTIAL)

0-200 kWh	0.05294/kWh		
200-800 kWh	0.04794/kWh		1000 kWh EFFECTIVE
800+ kWh	0.03894/kWh	NOV-MAY	RATE = 0.069576 $/kWh
OR			YEAR-AROUND
800 + kWh	0.04094/kWh	JUN-OCT	

FUEL RATE ADJUSTMENT $0.016680/kWh
SERVICE CHARGE $2.60
TAX 4.5%

FUEL OIL

$0.999/GAL+ 4% TAX

FORT WORTH, TEXAS

GAS

0-1000 MCF	\$4.05/MCF	MCF = 1000 CFM = 10^6 BTU
1000-MCF	\$2.433/MCF	

SERVICE CHARGE	0
TAX	0

ELECTRICITY

0- 25 kWh	\$6.00 (MINIMUM)
25+ kWh	0.0285/kWh
FUEL CHARGE	\$0.008899/kWh
SALES TAX	4%

1000 kWh EFFECTIVE RATE \$0.0444/kWh

FUEL OIL

NOT USED IN FORT WORTH AREA

MADISON, WI

GAS

0-20	THERMS	$0.28732/THERM
20-50	THERMS	0.27936/THERM
50+	THERMS	0.26892/THERM

ALSO	FUEL RATE CHARGE	$0.0762/THERM
	TAX	0.
	SERVICE CHARGE	$2.00/MONTH

ELECTRICITY (RESIDENTIAL)

0- 100	kWh	$0.0360/kWh
100- 500	kWh	0.0350/kWh
500-1000	kWh	0.0320/kWh
1000+	kWh	0.0275/kWh

ALSO FUEL RATE CHARGE (JAN) $0.00607/kWh
TAX 0
SERVICE CHARGE $2.00/MONTH

1000 kWh EFFECTIVE RATE $0.04167/kWh

FUEL OIL

$0.919/GAL

TAX 0 FOR RESIDENTIAL 4% FOR COMMERCIAL

WASHINGTON, DC

GAS

$5.00/MO SERVICE CHARGE   1 THERM = 100,000 Btu
$0.3255/THERM + 5% TAX

ELECTRICITY (RESIDENTIAL RATES)

$5.00/MO SERVICE CHARGE

NOV - MAY WINTER RATES				JUNE - OCT SUMMER RATES		
0 - 600	kWh	0.06024	$/kWh	0 - 600	0.06024	$/kWh
600 - 1500	kWh	0.05334	$/kWh	600 - 1500	0.06924	$/kWh
1500 +	kWh	0.04289	$/kWh	1500 +	0.26638	$/kWh

TAX 16% OF FIRST $15.00 ($2.40 MAX)
FUEL CHARGE 0.01500 $/kWh (INCLUDED IN ABOVE RATES)

1000 kWh EFFECTIVE RATE = 0.0675 $/kWh YEAR-ROUND

FUEL OIL

$0.989/GAL

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