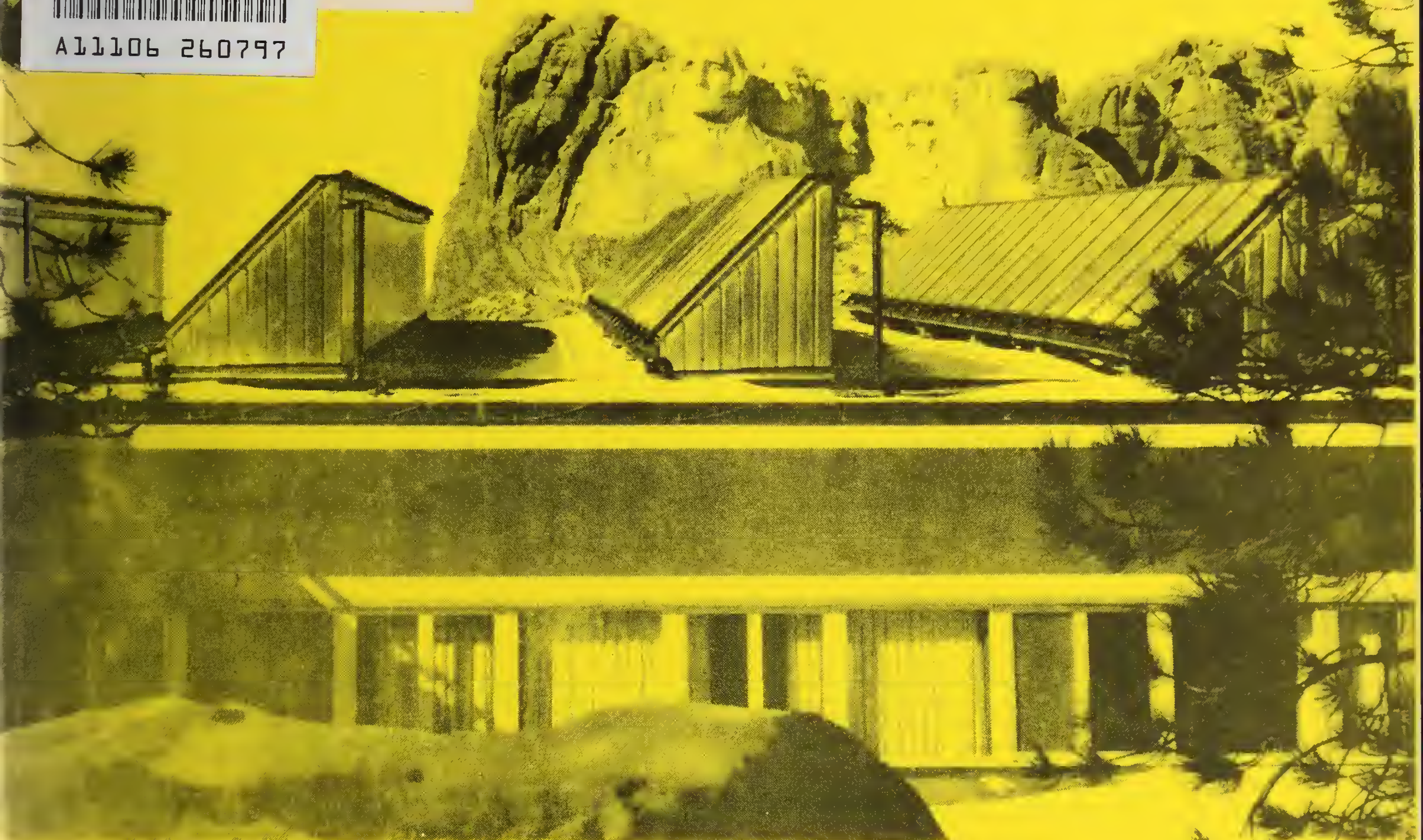

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FEDSOL: Program User's Manual and Economic Optimization Guide for Solar Federal Buildings Projects

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U.S. DEPARTMENT OF COMMERCE
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FEDSOL: PROGRAM USER'S MANUAL AND ECONOMIC OPTIMIZATION GUIDE FOR SOLAR FEDERAL BUILDINGS PROJECTS

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DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report provides a user's manual for the FEDSOL computer program and a guide for designing and sizing solar energy projects for Federal buildings. The life-cycle cost procedures implemented by the computer program and explained in the report are consistent with the Federal Rules for Life-Cycle Costing (10 CFR Part 436) as applied to solar energy projects.

The FEDSOL program determines the economically optimal size of a solar energy system for a user-specified building, location, system type, and set of economic conditions; it conducts numerous breakeven and sensitivity analyses; and it calculates measures of economic performance as required under the Federal Rules. The economic model in the program is linked with the SLR (Solar Load Ratio) design method developed at Los Alamos National Laboratory to predict the performance of active systems. The economics portion of the program can, however, be used apart from the SLR method, with performance data provided by the user. An environmental data file for 243 U.S. cities is included in the program. Highly user oriented, the FEDSOL program is intended as a design and sizing tool for use by architects, engineers, and facilities managers in developing plans for Federal solar energy projects.

Key words: cost effectiveness; economic optimization; Federal buildings; life-cycle costing; solar economics; solar energy.

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Special acknowledgment and appreciation are extended to Drs. Norman E. Schnurr and Bruce D. Hunn of Los Alamos National Laboratory for their encouragment and technical assistance in incorporating "The Solar Load Ratio Method Applied to Commercial Building Active System Sizing"[3] within the FEDSOL program and for reviewing this report.

The authors also wish to thank Mr. William Lemeshewsky of the Department of Energy, Program Coordinator of the Solar Federal Buildings Program, and Mr. Robert Lorand of JRB Associates, Inc., Contract Manager, for providing financial support and guidance to this project.

PREFACE

This report was prepared by the Applied Economics Group, Building Economics and Regulatory Technology Division, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards (NBS), for the Department of Energy, Office of Solar Applications for Buildings, under Interagency Agreement E(49-1)-3800, EA-77-A-01-6010.

The work is in support of the Solar Federal Buildings Program, whose broad objective is to stimulate the growth and improve the efficiency of the solar industry by providing funds to Federal agencies for the design, acquisition, construction, and installation of commercially applicable solar hot water, heating, cooling, and process systems in new and existing Federal buildings. The authorizing legislation for the Solar Federal Buildings Program (the National Energy Conservation and Policy Act of 1978) further ordered that a life-cycle cost analysis conducted in accordance with a uniform methodology and procedures to be established by the Department of Energy accompany proposals for project funding.

This report provides a comprehensive guide for applying life-cycle cost analysis to the economic evaluation, design, and sizing of Federal solar energy projects with FEDSOL, an interactive computer program that is fully consistent with the methodology and procedures for life-cycle cost analysis established by the Department of Energy. FEDSOL can be accessed through the Solar Energy Information Data Bank (SEIDB), the computer time-sharing network operated by the Solar Energy Research Institute, and is available on magnetic tape from the National Technical Information Service. The FEDSOL program and user instructions (section 2 of this report) were prepared by Richard C. Rodgers, Jr., Consultant in Solar Energy Research, Development, and Design, P. O. Box 1365, Palo Alto, California 94302.

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1. INTRODUCTION

To design and size solar energy systems for maximum economic efficiency, it is important to use life-cycle cost (LCC) analysis throughout the planning and design stages of a project. Federal agencies are required to submit a life-cycle cost evaluation consistent with a prescribed methodology and procedures for life-cycle cost analyses before undertaking an investment in solar energy.

1.1 BACKGROUND

The National Energy Conservation and Policy Act of 1978 (NECPA) authorized the Solar Federal Buildings Program (SFBP), a multi-year program designed to promote the use of solar energy and to develop a more efficient solar industry. The NECPA directed the Department of Energy to develop uniform LCC methods and procedures to be followed by all Federal agencies in evaluating the cost effectiveness of potential energy conservation and renewable energy investments in Federally owned and leased buildings. According to Title 5, Part 2, Sec. 523, of NECPA, these LCC procedures must be applied to projects funded under the Solar Federal Buildings Program.

The Federal LCC Rule was published in the January 23, 1980 issue of the Federal Register [4], with energy price data then current. A revision of the Rule, including new energy price data and other changes pursuant to the Energy Security Act of 1980, was proposed in the October 27, 1980 issue of the Federal Register [5] and was published in final form on September 1981 [6]. Further revisions to the LCC Rule, primarily to update energy prices, will be made periodically.[1] The "Methodology and Procedures for Life-Cycle Cost Analyses" is Subpart A of Part 436 of Title 10 of the Code of Federal Regulations. Subpart D of Part 436 sets forth guidelines for the Solar Federal Buildings Program.

To help implement the LCC methodology and procedures, an LCC Manual [1] has been prepared. The LCC Manual explains the life-cycle costing method, defines the terms, describes assumptions and procedures to follow in performing evaluations, and gives examples. In addition, it provides a set of worksheets, a computer program, and step-by-step instructions for performing the LCC evaluations of energy conservation and renewable energy projects for Federal buildings. The Solar Project worksheets were submitted with proposals for project funding under the Solar Federal Buildings Program.[2]

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[1] The status of current energy price data for use in carrying out the Federal LCC evaluation can be ascertained by contacting Jack Vitullo, Federal Energy Management Program Office, Forrestal Building, U. S. Department of Energy, Washington, D.C. 20585. Telephone: 202-252-9471.

[2] The reader is referred to the LCC Rules, the LCC Manual [1], and to the A-2 Cost Data forms for Solar Federal Buildings projects for further information in applying the Federal LCC procedures and computer program contained in this report to solar projects in Federal buildings.

The worksheet evaluations are used as an indication of the relative cost effectiveness of various candidate projects. The resulting data are useful in selecting and sizing projects, and add to the body of knowledge concerning the economic viability of solar investments for Federal buildings.[1]

To promote the economically efficient use of solar energy, the Solar Federal Buildings Program encourages selection of the system size which gives the greatest total net savings based on a life-cycle cost comparison of alternative solar energy systems and a reference energy system.[2] Proposals for funding must state the method of calculation used in optimizing collector area.

A number of solar analysis computer programs with life-cycle cost routines for system size optimization are available. Unfortunately, use of these programs to evaluate Federal building projects is difficult, requiring a thorough understanding of the economic models contained in them and considerable manipulation of data and program output to bring them into conformance with the Federal LCC Rule and SFBP Rule.[3] The worksheets contained in Solar Form A-2 and the computer program in the LCC Manual are convenient for evaluating a single project. However, using them to evaluate a large number of design/size configurations requires laborious, repetitive calculations. This process can be streamlined by using a computerized economic optimization algorithm with a built-in thermal performance model.

1.2 PURPOSE AND SCOPE

The purpose of this report is to provide an easy-to-use computer program, FEDSOL, and guide for designing and sizing solar energy projects for Federal buildings according to required life-cycle cost procedures.

Although the FEDSOL program and guide should be useful to researchers and students in general in the solar energy field, they are intended primarily as

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[1] The LCC data for projects funded under the Solar Federal Buildings Program are available through the Solar Data Center at the National Bureau of Standards. The data may be obtained in hard-copy report form or accessed interactively through an on-line, data retrieval system [8].

[2] A solar project need not be cost effective to be approved for SFBP funding although its comparative degree of cost effectiveness is one criterion, accounting for up to 20 percentage points, that is considered in its approval. "Cost effective" means that the estimated benefits (savings) from a project exceed its costs, where both are assessed over the life of the project (not to exceed 25 years) in accordance with the Federal LCC Rules.

[3] F-CHART and SOLCOST, for example, contain life-cycle cost routines, including system size optimization. However, the users' guides provide little information about the life-cycle cost models contained in the programs. The NBS is currently preparing a report which compares the LCC sections of the following computer models: F-CHART 3.0, F-CHART 4.0, SOLCOST, BLAST, DOE-2, and FEDSOL [9].

working tools for practicing architects, engineers, facilities managers, and others engaged in the economic evaluation and design of Federal solar energy projects.

In addition to serving as a user's manual for the FEDSOL program, this guide describes the model for optimizing the size of a solar energy system according to the Federal LCC Rules. Since the FEDSOL program contains as default values the data and assumptions required (or recommended) under the Federal Rules, it is considerably easier to use for evaluating a Federal project than existing solar simulation programs with life-cycle cost routines.[1] At the same time, the life-cycle cost model contained in the program is sufficiently general to be applicable to a broad range of solar energy investment decisions undertaken in the public or other non-profit sectors.[2]

Using the solar load ratio (SLR) method for estimating solar energy system performance, FEDSOL determines the economically optimal size for a solar energy system and calculates the required life-cycle cost measures of economic performance for the optimal system. It also conducts sensitivity analyses of the effects on life-cycle costs of oversizing and undersizing systems. For systems that are not cost effective under the conditions specified, it determines the energy price assumptions and investment cost assumptions for which the system would be cost effective.

1.3 APPROACH AND ORGANIZATION

The approach taken in this users' manual and guide is, first, to provide instructions for operating the FEDSOL computer program and, second, to provide guidance in understanding the procedure and in applying the computer program to different kinds of solar projects for Federal buildings.

Section 2 provides a general overview of the thermal and economic analysis options contained in the FEDSOL program and step-by-step instructions for implementing the program on the SEIDB time-sharing system. Included are instructions for 1) calling the program, 2) using the program commands, 3) selecting an analysis option appropriate to a specified project, 4) changing the default values for input variables, 5) rerunning the program with changes in input values, and 6) saving input data for future use.

Section 3 explains the economic evaluation model for Federal buildings projects upon which the FEDSOL program is based. It describes the procedures, data, and assumptions required for conducting a life-cycle cost evaluation of a solar project undertaken in the Federal sector and provides guidelines for developing the additional data required.

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[1] The program will assume these default values unless the user specifies otherwise.

[2] For more detailed economic models providing for in-depth analysis of investments in active and passive solar energy systems for commercial buildings, the reader is directed to references [10, 11, 12, 13]; for models that treat solar investments for buildings of State and local governments and non-profit organizations, the reader is directed to references [12, 13, 14].

Annotated examples of program input and output listings are provided in section 4. Appendices include a listing of the FEDSOL program code, documentation of the major algorithms contained in the program, discount formulas referenced in this report, and a map and coded list of 243 cities for which the program contains environmental and weather data.

Those who are familiar with the LCC method and the Federal requirements regarding data and assumptions may wish to proceed directly to the instructions for operating the FEDSOL computer program in section 2; those who are not may wish to review section 3, a primer on the method, data, and assumptions, before going to section 2.

2. INSTRUCTIONS FOR OPERATING THE FEDSOL COMPUTER PROGRAM

2.1 OVERVIEW

FEDSOL is a completely interactive, easy-to-use computer program available to Federal agencies and contractors to Federal agencies in the Program Library of the Solar Energy Information Data Bank (SEIDB) computer time-sharing system. This system is operated by the Solar Energy Research Institute through the TYMNET communications network. No computer programming knowledge or computer experience is required to use the program.

FEDSOL was designed to evaluate active solar domestic hot water and/or space-heating systems using the solar load ratio (SLR) method of predicting performance. Two solar analysis options are available:

1. a Thermal (Solar Load Ratio method) and Economic Performance Analysis, for situations where both thermal and economic analyses are desired, and

2. an Economic Analysis Only, for evaluating the economic performance of projects whose thermal performance is already known or has been projected by some other means.

2.1.1 Thermal (SLR) and Economic Performance Analysis

FEDSOL produces a thermal analysis for the type of "standard" active solar energy system that you, the program operator, specify. It then uses this thermal analysis as input, along with additional economic information that you are asked to supply, to perform a life-cycle cost analysis for the system under consideration. Once this analysis has been generated, you may return to the original data and change one or more items, then run the analysis again to obtain new results.

You have a choice of pre-specifying the size of the solar energy system or of solving for the size:

a. you may specify the collector area of the system you wish to analyze, and FEDSOL will generate the thermal and economic analyses of a system of that size; or,

b. you may request an optimization analysis, and FEDSOL will determine the optimal collector area (collector area which results in the lowest life-cycle cost).

2.1.2 Economic Analysis Only

If you wish to perform an economic analysis only, FEDSOL will accept the pre-estimated performance of the system as input data along with economic data for the project. It will then generate an economic analysis from these two sets of data. You may wish to employ this alternative if you already have a thermal analysis from another source. You will be asked to supply the annual heating requirement and annual solar heating fraction obtained from this source.

2.2 GETTING STARTED

To access and use FEDSOL, you will need a terminal, an acoustic or direct connect modem, and a telephone. The modem may be a separate unit or may be built into the terminal.

For information about accessing the SEIDB System, contact

> Mr. Rafael E. Ubico
> SEIDB Network Coordinator
> Solar Energy Research Institute
> 1617 Cole Blvd.
> Golden, CO 80401
> (FTS 327-1032 or 303-231-1032).

The program code, written in BASIC, is reprinted in Appendix A and is available on tape from

> National Technical Information Service
> U.S. Department of Commerce
> 5285 Port Royal Road
> Springfield, VA 22161.

2.2.1 Calling Up FEDSOL

To call up FEDSOL, dial the TYMNET number for your city and fit the telephone receiver into the acoustic coupler. Be sure that all of the components of your system are turned ON. The terminal should be set for FULL DUPLEX and upper case (for alpha entries).

After a brief pause the timeshare system should communicate with your terminal. You will receive information about log-in procedures when you obtain your account with the SEIDB system. NOTE: (A carriage return (hereafter referred to as (CR)) must follow each entry.

After you have completed the "sign on" procedure, the terminal will respond with the prompt character (*). The next step is to access FEDSOL by entering

> - FEDSOL (CR).

Now the terminal will print:

```
FEDSOL - VERSION 1.0 ***
NATIONAL BUREAU OF STANDARDS

COMMAND:  N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE,Q=QUIT, H=HELP ?
```

N allows you to create a completely new file, regardless of data previously entered;

O calls up any previously saved FEDSOL file when you enter the name of the file;

C permits you to edit data already present in a file;

L lists the data elements of the current file, along with their current values;

R executes either the economic analysis only or the thermal AND economic performance analyses;

S saves the data in the current file and allows you to name the file;

Q stops execution of FEDSOL and returns you to system;

H accesses and prints the instructions for using FEDSOL.

You may enter data in either English or Standard International (SI) units. In addition, once the file has been created using one set of units, you may list (L) the data or run (R) the program in either that same set of units or the alternative set. There is no need for the program operator to make any unit conversions.

2.2.2 Getting Acquainted with FEDSOL

Each time you begin a session with FEDSOL you must select either N (New) or O (Old). N allows you to create an input file, and O retrieves an existing input file from storage. You may not perform the remaining operations, C, L, R, or S, until you have used N or O to create or access an input file. A demonstration file for a system for space and service water heating in an office building in Washington, D.C. is stored permanently under the filename "SAMPLE."

Retrieving an Existing File. The first time you run the program you may wish to call the demonstration file SAMPLE. This will help familiarize you with the required input data elements and with the C, L, and R commands.

Select O (CR) to retrieve an existing input file. You will be asked for the name of the file you are requesting. Type in SAMPLE (CR) in response to this prompt. Answer the next prompt, ENGLISH OR SI UNITS (E OR SI)? with E (CR) or SI (CR), depending on which units you wish to use. The command selection

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP ? will now print again. Select L (CR) to list SAMPLE.

Note carefully the data elements appearing in this SAMPLE listing. These are the data elements for which you will need to provide values when you create or change your own data files.

Now that you have listed SAMPLE, the command selection will reappear. Select R (CR) to run the analyses for this SAMPLE input file.

After the analyses have been completed and the results printed, the command selection menu will reappear. Select C (CR) to change any values in the input file. Type in the number of the line you wish to change (refer to listing) (CR). The description of the parameter and its current value will be displayed. In response to the LINE NUMBER? query, type in the new value you wish to use, followed by (CR). When you have completed making changes, you may exit the change mode by typing a (CR) in response to the LINE NUMBER? query. This will return you to the command selection. You may wish, for example, to change the last item (data input #70) in order to generate the "Extended" output (by entering "2" as the new value) or the "Summary" output (by entering "3" as the new value).

NOTE: To change units at this (or any) time, first select S (CR) to save the modified input data file under a filename. Then select O (CR) to recall the file by its name, and enter E or SI (CR) to designate the units you desire. If you have made changes to the input file since first retrieving it from storage, it is important to use the S command to save the current input file before you use the O command to recall it. Otherwise, you will lose any changes you have made since retrieving the input file from storage. Now you may list the file or run the analyses in the new units.

Once having made the desired changes in the data file, you may re-run the analyses (R), re-list the input data file (L), save the file in permanent storage, (S), terminate execution of FEDSOL (Q), or create a new file (N).

NOTE: You may not change a file to describe a system in a different location. Create a new file to consider a new location or different type of building. FEDSOL will then automatically select the appropriate geographical and energy price data for the new building and location.

2.3 CREATING A NEW FILE

Select N (CR) from the command selection to create a new file. Be sure first to save your previous file if you wish to retain it for later reference. If you have not saved it, the N command will cause that data to be lost.

In creating a new file, you will need to supply a minimum set of data. Once you have responded to the queries for this data, the program will supply its own default values for the remaining data elements. This enables you to create a usable data file almost immediately with little chance of error. At this point, you may list the file (L) to see your new input data along with the default values for the location you selected. Change (C) any of the data you wish, or simply run (R) the analyses.

2.3.1 Supplying the Required Data

Once you have given the N command, you will be queried for the following data:

ENGLISH OR SI UNITS? (E OR SI)?

Enter E (CR) for English units, SI (CR) for Standard International units.

PERFORMANCE ANALYSIS USING SLR METHOD (Y OR N)?

Enter Y (CR) if you wish a thermal analysis (using the Solar Load Ratio method) as well as the economic analysis. Enter N (CR) if you want the economic analysis alone.

ENTER CITY ID NUMBER?

Enter a number from 1 to 243 (CR) to designate the location (or nearest city in file) for the system you are evaluating. You will find the cities and their ID numbers listed in Appendix B.

RESIDENTIAL = 1; COMMERCIAL = 2; INDUSTRIAL = 3?

Enter 1,2, or 3 (CR). This response determines which set of base-year fuel prices and energy price escalation rates the program will use. These values are contained in the energy price data file used by FEDSOL. (Normally this prompt would be used to determine the type of ownership of the proposed project and the appropriate tax assumptions; however, this distinction is not relevant to this program since it is designed specifically for Federal buildings.)

THE FOLLOWING DATA ITEMS REPRESENT THE MINIMUM INFORMATION REQUIRED TO CREATE A USABLE INPUT DATA FILE. ITEMS PRECEDED BY (*T) ARE REQUIRED ONLY IF YOU REQUEST THE THERMAL-AND-ECONOMIC PERFORMANCE ANALYSIS USING SLR METHOD (ABOVE), ITEMS PRECEDED BY (*E) ARE REQUIRED ONLY IF YOU REQUEST THE ECONOMIC ANALYSIS ALONE. ITEMS NOT PRECEDED BY AN ASTERISK ARE REQUIRED IN BOTH CASES.

NOTE: Create a new data file to change from a combined thermal and economic performance analysis to an economic analysis alone, or vice versa. Since the two types of analyses require different data, the same data file cannot be used for both types of analyses.

(*T) TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)?

Enter a number from 1 to 19 (CR). The 19 "standard systems" are shown in table 2.1.

(*T) ENTER LOAD TYPE: 1=WATER HTG; 2=SPACE HTG; 3=BOTH?

Enter the appropriate number from 1 to 3 (CR).

(*T) DOMESTIC HOT WATER USAGE?

Enter hot water use (in gallons/day or liters/day) (CR). This prompt will occur only if you have indicated that your evaluation refers to a water heating or water/space heating combination system.

NOTE: Enter only the numeric value, expressed in the units shown (E or SI as you requested in creating the file). Do not type the units (gallons/day, MMBtu/Month, etc.).

(*T) MONTHLY SPACE HEATING LOADS?

Enter the 12 values representing the building's monthly space heating requirements (in MMBtu/month or GJ/month) (CR). Do not adjust for the operating efficiency of the non-solar heating plant. This prompt will occur only if you have indicated that the system under consideration is a space heating system or combined water/space heating system.

Table 2.1 Standard System Types

NO.	SYSTEM TYPE	COLLECTOR DESCRIPTION	OPERATING TEMPERATURE, °F
1	SHW	1 COVER, SELECTIVE	110 OUTLET WATER TEMP.
2	SHW	1 COVER, SELECTIVE	130 OUTLET WATER TEMP.
3	SHW	1 COVER, SELECTIVE	150 OUTLET WATER TEMP.
4	SHW	1 COVER, SELECTIVE	170 OUTLET WATER TEMP.
5	SHW	1 COVER, NON-SELECTIVE	110 OUTLET WATER TEMP.
6	SHW	1 COVER, NON-SELECTIVE	130 OUTLET WATER TEMP.
7	SHW	1 COVER, NON-SELECTIVE	150 OUTLET WATER TEMP.
8	SHW	1 COVER, NON-SELECTIVE	170 OUTLET WATER TEMP.
9	SHW	2 COVERS, NON-SELECTIVE	110 OUTLET WATER TEMP.
10	SHW	2 COVERS, NON-SELECTIVE	130 OUTLET WATER TEMP.
11	SHW	2 COVERS, NON-SELECTIVE	150 OUTLET WATER TEMP.
12	SHW	2 COVERS, NON-SELECTIVE	170 OUTLET WATER TEMP.
13	SHLS	1 COVER, SELECTIVE	---
14	SHLS	1 COVER, NON-SELECTIVE	---
15	SHLS	2 COVERS, NON-SELECTIVE	---
16	SHAS	1 COVER, SELECTIVE	---
17	SHAS	1 COVER, NON-SELECTIVE	---
18	SHAS	2 COVERS, NON-SELECTIVE	---
19	SH(R)	1 COVER, NON-SELECTIVE	---

SHW = Service Hot Water only, Commercial
SHLS = Space Heating with or without SHW, Liquid System, Commercial
SHAS = Space Heating with or without SHW, Air System, Commercial
SH(R) = Space Heating, Residential

NOTE: Systems 1 through 12 refer to water heating-only systems. Systems 13 through 18 refer to space heating systems or to combined space and water heating systems. System 19 refers to space heating-only systems or combined space and water heating systems where the hot water load is less than 20 percent of the total annual heating load. For systems other than those listed above, you may obtain a thermal analysis from other sources and use that information as input for the economic analysis.

(*E) ANNUAL ENERGY LOAD?

Enter the total annual energy requirement for water heating only (systems 1-12), space heating only, or both (MMBtu/year or GJ/year) (CR). Do not adjust for furnace efficiency.

(*E) ANNUAL SOLAR FRACTION?

Enter your precalculated annual solar heating fraction (as percent) (CR). This is the annual percentage value (obtained from another analysis) of the total annual energy load which is to be supplied by the solar energy system.

(*E) COLLECTOR AREA?

Specify the area of the solar collector (in square feet or square meters) (CR) which corresponds to the solar fraction value specified above.

SOLAR ENERGY INVESTMENT - FIXED COST?

Enter the cost (in dollars) (CR) of the portion of the total system cost which tends to be independent of system size within the size range considered. This may be difficult to determine, but the accuracy of the optimization analysis depends on this breakdown of costs. See section 3.2.1 for further discussion.

SOLAR ENERGY INVESTMENT - VARIABLE COST?

Enter the size dependent cost of the system (dollars per square foot or square meter of collector area) (CR). See section 3.2.1 for a further discussion.

TYPE OF FUEL USED IN AUXILIARY SYSTEM?

Enter a number from 1 to 6 (CR) where

1=electric
2=distillate oil
3=residual oil
4=natural gas
5=coal
6=liquid propane gas

TYPE OF FUEL USED IN REFERENCE SYSTEM?

Enter a number from 1 to 6 (CR) as above.

2.3.2 Changing Default Values

Once the above information has been entered, FEDSOL supplements it with default values for the remaining data elements. You may see these values along with the values you supplied for the required data by listing your file at this point with the L (List) command. FEDSOL will assume these values unless you specify other values using the C (Change) command. You may change the value of any data element by specifying the number of that data item and the new numeric value in response to the LINE NUMBER? and NEW VALUE? queries.

The entire set of data inputs for the FEDSOL program and the default values are reprinted below. These data elements provide for a life-cycle cost comparison of a combined solar and auxiliary back-up system with a reference non-solar system. Items under "Data for Performance Analysis (SLR Method)" will print only if you requested a performance analysis; items under "Data for Economic Analysis Only" will print only if you requested an economic analysis alone. For a further discussion of the individual data elements, see sections 3.1 and 3.2. The range of acceptable values for each data element is shown in Appendix G.

ENERGY ANALYSIS DATA

DATA FOR SOLAR PERFORMANCE ANALYSIS (SLR METHOD)

1. Type of Solar Energy System (from coded list)

See table 2.1.

2. Collector Tilt Angle

Number of degrees (from horizontal) that the collector is tilted. To change the tilt angle, enter the total number of degrees (from horizontal).

DEFAULT = LAT. + 10°

3. Optimization Analysis

If you wish an optimization analysis, enter 1. If you do not wish an optimization analysis, enter 2 and specify the collector area being considered (in data element #4). See section 3.4.5 for a more complete description of the optimization analysis provided by FEDSOL.

DEFAULT = 1

4. Collector Area

FEDSOL will ignore this value if you have requested an optimization analysis.

DEFAULT = 0 ft^2 (m^2)

5. Minimum Acceptable Solar Fraction

In an optimization analysis, the program will consider only system sizes that generate a minimum of this annual solar fraction.

DEFAULT = 30 percent

6. Operating Efficiency of Auxiliary System

The annual average percentage efficiency of the auxiliary system in meeting the load specified (space heating, water heating, or both).

DEFAULT = 60 percent

7. Operating Efficiency of Reference Non-Solar System

The annual average percentage efficiency of the reference non-solar system in meeting the load specified (space heating, water heating, or both).

DEFAULT = 60 percent

8. Electric Energy as Percent of Useful Solar Energy

Nearly all active solar thermal energy systems require electric energy for pumps and controls. Because electricity consumption is dependent on system size and operating time, it is expressed as a percentage of useful solar energy provided by the system.

DEFAULT = 6 percent

9. Domestic Hot Water Usage

This value will default to zero if you specified 2 (SPACE HTG) in response to the LOAD TYPE? query.

10. Building Use Schedule

This value is only used in calculating hot water loads. It refers to the number of days per week the building is in normal (or near-normal) use.

11. Monthly Space Heating Loads

This value will default to zero if you specified 1 (WATER HTG) in response to the LOAD TYPE? query.

12. Average Daily Horizontal Radiation

These values are supplied by the program. When you select a city in the geographical data bank and create a new file, the program reads its stored environmental and weather data for that location. You may change these data by using the C (Change) command.

13. Average Ground Water Temperatures

Data are supplied by the program, from the geographical data bank. Values are entered as quarterly averages for DEC-FEB, MAR-MAY, JUN-AUG, SEP-NOV.

The default values for your location should be examined and changed as necessary to adjust for the position and type of water supply facility of the building under study.

DATA FOR ECONOMIC ANALYSIS ONLY

20. Annual Energy Load

21. Annual Solar Fraction

22. Collector Area

23. Operating Efficiency of Auxiliary System

DEFAULT = 60 percent

24. Operating Efficiency of Reference System

DEFAULT = 60 percent

25. Electrical Energy as Percent of Useful Solar Energy

DEFAULT = 6 percent

LIFE-CYCLE COST DATA

See section 3.2 for a further discussion of these data elements.

BASE YEAR INVESTMENT COSTS

30. Solar Energy Investment - Fixed Cost

31. Solar Energy Investment - Variable Cost

32. Investment Credit (Externality Adjustment)

DEFAULT = 10 percent

33. Investment Cost for Auxiliary System

DEFAULT = $0

34. Investment Cost for Reference Non-Solar System

DEFAULT = $0

FUTURE NON-FUEL COSTS

SOLAR ENERGY SYSTEM

40. Annually Recurring O&M Cost (percent of investment cost)

Do not include electrical energy operating costs.

DEFAULT = 1 percent

41. Replacement Cost and Year

Include repair and replacement costs which are expected to occur on an irregular basis. Do not include costs covered under item #40. Six values must be entered when responding to this item. Each replacement cost is to be followed by the year of its occurrence (number of years after system purchase). Three different occurrences are allowed for. If there are fewer than three occurrences, enter zero's for the remaining positions. For example, if replacements of $5000 occur at 5 years and $7500 at 10 years, then the entry should appear as

5000,5,7500,10,0,0

ALL DEFAULTS = 0

42. Salvage Value at End of Study Period (precent of investment cost)

DEFAULT = 0 percent

AUXILIARY SYSTEM

44. Annually Recurring O&M Cost (dollars per year)

DEFAULT = $0

45. Replacement Cost and Year

Same format as item #41.

ALL DEFAULTS = 0

46. Salvage Value at End of Study Period (dollars)

DEFAULT = $0

REFERENCE NON-SOLAR SYSTEM

47. Annually Recurring O&M Cost (dollars per year)

DEFAULT = $0

48. Replacement Cost and Year

Same format as item #41.

ALL DEFAULTS = 0

49. Salvage Value at End of Study Period (dollars)

DEFAULT = $0

FUEL COSTS

The base-year energy prices and projected rates of energy price escalation published by the DoE are contained in the program as default values (see section 3.2.4). FEDSOL automatically calls the data for the type of building and location under study. Use the actual price (per MMBtu or GJ) to the agency undertaking the project, if available.

50. Electricity Price in Base Year

51. Distillate Oil Price in Base Year

52. Residual Oil Price in Base Year

53. Natural Gas Price in Base Year

54. Coal Price in Base Year

55. Liquid Propane Gas Price in Base Year

56. Type of Fuel Used in Auxiliary System

Enter a number from 1 to 6 (CR) where

1=electric
2=distillate oil
3=residual oil
4=natural gas
5=coal
6=liquid propane gas

57. Type of Fuel Used in Reference system

Enter a number from 1 to 6 (CR) as above.

58. Energy Price Escalation (percent per year, excluding inflation)

DISCOUNT RATE AND STUDY PERIOD

60. Real Discount Rate (excludes inflation)

The Federal Rules require a value of 7 percent.

DEFAULT = 7 percent

51. Study Period

The value entered will be the period of the life-cycle cost analysis. The maximum value allowed under the Federal Rules is 25 years.

DEFAULT = 20 years

ANALYSIS OUTPUT

70. 1=STANDARD; 2=EXTENDED; 3=SUMMARY

This item controls the length and content of the analysis report generated by FEDSOL. The potential output created by FEDSOL consists of the following sections:

1. Table of solar fractions and net savings for a range of system sizes

2. Monthly thermal performance table

3. Life-cycle cost summary table showing breakdown of life-cycle costs

4. Measures of economic performance

5. Simple cash flow analysis: not discounted and not escalated

6. Discounted cash flow analysis: discounted and escalated

7. Breakeven analysis (generated only when net savings are negative) for investment costs, base-year energy prices, and rates of energy price escalation.

The standard analysis consists of sections 1 through 4; the extended analysis, sections 1 through 7. The summary analysis is a one line output showing only the optimized or prespecified collector area, annual solar fraction, and net savings.

2.4 RUNNING THE ANALYSIS

Once you have called up an old file (O command) or created a new file (N command) and made any necessary changes (C command), you may run the analyses by simply selecting R (CR) from the command selection. The output selections are described above.

NOTE: If you previously answered Y to the prompt: PERFORMANCE ANALYSIS USING SLR METHOD (Y OR N)? you will receive both thermal and economic analyses. If you answered N, you will receive an economic analysis only.

2.5 SAVING A FILE

If you have changed an old file or created a new file without SAVING the current file, you will lose the data in the current file. Whenever you are satisfied with the data contained in your file, or think you might want to refer to it later, select the S option from the command selection to SAVE the file in permanent storage.

When you enter the S command (CR), you will be prompted with: STORE DATA UNDER WHAT NAME? Your response should be a filename of your choosing of up to 7 characters in length (CR). The filename must begin with a letter and contain alpha-numeric characters only. Certain filenames are forbidden. The user will be notified if a forbidden filename has been entered. Selecting a name related to the actual data, such as the name of the city or building in which your system is located, is helpful for later retrieval. If you have more than one file for a system, you might want to code it by number, date, or code letter as well as a name, e.g., BDWYP01, BDWYP02 (Broadway Post Office 1st run, 2nd run, etc.). If an existing file already has that name, the terminal will respond with: "FILENAME" ALREADY EXISTS. DO YOU WISH TO USE THIS NAME (Y/N)? If a Y is entered, the current input data will be entered under this filename and will REPLACE the file previously stored under that name. If an N is entered, the current input data will not be saved under this filename, and the command prompt will appear again. If desired, this data file may be saved under some other valid filename by repeating the SAVE procedure.

NOTE: When you retrieve an existing file from storage, it is called into the computer's memory, but still remains in the long-term disk storage. You cannot lose a file that has been permanently saved unless you actually PURGE it. (This is done after exiting FEDSOL and is a system command.)

If you forget the name of the file you want to use, exit FEDSOL with a Q (CR) and then type CATLIST (CR). All files saved under your ID number will be displayed.

If you forget these procedures or instructions or need a brief refresher course on the operation of FEDSOL, type H (CR) to obtain the help instructions. It's a good idea to use the H command in your first session with FEDSOL and to keep a copy of the instructions near the terminal.

2.6 <u>TERMINATING EXECUTION OF FEDSOL</u>

Use the Q (Quit) command (CR) to end execution of FEDSOL. The terminal will respond with

```
READY

 *
```

Type: BYE (CR) to terminate the session.

Now the timeshare system will log off, telling you the connection time and the system response units used in this session.

2.7 <u>LEARNING FEDSOL</u>

The following approach is recommended for learning to use FEDSOL:

1. Call upon the program;
2. Select 0 (CR) from the command selection menu;
3. Retrieve the file SAMPLE;

4. Run through SAMPLE, listing, making changes, running the analyses, and saving it under your ID with another name until you are comfortable with operating the program;

5. Gather the data you need to evaluate your particular solar heating system and to create your own files. (Keep a copy of the SAMPLE listing to remind you what data you need to prepare); and

6. When your data are prepared, return to the system, call up the program, and begin new FEDSOL analyses.

3. THE LIFE-CYCLE COST METHOD FOR SELECTING SOLAR ENERGY SYSTEMS FOR FEDERAL BUILDINGS[1]

Life-cycle costing (LCC) is a method of economic evaluation by which all relevant costs over the life of a project are accounted for when determining the economic feasibility of projects. It is particularly suited for the evaluation of projects such as energy conservation and solar energy that realize their benefits primarily through long-run fuel cost avoidance.

Applied to solar energy projects, the Federal life-cycle cost method and procedures can be summarized in the following five steps:

1) Compare energy use in the building with and without the proposed solar project.

2) Identify the relevant costs, constraints, and assumptions associated with the project, including the special requirements under the Federal LCC Rules.

3) Calculate total life-cycle costs of the building with and without use of solar energy.

4) Using the Federal life-cycle cost procedures, determine the optimal solar energy system size and design with the lowest life-cycle cost.

5) Calculate other measures of economic performance for this system as needed to determine project priorities and to meet Federal LCC requirements.

An economic model for determining the optimal solar design/size for a Federal building project is developed graphically and algebraically in this section within the framework of these steps. This is the model implemented by the FEDSOL computer program described in section 2. In addition, this section reviews the options and capabilities in FEDSOL for performing each step of the analysis.

3.1 COMPARING ENERGY USE WITH AND WITHOUT SOLAR

An essential first step in the life-cycle cost evaluation of a solar energy project is to determine the end-use energy requirements of the process to which solar energy is to be applied and the potential contribution of the proposed solar energy system in meeting these energy requirements. The application might be space heating, domestic hot water, process water, space cooling, or some combination thereof.

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[1] Much of parts 3.1, 3.3, and 3.4 extending to 3.4.4 is taken from "Life-Cycle Cost Evaluation of Solar Energy Investments," Chapter 11 of the Solar Design Workbook, prepared by Rosalie T. Ruegg, G. Thomas Sav, and Jeanne W. Powell [2].

3.1.1 Estimating Building Energy Requirements

Energy requirements for hot water are generally determined by a static heat balance equation, whereby the energy requirement for water heating in a given period (E_w) is directly proportional to the hot water demand (D) and to the difference between the desired water temperature (T_d) and the temperature of water supplied to the building from the local sanitation system or other water source (T_{in}):

$$E_w = w \cdot c_p \cdot D \cdot (T_d - T_{in}). \tag{3.1}$$

The proportionality factors w and c_p represent the density of water (8.33 lb/gal) and specific heat of water (1 Btu/lb/°F), respectively.

The method used to calculate energy requirements for space conditioning should be tailored to the type of buildings and systems evaluated.[1] In analyzing a small envelope-dominated structure for residential or light commercial use, a steady-state method based on the heat loss coefficient (UA) and degree days is generally sufficient.[2] Larger buildings with complex HVAC systems require more sophisticated transient analysis models which account for hourly differences in the building thermal capacity, heat generated by solar loading on the building envelope, and loads generated by mechanical systems, occupants, lights, and equipment. Examples of energy analysis computer programs with these capabilities are BLAST [15] and DOE-2 [16].

Energy loads for heating or cooling are usually calculated for each month and then summed to an annual value.[3] Once the annual energy requirement for heating or cooling is known, the annual quantity of non-solar energy required to meet the load can be calculated based on the energy content of conventional fuel and the conventional energy equipment efficiency. Algebraically, the annual quantity of conventional energy required (E) is calculated as follows:

$$E = \frac{L}{e}, \tag{3.2}$$

where L represents the annual load for heating or cooling, and e, the annual efficiency of conventional energy equipment.

For example, assume that the space heating load of a building is 800 MMBtu per annum, the conventional fuel is oil, and the average annual efficiency of the furnace is 0.6. Then,

---

1 For a more extensive overview of methods of evaluating building energy requirements, see reference [17].

2 A variable base degree day method is preferred. A simplified method suitable for a hand calculator is described in reference [18].

3 Provided that the same energy source is used, water and space heating loads each month are summed to determine the total monthly energy requirements for heating.

$$E = \frac{800}{0.6} = 1{,}333.$$

Thus, it is estimated that 1,333 MMBtu of oil per annum are required for space heating purposes.

3.1.2 Estimating Energy Savings

The contribution of the solar energy system towards meeting the monthly energy requirement is a key measure of performance of the solar energy system. It generally is the major source of savings from undertaking the investment in solar energy.[1]

Solar performance is incorporated into the economic analysis by expressing the useful monthly output of the solar energy system as a fraction of the monthly energy requirement and then determining the annual solar fraction corresponding to the total monthly solar contribution.[2] Thus, if the solar energy system is estimated to deliver a total quantity of useful Btu's per month (S_m), then the monthly fraction (F_m) of monthly load (L_m) met by solar is

$$F_m = \frac{S_m}{L_m}, \tag{3.3}$$

and the annual fraction is

$$F = \left(\sum_{m=1}^{12} L_m \cdot F_m\right)/L. \tag{3.4}$$

for m=1, January, m=2, February, etc.

Continuing with our previous example (L = 800 MMBtu), suppose a solar energy system of a particular design and size is expected to deliver 62.5 percent of the load for space heating during a year. Then it is expected to deliver .625 • 800 MMBtu.

If the auxiliary heating system is assumed to be the same type and to have the same operating efficiency as the reference non-solar energy system used alone, the annual quantity of non-solar (fuel oil, in this example) energy required would be reduced from 1,333 MMBtu to 500 MMBtu using this solar energy system. That is, the annual quantity of non-solar energy (fuel oil) required by this solar auxiliary system (E_A) is

$$E_A = \frac{L(1 - F)}{e} = \frac{800 \cdot (1 - 0.625)}{(0.6)} = 500 \tag{3.5}$$

---

[1] Methods of evaluating non-energy benefits of investments in passive solar energy are treated in reference [10].

[2] In analyzing systems for service hot water only, annual calculations may often be used.

for savings of 833 MMBtu of oil per annum, assuming a constant system efficiency and a constant building energy load over the study period.

Energy required to operate the solar energy system components, such as electrical energy required to operate the pumps or fans and the control system, may also be significant to the analysis. Energy costs to operate the solar energy system reduce the overall savings in fuel from the solar energy system.

In the above example, the solar auxiliary system and the reference non-solar energy system are, for simplicity, assumed to be identical. This, of course, need not be the case. If the energy system used as an auxiliary to solar is different from the reference non-solar energy system, it may use a different type of fuel and have a different operational efficiency, as well as different investment and non-fuel operation and maintenance costs.

Furthermore, even if the two systems are identical, the part-load contribution of the auxiliary solar energy system may cause it to have a lower efficiency than the reference system. For example, if, in the above example, the system efficiency dropped from $e_N = .6$ for the reference non-solar energy system to $e_A = .5$ for that same system used as the solar auxiliary, the annual oil savings, S, would decrease from 833 MMBtu to 733 MMBtu; i.e.,

$$S = L \cdot \left(\frac{1}{e_N} - \frac{(1 - F)}{e_A}\right) = 800 \cdot \left(\frac{1}{.6} - \frac{(1 - .625)}{.5}\right) = 733. \qquad (3.6)$$

3.1.3 Estimating Energy Savings with FEDSOL: The SLR Method

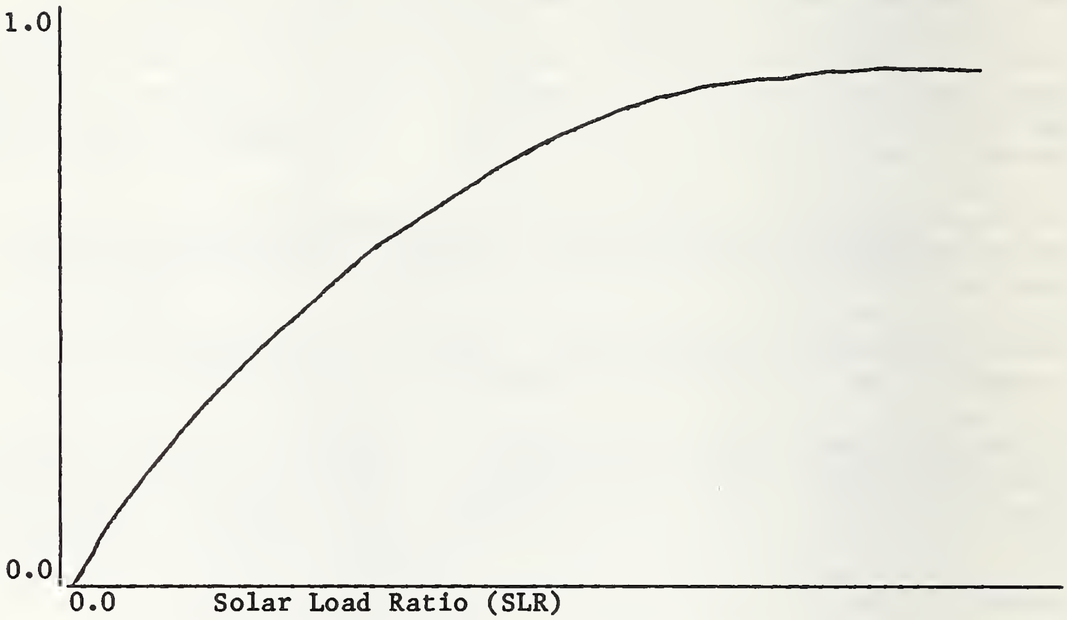
Brief Description. The solar load ratio (SLR) method for active systems is a simplified design method for analyzing solar energy systems in commercial and residential buildings employing flat plate collectors for space and/or water heating.[1] It was developed at Los Alamos National Laboratory by applying correlation analysis to numerous hour-by-hour computer simulations of a reference system in a large variety of locations performed with the DOE-2 building energy analysis computer program. The results of the simulation and correlation analyses are a set of "universal" design and sizing curves describing the solar heating fraction vs. the solar load ratio (SLR), as illustrated in figure 3.1.

The solar load ratio method for active systems in commercial buildings has recently been revised and extended by Schnurr, Hunn, and Williamson [3] to take account of advances in energy analysis techniques since the time of the original work reported in the DoE Facilities Solar Design Handbook [19]. The FEDSOL program incorporates the new set of design curves published in this recent study. The mathematical equations specifying the curves for 18 system types (six systems for space heating or combined space and water heating and

---

[1] The solar load ratio method is documented in references [3, 19, 20, 21]. For further information about the general applicability of this method and the validation tests conducted by Los Alamos National Laboratory, see these publications.

Figure 3.1 The Solar Load Ratio Method: A Generalized Design Curve



where SLR = A•I/L and

A = gross collector area;

I = insolation on tilted collector surface, monthly for space heating or combined space heating and hot water systems; annually for service hot water only systems; and

L = energy load to which solar energy is applied, monthly for space heating or combined space heating and hot water systems; annually for service hot water only systems.

---

twelve systems for water heating only) are included within FEDSOL. The complete set of curves is shown in Appendix D.[1]

[1] The recent Los Alamos study included evacuated tube collectors, as well as flat plate collectors, in its analyses of service hot water systems. Reference [3] includes design curves for service hot water systems with evacuated tube collectors. However, FEDSOL is limited to systems with flat plate collectors.

Unlike with the original SLR method for commercial buildings, the analysis of systems for service hot water only is performed on an annual instead of a monthly basis and different performance curves corresponding to the annual heating degree days are derived for different locations. These changes are due to research findings showing that 1) a better correlation of solar hot water system performance to the SLR is obtained on an annual than on a monthly basis because of the relative uniformity of water heating loads and 2) the performance of service hot water systems is highly correlated with ambient temperature. For a given value of the SLR, system performance is better in warmer climates than in colder climates because of smaller heat losses from the collector and higher collector efficiencies. The recent Los Alamos study suggests that the original design curves tend to overstate the performance of systems for hot water only in locations with substantial heating degree days.

In the recent study, the effect of location on the performance of systems for space heating was found to be sufficiently small that separate design curves corresponding to different degree day ranges were not required [3]. The major differences between the original and revised SLR methods as applied to systems for space heating reflect the lower collector efficiencies assumed in the recent study. Accordingly, the revised design curves can be expected to yield somewhat lower solar heating fractions than the original curves.

For the analysis of active systems in residential buildings, the curve-fit equation developed by Balcomb and Hedstrom for the design and sizing of a standard, residential system for space heating has been included in the FEDSOL program [21].

The FEDSOL data files contain values for monthly average daily solar radiation, latitude, the heating degree day range, and average earth temperatures (for estimating hot water loads) for the 243 cities shown on the map and coded list printed in Appendix B.[1] Using the data for the city, collector tilt, and water usage schedule specified by the user, the program calculates monthly solar radiation on a tilted surface, estimates the monthly energy requirement for hot water, combines the monthly energy requirement for hot water with the user specified monthly energy requirement for space heating, and calculates the SLR and solar heating fraction for each month. If the system being analyzed is for service hot water only, the program selects the curve corresponding to the ambient temperature (degree days) of the location being analyzed and uses annual calculations for the SLR and solar heating fraction. The program then adjusts for differences in predicted annual solar fraction provided by the ambient temperature curve, based on a single-glazed selective collector and design water temperature of 130°F, and predictions of annual solar fraction for the type of collector and for the design water temperature specified for study.[2]

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[1] The solar radiation data contained in the program files are taken directly from Input Data for Solar Systems, by V. Cinquemani, a report prepared by the U.S. Dept. of Commerce, National Oceanographic and Atmospheric Administration for use in energy analysis programs requiring monthly data [22]. These data are derived from SOLMET weather tapes. Earth temperature data are obtained from tables of average earth temperatures 1-10 feet below the surface published by Kusuda and Saitoh [18].

[2] This adjustment procedure is described in detail in reference [3].

The user must specify: a) the energy requirements for space heating (by month, in the case of the SLR analysis; by year, in the case of the economics only analysis), b) the type of fuel used in the non-solar reference system and auxiliary system, c) the operating efficiencies of the reference non-solar and auxiliary heating plants,[1] and d) the electricity required to operate the solar energy system as energy data inputs to the program. Different fuel types and operating efficiencies are allowed for the reference non-solar system and the auxiliary system. (The default values for operating efficiencies of both the reference and the auxiliary systems are 60 percent. Electricity to operate the solar energy system is expressed as a percent of useful solar energy collected. The default value is 6 percent.)

The thermal analysis performed by FEDSOL for a sample office building system for space and water heating in Washington, D.C. is reprinted in table 3.1.[2]

Table 3.1 Thermal Performance for SAMPLE Case

THERMAL PERFORMANCE

COLLECTOR AREA = 1659.00 SQFT TILT ANGLE = 48.57 DEGREES

	SOLAR FRACTION	AVG DAILY HORZ RAD. (1)	INCIDENT COLLECTOR (1)	SPACE LOAD (2)	WATER LOAD	USEFUL SOLAR (2)
JAN	.190	572.00	882.01	71.20	4.58	14.38
FEB	.347	815.00	1094.16	42.30	4.13	16.11
MAR	.491	1125.00	1272.36	37.90	4.36	20.77
APR	.744	1458.00	1384.72	21.60	4.22	19.21
MAY	.734	1718.00	1437.81	24.00	4.36	20.82
JUN	.690	1900.00	1496.00	28.20	3.41	21.81
JUL	.619	1817.00	1470.40	33.90	3.53	23.18
AUG	.756	1617.00	1455.68	23.70	3.53	20.60
SEP	.791	1340.00	1430.91	20.20	3.57	18.79
OCT	.755	1003.00	1316.55	21.00	3.69	18.65
NOV	.480	650.00	980.75	28.70	3.57	15.49
DEC	.211	481.00	753.07	53.60	4.58	12.28
YEAR	.489			406.30	47.53	222.09

(1) = BTU/SQFT-DAY
(2) = MMBtu/MONTH

[1] The operating efficiencies of the auxiliary and reference non-solar heating plants have a large impact on the outcome of the investment in solar energy because the value of a unit of solar energy delivered increases directly as the operating efficiency of the auxiliary heating system declines. In determining the appropriate auxiliary and reference system operating efficiencies to use in the life-cycle cost analysis of a solar energy system, care should be taken to include only those inefficiencies in the auxiliary and reference systems that are relatively independent of those in the solar energy system. Do not include, for example, inefficiencies in the heat distribution system of the building that are common to the solar and auxiliary systems as well as to the reference system. Differences in efficiencies assumed for the reference and auxiliary systems should reflect any anticipated part-loading effects induced by the combined use of solar and auxiliary energy.

[2] The input data for this sample project are shown in section 4, case 1.

Limitations of the SLR Method. The SLR universal design and sizing curves are based on standard reference liquid and air systems. The design parameters for the standard systems simulated in the Los Alamos study were derived from a large number of parameteric optimization studies conducted at Los Alamos National Laboratory. The collector efficiencies assumed correspond to those considered typical of collectors of four generic types. Tables 3.2 and 3.3 show the collector performance coefficients and design values for these reference systems.[1] Schematic diagrams are shown in Appendices D.7-D.9.

Use of different design parameters from those used in the Los Alamos simulations will affect system performance, life-cycle costs for combined solar/auxiliary heating, and optimal system size. Thus, caution should be taken in using FEDSOL to predict the solar heating performance of systems with design parameters significantly different from those assumed in the Los Alamos study.

For evaluating passive systems, systems with combined solar/heat pump, systems for space cooling, or other systems whose design parameters differ significantly from those in tables 3.2, and 3.3, it is important that a method suited to that type of system be used to predict solar performance.[2] One can then use FEDSOL to perform an economic analysis by selecting the "economic analysis only" option and supplying as input data the solar heating fraction derived apart from FEDSOL by another method and the annual thermal energy load.

Comparison of the SLR Method With Other Methods. When applied to standard residential systems for space and water heating, the SLR method can be expected to give similar predictions of solar performance on an annual basis to those obtained from F-CHART, the design method most widely used, and from SOLCOST [9, 20, 23]. Unlike SOLCOST and F-CHART, the SLR method is designed specifically for office (or commercial) building systems. It should simulate the size and demand patterns of these buildings more accurately than these other programs [20]. Note, however, these studies by Los Alamos National Laboratory have shown that the SLR sizing curves are not highly sensitive to substantial differencces in load and use patterns.

3.2 IDENTIFYING RELEVANT COSTS, ASSUMPTIONS, AND CONSTRAINTS[3]

The life-cycle cost evaluation of an investment in solar energy for a Federal building requires and assessment of the following kinds of solar-related costs over the time horizon of the investment: 1) investment costs (capital costs),

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[1] Considerable sensitivity analyses have been conducted at Los Alamos to determine the effect of changing these design parameters; however, most of the resulting data reflect changes occurring when only one parameter is varied at a time [19]. For further documentation of results of studies performed at Los Alamos, see references [19, 21].

[2] For a discussion of the different types of methods available for predicting solar heating performance and of recommended applications, see reference [20].

[3] These guidelines for identifying costs, assumptions, and constraints are consistent with the Federal LCC Rule [4, 5, 6].

Table 3.2 Efficiency Curve Coefficients Used to Characterize the Generic Types of Flat Plate Collectors[a]

Type	Transfer Medium	A	B	
			($W/m^2 \cdot K$)	($Btu/h \cdot ft^2 \cdot °F$)
Single-glazed, selective	LIQ	0.705	-5.04	-0.887
Single-glazed, nonselective	LIQ	0.780	-7.50	-1.320
Double-glazed, nonselective	LIQ	0.643	-5.00	-0.880
Single-glazed, selective	AIR	0.550	-4.89	-0.860
Single-glazed, nonselective	AIR	0.590	-6.25	-1.100
Double-glazed, nonselective	AIR	0.475	-4.15	-0.730

[a] Collector type is designated by the collector efficiency curve, as specified by

$$E = A + Bx,$$

where

$x = (T_f - T_a)/(I)$

for

T_f = inlet fluid temperature;

T_a = ambient temperature; and

I = total solar radiation.

The collector efficiency coefficients in this table are intended to correspond to typical flat plate collectors of each type (single- or double-glazed with selective or nonselective absorber coatings).

Source - "The Solar Load Ratio Method Applied to Commercial Building Active Solar System Sizing" [3].

Table 3.3 The Standard Active System

Parameter	Nominal Value
SOLAR COLLECTOR	
Orientation	Due south
Tilt (from horizontal)	Latitude + 10°[a]
Coolant flow rate	Liquid[b]
	112.6 kg/h per m^2 of collector area
	(0.046 gpm per ft^2 of collector area)
	Air
	2 scfm per ft^2 of collection area
	(0.0006 L/S per m^2 of collector area)
HEAT EXCHANGER	
Effectiveness	0.70
Cold site flow rate	112.6 kg/h per m^2 of collector area
	(0.046 gpm per ft^2 of collector area)
STORAGE TANKS	
Capacity	Liquid (storage tank)
	73.4 kg of water per m^2 of collector area
	(15 lb. of water per ft^2 of collector area)
	Air (Rock bed)
	0.22 m^3 per m^2 of collector
	(0.72 ft^3 per ft^2 of collector)
	Air (Hot Water Storage Mass)
	3.67 kg of water per m^2 ft collector
	(0.75 lb of water per ft^2 of collector)
Height to diameter ratio (Liquid System)	3.0
Loss Coefficient	0.28 $W/m^2 \cdot K$
	(0.05 $Btu/h \cdot ft^2 \cdot °F$)
Environment temperature	21.1°C (70°F)[c]
Cold water supply temperature (to BSHW system)	15.6°C (60°F)

[a] Parametric studies conducted at Los Alamos showed that for commercial building systems such as those described in reference [3], latitude + 10° was the optimal tilt angle for collectors in systems for space heating only or in combined service hot water and space heating systems; for service hot water only systems, a tilt angle of latitude + 5° was optimal. These studies also showed that system performance was relatively insensitive to variations in collector tilt angle within ± 10° of the optimum.

[b] Water, water/glycol, or nonaqueous collector heat transfer fluid could be used in liquid system.

[c] Assumes storage losses do not contribute to meeting the heating load.

Source - "The Solar Load Ratio Method Applied to Commercial Building Active Solar System Sizing" [3].

2) non-fuel operation and maintenance costs, 3) replacement costs, 4) energy costs, and 5) salvage or resale value net of removal and disposal costs. Since solar energy systems will generally be used in conjunction with an auxiliary energy system (e.g., electricity, natural gas, or oil), rather than alone, it is necessary to consider the costs of both the solar energy system and the auxiliary energy system to the extent that they differ from the reference non-solar energy system. The special requirements for Federal building projects are highlighted with outline boxes in the sections to follow.

To establish a basis for comparison, these same elements of costs must be assessed for the reference non-solar energy system. As indicated above, costs which are expected to be approximately the same for the reference system as for the auxiliary system need not be included because they will be the same regardless of the solar investment decision. Additional costs which need not be considered are "sunk costs." These are costs incurred prior to the life-cycle cost analysis, for example, for planning, and preparation of preliminary designs.

3.2.1 Investment Costs

Solar energy investment costs include the costs of design, engineering, purchase, and installation (exclusive of sunk costs) of the proposed system. Consider all components necessary for the solar energy system's operation: 1) solar collectors, 2) thermal storage, 3) distribution systems (for transporting solar energy alone), 4) controls, motors, pumps, fans, and other ancillary equipment, and 5) special building features such as roof and wall modifications. In evaluating a system for retrofit to an existing building, the costs of building modifications required to install the solar energy system should be included among solar energy investment costs.

In evaluating passive systems, the cost of additional thermal mass for exterior walls or interior spaces in excess of conventional building costs, plus the cost of movable insulation and sensor controls, should be included among solar energy investment costs. Capital costs of the auxiliary heating plant and non-solar reference heating plant and mechanical systems should also be included in the life-cycle cost evaluation if these costs are different for the solar and reference buildings.

Federal LCC Rule: 1) Assume the investment costs occur in a lump sum at the beginning of the base year.[1] 2) Adjust investment costs to 90 percent of their actual value.[2]

[1] The base year is the year in which the life-cycle cost analysis is conducted.

[2] The 10 percent investment credit is intended to serve as an interim adjustment for externality costs, such as the effect of imported oil use on strategic vulnerability, until improved measures are developed.

Since the economically optimal solar energy system size depends on the incremental costs of solar energy and non-solar energy, it is important to make as accurate a distinction as possible between fixed and variable (size dependent) components of solar energy costs.[1] Fixed costs are costs that are relatively independent of the size of the solar energy system. For example, the costs of system controls and some minimum set of pumps, heat exchangers, valves, piping and fittings may remain relatively constant over a substantial initial range of collector and storage sizes, and hence, be considered fixed costs.[2] The variable cost is the cost associated directly with each unit of collector area, plus the corresponding incremental costs of storage and piping.

It is important to note that for solar energy systems with significant fixed costs, using the average cost per square foot as the measure of investment cost will significantly underestimate the optimal system size.[3] To simplify the calculation of the two types of costs, and at the same time to avoid the common tendency of underestimating the variable unit cost, the fixed cost may be defined as the cost for the smallest system that is realistic for a particular application of solar energy, including materials, labor, and design and engineering services; and the variable cost as the corresponding cost for each additional unit of system size.

FEDSOL contains separate parameters for investment costs for the solar, the reference non-solar, and the auxiliary energy systems. (The default values for investment costs for each of these systems are zero. The user <u>must</u> supply values for solar energy investment costs in order for the program to conduct a life-cycle cost analysis. Values for the reference and the auxiliary systems need be supplied only if they differ from one another.)

3.2.2 Recurring Non-Fuel Operation and Maintenance Costs

Recurring non-fuel operation and maintenance (O&M) costs are costs other than for fuel that are expected to recur uniformly in constant dollars every year over the life cycle of the solar investment.

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[1] The trade-offs between solar energy costs and non-solar energy costs are illustrated graphically in section 3.4.1.

[2] Design and engineering typically are placed in this category. However, design and engineering costs may have both fixed and variable components. A survey of fee schedules for architectural and engineering services conducted by the State of Florida in 1977 showed that the basic rate for these services was dependent upon total construction costs; however, the basic percentage rate dropped substantially as construction costs increased. The cost of engineering services, for example, ranged from 15 percent of construction costs for small projects to 6 percent for multi-million dollar projects [24].

[3] In a recent study, Los Alamos National Laboratory reports that significant fixed costs could not be identified for passive systems in residential buildings, but are expected to be significant for active systems [25]. Cost estimating equations developed by Honeywell, Inc. for NBS suggest high fixed costs for large active systems for commercial buildings [11].

Federal LCC Rule: Assume that annually recurring non-fuel operation and maintenance costs begin to accrue at the beginning of the base year and are evaluated as a lump-sum payment at the end of each year of the study period, starting at the end of base year.

The annual non-fuel operation and maintenance costs for the solar energy system, auxiliary system, and reference non-solar system are separate data inputs to the FEDSOL program. Non-fuel O&M costs for the solar energy system are expressed as a percentage of unadjusted solar energy investment costs, i.e., of the total investment costs before applying the externality adjustment. For non-fuel O&M costs of the auxiliary and reference systems, the user must specify the actual estimated annual cost, in constant dollar prices of the base year. (The default value for the solar energy system is 1 percent; for the auxiliary and reference systems, 0 percent.[1])

3.2.3 Replacement Costs and Salvage Value

Replacement solar energy costs are costs that occur on an irregular basis for major repair or replacement of damaged or worn out components of the solar energy system. The estimated repair or replacement cost(s), net of salvage value of the component(s) replaced, the year(s) of occurrence of repair or replacement(s), and the salvage value of the system at the end of the study period are separate inputs to the FEDSOL program. Solar energy replacement costs in up to three different years are allowed.

Replacement costs may, of course, arise for components of the reference or auxiliary systems as well as the solar energy system. If major repair or replacement costs (net of salvage value of the components replaced) are expected to be significantly different (in size or timing) for the reference and auxiliary systems, these costs should be included in the life-cycle cost evaluation of the solar energy system. FEDSOL contains separate variables for the costs of replacement parts for the reference and auxiliary systems and allows for three occurrences of replacement costs for each system. In addition, the program allows the user to specify separate values for the salvage or resale value of the auxiliary system and the reference non-solar system at the end of the study period.

Federal LCC Rule: Assume that replacement costs and salvage values are evaluated as lump-sum payments at the end of the year in which they are expected to occur.

(FEDSOL assumes zero values for all replacement costs and salvage values unless the user specifies otherwise.)

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[1] The default values of 0 percent for non-fuel O&M costs for the auxiliary and reference systems should be maintained if non-fuel O&M costs are expected to be approximately the same for these systems.

3.2.4 Energy Costs

<u>Federal LCC Rule</u>: 1) Estimate the quantity of energy delivered annually to the building boundary with and without use of solar energy.[1] 2) Use actual prices to the agency undertaking the solar project, or use energy prices published by the Department of Energy in the LCC Program Rule (and revised periodically).[2] 3) Use projected annual real rates of fuel price escalation (rates excluding inflation) published by the Department of Energy in the LCC Program Rule (and revised periodically).[3] If electricity component prices are used and forecasts of component price escalations are available from the local utility, they may be used in pricing electricity. 4) Assume fuel costs are paid annually in lump-sum payments at the end of each year, starting at the end of the base year.

The energy price data contained in the LCC Program Rule, as revised in the <u>Federal Register</u>, September 1981, are included in the FEDSOL Program as default values for the base year fuel prices and rates of energy price escalation for locations in each of the 10 DoE regions.

3.2.5 Inflation and the Discount Rate

In accounting for project costs, life-cycle costing requires that dollar costs occurring at different calendar times be adjusted to a common time basis, taking into account the cost of money over time. This technique is referred to as discounting. Discounting is necessary for a valid economic comparison because money in hand can be invested to yield a return over time, causing an expenditure or receipt that occurs at some future date not to have the same value as if it occurred today. This is true whether or not there is price inflation that changes the value of money over time.

Discounting is accomplished by applying discount formulas--or multiplicative factors pre-calculated from the formulas--to each item of cost. There are

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[1] Energy analysis procedures have been discussed in section 3.1.

[2] Average prices are now provided for each of 10 DoE regions, by sector -- residential, commercial, and industrial, -- and by fuel type -- electricity, distillate, natural gas, residual, and coal [6]. The Department of Energy (DoE) is developing marginal energy prices adjusted to reflect special subsidies and externalities such as the effect of imported oil use on national security [26].

[3] Projected real rates of energy price escalation (excluding inflation) are provided for each of 10 DoE regions, by sector -- residential, commercial, and industrial --, by fuel type -- electricity, distillate, natural gas, residual, and coal -- and based on EIA price projection for four benchmarks -- 1980, 1985, 1990, and 1995. They appear in tables C-1 through C-11 of the LCC Rules [6]. Discount factors incorporating the energy price escalation rates have been developed to simplify the hand calculation of life-cycle energy costs. These are found in tables B-1 to B-11 of the LCC Rules [6]. (These data are subject to periodic revision.)

formulas or factors that can be used to discount each of the various patterns of cash flow: single future amounts such as replacement costs, recurring future amounts such as maintenance and repair costs, and escalating future amounts such as energy costs.

Discounting requires the selection of a discount rate that reflects the investor's time value of money. The discount rate is used either directly in the discounting formulas or--if factors are used--to select the appropriate factor from discount factor tables. If inflation is included in estimates of future costs and savings, then it must also be included in the discount rate. Alternatively, if all costs and savings are expressed in constant dollars, inflation should not be included in the discount rate. Working with constant dollars and a real discount rate, present prices can be used as estimates of future prices in constant dollars for those items whose prices can be expected to inflate at about the same rate as prices in general.

For future amounts that are expected to change at a rate different from the general rate of inflation, present prices will require adjusting in order to serve as estimates of future prices. In the case of future amounts that are not subject to price inflation, such as services fixed by contractual agreement, a price deflator index can be used to convert the future amounts to constant dollars prior to discounting. In the case of future amounts that are expected to increase faster than the rate of general price inflation, such as energy costs, differential price escalation rates can be used to find the future constant dollar equivalents.

The Office of Management and Budget (OMB) imposes specific requirements which all agencies must follow in adjusting costs for the time value of money. The Federal LCC Rule reflects the OMB requirements.

<u>Federal LCC Rule</u>: 1) Estimate all future amounts in constant dollars, i.e., in terms of the purchasing power of the dollar at the beginning of the base year, at the time the investment is made; 2) Discount all future amounts to their present values, using a 7 percent real discount rate;[1] i.e., the present rate is assumed to exclude expected inflation.

FEDSOL assumes that all cost inputs and salvage values represent purchasing power at the beginning of the base year; i.e., that they do not include expected inflation. The program discounts all future costs using a 7 percent discount rate unless the user specifies otherwise.

[1] A rate of 10 percent is dictated by the Office of Management and Budget in Circular A-94 [27]. On June 30, 1980, however, President Carter signed the Energy Security Act which requires a real discount rate of 7 percent per year in evaluating energy conservation and renewable energy projects for Federal buildings [28]. The Federal LCC Rule, as amended, reflects this legislation.

3.2.6 Study Period

The study period is the length of time covered by the life-cycle cost analysis. In comparing alternative energy systems for a given building application, the same study period should be used in evaluating each project and that period should not exceed the life of the building (or lease).

Federal LCC Rule: Select a study period that does not exceed 25 years.[1]

3.3 CALCULATING TOTAL LIFE-CYCLE COSTS WITH AND WITHOUT SOLAR[2]

A life-cycle costing approach can be implemented by applying any or all of the following evaluation techniques or "modes of analysis": 1) total life-cycle cost (TLCC) analysis, which sums the discounted value of all the equivalent costs over the investor's time horizon; 2) net savings (NS) analysis, which finds the difference between the TLCC's of a proposed project and its alternative; a 3) savings-to-investment ratio (SIR) method, which indicates by a numerical ratio the size of savings relative to costs; and 4) internal-rate-of-return (IRR) technique, which gives the percentage yield on an investment.

Often these life-cycle costing techniques are supplemented by additional techniques of economic evaluation which focus upon some particular aspect of the investment, such as the time to payback (PB). Not a full life-cycle costing technique itself, the payback measure indicates the elapsed time until cumulative savings (or receipts) are sufficient to cover cumulative costs. There are two versions of the payback measure that are often used. Discounted Payback (DPB) takes into account the cost of money through discounting. Simple Payback (SPB) does not include discounting, nor does it typically include future escalation in energy prices.

Each of these evaluation techniques has its advantages and disadvantages that make it particularly appropriate for some purposes and less appropriate for others.[3] The TLCC and NS techniques are especially useful for designing and sizing projects, while the SIR and IRR techniques are particularly useful for assigning priority to projects when the budget is limited. The DPB technique is useful when project life is very uncertain or when a speculative investment requires quick recovery of funds. Collectively they form tools of analysis which can be used in determining the cost-effective design and size of solar energy systems, the type of auxiliary energy system, the kinds and amounts of other energy conservation investments to use in conjunction with solar energy, and, when the budget is limited, the economic priorities that should be assigned to competing projects.

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[1] A cut-off for the study period of 30 years was originally adopted in the Federal LCC Rule. This limit is lowered to 25 years by the provisions of the Energy Security Act of 1980 [28].

[2] The discount formulas referred to in this section appear in Appendix C.

[3] The advantages and disadvantages and recommended applications of these techniques are explained in some detail in reference [29].

The total life-cycle cost (TLCC) and Net Savings (NS) measures of economic performance provide the framework for describing the economic optimization model contained in the FEDSOL program. Other measures of economic performance required under the Federal LCC Rule are described in section 3.5.

Since solar energy systems will generally be used in conjunction with an auxiliary energy system (electricity, natural gas, oil, etc.), rather than alone, it is necessary to compare the Total Life-Cycle Costs (TLCC) of the combined solar energy/auxiliary energy system ($TLCC_{s,a}$) to the TLCC of a reference non-solar energy system ($TLCC_w$) which would be used in lieu of solar. If $TLCC_{s,a}$ is lower than $TLCC_w$, the solar energy/auxiliary energy system is more cost effective than the non-solar energy system alone.

3.3.1 Total Life-Cycle Costs Without Solar

$TLCC_w$ may be calculated as follows:

$$TLCC_w = P_w \cdot \frac{L}{e_w} \cdot UPW^*_{w_n} + I_w + \left(\sum_{t=1}^{n} R_{w_t} \cdot SPW_t \right) + (M_w \cdot UPW_n) - (S_w \cdot SPW_n), \tag{3.7}$$

where the subscript "w" designates costs of the reference non-solar energy system; P_w represents the current price per energy unit of fuel used in the reference non-solar energy system (\$/MMBtu); L, the annual heating load; e_w, the average annual efficiency of this system; $UPW^*_{w_n}$, the uniform present worth factor for the specified discount rate and period of study, n, modified to include projected price escalation rates for the fuel used in this system; I_w, the initial investment costs for this system; n, the number of years in the study period; R_{w_t}, the costs of replacements of this system net of salvage value of components replaced in year t; SPW_t, the single present worth factor for the specific discount rate and the year, t, in which the replacement is expected to occur; M_w, the annually recurring non-fuel operation and maintenance cost for this system; UPW_n, the uniform present worth discount factor for the specified discount rate and period of study; S_w, the estimated salvage value of this system net of disposal costs at the end of the study period; and SPW_n, the single present worth discount factor for the specified discount rate and last year in the study period.

3.3.2 Total Life-Cycle Costs With Solar

$TLCC_{s,a}$ is determined as follows:

$$TLCC_{s,a} = LCC_s + LCC_a \tag{3.8}$$

where LCC_s represent the life-cycle costs of the solar energy system, and LCC_a represents the life-cycle costs of the auxiliary system in a combined solar/auxiliary system.

LCC_s is calculated in the following manner:[1]

$$LCC_s = C_s + (V_s \cdot A_s) + (M_s \cdot UPW_n) + (P_s \cdot Q_s \cdot UPW^*_{s_n}) + (\sum_{j=1}^{n} R_{s_t} \cdot SPW_t) - (S_s \cdot SPW_n), \tag{3.9}$$

where C_s represents the fixed costs of the solar energy system; V_s, the variable costs of the solar energy system per unit of solar collector area, A_s; M_s, the annually recurring costs of maintaining the solar energy system, UPW_n, the uniform present worth factor for the specified discount rate and study period, n; P_s, the price of electricity per energy unit; Q_s, the quantity of electricity required annually to operate the fans, pumps, and controls of the solar energy system; $UPW^*_{s_n}$, the uniform present worth factor for the specified discount rate and study period, n, modified to include a set of projected energy price escalation rates for electricity; R_{s_t}, the costs of major replacements to the solar energy system net of salvage value of components replaced in year t; SPW_t, the single present worth factor for the specified discount rate and year t, in which the repair or replacement is expected to occur; S_s, the estimated salvage value of the system at the end of the study period net of removal and disposal costs; and SPW_n, the single present worth factor for the specified discount rate and the last year in the study period.

LCC_a is calculated as follows:

$$LCC_a = P_a \cdot \frac{L(1-F)}{e_a} \cdot UPW^*_{a_n} + I_a + (\sum_{j=1}^{n} R_{a_t} \cdot SPW_t) + (M_a \cdot UPW_n) - (S_a \cdot SPW_n), \tag{3.10}$$

where the subscript "a" designates costs of the auxiliary energy system; P_a represents the current price per energy unit of fuel consumed in the auxiliary system; L, the annual heating load; e_a, the average annual efficiency of the auxiliary heating system; F, the annual fraction of the heating load supplied by solar; $UPW^*_{a_n}$, the uniform present worth factor for the specified discount rate and period of study, n, modified to include projected energy escalation rates for the auxiliary fuel; I_a, the initial investment costs for the auxiliary backup system; R_{a_t}, the costs of replacements to the auxiliary system

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[1] This equation assumes that solar storage volume and all other variable system components increase proportionately with installed collector area. Therefore, the variable cost component (V_s) includes the cost of storage per unit of collector area, as well as all other variable system costs which increase proportionately with collector area.

net of salvage in year t; SPW_t, the single present worth factor for the specified discount rate and the year, t, in which the replacement is expected to occur; M_a, the annually recurring non-fuel operation and maintenance cost of the auxiliary system; UPW_n, the uniform present worth discount factor for the specified discount rate and study period, n; S_a, the estimated salvage of the auxiliary system net of disposal costs at the end of the study period; and SPW_n, the single present worth discount factor for the specified discount rate and the last year in the study period.

3.3.3 Net Savings

Assuming that an auxiliary system for the solar energy system is required, Net Savings (NS) is computed for a given thermal load by subtracting $TLCC_{s,a}$ from $TLCC_w$; i.e.,

$$NS = TLCC_w - TLCC_{s,a}. \tag{3.11}$$

3.4 OPTIMIZING SYSTEM DESIGN

The TLCC for each alternative design and size under consideration can be calculated and compared. The alternative with the lowest TLCC is the most cost-effective choice, provided possible differences in comfort and other effects not quantified in the cost equations do not outweigh the results of the life-cycle cost evaluation.

Similarly, projects can be designed and sized on the basis of their comparative NS. For example, the NS of a solar energy system of a given design and size can be found by subtracting the TLCC of the combined solar energy/auxiliary system from the TLCC of the reference non-solar energy system. If a project has a positive NS, it recovers its full costs plus a surplus, and, hence, is economically desirable. The system with the highest NS relative to the reference non-solar case is the most cost effective choice, other things being the same.

By repeating the procedures described above for a number of system designs and sizes (including different auxiliary systems), the system design/size configuration with the highest net savings and lowest total life-cycle cost can be identified.

3.4.1 Framework for Optimization

The optimal system design for a given application, building, and location depends on the trade-off between auxiliary energy costs (LCC_a) and solar energy system costs (LCC_s) as the size of a solar energy system of a given design is increased.

Consider the trade-off between solar energy system size and auxiliary energy cost for a system of a given design, as depicted graphically in figure 3.2. Collector area, as an indicator of overall system size, is shown along the horizontal axis. Present value costs are shown along the vertical axis. As collector area increases, the amount of energy supplied by the solar energy

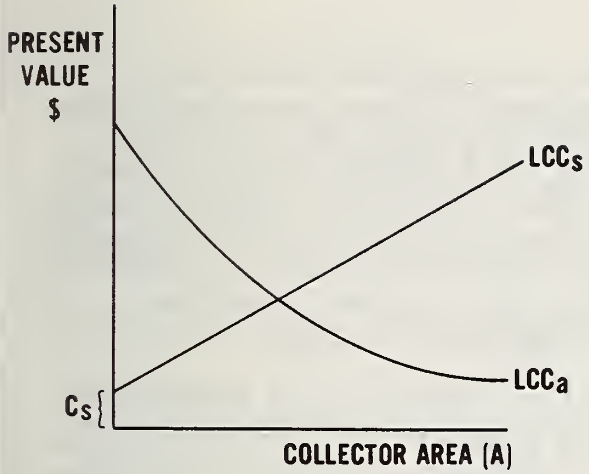

Figure 3.2 LCC Trade-off Between Conventional Energy and Solar Energy

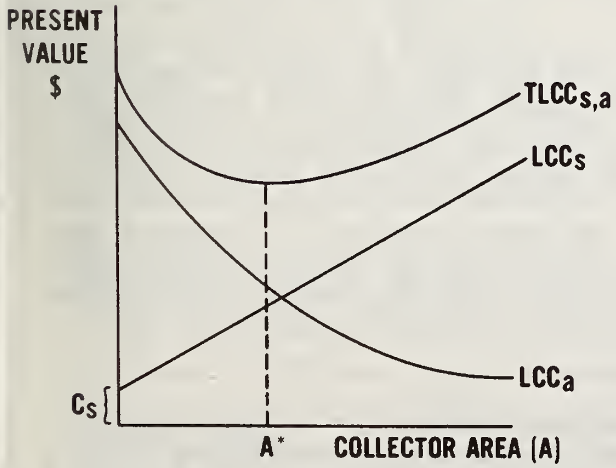

Figure 3.3 Determining the Economically Optimal System Size Through Minimizing $TLCC_{s,a}$

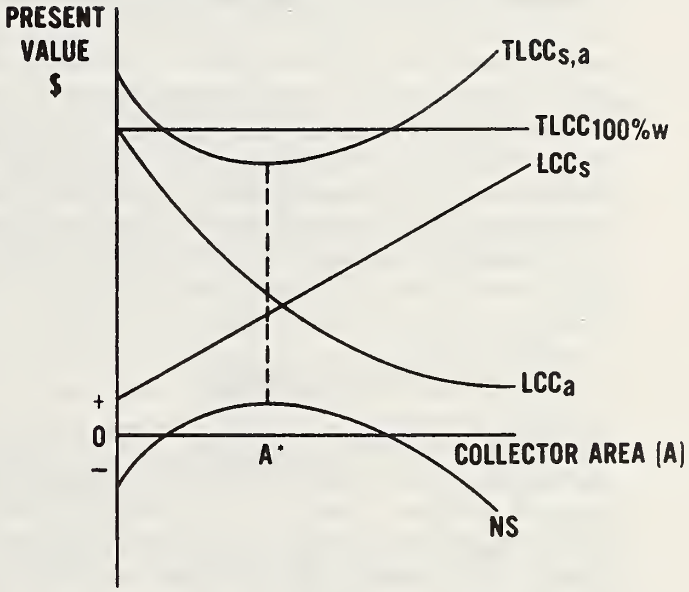

Figure 3.4 Determining the Economically Optimal System Size Through Maximizing Savings

system increases. Thus, auxiliary energy usage and LCC_a decrease as LCC_s increases. The LCC_a line is curved toward the origin because additional units of A generally increase the fraction of the load supplied by solar by ever smaller amounts, i.e., as additional units of A are installed, the LCC_a curve declines at a decreasing rate. LCC_s, in contrast, is shown to increase linearly with A in figure 3.2, as would happen if there were a constant variable cost per each additional unit of A. C_s on the vertical axis indicates those system costs that are relatively insensitive to system size, that is, the "fixed costs." C_s may be much larger or it could be smaller than portrayed in figure 3.2.

The trade-off depicted in figure 3.2 suggests that there may be a solar energy system size which just balances the decrease in LCC_a with the increase in LCC_s as additional units of collector area (A) are installed. At this point $TLCC_{s,a}$ would reach a minimum value. This is depicted in figure 3.3, which is identical to figure 3.2 with the addition of the $TLCC_{s,a}$ curve. The $TLCC_{s,a}$ curve, obtained by adding LCC_a and LCC_s vertically, is U-shaped (although other shapes are possible, depending upon the shape of LCC_a and LCC_s). The $TLCC_{s,a}$ curve is shown as first decreasing, reaching a minimum value at A*, and thereafter increasing. The system size represented by A* collector area is the economically optimal size for the solar energy system. It is economically optimal in the sense that it minimizes the total life-cycle costs of the combined system, $TLCC_{s,a}$. Any other size would result in greater $TLCC_{s,a}$.

3.4.2 Maximizing Savings

Thus far we have considered trade-offs between LCC_a and LCC_s in order to determine the total costs of various size combinations of the solar/auxiliary energy system. Now let us examine the cost effectiveness of the combined solar/auxiliary energy system relative to the reference non-solar energy system. Figure 3.4 shows the TLCC curve for the reference non-solar energy system ($TLCC_{100\%W}$), added to the curves of figure 3.3. $TLCC_{100\%W}$ is independent of collector area because it represents the total life-cycle cost without the solar energy system. Figure 3.4 also shows the NS curve for the combined solar/auxiliary energy system of alternative sizes. The NS curve is found by taking the difference between the $TLCC_{100\%W}$ curve and the $TLCC_{s,a}$ curve. NS is shown to be initially below the horizontal axis, indicating higher life-cycle costs for small sizes of the combined solar/auxiliary energy system than for the reference non-solar energy system. NS then increases, rises above the horizontal axis, and reaches a maximum value for the solar energy system size designated A*. NS decreases thereafter and losses are incurred for the largest system sizes. (Other shapes of the NS curve are possible, depending on the shapes of LCC_a, LCC_s, and $TLCC_{s,a}$.)

It is important to note that NS reaches a maximum value at A* coincident with the minimum value of $TLCC_{s,a}$. Maximizing NS is identical to minimizing $TLCC_{s,a}$ in determining the optimal system size, A*. Only by selecting the economically optimal size (A*) of the solar energy system will the maximum cost effectiveness of the system be obtained.

3.4.3 Minimizing Losses

In the graphic exposition of figure 3.4, NS is positive at A* and, therefore, the solar energy system is cost effective. It recovers its full cost over the life-cycle plus some surplus, NS. The value of the surplus is over and above the opportunity cost of money, since all costs and savings are assumed to have undergone the discounting procedure.

The collector area which minimizes $TLCC_{s,a}$ will not necessarily produce a positive NS. That is, the minimum-cost solar energy system may not be cost effective relative to the 100 percent non-solar energy system. This situation is depicted graphically in figure 3.5. The collector size A* in figure 3.5 minimizes $TLCC_{s,a}$, but results in a negative NS, which means a higher life-cycle cost of supplying energy to the building.

If a solar energy system is to be installed regardless of its cost effectiveness, A* (as depicted in figure 3.5) is the optimally sized system to install, based on economic efficiency considerations. Although it is not cost effective, A* is optimal in the sense of minimizing total life-cycle losses (-NS), or "excess cost," from using solar energy. Any other size for this solar energy system, other than zero, would result in greater excess cost over the life of the system than size A*.

This same trade-off procedure could be applied to alternative system designs, for example, flat-plate collectors versus advanced technology collectors and air systems versus water systems. The system design and size with the highest net savings, or the lowest -NS, excess cost, is the economically preferred solar energy system, other things being equal.

3.4.4 What To Do When the Economically Optimal Solar Energy System Size Is Zero or Very Small

Figure 3.6 depicts a third possible configuration for the $TLCC_{s,a}$ and NS curves. The $TLCC_{s,a}$ curve is continuously increasing and lies everywhere above the $TLCC_{100\%W}$ curve. Thus net losses result for all sizes of the solar energy system and continuously increase as solar is increased. In this situation, a collector area of zero minimizes losses.

What should one do if the life-cycle cost analysis shows that the optimal system size is 0 or so small that it does not represent a viable or realistic design decision? Answers to the following questions provide guidance:

1) Would a different type of system, with different cost and efficiency profiles, result in different trade-offs between solar costs and auxiliary energy costs?

2) What is the minimum acceptable solar heating contribution? What is the cost penalty for selecting the size that will meet the minimum requirement? Should this minimum solar contribution be used as a minimum size constraint?

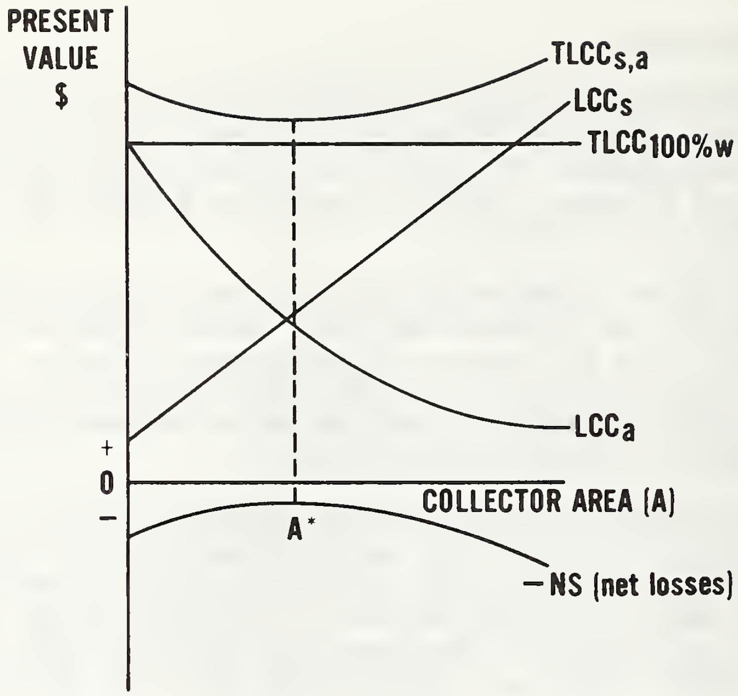

Figure 3.5 Minimizing Losses (-NS) Associated with Solar Projects

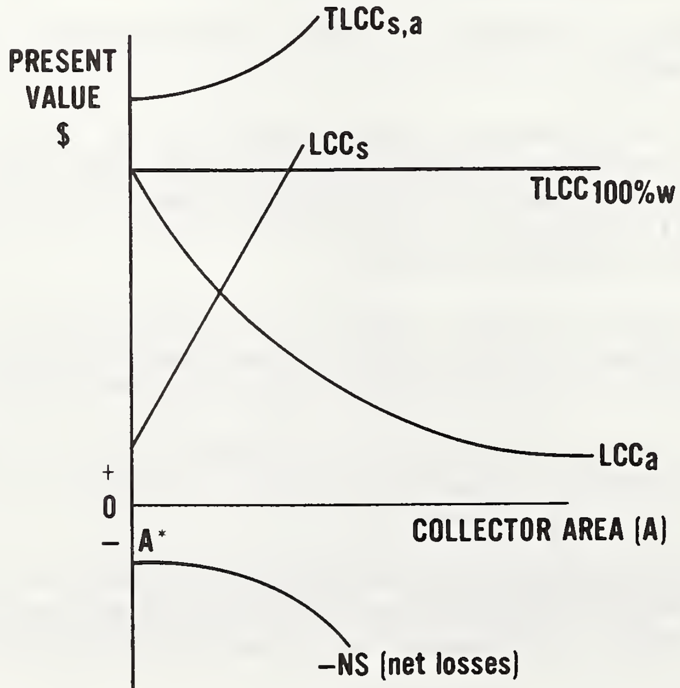

Figure 3.6 Sizing Systems When No Optimization Is Possible (A System Size of Zero Minimizes Net Losses)

3) Can the system size be expanded beyond the minimum acceptable level without a large increase in dollar losses? That is, is the NS curve steep or flat in the region of the minimum acceptable size?

4) How sensitive is the outcome of the economic optimization to key assumptions, for example, investment costs and fuel costs, and how reasonable are those assumptions? Has sufficient care been taken to differentiate the solar energy investment costs that are relatively independent of system size (fixed costs), from those that vary directly with system size (variable costs)?

5) How important is it to the agency to have an alternative energy source? Are there benefits not accounted for in the life-cycle cost analysis? Do these expected benefits exceed the excess costs or net losses of a project of acceptable size?

Sections 3.4.5 and 3.4.6 describe special features of the FEDSOL program that are useful in developing answers to these questions.

3.4.5 Optimizing System Size with FEDSOL

FEDSOL identifies the economically optimal collector area (greater than zero) by computer search of net savings for a combined solar/auxiliary system relative to a reference non-solar energy system over a wide range of sizes of the solar energy system.

In essence FEDSOL constructs and scans the NS curve, locates the combined solar/auxiliary system resulting in highest net savings (or lowest net losses), and prints out the size, solar fraction, net savings measures for this optimal system, as illustrated for a sample case--an office building system for service hot water and space heating in Washington, D.C.--reprinted in table 3.4.[1] The table of solar fractions and net savings results for a range of system sizes is reprinted in table 3.5.

In FEDSOL, the optimal collector area is determined using an optimization technique called the "Golden Section Search." The "Golden Section" is a portion of the interval between specified lower and upper bounds, calculated by taking (SQR(5)-1)/2, or approximately 0.618, times the distance between these bounds. This distance is added to the lower bound and subtracted from the upper bound to determine the first two points at which to evaluate the net present value savings of the solar energy investment. The net present value savings at the two points are compared to determine which is greater, and, consequently, which end of the interval should move to form a new search interval. The procedure is repeated until the bounds converge on the optimal collector area.

This method allows one to find a maximum or minimum value, or constrained optimum, of a function over a specified interval with very few computer

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[1] The input data for this sample Washington, D.C., case is shown in section 4, case 1.

Table 3.4 Life-Cycle Cost Summary for the SAMPLE Case

LIFE CYCLE COST SUMMARY

OPTIMAL COLLECTOR AREA = 1659.00 SQFT
OPTIMAL SOLAR FRACTION = .489

	SOLAR ENERGY SYSTEM	AUXILIARY SYSTEM	REFERENCE SYSTEM
INVESTMENT (ADJ)	$ 93792.	$ 0.	$ 0.
FUEL	$ 2833.	$ 61303.	$ 120054.
O&M	$ 11040.	$ 0.	$ 0.
REPLACEMENTS	$ 0.	$ 290.	$ 767.
SALVAGE	$ 4040.	$ 0.	$ 0.
TOTAL LCC	$ 103626.	$ 61593.	$ 120820.

Table 3.5 Table of Solar Fractions and Net Savings for the SAMPLE Case

SOLAR FRACTION AND NS FOR A RANGE OF SYSTEM SIZES

AREA (SQFT)	SOLAR FRACTION	NET SAVINGS
250.0	.08	$ -56202.
550.0	.18	$ -52749.
850.0	.27	$ -49293.
1250.0	.39	$ -45585.
1700.0	.50	$ -44411.
2300.0	.61	$ -46994.
3050.0	.70	$ -54843.
4200.0	.80	$ -72484.
6350.0	.89	$-114919.
12700.0	.98	$-262959.

iterations. In FEDSOL, the lower bound of this interval initially is set equal to zero, and the upper bound set equal to the area which produces an annual solar fraction of approximately 99 percent.

In some cases, the optimization analysis performed by FEDSOL can result in a system too small or too large to be feasible in an engineering or design sense for the building to which it is to be attached. To avoid the outcome of too small a system, the minimum acceptable solar fraction input (FEDSOL line number 5) should be used to constrain the optimization analysis to systems with performance capabilities above some minimum acceptable level.[1] Furthermore, the

[1] The FEDSOL program sets zero square feet of collector area as the absolute minimum size constraint. This constraint is adjusted upward by changing the value of the minimum solar fraction input variable over the range of one to 98 percent solar. The default value is 30 percent.

table of solar fractions and net savings in the program output can be examined for the penalty of selecting a larger or smaller system than optimal on the basis of life-cycle cost considerations. For many buildings and locations, there is little change in net savings over a wide range of system sizes and performance capabilities. In other situations or over other size ranges, the effects on life-cycle cost and net savings from under- or over-sizing systems can be major. The maximum feasible system size from an engineering or design standpoint sets the upper size limit in interpreting the life-cycle costing results.

Consider the following example, illustrated in figure 3.7. The table of net savings and annual solar fraction results obtained for a similar building and system in four cities--Washington, D.C., Los Angeles, Phoenix, and Bismarck--are plotted in the figure.[1] Annual solar fraction is plotted as a function of collector area in the upper quadrant; net losses (negative savings) as a function of collector area in the lower quadrant.

Note that net losses result from the use of solar energy in all four cases. However, in each case, net losses are minimized by a system size greater than zero. The collector area that minimizes net losses ranges from 628 square feet in Los Angeles to 1,659 square feet in Washington, D.C. Note further that in the Bismarck case, the optimally sized system provides only 15 percent of the annual energy requirement for space and water heating. This fraction is probably smaller than is feasible in an engineering sense. A further examination of the net losses curve for Bismarck shows it to be relatively flat for collector areas up to approximately 2,500 square feet, corresponding to a solar fraction of 22 percent. This suggests that the system could be expanded to 2,500 square feet with a relatively small economic or cost penalty. On the other hand, expanding the solar capability system to provide 40-50 percent or more of the energy load fraction capability would entail a substantial penalty.

3.4.6 Conducting Sensitivity Analyses with FEDSOL

FEDSOL contains a number of features that are useful in examining the sensitivity of analysis results to specific assumptions and in comparing the economic performance and optimal sizing of different types of systems.

Breakeven Analysis. The breakeven analysis portion of the program output provides a comprehensive sensitivity analysis for three key economic input variables:

- investment costs for solar energy system (fixed and variable components)
- base-year energy prices
- energy price escalation rates.

In the breakeven analysis, these variables are adjusted one at a time, with the others held at their original values, until the net life-cycle savings from the solar energy investment equal zero, the minimum conditions for cost effectiveness.

---

[1] The building and system are as described for the sample Washington, D.C., case described above.

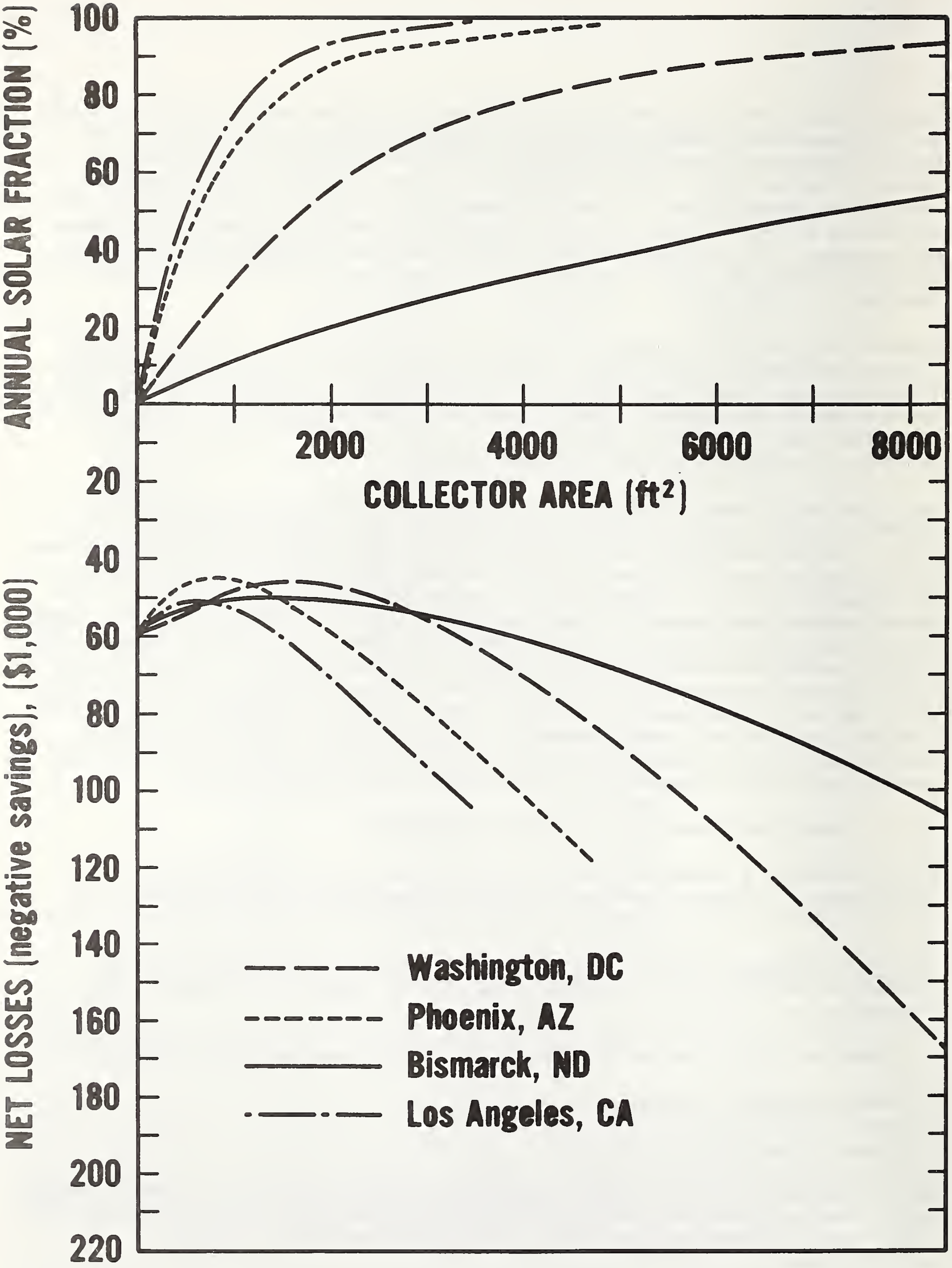

Figure 3.7 Annual Solar Fraction vs. Net Losses--Sample Test Results for an Office Building System for Space and Service Water Heating in Four U.S. Cities

Fuel price escalation rates and investment costs are adjusted by applying incremental multipliers to the original values. The multiplier which causes net savings to equal zero is called the breakeven value. The breakeven base-year fuel price is found by incrementing the original value for the base-year fuel price until net savings equal zero. Fuel prices and escalation rates are, of course, adjusted upward; investment costs downward. System size is reoptimized as prices and escalation rates are adjusted.

Note that FEDSOL conducts this breakeven analysis only when all of the following conditions apply:

1. the SLR performance analysis has been selected

2. the optimization option has been selected

3. the reference and auxiliary fuel types are the same

4. the extended output option has been selected

5. net life-cycle savings are negative for the original data and assumptions.

In situations where solar energy currently is not cost effective, this analysis serves to pinpoint the magnitude of the change required for the optimally-sized solar energy system, of the type specified, to become cost effective; i.e., it shows the "gap" between the current cost conditions and cost effectiveness.

The breakeven analysis for the sample Washington, D.C., project is reprinted in table 3.6.

Table 3.6 Breakeven Analysis for the SAMPLE Case

```
BREAKEVEN ANALYSIS

OPTIMAL AREA =     2585.00 SQFT
SOLAR FRACTION =       .647

BREAKEVEN FUEL PRICE = 15.148908 $/MMBtu

BREAKEVEN SYSTEM COST MULTIPLIER = .600340

BREAKEVEN FUEL ESCALATION RATE MULTIPLIER = 1.357
BREAKEVEN FUEL ESCALATION RATES   6.9729   7.1900   12.1557
```

This breakeven analysis shows that conventional fuel used as auxiliary to solar must cost at least $15.15/MMBtu for the project to break even, i.e., for net savings to equal zero, given the conditions assumed. This minimum required cost can be compared with the default price of oil for commercial use in Washington, D.C., in 1981 of $9.25. Alternatively, given the current price of oil, the breakeven analysis shows that reducing fixed and variable (per unit) solar energy investment costs to 60 percent of the costs assumed in the base-case analyses would cause the project to break even. Or, thirdly given the current price of distillate, investment and other costs assumed in the base-case analyses, the breakeven analysis shows that rates of fuel price escalation 1.36 times the current projections would be necessary for project savings to equal the costs.

Note that the optimal solar fraction and optimal system size in the Washington, D.C. case (project SAMPLE) increase from 49 percent and 1,659 square feet to 65 percent and 2,585 square feet, respectively, as solar energy investment costs or fuel prices approach their breakeven values.[1] (This can be seen by comparing tables 3.4 and 3.6.)

Flexibility in Changing Input Data. The FEDSOL user can take advantage of the ease with which FEDSOL's input data can be changed to develop economic profiles for making design and sizing decisions. All of the numbered items in the input data listing can be changed with the C (Change) command. Only if the location, the type of building, or the type of analysis (SLR or economic analysis alone) is changed is it necessary to start the program over by stopping execution of the current file and creating a new file. The summary output can be used to obtain a quick one-line summary of the results for alternative sets of data and assumptions (see data item 70, section 2.3.2).

3.4.7 Making the Design and Sizing Decision

By evaluating different types of systems and considering realistic ranges of values for key economic variables, one can develop a much more complete picture of the economic consequences of an investment in solar energy than that given by a single computer run for a single set of assumptions. After weighing the effects of uncertainties about investment costs, energy prices, and other costs and after considering engineering practice and architectural considerations, it remains for the decision maker to exercise a reasoned judgment as to the most economically efficient design and size under these conditions.

3.5 CALCULATING OTHER MEASURES OF ECONOMIC PERFORMANCE

The Federal LCC Rule requires the savings-to-investment ratio (SIR) and simple payback (SPB) measures of economic performance in addition to net savings (NS).

The SIR is a numerical ratio calculated with the combined change in energy costs and non-fuel operation and maintenance costs as the numerator, and the combined

---

[1] Given the particular mathematical model contained in the FEDSOL program, the breakeven optimal collector area and solar fraction are approximately the same regardless of whether base-year fuel prices, escalation rates, or investment costs are adjusted. Because of this approximate equality and in order to simplify the program output, a single set of breakeven optimal area and fraction values is printed.

change in investment costs, salvage values, and replacement costs in the denominator:[1]

$$SIR = \frac{\Delta E - \Delta M}{\Delta I - \Delta S + \Delta R}, \tag{3.12}$$

where all amounts are expressed in present value dollars, and E represents energy costs; M, non-fuel operation and maintenance costs; I, investment costs; S, salvage value; and R, replacement costs. The delta symbol (Δ) indicates that only those changes attributable to the solar energy system need be considered. ΔE is calculated by subtracting life-cycle energy costs for the combined solar/auxiliary system from energy costs for the reference system; ΔM, ΔI, ΔS, and ΔR are calculated by subtracting the respective life-cycle cost for the reference system from the corresponding life-cycle cost for the combined solar/auxiliary system. A SIR value greater than 1 means the project is cost effective. This measure is useful for ranking projects in descending order of their return per dollar cost and thus assigning priorities to projects competing for a limited budget, once the optimal size/design for a given project has been defined using the TLCC or NS measures. (For further explanation see the LCC Manual [1].)

The SPB measure computes the elapsed time between the time of the initial investment and the time at which cumulative savings through reductions in energy costs, net of other future costs, just offset the initial investment cost (ignoring the cost of money and energy price escalation). A payback period equal to or shorter than the study period means that the project is cost effective according to this measure.

If future costs and savings are estimated to occur in even yearly amounts, the following formula can be used to determine SPB:

$$SPB = \frac{\Delta I}{\Delta\overline{E} - \Delta\overline{M} - \Delta\overline{R}} \tag{3.13}$$

where I represents investment costs; $\overline{E}$, annual energy costs evaluated at base-year energy prices; $\overline{M}$, annual non-fuel operation and maintenance costs at base-year prices; and $\overline{R}$ annual replacement costs at base-year prices. The bar above the symbols indicates that the base-year costs have not been discounted to present value and summed. If future costs and savings are not uniform, the following equation can be used:

$$\text{Find } y\text{, the number of years, such that } \sum_{L=1}^{y} (\Delta\overline{E}_L - \Delta\overline{M}_L - \Delta\overline{R}_L) = \Delta I. \tag{3.14}$$

---

[1] The assignment of values to the numerator and denominator varies, but this version is widely used and has been adopted for Federal LCC Rule [1, 4].

Otherwise, differences are calculated as for the SIR. The SPB is a rough, approximate measure of economic performance and should not be relied upon as the primary basis for an investment decision. (For further explanation, see the LCC Manual [1].)

The FEDSOL program output includes these additional measures in the results of the life-cycle cost analysis. In addition, it provides two cash flow analyses. The first shows annual and cumulative dollar values for the undiscounted net cash flow over each year of the study period. The second cash flow analysis shows discounted values for the annual and cumulative net cash flow over the study period. This second cash flow analysis includes the effects of escalation in fuel prices, while the first does not. (See section 4, case 1.)

4. CASE EXAMPLES ILLUSTRATING THE FEDSOL PROGRAM[1]

This section includes five computer runs of the FEDSOL program. Case 1 illustrates the sample case stored permanently in the program files under the name "SAMPLE" (see section 2). Major elements of the program output are annotated for easy reference.

Case 1. Optimization analysis of an office building system in Washington, D.C., for space heating and service water heating.

Case 2. Thermal and economic analysis of a 800 ft^2 office building system for space heating and service hot water in Washington, D.C. (same building and location as Case 1).

Case 3. Optimization analysis of an office building system for service water heating only in Washington, D.C. (same building and location as case 1).

Case 4. Optimization analysis of a residential system in Bismarck, N.D. for space heating and service water heating.

Case 5. Economic analysis only of a residential system for space heating in Bismarck, N.D. (same building and location as case 4; thermal performance estimate from F-CHART 3.0).

---

[1] The buildings and systems analyzed in the test cases are hypothetical in that they do not actually exist, nor have they been proposed for construction. The office building cases are based on a prototypical 3-story office building of 30,000 square feet with 300 occupants; the residential case, a single-story detached residence of 1,500 square feet with four occupants. Solar energy systems costs are based on generalized cost functions for active solar energy systems prepared by Honeywell, Inc., under contract to the National Bureau of Standards [11].

Case 1. This case shows an economic optimization analysis of an office building system in Washington, D.C., for space heating and service water heating. It illustrates the use of the demonstration file called SAMPLE.

```
                    FEDSOL - VERSION 1.0 ***
                    NATIONAL BUREAU OF STANDARDS

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? O

ENTER NAME OF DESIRED FILE >>>? SAMPLE

ENGLISH OR SI UNITS (E OR SI) ? E

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? L

ANALYSIS FOR A FEDERAL OFFICE BUILDING IN WASHINGTON-STERLING, DC

     *********************************************************
     *****************  ENERGY ANALYSIS DATA  ****************
     *********************************************************

DATA FOR SOLAR PERFORMANCE ANALYSIS (SLR METHOD)

  1  TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)          13.00
  2  COLLECTOR TILT ANGLE                                    48.57 DEGREES
  3  OPTIMIZATION ANALYSIS (YES=1;NO=2)                      1.00
  4  COLLECTOR AREA                                           .00 SQFT
  5  MINIMUM ACCEPTABLE SOLAR FRACTION                       30.00 %
  6  OPERATING EFFICIENCY OF AUXILIARY SYSTEM                51.00 %
  7  OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM       51.00 %
  8  ELECTRIC ENERGY AS % OF USEFUL SOLAR ENERGY             6.00 %

-----------------------------------------------------------------
ENERGY REQUIREMENTS DATA

  9  DOMESTIC HOT WATER USAGE                               300.00 GALLONS/DAY
 10  BUILDING USE SCHEDULE                                    5.00 DAYS/WEEK
 11  MONTHLY SPACE HEATING LOADS - MMBTU/MONTH
       JAN   -   71.20       JUL   -   33.90
       FEB   -   42.30       AUG   -   23.70
       MAR   -   37.90       SEP   -   20.20
       APR   -   21.60       OCT   -   21.00
       MAY   -   24.00       NOV   -   28.70
       JUN   -   28.20       DEC   -   53.60

-----------------------------------------------------------------
ENVIRONMENTAL DATA

 12  AVERAGE DAILY HORIZONTAL RADIATION - BTU/SQFT-DAY
       JAN    -  572.00      JUL    - 1817.00
       FEB    -  815.00      AUG    - 1617.00
       MAR    - 1125.00      SEP    - 1340.00
       APR    - 1458.00      OCT    - 1003.00
       MAY    - 1718.00      NOV    -  650.00
       JUN    - 1900.00      DEC    -  481.00

 13  AVERAGE GROUND WATER TEMPERATURES - DEGREES F
       DEC  - FEB  =  47.0
       MAR  - MAY  =  51.0
       JUN  - AUG  =  66.0
       SEP  - NOV  =  63.0
```

The demonstration file SAMPLE is called from permanent storage.

Input data for SAMPLE are listed.

(The coded list of types of systems appears in table 2.1).

```
************************************************************
*****************  LIFE CYCLE COST DATA  ***************
************************************************************

BASE YEAR INVESTMENT COSTS

 30  SOLAR ENERGY INVESTMENT - FIXED COST                61577.00 $
 31  SOLAR ENERGY INVESTMENT - VARIABLE COST                25.70 $/SQFT
 32  INVESTMENT CREDIT (EXTERNALITY ADJUSTMENT)             10.00 %
 33  INVESTMENT COST FOR AUXILIARY SYSTEM                     .00 $
 34  INVESTMENT COST FOR REFERENCE NONSOLAR SYSTEM            .00 $

-----------------------------------------------------------------
FUTURE NON-FUEL COSTS

SOLAR ENERGY SYSTEM
 40  ANNUALLY RECURRING O&M COST (% OF SYSTEM COST)          1.00 %
 41  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 42  SALVAGE VALUE AT END OF STUDY PERIOD                   15.00 %

AUXILIARY SYSTEM
 44  ANNUALLY RECURRING O&M COST                              .00 $
 45  REPLACEMENT COST AND YEAR
       $    800 AT YEAR 15
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 46  SALVAGE VALUE AT END OF STUDY PERIOD                     .00 $

REFERENCE NON-SOLAR SYSTEM
 47  ANNUALLY RECURRING O&M COST                              .00 $
 48  REPLACEMENT COST AND YEAR
       $   1000 AT YEAR 10
       $   1000 AT YEAR 20
       $      0 AT YEAR  0
 49  SALVAGE VALUE AT END OF STUDY PERIOD                     .00 $

-----------------------------------------------------------------
FUEL COSTS

 50  ELECTRICITY PRICE IN BASE YEAR                         16.38 $/MMBTU
 51  DISTILLATE OIL PRICE IN BASE YEAR                       9.25 $/MMBTU
 52  RESIDUAL OIL PRICE IN BASE YEAR                         6.66 $/MMBTU
 53  NATURAL GAS PRICE IN BASE YEAR                          3.93 $/MMBTU
 54  COAL PRICE IN BASE YEAR                                 1.84 $/MMBTU
 55  LPG PRICE IN BASE YEAR                                   .00 $/MMBTU
 56  TYPE OF FUEL USED IN AUXILIARY SYSTEM                   2.00
 57  TYPE OF FUEL USED IN REFERENCE SYSTEM                   2.00

DOE REGION =  3
 58  ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION) - COMMERCIAL

      TIME PERIODS:   1ST 4 YRS  NEXT 5 YRS  AFTER 9 YRS
      ELECTRICITY        5.29        .66         .14
      DISTILLATE OIL     2.51       2.67        6.33
      RESIDUAL OIL       9.00       2.52        5.56
      NATURAL GAS        8.84       2.87        2.75
      COAL               6.04       2.36         .90
      LPG                 .00        .00         .00
```

```
---------------------------------------------------------------
DISCOUNT RATE AND STUDY PERIOD

 60  REAL DISCOUNT RATE (EXCLUDES INFLATION)                 7.00 %
 61  STUDY PERIOD                                           20.00 YEARS

---------------------------------------------------------------
ANALYSIS OUTPUT

 70  1=STANDARD; 2=EXTENDED; 3=SUMMARY                       1.00


COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? C

LINE NUMBER ? 70
 70   1=STANDARD; 2=EXTENDED; 3=SUMMARY
CURRENT VALUE =  1       NEW VALUE = ? 2

LINE NUMBER ?

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? R
* NET SAVINGS = $  -44399 * AREA =   1659 SQFT * SOLAR FRACTION = .489 *


     *********************************************************
     ************** THERMAL & ECONOMIC ANALYSIS **************
     *********************************************************

WASHINGTON-STERLING, DC
SYSTEM TYPE = 13

-----------------------------------------------------------------
SOLAR FRACTION AND NS FOR A RANGE OF SYSTEM SIZES

        AREA       SOLAR FRACTION      NET SAVINGS
        (SQFT)

        250.0           .08           $ -56202.
        550.0           .18           $ -52749.
        850.0           .27           $ -49293.
       1250.0           .39           $ -45585.
       1700.0           .50           $ -44411.
       2300.0           .61           $ -46994.
       3050.0           .70           $ -54843.
       4200.0           .80           $ -72484.
       6350.0           .89           $-114919.
      12700.0           .98           $-262959.


-----------------------------------------------------------------
THERMAL PERFORMANCE

COLLECTOR AREA =    1659.00 SQFT          TILT ANGLE = 48.57 DEGREES

        SOLAR     AVG DAILY    INCIDENT    SPACE     WATER     USEFUL
      FRACTION    HORZ RAD.    COLLECTOR   LOAD      LOAD      SOLAR
                     (1)          (1)       (2)       (2)        (2)

JAN     .190      572.00        882.01     71.20     4.58      14.38
FEB     .347      815.00       1094.16     42.30     4.13      16.11
MAR     .491     1125.00       1272.36     37.90     4.36      20.77
APR     .744     1458.00       1384.72     21.60     4.22      19.21
MAY     .734     1718.00       1437.81     24.00     4.36      20.82
JUN     .690     1900.00       1496.00     28.20     3.41      21.81
```

Input #70 is changed from "1" to "2" to request extended analysis output. A (CR) is entered in response to the line number query when no further changes are desired. The Run command is given.

JUL	.619	1817.00	1470.40	33.90	3.53	23.18
AUG	.756	1617.00	1455.68	23.70	3.53	20.60
SEP	.791	1340.00	1430.91	20.20	3.57	18.79
OCT	.755	1003.00	1316.55	21.00	3.69	18.65
NOV	.480	650.00	980.75	28.70	3.57	15.49
DEC	.211	481.00	753.07	53.60	4.58	12.28
YEAR	.489			406.30	47.53	222.09

(1) = BTU/SQFT-DAY
(2) = MMBTU/MONTH

LIFE CYCLE COST SUMMARY

OPTIMAL COLLECTOR AREA = 1659.00 SQFT
OPTIMAL SOLAR FRACTION = .489

	SOLAR ENERGY SYSTEM	AUXILIARY SYSTEM	REFERENCE SYSTEM
INVESTMENT (ADJ)	$ 93792.	$ 0.	$ 0.
FUEL	$ 2833.	$ 61303.	$ 120054.
O&M	$ 11040.	$ 0.	$ 0.
REPLACEMENTS	$ 0.	$ 290.	$ 767.
SALVAGE	$ 4040.	$ 0.	$ 0.
TOTAL LCC	$ 103626.	$ 61593.	$ 120820.

MEASURES OF ECONOMIC PERFORMANCE

TOTAL LCC WITHOUT SOLAR = $ 120820.
TOTAL LCC WITH SOLAR = $ 165219.
NET SAVINGS = $ -44399.

SIMPLE PAYBACK TIME = 33.17 YEARS

SAVINGS TO INVESTMENT RATIO = .503

CASH FLOW ANALYSIS

	SIMPLE		DISCOUNTED	
YEAR	ANNUAL	CUMULATIVE	ANNUAL	CUMULATIVE
0	$ -93792.	$ -93792.	$ -93792.	$ -93792.
1	$ 2768.	$ -91024.	$ 2670.	$ -91122.
2	$ 2768.	$ -88257.	$ 2576.	$ -88546.
3	$ 2768.	$ -85489.	$ 2483.	$ -86063.
4	$ 2768.	$ -82721.	$ 2394.	$ -83669.
5	$ 2768.	$ -79954.	$ 2320.	$ -81349.
6	$ 2768.	$ -77186.	$ 2249.	$ -79100.
7	$ 2768.	$ -74418.	$ 2178.	$ -76921.
8	$ 2768.	$ -71650.	$ 2110.	$ -74812.
9	$ 2768.	$ -68883.	$ 2042.	$ -72769.
10	$ 3768.	$ -65115.	$ 2580.	$ -70189.
11	$ 2768.	$ -62347.	$ 2098.	$ -68090.
12	$ 2768.	$ -59580.	$ 2122.	$ -65968.
13	$ 2768.	$ -56812.	$ 2144.	$ -63825.
14	$ 2768.	$ -54044.	$ 2162.	$ -61662.
15	$ 1968.	$ -52077.	$ 1889.	$ -59773.
16	$ 2768.	$ -49309.	$ 2194.	$ -57580.
17	$ 2768.	$ -46541.	$ 2206.	$ -55374.
18	$ 2768.	$ -43774.	$ 2217.	$ -53157.
19	$ 2768.	$ -41006.	$ 2226.	$ -50930.
20	$ 19400.	$ -21606.	$ 6532.	$ -44399.

```
---------------------------------------------------------------------
BREAKEVEN ANALYSIS

OPTIMAL AREA =   2585.00 SQFT
SOLAR FRACTION =     .647

BREAKEVEN FUEL PRICE =  15.148908 $/MMBTU

BREAKEVEN SYSTEM COST MULTPLIER =  .600340

BREAKEVEN FUEL ESCALATION RATE MULTIPLIER =  1.357
BREAKEVEN FUEL ESCALATION RATES    6.9729    7.1900   12.1557

---------------------------------------------------------------------
```

Case 2. This case shows a thermal and economic analysis of a 800 ft^2 office building system for space heating and service hot water in Washington, D.C. It is based on the file SAMPLE.

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? C

LINE NUMBER ? 3
 3   OPTIMIZATION ANALYSIS (YES=1;NO=2)
CURRENT VALUE =  1       NEW VALUE = ? 2

LINE NUMBER ? 4
 4   COLLECTOR AREA
CURRENT VALUE =  0  SQFT   NEW VALUE =  ? 800

LINE NUMBER ? 70
 70   1=STANDARD; 2=EXTENDED; 3=SUMMARY
CURRENT VALUE =  2       NEW VALUE = ? 1

LINE NUMBER ?
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? L
```

The input data in SAMPLE are changed to specify 800 ft^2 of collector area and the "standard" output.

```
ANALYSIS FOR A FEDERAL OFFICE BUILDING IN WASHINGTON-STERLING, DC

        ********************************************************
        *****************  ENERGY ANALYSIS DATA  ***************
        ********************************************************

DATA FOR SOLAR PERFORMANCE ANALYSIS (SLR METHOD)

  1  TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)            13.00
  2  COLLECTOR TILT ANGLE                                     48.57 DEGREES
  3  OPTIMIZATION ANALYSIS (YES=1;NO=2)                        2.00
  4  COLLECTOR AREA                                          800.00 SQFT
  5  MINIMUM ACCEPTABLE SOLAR FRACTION                        30.00 %
  6  OPERATING EFFICIENCY OF AUXILIARY SYSTEM                 51.00 %
  7  OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM        51.00 %
  8  ELECTRIC ENERGY AS % OF USEFUL SOLAR ENERGY               6.00 %

-----------------------------------------------------------------
ENERGY REQUIREMENTS DATA

  9  DOMESTIC HOT WATER USAGE                                300.00 GALLONS/DAY
 10  BUILDING USE SCHEDULE                                     5.00 DAYS/WEEK
 11  MONTHLY SPACE HEATING LOADS - MMBTU/MONTH
        JAN    -    71.20         JUL    -    33.90
        FEB    -    42.30         AUG    -    23.70
        MAR    -    37.90         SEP    -    20.20
        APR    -    21.60         OCT    -    21.00
        MAY    -    24.00         NOV    -    28.70
        JUN    -    28.20         DEC    -    53.60

-----------------------------------------------------------------
ENVIRONMENTAL DATA

 12  AVERAGE DAILY HORIZONTAL RADIATION - BTU/SQFT-DAY
        JAN    -  572.00          JUL    - 1817.00
        FEB    -  815.00          AUG    - 1617.00
        MAR    - 1125.00          SEP    - 1340.00
        APR    - 1458.00          OCT    - 1003.00
        MAY    - 1718.00          NOV    -  650.00
        JUN    - 1900.00          DEC    -  481.00
```

The revised input data are listed.

```
 13  AVERAGE GROUND WATER TEMPERATURES - DEGREES F
        DEC  - FEB  =  47.0
        MAR  - MAY  =  51.0
        JUN  - AUG  =  66.0
        SEP  - NOV  =  63.0

        *******************************************************
        *****************  LIFE CYCLE COST DATA  ***************
        *******************************************************

BASE YEAR INVESTMENT COSTS

 30  SOLAR ENERGY INVESTMENT - FIXED COST                      61577.00 $
 31  SOLAR ENERGY INVESTMENT - VARIABLE COST                      25.70 $/SQFT
 32  INVESTMENT CREDIT (EXTERNALITY ADJUSTMENT)                   10.00 %
 33  INVESTMENT COST FOR AUXILIARY SYSTEM                           .00 $
 34  INVESTMENT COST FOR REFERENCE NONSOLAR SYSTEM                  .00 $

-----------------------------------------------------------------
FUTURE NON-FUEL COSTS

SOLAR ENERGY SYSTEM
 40  ANNUALLY RECURRING O&M COST (% OF SYSTEM COST)                1.00 %
 41  REPLACEMENT COST AND YEAR
      $      0 AT YEAR  0
      $      0 AT YEAR  0
      $      0 AT YEAR  0
 42  SALVAGE VALUE AT END OF STUDY PERIOD                         15.00 %

AUXILIARY SYSTEM
 44  ANNUALLY RECURRING O&M COST                                    .00 $
 45  REPLACEMENT COST AND YEAR
      $    800 AT YEAR 15
      $      0 AT YEAR  0
      $      0 AT YEAR  0
 46  SALVAGE VALUE AT END OF STUDY PERIOD                           .00 $

REFERENCE NON-SOLAR SYSTEM
 47  ANNUALLY RECURRING O&M COST                                    .00 $
 48  REPLACEMENT COST AND YEAR
      $  1000 AT YEAR 10
      $  1000 AT YEAR 20
      $     0 AT YEAR  0
 49  SALVAGE VALUE AT END OF STUDY PERIOD                           .00 $

-----------------------------------------------------------------
FUEL COSTS

 50  ELECTRICITY PRICE IN BASE YEAR                               16.38 $/MMBTU
 51  DISTILLATE OIL PRICE IN BASE YEAR                             9.25 $/MMBTU
 52  RESIDUAL OIL PRICE IN BASE YEAR                               6.66 $/MMBTU
 53  NATURAL GAS PRICE IN BASE YEAR                                3.93 $/MMBTU
 54  COAL PRICE IN BASE YEAR                                       1.84 $/MMBTU
 55  LPG PRICE IN BASE YEAR                                         .00 $/MMBTU
 56  TYPE OF FUEL USED IN AUXILIARY SYSTEM                         2.00
 57  TYPE OF FUEL USED IN REFERENCE SYSTEM                         2.00

DOE REGION =  3
 58  ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION) - COMMERCIAL

      TIME PERIODS:    1ST 4 YRS   NEXT 5 YRS   AFTER 9 YRS
      ELECTRICITY        5.29         .66          .14
      DISTILLATE OIL     2.51        2.67         6.33
      RESIDUAL OIL       9.00        2.52         5.56
      NATURAL GAS        8.84        2.87         2.75
      COAL               6.04        2.36          .90
      LPG                 .00         .00          .00
```

```
------------------------------------------------------------
DISCOUNT RATE AND STUDY PERIOD

 60  REAL DISCOUNT RATE (EXCLUDES INFLATION)              7.00 %
 61  STUDY PERIOD                                        20.00 YEARS

------------------------------------------------------------
ANALYSIS OUTPUT

 70  1=STANDARD; 2=EXTENDED; 3=SUMMARY                    1.00

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? R
* NET SAVINGS = $  -49872 * AREA =    800 SQFT * SOLAR FRACTION = .255 *
```

No further changes are made. The Run command is given.

```
     ************************************************************
     *************** THERMAL & ECONOMIC ANALYSIS ***************
     ************************************************************

WASHINGTON-STERLING, DC
SYSTEM TYPE = 13

--------------------------------------------------------------
SOLAR FRACTION AND NS FOR A RANGE OF SYSTEM SIZES
```

AREA (SQFT)	SOLAR FRACTION	NET SAVINGS
250.0	.08	$ -56202.
550.0	.18	$ -52749.
850.0	.27	$ -49293.
1250.0	.39	$ -45585.
1700.0	.50	$ -44411.
2300.0	.61	$ -46994.
3050.0	.70	$ -54843.
4200.0	.80	$ -72484.
6350.0	.89	$-114919.
12700.0	.98	$-262959.

```
--------------------------------------------------------------
THERMAL PERFORMANCE

COLLECTOR AREA =     800.00 SQFT         TILT ANGLE = 48.57 DEGREES
```

	SOLAR FRACTION	AVG DAILY HORZ RAD. (1)	INCIDENT COLLECTOR (1)	SPACE LOAD (2)	WATER LOAD (2)	USEFUL SOLAR (2)
JAN	.092	572.00	882.01	71.20	4.58	6.93
FEB	.167	815.00	1094.16	42.30	4.13	7.77
MAR	.237	1125.00	1272.36	37.90	4.36	10.00
APR	.408	1458.00	1384.72	21.60	4.22	10.53
MAY	.399	1718.00	1437.81	24.00	4.36	11.30
JUN	.360	1900.00	1496.00	28.20	3.41	11.38
JUL	.309	1817.00	1470.40	33.90	3.53	11.56
AUG	.420	1617.00	1455.68	23.70	3.53	11.44
SEP	.458	1340.00	1430.91	20.20	3.57	10.89
OCT	.419	1003.00	1316.55	21.00	3.69	10.35
NOV	.231	650.00	980.75	28.70	3.57	7.46
DEC	.102	481.00	753.07	53.60	4.58	5.92
YEAR	.255			406.30	47.53	115.55

```
  (1) = BTU/SQFT-DAY
  (2) = MMBTU/MONTH
```

LIFE CYCLE COST SUMMARY

COLLECTOR AREA = 800.00 SQFT
SOLAR FRACTION = .255

	SOLAR ENERGY SYSTEM	AUXILIARY SYSTEM	REFERENCE SYSTEM
INVESTMENT (ADJ)	$ 73923.	$ 0.	$ 0.
FUEL	$ 1474.	$ 89487.	$ 120054.
O&M	$ 8702.	$ 0.	$ 0.
REPLACEMENTS	$ 0.	$ 290.	$ 767.
SALVAGE	$ 3184.	$ 0.	$ 0.
TOTAL LCC	$ 80915.	$ 89777.	$ 120820.

MEASURES OF ECONOMIC PERFORMANCE

TOTAL LCC WITHOUT SOLAR = $ 120820.
TOTAL LCC WITH SOLAR = $ 170692.
NET SAVINGS = $ -49872.

SIMPLE PAYBACK TIME = 60.55 YEARS

SAVINGS TO INVESTMENT RATIO = .290

Case 3. This is an economic optimization analysis of an office building system for service water heating only in Washington, D.C. A new data file is established to describe a service water heating system with single-glazed collectors, a selectively coated absorber surface, and water delivery temperature of 130°F.

The user is queried for the minimum data required for a life-cycle cost analysis.

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? N

ENGLISH OR SI UNITS (E OR SI) ? E

PERFORMANCE ANALYSIS USING SLR METHOD (Y OR N)? Y

ENTER CITY ID NUMBER? 52

RESIDENTIAL=1;COMMERCIAL=2;INDUSTRIAL=3 ? 2


THE FOLLOWING DATA ITEMS REPRESENT THE MINIMUM INFORMATION
REQUIRED TO CREATE A USEABLE INPUT DATA FILE. ADDITIONAL
CHANGES CAN BE MADE BY THE CHANGE COMMAND.


TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)                      = ? 2

ENTER LOAD TYPE: 1=WATER HTG. 2=SPACE HTG. 3=BOTH                  = ? 1

DOMESTIC HOT WATER USAGE                        GALLONS/DAY        = ? 300
BUILDING USE SCHEDULE                           DAYS/WEEK          = ? 5

SOLAR ENERGY INVESTMENT - FIXED COST            $                  = ? 12000
SOLAR ENERGY INVESTMENT - VARIABLE COST         $/SQFT             = ? 18.00

TYPES OF FUELS USED IN AUXILIARY AND REFERENCE SYSTEMS
1 = ELECTRIC
2 = DISTILLATE OIL
3 = RESIDUAL OIL
4 = NATURAL GAS
5 = COAL
6 = LPG

TYPE OF FUEL USED IN AUXILIARY SYSTEM                              = ? 1
TYPE OF FUEL USED IN REFERENCE SYSTEM                              = ? 1


COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? L

ANALYSIS FOR A FEDERAL OFFICE BUILDING IN WASHINGTON-STERLING, DC

        **********************************************************
        *****************  ENERGY ANALYSIS DATA  ****************
        **********************************************************

DATA FOR SOLAR PERFORMANCE ANALYSIS (SLR METHOD)

  1  TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)             2.00
  2  COLLECTOR TILT ANGLE                                     48.57 DEGREES
  3  OPTIMIZATION ANALYSIS (YES=1;NO=2)                        1.00
  4  COLLECTOR AREA                                             .00 SQFT
  5  MINIMUM ACCEPTABLE SOLAR FRACTION                        30.00 %
  6  OPERATING EFFICIENCY OF AUXILIARY SYSTEM                 60.00 %
  7  OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM        60.00 %
  8  ELECTRIC ENERGY AS % OF USEFUL SOLAR ENERGY               6.00 %
```

The current data (user supplied values and default values) are listed.

ENERGY REQUIREMENTS DATA

```
 9  DOMESTIC HOT WATER USAGE                               300.00 GALLONS/DAY
10  BUILDING USE SCHEDULE                                    5.00 DAYS/WEEK
11  MONTHLY SPACE HEATING LOADS - MMBTU/MONTH
      JAN   -     .00      JUL   -     .00
      FEB   -     .00      AUG   -     .00
      MAR   -     .00      SEP   -     .00
      APR   -     .00      OCT   -     .00
      MAY   -     .00      NOV   -     .00
      JUN   -     .00      DEC   -     .00
```

ENVIRONMENTAL DATA

```
12  AVERAGE DAILY HORIZONTAL RADIATION - BTU/SQFT-DAY
      JAN    -  572.00      JUL    - 1817.00
      FEB    -  815.00      AUG    - 1617.00
      MAR    - 1125.00      SEP    - 1340.00
      APR    - 1458.00      OCT    - 1003.00
      MAY    - 1718.00      NOV    -  650.00
      JUN    - 1900.00      DEC    -  481.00

13  AVERAGE GROUND WATER TEMPERATURES - DEGREES F
      DEC  - FEB  =  47.0
      MAR  - MAY  =  51.0
      JUN  - AUG  =  66.0
      SEP  - NOV  =  63.0
```

****
***************** LIFE CYCLE COST DATA ***************
****

BASE YEAR INVESTMENT COSTS

```
30  SOLAR ENERGY INVESTMENT - FIXED COST                 12000.00 $
31  SOLAR ENERGY INVESTMENT - VARIABLE COST                 18.00 $/SQFT
32  INVESTMENT CREDIT (EXTERNALITY ADJUSTMENT)              10.00 %
33  INVESTMENT COST FOR AUXILIARY SYSTEM                      .00 $
34  INVESTMENT COST FOR REFERENCE NONSOLAR SYSTEM             .00 $
```

FUTURE NON-FUEL COSTS

```
SOLAR ENERGY SYSTEM
 40  ANNUALLY RECURRING O&M COST (% OF SYSTEM COST)         1.00 %
 41  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 42  SALVAGE VALUE AT END OF STUDY PERIOD                    .00 %

AUXILIARY SYSTEM
 44  ANNUALLY RECURRING O&M COST                             .00 $
 45  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 46  SALVAGE VALUE AT END OF STUDY PERIOD                    .00 $

REFERENCE NON-SOLAR SYSTEM
 47  ANNUALLY RECURRING O&M COST                             .00 $
 48  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 49  SALVAGE VALUE AT END OF STUDY PERIOD                    .00 $
```

```
--------------------------------------------------------------
FUEL COSTS

 50  ELECTRICITY PRICE IN BASE YEAR                         16.38 $/MMBTU
 51  DISTILLATE OIL PRICE IN BASE YEAR                       9.25 $/MMBTU
 52  RESIDUAL OIL PRICE IN BASE YEAR                         6.66 $/MMBTU
 53  NATURAL GAS PRICE IN BASE YEAR                          3.93 $/MMBTU
 54  COAL PRICE IN BASE YEAR                                 1.84 $/MMBTU
 55  LPG PRICE IN BASE YEAR                                   .00 $/MMBTU
 56  TYPE OF FUEL USED IN AUXILIARY SYSTEM                   1.00
 57  TYPE OF FUEL USED IN REFERENCE SYSTEM                   1.00

DOE REGION =  3
 58  ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION) - COMMERCIAL

      TIME PERIODS:   1ST 4 YRS  NEXT 5 YRS  AFTER 9 YRS
      ELECTRICITY        5.29         .66         .14
      DISTILLATE OIL     2.51        2.67        6.33
      RESIDUAL OIL       9.00        2.52        5.56
      NATURAL GAS        8.84        2.87        2.75
      COAL               6.04        2.36         .90
      LPG                 .00         .00         .00

--------------------------------------------------------------
DISCOUNT RATE AND STUDY PERIOD

 60  REAL DISCOUNT RATE (EXCLUDES INFLATION)                 7.00 %
 61  STUDY PERIOD                                           20.00 YEARS

--------------------------------------------------------------
ANALYSIS OUTPUT

 70  1=STANDARD; 2=EXTENDED; 3=SUMMARY                       1.00


COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? C

LINE NUMBER ? 2
 2   COLLECTOR TILT ANGLE
CURRENT VALUE =  48.57  DEGREES   NEW VALUE = ? 43.57

LINE NUMBER ? 6
 6   OPERATING EFFICIENCY OF AUXILIARY SYSTEM
CURRENT VALUE =  60  %   NEW VALUE =  ? 100

LINE NUMBER ? 7
 7   OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM
CURRENT VALUE =  60  %   NEW VALUE =  ? 100

LINE NUMBER ?
```

Changes are made in the collector tilt angle and in the operating efficiencies of the auxiliary and reference systems.

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? R
* NET SAVINGS = $  -10147 * AREA =    151 SQFT * SOLAR FRACTION = .490 *


      ***********************************************************
      *************** THERMAL & ECONOMIC ANALYSIS ***************
      ***********************************************************

WASHINGTON-STERLING, DC
SYSTEM TYPE = 2
```

The Run command is given.

SOLAR FRACTION AND NS FOR A RANGE OF SYSTEM SIZES

AREA (SQFT)	SOLAR FRACTION	NET SAVINGS
20.0	.10	$ -11471.
50.0	.22	$ -10842.
80.0	.32	$ -10455.
110.0	.40	$ -10241.
160.0	.51	$ -10151.
210.0	.59	$ -10286.
280.0	.68	$ -10723.
380.0	.77	$ -11672.
570.0	.87	$ -14097.
1140.0	.98	$ -23409.

THERMAL PERFORMANCE

COLLECTOR AREA = 151.00 SQFT TILT ANGLE = 43.57 DEGREES

	SOLAR FRACTION	AVG DAILY HORZ RAD. (1)	INCIDENT COLLECTOR (1)	SPACE LOAD (2)	WATER LOAD (2)	USEFUL SOLAR (2)
JAN	*	572.00	869.80	.00	4.58	*
FEB	*	815.00	1090.37	.00	4.13	*
MAR	*	1125.00	1286.82	.00	4.36	*
APR	*	1458.00	1424.45	.00	4.22	*
MAY	*	1718.00	1498.08	.00	4.36	*
JUN	*	1900.00	1569.07	.00	3.41	*
JUL	*	1817.00	1537.68	.00	3.53	*
AUG	*	1617.00	1506.03	.00	3.53	*
SEP	*	1340.00	1456.10	.00	3.57	*
OCT	*	1003.00	1315.43	.00	3.69	*
NOV	*	650.00	968.90	.00	3.57	*
DEC	*	481.00	741.58	.00	4.58	*
YEAR	.490			.00	47.53	23.31

(1) = BTU/SQFT-DAY
(2) = MMBTU/MONTH

LIFE CYCLE COST SUMMARY

OPTIMAL COLLECTOR AREA = 151.00 SQFT
OPTIMAL SOLAR FRACTION = .490

	SOLAR ENERGY SYSTEM	AUXILIARY SYSTEM	REFERENCE SYSTEM
INVESTMENT (ADJ)	$ 13246.	$ 0.	$ 0.
FUEL	$ 297.	$ 5149.	$ 10105.
O&M	$ 1559.	$ 0.	$ 0.
REPLACEMENTS	$ 0.	$ 0.	$ 0.
SALVAGE	$ 0.	$ 0.	$ 0.
TOTAL LCC	$ 15103.	$ 5149.	$ 10105.

MEASURES OF ECONOMIC PERFORMANCE

TOTAL LCC WITHOUT SOLAR = $ 10105.
TOTAL LCC WITH SOLAR = $ 20252.
NET SAVINGS = $ -10147.

SIMPLE PAYBACK TIME = 62.57 YEARS

SAVINGS TO INVESTMENT RATIO = .234

Case 4. This case set up a new data file for a residential system for space and water heating in Bismarck, N.D. and shows the economic optimization analysis for this system.

The user is queried for the minimum set of data.

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? N

ENGLISH OR SI UNITS (E OR SI) ? E

PERFORMANCE ANALYSIS USING SLR METHOD (Y OR N)? Y

ENTER CITY ID NUMBER? 132

RESIDENTIAL=1;COMMERCIAL=2;INDUSTRIAL=3 ? 1


THE FOLLOWING DATA ITEMS REPRESENT THE MINIMUM INFORMATION
REQUIRED TO CREATE A USEABLE INPUT DATA FILE. ADDITIONAL
CHANGES CAN BE MADE BY THE CHANGE COMMAND.


TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)                   = ? 19

ENTER LOAD TYPE: 1=WATER HTG. 2=SPACE HTG. 3=BOTH               = ? 3

DOMESTIC HOT WATER USAGE                      GALLONS/DAY       = ? 80
BUILDING USE SCHEDULE                         DAYS/WEEK         = ? 7


MONTHLY SPACE HEATING LOADS                   MMBTU/MONTH
JAN-? 21.12
FEB-? 17.3
MAR-? 14.84
APR-? 7.93
MAY-? 4.06
JUN-? 1.47
JUL-? .22
AUG-? .41
SEP-? 3.02
OCT-? 6.76
NOV-? 13.
DEC-? 18.38

SOLAR ENERGY INVESTMENT - FIXED COST          $                 = ? 10270
SOLAR ENERGY INVESTMENT - VARIABLE COST       $/SQFT            = ? 17.78

TYPES OF FUELS USED IN AUXILIARY AND REFERENCE SYSTEMS
1 = ELECTRIC
2 = DISTILLATE OIL
3 = RESIDUAL OIL
4 = NATURAL GAS
5 = COAL
6 = LPG

TYPE OF FUEL USED IN AUXILIARY SYSTEM                           = ? 1
TYPE OF FUEL USED IN REFERENCE SYSTEM                           = ? 1
```

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP ? L

Current data (user supplied values plus default values) are listed.

```
ANALYSIS FOR A FEDERAL RESIDENTIAL BUILDING IN BISMARCK, ND

        ***********************************************************
        *****************  ENERGY ANALYSIS DATA  ****************
        ***********************************************************

DATA FOR SOLAR PERFORMANCE ANALYSIS (SLR METHOD)

  1  TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)          19.00
  2  COLLECTOR TILT ANGLE                                   56.46 DEGREES
  3  OPTIMIZATION ANALYSIS (YES=1;NO=2)                      1.00
  4  COLLECTOR AREA                                           .00 SQFT
  5  MINIMUM ACCEPTABLE SOLAR FRACTION                      30.00 %
  6  OPERATING EFFICIENCY OF AUXILIARY SYSTEM               60.00 %
  7  OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM      60.00 %
  8  ELECTRIC ENERGY AS % OF USEFUL SOLAR ENERGY             6.00 %

-----------------------------------------------------------------
ENERGY REQUIREMENTS DATA

  9  DOMESTIC HOT WATER USAGE                               80.00 GALLONS/DAY
 10  BUILDING USE SCHEDULE                                   7.00 DAYS/WEEK
 11  MONTHLY SPACE HEATING LOADS - MMBTU/MONTH
        JAN   -   21.12        JUL    -     .22
        FEB   -   17.30        AUG    -     .41
        MAR   -   14.84        SEP    -    3.02
        APR   -    7.93        OCT    -    6.76
        MAY   -    4.06        NOV    -   13.00
        JUN   -    1.47        DEC    -   18.38

-----------------------------------------------------------------
ENVIRONMENTAL DATA

 12  AVERAGE DAILY HORIZONTAL RADIATION - BTU/SQFT-DAY
        JAN   -  466.00        JUL    - 2183.00
        FEB   -  775.00        AUG    - 1876.00
        MAR   - 1168.00        SEP    - 1354.00
        APR   - 1459.00        OCT    -  907.00
        MAY   - 1848.00        NOV    -  507.00
        JUN   - 2059.00        DEC    -  372.00

 13  AVERAGE GROUND WATER TEMPERATURES - DEGREES F
        DEC  - FEB  =  33.0
        MAR  - MAY  =  33.0
        JUN  - AUG  =  56.0
        SEP  - NOV  =  51.0

        ***********************************************************
        *****************  LIFE CYCLE COST DATA  ***************
        ***********************************************************

BASE YEAR INVESTMENT COSTS

 30  SOLAR ENERGY INVESTMENT - FIXED COST                 10270.00 $
 31  SOLAR ENERGY INVESTMENT - VARIABLE COST                 17.78 $/SQFT
 32  INVESTMENT CREDIT (EXTERNALITY ADJUSTMENT)              10.00 %
 33  INVESTMENT COST FOR AUXILIARY SYSTEM                      .00 $
 34  INVESTMENT COST FOR REFERENCE NONSOLAR SYSTEM             .00 $
```

```
------------------------------------------------------------------
FUTURE NON-FUEL COSTS

SOLAR ENERGY SYSTEM
 40  ANNUALLY RECURRING O&M COST (% OF SYSTEM COST)          1.00 %
 41  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 42  SALVAGE VALUE AT END OF STUDY PERIOD                      .00 %

AUXILIARY SYSTEM
 44  ANNUALLY RECURRING O&M COST                               .00 $
 45  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 46  SALVAGE VALUE AT END OF STUDY PERIOD                      .00 $

REFERENCE NON-SOLAR SYSTEM
 47  ANNUALLY RECURRING O&M COST                               .00 $
 48  REPLACEMENT COST AND YEAR
       $      0 AT YEAR  0
       $      0 AT YEAR  0
       $      0 AT YEAR  0
 49  SALVAGE VALUE AT END OF STUDY PERIOD                      .00 $

------------------------------------------------------------------
FUEL COSTS

 50  ELECTRICITY PRICE IN BASE YEAR                          16.35 $/MMBTU
 51  DISTILLATE OIL PRICE IN BASE YEAR                        9.48 $/MMBTU
 52  RESIDUAL OIL PRICE IN BASE YEAR                           .00 $/MMBTU
 53  NATURAL GAS PRICE IN BASE YEAR                           4.00 $/MMBTU
 54  COAL PRICE IN BASE YEAR                                   .00 $/MMBTU
 55  LPG PRICE IN BASE YEAR                                   9.44 $/MMBTU
 56  TYPE OF FUEL USED IN AUXILIARY SYSTEM                    1.00
 57  TYPE OF FUEL USED IN REFERENCE SYSTEM                    1.00

DOE REGION =  8
 58  ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION) - RESIDENTIAL

      TIME PERIODS:    1ST 4 YRS  NEXT 5 YRS  AFTER 9 YRS
      ELECTRICITY        5.29       -3.87       -3.06
      DISTILLATE OIL     2.54        2.54        6.31
      RESIDUAL OIL        .00         .00         .00
      NATURAL GAS        8.89         .00        1.61
      COAL                .00         .00         .00
      LPG                2.53        2.35        5.99

------------------------------------------------------------------
DISCOUNT RATE AND STUDY PERIOD

 60  REAL DISCOUNT RATE (EXCLUDES INFLATION)                  7.00 %
 61  STUDY PERIOD                                            20.00 YEARS

------------------------------------------------------------------
ANALYSIS OUTPUT

 70  1=STANDARD; 2=EXTENDED; 3=SUMMARY                        1.00


COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? C

LINE NUMBER ? 6
 6   OPERATING EFFICIENCY OF AUXILIARY SYSTEM
CURRENT VALUE =  60  %   NEW VALUE =  ? 100
```

Input data for operating efficiencies of auxiliary and reference systems are changed.

```
LINE NUMBER ? 7
 7   OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM
CURRENT VALUE =  60  %   NEW VALUE =  ? 100

LINE NUMBER ? 45

AUXILIARY SYSTEM
REPLACEMENT COST AND YEAR
ENTER SIX VALUES, COST, YEAR, ETC.
? 1250,15,0,0,0,0

LINE NUMBER ? 48

REFERENCE NON-SOLAR SYSTEM
REPLACEMENT COST AND YEAR
ENTER SIX VALUES, COST, YEAR, ETC.
? 1500,8,1500,18,0,0

LINE NUMBER ?

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? R
* NET SAVINGS = $   -7488 * AREA =    269 SQFT * SOLAR FRACTION = .316 *
```

The Run command is given.

```
      ********************************************************
      ************** THERMAL & ECONOMIC ANALYSIS **************
      ********************************************************

BISMARCK, ND
SYSTEM TYPE = 19

-------------------------------------------------------------------
SOLAR FRACTION AND NS FOR A RANGE OF SYSTEM SIZES

       AREA        SOLAR FRACTION       NET SAVINGS
       (SQFT)

       100.0            .15             $  -8118.
       150.0            .20             $  -7766.
       300.0            .34             $  -7501.
       400.0            .41             $  -7729.
       550.0            .50             $  -8465.
       750.0            .60             $ -10003.
      1000.0            .69             $ -12517.
      1350.0            .78             $ -16800.
      2000.0            .89             $ -26135.
      4000.0            .99             $ -59701.

-------------------------------------------------------------------
THERMAL PERFORMANCE

COLLECTOR AREA =    269.00 SQFT          TILT ANGLE = 56.46 DEGREES

        SOLAR    AVG DAILY    INCIDENT    SPACE     WATER     USEFUL
      FRACTION   HORZ RAD.   COLLECTOR    LOAD      LOAD      SOLAR
                    (1)         (1)        (2)       (2)        (2)

JAN     .146     466.00       978.51     21.12     2.00       3.38
FEB     .212     775.00      1323.48     17.30     1.80       4.04
MAR     .296    1168.00      1522.68     14.84     2.00       4.99
```

APR	.433	1459.00	1436.03	7.93	1.93	4.27
MAY	.668	1848.00	1541.13	4.06	2.00	4.04
JUN	.939	2059.00	1589.97	1.47	1.47	2.76
JUL	1.000	2183.00	1739.39	.22	1.52	1.74
AUG	1.000	1876.00	1747.98	.41	1.52	1.93
SEP	.783	1354.00	1592.03	3.02	1.57	3.60
OCT	.503	907.00	1428.37	6.76	1.63	4.22
NOV	.219	507.00	976.00	13.00	1.57	3.19
DEC	.137	372.00	805.09	18.38	2.00	2.79
YEAR	.316			108.51	21.02	40.97

(1) = BTU/SQFT-DAY
(2) = MMBTU/MONTH

LIFE CYCLE COST SUMMARY

OPTIMAL COLLECTOR AREA = 269.00 SQFT
OPTIMAL SOLAR FRACTION = .316

	SOLAR ENERGY SYSTEM	AUXILIARY SYSTEM	REFERENCE SYSTEM
INVESTMENT (ADJ)	$ 13548.	$ 0.	$ 0.
FUEL	$ 433.	$ 15615.	$ 22839.
O&M	$ 1595.	$ 0.	$ 0.
REPLACEMENTS	$ 0.	$ 453.	$ 1317.
SALVAGE	$ 0.	$ 0.	$ 0.
TOTAL LCC	$ 15576.	$ 16068.	$ 24156.

MEASURES OF ECONOMIC PERFORMANCE

TOTAL LCC WITHOUT SOLAR = $ 24156.
TOTAL LCC WITH SOLAR = $ 31643.
NET SAVINGS = $ -7488.

SIMPLE PAYBACK TIME = 23.91 YEARS

SAVINGS TO INVESTMENT RATIO = .410

Case 5. This case shown an economic analysis only of a residential system for space heating in Bismarck, N.D. A new file is established with thermal analysis data from another source (F-CHART 3.0).

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? N

ENGLISH OR SI UNITS (E OR SI) ? E

PERFORMANCE ANALYSIS USING SLR METHOD (Y OR N)? N

ENTER CITY ID NUMBER? 132

RESIDENTIAL=1;COMMERCIAL=2;INDUSTRIAL=3 ? 1


THE FOLLOWING DATA ITEMS REPRESENT THE MINIMUM INFORMATION
REQUIRED TO CREATE A USEABLE INPUT DATA FILE. ADDITIONAL
CHANGES CAN BE MADE BY THE CHANGE COMMAND.


ANNUAL ENERGY LOAD                          MMBTU/YEAR    = ? 162.78
ANNUAL SOLAR FRACTION                       %             = ? 27.5
COLLECTOR AREA                              SQFT          = ? 350

SOLAR ENERGY INVESTMENT - FIXED COST        $             = ? 10270
SOLAR ENERGY INVESTMENT - VARIABLE COST     $/SQFT        = ? 17.78

TYPES OF FUELS USED IN AUXILIARY AND REFERENCE SYSTEMS
1 = ELECTRIC
2 = DISTILLATE OIL
3 = RESIDUAL OIL
4 = NATURAL GAS
5 = COAL
6 = LPG

TYPE OF FUEL USED IN AUXILIARY SYSTEM                     = ? 1
TYPE OF FUEL USED IN REFERENCE SYSTEM                     = ? 1
```

The user is queried for the minimum data required to perform an economic analysis only.

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? L

        ***********************************************************
        *****************  ENERGY ANALYSIS DATA  ****************
        ***********************************************************

 DATA FOR ECONOMIC ANALYSIS ONLY

  20  ANNUAL ENERGY LOAD                                  162.78 MMBTU/YEAR
  21  ANNUAL SOLAR FRACTION                                27.50 %
  22  COLLECTOR AREA                                      350.00 SQFT
   23  OPERATING EFFICIENCY OF AUXILIARY SYSTEM            60.00 %
  24  OPERATING EFFICIENCY OF REFERENCE SYSTEM             60.00 %
  25  ELECTRICAL ENERGY AS % OF USEFUL SOLAR ENERGY         6.00 %

        ***********************************************************
        *****************  LIFE CYCLE COST DATA  ****************
        ***********************************************************

 BASE YEAR INVESTMENT COSTS

  30  SOLAR ENERGY INVESTMENT - FIXED COST              10270.00 $
  31  SOLAR ENERGY INVESTMENT - VARIABLE COST              17.78 $/SQFT
  32  INVESTMENT CREDIT (EXTERNALITY ADJUSTMENT)           10.00 %
  33  INVESTMENT COST FOR AUXILIARY SYSTEM                   .00 $
  34  INVESTMENT COST FOR REFERENCE NONSOLAR SYSTEM          .00 $
```

The current data are listed.

FUTURE NON-FUEL COSTS

SOLAR ENERGY SYSTEM

40	ANNUALLY RECURRING O&M COST (% OF SYSTEM COST)	1.00 %
41	REPLACEMENT COST AND YEAR	
	$ 0 AT YEAR 0	
	$ 0 AT YEAR 0	
	$ 0 AT YEAR 0	
42	SALVAGE VALUE AT END OF STUDY PERIOD	.00 %

AUXILIARY SYSTEM

44	ANNUALLY RECURRING O&M COST	.00 $
45	REPLACEMENT COST AND YEAR	
	$ 0 AT YEAR 0	
	$ 0 AT YEAR 0	
	$ 0 AT YEAR 0	
46	SALVAGE VALUE AT END OF STUDY PERIOD	.00 $

REFERENCE NON-SOLAR SYSTEM

47	ANNUALLY RECURRING O&M COST	.00 $
48	REPLACEMENT COST AND YEAR	
	$ 0 AT YEAR 0	
	$ 0 AT YEAR 0	
	$ 0 AT YEAR 0	
49	SALVAGE VALUE AT END OF STUDY PERIOD	.00 $

FUEL COSTS

50	ELECTRICITY PRICE IN BASE YEAR	16.35 $/MMBTU
51	DISTILLATE OIL PRICE IN BASE YEAR	9.48 $/MMBTU
52	RESIDUAL OIL PRICE IN BASE YEAR	.00 $/MMBTU
53	NATURAL GAS PRICE IN BASE YEAR	4.00 $/MMBTU
54	COAL PRICE IN BASE YEAR	.00 $/MMBTU
55	LPG PRICE IN BASE YEAR	9.44 $/MMBTU
56	TYPE OF FUEL USED IN AUXILIARY SYSTEM	2.00
57	TYPE OF FUEL USED IN REFERENCE SYSTEM	2.00

DOE REGION = 8

58 ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION) - RESIDENTIAL

TIME PERIODS:	1ST 4 YRS	NEXT 5 YRS	AFTER 9 YRS
ELECTRICITY	5.29	-3.87	-3.06
DISTILLATE OIL	2.54	2.54	6.31
RESIDUAL OIL	.00	.00	.00
NATURAL GAS	8.89	.00	1.61
COAL	.00	.00	.00
LPG	2.53	2.35	5.99

DISCOUNT RATE AND STUDY PERIOD

60	REAL DISCOUNT RATE (EXCLUDES INFLATION)	7.00 %
61	STUDY PERIOD	20.00 YEARS

ANALYSIS OUTPUT

70	1=STANDARD; 2=EXTENDED; 3=SUMMARY	1.00

```
COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? R
* NET SAVINGS = $    -6786 * AREA =     350 SQFT * SOLAR FRACTION = .275 *

      ************************************************************
      ******************  ECONOMIC ANALYSIS  ******************
      ************************************************************

BISMARCK, ND
----------------------------------------------------------------------
LIFE CYCLE COST SUMMARY

TOTAL ANNUAL LOAD =     162.78 MMBTU/YEAR
COLLECTOR AREA =        350.00 SQFT
SOLAR FRACTION =          .275

                  SOLAR ENERGY    AUXILIARY     REFERENCE
                     SYSTEM         SYSTEM        SYSTEM
INVESTMENT (ADJ)   $  14844.      $      0.     $      0.

FUEL               $    474.      $  27099.     $  37378.

O&M                $   1747.      $      0.     $      0.

REPLACEMENTS       $      0.      $      0.     $      0.

SALVAGE            $      0.      $      0.     $      0.

TOTAL LCC          $  17065.      $  27099.     $  37378.

----------------------------------------------------------------------
MEASURES OF ECONOMIC PERFORMANCE

TOTAL LCC WITHOUT SOLAR = $    37378.
TOTAL LCC WITH SOLAR    = $    44163.
NET SAVINGS             = $    -6786.

SIMPLE PAYBACK TIME         =  29.78 YEARS

SAVINGS TO INVESTMENT RATIO =   .543

COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE, Q=QUIT, H=HELP  ? Q
 READY.
BYE
```

No changes are made. The Run command is given.

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APPENDIX A - FEDSOL PROGRAM CODE

```
00100 REM *********************************************************************
00110 REM ************************* FEDSOL ***********************************
00120 REM *********************************************************************
00130 REM
00140 REM SPONSOR: NATIONAL BUREAU OF STANDARDS
00150 REM          CENTER FOR BUILDING TECHNOLOGY
00160 REM          APPLIED ECONOMICS GROUP
00170 REM          WASHINGTON D.C.
00180 REM         VERSION 1.0
00190 REM         MARCH 1981
00200 REM
00210 REM AUTHOR: RICHARD C. RODGERS JR.
00220 REM
00230 REM DESCRIPTION: THE PROGRAM ANALYZES THE PERFORMANCE OF A STANDARD
00240 REM              SOLAR ENERGY SYSTEM ON A FEDERAL BUILDING. THE PROGRAM
00250 REM              WILL DETERMINE THE COLLECTOR AREA WHICH RESULTS IN
00260 REM              THE LOWEST LIFE CYCLE COST AND  PERFORM AN ECONOMIC
00270 REM              ANALYSIS OF THIS OPTIMAL AREA OR OTHER SPECIFIED AREA.
00280 REM              AN ALTERNATIVE MODE WILL ACCEPT THE THERMAL RESULTS
00290 REM              FROM ANY OTHER SOLAR PERFORMANCE ANALYSIS (FOR NON-
00300 REM              STANDARD SYSTEM TYPES) AND PERFORM AN ECONOMIC ANALYSIS
00310 REM              CONFORMING TO THE FEDERAL RULES.
00320 REM
00330 REM -------------------------------------------------------------------
00340 REM
00350 REM                              MAIN LEVEL
00360 REM
00370      GOSUB 00710
00380      PRINT "                               FEDSOL - VERSION 1.0 ***"
00390      PRINT "                               NATIONAL BUREAU OF STANDARDS"
00400      PRINT
00410      PRINT "COMMAND: N=NEW, O=OLD, L=LIST, C=CHANGE, R=RUN, S=SAVE,";
00420      PRINT " Q=QUIT, H=HELP ";
00430      ON ERROR GOTO 00410
00440      INPUT X$
00450      ON ERROR
00460      IF X$ = "N" THEN 00550
00470      IF X$ = "O" OR X$ = "0" OR X$ = "F" THEN 00570
00480      IF X$ = "C" THEN 00590
00490      IF X$ = "L" THEN 00610
00500      IF X$ = "R" THEN 00630
00510      IF X$ = "H" THEN 00650
00520      IF X$ = "S" THEN 00670
00530      IF X$ = "Q" THEN 00690
00540      GOTO 00410
00550      GOSUB 01010                ' CREATE NEW INPUT FILE
00560      GOTO 00400
00570      GOSUB 02580                ' GET OLD INPUT FILE
00580      GOTO 00400
00590      GOSUB 03010                ' CHANGE INPUT FILE DATA
00600      GOTO 00400
00610      GOSUB 08800                ' LIST CURRENT INPUT FILE
00620      GOTO 00400
00630      GOSUB 04410                ' RUN CURRENT INPUT FILE
00640      GOTO 00400
00650      GOSUB 00870                ' PRINT "HELP" INSTRUCTIONS
00660      GOTO 00400
00670      GOSUB 06170                ' SAVE CURRENT INPUT FILE
00680      GOTO 00400
00690      STOP                       ' STOP PROGRAM OPERATION
00700      GOTO 00400
```

```
00710 REM ************************ DIMENSION ************************************
00720     MARGIN #0,80
00730     Z9 = 0
00740 L$ = "THERE IS NO CURRENT INPUT DATA FILE. USE NEW OR OLD COMMAND TO GET ONE."
00750       OPTION BASE 1
00760     DIM Y(12),X(12),K(12),I(19),B(40),V(40)
00770     DIM A(12),U(12),P(12)
00780     DIM N(12),S(12)
00790     DIM C(19,4),Q(12),G(12)
00800     DIM D$(70),U$(70),D(70)
00810     DIM L(12),M$(12),R(20)
00820     DIM E(6,3),H(12),T(70,2)
00830     DIM F(6,10),J(12),Z(12)
00840     DIM O(50)
00850     DIM A$(100)
00860     RETURN
00865     JUMP (ESL(X)-20)
00870 REM ********************** INSTRUCTIONS ***********************************
00880      FILE #1 = "INSTRUC"
00890      RESTORE #1
00900      MARGIN #0,100
00910      MARGIN #1,100
00920      PRINT
00930      PRINT
00940      IF END#1 THEN 00990
00950      DELIMIT #1,(CR)
00960      INPUT #1,A$(1)
00970      PRINT A$(1)
00980      GOTO 00940
00990      CLOSE #1
01000      RETURN
01010 REM *********************** DATA INPUT ************************************
01020      Z9 = 1
01030      PRINT
01040      PRINT "ENGLISH OR SI UNITS (E OR SI)";
01045      ON ERROR GOTO 1040
01050      INPUT U$
01060      IF U$= "E" THEN 01090
01070      IF U$= "SI" THEN 01090
01080      GOTO 01030
01090      PRINT
01100      PRINT "PERFORMANCE ANALYSIS USING SLR METHOD (Y OR N)";
01105      ON ERROR GOTO 1100
01110      INPUT M$
01120      IF M$ = "Y" THEN 01150
01130      IF M$ = "N" THEN 01150
01140      GOTO 01100
01150      PRINT
01160      PRINT "ENTER CITY ID NUMBER";
01165      ON ERROR GOTO 1160
01170      INPUT C9
01180      IF C9 <= 0 THEN 01160
01190      IF C9 > 243 THEN 01160
01200      PRINT
01210      PRINT "RESIDENTIAL=1;COMMERCIAL=2;INDUSTRIAL=3";
01215      ON ERROR GOTO 1210
01220      INPUT S1
01230      IF S1 = 1 THEN 01270
01240      IF S1 = 2 THEN 01270
01250      IF S1 = 3 THEN 01270
01260      GOTO 01210
01270      FILE #2 = "DEFALT1"
01280      RESTORE #2
01290      MAT INPUT #2,D
01300      FILE #3 = "DATA"
01310      RESTORE #3
```

```
01315       ON ERROR
01320       FOR I = 1 TO C9
01330         INPUT #3,Y3,X1,C$,S$,L1,R1,J8,N1,N2,N3,N4
01340         INPUT #3,Y3
01350         MAT INPUT #3,H
01360       NEXT I
01370       CLOSE #2
01380       CLOSE #3
01390       FILE #4 = "PRICE"
01400       RESTORE #4
01410       FOR J = 1 TO 3
01420         MAT INPUT #4,F
01430         IF J <> S1 THEN 01470
01440         FOR I = 1 TO 6
01450           D(49+I) = F(I,R1)
01460         NEXT I
01470       NEXT J
01480       FOR K = 1 TO 3
01490         FOR J = 1 TO 3
01500           MAT INPUT #4,F
01510           IF J <> S1 THEN 01550
01520           FOR I = 1 TO 6
01530             E(I,K) = F(I,R1)
01540           NEXT I
01550         NEXT J
01560       NEXT K
01570       CLOSE #4
01580       D(2) = L1 + 10
01590       GOSUB 10220
01600 REM
01610       IF U$= "E" THEN 01640
01620       GOSUB 13060
01630 REM
01640       FOR M = 1 TO 12
01650         L(M) = 0
01660         K(M) = 0
01670       NEXT M
01680       FOR I = 1 TO 18
01690         R(I) = 0
01700       NEXT I
01710       PRINT
01720       PRINT
01730       PRINT "THE FOLLOWING DATA ITEMS REPRESENT THE MINIMUM INFORMATION"
01740       PRINT "REQUIRED TO CREATE A USEABLE INPUT DATA FILE. ADDITIONAL";
01750       PRINT "CHANGES CAN BE MADE BY THE CHANGE COMMAND."
01760       PRINT
01770       PRINT
01780       IF M$ = "N" THEN 02500
01790       PRINT D$(1);TAB(65);" = ";
01795       ON ERROR GOTO 1790
01800       INPUT D(1)
01810       IF D(1) => T(1,1) AND D(1) <= T(1,2) THEN 01840
01820       PRINT D$
01830       GOTO 01790
01840       PRINT
01850       PRINT "ENTER LOAD TYPE: 1=WATER HTG. 2=SPACE HTG. 3=BOTH";
01860       PRINT TAB(65);" = ";
01865       ON ERROR GOTO 1850
01870       INPUT J
01880       ON J GOTO 01900,02000,01900
01890       GOTO 01870
01900       PRINT
```

```
01910      FOR I = 9 TO 10
01920        PRINT D$(I);TAB(52);U$(I);TAB(65);" = ";
01925        ON ERROR GOTO 1920
01930        INPUT D(I)
01940        IF D(I) => T(I,1) AND D(I) <= T(I,2) THEN 01970
01950        PRINT D$
01960        GOTO 01920
01970      NEXT I
01980      PRINT
01990      IF J = 1 THEN 02100
02000      PRINT
02010      PRINT "MONTHLY SPACE HEATING LOADS";TAB(52);U$(11)
02020      FOR I = 1 TO 12
02030      PRINT M$(I);"-";
02035      ON ERROR GOTO 2030
02040      INPUT L(I)
02050      IF L(I) => 0 AND L(I) <= 1E7 THEN 02080
02060      PRINT D$
02070      GOTO 02030
02080      NEXT I
02090      PRINT
02100      FOR I = 30 TO 31
02110        PRINT D$(I);TAB(52);U$(I);TAB(65);" = ";
02115        ON ERROR GOTO 2110
02120        INPUT D(I)
02130        IF D(I) => T(I,1) AND D(I) <= T(I,2) THEN 02160
02140        PRINT D$
02150        GOTO 02110
02160      NEXT I
02170      PRINT
02180      PRINT "TYPES OF FUELS USED IN AUXILIARY AND REFERENCE SYSTEMS"
02190      PRINT "1 = ELECTRIC"
02200      PRINT "2 = DISTILLATE OIL"
02210      PRINT "3 = RESIDUAL OIL"
02220      PRINT "4 = NATURAL GAS"
02230      PRINT "5 = COAL"
02235      PRINT "6 = LPG"
02240      PRINT
02250      FOR I = 56 TO 57
02260        PRINT D$(I);TAB(52);U$(I);TAB(65);" = ";
02265      ON ERROR GOTO 2260
02270        INPUT D(I)
02280        IF D(I) => T(I,1) AND D(I) <= T(I,2) THEN 02310
02290        PRINT D$
02300        GOTO 02260
02310      NEXT I
02320      PRINT
02330      B(1) = N1
02340      B(2) = N2
02350      B(3) = N3
02360      B(4) = N4
02370      FOR I = 1 TO 4
02380        IF U$ = "E" THEN 02420
02390        IF B(I) => (5/9) THEN 02440
02400        B(I) = (5/9)
02410        GOTO 02440
02420        IF B(I) => 33 THEN 02440
02430        B(I) = 33
02440      NEXT I
02450      N1 = B(1)
02460      N2 = B(2)
02470      N3 = B(3)
02480      N4 = B(4)
02490      RETURN
```

```
02500      FOR I = 20 TO 22
02510      PRINT D$(I);TAB(52);U$(I);TAB(65);" = ";
02515      ON ERROR GOTO 2510
02520      INPUT D(I)
02530      IF D(I) => T(I,1) AND D(I) <= T(I,2) THEN 02560
02540      PRINT D$
02550      GOTO 02510
02560      NEXT I
02570      GOTO 02090
02580REM ************************ GET OLD ENTRY ****************************
02590      Z9 = 1
02600      PRINT
02610      PRINT "ENTER NAME OF DESIRED FILE >>>";
02615      ON ERROR GOTO 2950
02620      INPUT F$
02625      ON ERROR
02630      IF LEN(F$) > 7 THEN 02720
02640      FOR I = 1 TO LEN(F$)
02650        A = ORD(F$(I:I))
02660        IF ( A=>48 AND A<=57 ) OR ( A=>65 AND A<=90 ) THEN 02680
02670        GOTO 02720
02680      NEXT I
02690      CALL PF("GET",F$,F$,"RRC",K,"NA",J)
02700      I = INT(K)
02710      IF I = 0 THEN 02740
02720      PRINT "FILE NAME *** ";F$;" *** IS INVALID.  TRY AGAIN!"
02730      GOTO 02610
02740      FILE #1 = F$
02750 REM >>>>>>>>>>>>>>>  READ FILE #1 INPUT DATA  <<<<<<<<<<<<<<<<<<
02760      ON ERROR GOTO 02980
02770      MAT READ #1,D
02780      MAT READ #1,H
02790      MAT READ #1,L
02800      READ #1,N1,N2,N3,N4
02810      MAT READ #1,R
02820      MAT READ #1,E
02830      READ #1,R1,L1,S1,J8
02840      READ #1,C$,S$,M$,U$
02850      CLOSE #1
02860      ON ERROR
02870      GOSUB 10220
02880      PRINT
02890      PRINT"ENGLISH OR SI UNITS (E OR SI)";
02895      ON ERROR GOTO 2890
02900      INPUT U$
02910      IF U$ = "E" THEN 02950
02920      IF U$= "SI" THEN 02940
02930      GOTO 02890
02940      GOSUB 13060
02950      RETURN
02980      PRINT "DATA IN ";F$;" IS INVALID"
02990      CLOSE #1
03000      GOTO 02610
03010 REM ************************** EDIT ****************************************
03020      IF Z9 = 1 THEN 03050
03030      PRINT L$
03040      RETURN
03050      PRINT
03060      PRINT "LINE NUMBER";
03070      ON ERROR GOTO 04400
03080      INPUT X
03090      ON ERROR
03100      P = X
```

```
03110    IF X = 0 THEN 04400
03120    IF X <> INT(X) THEN 03050
03130    IF X < 1 OR X > 70 THEN 03050
03140    IF X => 1 AND X <= 10 THEN 03280
03150    IF X = 11 THEN 03360
03160    IF X = 12 THEN 03460
03170    IF X = 13 THEN 03560
03180    IF X => 20 AND X <= 25 THEN 03280
03190    IF X => 30 AND X <= 34 THEN 03280
03200    IF X => 40 AND X <= 42 THEN 03820
03210    IF X => 44 AND X <= 46 THEN 03980
03220    IF X => 47 AND X <= 49 THEN 04140
03230    IF X => 50 AND X <= 57 THEN 03280
03240    IF X = 58 THEN 04300
03250    IF X => 60 AND X <= 61 THEN 03280
03260    IF X = 70 THEN 03280
03270    GOTO 03050
03280    PRINT P;"  ";D$(P)
03285    I1 = D(P)
03290    PRINT "CURRENT VALUE = ";D(P);" ";U$(P);"   NEW VALUE = ";
03300    ON ERROR GOTO 3290
03310    INPUT D(P)
03320    IF D(P) => T(P,1) AND D(P) <= T(P,2) THEN 03050
03330    PRINT D$
03340    D(P) = I1
03350    GOTO 3285
03360    PRINT
03370    PRINT "MONTHLY SPACE HEATING LOADS - "; U$(P)
03380    FOR I = 1 TO 12
03390      PRINT M$(I); "-";
03395      ON ERROR GOTO 3390
03400      INPUT L(I)
03410      IF L(I) => 0 AND L(I) <= 1E7 THEN 03440
03420      PRINT D$
03430      GOTO 03390
03440    NEXT I
03450    GOTO 03050
03460    PRINT
03470    PRINT "AVERAGE DAILY HORIZONTAL RADIATION - "; U$(P)
03480    FOR I = 1 TO 12
03490      PRINT M$(I); "-";
03495      ON ERROR GOTO 3490
03500      INPUT H(I)
03510      IF H(I) => 0 AND H(I) <= 3E3 THEN 03540
03520      PRINT D$
03530      GOTO 03490
03540    NEXT I
03550    GOTO 03050
03560    PRINT
03570    PRINT "AVERAGE GROUND WATER TEMPERTURES - ";U$(P)
03580    PRINT M$(12); " TO "; M$(2);
03585    ON ERROR GOTO 3580
03590    INPUT N1
03600    IF U$ = "E" AND N1 => 33 AND N1 <= 212 THEN 03640
03610     IF U$ = "SI" AND N1 => 5/9 AND N1 <= 100 THEN 03640
03620    PRINT D$
03630    GOTO 03580
03640    PRINT M$(3); " TO "; M$(5);
03645    ON ERROR GOTO 3640
03650    INPUT N2
03660    IF U$ = "E" AND N2 => 33 AND N2 <= 212 THEN 03700
03670     IF U$ = "SI" AND N2 => 5/9 AND N1 <= 100 THEN 03700
03680    PRINT D$
03690    GOTO 03640
03700    PRINT M$(6); " TO "; M$(8);
```

```
03705       ON ERROR GOTO 3700
03710       INPUT N3
03720        IF U$ = "E" AND N3 => 33 AND N3 <= 212 THEN 03760
03730        IF U$ = "SI" AND N3 => 5/9 AND N3 <= 100 THEN 03760
03740        PRINT D$
03750        GOTO 03700
03760       PRINT M$(9); " TO "; M$(11);
03765       ON ERROR GOTO 3760
03770       INPUT N4
03780        IF U$ = "E" AND N4 => 33 AND N4 <= 212 THEN 03050
03790        IF U$ = "SI" AND N4 => 5/9 AND N4 <= 100 THEN 03050
03800        PRINT D$
03810        GOTO 03760
03820       PRINT
03830       PRINT "SOLAR ENERGY SYSTEM"
03840       IF P = 41 THEN 03860
03850       GOTO 03280
03860       PRINT "REPLACEMENT COST AND YEAR - "
03870       PRINT "ENTER SIX VALUES, COST, YEAR, ETC."
03875       ON ERROR GOTO 3870
03880       INPUT R(1),R(2),R(3),R(4),R(5),R(6)
03890       I$ = "NO ERROR"
03900       FOR I = 1 TO 5 STEP 2
03910         IF R(I) => 0 AND R(I) <= 1E8 THEN 03920 ELSE 03930
03920         IF R(I+1) => 0 AND R(I+1) <= D(61) THEN 03950
03930         PRINT D$
03940         I$ = "ERROR"
03950       NEXT I
03960       IF I$ = "ERROR" THEN 03870
03970       GOTO 03050
03980       PRINT
03990       PRINT "AUXILIARY SYSTEM"
04000       IF P = 45 THEN 04020
04010       GOTO 03280
04020       PRINT "REPLACEMENT COST AND YEAR"
04030       PRINT "ENTER SIX VALUES, COST, YEAR, ETC."
04035       ON ERROR GOTO 4030
04040       INPUT R(7),R(8),R(9),R(10),R(11),R(12)
04050       I$ = "NO ERROR"
04060       FOR I = 7 TO 11 STEP 2
04070         IF R(I) => 0 AND R(I) <= 1E8 THEN 04080 ELSE 04090
04080         IF R(I+1) => 0 AND R(I+1) <= D(61) THEN 04110
04090         PRINT D$
04100         I$ = "ERROR"
04110       NEXT I
04120       IF I$ = "ERROR" THEN 04030
04130       GOTO 03050
04140       PRINT
04150       PRINT "REFERENCE NON-SOLAR SYSTEM"
04160       IF P = 48 THEN 04180
04170       GOTO 03280
04180       PRINT "REPLACEMENT COST AND YEAR"
04190       PRINT "ENTER SIX VALUES, COST, YEAR, ETC."
04195       ON ERROR GOTO 4190
04200       INPUT R(13), R(14), R(15), R(16), R(17), R(18)
04210       I$ = "NO ERROR"
04220       FOR I = 13 TO 17 STEP 2
04230         IF R(I) => 0 AND R(I) <= 1E8 THEN 04240 ELSE 04250
04240         IF R(I+1) => 0 AND R(I+1) <= D(61) THEN 04270
04250         PRINT D$
04260         I$ = "ERROR"
04270       NEXT I
04280       IF I$ = "ERROR" THEN 04190
04290       GOTO 03050
```

```
04300      PRINT "ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION)"
04310 PRINT "1=ELEC;  2=DIST OIL;  3=RES OIL;  4=NAT GAS;  5=COAL;  6=LPG;  0=FINISHED"
04315      ON ERROR GOTO 4310
04320      INPUT I
04330      IF I = 0 THEN 03050
04340      IF I => 1 AND I <= 6 THEN 04370
04350      PRINT D$
04360      GOTO 04310
04370      PRINT "ENTER THREE VALUES: 1ST 4 YRS, NEXT 5 YRS, AFTER 9 YRS"
04375      ON ERROR GOTO 4370
04380      INPUT E(I,1),E(I,2),E(I,3)
04390      GOTO 04310
04400      RETURN
04410 REM ************************** ANALYSIS****************************
04420     IF Z9 = 1 THEN 04450
04430     PRINT L$
04440     RETURN
04450     IF U$ = "E" THEN 04470
04460     GOSUB 13490
04470     J9 = D(1)
04480     X5 = 0
04490     IF M$ = "N" THEN 06020
04500     GOSUB 11700
04510     GOSUB 08230
04520     GOSUB 04800
04530     IF D(3) = 2 THEN 04580
04540     GOSUB 05750
04550     GOSUB 05490
04560     A5 = A9
04570     GOTO 04590
04580     A9 = D(4)
04590     GOSUB 12190
04600     GOSUB 13800
04610     GOSUB 14410
04620     C5 = C9
04630     F5 = F9
04640     GOSUB 15130
04650     A6 = A0
04660     F6 = F9
04670     IF D(70) = 1 THEN 04750
04680     IF D(3) = 2 THEN 04710
04690     A9 = A5
04700     GOTO 04720
04710     A9 = D(4)
04720     GOSUB 12190
04730     GOSUB 13800
04740     GOSUB 14410
04750     IF U$ = "E" THEN 04770
04760     GOSUB 13060
04770     IF D(70) = 3 THEN 04790
04780     GOSUB 06660
04790     RETURN
04800 REM -------------------------------------------------------------------
04810     V1 = C(J8,1)
04820     V2 = C(J8,2)
04830     V3 = C(J8,3)
04840     V4 = C(J8,4)
04850     V5 = 1.4
04860 REM         CALCULATE TEN SOLAR FRACTIONS FOR 10 EVENLY SPACED COLLECTOR
04870 REM        AREAS FROM .1 TO .95 AND DETERMINE TOTAL LCC FOR EACH.
04880     IF J9 = 19 THEN 05020
04890     IF J9 > 12 THEN 05000
04900     IF J8 > 1 THEN 04930
```

```
04910    E = 1E6*X9*LOG(2*C(1,3))/(C(1,4)*Z8)
04920    GOTO 05040
04930    A = -.5*(V1*(V2^2)*EXP(-V2*V5) + V3*(V4^2)*EXP(-V4*V5))
04940    B = V1*V2*EXP(-V2*V5) + V3*V4*EXP(-V4*V5)
04950    C = .5 - V1*EXP(-V2*V5) - V3*EXP(-V4*V5)
04960    V6 = (-B + SQR((B^2)-4*A*C))/(2*A)
04970    V7 = V6 + V5
04980    E = 1E6*X9*V7/Z8
04990    GOTO 05040
05000    J7 = J9 + 1
05010    GOTO 05030
05020    J7 = 15
05030    E = 1E6*X(3)/(2*C(J7,2)*Z(3)*N(3))
05040    A1 = E
05050    A9 = A1
05060    GOSUB 12190
05070    F1= F9
05080    A2 = 8*A1
05090    A9 = A2
05100    GOSUB 12190
05110    F2 = F9
05120    GOSUB 13800
05130    C1 = (A2*(-LOG(1-F1)) - A1*(-LOG(1-F2))) / (A2*A1^2 - A1*A2^2)
05140    C2 = ((A1^2)*(-LOG(1-F2)) - (A2^2)*(-LOG(1-F1))) / (A2*A1^2 - A1*A2^2)
05150    IF A1 <= 50 THEN 05220
05160    IF A1 <= 100 THEN 05240
05170    IF A1 <= 200 THEN 05260
05180    IF A1 <= 500 THEN05280
05190    IF A1 <= 5000 THEN 05300
05200    R9 = 100
05210    GOTO 05310
05220    R9 = 1
05230    GOTO 05310
05240    R9 = 5
05250    GOTO 05310
05260    R9 = 10
05270    GOTO 05310
05280    R9 = 25
05290    GOTO 05310
05300    R9 = 50
05310    FOR F = 1 TO 9
05320      C3 = LOG(1-(F/10))
05330      A(F) = (-C2+SQR((C2^2)-4*C1*C3)) / (2*C1)
05340      A(F) = R9*INT( (A(F)/R9)+.5 )
05350      A9 = A(F)
05360      GOSUB 12190
05370      P(F) = F9
05380      GOSUB 14410
05390      U(F) = C9
05400    NEXT F
05410    A(10) = 2*A(9)
05420    A(10) = R9*INT( (A(10)/R9)+.5 )
05430    A9 = A(10)
05440    GOSUB 12190
05450    P(10) = F9
05460    GOSUB 14410
05470    U(10) = C9
05480    RETURN
```

```
05490 REM -----------------------------------------------------------------------
05500 REM        CALCULATE AREA FOR AREA CORRESPONDING TO MIN SOLAR FRACTION
05510       IF F9 => D(5)/100 THEN 05720
05520       X5 = 1
05530       C3 = LOG(1-(D(5)/100))
05540       A9 = (-C2+SQR((C2^2)-4*C1*C3))/(2*C1)
05550       GOSUB 12190
05560       IF (F9*100) < (D(5)-.4) THEN 05590
05570       IF (F9*100) > (D(5)+.4) THEN 05670
05580       RETURN
05590       A8 = A9
05600       A9 = 1.1*A9
05610       GOSUB 12190
05620       IF (F9*100) < (D(5)-.4) THEN 05590
05630       IF (F9*100) > (D(5)+.4) THEN 05650
05640       RETURN
05650       A9 = (A8+A9)/2
05660       GOTO 05610
05670       A8 = A9
05680       A9 = .9*A9
05690       GOSUB 12190
05700       IF (F9*100) < (D(5)-.4) THEN 05730
05710       IF (F9*100) > (D(5)+.4) THEN 05670
05720       RETURN
05730       A9 = (A8+A9)/2
05740       GOTO 05690
05750 REM -----------------------------------------------------------------------
05760 REM         THE OPTIMAL COLLECTOR AREA WILL NOW BE FOUND
05770 REM
05780       B1 = 0
05790       B2 = A(10)
05800       G = (SQR(5)-1)/2
05810       R = B2-B1
05820       IF R <= 1 THEN 05990
05830       T1 = B2 - R*G
05840       T2 = B1 + R*G
05850       A9 = T1
05860       GOSUB 12190
05870       GOSUB 14410
05880       P1 = C9
05890       A9 = T2
05900       GOSUB 12190
05910       GOSUB 14410
05920       P2 = C9
05930       IF P2 < P1 THEN 05950
05940       GOTO 05970
05950       B2 = T2
05960       GOTO 05810
05970       B1 = T1
05980       GOTO 05810
05990       A0 = INT(B1)
06000       A9 = A0
06010       RETURN
06020 REM -----------------------------------------------------------------------
06030 REM        PERFORM ECONOMIC ANALYSIS ON NON-STARDARD ANALYSIS
06040       X9 = D(20)
06050       F9 = D(21)/100
06060       A9 = D(22)
06070       D(6) = D(23)
06080       D(7) = D(24)
06090       D(8) = D(25)
06100       GOSUB 13800
06110       GOSUB 14410
06120       GOSUB 15130
06130       IF U$ = "E" THEN 06150
06140       GOSUB 13060
06150       GOSUB 06660
06160       RETURN
```

```
06170 REM ************************** SAVE DATA ****************************
06180      IF Z9 = 1 THEN 06210
06190      PRINT L$
06200      RETURN
06210       PRINT
06220       PRINT "STORE DATA UNDER WHAT NAME";
06225       ON ERROR GOTO 6650
06230       INPUT X$
06240       IF X$ = "FEDSOL" OR X$ = "DATA" THEN 06300
06250       IF X$ = "DEFALT1" OR X$ = "PRICE" THEN 06300
06260       IF X$ = "INSTRUC" OR X$ = "SAMPLE" THEN 06300
06270       GOTO 06320
06280       PRINT "FILE NAME *** ";X$;" *** IS INVALID.  TRY AGAIN!"
06290       GOTO 06220
06300       PRINT "FORBIDDEN NAME.  USE ANOTHER NAME!"
06310       GOTO 06220
06320       IF LEN(X$) > 7 THEN 06280
06330       FOR I = 1 TO LEN(X$)
06340         A = ORD(X$(I:I))
06350         IF ( A=>48 AND A<=57 ) OR ( A=>65 AND A<=90 ) THEN 06370
06360       GOTO 06280
06370       NEXT I
06380       FILE #1 = X$
06390       RESTORE #1
06400       MAT WRITE #1,D
06410       MAT WRITE #1,H
06420       MAT WRITE #1,L
06430       WRITE #1,N1,N2,N3,N4
06440       MAT WRITE #1,R
06450       MAT WRITE #1,E
06460       WRITE #1,R1,L1,S1,J8
06470       WRITE #1,C$,S$,M$,U$
06480       CLOSE #1
06490       CALL PF("SAVE",X$,X$,"RRC",K1,"NA",J)
06500       I = INT(K1)
06510       IF I = 0 THEN 06650
06520       IF I = 5 THEN 06540
06530       GOTO 06280
06540       PRINT X$;" ALREADY EXISTS. DO YOU WISH TO USE THIS NAME (Y/N) ";
06550       ON ERROR GOTO 06650
06560       INPUT Y$
06570       ON ERROR
06580       IF Y$ = "N" THEN 06650
06590       IF Y$ = "Y" THEN 06610
06600       GOTO 06540
06610       CALL PF("REPLACE",X$,X$,"RRC",K2,"NA",J)
06620       I1 = INT(K2)
06630       IF I1 = 0 THEN 06650
06640       GOTO 06280
06650       RETURN
06660 REM ************************ PRINT REPORT ************************************
06670       IF M$ = "Y" THEN 06800
06680       PRINT
06690 PRINT "       ****************************************************************"
06700 PRINT "       ******************  ECONOMIC ANALYSIS  ******************"
06710 PRINT "       ****************************************************************"
06720       PRINT
06730       PRINT C$;", ";S$
06740 PRINT "-----------------------------------------------------------------"
06750       PRINT "LIFE CYCLE COST SUMMARY"
06760       PRINT
06770       PRINTUSING 06780,D(20),U$(20)
06780       :TOTAL ANNUAL LOAD = ######.## <#########
06790       GOTO 07320
06800       PRINT
06810       PRINT
06820 PRINT "       ****************************************************************"
06830 PRINT "       *************** THERMAL & ECONOMIC ANALYSIS ***************"
06840 PRINT "       ****************************************************************"
06850       PRINT
```

```
06860      PRINT C$;", ";S$
06870      PRINT "SYSTEM TYPE =";D(1)
06880      PRINT
06890 PRINT "-----------------------------------------------------------------"
06900      PRINT "SOLAR FRACTION AND NS FOR A RANGE OF SYSTEM SIZES"
06910      PRINT
06920      PRINT "         AREA        SOLAR FRACTION       NET SAVINGS"
06930      PRINT "         (";U$(4);")"
06940      PRINT
06950      FOR I = 1 TO 10
06960        PRINTUSING06970,A(I),P(I),U(I)
06970        :    ######.#            #.##           $#######.
06980      NEXT I
06990      PRINT
07000      PRINT
07010 PRINT "-----------------------------------------------------------------"
07020      PRINT "THERMAL PERFORMANCE"
07030      PRINT
07040      PRINTUSING 07050,A9,U$(4),D(2)
07050      :COLLECTOR AREA = ######.## <#########     TILT ANGLE = ##.## DEGREES
07060      PRINT
07070 PRINT "       SOLAR    AVG DAILY    INCIDENT    SPACE     WATER      USEFUL"
07080 PRINT "     FRACTION   HORZ RAD.    COLLECTOR   LOAD      LOAD       SOLAR"
07090 PRINT "                   (1)          (1)       (2)       (2)         (2)"
07100      PRINT
07110      FOR M = 1 TO 12
07120        IF J9 < 13 THEN 07150
07130        PRINTUSING 07160,M$(M),G(M),H(M),Z(M),L(M),K(M),Q(M)
07140        GOTO 07180
07150        PRINTUSING 07170,M$(M),H(M),Z(M),L(M),K(M)
07160        :<####  #.###    ####.##       ####.##  ####.##  ####.##    ####.##
07170        :<####    *      ####.##       ####.##  ####.##  ####.##       *
07180      NEXT M
07190      PRINTUSING 07200,F9,L9,K9,Q9
07200      :YEAR   #.###                   #######.## #####.## #######.##
07210      PRINT
07220      PRINT " (1) = ";U$(12)
07230      PRINT " (2) = ";U$(11)
07240      PRINT
07250      PRINT
07260 PRINT "-----------------------------------------------------------------"
07270      PRINT "LIFE CYCLE COST SUMMARY"
07280      PRINT
07290      IF X5 = 1 THEN 07320
07300      IF D(3) = 1 THEN 07380
07310      A9 = D(4)
07320      PRINTUSING 07330,A9,U$(4)
07330      :COLLECTOR AREA = ##########.## <#########
07340      PRINTUSING 07350,F9
07350      :SOLAR FRACTION =        #.###
07360      PRINT
07370      GOTO 07430
07380      PRINTUSING 07390,A5,U$(4)
07390      :OPTIMAL COLLECTOR AREA = #######.## <########
07400      PRINTUSING 07410,F5
07410      :OPTIMAL SOLAR FRACTION =      #.###
07420      PRINT
07430      PRINTUSING 07590
07440      PRINTUSING 07600
07450      PRINT
07460      PRINTUSING 07610,"INVESTMENT (ADJ)",P6,D(33),D(34)
07470      PRINT
07480      PRINTUSING 07610,"FUEL",G3,G2,G1
07490      PRINT
07500      PRINTUSING 07610,"O&M",M3,M2,M1
07510      PRINT
```

```
07520       PRINTUSING 07610,"REPLACEMENTS",H3,H2,H1
07530       PRINT
07540       PRINTUSING 07610,"SALVAGE",Z3,Z2,Z1
07550       PRINT
07560       PRINTUSING 07610,"TOTAL LCC",J3,J2,J1
07570       PRINT
07580       PRINT
07590       :                    SOLAR ENERGY     AUXILIARY      REFERENCE
07600       :                        SYSTEM        SYSTEM          SYSTEM
07610       :<################  $#######.     $#######.      $#######.
07620 PRINT "-----------------------------------------------------------------"
07630       PRINT "MEASURES OF ECONOMIC PERFORMANCE"
07640       PRINT
07650       PRINTUSING 07680,J1
07660       PRINTUSING 07690,J4
07670       PRINTUSING 07700,C9
07680       :TOTAL LCC WITHOUT SOLAR = $#########.
07690       :TOTAL LCC WITH SOLAR    = $#########.
07700       :NET SAVINGS             = $#########.
07710       PRINT
07720       :SAVINGS TO INVESTMENT RATIO = ##.###
07730       IF P8 => 0 THEN 07760
07740       PRINT "SIMPLE PAYBACK TIME = NEVER"
07750       GOTO 07780
07760       PRINTUSING 07770,P8
07770       :SIMPLE PAYBACK TIME         = ###.## YEARS
07780       PRINT
07790       PRINTUSING 07720,R8
07800       PRINT
07810       IF D(70) = 1 THEN 08220
07820 PRINT "-----------------------------------------------------------------"
07830       PRINT "CASH FLOW ANALYSIS"
07835       PRINT
07840       PRINT "                   SIMPLE                        DISCOUNTED"
07850       PRINT " YEAR       ANNUAL    CUMULATIVE            ANNUAL   CUMULATIVE"
07855       PRINT
07860       T2 = X8
07870       T3 = X7
07880       PRINTUSING 07930,0,X8,T2,X7,T3
07890       FOR Y =  1 TO N5
07900       T2 = T2 + O(Y)
07910       T3 = T3 + V(Y)
07920       PRINTUSING 07930,Y,O(Y),T2,V(Y),T3
07930       :  ##      $#######.   $#########.        $#######.   $########.
07940       NEXT Y
07950       PRINT
07960       PRINT
07970       IF C9 > 0 THEN 08220
07980       IF D(3) = 2 THEN 08220
07990       IF M$ = "N" THEN 08220
08000       IF D(56) <> D(57) THEN 08220
08010 PRINT "-----------------------------------------------------------------"
08020       PRINT "BREAKEVEN ANALYSIS"
08030       PRINT
08040       PRINTUSING 08050,A6,U$(4)
08050       :OPTIMAL AREA = ######.## <#######
08060       PRINTUSING 08070,F6
08070       :SOLAR FRACTION =   #.###
08080       PRINT
08090       PRINTUSING 08100,Q4,U$(50)
08100       :BREAKEVEN FUEL PRICE = ###.###### <########
08110       PRINT
08120       PRINTUSING 08130,Y1
08130       :BREAKEVEN SYSTEM COST MULTPLIER = #.######
08140       PRINT
08150       PRINTUSING 08160,A3
08160       :BREAKEVEN FUEL ESCALATION RATE MULTIPLIER = ##.###
08170       PRINTUSING 08180,W(1),W(2),W(3)
08180       :BREAKEVEN FUEL ESCALATION RATES   ##.####   ##.####   ##.####
08190       PRINT
```

```
08200 PRINT "----------------------------------------------------------------------"
08210       PRINT
08220       RETURN
08230 REM ********************** LOAD CALCULATION *************************
08240 REM
08250       K9 = 0
08260       B(1) = N1
08270       B(2) = N1
08280       B(3) = N2
08290       B(4) = N2
08300       B(5) = N2
08310       B(6) = N3
08320       B(7) = N3
08330       B(8) = N3
08340       B(9) = N4
08350       B(10) = N4
08360       B(11) = N4
08370       B(12) = N1
08380       I(1) = 110
08390       I(2) = 130
08400       I(3) = 150
08410       I(4) = 170
08420       I(5) = 110
08430       I(6) = 130
08440       I(7) = 150
08450       I(8) = 170
08460       I(9) = 110
08470       I(10) = 130
08480       I(11) = 150
08490       I(12) = 170
08500       FOR I = 13 TO 19
08510         I(I) = 130
08520       NEXT I
08530       FOR M = 1 TO 12
08540         K(M) = 0
08550       NEXT M
08560      IF J9 > 12 THEN 08600
08570       FOR M = 1 TO 12
08580         L(M) = 0
08590       NEXT M
08600       FOR M = 1 TO 12
08610         K(M) = D(9)*D(10)*(N(M)/7)*8.3*(I(D(1))-B(M))
08620         K(M) = K(M)/1000000
08630         K9 = K9 + K(M)
08640       NEXT M
08650 REM           B(M) = MONTHLY GROUND WATER TEMPERATURE
08660 REM           I(D(1)) = WATER HEATER SET TEMPERATURE
08670 REM           D(9) = GALLONS/DAY USAGE
08680 REM           D(10) = DAYS/WEEK USAGE
08690 REM           N(M)/7 = NUMBER OF WEEKS IN EACH MONTH
08700 REM           K(M) = DHW MONTHLY LOAD IN MMBTU/MONTH
08710 REM           K9 = ANNUAL DHW LOAD IN MMBTU/YEAR
08720       X9 = 0
08730       L9 = 0
08740       FOR M = 1 TO 12
08750         X(M) = L(M) + K(M)
08760         X9 = X9 + X(M)
08770         L9 = L9 + L(M)
08780       NEXT M
08790       RETURN
08800 REM ******************** PROMPTED INPUT ******************************
08810 IF Z9 = 1 THEN 08840
08820 PRINT L$
08830 RETURN
08840 IF M$ = "N" THEN 09280
08850 PRINT
08860 PRINT "ANALYSIS FOR A FEDERAL ";T$(S1);" IN ";C$;", ";S$
08870 PRINT
```

```
08880 PRINT "        ************************************************************"
08890 PRINT "        ******************  ENERGY ANALYSIS DATA  *****************"
08900 PRINT "        ************************************************************"
08910 PRINT
08920 PRINT "DATA FOR SOLAR PERFORMANCE ANALYSIS (SLR METHOD)"
08930 PRINT
08940 FOR I = 1 TO 8
08950 PRINTUSING 08970,I,D$(I),D(I);
08960 PRINT " ";U$(I)
08970: ##  <################################################## #######.##
08980 NEXT I
08990 PRINT
09000 PRINT "----------------------------------------------------------------------"
09010 PRINT "ENERGY REQUIREMENTS DATA"
09020 PRINT
09030 PRINTUSING 08970,9,D$(9),D(9);
09040 PRINT " ";U$(9)
09050 PRINTUSING 08970,10,D$(10),D(10);
09060 PRINT " ";U$(10)
09070 PRINT " 11  MONTHLY SPACE HEATING LOADS - ";U$(11)
09080 FOR I = 1 TO 6
09090 PRINTUSING 09180,M$(I),L(I),M$(I+6),L(I+6)
09100 NEXT I
09110 PRINT
09120 PRINT "----------------------------------------------------------------------"
09130 PRINT "ENVIRONMENTAL DATA"
09140 PRINT
09150 PRINT " 12  AVERAGE DAILY HORIZONTAL RADIATION - ";U$(12)
09160 FOR I = 1 TO 6
09170 PRINTUSING 09180,M$(I),H(I),M$(I+6),H(I+6)
09180:        <##### - ####.##        <##### - ####.##
09190 NEXT I
09200 PRINT
09210 PRINT " 13  AVERAGE GROUND WATER TEMPERATURES - ";U$(13)
09220 PRINTUSING 09260,M$(12),M$(2),N1
09230 PRINTUSING 09260,M$(3),M$(5),N2
09240 PRINTUSING 09260,M$(6),M$(8),N3
09250 PRINTUSING 09260,M$(9),M$(11),N4
09260:        <### - <### = ###.#
09270 IF M$ = "Y" THEN 09400
09280 PRINT
09290 PRINT
09300 PRINT "        ************************************************************"
09310 PRINT "        ******************  ENERGY ANALYSIS DATA  *****************"
09320 PRINT "        ************************************************************"
09330 PRINT
09340 PRINT "DATA FOR ECONOMIC ANALYSIS ONLY"
09350 PRINT
09360FOR I = 20 TO 25
09370 PRINTUSING 08970,I,D$(I),D(I);
09380 PRINT " ";U$(I)
09390 NEXT I
09400 PRINT
09410 PRINT "        ************************************************************"
09420 PRINT "        ******************  LIFE CYCLE COST DATA  *****************"
09430 PRINT "        ************************************************************"
09440 PRINT
09450 PRINT "BASE YEAR INVESTMENT COSTS"
09460 PRINT
09470 FOR I = 30 TO 34
09480 PRINTUSING 08970,I,D$(I),D(I);
09490 PRINT " ";U$(I)
09500 NEXT I
09510 PRINT
09520 PRINT "----------------------------------------------------------------------"
09530 PRINT "FUTURE NON-FUEL COSTS"
09540 PRINT
09550 PRINT "SOLAR ENERGY SYSTEM"
09560 PRINTUSING 08970,40,D$(40),D(40);
09570 PRINT " ";U$(40)
```

```
09580 PRINT " 41  REPLACEMENT COST AND YEAR"
09590 PRINTUSING 09620,R(1),R(2)
09600 PRINTUSING09620,R(3),R(4)
09610  PRINTUSING 09620,R(5),R(6)
09620:      $###### AT YEAR ##
09630 PRINTUSING 08970,42,D$(42),D(42);
09640 PRINT " ";U$(42)
09650 PRINT
09660 PRINT "AUXILIARY SYSTEM"
09670 PRINTUSING 08970,44,D$(44),D(44);
09680 PRINT " ";U$(44)
09690 PRINT " 45  REPLACEMENT COST AND YEAR"
09700 PRINTUSING 09620,R(7),R(8)
09710 PRINTUSING 09620,R(9),R(10)
09720 PRINTUSING 09620,R(11),R(12)
09730 PRINTUSING 08970,46,D$(46),D(46);
09740 PRINT " ";U$(46)
09750 PRINT
09760 PRINT "REFERENCE NON-SOLAR SYSTEM"
09770 PRINTUSING 08970,47,D$(47),D(47);
09780 PRINT " ";U$(47)
09790 PRINT " 48  REPLACEMENT COST AND YEAR"
09800 PRINTUSING 09620,R(13),R(14)
09810 PRINTUSING09620,R(15),R(16)
09820 PRINTUSING 09620,R(17),R(18)
09830 PRINTUSING 08970,49,D$(49),D(49);
09840 PRINT " ";U$(49)
09850 PRINT
09860 PRINT "----------------------------------------------------------------"
09870 PRINT "FUEL COSTS"
09880PRINT
09890 FOR I = 50 TO 57
09900 PRINTUSING 08970,I,D$(I),D(I);
09910 PRINT " ";U$(I)
09920 NEXTI
09930 PRINT
09940 PRINT "DOE REGION = ";R1
09950 PRINT " 58  ENERGY PRICE ESCALATION (% PER YEAR ABOVE INFLATION) - ";S$(S1)
09960 PRINT
09970 PRINT "      TIME PERIODS:   1ST 4 YRS  NEXT 5 YRS  AFTER 9 YRS"
09980 PRINTUSING 10030,"ELECTRICITY",E(1,1),E(1,2),E(1,3)
09990 PRINTUSING 10030,"DISTILLATE OIL",E(2,1),E(2,2),E(2,3)
10010 PRINTUSING 10030,"RESIDUAL OIL",E(3,1),E(3,2),E(3,3)
10015 PRINTUSING 10030,"NATURAL GAS",E(4,1),E(4,2),E(4,3)
10020 PRINTUSING 10030,"COAL",E(5,1),E(5,2),E(5,3)
10025 PRINTUSING 10030,"LPG",E(6,1),E(6,2),E(6,3)
10030      :      <############## ###.##      ###.##      ###.##
10040 PRINT
10050 PRINT "----------------------------------------------------------------"
10060 PRINT "DISCOUNT RATE AND STUDY PERIOD"
10070 PRINT
10080 PRINTUSING 08970,60,D$(60),D(60);
10090 PRINT " ";U$(60)
10100 PRINTUSING 08970,61,D$(61),D(61);
10110 PRINT " ";U$(61)
10120 PRINT
10130 PRINT "----------------------------------------------------------------"
10140 PRINT "ANALYSIS OUTPUT"
10150 PRINT
10160 PRINTUSING 08970,70,D$(70),D(70);
10170 PRINT
10180 PRINT
10190 RETURN
```

```
10200 REM ************************ CHANGE UNITS TO SI UNITS ***************
10210 RETURN
10220 REM *************** DEFINITION OF VARIABLES **********************
10230 RESTORE
10240 D$(1) = "TYPE OF SOLAR ENERGY SYSTEM (FROM CODED LIST)"
10250 D$(2) = "COLLECTOR TILT ANGLE"
10260 D$(3) = "OPTIMIZATION ANALYSIS (YES=1;NO=2)"
10270 D$(4) = "COLLECTOR AREA"
10280 D$(5) = "MINIMUM ACCEPTABLE SOLAR FRACTION"
10290 D$(6) = "OPERATING EFFICIENCY OF AUXILIARY SYSTEM"
10300 D$(7) = "OPERATING EFFICIENCY OF REFERENCE NONSOLAR SYSTEM"
10310 D$(8) = "ELECTRIC ENERGY AS % OF USEFUL SOLAR ENERGY"
10320 D$(9) = "DOMESTIC HOT WATER USAGE"
10330 D$(10) = "BUILDING USE SCHEDULE"
10340 D$(20) = "ANNUAL ENERGY LOAD"
10350 D$(21) = "ANNUAL SOLAR FRACTION"
10360 D$(22) ="COLLECTOR AREA"
10370 D$(23) = "OPERATING EFFICIENCY OF AUXILIARY SYSTEM"
10380 D$(24) = "OPERATING EFFICIENCY OF REFERENCE SYSTEM"
10390 D$(25) = "ELECTRICAL ENERGY AS % OF USEFUL SOLAR ENERGY"
10400 D$(30) = "SOLAR ENERGY INVESTMENT - FIXED COST"
10410 D$(31) = "SOLAR ENERGY INVESTMENT - VARIABLE COST"
10420 D$(32) = "INVESTMENT CREDIT (EXTERNALITY ADJUSTMENT)"
10430 D$(33) = "INVESTMENT COST FOR AUXILIARY SYSTEM"
10440 D$(34) = "INVESTMENT COST FOR REFERENCE NONSOLAR SYSTEM"
10450 D$(40) = "ANNUALLY RECURRING O&M COST (% OF SYSTEM COST)"
10460 D$(42) = "SALVAGE VALUE AT END OF STUDY PERIOD"
10470 D$(44) = "ANNUALLY RECURRING O&M COST"
10480 D$(46) = "SALVAGE VALUE AT END OF STUDY PERIOD"
10490 D$(47) = "ANNUALLY RECURRING O&M COST"
10500 D$(49) = "SALVAGE VALUE AT END OF STUDY PERIOD"
10510 D$(50) = "ELECTRICITY PRICE IN BASE YEAR"
10520 D$(51) = "DISTILLATE OIL PRICE IN BASE YEAR"
10530 D$(52) = "RESIDUAL OIL PRICE IN BASE YEAR"
10540 D$(53) = "NATURAL GAS PRICE IN BASE YEAR"
10550 D$(54) = "COAL PRICE IN BASE YEAR"
10555 D$(55) = "LPG PRICE IN BASE YEAR"
10560 D$(56) = "TYPE OF FUEL USED IN AUXILIARY SYSTEM"
10570 D$(57) = "TYPE OF FUEL USED IN REFERENCE SYSTEM"
10580 D$(60) = "REAL DISCOUNT RATE (EXCLUDES INFLATION)"
10590 D$(61) = "STUDY PERIOD"
10600 D$(70) = "1=STANDARD; 2=EXTENDED; 3=SUMMARY"
10610 D$ = "DATA OUT OF RANGE. TRY AGAIN!"
10620 J9 = D(1)
10630 Q1 = D(49+D(57))
10640 Q2 = D(49+D(56))
10650 Q3 = D(50)
10660 U$(1) = " "
10670 U$(2) = "DEGREES"
10680 U$(3) = " "
10690 U$(4) = "SQFT"
10700 U$(5) = "%"
10710 U$(6) = "%"
10720 U$(7) = "%"
10730 U$(8) = "%"
10740 U$(9) = "GALLONS/DAY"
10750U$(10) = "DAYS/WEEK"
10760 U$(11) = "MMBTU/MONTH"
10770 U$(12) = "BTU/SQFT-DAY"
```

```
10780 U$(13) = "DEGREES F"
10790 U$(20) = "MMBTU/YEAR"
10800 U$(21) = "%"
10810 U$(22) = "SQFT"
10820U$(23) = "%"
10830U$(24) = "%"
10840 U$(25) = "%"
10850 U$(30) = "$"
10860 U$(31) = "$/SQFT"
10870 U$(32) = "%"
10880 U$(33) = "$"
10890 U$(34) = "$"
10900 U$(40) = "%"
10910 U$(42) = "%"
10920 U$(44) = "$"
10930 U$(46) = "$"
10940 U$(47) = "$"
10950 U$(49) = "$"
10960 U$(50) = "$/MMBTU"
10970 U$(51) = "$/MMBTU"
10980 U$(52) = "$/MMBTU"
10990 U$(53) = "$/MMBTU"
11000 U$(54) = "$/MMBTU"
11010 U$(55) = "$/MMBTU"
11020 U$(56) = " "
11025 U$(57) = " "
11030 U$(60) = "%"
11040 U$(61) = "YEARS"
11050 U$(70) = " "
11060 S$(1) = "RESIDENTIAL"
11070 S$(2) = "COMMERCIAL"
11080 S$(3) = "INDUSTRIAL"
11090 T$(1) = "RESIDENTIAL BUILDING"
11100 T$(2) = "OFFICE BUILDING"
11110 T$(3) = "INDUSTRIAL FACILITY"
11120 M$(1) = "JAN"
11130 M$(2) = "FEB"
11140 M$(3) = "MAR"
11150 M$(4) = "APR"
11160 M$(5) = "MAY"
11170M$(6) = "JUN"
11180 M$(7) = "JUL"
11190 M$(8) = "AUG"
11200 M$(9) = "SEP"
11210 M$(10) = "OCT"
11220 M$(11) = "NOV"
11230 M$(12) = "DEC"
11240 MAT READ C
11250 DATA  .366, .573, 1.026, .713
11260 DATA  .815, .470, .185, 2.003
11270 DATA  .570, .336, .430, .946
11280 DATA  .783, .327, .217, 1.429
11290 DATA  .638, .269, .362, .966
11300 DATA  .438, .159, .562, .740
11310 DATA  .092, .080, .908, .690
11320 DATA  .652, .328, .348, 1.074
11330 DATA  .819, .308, .181, 2.020
```

```
11340 DATA  .819, .248, .181, 2.342
11350 DATA  .652, .328, .348, 1.074
11360 DATA  .627, .255, .373, 1.239
11370 DATA  .660, .278, .340, 1.011
11380 DATA 1.478, .317, 1.314, .613
11390 DATA 1.581, .291, 1.298, .555
11400 DATA 1.605, .287, 1.302, .550
11410 DATA 1.187, .415, 1.360, .830
11420 DATA 1.177, .426, 1.392, .872
11430 DATA 1.314, .371, 1.353, .739
11440 MAT READ N
11450 DATA 31,28,31,30,31,30,31,31,30,31,30,31
11460 MAT READ Y
11470 DATA 17,47,75,105,135,162,198,228,258,288,318,344
11480 FOR I = 1 TO 70
11490   READ X$,T(I,1),T(I,2)
11500 NEXT I
11510 DATA   #1, 1,  19,   #2, 0,  90,   #3, 1,   2,   #4, 0, 1E6
11520 DATA   #5, 0, 100,   #6, 0, 1E3,   #7, 0, 1E3,   #8, 0, 100
11530 DATA   #9, 0, 1E6,  #10, 1,   7,  #11, 0,   0,  #12, 0,   0
11540 DATA  #13, 0,   0,  #14, 0,   0,  #15, 0,   0,  #16, 0,   0
11550 DATA  #17, 0,   0,  #18, 0,   0,  #19, 0,   0,  #20, 0, 1E6
11560 DATA  #21, 0, 100,  #22, 0, 1E6,  #23, 0, 100,  #24, 0, 100
11570 DATA  #25, 0, 100,  #26, 0,   0,  #27, 0,   0,  #28, 0,   0
11580 DATA  #29, 0,   0,  #30, 0, 1E8,  #31, 0, 1E4,  #32, 0, 100
11590 DATA  #33, 0, 1E8,  #34, 0, 1E8,  #35, 0,   0,  #36, 0,   0
11600 DATA  #37, 0,   0,  #38, 0,   0,  #39, 0,   0,  #40, 0, 100
11610 DATA  #41, 0,   0,  #42, 0, 100,  #43, 0,   0,  #44, 0, 1E7
11620 DATA  #45, 0,   0,  #46, 0, 1E8,  #47, 0, 1E7,  #48, 0,   0
11630 DATA  #49, 0, 1E8,  #50, 0, 1E3,  #51, 0, 1E3,  #52, 0, 1E3
11640 DATA  #53, 0, 1E6,  #54, 0, 1E3,  #55, 0, 1E3,  #56, 1,   6
11650 DATA  #57, 1,   6,  #58, 0,   0,  #59, 0,   0,  #60, 0, 100
11660 DATA  #61, 1,  40,  #62, 0,   0,  #63, 0,   0,  #64, 0,   0
11670 DATA  #65, 0,   0,  #66, 0,   0,  #67, 0,   0,  #68, 0,   0
11680 DATA  #69, 0,   0,  #70, 1,   3
11690 RETURN
11700REM *********** CALCULATE SOLAR RADIATION ON TILTED SURFACE ************
11710 REM
11720 P1 = 3.1415926
11730 P2 = 57.295779
11740 I9 =428.9
11750 S = D(2)
11760 L = L1
11770 Z8 = 0
11780 FOR M = 1 TO 12
11790 N = Y(M)
11800 D1 = 23.45*SIN(360*(284+N)/(365*P2))
11810 W1 = -TAN(L/P2)*TAN(D1/P2)
11820 IF W1 > .999 THEN 11870
11830 IF W1 < -.999 THEN 11850
11840 GOTO 11890
11850 W1 = P1
11860 GOTO 11900
11870 Z(M) = 0
11880 GOTO 12040
11890 W1 = (P1/2) - ATN(W1/((1-W1^2)^.5))
11900 G = (24/P1)*I9*(1+.033*COS(360*N/(365*P2)))
11910 G = G * ( COS(L/P2)*COS(D1/P2)*SIN(W1)+W1*SIN(L/P2)*SIN(D1/P2) )
11920 K = H(M)/G
11930 D = 1.00 - 1.13*K
11940 W2 = -TAN((L-S)/P2)*TAN(D1/P2)
11950 W2 = (P1/2) - ATN(W2/((1-W2^2)^.5))
11960 IF W1 < W2 THEN 11990
11970 W3 = W2
11980 GOTO 12000
```

```
11990 W3 = W1
12000 J = COS((L-S)/P2)*COS(D1/P2)*SIN(W3) + W3*SIN((L-S)/P2)*SIN(D1/P2)
12010 J = J / ( COS(L/P2)*COS(D1/P2)*SIN(W1) + W1*SIN(L/P2)*SIN(D1/P2) )
12020 J(M) = (1-D)*J + D*(1+COS(S/P2))/2 + .2*(1-COS(S/P2))/2
12030 Z(M) = J(M)*H(M)
12040 Z8 = Z8 + Z(M)*N(M)
12050 NEXT M
12060 REM      I9 = SOLAR CONSTANT
12070 REM       N = DAY OF YEAR
12080 REM       S = COLLECTOR TILT ANGLE IN DEGREES
12090 REM      D1 = SOLAR DECLINATION ANGLE IN DEGREES
12100 REM      W1 = SUNSET ANGLE ON HORIZONTAL SURFACE IN RADIANS
12110 REM      W2 = SUNSET ANGLE ON TILTED SURFACE IN RADIANS
12120 REM      W3 = MINIMUM OF W1 AND W2
12130 REM       K = K SUB T
12140 REM       D = RATIO OF AVG HORIZ DIFFUSE TO AVG HORIZ TOTAL RADIATION
12150 REM       J = RATIO OF BEAM ON TILTED SURFACE TO BEAM ON HORIZ SURFACE
12160 REM    J(M) = RATIO OF AVG DAILY RADIATION ON TILTED TO HORIZ SURFACE
12170 REM    Z(M) = AVERAGE DAILY RADIATION ON TILTED SURFACE (BTU/SQFT*DAY)
12180 RETURN
12190 REM ************** SOLAR LOAD RATIO CALCULATION *********************
12200 REM
12210 REM     ENTER WITH COLLECTOR AREAEQUAL TO A9
12220 REM      EXIT WITH F9, Q(M), F(M), Q9, L9
12230 REM
12240      Q9 = 0
12250      IF J9 = 19 THEN 12920
12260      IF J9 > 12 THEN 12780
12270 REM *****  SYS 1 THRU SYS 12  DHW ONLY  *****
12280      S9 = Z8*A9/(1E6*K9)
12290     IF J8 > 1 THEN 12350
12300     IF S9 > C(1,1) THEN 12330
12310     K1 = C(1,2)*S9
12320     GOTO 12360
12330     K1 = 1 - C(1,3)*EXP(-C(1,4)*S9)
12340     GOTO 12360
12350      K1 = 1 - C(J8,1)*EXP(-C(J8,2)*S9) - C(J8,3)*EXP(-C(J8,4)*S9)
12360 ON J9 GOTO 12370,12400,12430,12460,12490,12520,12550,12580,12610,12640,12670,12700
12370      E1 = 7
12380      E2 = 11
12390      GOTO 12720
12400      E1 = 8
12410      E2 = 11
12420      GOTO 12720
12430      E1 = 9
12440      E2 = 11
12450      GOTO 12720
12460      E1 = 10
12470      E2 = 11
12480      GOTO 12720
12490      E1 = 7
12500      E2 = 12
12510      GOTO 12720
12520      E1 = 8
12530      E2 = 12
12540      GOTO 12720
12550      E1 = 9
12560      E2 = 12
12570      GOTO 12720
12580      E1 = 10
12590      E2 = 12
12600      GOTO 12720
12610      E1 = 7
12620      E2 = 13
12630      GOTO 12720
```

```
12640      E1 = 8
12650      E2 = 13
12660      GOTO 12720
12670      E1 = 9
12680      E2 = 13
12690      GOTO 12720
12700      E1 = 10
12710      E2 = 13
12720      K2 = 1 - C(8,1)*EXP(-C(8,2)*S9) - C(8,3)*EXP(-C(8,4)*S9)
12730      K3 = 1 - C(E1,1)*EXP(-C(E1,2)*S9) - C(E1,3)*EXP(-C(E1,4)*S9)
12740      K4 = 1 - C(E2,1)*EXP(-C(E2,2)*S9) - C(E2,3)*EXP(-C(E2,4)*S9)
12750      F9 = K1 + (K3-K2) + (K4-K2)
12760      Q9 = F9*K9
12770      RETURN
12780 REM ***** SYS 13 THRU SYS 18  SPACE + DHW COMBINED
12790      J7 = J9 + 1
12800      FOR M = 1 TO 12
12810        IF X(M) = 0 THEN 12870
12820        S(M) = Z(M)*A9*N(M)/(1E6*X(M))
12830        IF S(M) > C(J7,1) THEN 12860
12840        G(M) = C(J7,2)*S(M)
12850        GOTO 12870
12860        G(M) = 1 - C(J7,3)*EXP(-C(J7,4)*S(M))
12870        Q(M) = G(M)*X(M)
12880        Q9 = Q9 + Q(M)
12890      NEXT M
12900      F9 = Q9/X9
12910      RETURN
12920 REM *****  SYS 19 - SPACE HEATING RESIDENTIAL  *****
12930      FOR M = 1 TO 12
12940        G(M) = 0
12950        IF X(M) = 0 THEN 13010
12960        S(M) = Z(M)*A9*N(M)/(1E6*X(M))
12970        IF S(M) > 5.66 THEN 13000
12980        G(M) = 1.06 - 1.366*EXP(-.55*S(M)) + .306*EXP(-1.05*S(M))
12990        GOTO 13010
13000        G(M) = 1
13010        Q(M) = G(M)*X(M)
13020        Q9 = Q9 + Q(M)
13030      NEXT M
13040      F9 = Q9/X9
13050      RETURN
13060 REM *********** CHANGE UNITS FROM ENGLISH TOSI UNITS *****************
13070      U$(4) = "M2"
13080      U$(9) = "LITERS/DAY"
13090      U$(11) = "GJ/MONTH"
13100      U$(12)= "MJ/M2-DAY"
13110      U$(13) = "DEGREES C"
13120      U$(20) = "GJ/YEAR"
13130      U$(22) = "M2"
13140      U$(31) ="$/M2"
13150      D(4) = D(4)*.092903
13160      D(9) = D(9)*3.78544
13170      D(20) = D(20)*1.05506
13180      D(22) = D(22)*.092903
13190      D(31) = D(31)/.092903
13200      FOR I = 50 TO 54
13210        U$(I) = "$/GJ"
13220        D(I) = D(I)*(1/1.05506)
13230      NEXT I
13240      FOR M = 1 TO 12
13250        L(M) = L(M)*1.05506
13260        K(M) = K(M)*1.05506
13270        X(M) = X(M)*1.05506
13280        Q(M) = Q(M)*1.05506
13290        H(M) = H(M)/88.05
13300        Z(M) = Z(M)/88.05
13310      NEXT M
```

```
13320     N1 = (N1-32)*5/9
13330     N2 = (N2-32)*5/9
13340     N3 = (N3-32)*5/9
13350     N4 = (N4-32)*5/9
13360     FOR I = 1 TO 10
13370       A(I) = A(I)*.092903
13380     NEXT I
13390     A9 = A9*.092903
13400     A5 = A5*.092903
13410     A6 = A6*.092903
13420     A0 = A0*.092903
13430     K9 = K9*1.05506
13440     L9 = L9*1.05506
13450     X9 = X9*1.05506
13460     Q9 = Q9*1.05506
13470     Q4= Q4/1.05506
13480     RETURN
13490 REM *************** CHANGE UNITS FROM SI TO ENGLISHUNITS ************
13500     U$(4) = "SQFT"
13510     U$(9) = "GALLONS/DAY"
13520     U$(11) = "MMBTU/MONTH"
13530     U$(12) = "BTU/SQFT-DAY"
13540     U$(13) = "DEGREES F"
13550     U$(20) = "MMBTU/YEAR"
13560     U$(22) = "SQFT"
13570     U$(31) = "$/SQFT"
13580     D(4) = D(4)/.092903
13590     D(9) = D(9)/3.78544
13600     D(20) = D(20)/1.05506
13610     D(22) = D(22)/.092903
13620     D(31) = D(31)*.092903
13630     FOR I = 50 TO 54
13640       U$(I) = "$/MMBTU"
13650       D(I) = D(I)*1.05506
13660     NEXT I
13670     FOR M = 1 TO 12
13680       L(M) = L(M)/1.05506
13690       K(M) = K(M)/1.05506
13700       X(M) = X(M)/1.05506
13710       Q(M) = Q(M)/1.05506
13720       H(M) = H(M)*88.05
13730       Z(M) = Z(M)*88.05
13740     NEXT M
13750     N1 = (N1*9/5)+32
13760     N2 = (N2*9/5)+32
13770     N3 = (N3*9/5)+32
13780     N4 = (N4*9/5)+32
13790     RETURN
13800 REM ******************** LIFE CYCLE COST ANALYSIS ********************
13810 REM ------------------------ PART 1 OF LCCA ------------------------
13820     N5 = D(61)
13830     I5 = D(60)/100
13835     I6 = N5
13836     IF I5 = 0 THEN 13850
13840     I6 = (((1+I5)^N5)-1) / (I5*((1+I5)^N5))
13850     I7 = 1 / (1+I5)^N5
13860     GOSUB 13880
13870     GOTO 14030
13880 REM --------------- YEAR BREAKS FOR MPW FUEL FACTOR -----------
13890     IF N5 => 9 THEN 13990
13900     IF N5 => 4 THEN 13950
13910     M(1) = N5
13920     M(2) = 0
13930     M(3) = 0
13940     GOTO 14020
```

```
13950       M(1) = 4
13960       M(2) = N5 - 4
13970       M(3) = 0
13980       GOTO 14020
13990       M(1) = 4
14000       M(2) = 5
14010       M(3) = N5 - 9
14020       RETURN
14030 REM --------- REFERENCE SYSTEM ----------
14040       T5 = D(57)
14050 Q1 = D(49+T5)
14060       GOSUB 14260
14070       D1 = D
14080       M1 = D(47)*I6
14090       H1 = R(13)/((1+I5)^R(14))+R(15)/((1+I5)^R(16))+R(17)/((1+I5)^R(18))
14100       Z1 = D(49)*I7
14110 REM --------- AUXILIARY SYSTEM ----------
14120       T5 = D(56)
14130       Q2 = D(49+T5)
14140       GOSUB 14260
14150       D2 = D
14160       M2 = D(44)*I6
14170       H2 = R(7)/((1+I5)^R(8)) + R(9)/((1+I5)^R(10)) + R(11)/((1+I5)^R(12))
14180       Z2 = D(46)*I7
14190 REM -------- SOLAR SYSTEM --------------
14200       T5 = 1
14210       Q3 = D(50)
14220       GOSUB 14260
14230       D3 = D
14240       H3 = R(1)/((1+I5)^R(2)) + R(3)/((1+I5)^R(4)) + R(5)/((1+I5)^R(6))
14250       RETURN
14260 REM ------------ MOD NPW FACTOR FOR FUEL PRICE ----------------
14270       I(1) = E(T5,1)/100
14280       I(2) = E(T5,2)/100
14290       I(3) = E(T5,3)/100
14300       D = 0
14310       D5 = 1
14320       FOR J = 1 TO 3
14330       IF I(J) = I5 THEN 14360
14340 D4 = D5*((1+I(J))/(I5-I(J)))*((1+I5)^M(J)-(1+I(J))^M(J))/(1+I5)^M(J)
14350       GOTO 14370
14360       D4 = D5*M(J)
14370       D5 = D5*((1+I(J))/(1+I5))^M(J)
14380       D = D + D4
14390       NEXT J
14400       RETURN
14410 REM ----------- PART 2 OF LCCA ------------
14420 REM -------- REFERENCE SYSTEM ----------
14430       G1 = 100*Q1*X9*D1/D(7)
14440       J1 = D(34) + G1 + M1 + H1 - Z1
14450 REM -------- AUXILIARYSYSTEM ---------
14460       G2 = 100*Q2*(1-F9)*X9*D2/D(6)
14470       J2 = D(33) + G2 + M2 + H2 - Z2
14480 REM -------- SOLAR SYSTEM -------------
14490       P5 = D(30) + D(31)*A9
14500       P6 = (1-(D(32)/100))*P5
14510       E3 = D(8)*F9*X9/100
14520       G3 = Q3*E3*D3
14530       M3 = P5*D(40)*I6/100
14540     Z3 = D(42)*P5*I7/100
14550       J3 = P6 + G3 + M3 + H3 - Z3
14560       J4 = J2 + J3
14570       C9 = J1 - J4
14580       RETURN
```

```
14590 REM -------------- SET UP FOR ANNUAL DISC CASH FLOW
14600      X6 = 0
14610      FOR N5 = 1 TO D(61)
14620        GOSUB 13880
14630        GOSUB 14260
14640        B(N5) = D
14650      NEXT N5
14660      N5 = D(61)
14670      RETURN
14680 REM --------------- DISC CASH FLOW ---------------
14690      FOR I = 1 TO N5
14700      V(I) = 0
14710      NEXT I
14720      F1 = Q1*X9*100/D(7)
14730      F2 = Q2*(1-F9)*X9*100/D(6)
14740      F3 = Q3*F9*X9*D(8)/100
14750      X7 = D(34) - (D(33)+P6)
14760      T5 = D(57)
14770      GOSUB 14590
14780      FOR Y = 1 TO D(61)
14790        IF Y = 1  THEN V(1) = F1*B(1)
14800        IF Y > 1  THEN V(Y) = F1*(B(Y)-B(Y-1))
14810      NEXT Y
14820      T5 = D(56)
14830      GOSUB 14590
14840      FOR Y = 1 TO D(61)
14850        IF Y = 1  THEN V(1) = V(1) - F2*B(1)
14860        IF Y > 1  THEN V(Y) = V(Y) - F2*(B(Y)-B(Y-1))
14870      NEXT Y
14880      T5 = 1
14890      GOSUB 14590
14900      FOR Y = 1 TO D(61)
14910        IF Y = 1  THEN V(1) = V(1) - F3*B(1)
14920        IF Y > 1  THEN V(Y) = V(Y) - F3*(B(Y)-B(Y-1))
14930      NEXT Y
14940      FOR I = 2 TO 12 STEP 2
14950        IF R(I) = 0 THEN 14970
14960        V(R(I)) = V(R(I)) - R(I-1)/((1+I5)^R(I))
14970      NEXT I
14980      FOR I = 14 TO 18 STEP 2
14990        IF R(I) = 0 THEN 15010
15000        V(R(I)) = V(R(I)) + R(I-1)/((1+I5)^R(I))
15010      NEXT I
15020      FOR Y = 1 TO N5
15030        V(Y) = V(Y) + D(47)/((1+I5)^Y)
15040      NEXT Y
15050      FOR Y = 1 TO N5
15060        V(Y) = V(Y) - D(44)/((1+I5)^Y)
15070      NEXT Y
15080      FOR Y = 1 TO N5
15090        V(Y) = V(Y) - D(40)*(P5/100)/((1+I5)^Y)
15100      NEXT Y
15110      V(N5) = V(N5) + Z2 +Z3 - Z1
15120      RETURN
15130 REM ********************** FINANCE DETAIL ********************************
15140:* NET SAVINGS = $######### * AREA = ###### SQFT * SOLAR FRACTION = .### *
15150:* NET SAVINGS = $######### * AREA = ###### M2 * SOLAR FRACTION = .### *
15160 IF U$ = "E" THEN 15190
15170 PRINTUSING 15150,C9,A9*.092903,F9
15180 GOTO 15210
15190 PRINTUSING 15140,C9,A9,F9
15200 GOSUB 14680
```

```
15210 REM --------- SAVINGS TO INVESTMENT RATIO -----------
15220     R8 = (G1-G2-G3+M1-M2-M3)/(P6+D(33)-D(34)+Z1-Z2-Z3+H2+H3-H1)
15230      IF R8 > 0 THEN 15250
15240      R8 = 0
15250 REM --------- SIMPLE PAYBACK TIME -------------------
15260      F1 = Q1*X9*100/D(7)
15270      F2 = Q2*(1-F9)*X9*100/D(6)
15280      F3 = Q3*F9*X9*D(8)/100
15290      X8 = D(34) - ( D(33) + P6 )
15300      FOR Y = 1 TO N5
15310        O(Y) = (F1+D(47)) - (F2+D(44)) - (F3+D(40)*P5/100)
15320      NEXT Y
15330      FOR Y = 2 TO 12 STEP 2
15340        IF R(Y) = 0 THEN 15360
15350        O(R(Y)) = O(R(Y)) -R(Y-1)
15360      NEXT Y
15370      T2 = 0
15380      FOR Y = 14 TO 18 STEP 2
15390        IF R(Y) = 0 THEN 15410
15400        O(R(Y)) = O(R(Y)) + R(Y-1)
15410      NEXT Y
15420      Y = 0
15430      T2 = 0
15440      T1 = T2
15450      IF Y = 0 THEN  T2 = T2 + X8
15460      IF Y > 0 THEN  T2 = T2 + O(Y)
15470      IF T2 > 0 THEN 15510
15480      IF Y = N5 THEN 15530
15490      Y = Y + 1
15500      GOTO 15440
15510      P8 = Y - (T2/(T2-T1))
15520      GOTO 15550
15530      T2 = T2 - X8
15540      P8 = -X8/(T2/N5)
15550      O(N5) = O(N5) + D(46) + D(42)*P5/100 - D(49)
15560      IF M$ = "N" THEN 16520
15570     IF D(3) = 2 THEN 16520
15580      IF C9 => 0 THEN 16520
15590      IF D(56) <> D(57) THEN 16520
15600      IF D(70) = 1 THEN 16520
15610      IF D(70) = 3 THEN 16520
15620 REM ---------- BREAKEVEN FUEL PRICE --------
15630      N7 = Q2
15640      P4 = C9
15650      B3 = Q2
15660      B4 = B3 + N7
15670      P3 = P4
15680      Q1 = B4
15690      Q2 = B4
15700      IF D(56) > 1 THEN 15720
15710      Q3 = B4
15720      GOSUB 05750
15730      P4 = C9
15740      IF P4 > 0 THEN 15760
15750      GOTO 15650
15760       Q4 = B3 + ( -P3*(B4-B3)/(P4-P3) )
15770      Q1 = Q4
15780      Q2 = Q4
15790      IF D(56) > 1 THEN 15810
15800      Q3 = B4
15810      GOSUB 05750
15820      IF ABS(C9) < 1 THEN 15930
15830      P3 = C9
15840      B3 = Q4
15850      B4 = B3 - 2*C9*((B4-B3)/(P4-P3))
```

```
15860      Q1 = B4
15870      Q2 = B4
15880      IF D(56) > 1 THEN 15900
15890      Q3 = B4
15900      GOSUB 05750
15910      P4 = C9
15920      GOTO 15760
15930       REM
15940 REM --------- BREAKEVEN FUEL ESCALATION RATE ---------
15950      T5 = D(56)
15960      FOR I = 1 TO 3
15970        J(I) = E(T5,I)
15980      NEXT I
15990      A1 = Q4*D2
16000      A2 = 1
16010      A3 = 1.3*A2
16020      FOR I = 1 TO 3
16030        W(I) = A3*(J(I)+10)
16040        W(I) = W(I)-10
16050        I(I) = W(I)/100
16060      NEXT I
16070      GOSUB 14300
16080      IF N7*D => A1 THEN 16110
16090      A2 = A3
16100      GOTO 16010
16110      A4 = A3
16120      IF ABS(N7*D-A1) < .01 THEN 16230
16130      A3 = (A2+A4)/2
16140      FOR I = 1 TO 3
16150        W(I) = A3*(J(I)+10)
16160        W(I) = W(I)-10
16170        I(I) = W(I)/100
16180      NEXT I
16190       GOSUB 14300
16200      IF N7*D => A1 THEN 16110
16210      A2 = A3
16220      GOTO 16120
16230 REM -----------BREAKEVEN SYSTEMCOST ----------------
16240      A9 = A5
16250      P3 = C5
16260      GOSUB 13800
16270      S5 = D(30)
16280      S6 = D(31)
16290      Y1 = D(49+D(56))/Q4
16300      D(30) = S5*Y1
16310      D(31) = S6*Y1
16320      GOSUB 05750
16330      P4 = C9
16340      Y2 = 1 + P3*(1-Y1)/(P4-P3)
16350      P3 = P4
16360      D(30) = S5*Y2
16370      D(31) = S6*Y2
16380      GOSUB05750
16390      P4 = C9
16400      S7 = (Y1-Y2)/(P4-P3)
16410      Y1 = Y2 + P4*S7
16420      D(30) = S5*Y1
16430      D(31) = S6*Y1
16440      GOSUB 05750
16450      P3 = C9
16460      IF ABS(P3) < 1 THEN 16490
16470      Y2 = Y1 + 2*P3*S7
16480      GOTO 16360
16490      REM
16500      D(30) = S5
16510      D(31) = S6
16520      RETURN
```

APPENDIX B - MAP AND CODED LIST OF CITIES IN FEDSOL GEOGRAPHICAL DATA BANK

B.1 MAP OF CITIES IN GEOGRAPHICAL DATA BANK

B.2 CODED LIST OF CITIES IN FEDSOL GEOGRAPHICAL DATA BANK

City Code	City	State	Latitude
1	ADAK	AK	51.53
2	ANNETTE	AK	55.02
3	BARROW	AK	71.18
4	BETHEL	AK	60.47
5	BETTLES	AK	66.55
6	BIG DELTA	AK	64.00
7	FAIRBANKS	AK	64.49
8	GULKANA	AK	62.09
9	HOMER	AK	59.38
10	JUNEAU	AK	58.22
11	KING SALMON	AK	58.41
12	KODIAK	AK	57.45
13	KITZEBUE	AK	66.52
14	MCGRATH	AK	62.58
15	NOME	AK	64.30
16	SUMMIT	AK	63.20
17	YAKUTAT	AK	59.31
18	BIRMINGHAM	AL	33.34
19	MOBILE	AL	30.41
20	MONTGOMERY	AL	32.18
21	FORT SMITH	AR	35.20
22	LITTLE ROCK	AR	34.44
23	PHOENIX	AZ	33.26
24	PRESCOTT	AZ	34.39
25	TUSCON	AZ	32.07
26	WINSLOW	AZ	35.01
27	YUMA	AZ	32.40
28	ARCATA	CA	40.59
29	BAKERSFIELD	CA	35.25
30	CHINA LAKE	CA	35.41
31	DAGGETT	CA	34.52
32	EL TORO	CA	33.40
33	FRESNO	CA	36.46
34	LONG BEACH	CA	33.49
35	LOS ANGELES	CA	33.56
36	MOUNT SHASTA	CA	41.19
37	NEEDLES	CA	34.46
38	OAKLAND	CA	37.44
39	POINT MUGU	CA	34.07
40	RED BLUFF	CA	40.09
41	SACRAMENTO	CA	38.31
42	SAN DIEGO	CA	32.44
43	SAN FRANCISCO	CA	37.37
44	SANTA MARIA	CA	34.54
45	SUNNYVALE	CA	37.25
46	COLORADO SPRINGS	CO	38.49

City Code	City	State	Latitude
47	DENVER	CO	39.45
48	EAGLE	CO	39.39
49	GRAND JUNCTION	CO	39.07
50	PUEBLO	CO	38.17
51	HARTFORD	CT	41.56
52	WASHINGTON-STERLING	DC	38.57
53	WILMINGTON	DE	39.40
54	APALACHICOLA	FL	29.44
55	DAYTONA BEACH	FL	29.11
56	JACKSONVILLE	FL	30.30
57	MIAMI	FL	25.48
58	ORLANDO	FL	28.33
59	TALLAHASSEE	FL	30.23
60	TAMPA	FL	27.58
61	WEST PALM BEACH	FL	26.41
62	ATLANTA	GA	33.39
63	AUGUSTA	GA	33.22
64	MACON	GA	32.42
65	SAVANNAH	GA	32.08
66	BARBERS POINT	HI	21.19
67	HILO	HI	19.43
68	HONOLULU	HI	21.20
69	LIHUE	HI	21.59
70	BURLINGTON	IA	40.47
71	DES MOINES	IA	41.32
72	MASON CITY	IA	43.09
73	SIOUX CITY	IA	42.24
74	BOISE	ID	43.34
75	LEWISTON	ID	46.23
76	POCATELLO	ID	42.55
77	CHICAGO	IL	41.47
78	MOLINE	IL	41.27
79	SPRINGFIELD	IL	39.50
80	EVANSVILLE	IN	38.03
81	FORT WAYNE	IN	41.00
82	INDIANAPOLIS	IN	39.44
83	SOUTH BEND	IN	41.42
84	DODGE CITY	KS	37.46
85	GOODLAND	KS	39.22
86	TOPEKA	KS	39.04
87	WICHITA	KS	37.39
88	LEXINGTON	KY	38.02
89	LOUISVILLE	KY	38.11
90	BATON ROUGE	LA	30.32
91	LAKE CHARLES	LA	30.07
92	NEW ORLEANS	LA	29.59
93	SHREVEPORT	LA	32.28
94	BOSTON	MA	42.22
95	BALTIMORE	MD	39.11

City Code	City	State	Latitude
96	PATUXENT	MD	38.17
97	BANGOR	ME	44.48
98	CARIBOU	ME	46.52
99	PORTLAND	ME	43.39
100	ALPENA	MI	45.04
101	DETROIT	MI	42.25
102	FLINT	MI	42.58
103	GRAND RAPIDS	MI	42.53
104	HOUGHTON	MI	47.10
105	SAULT SAINT MARIE	MI	46.28
106	TRAVERSE CITY	MI	44.44
107	DULUTH	MN	46.50
108	INTERNATIONAL FALLS	MN	48.34
109	MINNEAPOLIS-ST. PAUL	MN	44.53
110	ROCHESTER	MN	43.55
111	COLUMBIA	MO	38.49
112	KANSAS CITY	MO	39.18
113	SPRINGFIELD	MO	37.14
114	ST. LOUIS	MO	38.45
115	JACKSON	MS	32.19
116	MERIDIAN	MS	32.20
117	BILLINGS	MT	45.48
118	CUT BANK	MT	48.36
119	DILLON	MT	45.15
120	GLASGOW	MT	48.13
121	GREAT FALLS	MT	47.29
122	HELENA	MT	46.36
123	LEWISTOWN	MT	47.03
124	MILES CITY	MT	46.26
125	MISSOULA	MT	46.55
126	ASHEVILLE	NC	35.26
127	CAPE HATTERAS	NC	35.16
128	CHARLOTTE	NC	35.13
129	CHERRY POINT	NC	34.54
130	GREENSBORO	NC	36.05
131	RALEIGH-DURHAM	NC	35.52
132	BISMARCK	ND	46.46
133	FARGO	ND	46.54
134	MINOT	ND	48.16
135	GRAND ISLAND	NE	40.58
136	NORTH OMAHA	NE	41.22
137	NORTH PLATTE	NE	41.08
138	SCOTTSBLUFF	NE	41.52
139	CONCORD	NH	43.12
140	LAKEHURST	NJ	40.02
141	NEWARK	NJ	40.42
142	ALBUQUERQUE	NM	35.03
143	CLAYTON	NM	36.27
144	FARMINGTON	NM	36.45

City Code	City	State	Latitude
145	ROSWELL	NM	33.24
146	TRUTH OR CONSEQUENCES	NM	33.14
147	TUCUMCARI	NM	35.11
148	ZUNI	NM	35.06
149	ELKO	NV	40.50
150	ELY	NV	39.17
151	LAS VEGAS	NV	36.05
152	LOVELOCK	NV	40.04
153	RENO	NV	39.30
154	TOWOPAH	NV	38.04
155	WINNEMUCCA	NV	40.54
156	YUCCA FLATS	NV	36.57
157	ALBANY	NY	42.45
158	BINGHAMPTON	NY	42.13
159	BUFFALO	NY	42.56
160	MASSENA	NY	44.56
161	NYC (CENTRAL PARK)	NY	40.47
162	NYC (LA GUARDIA)	NY	40.46
163	ROCHESTER	NY	43.07
164	SYRACUSE	NY	43.07
165	ADRON-CANTON	OH	40.55
166	CINCINNATI	OH	39.04
167	CLEVELAND	OH	41.24
168	COLUMBUS	OH	40.00
169	DAYTON	OH	39.54
170	TOLEDO	OH	41.36
171	YOUNGSTOWN	OH	41.16
172	OKLAHOMA CITY	OK	35.24
173	TULSA	OK	36.12
174	ASTORIA	OR	46.09
175	BURNS	OR	43.35
176	MEDFORD	OR	42.22
177	NORTH BEND	OR	43.25
178	PENDLETON	OR	45.41
179	PORTLAND	OR	45.36
180	REDMOND	OR	44.16
181	SALEM	OR	44.55
182	ALLENTOWN	PA	40.39
183	ERIE	PA	42.05
184	HARRISBURG	PA	40.13
185	PHILADELPHIA	PA	39.53
186	PITTSBURGH	PA	40.30
187	WILKES-BARRE-SCRANTON	PA	41.20
188	PROVIDENCE	RI	41.44
189	CHARLESTON	SC	32.54
190	COLUMBIA	SC	33.57
191	GREENVILLE-SPARTANBURG	SC	34.54
192	HURON	SD	44.23
193	PIERRE	SD	44.23

City Code	City	State	Latitude
194	RAPID CITY	SD	44.03
195	SIOUX FALLS	SD	43.34
196	CHATTANOOGA	TN	35.02
197	KNOXVILLE	TN	35.49
198	MEMPHIS	TN	35.03
199	NASHVILLE	TN	36.07
200	ABILENE	TX	32.26
201	AMARILLO	TX	35.14
202	AUSTIN	TX	30.18
203	BROWNSVILLE	TX	25.54
204	CORPUS CHRISTI	TX	27.46
205	DALLAS	TX	32.51
206	DEL RIO	TX	29.22
207	EL PASO	TX	31.48
208	FORT WORTH	TX	32.50
209	HOUSTON	TX	29.59
210	KINGSVILLE	TX	27.31
211	LAREDO	TX	27.32
212	LUBBOCK	TX	33.39
213	LUFKIN	TX	31.14
214	MIDLAND-ODESSA	TX	31.56
215	PORT ARTHUR	TX	29.57
216	SAN ANGELO	TX	31.22
217	SAN ANTONIO	TX	29.32
218	SHERMAN	TX	33.43
219	WACO	TX	31.37
220	WICHITA FALLS	TX	33.58
221	BRYCE CANYON	UT	37.42
222	CEDAR CITY	UT	37.42
223	SALT LAKE CITY	UT	40.46
224	NORFOLK	VA	36.54
225	RICHMOND	VA	37.30
226	ROANOKE	VA	37.19
227	BURLINGTON	VT	44.28
228	OLYMPIA	WA	46.58
229	SEATTLE-TACOMA	WA	47.27
230	SPOKANE	WA	47.38
231	WHIDBEY ISLAND	WA	48.21
232	YAKIMA	WA	46.34
233	EAU CLAIRE	WI	44.52
234	GREEN BAY	WI	44.29
235	LA CROSSE	WI	43.52
236	MADISON	WI	43.08
237	MILWAUKEE	WI	42.57
238	CHARLESTON	WV	38.22
239	HUNTINGTON	WV	38.22
240	CASPER	WY	42.55
241	CHEYENNE	WY	41.09
242	ROCK SPRINGS	WY	41.36
243	SHERIDAN	WY	44.46

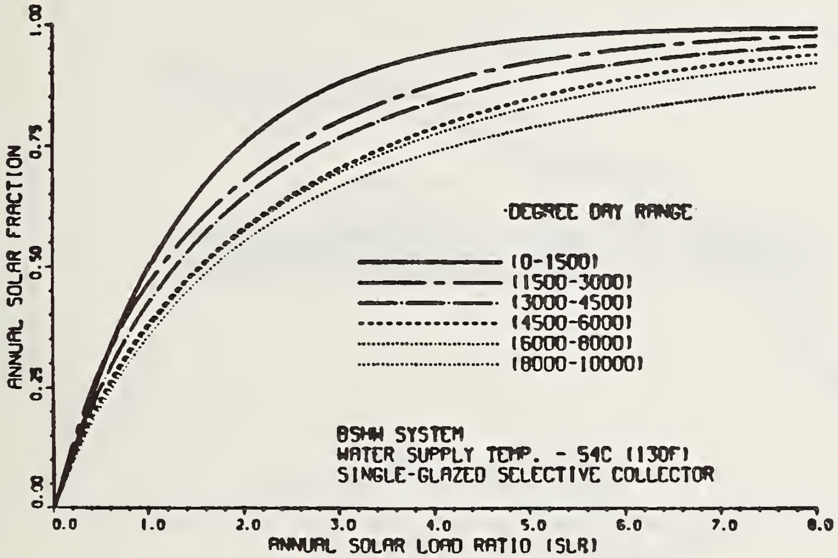
APPENDIX C - DISCOUNT FORMULAS*

Nomenclature	Use When	Algebraic Form
Single Present Worth (SPW)	Given a future sum of money expressed in current (future year) dollars; to find a present sum of money	$SPW = \frac{1}{(1+d)^n}$
Uniform Present Worth (UPW)	Given a uniform annual, end-of-period payment; to find a present sum of money	$UPW = \frac{(1+d)^n - 1}{d\,(1+d)^n}$
Modified Uniform Present Worth (UPW*)	Given an annual end-of-period payment, escalating at an annual rate of e_1 for the first n_1 years, e_2 for the next n_2 years, and e_3 for the last n_3 years; to find a present sum of money	see below

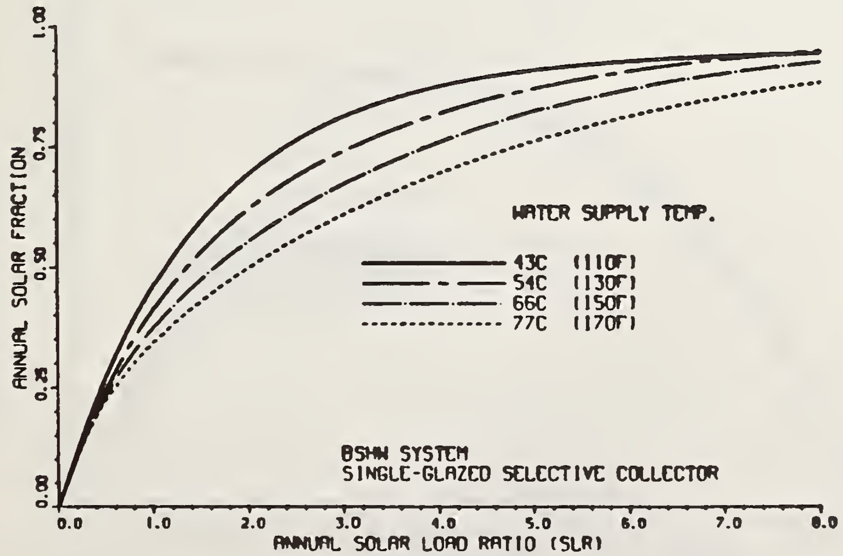
$$UPW^* = \left(\frac{1+e_1}{d-e_1}\right) \cdot \left[1 - \left(\frac{1+e_1}{1+d}\right)^{n_1}\right]$$
$$+ \left(\frac{1+e_2}{d-e_2}\right) \cdot \left[1 - \left(\frac{1+e_2}{1+d}\right)^{n_2}\right] \cdot \left(\frac{1+e_1}{1+d}\right)^{n_1}$$
$$+ \left(\frac{1+e_3}{d-e_3}\right) \cdot \left[1 - \left(\frac{1+e_3}{1+d}\right)^{n_3}\right] \cdot \left(\frac{1+e_2}{1+d}\right)^{n_2} \cdot \left(\frac{1+e_1}{1+d}\right)^{n_1}$$

* d = the discount rate, and n = the number of periods (years).

APPENDIX D - THE SOLAR LOAD RATIO DESIGN METHOD: PERFORMANCE CURVES AND SCHEMATIC DIAGRAMS

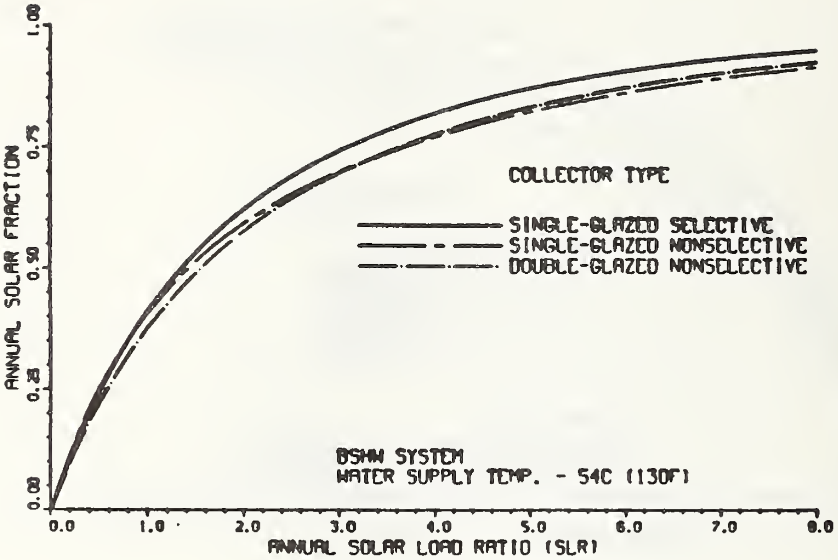


D.1 Design Curves for Various Degree-Day Ranges, Service Hot Water Only, Commercial Buildings

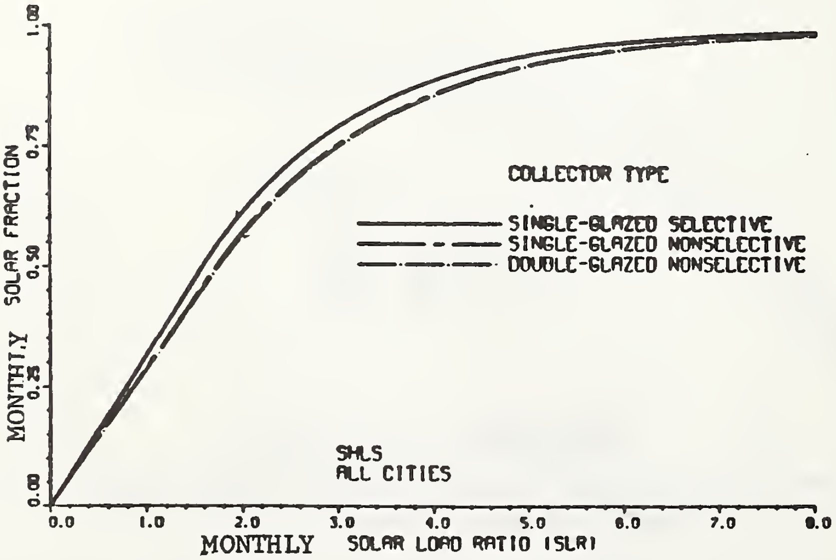


D.2 Design Curves for Various Delivery Temperatures, Service Hot Water Only, Commercial Buildings

SOURCE: "The Solar Load Ratio Method Applied to Commercial Building Active System Sizing" [3].

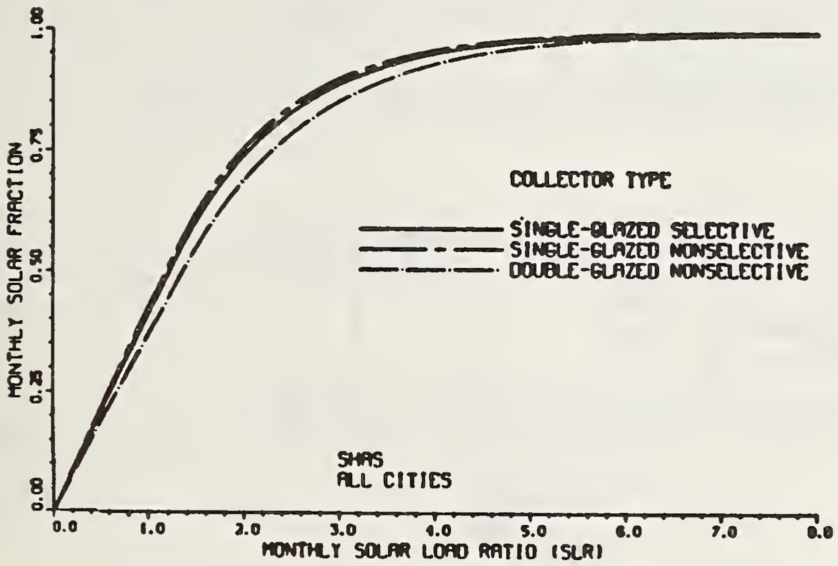


D.3 Design Curves for Various Collector Types, Service Hot Water Only, Commercial Buildings

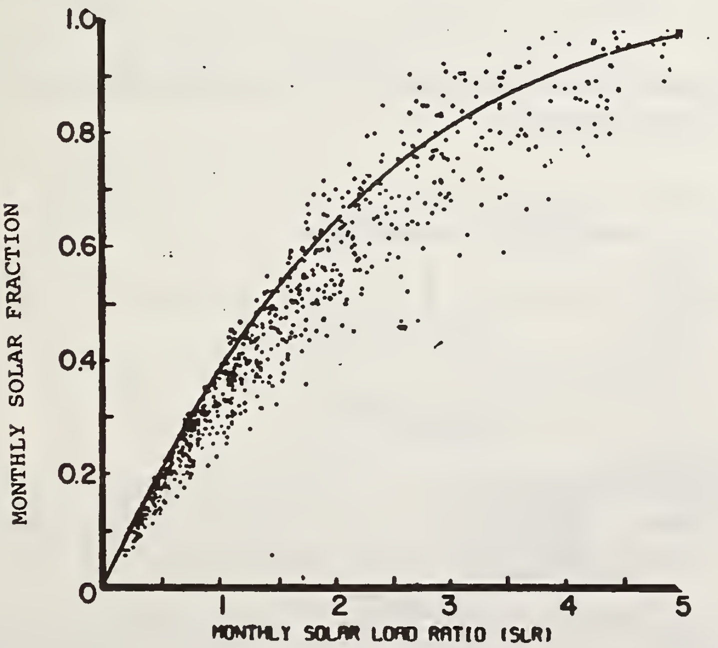


D.4 Design Curves for Various Collector Types, Space Heating, Liquid Systems, in Commercial Buildings

SOURCE: "The Solar Load Ratio Method Applied to Commercial Building Active System Sizing" [3].



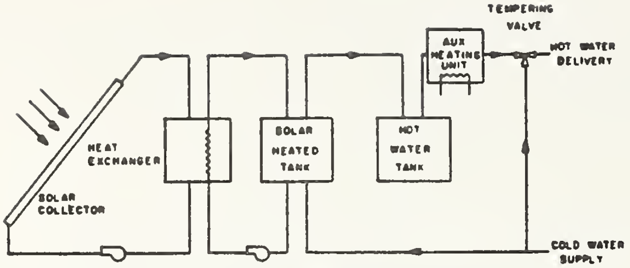
D.5 Design Curves for Various Collector Types, Space Heating, Air Systems, in Commercial Buildings[a]



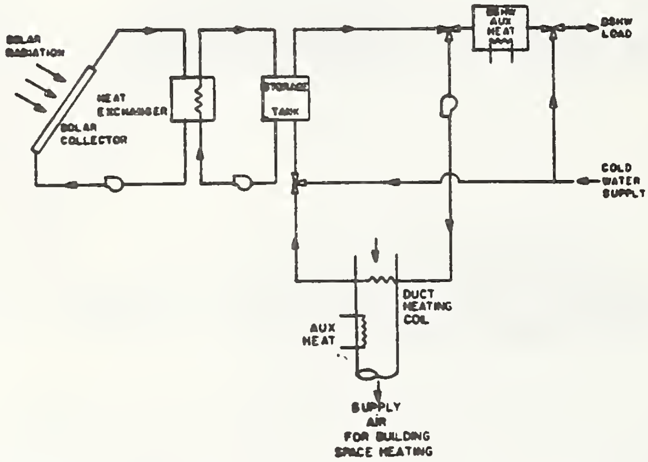
D.6 Design Curve for Space Heating System, Residential Building[b]

[a]SOURCE: "The Solar Load Ratio Method Applied to Commercial Building Active System Sizing" [3].

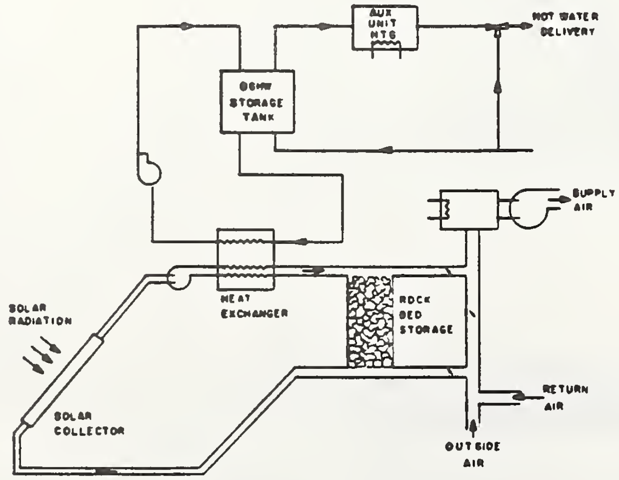
[b]SOURCE: ERDA'S Pacific Regional Solar Design Handbook [21].



D.7 Schematic Diagram of Standard Service Hot Water Systems



D.8 Schematic Diagram of Standard Space Heating (or Combined Space and Service Water Heating) Liquid System



D.9 Schematic Diagram of Standard Space Heating (or Combined Space and Service Water Heating) Air System

SOURCE: "The Solar Load Ratio Method Applied to Commercial Building Active System Sizing" [3].

APPENDIX E - ILLUSTRATIONS AND EXPLANATIONS OF KEY ALGORITHMS

E.1 CALCULATION OF AVERAGE SOLAR RADIATION ON A TILTED SURFACE

In order to use the Solar Load Ratio (SLR) design method, or other methods based on monthly calculations, such as F-CHART, it is necessary to estimate the solar radiation incident on the collector surface monthly, from average daily values. The total solar radiation incident on any surface is the sum of the direct beam, diffuse, and reflected components. The radiation model used in FEDSOL to calculate monthly values for the average daily total radiation is that devised by Liu and Jordan and improved upon by Page and Klein [30]. It is limited to south-facing surfaces.

The only data required by this model are: 1) the slope of a collector surface, 2) the ground reflectance near the collector, 3) the monthly average daily total horizontal solar radiation (measured), and 4) the latitude of the site. This model is summarized below:

Let

$\overline{H}_T$ = total monthly average daily solar radiation on a tilted surface, and

$\overline{H}_T = \overline{R} \cdot \overline{H}$,

where

$\overline{H}$ = monthly average daily total solar radiation on the horizontal surface,

$\overline{R}$ = ratio of the monthly average total daily solar radiation on a tilted surface to that on a horizontal surface, and

$$\overline{R} = (1 - (\overline{H}_D/\overline{H}))\overline{R}_B + (\overline{H}_D/\overline{H})\ [1 + \cos(S)]/2 + \rho\ [1 - \cos(S)]/2.$$

Then:

$\overline{H}(1 - (\overline{H}_D/\overline{H}))\overline{R}_B$ = monthly average daily beam component on a tilted surface,

$\overline{H}(\overline{H}_D/\overline{H})[1 + \cos(S)]/2$ = monthly average daily diffuse component on a tilted surface, and

$\overline{H} \cdot \rho[1 - \cos(S)]/2$ = monthly average daily reflected component on a tilted surface.

The monthly average total daily solar radiation, $\overline{H}$, has been measured for over 250 sites around the United States. The solar radiation data used by FEDSOL was obtained from Input Data for Solar Systems [22].

FEDSOL uses the value of 0.2 for ground reflectance, ρ. This value may tend to underestimate incident radiation on tilted collectors at sites where there is snow cover during winter months. However, the error should be small and may be expected to result in only a slightly conservative estimate of solar fraction.

$(\overline{H}_D/\overline{H})$ and $\overline{R}_B$ are calculated with the following equations:

$(\overline{H}_D/\overline{H})$ = ratio of monthly average daily diffuse radiation to daily average total radiation on a horizontal surface,

$(\overline{H}_D/\overline{H})$ = $1 - 1.13\ \overline{K}_T$,

$\overline{R}_B$ = ratio of monthly average daily beam radiation on a tilted surface to daily beam radiation on a horizontal surface,

$$\overline{R}_B = \frac{\cos(L-S)\ \cos(\delta)\ \sin(\omega_s') + \omega_s'\ \sin(L-S)\ \sin(\delta)}{\cos(L)\ \cos(\delta)\ \sin(\omega_s) + \omega_s\ \sin(L)\ \sin(\delta)}$$

where

S = slope of collector surface (tilt angle),

L = latitude,

δ = solar declination angle,

δ = $23.45\ \sin[360(284+n)/365]$,

n = day of the year,

$\overline{K}_T$ = ratio of monthly average daily total radiation to the extraterrestrial daily solar radiation (both horizontal),

$\overline{K}_T$ = $\overline{H}/(H_o)_n$,

$(H_o)_n$ = extraterrestrial daily solar radiation on a horizontal surface on day n,

$(H_o)_n$ = $(24/\pi)I_{sc}\ [1+.033\cos(360n/365)]\ [\cos(L)\cos(\delta)\cos(\omega_s) + \omega_s\sin(L)\ \sin(\delta)]$,

I_{sc} = solar constant (1353 watts/sq. meter),

ω_s = sunset hour angle on horizontal plane, radians,

ω_s = $\arccos\ [\ -\ \tan(L)\tan(\delta)\ ]$,

ω_s' = sunset hour angle on tilted surface, radians, and

ω_s' = minimum of ω_s and $\arccos\ [\ -\ \tan(L-S)\tan(\delta)\ ]$.

In order to evaluate $\overline{K}_T$, and therefore $(\overline{H}_D/\overline{H})$, it is necessary to know the average monthly extraterrestrial radiation. The equation above for $(H_o)_n$ calculates the value for only one day of the year. It is necessary either to calculate $(H_o)_n$ for each day of the month and average all the days to one average monthly value or to use a day within the month which yields a value near the average value. Klein has determined that the following days give good results:

month		Julian Day
Jan	-	17
Feb	-	47
Mar	-	75
Apr	-	105
May	-	135
Jun	-	162
Jul	-	198
Aug	-	228
Sep	-	258
Oct	-	288
Nov	-	318
Dec	-	344

As described for FEDSOL, this method is designed for collectors facing due south. However, collectors which face within 20 degrees east or west of south can be evaluated with this radiation model without significant error.

E.2. CALCULATION OF RANGE OF SYSTEM SIZES AND SOLAR FRACTIONS

OVERVIEW:

The table of solar fractions and net savings for a range of system sizes included in the FEDSOL program output is derived using a mathematical model that combines elements of the GFL(G-CHART) design method [31] with the SLR design method [3, 19, 21] taking advantage of the simplicity of the annual methods such as the former and the greater flexibility and accuracy of monthly analysis methods such as the SLR or F-CHART.

A primary assumption of the GFL method, as derived by Lameiro and Bendt, is that the annual performance (annual solar fraction, f_a) for any active solar energy system for service hot water, space heating, or combination thereof, can be described by the following equation [31]:

$$f_a = 1 - e^{-(RA + SA^2)} \tag{E.2.1}$$

where A is the collector area and R and S are constants that can be calculated. If one knows the annual solar fractions associated with any two collector areas for a system, the SLR method can be used to generate two initial predictions of annual solar fraction. These two pairs of collector areas and annual solar fractions are then employed to calculate R and S, and finally an expression is developed to determine the area required to give any desired solar fraction (see eq. (E.2.5)). Lastly, the SLR method is employed to obtain more accurate annual solar fraction solutions for the collector areas identified with GFL method.

By expressing the annual solar fraction as a function of collector area, one can print a table of system sizes and solar fractions (as in the FEDSOL program output) or plot a curve of solar fraction vs. collector area. Moreover, when combined with a model for life-cycle cost analysis, the model provides the basis for a very fast method of calculating the economically optimal collector area.

SHW SYSTEMS (TYPES 1 - 12)

Earlier versions of the SLR method and the initial version of the FEDSOL program expressed the monthly solar fraction of SHW (service hot water) systems as a function of the monthly SLR. The annual solar fraction was calculated from the results of the twelve monthly calculations.

The recently revised SLR method expresses the annual solar fraction for service hot water only systems as a function of the annual SLR [3]. With this revised method, it is possible to calculate the annual solar fraction directly from the annual SLR and, hence, from the collector area. However, the combined GFL - SLR approach was still useful in generating a series of collector areas, solar fractions, and net savings values for which solar fractions are evenly spaced over a range from 10 percent to 90 percent.

The SLR annual solar fraction equation for SHW systems has the form

$$f_a = 1 - a_1 e^{-a_2 x_a} - a_3 e^{-a_4 x_a} , \qquad (E.2.2)$$

where

f_a = annual solar fraction,

x_a = annual solar load ratio = $A_c\ H_a/Q_a$,

A_c = collector area,

H_a = solar energy per unit area incident annually on the plane of the collector, and

Q_a = annual SHW load.

In order to calculate the area required to produce a desired solar fraction, one may guess an area, solve equation (E.2.2) to obtain a solar fraction, guess a new area larger or smaller depending on the outcome of the first guess, and solve the equation again, until the area which gives the desired solar fraction is found. An alternative method, that adopted in FEDSOL, is to solve equation (E.2.2) for x_a and hence A_c. Unfortunately, it is not a simple matter to solve this equation for x_a as a function of f_a. However, for reasons which will become obvious later, it is necessary only to solve the equation for f_a equal to .5. This has been done by expanding a Taylor's series about a = 1.4, using only the first three terms of the series to approximate the function f_a when the value of f_a is near 0.5:

$$f_a(x_a) = 1 - a_1 e^{-1.4a_2} - a_3 e^{-1.4a_4} + [a_1 a_2 e^{-1.4a_2} + a_3 a_4 e^{-1.4a_4}]\ (x_a - 1.4)$$
$$+ .5\ [a_1 a_2 e^{-1.4a_2} + a_3 a_4 e^{-1.4a_4}]\ (x_a - 1.4)^2 .$$

Setting f = .5 and solving for x_a gives

$$x_a = \frac{[- B + (B^2 - 4AC)^{.5}]}{2A} + 1.4 ,$$

where

$$A = .5\ [\ a_1 a_2 e^{-1.4a_2} + a_3 a_4 e^{-1.4a_4}] ,$$

$$B = a_1 a_2 e^{-1.4a_2} + a_3 a_4 e^{-1.4a_4} , \text{ and}$$

$$C = .5 - a_1 e^{-1.4a_2} - a_3 e^{-1.4a_4} ,$$

and

$x_a \quad = \quad A_c \; H_a/Q_a$ and

$A_{50} \quad = \quad x_a \; Q_a/H_a$

because x_a was solved for $f = 0.5$.

We now have a good estimate of the collector area which will give this system a 50 percent solar fraction. This value, A_{50}, is put into equation (E.2.2) and the equation is solved for f_a. The value of f_a will be close to .5, which is all that is necessary at this point. The area (A_{50}) and its corresponding solar fraction are denoted as A_1 and F_1 respectively. Another area, A2, is obtained by multiplying A_1 by 8. There is nothing special about the number 8 except that it causes A2 to be significantly larger than A_1. (Smaller numbers cause computational problems at a later point in the procedure.) The new area A2 is put into equation (E.2.2) and the equation is solved again for f_a. The solar fraction associated with area A2 is labeled F2. Recalling equation (E.2.1) and expressing it as two equations with two unknowns:

$$F1 = 1 - e^{-(RA1 + SA1^2)}, \text{ and}$$

$$F2 = 1 - e^{-(RA2 + SA2^2)}.$$

The two equations can be solved for R and S:

$$R = \frac{A1^2 \; [\; -\ln(1-F2) \;] \; - \; A2^2 \; [\; -\ln(1-F1) \;]}{A1^2A2 \; - \; A1 \; A2^2}, \text{ and} \tag{E.2.3}$$

$$S = \frac{A2 \; [\; -\ln(1-F1) \;] \; - \; A1 \; [\; -\ln(1-F2) \;]}{A1^2A2 \; - \; A1 \; A2^2}. \tag{E.2.4}$$

Finally solving equation (E.2.1) for A gives

$$A_c = \frac{-S + [S^2 - 4 \; R \; \ln(\; 1/(1-f_a) \;) \;]^{.5}}{2 \; R}. \tag{E.2.5}$$

Once S and R have been calculated for a specific solar energy system, it becomes a quick matter to determine the collector area which will give any desired solar fraction. For example, if a system with a solar fraction of .65 were desired, equation (E.2.5) would be solved simply with f_a=.65 to determine the required area (A_c).

The FEDSOL program uses the above method to predict collector areas corresponding to annual solar fractions of .1, .2, 3, up to .9. Each collector area predicted with this method is then put into equation (E.2.2) to obtain the exact annual solar fraction according to the SLR method.

SPACE HEATING SYSTEMS (TYPES 13 - 19)

The SLR design for space heating systems does not give annual results directly. Calculations must be performed monthly and the annual solar fraction determined from those results. The same is true with F-CHART. The following method is particularly useful for this situation.

The SLR method for space heating systems calculates monthly solar fractions with the following equations

$$f_m = b_1 x_m \qquad \text{for } 0 < x_m < b_2 \text{, and} \tag{E.2.6a}$$

$$f_m = 1 - b_3 e^{-b_4 x_m} \qquad \text{for } x_m > b_2, \tag{E.2.6b}$$

where

f_m = monthly solar fraction,

x_m = monthly solar load ratio = $A_c\ \overline{H}_T/Q_m$,

A_c = collector area,

$\overline{H}_t$ = solar energy per unit area incident monthly on the plane of the collector, and

Q_m = monthly load.

It is possible to solve equation (E.2.6b) for x_m in terms of f_m. Recalling that $x_m = \overline{H}_T\ A_c/Q_m$, the following equation will predict the area required to give any specified monthly solar fraction:

$$A_c = \frac{Q_m \cdot \ln\left(b_3/(1-f_m)\right)}{b_4\ \overline{H}_T}\ .$$

However, an annual, not a monthly fraction is needed. Drawing on past experience, we know that if a space heating system has an annual solar fraction near 50 percent, the average of the February and March monthly fractions is in nearly all cases within 1 percent of 50 percent. This observation is exploited here. For simplicity, we assume that the collector that provides a solar fraction of 50 percent in March will also give approximately a 50 percent solar fraction on an annual basis:

$$A_c = \frac{Q_{Mar}\ \ln(2 \cdot b_3)}{b_4\ \overline{H}_{T\ Mar}}\ .$$

We call this area A1. Area A1 is evaluated with the SLR subroutine for twelve months to determine an annual solar fraction F1. Then area A1 is multiplied by

8, as before, to yield the new area A2. Area A2 is evaluated with the SLR subroutine for twelve months and an annual solar fraction F2 determined, also as before. Again, we have two equations and two unknowns:

$$F1 = 1 - e^{-(RA1 + SA1^2)}, \text{ and}$$

$$F2 = 1 - e^{-(RA2 + SA2^2)},$$

and these equations are solved for R and S as before:

$$R = \frac{A1^2 [-\ln(1-F2)] - A2^2 [- \ln(1-F1)]}{A1^2A2 - A1\ A2^2}, \text{ and}$$

$$S = \frac{A2 [-\ln(1-F1)] - A1 [-\ln(1-F2)]}{A1^2A2 - A1\ A2^2},$$

Solving equation E.2.1 for A_c yields

$$A_c = \frac{-S + (S^2 - 4\ R \ln(1/(1-f_a))]^{.5}}{2R}.$$

We then determine the areas corresponding to the series of solar fractions .1, .2, .3, up to .9, and submit each of these areas to the SLR subroutine for a more exact prediction based on monthly calculations.

APPENDIX F - CONVERSION FACTORS FOR THE MOST COMMON UNITS USED IN SOLAR ENERGY SYSTEM DESIGN AND EVALUATION

Length:	1 inch (in) = 25.4 millimeters (mm) 1 foot (ft) = 0.3048 meter (m)
Area:	1 ft^2 = 0.092903 m^2
Volume:	1 ft^3 = 0.028317 m^3
Fluid Capacity:	1 gallon (gal) = 3.78541 liters (L)
Temperature:	1°F = 9/5°C + 32
Temperature Interval:	1°F = 5/9°C or K
Mass:	1 pound (lb) = 0.453592 kilogram (kg)
Mass per unit length:	1 lb/ft = 1.48816 kg/m
Mass per unit area:	1 lb/ft^2 = 4.88243 kg/m^2
Mass per unit volume:	1 lb/ft^3 = 16.0185 kg/m^3
Energy:	1 Btu = 1.05506 kilojoules (kJ)
Heat flow rate:	1 Btu/h = 0.293071 Watt (W)
Specific heat:	1 Btu/(lb)(°F) = 4.1868 kJ/(kg)(K)
U-value:	1 Btu/(ft^2)(h)(°F) = 5.67826 W/(m^2)(K)
Energy per unit area:	1 Btu/ft^2 = 0.011357 MJ/m^2

APPENDIX G - RANGE OF ACCEPTABLE VALUES FOR INPUT DATA

DATA ITEM	MINIMUM VALUE (SI)	MAXIMUM VALUE (SI)
1	1	19
2	0	90
3	1	2
4	0	1,000,000
5	0	100
6	0	1,000
7	0	1,000
8	0	100
9	0	1,000,000
10	1	7
11	0	10,000,000
12	0	3,000
13	33(5/8)	212(100)
20	0	1,000,000
21	0	100
22	0	1,000,000
23	0	100
24	0	100
25	0	100
30	0	100,000,000
31	0	10,000
32	0	100
33	0	100,000,000
34	0	100,000,000
40	0	100
41	0	100,000,000
42	0	100
44	0	10,000,000
45	0	100,000,000
46	0	100,000,000
47	0	10,000,000
48	0 year $\leq$ study period	100,000,000
49	0	100,000,000
50	0	1,000
51	0	1,000
52	0	1,000
53	0	1,000,000
54	0	1,000
55	0	1,000
56	1	6
57	1	6
58	any number (+/-)	
60	0	100
61	1	40
70	1	3

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report provides a user's manual for the FEDSOL computer program and a guide for designing and sizing solar energy projects for Federal buildings. The life-cycle cost procedures implemented by the computer program and explained in the report are consistent with the Federal Rules for Life-Cycle Costing (10 CFR Part 436) as applied to solar energy projects.

The FEDSOL program determines the economically optimal size of a solar energy system for a user-specified building, location, system type, and set of economic conditions; it conducts numerous breakeven and sensitivity analyses; and it calculates measures of economic performance as required under the Federal Rules. The economic model in the program is linked with the SLR (Solar Load Ratio) design method developed at Los Alamos National Laboratory to predict the performance of active systems. The economics portion of the program can, however, be used apart from the SLR method, with performance data provided by the user. An environmental data file for 243 U.S. cities is included in the program. Highly user oriented, the FEDSOL program is intended as a design and sizing tool for use by architects, engineers, and facilities managers in developing plans for Federal solar energy projects.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

economic optimization; life-cycle costing; solar economics; solar energy.

13. AVAILABILITY

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