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Solcom: A Computer Program to Integrate Solar and Conservation Economics For New Commercial Buildings

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SOLCOM: A COMPUTER PROGRAM TO INTEGRATE SOLAR AND CONSERVATION ECONOMICS FOR NEW COMMERCIAL BUILDINGS

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
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ABSTRACT

This report provides a methodology, algorithms and a computer program for determining the minimum life-cycle cost combination of three interdependent conservation strategies in new commercial buildings. These three strategies consist of (1) envelope modifications to reduce seasonal and peak load heating and cooling requirements, (2) heating and cooling plant modifications to increase their seasonal efficiency, and (3) the use of an active solar space and water heating system. The resulting computer program, called SOLCOM, can be run on a microcomputer in three stages.

The SOLCOM program performs a complete life-cycle cost analysis for the active solar system and for each envelope and plant modification to be considered, including tax and mortgage effects. The program then determines the optimal overall conservation investment strategy, including envelope modifications and the corresponding seasonal and peak load heating and cooling requirements; space heating, water heating, and space cooling plant efficiencies; and collector size for the active solar heating system.

Key words: building economics, commercial buildings; energy conservation; engineering economics; heating and cooling equipment; heating and cooling loads; life-cycle cost analysis; optimization algorithms; solar heating.

PREFACE

This report describes a computer program, developed at the National Bureau of Standards, for the simultaneous optimization of a number of interdependent energy-conservation-related investments in new commercial buildings. At present, this computer program, called "SOLCOM", is still experimental in nature. It has not been field tested in actual building design exercises. While the SOLCOM program provides a technically sound basis for the application of a microcomputer to complex economic decisions in new buildings, some improvements may be needed to make the program more user oriented. Use of the SOLCOM program in actual building design problems must be made at the users own risk.

For a limited time, NBS will provide a copy of the SOLCOM program, for experimentation and field testing use, by written request if accompanied by a 5 1/4-in "floppy" disk (compatible with the Radio Shack TRS-80 model III microcomputer) and a self-addressed return envelope. Requests should be addressed to:

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1. INTRODUCTION

The large number of design measures for reducing purchased energy use in new commercial buildings can make the final design decision a difficult one. There are literally hundreds of different energy-conserving methods that can be incorporated into a new building design, from insulation to energy management systems. The designer seeks the optimal combination of these measures -- not only in terms of today's energy market, but in terms of his projection of the future energy market as well. Failure to plan for the future during the design stage could significantly reduce the economic life of a building. While retrofitting of the building with additional energy conservation features at some point in time may stave off economic obsolescence, these same features can usually be incorporated into the original design at considerably lower cost.

Economic analysis plays an important role in the building design process by providing systematic and objective decision-making methods for evaluating energy-saving measures in new buildings. For example, life-cycle cost methods can be used to determine which of several alternatives is least expensive in doing a certain job (e.g., reducing heat loss or heat gain through windows to a specified rate), not only in terms of initial cost but also in terms of maintenance, repair and replacement costs over the building life. Economic analysis can also be used with life-cycle costs and benefits to help to determine how much of a particular conservation measure should be used, (e.g., how much insulation should be used in exterior walls). Ultimately, these same analytical methods can be used to determine the economically optimal combination of all conservation measures to be incorporated into the building design. The economically optimal combination of conservation measures is defined here as that combination of measures which minimizes total present-value, energy-related costs over the life of the building (or over a specified study period), while satisfying required building performance objectives (e.g., thermal comfort and design aesthetics).

Design measures for conserving energy in new buildings can be classified into four general categories, each of which competes somewhat with the others in reducing purchased energy requirements:

(1) envelope or other structural modifications which reduce end-use energy requirements (e.g., space heating and cooling requirements),

(2) equipment modifications which increase the efficiency of energy conversion to its end use form,

(3) renewable energy systems which substitute "free" energy available at the building site (e.g., solar and wind power) for purchased energy usage, and

(4) energy management systems to cut back or shut down energy using systems when demand is reduced or eliminated during certain hours of the day or days of the week.

This report explicitly addresses economic optimization procedures for the first three of these design categories, specifically with regard to space heating, space cooling, and service water heating. The fourth category essentially establishes the operational profile for which the first three categories of conservation measures must be evaluated. As such, energy management systems are not explicitly considered as a design variable to be optimized in this report.

A major obstacle to the determination of an overall minimum life-cycle cost design is the functional interdependence among the first three of these competing approaches to energy conservation. For example, as the envelope of the building is tightened up to reduce space heating loads, smaller purchased energy savings are attributable to improvements in the heating plant efficiency, or to the addition of a solar heating system. The substitution of solar heating for conventional heating results in smaller operating cost savings from both envelope and conventional equipment improvements. And efficiency improvements to conventional space heating equipment reduce the energy-saving benefits from improvements in the building envelope and solar heating system. Determining the optimal allocation of conservation investment among these three categories must be undertaken simultaneously. This requires a systematic procedure that can be employed within a reasonable amount of time and with a reasonable amount of effort.

The purpose of this report is to provide a methodology, algorithms, and a supporting computer program that can be used by building design professionals to determine the optimal amount of conservation investment to be made in each of these three competing conservation categories. The resulting computer program, called SOLCOM, is primarily intended for use as a design tool for new commercial buildings with active solar space and water heating equipment. However, it can be used in the analysis of residential building designs with active solar heating equipment as well. SOLCOM integrates a wide range of building and component performance data, cost data and financial analysis criteria for a specific building design. It then determines the economically optimal combination of conservation measures, including envelope conservation features, conventional space heating, water heating, and space cooling equipment efficiencies, and solar heating equipment size. Changes in energy costs, conservation costs, the discount rate, study period, tax treatments and other financial analysis criteria can be entered into the program in order to determine the sensitivity of the optimal design configuration to these variables.

A significant amount of thermal performance data and economic-engineering analysis is needed before the SOLCOM program can be used. Space heating and cooling requirements, water heating requirements, and peak heating and cooling loads for the basic building envelope design must be determined, based on an anticipated occupancy profile and the climatic location. Appropriate envelope modifications must be selected and their impact on heating and cooling requirements and peak loads estimated. Space heating, water heating, and space cooling plant efficiencies and distribution energy requirements must be determined for each alternative system to be evaluated. Also, specific thermal performance parameters for the solar heating equipment must be known. Building energy analysis programs, such as BLAST[1], DOE-2[2], and TRNSYS[3], can be used to obtain most of these physical performance data requirements. Solar performance parameters are based on the Solar Load Ratio[4] method. The report serves primarily as a users guide to the SOLCOM program. However, the life-cycle cost and economic optimization methodologies and algorithms used in SOLCOM are thoroughly documented and can be used independently of SOLCOM if desired. Examples of SOLCOM optimization analyses are shown for a hypothetical building design but are not intended to provide insight into the relative merits of any of the conservation methods examined.

This report represents a considerable extension of previous work on simultaneous optimization of energy conservation measures in buildings. Sav[5] has stated the economic optimality conditions that must be satisfied in order to find a simultaneous solution to the design problem. Balcomb[6] has reported a methodology to determine the optimal mix of conservation and solar energy in building design for residential applications, but without consideration of domestic hot water, space cooling or simultaneous optimization of the conventional equipment efficiencies. Noll and Thayer[7] have examined graphically the nature of the tradeoff between solar equipment sizing and envelope performance improvements. Barley[8] has developed an algorithm for optimizing both the relative size of active solar equipment and insulation levels in each portion of a building independently of the other portions, and includes water heating as well as space heating in the analysis. None of these reports focuses on commercial building applications, nor do they allow optimization of the heating and cooling equipment as in SOLCOM. The SOLCOM computer program, which can be run

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[1] Hittle, D. C., BLAST, The Building Loads Analysis and System Thermodynamics Program, CEEDO-TR-77-35/CERL-TR-E-119/ADA048734, U.S. Army Construction Engineering Research Laboratory Systems [CERL], December 1977.

[2] DOE-2 Reference Manual (Version 2.1), eds. D.A. York and E. F. Tucker, LBL-8706 Rev. 1, Lawrence Berkeley Laboratory, Berkeley, CA, and LA-7689-M. Ver. 2.1., Los Alamos National Laboratory, Los Alamos, N.M., 1980.

[3] TRNSYS - A Transient Simulation Program. Solar Energy Laboratory, Report 38, University of Wisconsin, Madison, WI. November 1976.

[4] See both Schnurr, Norman M., Hunn, Bruce D., and Williamson, III, Kenneth D., "The Solar Load Ratio Method Applied to Commercial Building Active Solar System Sizing," Solar Engineering - 1981 Proceedings of the ASME Solar Energy Division 3rd Annual Conference on Systems Simulation, Economic Analysis/Solar Heating and Cooling Operation Results, Reno, Nevada, April 27-May 1, 1981, American Society of Mechanical Engineers, New York, N.Y., 1981, and Department of Energy, DoE Facilities Solar Design Handbook, DoE/AD-0006/1, U.S. Government Printing Office, Washington, D.C., 1978.

[5] Sav, G. Thomas, "Economic Optimization of Solar Energy and Energy Conservation in Commercial Buildings," Systems Simulations and Economic Analysis for Solar Heating and Cooling, Proceedings of the U.S. Department of Energy Conference, San Diego, CA, June 27-29, 1978, pp. 88-90.

on a microcomputer in three stages, provides a ready facility for solving large-scale design optimization problems not available in these other reports.

Because this report serves primarily as a users guide to the SOLCOM computer program, the program is described first. In section 2, three SOLCOM subprograms are discussed, input data requirements are detailed, and examples of the output are provided. In section 3, the computational procedures used in SOLCOM to calculate annual energy use in a commercial building are discussed, and the Solar Load Ratio (SLR) method of calculating solar fractions for space heating and water heating is outlined.

In section 4, the optimization criteria for determining the least life-cycle cost combination of conservation measures in a building are examined. Optimization criteria are first presented for determining the optimal value of a single variable in a simple space-heating-only model. Simultaneous optimization methods are then discussed for the same model. Finally, the algorithms for determining the optimal combination of envelope modifications, the optimal solar collector area, and the optimal efficiency of the space heating plant and water heating plant, as used in SOLCOM, are presented.

In section 5, the financial analysis method needed to determine the present value of all conservation-related costs and energy costs are discussed. This includes the analysis of initial costs, future operating and maintenance costs, and salvage (or resale) value, tax adjustments, and mortgage arrangements. Appendix A provides blank data sheets which can be used to organize the data input needed to run the SOLCOM program. Appendix B lists the SLR coefficients of six different active solar heating systems for commercial buildings that can be used in the SOLCOM program. Appendix C provides listings of the SOLCOM program itself.

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[6] Balcomb, J. Douglas, "Conservation and Solar: Working Together," LA-UR-80-2330, Los Alamos Scientific Laboaratory, Los Alamos, N.M., 1980. and "Optimum Mix of Conservation and Solar Energy in Building Design," Proceedings of the 1980 Annual Meeting of the AS/ISES, June 2-6, 1980; Phoenix, AZ, pp. 1202-1206.

[7] Noll, Scott and Thayer, Mark, "Passive Solar Auxiliary, Heat and Building Conservation Optimization: A Graphical Analysis," Fourth Passive Solar Conference Proceedings, Kansas City, Oct 3-5, 1979.

[8] Barley, C. Dennis, "Load Optimization in Solar Space Heating Systems," Solar Energy, Vol. 23, pp. 149-156.

2. THE SOLCOM PROGRAM

2.1 WHAT SOLCOM CAN DO

The SOLCOM program was developed primarily to serve as a computer tool for use by architects, engineers, and building researchers. Its purpose is to determine the economically optimal mix of certain energy conservation measures in a new commercial building design. More specifically, it allows the designer to evaluate the technical and economic tradeoffs between three competing conservation approaches: (1) improvements in the thermal performance of the building envelope to reduce space heating and cooling requirements, both in peak load and annual terms; (2) higher efficiency conventional space heating, water heating, and space cooling equipment; and (3) more use of active solar heating equipment.

The SOLCOM program is written in BASIC computer language and is compatible at present with the Radio Shack TRS-80 Model III microcomputer (48K RAM) with one or more disk drives and a compatible line printer with 132-character line width.[1] The SOLCOM program actually consists of three subprograms which are run in sequence: SOLCOM1, SOLCOM2, and SOLCOM3. It is assumed that the user is familiar with the steps required to load and run a BASIC program from a 5 1/4-in disk.

(1) SOLCOM1 is a financial analysis subprogram which computes the present value cost associated with each design option to be evaluated, including a variety of tax effects and financing arrangements, over the study period selected by the user. SOLCOM1 also computes the present value of unit energy costs over the study period for each energy type specified. All of the conservation measures to be evaluated, as well as base efficiency data for the conventional heating and cooling systems are entered in the SOLCOM1 program. Pertinent cost data, financial analysis assumptions, and borrowing terms, if any, are also entered in SOLCOM1. The results of SOLCOM1 analysis are stored in an intermediate data file which is then read by SOLCOM2.

(2) SOLCOM2 is an optimization subprogram which determines the minimum life-cycle cost combination of solar equipment size, conventional equipment efficiencies, and envelope modifications. SOLCOM2 also determines the corresponding annual heating and cooling requirements, peak heating and cooling loads, and conventional equipment size requirements. It reads in life-cycle cost data from the intermediate file created in SOLCOM1. Relevant optimization results and financial analysis data are stored in a second intermediate file to be passed on the SOLCOM3.

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[1] Certain trade names and company products are identified in order to adequately specify the computer equipment used. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products are necessarily the best available for the purpose.

(3) SOLCOM3 provides the format needed to print out the results of the SOLCOM analysis. The intermediate file created by SOLCOM2 is read into SOLCOM3. This data is processed into a comprehensive LCC report, which includes many of the assumptions, the optimal combination of conservation measures, and the resulting annual and peak load energy requirements for each end use.

SOLCOM determines the economically optimal solar collector size and space heating and water heating plant efficiencies in a single run. However, in order to optimize the space cooling plant efficiency, individual runs of SOLCOM must be made for each alternative cooling efficiency level considered. The results of these runs can then be compared manually in order to select the overall configuration with the lowest total life-cycle cost. (Inclusion of alternative cooling efficiency levels in a single analysis results in unacceptably long run times.)

Two different types of analysis can be made with SOLCOM, as specified by the user during execution. The overall optimization mode finds the minimum life-cycle cost combination of envelope modifications, conventional equipment efficiencies and solar collector area. An example of the output for this overall optimization is shown in Table 2.1. The sample output first lists many of the basic assumptions used in the life-cycle cost analysis and then provides the results of the actual optimization analysis. Note that the life-cycle costs attributed to the three categories of conservation expenditures do not include energy costs or savings. Energy costs make up a fourth category of costs. While the envelope modifications to be included in the optimal design are printed out in decreasing order of cost effectiveness, their absolute cost effectiveness (based on the energy savings attributable to each) is not included in this report.

The solar-only optimization mode prints out the annual heating and cooling requirements, the optimal solar collector area and corresponding solar fraction for the base envelope configuration and subsequent configurations with cumulative conservation modifications (in the order that these modifications are entered in the supporting data files). An example of this solar-only optimization is shown in Table 2.2. The first line of calculated values pertains to the base envelope configuration and each subsequent line gives results for a new envelope configuration containing an additional conservation measure. In order to run the solar-only optimization, the user must specify which of the space heating and water heating efficiencies contained in the input data files to use. This solar-only optimization mode is useful for observing the relationship between the optimal collector size and the annual space heating and water heating requirements for a building. In addition, the solar-only optimization shows the corresponding cumulative envelope modification costs, equipment costs, energy cost, and the total life-cycle cost corresponding to each alternative envelope configuration. If the envelope modifications are entered in order of decreasing cost effectiveness, the optimal envelope configuration includes all conservation modifications up to and including the modification resulting in the lowest total life-cycle cost. In table 2.2, the total (life-cycle) cost is minimized for a building having a space heating plant efficiency of 60 percent, a water heating plant efficiency of 60 percent, and a cooling plant efficiency of 200 percent (i.e., coefficient of performance of 2.0) by

Table 2.1 Sample Output from Overall Optimization Analysis (SI Units)

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                               *
*  PROJECT NAME: TEST PROBLEM (SI UNITS)                        *
*  RUN DATE:01/08/83 00:11:00                                   *
*  STUDY PERIOD: 20 YEARS (1982 TO 2001)                        *
*  TAX STATUS: TAX-PAYING BUSINESS                              *
*  INCOME TAX RATE:  FEDERAL=46.00%, STATE= 5.00%               *
*  PROPERTY TAX RATE:  2.00%  STATE SALES TAX RATE:  0.00%      *
*  CAPITAL GAINS MULTIPLIER: FEDERAL=40.00%, STATE=40.00%       *
*  SUPPORTING FILE: FL2                                         *
*                                                               *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

ANNUAL DISCOUNT RATE AND COST ESCALATION RATES

	1982	1987	1992
FROM:	1982	1987	1992
TO:	1986	1991	2001
DISCOUNT RATE	10.00%	10.00%	10.00%
AVERAGE ANNUAL COST INCREASE:			
MAINTENANCE	10.00%	10.00%	10.00%
BLDG VALUE	10.00%	10.00%	10.00%
NATURAL GAS	12.00%	11.00%	10.00%
ELECTRICITY	10.00%	10.00%	10.00%

BASE YEAR UNIT ENERGY COSTS

END USE	ENERGY TYPE	UNIT	KJ /UNIT	UNIT COST
SPACE HEATING	NATURAL GAS	GJ	1000000	$9.478
WATER HEATING	NATURAL GAS	GJ	1000000	$9.478
SPACE COOLING	ELECTRICITY	KWH	3600	$0.060
FANS/PUMPS: SOLAR	ELECTRICITY	KWH	3600	$0.060
DISTRIBUTION: HTG	ELECTRICITY	KWH	3600	$0.060
DISTRIBUTION: CLG	ELECTRICITY	KWH	3600	$0.060

Table 2.1 (continued)

OPTIMIZATION ANALYSIS

* * * * * * * * * * *

(1) OPTIMAL ENVELOPE MODIFICATIONS (IN DECREASING ORDER OF COST EFFECTIVENESS):

	FIRST COST	LIFE-CYCLE COST*
MOD1	$1,000	$835
MOD2	$1,500	$790
MOD3	$2,000	$1,054
TOTAL ENVELOPE MODIFICATION COST	$4,500	$2,679
APPLICABLE TAX CREDITS	$693	
NET FIRST COST	$3,807	

(2) OPTIMAL CONVENTIONAL EQUIPMENT EFFICIENCY:

	OUTPUT CAP. (MJ/HR)	SEASONAL EFFICIENCY	FIRST COST	LIFE-CYCLE COST*
SPACE HEATING	397	75.00%	$10,260	$9,090
WATER HEATING	N/A	75.00%	$3,700	$3,956
SPACE COOLING	182	200.00%	$6,721	$6,586
TOTAL CONVENTIONAL EQUIPMENT COST			$20,681	$19,632
APPLICABLE TAX CREDITS			$231	
NET FIRST COST			$20,450	

	FIRST COST	LIFE-CYCLE COST*
(3) SOLAR HEATING SYSTEM	$22,017	$16,581
APPLICABLE TAX CREDITS	$3,391	
NET FIRST COST	$18,626	

OPTIMAL COLLECTOR SIZE	78.1 SQ. M	
SOLAR FRACTION(S):		
SPACE HEATING	18.2%	
WATER HEATING	40.1%	
COMBINED	23.8%	
FIXED COST		$1,000
COST PER SQ. M		$269

(4) ENERGY REQUIREMENTS AND COST:

OUTPUT ENERGY REQUIREMENTS	ANNUAL (GJ/YR)	PEAK LOAD (MJ/HR)
SPACE HEATING	375	269
WATER HEATING	127	N/A
SPACE COOLING	149	149

INPUT ENERGY REQUIREMENTS	******ANNUAL******		FIRST-YR COST	LIFE-CYCLE COST*
SPACE HEATING PLANT	402 GJ	NATUR	$3,808	$43,661
WATER HEATING PLANT	101 GJ	NATUR	$958	$10,988
SPACE COOLING PLANT	21,015 KWH	ELECT	$1,261	$12,937
SOLAR FANS/PUMPS	557 KWH	ELECT	$33	$343
DISTRIBUTION SYSTEM:				
SPACE HEATING	1,775 KWH	ELECT	$107	$1,093
SPACE COOLING	705 KWH	ELECT	$42	$434
TOTAL ENERGY COST			$6,209	$69,456

(5) TOTAL LIFE CYCLE COST $108,348

* * * * * * * * * * * * * * * * * *

* AFTER-TAX LIFE-CYCLE COST

Table 2.2 Sample Output from Solar-Only Optimization Analysis (SI Units)

SOLAR COLLECTOR SIZE OPTIMIZATION ANALYSIS FOR TEST PROBLEM (SI UNITS)
SPACE HTG PLANT EFF = 60.0%; WATER HTG PLANT EFF = 60.0%; SPACE CLG PLANT EFF = 200.0%
PRESENT-VALUE SOLAR HTG SYSTEM COSTS: FIXED = $ 2467; VARIABLE = $ 181/SQ M
LIFE-CYCLE COST PER MILLION BTU PURCHASED ANNUALLY:
SPACE HEATING = $108.67 WATER HEATING = $108.67 SPACE COOLING = $171.00
SP HGT DIST = $171.00 SP CLG DIST = $171.00 SOLAR FANS/PUMPS = $171.00

AHR	ACR	AWR	OPTIMAL	OPTIMAL FRACTION			ENERGY	SHELL	SOLAR	SP.HT EQ.	CL. EQ.	W.H. EQ.	TOTAL
			COL. AREA	TOTAL	SPACE	WATER	COST	COST	COST	COST	COST	COST	COST
(GJ)	(GJ)	(GJ)	(SQ.M.)	(%)	(%)	(%)	($)	($)	($)	($)	($)	($)	($)
422.0	158.3	126.6	140.5	35.0	29.2	53.9	79790	0	27853	8080	6659	3540	125922
400.9	154.0	126.6	136.6	35.5	29.5	54.1	76406	835	27149	7883	6626	3540	122440
385.1	150.9	126.6	134.0	36.0	29.9	54.3	73790	1625	26688	7736	6602	3540	119981
374.6	148.8	126.6	132.7	36.4	30.2	54.5	71960	2679	26456	7638	6586	3540	118858
369.3	147.7	126.6	132.7	36.8	30.6	54.6	70910	3996	26457	7588	6578	3540	119069
364.0	146.7	126.6	132.7	37.2	31.0	54.8	69865	5577	26453	7539	6569	3540	119543

using the first three envelope modifications and a solar heating system with a total collection area of 132.7 m^2, resulting in a total life-cycle cost of $118,858.

2.2 DATA ENTRY FOR SOLCOM

One supporting data file is needed to run the SOLCOM1 program. This file, contains cost data, financial analysis assumptions, descriptors of the modifications to be examined, thermal performance data for the basic building and the envelope modifications, and incident solar radiation data.[1] All input data are entered directly by the user into the data file using line numbers specified in the data sheets. Interactive commands are used only for procedural decisions during execution. The data file can be easily modified using the BASIC edit mode of the microcomputer. In general, these data files are too long and complicated to warrant the use of an interactive file-creating subroutine for data entry and modification. It is recommended that supporting files be created separately from the SOLCOM program, saved[2] under their own names, and merged with the SOLCOM1 program upon execution. This allows a permanent record of the data file used for a given building analysis and allows it to be rerun at some future time.

SOLCOM analyses can be made in either SI units or conventional units of measurement. Care must be exercised to use consistent units in the data entry stage.

Because of the number and diversity of the data requirements needed in the supporting file, 18 data entry sheets have been prepared to assist the SOLCOM user. These data sheets are located in Appendix A. Not all of these data sheets or data entries will be needed for every case, but they cover every currently allowable input to the SOLCOM program. However, no default values are provided, so that all relevant data entries must be made. The line numbering scheme for the data entries does not have to be adhered to rigidly, but each data point must be entered in the order shown and each data line must be numbered higher than the one preceeding. The highest data line number that

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[1] The average daily incident solar radiation, by month, needed to run the SOLCOM program requires that the angle and orientation of the solar collectors be known and used to modify the available solar radiation on a horizontal plane at the building site. For a discussion of this procedure see Powell, Jeanne W., and Rodgers Jr., Richard C., FEDSOL: Program User's Manual and Economic Optimization Guide for Solar Federal Buildings Projects, NBSIR 81-2342, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., August 1981.

[2] A data file which is to be merged into a program must be saved in ASCII format if the TRS-80 microcomputer is used. This is accomplished as: SAVE "FILE NAME", A. After the SOLCOM1 program is loaded, the command MERGE "FILE NAME" will pull the file into the program. The user should take care that no other data lines (lines with the word "DATA" after the line number) are in the SOLCOM program before the merge is made.

can be used is 19999. The term "DATA" must follow immediately after each line number as shown. Each data entry must be separated by a comma, but no trailing commas are permitted. Extreme care must be used in the data entry process since no error checking routine is presently available. Actual examples of the supporting data file are shown in section 2.3, along with the corresponding SOLCOM optimization analysis.

2.3 RUNNING THE SOLCOM PROGRAM

As described in section 2.1, the SOLCOM program is run in three stages: SOLCOM1, SOLCOM2 and SOLCOM3, respectively. The TRS-80 microcomputer has two ways of displaying output data: on the CRT screen (soft copy) and on the printer (hard copy). The SOLCOM program has user-interactive data input requests and error messages which show on the CRT screen. Only the final formatted output from SOLCOM3, and the collector-only optimization analysis in SOLCOM2, are printed out in hard copy.

To run SOLCOM, SOLCOM1 must first be loaded into the computer memory using the BASIC "LOAD" command. The supporting data file is then entered (or merged) into SOLCOM1 (see section 2.2). SOLCOM1 can then be started with a "RUN" command. When all of the computations are complete (this takes 2-5 minutes), a message will appear on the CRT screen:

"ENTER TRANSFER FILE NAME FOR SOLCOM2"

At this point the user must enter the name of the transfer file to be created in order to transfer the intermediate results to the SOLCOM2 program. (File names have a maximum of eight letters or numbers and must begin with a letter, e.g., "OUT1". Do not use the name of another program or file already stored on the same disk or that existing program or file will be erased.) Once the transfer file is created, the SOLCOM1 analysis is completed. SOLCOM2 can be automatically run at this point if the user responds affirmatively to the CRT message:

"DO YOU WANT TO RUN SOLCOM2?"

If the user answers negatively, the SOLCOM1 program ends and can then be run again with changes in the supporting data file or with a new supporting data file.

SOLCOM2 can be run separately (if a transfer file from SOLCOM1 is available) or by being called in by SOLCOM1. When SOLCOM2 is run, several user input requests are made on the CRT screen:

(1) "ENTER TRANSFER DATA FILE NAME FROM SOLCOM1"

The user should enter the same name as that entered in SOLCOM1 for transfer file (e.g., OUT1), or should enter the name of another file created in a previous run of SOLCOM1.

(2) "COMPLETE OPTIMIZATION (1) OR SOLAR COLLECTOR SIZE OPTIMIZATION ONLY (2)?"

Enter "1" or "2" as desired (see section 2.1).

If "1" is entered, the computer will request additional input:

"ENTER SEARCH STARTING POINT INDEXES (I,J,W) FOR ENVELOPE, SPACE HEATING EFF, WATER HEATING EFF"

These indexes correspond to the I^{th} envelope modification, J^{th} space heating plant efficiency, and W^{th} water heating plant efficiency, as described in the data file used in SOLCOM1 (Data sheets 6, 9, and 11, respectively). Entries should be separated by a comma. Good guesses as to what the optimal values of I, J, and W are will help SOLCOM2 converge more rapidly on the optimal combination of investments.

A second request is made for the complete optimization case:

"ENTER FIRST GUESS FOR THE OPTIMAL COLLECTOR AREA FOR THE STARTING POINTS USED."

This area (in m^2 for SI units or ft^2 for conventional units) should be between the minimum (M1) and maximum (M2) collector sizes specified in the SOLCOM1 data file. (See data sheet 15.)

If the solar collector size optimization only option is selected (2), SOLCOM2 requests the following data:

"ENTER INDEXES FOR SPACE HEATING (J) AND WATER HEATING (W) PLANTS."

The user enters 1 for the base heating plant efficiency or the appropriate J index for any other space heating plant efficiency used in the SOLCOM1 file, followed by a comma, and the desired value of the W index for the water heating plant efficiency. No further user input is required. The results of the solar-only optimization are output by the line printer.

If only the solar collector size optimization output is required, SOLCOM3 is not needed and no transfer file is created. If the complete optimization analysis is made in SOLCOM2, a transfer file to SOLCOM3 is needed. SOLCOM asks:

"ENTER TRANSFER FILE NAME FOR SOLCOM3."

The user enters a file name (e.g., OUT2). Then SOLCOM3 is automatically loaded and run at this point.

SOLCOM3 requires only one input from the user:

"ENTER TRANSFER FILE NAME FROM SOLCOM2."

The user enters the name of the transfer file used to save the results of the SOLCOM2 analysis. At this point the results of the complete SOLCOM analysis will be printed out.

Table 2.1 shows the results from a SOLCOM analysis of a hypothetical office building, based on the SOLCOM1 input data file shown in table 2.3 (FL2). This is an example of a run made in SI units. Envelope modifications are hypothetical and are identified here only by arbitrary designators (MOD1, MOD2, etc.). Table 2.2, which shows a solar-only optimization example for the same building, is also based on the data base in supporting file FL2.

Table 2.4 shows a SOLCOM analysis of the same building, made in conventional units, with supporting data file shown in table 2.5 (FL1). The same run was made in both SI and conventional units to assist the user in preparing data files in either measurement system and to show that the results are identical in terms of optimal design specifications and corresponding costs.

In both of these examples, the auxiliary space heating and water heating plants are separate. SOLCOM can also be used with a combined space and water heating auxiliary plant, or for space heating only, by proper specification of variables Q1 and Q2 in the supporting file to SOLCOM1. (See data sheet 11.)

Table 2.3 Supporting File FL2 (SI Units)

```
999 REM FILE NAME IS FL2. ANY CHANGES MUST BE SAVED IN ASCII FORMAT.
1000 REM DATA SHEET 1
1001 DATA FL2
1002 DATA TEST PROBLEM (SI UNITS)
1003 DATA 2,1982,20,1,46
1004 DATA 5,0,40,40,2
2000 REM DATA SHEET 2
2001 DATA 3
2101 DATA 5,10,10,10
2102 DATA 5,10,10,10
2103 DATA 10,10,10,10
3000 REM DATA SHEET 3
3001 DATA 2
3101 DATA 12,10
3102 DATA 11,10
3103 DATA 10,10
4000 REM DATA SHEET 4
4101 DATA 9.4778,1000000,NATURAL GAS,GJ
4102 DATA 0.06,3600,ELECTRICITY, KWH
5000 REM DATA SHEET 5
5001 DATA 0
6000 REM DATA SHEET 6
6001 DATA 5
6101 DATA 1, MOD1,1000,25,2
6102 DATA 2, MOD2,1500,0,0
6103 DATA 3, MOD3,2000,0,0
6104 DATA 4, MOD4,2500,0,0
6105 DATA 5, MOD5,3000,0,0
6201 DATA 50,50,25,10,10
6202 DATA 50,50,25,10,10
6203 DATA 50,50,25,10,10
6204 DATA 50,50,25,10,10
6205 DATA 50,50,25,10,10
7000 REM DATA SHEET 7
7100 REM DATA SHEET 7-1
7101 DATA 10,50
7102 DATA 15,50
8000 REM DATA SHEET 8
8001 DATA 15,0
8002 DATA 1
8101 DATA 6.667,6.667,6.667,6.667,6.667
8106 DATA 6.667,6.667,6.667,6.667,6.667
8111 DATA 6.667,6.667,6.667,6.667,6.667
9000 REM DATA SHEET 9
9001 DATA 3,1,2,1.5,4.739
9011 DATA 60,5000,9.4778,100,3
9012 DATA 70,500,25,0
9013 DATA 75,1000,50,0
9021 DATA 50,50,25,0,0
9022 DATA 0,50,25,10,10
9023 DATA 0,50,25,10,10
10000 REM DATA SHEET 10
10100 REM DATA SHEET 10-1
10101 DATA 5,500
10102 DATA 10,500
10103 DATA 15,500
```

Table 2.3 (continued)

```
11000 REM DATA SHEET 11
11001 DATA 2,2
11003 DATA 3,1
11011 DATA 60,3000,100,2
11012 DATA 70,200,0,0
11013 DATA 75,500,0,0
11021 DATA 50,50,25,0,0
11022 DATA 0,50,25,0,0
11023 DATA 0,50,25,0,0
12000 REM DATA SHEET 12
12100 REM DATA SHEET 12-1
12101 DATA 8,500
12102 DATA 16,500
13000 REM DATA SHEET 13
13001 DATA 2,2,200,1.2,4.739
13002 DATA 5000,9.4778,200,1
13003 DATA 50,50,25,0,0
13101 DATA 10,100
14000 REM DATA SHEET 14
14001 DATA 15,0
14002 DATA 1
14101 DATA 6.667,6.667,6.667,6.667,6.667
14106 DATA 6.667,6.667,6.667,6.667,6.667
14111 DATA 6.667,6.667,6.667,6.667,6.667
15000 REM DATA SHEET 15
15001 DATA 1000,269.1,2,1,4.739
15002 DATA 29,465,100,3
15003 DATA 50,50,0,10,10
15101 DATA 5,500
15102 DATA 10,500
15103 DATA 15,500
16000 REM DATA SHEET 16
16001 DATA 15,0
16002 DATA 1
16101 DATA 6.667,6.667,6.667,6.667,6.667
16106 DATA 6.667,6.667,6.667,6.667,6.667
16111 DATA 6.667,6.667,6.667,6.667,6.667
```

Table 2.3 (continued)

```
17000 REM DATA SHEET 17
17101 DATA 84.408,63.306,42.204,21.102
17105 DATA 21.102,0,0,0
17109 DATA 21.102,42.204,42.204,84.408
17113 DATA 316.53,158.265,158.265
17201 DATA 10.551,10.551,10.551,10.551
17205 DATA 10.551,10.551,10.551,10.551
17209 DATA 10.551,10.551,10.551,10.551
17301 DATA 10016,12423,14445,15728
17305 DATA 16330,16989,16693,16534
17309 DATA 16250,14956,11140,8551
18000 REM DATA SHEET 18
18099 REM DATA SHEET 18-1
18100 DATA 1
18101 DATA 4.2204,3.1653,2.1102,1.0551
18105 DATA 1.0551,0,0,0
18109 DATA 1.0551,2.1102,2.1102,4.2204
18113 DATA 21.102,4.2204,4.2204
18199 REM DATA SHEET 18-2
18200 DATA 2
18201 DATA 3.1653,2.1102,2.1102,1.0551
18205 DATA 0,0,0,0
18209 DATA 1.0551,1.0551,2.1102,3.1653
18213 DATA 15.8264,3.1653,3.1653
18299 REM DATA SHEET 18-3
18300 DATA 3
18301 DATA 2.1102,2.1102,1.0551,1.0551
18305 DATA 0,0,0,0
18309 DATA 0,1.0551,1.0551,2.1102
18313 DATA 10.551,2.1102,2.1102
18379 REM DATA SHEET 18-4
18400 DATA 4
18401 DATA 1.0551,1.0551,1.0551,0
18405 DATA 0,0,0,0
18409 DATA 0,0,1.0551,1.0551
18413 DATA 5.2755,1.0551,1.0551
18479 REM DATA SHEET 18-5
18500 DATA 5
18501 DATA 1.0551,1.0551,1.0551,0
18505 DATA 0,0,0,0
18509 DATA 0,0,1.0551,1.0551
18513 DATA 5.2755,1.0551,1.0551
```

Table 2.4 Sample Output from Overall Optimization Analysis (Customary Units)

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*                                                                 *
*  PROJECT NAME: TEST PROBLEM (CUST. UNITS)                       *
*  RUN DATE:01/08/83 01:52:13                                     *
*  STUDY PERIOD: 20 YEARS (1982 TO 2001)                          *
*  TAX STATUS: TAX-PAYING BUSINESS                                *
*  INCOME TAX RATE:  FEDERAL=46.00%, STATE= 5.00%                 *
*  PROPERTY TAX RATE:  2.00%  STATE SALES TAX RATE:  0.00%        *
*  CAPITAL GAINS MULTIPLIER: FEDERAL=40.00%, STATE=40.00%         *
*  SUPPORTING FILE: FL1                                           *
*                                                                 *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

ANNUAL DISCOUNT RATE AND COST ESCALATION RATES

* *

FROM: TO:	1982 1986	1987 1991	1992 2001
DISCOUNT RATE	10.00%	10.00%	10.00%
AVERAGE ANNUAL COST INCREASE:			
MAINTENANCE	10.00%	10.00%	10.00%
BLDG VALUE	10.00%	10.00%	10.00%
NATURAL GAS	12.00%	11.00%	10.00%
ELECTRICITY	10.00%	10.00%	10.00%

BASE YEAR UNIT ENERGY COSTS

* * * * * * * * * * * * * * *

END USE	ENERGY TYPE	UNIT	BTU/UNIT	UNIT COST
SPACE HEATING	NATURAL GAS	THERM	100000	$1.000
WATER HEATING	NATURAL GAS	THERM	100000	$1.000
SPACE COOLING	ELECTRICITY	KWH	3412	$0.060
FANS/PUMPS: SOLAR	ELECTRICITY	KWH	3412	$0.060
DISTRIBUTION: HTG	ELECTRICITY	KWH	3412	$0.060
DISTRIBUTION: CLG	ELECTRICITY	KWH	3412	$0.060

* *

Table 2.4 (continued)

OPTIMIZATION ANALYSIS

* * * * * * * * * * * *

(1) OPTIMAL ENVELOPE MODIFICATIONS (IN DECREASING ORDER OF COST EFFECTIVENESS):

	FIRST COST	LIFE-CYCLE COST*
MOD1	$1,000	$835
MOD2	$1,500	$790
MOD3	$2,000	$1,054
TOTAL ENVELOPE MODIFICATION COST	$4,500	$2,679
APPLICABLE TAX CREDITS	$693	
NET FIRST COST	$3,807	

(2) OPTIMAL CONVENTIONAL EQUIPMENT EFFICIENCY:

	OUTPUT CAP. (MBTU/HR)	SEASONAL EFFICIENCY	FIRST COST	LIFE-CYCLE COST*
SPACE HEATING	376	75.00%	$10,260	$9,090
WATER HEATING	N/A	75.00%	$3,700	$3,956
SPACE COOLING	172	200.00%	$6,721	$6,586
TOTAL CONVENTIONAL EQUIPMENT COST			$20,681	$19,632
APPLICABLE TAX CREDITS			$231	
NET FIRST COST			$20,450	

	FIRST COST	LIFE-CYCLE COST*
(3) SOLAR HEATING SYSTEM	$22,050	$16,603
APPLICABLE TAX CREDITS	$3,396	
NET FIRST COST	$18,654	

OPTIMAL COLLECTOR SIZE	842.0 SQ.FT.	
SOLAR FRACTION(S):		
SPACE HEATING	18.2%	
WATER HEATING	40.1%	
COMBINED	23.8%	
FIXED COST		$1,000
COST PER SQ.FT.		$25

(4) ENERGY REQUIREMENTS AND COST:

OUTPUT ENERGY REQUIREMENTS	ANNUAL (MMBTU/YR)	PEAK LOAD (MBTU/HR)
SPACE HEATING	355	255
WATER HEATING	120	N/A
SPACE COOLING	141	141

INPUT ENERGY REQUIREMENTS	******ANNUAL******			FIRST-YR COST	LIFE-CYCLE COST*
SPACE HEATING PLANT	3,807	THERM	NATUR	$3,807	$43,651
WATER HEATING PLANT	958	THERM	NATUR	$958	$10,983
SPACE COOLING PLANT	21,015	KWH	ELECT	$1,261	$12,937
SOLAR FANS/PUMPS	558	KWH	ELECT	$33	$343
DISTRIBUTION SYSTEM:					
SPACE HEATING	1,775	KWH	ELECT	$107	$1,093
SPACE COOLING	705	KWH	ELECT	$42	$434
TOTAL ENERGY COST				$6,208	$69,441

(5) TOTAL LIFE CYCLE COST $108,355

* * * * * * * * * * * * * * * * * *

* AFTER-TAX LIFE-CYCLE COST

NOTE: MBTU = 1,000 BTU; MMBTU = 1,000,000 BTU

Table 2.5 Supporting File "FL1" (Customary Units)

```
999 REM FILE NAME IS FL1. ANY CHANGES MUST BE SAVED IN ASCII FORMAT.
1000 REM DATA SHEET 1
1001 DATA FL1
1002 DATA TEST PROBLEM (CUST. UNITS)
1003 DATA 1,1982,20,1,46
1004 DATA 5,0,40,40,2
2000 REM DATA SHEET 2
2001 DATA 3
2101 DATA 5,10,10,10
2102 DATA 5,10,10,10
2103 DATA 10,10,10,10
3000 REM DATA SHEET 3
3001 DATA 2
3101 DATA 12,10
3102 DATA 11,10
3103 DATA 10,10
4000 REM DATA SHEET 4
4101 DATA 1.00,100000,NATURAL GAS,THERM
4102 DATA 0.06,3412,ELECTRICITY, KWH
5000 REM DATA SHEET 5
5001 DATA 0
6000 REM DATA SHEET 6
6001 DATA 5
6101 DATA 1, MOD1,1000,25,2
6102 DATA 2, MOD2,1500,0,0
6103 DATA 3, MOD3,2000,0,0
6104 DATA 4, MOD4,2500,0,0
6105 DATA 5, MOD5,3000,0,0
6201 DATA 50,50,25,10,10
6202 DATA 50,50,25,10,10
6203 DATA 50,50,25,10,10
6204 DATA 50,50,25,10,10
6205 DATA 50,50,25,10,10
7000 REM DATA SHEET 7
7100 REM DATA SHEET 7-1
7101 DATA 10,50
7102 DATA 15,50
8000 REM DATA SHEET 8
8001 DATA 15,0
8002 DATA 1
8101 DATA 6.667,6.667,6.667,6.667,6.667
8106 DATA 6.667,6.667,6.667,6.667,6.667
8111 DATA 6.667,6.667,6.667,6.667,6.667
9000 REM DATA SHEET 9
9001 DATA 3,1,2,1.5,5
9011 DATA 60,5000,10,100,3
9012 DATA 70,500,25,0
9013 DATA 75,1000,50,0
9021 DATA 50,50,25,0,0
9022 DATA 0,50,25,10,10
9023 DATA 0,50,25,10,10
10000 REM DATA SHEET 10
10100 REM DATA SHEET 10-1
10101 DATA 5,500
10102 DATA 10,500
10103 DATA 15,500
```

Table 2.5 (continued)

```
11000 REM DATA SHEET 11
11001 DATA 2,2
11003 DATA 3,1
11011 DATA 60,3000,100,2
11012 DATA 70,200,0,0
11013 DATA 75,500,0,0
11021 DATA 50,50,25,0,0
11022 DATA 0,50,25,0,0
11023 DATA 0,50,25,0,0
12000 REM DATA SHEET 12
12100 REM DATA SHEET 12-1
12101 DATA 8,500
12102 DATA 16,500
13000 REM DATA SHEET 13
13001 DATA 2,2,200,1.2,5
13002 DATA 5000,10,200,1
13003 DATA 50,50,25,0,0
13101 DATA 10,100
14000 REM DATA SHEET 14
14001 DATA 15,0
14002 DATA 1
14101 DATA 6.667,6.667,6.667,6.667,6.667
14106 DATA 6.667,6.667,6.667,6.667,6.667
14111 DATA 6.667,6.667,6.667,6.667,6.667
15000 REM DATA SHEET 15
15001 DATA 1000,25,2,1,5
15002 DATA 320,5000,100,3
15003 DATA 50,50,0,10,10
15101 DATA 5,500
15102 DATA 10,500
15103 DATA 15,500
16000 REM DATA SHEET 16
16001 DATA 15,0
16002 DATA 1
16101 DATA 6.667,6.667,6.667,6.667,6.667
16106 DATA 6.667,6.667,6.667,6.667,6.667
16111 DATA 6.667,6.667,6.667,6.667,6.667
```

Table 2.5 (continued)

```
17000 REM DATA SHEET 17
17101 DATA 80,60,40,20
17105 DATA 20,0,0,0
17109 DATA 20,40,40,80
17113 DATA 300,150,150
17201 DATA 10,10,10,10
17205 DATA 10,10,10,10
17209 DATA 10,10,10,10
17301 DATA 882,1094,1272,1385
17305 DATA 1438,1496,1470,1456
17309 DATA 1431,1317,981,753
18000 REM DATA SHEET 18
18099 REM DATA SHEET 18-1
18100 DATA 1
18101 DATA 4,3,2,1
18105 DATA 1,0,0,0
18109 DATA 1,2,2,4
18113 DATA 20,4,4
18199 REM DATA SHEET 18-2
18200 DATA 2
18201 DATA 3,2,2,1
18205 DATA 0,0,0,0
18209 DATA 1,1,2,3
18213 DATA 15,3,3
18299 REM DATA SHEET 18-3
18300 DATA 3
18301 DATA 2,2,1,1
18305 DATA 0,0,0,0
18309 DATA 0,1,1,2
18313 DATA 10,2,2
18399 REM DATA SHEET 18-4
18400 DATA 4
18401 DATA 1,1,1,0
18405 DATA 0,0,0,0
18409 DATA 0,0,1,1
18413 DATA 5,1,1
18499 REM DATA SHEET 18-5
18500 DATA 5
18501 DATA 1,1,1,0
18505 DATA 0,0,0,0
18509 DATA 0,0,1,1
18513 DATA 5,1,1
```

3. CALCULATION PROCEDURES USED IN SOLCOM

3.1 ENERGY ESTIMATING PROCEDURES

The methodology used in SOLCOM2 to estimate annual purchased and solar energy use for space heating, water heating, and space cooling in a commercial building is described in this section. Purchased energy requirements may be made up of several different energy types, specified individually by end use. For example, gas can be specified for space and water heating and electricity for space cooling. Electricity is always assumed to be used by the HVAC distribution system and by the fans and pumps in the solar heating equipment. However, only one type of energy can be specified for any given equipment type. (Switching among fuels for space heating cannot be handled in the program.)

Annual energy use is estimated separately for each of the following functions:

(1) space heating plant,
(2) water heating plant,
(3) space cooling plant,
(4) fans and pumps: solar equipment,
(5) distribution system: heating, and
(6) distribution system: cooling.

Energy prices can be specified individually for each of these functions, even if the same energy type is used, so that seasonal differences in utility rate structures can be reflected. For example, electricity rates are generally higher in summer than in winter, so that a higher average kWh price may be more appropriate for cooling than for space heating. Because water heating is required throughout the year, an average annual rate is most appropriate for this function. (Time-of-use rates cannot be handled by the SOLCOM program.)

Each kWh of electricity used to run the fans and/or pumps in the heating and cooling distribution system is assumed to result in the generation of 3,600 KJ (3,412 Btu) of thermal energy. During heating operations this additional thermal energy helps offset space heating requirements; during cooling operations the additional thermal energy adds to the space cooling requirements. The distribution system is assumed to provide space heating from both the conventional space heating plant and the solar heating equipment. The thermal energy from the fans and/or pumps in the solar heating system itself is assumed to be included in the useful energy output of that system and not in addition to that output. Energy use by the distribution system during periods when no space heating or cooling is required (i.e., for ventilation purposes only) is not accounted for in SOLCOM. It is assumed that any changes in ventilation requirements during these periods resulting from the envelope modifications made will be insignificant.

The following equations describe the calculation procedures used in SOLCOM2 to determine annual purchased energy requirements for each of the six functions listed above.

1. Space Heating Plant

$$\text{Purchased Energy Requirements (Units}_1\text{/yr)} = \frac{(1 - EE \cdot DE_1) \cdot AHR \cdot (1-FH) \cdot S}{HE \cdot Tu/Unit_1}, \qquad (3.1)$$

where
- EE = .0036/kWh if AHR is in GJ or 0.003412/kWh if AHR is in 10^6Btu,
- DE_1 = kWh consumed by distribution system per GJ or 10^6Btu of AHR,
- AHR = annual space heating requirements (in GJ or 10^6Btu),
- FH = annual solar fraction, space heating,
- HE = seasonal efficiency of the space heating plant (useful thermal output/thermal equivalent input),
- $Tu/Unit_1$ = thermal content (KJ or Btu) of energy units purchased for space heating, and
- S = 10^6.

2. Water Heating Plant

$$\text{Purchased Energy Requirements (Units}_2\text{/yr)} = \frac{AWR \cdot (1 - FW) \cdot S}{WE \cdot Tu/Unit_2} \qquad (3.2)$$

where
- AWR = annual water heating requirements (in GJ or 10^6Btu),
- FW = annual solar fraction, water heating,
- WE = annual average efficiency of water heating plant, and
- $Tu/Unit_2$ = thermal content (KJ or Btu) of energy units purchased for water heating.

3. Space Cooling Plant

$$\text{Purchased Energy Requirements (Units}_3\text{/yr)} = \frac{(1 + EE \cdot DE_2) \cdot ACR \cdot S}{CE \cdot Tu/Unit_3} \qquad (3.3)$$

where
- EE = 0.0036 if ACR is in GJ, or 0.003412 if ACR is in 10^6Btu
- DE_2 = kWh consumed by distribution system per GJ or 10^6Btu of ACR,
- ACR = annual space cooling requirements (in GJ or 10^6Btu),
- CE = seasonal efficiency (or seasonal performance factor if CE>1.0) of space cooling plant, and
- $Tu/Unit_3$ = thermal content (KJ or Btu) of energy units used for space cooling.

4. Solar Heating System: Pumps/fans

Purchased Energy Requirements $(kWh_4/yr) = [(1 - EE \cdot DE_1) \cdot AHR \cdot FH + AWR \cdot FW] \cdot DE_3$ (3.4)

where DE_3 = kWh consumed by solar heating system per GJ or 10^6Btu useful output.

5. Distribution System: Space Heating

Purchased Energy Requirements $(kWh_5/yr) = AHR \cdot DE_1$. (3.5)

6. Distribution System: Space Cooling

Purchased Energy Requirements $(kWh_6/yr) = ACR \cdot DE_2$. (3.6)

It should be recognized here that the seasonal efficiencies of the space and water heating plants are assumed to remain relatively constant as the envelope is upgraded and the solar fraction is increased. The degree to which this assumption is realistic depends largely on the type of equipment used, especially with regard to cycling performance. This assumption is not likely to be realistic if an air source heat pump is used in the heating mode, since the average air temperature during the on-cycle will be lower as the envelope is tightened up and the solar fraction increased. In general, it is best to use estimates of seasonal efficiency that are valid for the overall optimal design of the building, including the solar collector sizing. This may require several iterations with the SOLCOM program, with a reestimation of the seasonal efficiencies for the conventional heating and cooling equipment made after one SOLCOM run and used in the next until no significant differences appear.

3.2 SOLAR FRACTION ESTIMATING PROCEDURES

In order to estimate the optimal size of a solar heating system, it is necessary to be able to determine the annual solar fraction corresponding to any collector size based on the system type, building heating requirements, and incident solar radiation. Figure 3.1 shows the general relationship between the solar fraction and collector area for a particular building installation. This relationship is characterized by a curve which is relatively straight at first but gradually increases less and less as the collector area is increased more and more. Eventually very large increases are needed to produce even small increases in the solar fraction as it approaches 100 percent.

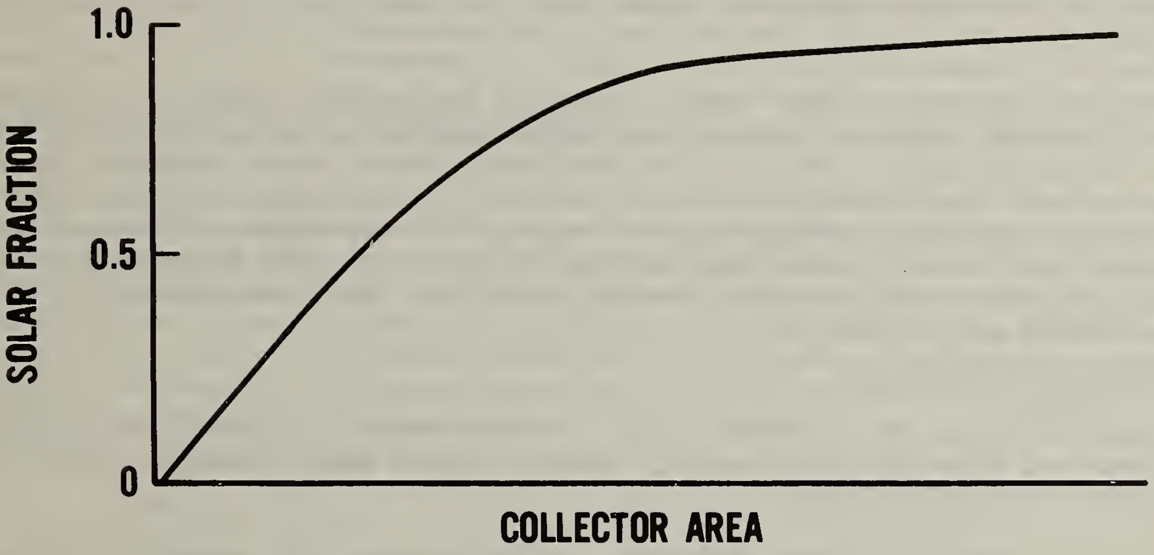

Figure 3.1 Solar fraction vs. collector area for given building (general form)

There are a variety of methods available to relate the annual solar fraction to collector area, with varying degrees of accuracy and computational requirements. These range from complex engineering algorithms which require hourly performance calculations over the entire year to a single equation with coefficients representative of a given system type and location. Ideally, a single equation method, such as that proposed by Lamerio and Bendt[1] would be used in the optimization analysis. With such an equation the total life-cycle cost curve could be differentiated (either mathematically or numerically) with respect to collector area to find the collector area for which total cost is minimized. However, single equation models do not represent the annual performance of a space heating system or combined space and water heating systems well enough for optimization purposes. The absolute value of the solar fraction may be reasonably well estimated for any given collector size using a single-equation method. But, the estimated change in the solar fraction due to the change in collector area - which is critical to the optimization analysis - does not appear to be accurate enough to give a reasonable estimate of the optimal collector size. This is unfortunate, because any alternative requires a separate algorithm to compute the annual solar fraction for a given collector area, heating load profile, and incident solar gain schedule. Since no continuous function relating solar fraction and collector area results, any optimization algorithm must make multiple entries into the subroutine used to compute the solar fraction as it converges on the optimal collector area. Since the determination of an optimal collector area is made repeatedly as the building envelope is modified and the equipment efficiencies are changed, it is important that the solar fraction algorithm be as efficient as practical. This essentially precludes the use of hourly or even daily estimates of solar fractions from collector areas. As a practical matter, a monthly calculation procedure is the least aggregated method that is compatible with microcomputer applications.

The Solar Load Ratio (SLR)[2] method for space heating and combined space and water heating systems is used in the SOLCOM program to estimate solar fractions from collector areas. This method calculates monthly solar fractions based on a solar load ratio particular to the building, its location, and collector size, using a set of four coefficients that typify the performance of a known heating system type. Monthly fractions and heating loads are then aggregated to provide an annual solar fraction. The following two equations are used to find the monthly solar fraction:

---

[1] Lamerio, Gerald F. and Bendt, Paul, "The GFL Method for Sizing Solar Energy Space and Water Heating Systems," SERI-30, Solar Energy Research Institute, Golden, Colorado, 1978.

[2] Schnurr, Norman M., Hunn, Bruce D., and Williamson, III, Kenneth D., "The Solar Load Ratio Method Applied to Commercial Building Active Solar System Sizing," Solar Engineering - 1981 Proceedings of the ASME Solar Energy Division 3rd Annual Conference on Systems Simulation, Economic Analysis/ Solar Heating and Cooling Operation Results, Reno, Nevada, April 27-May 1, 1981. American Society of Mechanical Engineers, New York, NY, 1981. See also Powell and Rodgers' FEDSOL Program User's Manual, Appendix E-2, and U.S. Department of Energy, DoE Facilities Solar Handbook.

$$F_m = b_1 X_m \qquad \text{for } 0 < X_m \leq b_2 \text{, and} \tag{3.1a}$$

$$F_m = 1 - b_3 e^{-b_4 X_m} \qquad \text{for } X_m > b_2 \text{,} \tag{3.1b}$$

where F_m = monthly solar fraction,
X_m = monthly solar load ratio = $A_c H_T / TL_m$,
A_c = collector area,
H_t = solar energy per unit area incident monthly on the plane of the collector,
TL_m = monthly combined space and water heating load (net of thermal output from fans and pumps in distribution system), and
b_1 through b_4 = system performance coefficients, based on the solar load ratio method (see appendix A).

The annual solar fraction (F) is then calculated by summing useful monthly solar energy output and monthly loads and dividing as follows:

$$F = \frac{\sum_{m=1}^{12} F_m \circ TL_m}{\sum_{m=1}^{12} TL_m} \ . \tag{3.2}$$

Appendix B lists system performance coefficients (b_1 - b_4) for several different solar heating equipment types compatible with commercial buildings. These coefficients are dimensionless; thus they work equally well with SI and conventional units of measurement. These coefficients are taken from Powell and Rodgers, FEDSOL Program User's Manual. Other coefficients can be substituted for these in the SOLCOM2 program before execution (lines 2460-2690).

The SLR method has been modified slightly in the SOLCOM program in order to provide separate estimates of the annual solar fraction for space heating (FH) and water heating (FW) when separate conventional heating plants are used. This is because separate plants will likely have different efficiencies and may even use different types of energy with different costs. The monthly fractions are calculated as shown in equations 3.1a and 3.1b. However, in calculating the annual fractions, the following equations are used in addition to equation 3.2 to break out FH and FW separately:

$$FH = \frac{\sum_{m=1}^{12} F_m \cdot HL_m}{\sum_{m=1}^{12} HL_m} \quad (3.3) \qquad \text{and} \qquad FW = \frac{\sum_{m=1}^{12} F_m \cdot WL_m}{\sum_{m=1}^{12} WL_m} \ . \quad (3.4)$$

4. OPTIMIZATION CRITERIA AND ALGORITHMS

A relatively simple model of the total heating-related life-cycle cost of a building is used in sections 4.1 and 4.2 to demonstrate the concepts of independent and simultaneous economic optimization criteria. A more complete exposition of the optimization algorithms used in SOLCOM is provided in section 4.3.

In its most elementary form, the total life-cycle heating-related cost of a solar-heated building can be expressed as

$$TC = \frac{AHR\ (1-F)}{EFF} \cdot Ke \cdot UPV^* + K_{env} + K_{equip} + K_{solar}, \text{ and} \tag{4.1}$$

$$K_{solar} = K_F + K_V \cdot A, \tag{4.2}$$

where TC = the total present-value of all heating-related costs over the study period used,
- AHR = annual heating requirements (in some units),
- F = solar fraction for a given collector area,
- EFF = seasonal efficiency of the heating equipment,
- K_e = unit price of energy (in the same units used to denote AHR),
- UPV^* = modified uniform present value factor based on the study period length, discount rate, and rate of price increase for the energy type used,
- K_{env} = present value cost of all envelope modifications corresponding to the AHR above,
- K_{equip} = present value cost of the conventional heating equipment corresponding to the EFF above,
- K_{solar} = present value cost of solar heating equipment with collector area A that provides the solar fraction F, given the AHR above,
- K_F = the fixed cost for the type of solar heating system used, and
- K_V = the variable cost per unit of collector area.[1]

K_{env}, K_{equip}, and K_{solar} include all costs incurred over the study period (e.g., initial cost; operating, maintenance and repair costs; tax adjustments), except for the energy used for heating. In general, it is assumed that the least costly means of achieving any given level of thermal performance for any given component modification is used, provided that it does not diminish other performance requirements of the same components. For example, the insulation material with the lowest effective cost per unit of thermal resistance would be used rather than a more expensive material, provided that it satisfied the minimum technical specifications for insulation materials.

---

[1] While K_V is related to the collector area, it also includes any other variable costs which occur as a result of scaling up the system (e.g., storage and plumbing costs). K_F and K_V may not be valid over the entire range of possible collector sizes but should be specified for the region in which the optimal area is expected to occur.

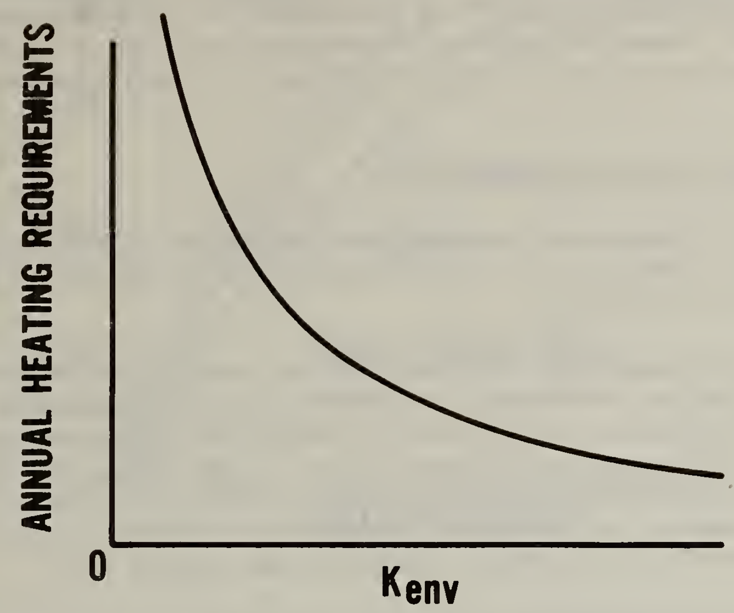

Figure 4.1 Cumulative envelope modification cost as a function of annual heating requirements (general form)

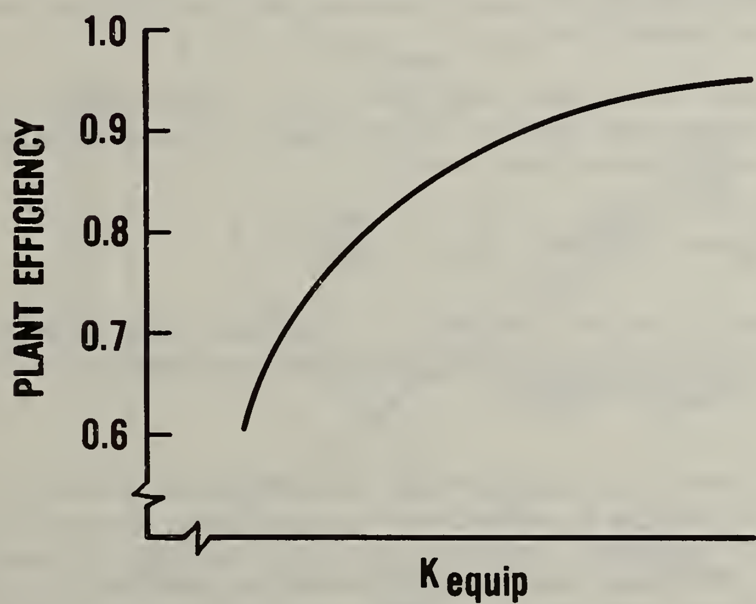

Figure 4.2 Plant cost as a function of efficiency (general form)

In section 4.1, the model described in equation (4.1) is used to formulate economic optimization criteria for AHR, EFF, and A, independently of one another. Optimization criteria are developed for both continuous and discrete changes in these three variables. In section 4.2, the same model is used to formulate simultaneous optimization criteria for both continuous and discrete functions.

4.1 INDEPENDENT OPTIMIZATION CRITERIA

In this section, independent economic optimization criteria are formulated for AHR, EFF, and A. That is, only one variable is optimized at a time while the other two are held constant.

Initially it is assumed that AHR and EFF are continuous functions of K_{env} and K_{equip}, respectively. Moreover, we assume that AHR decreases at a decreasing rate as K_{env} increases (see figure 4.1) while EFF increases at a decreasing rate as K_{equip} increases (see figure 4.2). In general, the solar fraction (F) increases at a decreasing rate as the solar collector area (A) increases (see figure 3.1). However, F is also a function of the AHR, since any decrease in AHR will increase F if A is held constant (see figure 4.3).

The functional relationships between total life-cycle cost and each of the three independent design variables are shown in figures 4.4, 4.5, and 4.6. In each of these figures, the total LCC curve is the sum of K_{env}, K_{equip}, K_{solar} and LC energy costs. In each case it is evident that increases in conservation investment initially reduce life-cycle costs, but that beyond some point, further increases result in higher life-cycle costs. The point at which the TLCC function is minimized for each of these three independent variables (AHR' EFF', and A' in figures 4.4, 4.5, and 4.6, respectively) can be found by finding the first derivative of equation 4.1 with respect to that variable, setting the first derivative equal to zero, and solving for the corresponding value of that variable.

Thus, to determine the optimal AHR (AHR') and corresponding envelope modifications, given that EFF and A are fixed, the partial derivative of TC with respect to AHR is set equal to 0,

$$\frac{\partial TC}{\partial AHR} = \left[\frac{K_e \cdot UPV^*}{EFF} \left(1-F-AHR\,\frac{dF}{dAHR}\right)\right] + \frac{dK_{env}}{dAHR} = 0, \qquad (4.3)$$

and this equation is solved for AHR'.[1] Note that both dF/dAHR and $dK_{env}/dAHR$ are needed to solve for the optimal AHR since both the solar fraction (F) and K_{env} change as AHR is changed.

---

[1] Second order conditions require that ∂'TC/∂'AHR be positive in order to assure that ∂TC/∂AHR = 0 occurs at a minimum point rather than a maximum point in the TC function. However, as specified, the TC function cannot have a maximum, so that this second order condition need not be demonstrated. Similar conditions hold for the total cost functions related to conventional and solar heating equipment in this report.

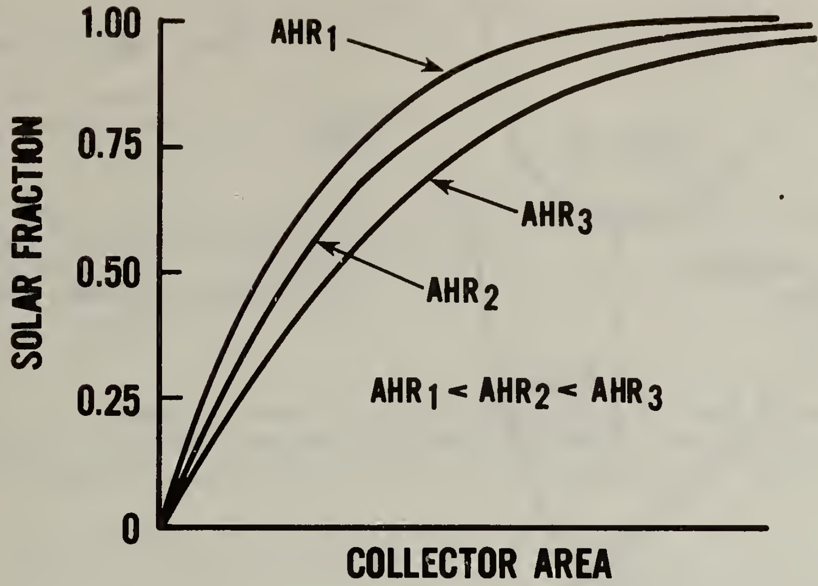

Figure 4.3 Solar fraction as a function of collector area and annual heating requirements (general form)

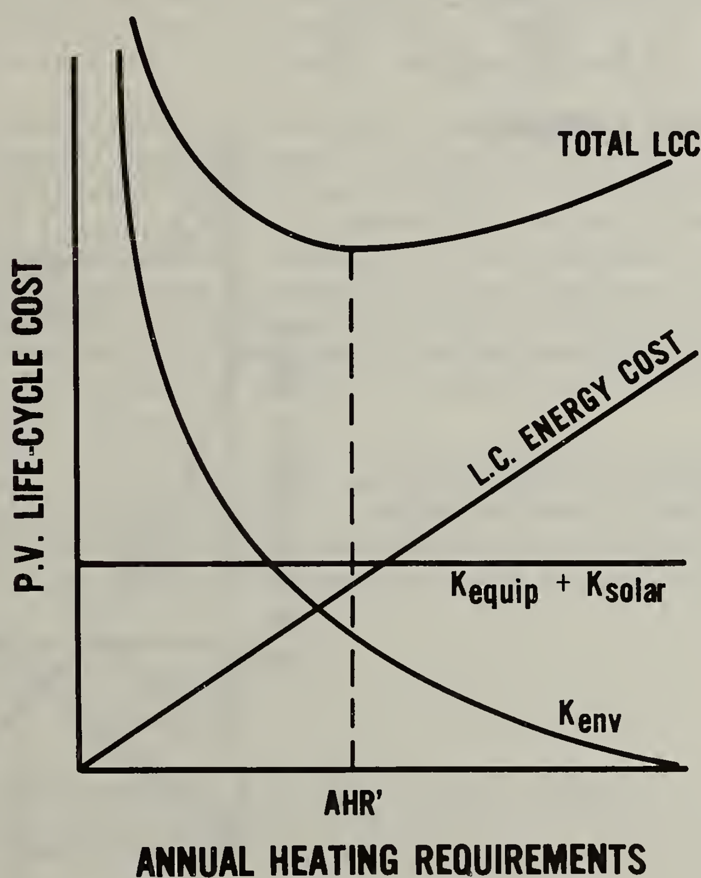

Figure 4.4 Total heating-related life-cycle costs: annual heating requirements variable

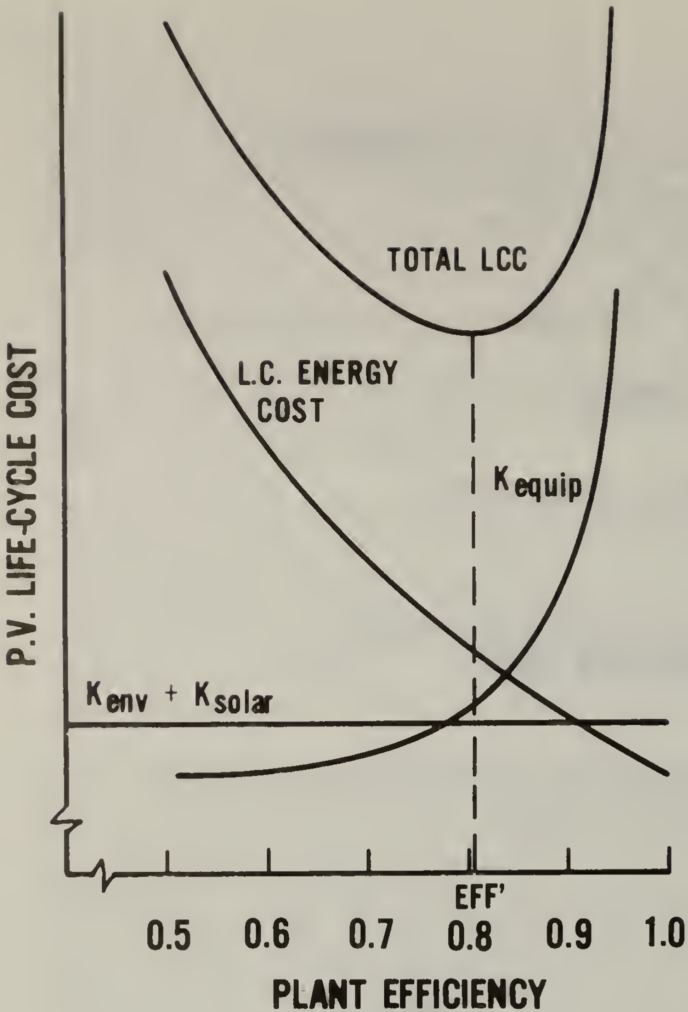

Figure 4.5 Total heating-related life-cycle costs: plant efficiency variable

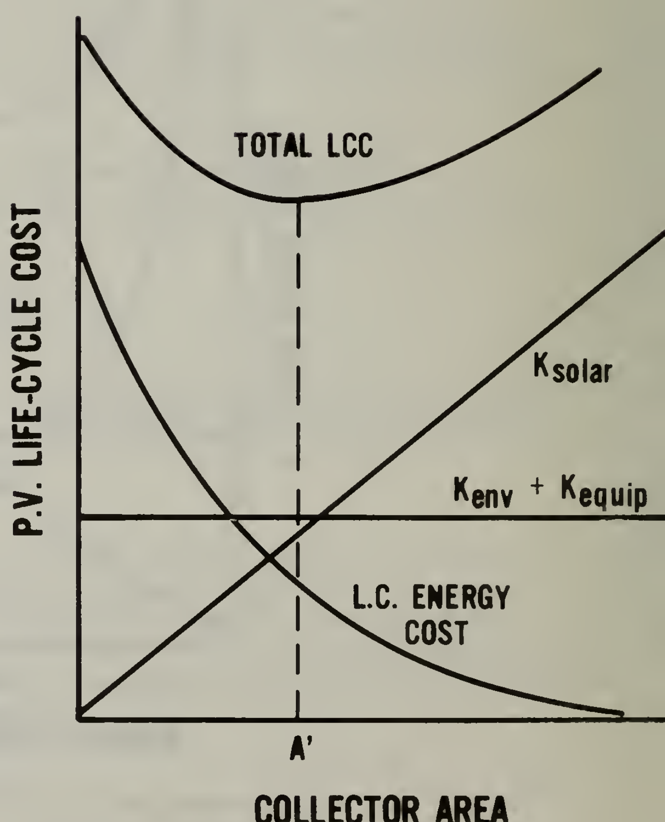

Figure 4.6 Total heating-related life-cycle costs: collector area variable

To determine the optimal heating equipment efficiency (EFF'), given that AHR and A are fixed in size, use:

$$\frac{\partial TC}{\partial EFF} = \frac{K_e \cdot UPV^* \cdot AHR(F-1)}{EFF^2} + \frac{dK_{equip}}{dEFF} = 0, \tag{4.4}$$

and solve for EFF'. Finally, to determine the optimal solar collector area (A'), given that AHR and EFF are fixed, find

$$\frac{\partial TC}{\partial A} = \frac{-K_e \cdot UPV^* \cdot AHR}{EFF} \frac{dF}{dA} + K_V = 0 \tag{4.5}$$

and solve for A'. However, because of the potentially high fixed cost component (K_F) associated with solar heating systems, an additional criterion must be satisfied. This additional criterion can be stated as

$$\frac{AHR \cdot F'}{EFF} \cdot K_e \cdot UPV^* > K_F + K_V \cdot A', \tag{4.6}$$

where F' is the optimal solar fraction corresponding to A'. In essence, equation 4.6 requires that the total energy savings attributable to the optimal size solar heating system are large enough to amortize not only the variable cost component but the fixed cost component as well, since the fixed cost component does not enter the area optimization equation (4.5). If equation 4.6 cannot be satisfied for F' (and the corresponding value of A'), the optimal solar heating size is zero; i.e., no solar heating is used at all.

If the functional relationships between K_{env} and AHR, K_{equip} and EFF, and K_{solar}, A, and F are continuously differentiable, the determination of optimal values for AHR, EFF, and A, independently of one another, is straightforward. The relationship between K_{solar}, A and F is generally continuous and thus the optimal A can be found as shown above. However it is impractical to modify most envelope or mechanical equipment components in any continuous sense. Instead, discrete modifications (e.g., double glazing, flue damper) are usually incorporated into their designs. In such cases, the optimal level of AHR and EFF must be determined using discrete evaluation techniques rather than through mathematical differentiation.

In order to determine the optimal level of AHR, and the corresponding combination of envelope modifications, independently of EFF and A and using discrete optimization techniques, the nl discrete envelope modifications to be considered must be first ranked in decreasing order of cost effectiveness. That is

$$\frac{-\Delta AHR_i \cdot K_e \cdot UPV^*}{\Delta K^i_{env}} > \frac{-\Delta AHR_{i+1} \cdot K_e \cdot UPV^*}{\Delta K^{i+1}_{env}} \tag{4.7}$$

for each envelope modification i = 1, 2, ..., nl-1, where

AHR_i = the AHR resulting when all envelope modifications 1, 2, ..., i are incorporated into the envelope design,

$\Delta AHR_i = AHR_i - AHR_{i-1}$,

K^i_{env} = cumulative total cost of all envelope modifications 1, 2, ...i, and

$\Delta K^i_{env} = K^i_{env} - K^{i-1}_{env}$.

Equation 4.1 can be restated as

$$TC_i = \frac{AHR_i\ (1-F_i)}{EFF} \cdot K_e \cdot UPV^* + K^i_{env} + K_{equip} + K_{solar}, \tag{4.8}$$

where TC_i = the total heating-related life-cycle cost of the building when all envelope modifications 1, 2, ..., i are incorporated into its design.

Now the change in TC per unit change in AHR ($\Delta TC_i/\Delta AHR_i$) can be calculated for each subsequent modification, i = 2, 3, ..., n1 as follows:

$$\frac{\Delta TC_i}{\Delta AHR_i} = \left[1 - F_{i-1} - AHR_i\left(\frac{\Delta F_i}{\Delta AHR_i}\right)\right] \cdot \frac{K_e \cdot UPV^*}{EFF} + \frac{\Delta K^i_{env}}{\Delta AHR_i}, \tag{4.9}$$

where F_i = solar fraction corresponding to AHR_i, given A, and

$\Delta F_i = F_i - F_{i-1}$ (F_o = solar fraction for unmodified (i.e., base) envelope configuration).

Since the envelope modifications are ranked in decreasing order of cost effectiveness, $\Delta TC_i/\Delta AHR_i$ will decrease for each additional modification and eventually turn negative. At the point where $\Delta TC_i/\Delta AHR_i$ turns negative, ΔTC_i begins to increase. Therefore, an optimization algorithm is required to find the last i for which $\Delta TC_i/\Delta AHR_i$ is greater than or equal to zero. From a practical standpoint, this is most easily accomplished by evaluating i= 1,2,3 ... stepwise until $\Delta TC_i/\Delta AHR_i$ turns negative, and then backing up one step to i', the optimal integer. (No further modifications need to be evaluated.) The optimal envelope design contains i' modifications (1,2,..., i').

Similarly, discrete equipment modifications to improve seasonal heating efficiency can be evaluated using

$$\frac{\Delta TC_j}{\Delta EFF_j} = \left[\frac{AHR\ (F-1)}{EFF_j \cdot EFF_{j-1}}\right] K_e \cdot UPV^* + \frac{\Delta K^j_{equip}}{\Delta EFF_j}, \tag{4.10}$$

where ΔTC_j = the change in total life-cycle heating-related cost attributable to the jth equipment modification, j = 2, 3, ..., n2,

EFF_1 = the seasonal efficiency of the base space heating equipment,

EFF_j = the seasonal efficiency of the upgraded space heating equipment with cumulative modifications 2, 3, ..., j, and

$\Delta EFF_j = Eff_j - EFF_{j-1}$.

If the n2 equipment modifications are ranked in order of decreasing cost effectiveness, then $\Delta TC_j/\Delta EFF_j$ will increase as j is increased, and eventually turn positive. (This is reversed from the envelope modification analysis because ΔEFF_j has a positive sign while ΔAHR_i has a negative sign.) The optimization algorithm then can find the optimal j by evaluating j=2,3 ... until $\Delta TC_j/\Delta EFF_j$ turns positive, and then backing up one step to j'. (Again, no further modifications need be considered.) The optimal heating equipment configuration includes j modifications (1,2,..., j').

Before continuing on to the discussion of simultaneous optimization methods in section 4.2, two important points should be noted:

(1) The value of the results are limited by the validity of the input data. Considerable effort prior to the optimization analysis described above is needed to make sure that the basic envelope design, equipment types, and modifications considered are the most appropriate and cost effective for the overall design objectives. Similarly, the type of solar heating equipment to be used, the ratio of storage volume to collector area, collector tilt angle, and other system parameters that affect performance and cost must be carefully selected in advance. Only the size of the solar heating system is determined in SOLCOM. However, the total life-cycle cost of buildings with different types of conventional heating systems, different solar heating systems, and different approaches to reducing space heating and cooling requirements can be compared through separate optimization analyses. In this way, the usefulness of these optimization methods and the SOLCOM computer program can be greatly expanded.

(2) When an individual component is optimized, independently of the other components, the life of the component can sometimes be used in the economic analysis if it is shorter than the life expectancy (or study period) for the overall building. (This does not hold true if the use of that component essentially "locks in" the replacement decision, in which case the analysis should be conducted over the entire study period.) However, when two or more components are to be optimized simultaneously, the same study period must be used for each. This requires a complete schedule of replacement and maintenance costs over the study period, as well as a careful consideration of the "salvage" (or resale) value of those components.

An important limitation to the methodology upon which SOLCOM is based is that any replacement to an original component is assumed to have the same performance characteristics as the original. Thus for instance, if the heating equipment is replaced at some point during the study period, its efficiency is assumed to be the same as before, even though it may be logical to increase it at that time when better information is available and new technologies have been introduced to improve efficiency or lower costs.

4.2 SIMULTANEOUS OPTIMIZATION OF DESIGN VARIABLES

In section 4.1, the methodology for determining independently the optimal level of annual space heating requirements (AHR), heating equipment efficiency (EFF), and solar collector size (A), was discussed. However, it is apparent from equation 4.1 that the purchased energy usage for space heating is dependent on all three of these design variables. As a result, the change in total life-cycle costs due to a change in any one of these three variables depends in part on the values assumed for the other two. In order to find the optimal level for any one, all three must be determined simultaneously.

If the optimal levels of AHR, EFF, and A can be determined mathematically, so that equations 4.3, 4.4, and 4.5 are specified, the simultaneous solution is relatively straightforward. Since there are three unknowns and three equations, the optimal level for each design variable can be found by a simultaneous solution of the equation system, using basic algebra to substitute terms.

In practice, however, discrete methods of evaluation are generally more applicable to the determination of optimal AHR and equipment efficiency in a building, while differentiation techniques can be used to find the optimal collector area. As a result, an iterative process must be used to identify the optimal combination of design variables. The iterative process described here is based on the same assumptions about the ranking of the envelope and equipment modifications (in terms of decreasing life-cycle cost effectiveness) outlined in section 4.1. It is actually a series of "nested" optimization algorithms which can be described by the following interrelated steps:

STEP 1: Determine the optimal collector area ($A'_{i,j}$) and corresponding solar fraction ($F_{i,j}$), using equations 4.5 and 4.6 for each AHR_i evaluated in STEP 2, and EFF_j from STEP 3.

STEP 2: Determine the optimal AHR (AHR^j) for each EFF_j evaluated in STEP 3, using:

$$\frac{\Delta TC_{i,j}}{\Delta AHR_i} = \left[1 - F'_{i-1,j} - AHR_i\left(\frac{\Delta F'_{i,j}}{\Delta AHR_i}\right)\right] \cdot \frac{K_e \cdot UPV^*}{EFF_j} + \frac{\Delta K^i_{env}}{\Delta AHR_i} + \frac{\Delta A'_{i,j} \cdot K_V}{\Delta AHR_i} \qquad (4.11)$$

where $\Delta A'_{i,j} = A'_{i,j} - A'_{i-1,j}$

$\Delta F'_{i,j} = F'_{i,j} - F'_{i-1,j}$, and

AHR_0 = annual heating requirements of unmodified envelope,

for $i = 1, 2, \ldots,$ until $\Delta TC_{i,j}/\Delta AHR_i$ turns negative.

AHR^j is then set equal to AHR_{i-1} (i.e. one step back from the point where $\Delta TC_{i,j}/\Delta AHR_i$ turns negative). If i is increased to nl (the total number of envelope modification identified) without $TC_{i,j}/AHR_i$ turning negative, then AHR^j is set equal to AHR_{nl}. A'_j, F'_j, and K^j_{env} are the optimal collector area, solar fraction, and total envelope modification cost, respectively, corresponding to AHR^j.

STEP 3: Determine the optimal heating equipment efficiency (EFF') using:

$$\frac{\Delta TC_j}{\Delta EFF_j} = \left[\frac{AHR^j \cdot EFF_{j-1} \cdot (1-F_j') - AHR^{j-1} \cdot EFF_j (1-F_{j-1}')}{EFF_j \cdot EFF_{j-1}}\right] \cdot K_e \cdot UPV^* \qquad (4.12)$$

$$+ \frac{\Delta K^j_{env}}{\Delta EFF_j} + \frac{\Delta K^j_{equip}}{\Delta EFF_j} + \frac{K_V \cdot \Delta A_j'}{\Delta EFF_j},$$

where $\Delta K^j_{env} = K^j_{env} - K^{j-1}_{env}$,

$\Delta K^j_{equip} = K^j_{equip} - K^{j-1}_{equip}$, and

$\Delta A_j' = A_j' - A_j'-1$,

for j= 2, 3, ... until $\Delta TC_j/\Delta EFF_j$ turns positive.

EFF' is then set equal to EFF_{j-1}. If j is increased to n2 (the total number of equipment efficiencies identified) without $\Delta TC_j/\Delta EFF_j$ turning positive, then EFF' is set equal to EFF_{n2}.

The number of iterations required to find optimal values of A, AHR, and EFF can be considerably reduced if good guesses (based on a priori information) are made and used as starting points. If the starting points selected for AHR_i or EFF_j result in an increase rather than a decrease in the total cost function, indices i or j must be decremented until a corresponding decrease in the total cost function results.

This three-step algorithm can be expanded to find optimal values of other design parameters which must be evaluated simultaneously with A, AHR, and EFF. For example, the optimal level of annual cooling requirements and the efficiency of the cooling equipment may also need to be included in the analysis. In the following subsection, a more complete description of the optimization algorithm used in SOLCOM is presented. This includes the determination of optimal water heating equipment efficiency, and incorporates space cooling considerations and electric energy used for fans and pumps in the underlying engineering equations upon which the optimization analysis is based.

4.3 OPTIMIZATION ALGORITHMS USED IN SOLCOM

In this subsection a more comprehensive examination of the optimization algorithms used in SOLCOM is presented. These include the determination of the optimal collector area (4.3.1), optimization of envelope modifications with respect to both space heating and space cooling requirements (4.3.2), optimization of the space heating plant (4.3.3), and optimization of the water heating plant (4.3.4).

4.3.1 Optimization of Solar Collector Area

Collector size is the only one of the design variables optimized in SOLCOM that is treated continuously, although lower and upper limits on permissible collector size do constrain the solution. Since an equation to relate the annual solar fractions for space heating (FH) and water heating (FW) to collector area (A) does not exist, direct differentation of the total life-cycle cost (LCC) function (which includes the collector area and corresponding solar fraction) is not possible. Instead, a convergence algorithm, based on the Newton-Raphson method of successive approximation and numerical difference methods, is used to find the minimum LCC collector area.

Before the actual convergence algorithm is executed, two tests are made in order to determine whether the optimal area is equal to either the minimum permissible or the maximum permissible collector size specified. These tests are made as follows:

<u>TEST 1</u> Is the minimum collector size optimal?

The SLR method (section 3.2) is used to estimate solar fractions FH and FW for M1 (the minimum collector area) and for M1-Z and M1+Z. (Z is a discrete interval size used to approximate the first and second derivatives of the total cost function with respect to A, based on numerical difference techniques. SOLCOM uses Z = 0.5 m^2 in SI calculations and 5 ft^2 for conventional unit calculations). Calculate the total energy and solar equipment cost (TC) for M1, M1-Z, and M1+Z (T1, T2, and T3 respectively) using

$$TC = \frac{KH}{HE} \cdot HL \cdot (1-FH) + \frac{KW}{WE} \cdot WL \cdot (1-FW) + QT \cdot DE_3 \cdot KS + K_F + K_V \cdot A \qquad (4.13)$$

where KH = cost per GJ (10^6 Btu) for space heating energy x UPV_h^*,

UPV_h^* = modified uniform present value factor for space heating energy[1],

HE = seasonal efficiency of space heating plant,

HL = net annual heating requirements = AHR ($1-EE \cdot DE_1$),

AHR = annual heating requirements in GJ (10^6Btu),

EE = 3.6 MJ/kWh (3412 Btu/kWh),

DE_1 = kWh per GJ (10^6Btu) AHR required for heating distribution system,

FH = annual solar fraction, space heating, based on HL,

KW = cost per GJ (10^6 Btu) for water heating energy x UPV_w^*,

UPV_w^* = modified present value factor for water heating energy[1],

---

[1] Modified uniform present value factors are discussed in section 5.1.

WE = seasonal efficiency of water heating plant,

WL = annual water heating requirements in GJ (10^6Btu) equivalent temperature rise,

FW = annual solar fraction, water heating, based on WL,

QT = useful energy output from solar heating equipment (annual) = HL•FH + WL•FW,

DE_3 = kWh per GJ (10^6Btu) useful output from solar heating equipment needed for fans and/or pumps,

KS = cost per kWh for electricity used to run fans and/or pumps in solar heating equipment x UPV_s^*,

UPV_s^* = modified uniform present value factor for electricity used by solar equipment[2],

K_F = fixed cost of solar heating equipment,

K_V = variable cost of solar heating equipment per m^2 (ft^2) of collector area, and

A = collector area in m^2 (ft^2).

Calculate D1 = (T3-T2)/(2•Z). (4.14)

D1 is a discrete approximation to the first derivative of the TC function at A=M1 (f'(M1)).

If D1 > 0, the optimal collector area would be less than M1 if M1 was not the minimum permissible area. In this case the optimal area (A') is set equal to M1. The net savings (NS) for the solar heating equipment are calculated for A' = M1 and the corresponding values of FH and FW using:

$$NS = (KH/HE_j) \cdot HL_i \cdot FH + (KW/WE_w) \cdot WL \cdot FW - (K_F + K_V \cdot A) - QT \cdot DE_3 \cdot KS \quad (4.15)$$

where i, j, and w are the indices for the envelope modifications, space heating equipment and water heating equipment respectively.

Now A' = M1 if NS $\geq$ 0, and (4.16a)
A' = 0 if NS $<$ 0. (4.16b)

If D1 < 0, then the optimal area must be greater than M1. Proceed to TEST 2.

If D1 = 0, use equations 4.15 and 4.16a or 4.16b to find A'.

<u>TEST 2</u> Is the maximum collector size optimal?

The SLR method is used to estimate FH and FW for M2 (the maximum permissible collector area), and for M2-Z and M2+Z. Calculate total energy and solar equipment cost corresponding to areas M2, M2-Z, and M2+Z (T1, T2, T3, respectively) using equation 4.13. Calculate D1 = (T3-T2)/(2•Z).

If D1>0, the optimal collector size must be less than M2. Proceed to convergence algorithm below.

If D1<0, the optimal area must be greater than M2. A' is set equal to M2 and net savings for A = M2 are calculated using equation 4.15.

Now $A' = M2$ if $NS \geq 0$, and (4.17a)
$A' = 0$ if $NS \leq 0$. (4.17b)

If D1 = 0, use equations 4.15 and 4.17a or 4.17b to find A'.

Convergence Algorithm

The convergence algorithm is used only when it is known that the optimal collector area (A') lies between M1 and M2, the minimum and maximum permissible collector areas, respectively. A' can generally be found in a few iterations using the Newton-Raphson method of successive approximation. The actual number of iterations needed depends on both the proximity of the starting point to A' and the slope of the solar fraction curve at A'. (As the slope of the solar fraction curve becomes relatively flat, more iterations will generally be needed for convergence.)

From equation 4.5 it is known that the first derivative of the total cost function at A' is zero (f'(A') = 0). Since the total cost function (equation 4.13) is U-shaped, f'(A) must be negative for values of A less than A' and positive for values of A greater than A'. Figure 4.7 shows the general shape of the f'(A) function. The optimization algorithm must converge on the point where the f'(A) function changes from negative to positive (i.e., where f'(A') = 0).

The Newton-Raphson method is very efficient at converging on f'(A) = 0. An initial guess as to A', A_k ($M1 < A_k < M2$), is made. The second derivative of the TC function at A_k ($F''(A_k)$ is approximated numerically by calculating D2 as follows:

$$D2 = (T3-2 \cdot T1+T2)/Z^2, \tag{4.18}$$

where T1, T2, and T3 are total costs calculated at A_k, A_k-Z and A_k+Z, respectively. The calculation of A_{k+1}, the trial solution to A', is made using

$$A_{k+1} = A_k - f'(A_k)/f''(A_k), \tag{4.19a}$$

or numerically

$$A_{k+1} = A_k - D1/D2. \tag{4.19b}$$

In essence, A_{k+1} is the point at which a line drawn tangent to $f'(A_k)$ intersects the horizontal axis, as shown in figure 4.8. This process is repeated, substituting A_{k+1} for A_k, until the difference between A_k and A_{k+1} converges to some specified tolerance level, say 1 m^2 (~10 ft^2). The last trial value obtained with such a tolerance will generally be within 0.1 m^2 (~1 ft^2) of the actual optimum and is used as A'.

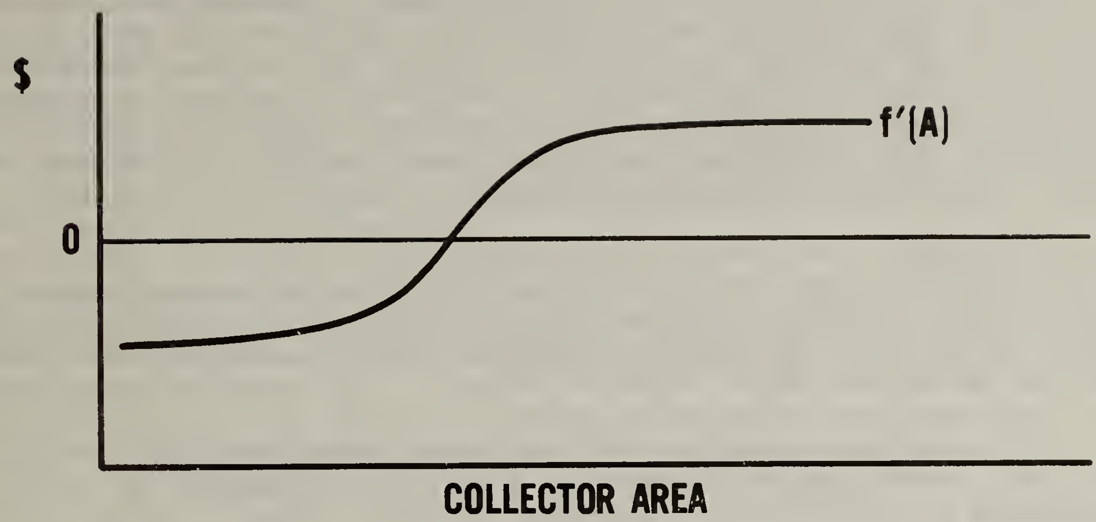

Figure 4.7 First derivative of the total cost curve as a function of collector area (f'(A))

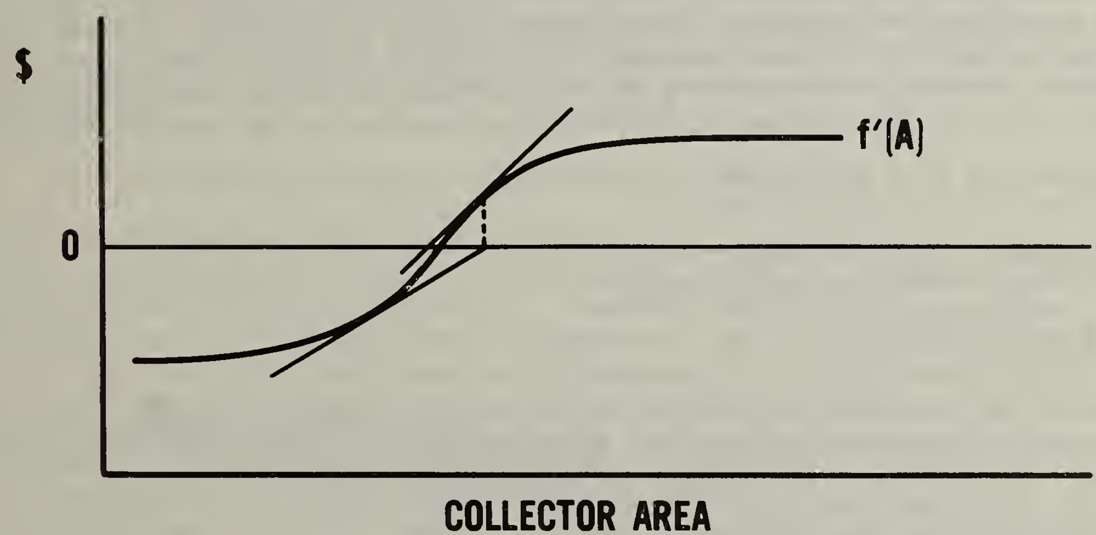

Figure 4.8 Convergence algorithms to locate f'(A) = 0

Since the calculation of FH and FW for any given collector area, space heating load, water heating load, and equipment efficiency level requires the solution of several equations in a monthly model, it is important that convergence be rapid. Rapid convergence is also important because this optimization algorithm is repeated many times as envelope modifications are analyzed and equipment efficiencies (space heating, water heating, and space cooling) are changed. When the initial guess for A_k is within 5 m^2 (~50 ft^2) of A', this algorithm can usually locate A' in one iteration. Under most conditions, convergence can be obtained in four iterations or less. However, several modifications have been made to this convergence algorithm, as used in SOLCOM, to improve its performance under certain conditions which might otherwise slow it down:

(1) Test for D2>0. The numerical approximation of $f''(A_k)$, D2, should have a positive value over the entire f'(A) function. That is, each additional unit area of collector yields a smaller increase in the solar fractions than the one before. (This is the second order condition needed to ensure that f'(A) = 0 occurs at the minimum point on the TC curve.) It is possible that discontinuities in the empirical relationship between the solar fraction and collector area will result in a negative value for D2 at some value of A_k, causing divergence from, rather than convergence on, A'. If D2 is found to be negative, A_k is increased by 2•Z and D2 is recomputed in order to move it out of the region of discontinuity.

It is conceivable that, for a particular type of solar heating system, or for a different model of solar heating performance than the SLR method used here, an additional unit of collector area may yield a larger increase in the solar fraction than the one preceding, at least initially when the solar fraction is very low. The optimal collector area cannot occur in this region (as long as the unit cost of collector area (K_v) is constant) since energy savings are increasing faster than costs. The second derivative of the total cost function will be negative throughout such a region, again preventing convergence on A'. Increasing A_k by 2•Z (as discussed above) will eventually move A_k out of this region. However, by specifying M1 (the minimum collector size) large enough to keep A_k out of this region, this potential problem can be avoided altogether.

(2) Test for M1 < A_{k+1} < M2.

If A_{k+1} < M1, set A_{k+1} = M1.
If A_{k+1} > M2, set A_{k+1} = M2.

(3) Test for M3 < A_{k+1} < M4.

In order to increase the rate of which the Newton-Raphson method converges to A' in some cases, it is useful to dynamically specify new lower and upper bounds (M3 and M4, respectively) on A_{k+1}, as follows:

If D1 for A_k < 0, set M3 = A_k;
if D1 for A_k > 0, set M4 = A_k.

Then, if A_{k+1} < M3, set A_{k+1} to (M3 + M4)/2;
if A_{k+1} > M4, set A_{k+1} to (M3 + M4)/2.

(4) Estimating A_k using A' from previous optimization.

As a general rule, if the total annual heating requirements are reduced by some given percentage, the optimal collector area will decrease by the same percentage and the corresponding solar fraction will remain unchanged[1]. This relationship is not exact if the percentage reduction in heating loads is not the same for each month of the year, nor if water heating loads (which remain constant) are included. However, this rule can be very helpful in determining a starting point for the convergence algorithm as AHR are reduced in the envelope optimization analysis. Usually only one iteration is needed to find the optimal collector area for a new AHR once the optimal area for the previous envelope configuration has been determined.

The starting point to find A'_{i+x} for HL_{i+x}, given A'_i for HL_i, where x is a positive or negative integer representing the number of envelope modifications added to or subtracted from the configuration with HL_i, is computed in SOLCOM as as follows:

$$A_{i+x} = \frac{A'_i[HL_{i+x} \cdot KH/HE + WL \cdot KW/WE + FT(HL_{i+x} + WL) \cdot DE_3 \cdot KS]}{HL_i \cdot KH/HE + WL \cdot KW/WE + FT(HL_i + WL) \cdot DE_3 \cdot KS} \qquad (4.20)$$

where FT = annual solar fraction for combined space and water heating (total output/total load).

No general rule exists for estimating the change in optimal collector area due to a change in energy prices or changes in conventional equipment efficiency. (In fact, the amount of change in optimal collector area due to a change in energy price depends in part where on the solar fraction curve the optimal fraction lies before the change is made, and the shape of the curve.) Since no expedient approximation rule could be worked out, the optimal collector area computed for a given HL and WL, based on HE_j and WE_w, is used as the starting point in SOLCOM to search for the new optimal area as HE and WE are increased or decreased.

4.3.2 Optimization of Envelope Modifications, AHR and ACR

The general search procedure used in SOLCOM to find the optimal combination of envelope modifications to reduce space heating loads is similar to that outlined in section 4.2 (Steps 1 and 2). However, the actual optimization algorithms used in SOLCOM are more comprehensive than the general search procedure in that the total cost function is expanded to include reductions in annual cooling requirements (ACR), separate space and water heating plants and solar fractions, and electricity usage for fans and/or pumps in both the heating/cooling distribution system and the solar heating equipment. Approximation techniques are used to provide a more efficient starting point for the search algorithm in order to reduce the number of times the optimal solar collector size must be determined. Ranking of the envelope modifications in

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[1] Sav, G. Thomas, "Economic Optimization of Solar Energy and Energy Conservation in Commercial Buildings."

decreasing order of cost effectiveness is also verified in this part of SOLCOM, and if necessary, redetermined as the space heating plant efficiency changes.

The total cost function in SOLCOM can be expressed as follows:

$$TC = ECSH + ECWH + ECSC + ECS + ECDH + ECDC + PCSH + PCWH + PCSC + MCE + SSC, \quad (4.21)$$

TC = total life cycle heating- and cooling-related costs,
ECSH = LC energy cost for space heating plant,
ECWH = LC energy cost for water heating plant,
ECSC = LC energy cost for space cooling plant,
ECS = LC electricity cost for space heating equipment,
ECDH = LC electricity cost for distribution system, heating,
ECDC = LC electricity cost for distribution system, cooling,
PCSH = LC plant cost, space heating,
PCWH = LC plant cost, water heating,
PCSC = LC plant cost, space cooling,
MCE = total LC envelope modification costs, and
SSC = LC solar heating system costs.

Life-cycle energy costs are found by multiplying annual energy use for each function by the cost per unit for the type of energy used (as of the beginning of the study period), a modified uniform present value factor (UPV*), and an after-tax equivalence (ATE) factor. Computation of annual energy use for each of the six energy use functions above is detailed in equations 3.1 through 3.6 in section 3. Computation of the UPV* and ATE factors is explained in sections 5.1 and 5.2. Unit energy costs are selected by the user to represent actual energy costs at the building site. Computation procedures to find the life-cycle costs of all equipment and envelope modifications, including initial costs as well as future costs and savings (e.g., maintenance, replacements, resale value and tax savings) are also detailed in section 5.

As each envelope modification is brought into the analysis, all of the cost elements in equation 4.21 (except for the water heating plant) may change. Modifications that reduce AHR will likely reduce the design heating load (DHL), allowing the use of a smaller space heating plant. The same envelope modification may lead to a reduction (or possibly an increase) in the annual cooling requirements (ACR) and the design cooling load (DCL) as well, resulting in a change in the size of the space cooling plant. As the AHR are reduced, a smaller solar collector size (if any) will be optimal, but solar fraction for water heating will be increased. Changes in AHR and ACR also result in proportional changes in distribution energy requirements.

The algorithms used in SOLCOM to determine the optimal combination of envelope modifications are divided into several stages:

(1) ranking of envelope modifications,
(2) first approximation to optimum, and
(3) actual determination of optimum.

(1) Ranking of Envelope Modifications

Each of the envelope modifications analyzed in SOLCOM must be ranked in decending order of life-cycle cost effectiveness or the optimization algorithm will fail. The incremental energy savings (in terms of ΔAHR, ΔDHL, ΔACR, and ΔDCL) entered into the program have ideally been determined in this order since there is some interdependence among the modifications. That is, when the incremental energy savings attributable to the i^{th} modification (M_i) are calculated for a specific building using a load determination model, all of the more cost-effective modifications (M_1, M_2, •••, M_{i-1}) have already been incorporated, while all of the less cost-effective modifications (M_{i+1}, M_{i+2}, ••• M_{nl}) have yet to be considered.

However, the proper economic ranking of the modifications may change as the plant efficiencies are changed or the solar fraction for space heating (FH) changes. Ideally, the optimal values for each of these parameters should be used when establishing the initial ordering of the modifications. Since these values are obviously not known at the outset, an informed estimate must be made for each. If the ranking of modifications determined in the SOLCOM analysis differs significantly from the ranking used in estimating the energy savings (especially for modifications near the cut-off point in the optimization) it may be wise to recalculate the energy savings based on this new ranking and rerun SOLCOM with the new data.

The SOLCOM program initially evaluates the list of envelope modifications, in the order entered, to determine the AHR, DHL, ACR, and DCL as each additional envelope modification is incorporated into the building design. Based on the initial search values (specified by the user), SOLCOM calculates an optimal collector area and corresponding solar fractions. Using these initial search values and solar fractions, SOLCOM then steps through the list of nl envelope modifications to make sure they are ranked in decending order of cost effectiveness, based on a benefit-cost ratio (R_i: i = 1, 2, •••, nl), so that $R_1 \geq R_2 \geq \cdots \geq R_{nl}$, where

$$R_i = [\Delta HL_i \cdot ((1-FH) \cdot KH/HE + DE_3 \cdot KS \cdot FH) + \Delta AHR_i \cdot DE_1 \cdot KD_1 + \Delta CL_i \cdot KC/CE + \Delta ACR_i \cdot DE_2 \cdot KD_2 + \Delta MH_i \cdot HO \cdot VCHE + \Delta MC_i \cdot CO \cdot VCCE] / \Delta MCE_i \quad (4.22)$$

and where[1]

KD_1 = cost per kWh for heating distribution system x UPV* for same,

KD_2 = cost per kWh for cooling distribution system x UPV* for same,

ΔACR_i = change in annual cooling requirements in GJ (10^6 Btu) due to i^{th} modification,

ΔCL_i = $\Delta ACR_i \cdot (1+EE \cdot DE_2)$,

[1] Other variables are described in section 4.3.1

DE_2 = kWh per GJ (10^6Btu) ACR required for cooling distribution system,

ΔMH_i = $(DHL_i - DHL_{i-1})(1 - EE \cdot DE_1)$,

ΔMC_i = $(DCL_i - DCL_{i-1})(1 + EE \cdot DE_2)$,

DHL_i = design heating load (MJ or 10^3Btu) for envelope with modifications 1 through i,

DCL_i = design cooling load (MJ or 10^3Btu) for envelope with modifications 1 through i,

HO = oversizing factor for heating plant,

CO = oversizing factor for cooling plant,

VCHE = variable cost per MJ (10^3Btu) output capacity for heating plant,

VCCE = variable cost per MJ (10^3Btu) output capacity for cooling plant, and

ΔMCE_i = $MCE_i - MCE_{i-1}$, the incremental cost of the i^{th} modification.

This ranking procedure is based on the assumption that the optimal solar fraction(s) remain unchanged as the AHR are reduced, as discussed in section 4.2. While this assumption is not exactly correct, it is so close that any difference would rarely affect the resulting ranking. (An extra step in the search procedure in SOLCOM is designed to catch an error here if this assumption causes a misordering of envelope modifications.)

If the order in which the modifications are initially entered does not satisfy this ranking criteria, it is changed internally in SOLCOM until it does. Note, however, that the values entered for ΔAHR, ΔDHL, ΔACR, and ΔDCL for any given modification do not change. In fact, if these values were to be recalculated in the load determination program based on this new order, there would probably be some difference from the original estimates because of the interdependent nature of the envelope modifications. For this reason, if the final ordering of the modifications (printed out after the optimization analysis) differs significantly from the initial ordering used to find ΔAHR_i, $\Delta ADHL_i$, ΔACR_i, and ΔDCL_i, especially for the last few modifications included in the optimum configuration, serious consideration should be given to recalculating the value of these changes in the new ordering.

(2) <u>First Approximation to Optimum Combination of Envelope Modifications</u>

A first approximation to the optimum combination of envelope modifications is sought in order to reduce the number of iterations for which the collector area must be optimized as SOLCOM steps through i = 1, 2, ... nl. This first approximation is based on the assumption that the optimal solar fractions remain unchanged as the envelope is modified and that the optimal collector area can be approximated using equation 4.20 above. The collector size is first optimized for the starting point designated by the user or determined in a previous iteration. Then TC_i and TC_{i-1} are determined using equation 4.21, with approximate values substituted for the collector area and solar fractions if the exact value is not known from a previous iteration. The difference is calculated as

$$DT_i = TC_i - TC_{i-1}. \quad (4.23)$$

If $DT_i > 0$, so that total costs increase as the i^{th} modification is brought in, i is decremented by 1 until either (a) $DT_i \leq 0$, in which case all modifications 1, 2, ..., i are cost effective, or (b) i = 1 and $DT_i > 0$, in which case no modifications are cost effective.

If $DT_i \leq 0$, so that total costs decrease or remain constant as the i^{th} modification is brought in, i is incremented by 1 until either

(a) $DT_i > 0$, in which case all modifications 1, 2, ... i-1 are cost effective (but i is not), or (b) i = nl and $DT_i \leq 0$, in which case all nl modifications are cost effective.

(3) Actual Determination of Optimum Combination of Envelope Modifications

At this point a first approximation to the optimum combination of envelope modifications has been found and it will serve as the starting point to find the actual optimum combination. In practice, this first approximation usually is the actual optimum as well but it must be verified and adjusted if not.

Starting with the last cost-effective modification determined above (say the i^{th}), TC_i and TC_{i-1} are recalculated using the actual optimum solar fractions and collector areas for AHR_i and AHR_{i-1} (as detailed in section 4.3.1). The same evaluation procedures for DT_i discussed in (2) above are used to find the actual optimum combination of modifications, but the solar collector area must be reoptimized with each step if it is unknown.

One additional check is made, however, to ensure that an error in the ranking of modifications does not terminate the optimization search prematurely. (The possibility of an error was discussed in (1) above.) The search algorithm goes one step past the termination point in order to ensure that the modifications are ranked properly at this critical point, i.e., the total cost continues to increase. If a ranking error is detected, the modifications are reordered and the search process is then continued as described above.

4.3.3 Optimization of Space Heating Plant Efficiency

Up to five space heating plant efficiencies may be specified in SOLCOM, listed in order of increasing efficiency. The incremental benefit-cost ratio (R_j^h) for each increase in efficiency must be smaller than the one preceding it, i.e.

$$R_2^h > R_3^h > \cdots > R_{n2}^h . \quad (4.24)$$

This benefit-cost ratio is calculated as follows:

$$R_j^h = \frac{\frac{1}{HE_j} - \frac{1}{HE_{j-1}}}{\Delta PCSH_j} , \quad (4.25)$$

where HE_j = seasonal efficiency of the j^{th} space heating plant, and

$\Delta PCSH_j$ = $PCSH_j - PCSH_{j-1}$, the incremental LCC of the j^{th} plant relative to the $(j-1)^{th}$ plant.

If $R_j^h \leq R_{j+1}^h$, the j^{th} plant is dropped out of the optimization analysis since it cannot be optimal. The incremental LCC of the $(j+1)^{th}$ plant ($\Delta PCSH_{j+1}$) is then increased to include $\Delta PCSH_j$, and n2 is decreased accordingly.

The search algorithm to find the optimal HE_j (j = 1, 2, ..., n2) in SOLCOM is analogous to the search algorithm used to find the optimal envelope configuration. Equation 4.21 is used to calculate TC_j and TC_{j-1}, given WE, for the starting point specified ($1 < j \leq n2$). The optimal combination of envelope modifications, optimal collector area and corresponding solar fractions are determined for both HE_j and HE_{j-1} and are used in the determination of TC_j and TC_{j-1}, respectively. The difference in total life cycle costs, DT_j, is computed as:

$$DT_j = TC_j - TC_{j-1}. \quad (4.26)$$

If $DT_j > 0$, j is decremented by 1 until either

(a) $DT_j \leq 0$, in which case HE_j is optimal or
(b) j=2 and $DT_j > 0$, in which case HE_1 is optimal.

If $DT_j \leq 0$, then j is incremented by 1 until either

(a) $DT_j > 0$, in which case HE_{j-1} is optimal, or
(b) j = n2 and $DT_j \leq 0$, in which case HE_{n2} is optimal.

At this point, the optimal efficiency for the space heating plant and the corresponding optimal combination of envelope modifications and collector area have all been identified, given WE, the efficiency of the water heating plant. If space heating and water heating are provided by the same plant, then WE is assigned the same value as HE_j (j = 1, 2, ... n2) in SOLCOM. In this case, no further iterations are needed, for WE is optimized at the same time as HE. If the water heating plant is separate, and more than one efficiency level is to be considered in the SOLCOM analysis, the optimization algorithm for the water heating plant must be executed.

4.3.4 Optimization of Water Heating Plant Efficiency

The search algorithm to find the optimal water heating plant efficiency is essentially the same as the search algorithm used for the space heating plant above. WE_1 is the efficiency of the basic water heating plant. WE_w (w = 2, 3, ..., n3) is the efficiency of the W^{th} improved plant. The incremental benefit-cost ratio (R_1^w) for each increase in efficiency must be smaller than the one preceding it, i.e.,

$$R_2^w > R_3^w > \cdots > R_{n3}^w. \qquad (4.27)$$

This benefit-cost ratio is similar to equation (4.25):

$$R_w^w = \frac{\frac{1}{WE_w} - \frac{1}{WE_{w-1}}}{\Delta PCWH_w} \quad , \qquad (4.28)$$

where WE_w = average efficiency of the w^{th} water heating plant, and

$\Delta PCWH_w = PCWH_w - PCWH_{w-1}$, the incremental LCC of the w^{th} plant relative to the $(w-1)^{th}$ plant.

If $R_w^w \leq R_{w+1}^w$, the w^{th} plant is dropped out of the optimization analysis since it cannot be optimal. The incremental LCC of the $(w+1)^{th}$ plant (ΔPCW_{w+1}) is then increased to include $\Delta PCWH_w$, and n3 is decreased accordingly.

An initial starting point for w ($1 < w \leq n3$) is specified by the user during the execution of SOLCOM2. The optimal heating system efficiency, combination of envelope modifications, and collector area and the corresponding total LCC (TC_w and TC_{w-1}) are determined for both WE_w and WE_{w-1}, as described in sections 4.3.1-4.3.3.

DT_w is then calculated as

$$DT_w = TC_w - TC_{w-1}. \qquad (4\text{-}29)$$

If $DT_w > 0$, then w is decremented by 1 until either:

(a) $DT_w \leq 0$, in which case WE_w is optimal, or

(b) $w = 2$ and $DT_w > 0$, in which case WE_1 is optimal.

If $DT_w \leq 0$, j is incremented by 1 until either

(a) $DT_w > 0$, in which case WE_{w-1} is optimal, or

(b) $w = n3$ and $DT_w \leq 0$, in which case WE_{n3} is optimal.

Optimal values have now been determined for the collector area and corresponding solar fractions; for envelope modifications and corresponding AHR, ACR, DHL, and DCL; and for space heating and water heating system efficiencies. In addition the total LCC associated with the overall conservation investment has been calculated. If it is desirable to determine an optimal cooling system efficiency (CE) as well, separate runs of SOLCOM can be made with each CE to be evaluated, along with its corresponding cost data. The CE resulting in the lowest overall total LCC indicates the optimal overall configuration, including CE.

5. FINANCIAL ANALYSIS METHODOLOGY

In this section the methodology used in SOLCOM1 to determine life-cycle costs for each of the envelope modifications, plant efficiency improvements, and the solar heating system, as well as for energy costs, is detailed. Tax treatments (including depreciation and tax credits), resale value, inflation, and financing arrangements are also discussed.

5.1 CALCULATION OF DISCOUNT FACTORS, COST ESCALATION FACTORS, AND UPV* FACTORS

The SOLCOM program requires that annual cost escalation rates be specified individually for several different categories of expenditures. These categories include individual energy types, operating and maintenance costs and conservation measure costs. These cost escalation rates, and the discount rate used to convert future costs to present value, can be changed during the study period to better track long term expectations of inflation and opportunity costs.

The methods used to convert annual price escalation rates and discount rates to cumulative escalation factors and discount factors are detailed in the following sections.

5.1.1 Cost Escalation Factors

The cost escalation factor for any given year i (CEF_i) represents the ratio of the cost for a given cost element at the end of year i to its cost at the beginning of the study period (i.e., the beginning of year 1). Cost escalation factors for each cost category are computed as follows:

$$CEF_0 = 1 \tag{5.1a}$$

$$CEF_i = CEF_{i-1} \cdot (1 + CER_i) \text{ for } i = 1, 2, ..., N \tag{5.1b}$$

where CER_i = the cost escalation rate in year i, and

N = length of the study period (in years).

5.1.2 Discount Factors

The discount factor for any given year i represents the ratio of the present value of a given dollar amount to the actual dollar amount incurred in year i for a given cost element. The discount factor is computed as follows:

$$DF_0 = 1 \tag{5.2a}$$

$$DF_i = DF_{i-1}/(1 + DR_i) \text{ for } i = 1, 2, ..., N \tag{5.2b}$$

where DF_i = discount factor in year i, and

DR_i = discount rate in year i.

5.1.3 Modified Uniform Present Value Factors

The modified uniform present value factor (UPV*) is used to find the present value of a stream of related costs (or savings) which occur annually over the study period (N), increasing (or decreasing) at some known rate. UPV* factors are used in SOLCOM to determine the present value of annual energy expenditures for each energy type and the present value of annually recurring operating and maintenance costs. Since the discount rate may not be constant over the entire study period, UPV* factors are computed using the following summation formula (instead of a closed-form equation):

$$UPV^{*} = \sum_{i=1}^{N} CEF_i \cdot DF_i \ .$$

5.2 GENERAL LCC MODEL FOR CONSERVATION INVESTMENTS IN BUILDINGS

5.2.1 Non-Energy Costs

Conservation measures to improve the overall energy efficiency of a new building generally have life-cycle costs (LCC) significantly different from their first cost alone. The LCC of any given conservation measure (distinct from its energy cost implications) is made up of a number of cost elements, each attributable specifically to that measure, as follows:

$$LCC = FC + ST - CT + AROM + NAROM + PT - RV + RT - TS \tag{5.3}$$

where FC = first cost,
ST = sales tax,
CT = investment or conservation tax credits,
AROM = annual recurring operating and maintenance costs,
NAROM = non-annual recurring operating and maintenance costs, including replacement cost,
PT = property taxes,
RV = resale value,
RT = capital gains and depreciation recapture taxes, and
TS = income tax savings (from ST, AROM, NAROM, PT, depreciation, and interest payments, if any),

and all costs are expressed in life-cycle, present-value dollar terms.

If the investment is financed, then

$$FC = DP + MP, \tag{5.4}$$

where DP = down payment (at beginning of study period), and
MP = present value of all principal and interest payments, and
TS is adjusted to include tax savings from interest payments.

The following calculation methods are used in SOLCOM to compute a LCC factor for each measure which incorporates each of these cost elements. (Note that all cost elements, except O&M-related costs, are calculated in SOLCOM as a percentage of the first cost. O&M-related costs can be calculated either as a percentage of the first cost or independently of first cost.) Each of these factors is computed once in the SOLCOM1 subprogram and then transferred to the SOLCOM2 subprogram.

(1) First Cost (FC) This variable is entered directly into the data list of SOLCOM1. If FC is financed, see subsection 5.3.2 which describes financing factors.

(2) Sales Tax (ST)

$$ST = FC \cdot AP \cdot TX, \tag{5.5}$$

where AP = percentage of first cost to which sales tax is applicable (%/100), and
TX = sales tax rate (%/100).

(3) Investment or Conservation Tax Credits (CT)

These tax credits are assumed to be realized at the end of the first year. State tax credits are adjusted to reflect increased Federal tax liability. Thus:

$$CT = CT_F + CT_S, \tag{5.6}$$

$$CT_F = (FC + ST) \cdot CF \cdot DF_1, \text{ and} \tag{5.7}$$

$$CT_S = (FC + ST) \cdot CS(1-TF) \cdot DF_1, \tag{5.8}$$

where CT_F = Federal tax credit,

CT_S = state tax credit (net),

CF = Federal tax credit rate (%/100),

CS = state tax credit rate (%/100),

DF_1 = discount factor at end of year 1, and

TF = Federal tax rate (%/100).

(4) Annually Recurring O & M Costs (AROM)

$$AROM = ARC \cdot UPV_m^*, \tag{5.9}$$

where ARC = annual recurring cost (in base-time dollars) and

UPV_m^* = UPV^* for O & M costs.

(5) Non-Annually Recurring O&M Costs (NAROM)

$$NAROM = \sum_{i=1}^{NN} NRC_i \cdot CEF^m_{yi} \cdot DF_{yi}, \qquad (5.10a)$$

where NN = number of non-annually recurring costs,

NRC_i = amount of i^{th} non-annually recurring cost (in base-time dollars),

CEF^m_{yi} = cost escalation factor for O&M expenditures in year yi,

DF_{yi} = discount factor for year yi, and

yi = year of occurrence of i^{th} cost (base year = 1).

Capital replacement costs are included in the NAROM cost element, which results in their treatment as a tax deductable expenditure in the year of occurrence, rather than capital expenditure which must be depreciated over time. A more comprehensive analysis would incorporate a depreciation schedule for capital replacements. However, it is unlikely that current depreciation schedules will still be in use at the time a replacement is made.

(6) Property Taxes (PT)

Property taxes are based on an assumed linear reduction in real asset value from first cost to remaining value (in constant dollars) at the end of the study period and a corresponding increase in nominal value due to the general rate of increase in prices for such measures. They are calculated as though they are paid at the beginning of each year, based on the asset value at that time, but the tax savings are discounted from the end of the year. Property taxes attributable to any given conservation measure can be set to zero by setting PP = 0 for that measure.

$$PT = FC \cdot PP \cdot TP \cdot \sum_{i=1}^{N} \left[1-\left(\frac{i-1}{N}\right)(1-RP)\right] \cdot CEF^c_{i-1} \cdot DF_{i-1}, \qquad (5.10b)$$

where PP = assessment rate for the particular measure (%/100),

TP = property tax rate (%/100),

RP = remaining value factor for measure at end of study period (in base year dollars), and

CEF^c_i = cost escalation factor for conservation measures in year i.

(7) Resale Value (RV)

Resale value is the remaining value of each conservation measure at the end of the study period, whether the building is to be sold, torn down, or held. RV can be set equal to zero by setting RP=0.

$$RV = FC \cdot RP \cdot CEF^c_N \cdot DF_N. \qquad (5.11)$$

(8) Capital Gains and Depreciation Recapture Taxes (RT)

Capital gains tax and depreciation recapture tax are calculated for both the state and Federal government if the nominal resale value (SP) of a given conservation measure is greater than its first cost less cumulative straight-line depreciation. RT can be set equal to zero by specifying $CG_1 = 0$ for Federal tax purposes and $CG_2 = 0$ for state tax purposes. (CG_1 and CG_2 are Federal and state capital gains factors, respectively, in data sheet 1.) Depreciation computations are discussed in subsection 5.3 below.

Capital gains tax liability to Federal (CGF) and state (CGS) tax agencies are calculated using the positive difference between the nominal resale value of an asset and its first cost as follows:

$$CGF = [SP-FC] \cdot TF \cdot CG_1 \cdot DF_N \quad \text{for } (SP>FC), \tag{5.12a}$$

$$CGS = [SP-FC] \cdot TS \cdot (1-TF) \cdot CG_2 \cdot DF_N \quad \text{for } (SP>FC), \tag{5.12b}$$

where $SP = FC \cdot RP \cdot CEF_N^c$,

TF = Federal income tax (marginal), and

TS = state income tax state (marginal).

Depreciation recapture tax liability (RT_f and RT_s for Federal and state, respectively) varies according to the type of property and appropriate recapture rule[1]. One of three different rules may apply:

(a) Recapture Rule 1: The positive difference between the nominal resale value (SP) and the remaining basis (first cost less cumulative depreciation) is taxed as ordinary income.

$$RT_f = (FC-RB_f) \cdot TF \cdot DF_N \quad \text{for } SP \geq FC, \text{ or} \tag{5.13a}$$

$$RT_f = (SP-RB_f) \cdot TF \cdot DF_N \quad \text{for } FC > SP > RB_f, \text{ and} \tag{5.13b}$$

$$RT_s = (FC-RB_s) \cdot TS(1-TF) \cdot DF_N \quad \text{for } SP \geq FC, \text{ or} \tag{5.14a}$$

$$RT_s = (SP-RB_s) \cdot TS(1-TF) \cdot DF_N \quad \text{for } FC > SP > RB_s, \tag{5.14b}$$

where $RB_f = FC-CD_f$, remaining basis using Federal depreciation schedule,

CD_f = cumulative depreciation using Federal depreciation schedule,

$RB_s = FC-CD_s$, remaining basis using state depreciation schedule, and

CD_s = cumulative depreciation using state depreciation schedule.

---

[1] A good overview of depreciation guidelines and recapture rules is available in the Commerce Clearing House, Editorial Staff Publication, "Economic Recovery Tax Act of 1981, Law and Explanation, Chapter 2 ("Business Tax Incentives"), Chicago, Illinois, August 1981.

(b) Recapture Rule 2: The positive difference between the nominal resale value and the remaining basis is taxed as capital gains.

$$RT_f = (FC-RB_f) \cdot TF \cdot CG_1 \cdot DF_N \quad \text{for } SP \geq FC, \text{ or} \qquad (5.15a)$$

$$RT_f = (SP-RB_f) \cdot TF \cdot CG_1 \cdot DF_N \quad \text{for } FC > SP > RB_f, \text{ and} \qquad (5.15b)$$

$$RT_s = (FC-RB_s) \cdot TS \cdot CG_2 \cdot (1-TF) \cdot DF_N \quad \text{for } SP \geq FC, \text{ or} \qquad (5.16a)$$

$$RT_s = (SP-RB_s) \cdot TS \cdot CG_2 \cdot (1-TF) \cdot DF_N \quad \text{for } FC > SP > RB_f. \qquad (5.16b)$$

(c) Recapture Rule 3: The positive difference between the nominal resale value and the remaining basis (first cost less straight-line depreciation) is taxed as capital gains. Any excess depreciation claimed through use of an accelerated method of depreciation is taxed as ordinary income.

$$RT_f = [(FC-RB_f')\cdot CG_1 + (RB_f'-RB_f)]\cdot TF\cdot DF_N \quad \text{for } SP\geq FC, \qquad (5.17a)$$

$$RT_f = [(SP-RB_f')\cdot CG_1 + (RB_f'-RB_f)]\cdot TF\cdot DF_N \quad \text{for } FC>SP>RB_f', \text{ or} \qquad (5.17b)$$

$$RT_f = (SP-RB_f)\cdot TF\cdot DF_N \quad \text{for } RB_f'>SP>RB_f, \text{ and} \qquad (5.17c)$$

$$RT_s = [(FC-RB_s')\cdot CG_2 + (RB_s'-RB_s)]\cdot TS(1-TF)\cdot DF_N \quad \text{for } SP\geq FC, \qquad (5.18a)$$

$$RT_s = [(SP-RB_s')\cdot CG_2 + (RB_s'-RB_s)]\cdot TS(1-TF)\cdot DF_N \quad \text{for } FC>SP>RB_f', \text{ or} \qquad (5.18b)$$

$$RT_s = (SP-RB_s)\cdot TS(1-TF)\cdot DF_N \quad \text{for } RB_s'>SP>RB_s, \qquad (5.18c)$$

where RB_f' = remaining basis using straight-line depreciation rules, Federal and

RB_s' = remaining basis using straight-line depreciation rules, state.

(9) Income Tax Savings

Present-value income tax savings are computed in SOLCOM1 as follows:

(a) Tax savings from sales tax payments (TS_{ST}):

$$TS_{ST} = ST\cdot(TF + TS(1-TF))\cdot DF_1. \qquad (5.19)$$

(b) Income tax savings from annually recurring O&M (TS_{AROM}):

$$TS_{AROM} = AROM\ (TF + TS(1-TF)). \qquad (5.20)$$

(c) Income tax savings from non-annually recurring O&M (TS_{NAROM}):

$$TS_{NAROM} = NAROM\ (TF + TS(1-TF)). \qquad (5.21)$$

(d) Income tax savings from property tax payments (TS_{PT}):

(Property taxes are assumed to be paid at the beginning of the year but not realized as tax savings until the end of the year.)

$$TS_{PT} = FC \cdot PP \cdot TP\left[\sum_{i=1}^{N} \left[1-\left(\frac{i-1}{N}\right)(1-RP)\right] \cdot CEF_{i-1}^{c} \cdot DF_i\right] \cdot (TF+TS(1-TF)). \quad (5.22)$$

(e) Income tax savings from depreciation (TS_{DEP}):

$$TS_{DEP} = DD_1 \cdot TF + DD_2 \cdot TS(1-TF). \quad (5.23)$$

where DD_1 = present value of cumulative depreciation, Federal, and

DD_2 = present value of cumulative depreciation, state.

(The methodology used to compute cumulative depreciation is detailed in section 5.3 below.)

(f) Income tax savings from interest payments (TS_{INT}):

$$TS_{INT} = IN' \cdot (TF+TS(1-TF)), \quad (5.24)$$

where IN' = present-value of interest payments, discounted from end of year.

(The methodology used to compute interest payments is detailed in section 5.3 below.)

5.2.2 Energy Costs

In addition to the life-cycle costs of the specific conservation measures examined in SOLCOM, life-cycle costs must be calculated for each energy type used in the building. Life-cycle energy costs are computed in terms of the cost per GJ or 10^6Btu of each energy type purchased per year each year over the study period.

$$EC_i = \$/U_i \cdot UPV_i^* \quad (5.25)$$

where EC_i = present-value life cycle cost of i^{th} energy type per GJ (10^6 Btu) per year for N years,

$\$/U_i$ = cost per GJ (10^6 Btu) of energy type i at beginning of study period, and

UPV_i^* = modified uniform p. v. factor for the i^{th} energy type.

Tax savings for energy type (TS_{Ei}) are computed as

$$TS_{Ei} = EC_i \; (TF + TS(1-TF)). \quad (5.26)$$

5.3 CALCULATION OF CUMULATIVE DEPRECIATION FACTORS AND FINANCING FACTORS

5.3.1 Cumulative Depreciation Factors

Cumulative depreciation factors for each of the three conservation investment classes (envelope modifications, conventional heating and cooling equipment improvements, solar equipment) are calculated for both Federal and state income tax purposes. These cumulative depreciation factors are calculated from depreciation schedules entered into the SOLCOM1 program. (Separate depreciation schedules for Federal and state tax purposes can be entered if warranted; otherwise, the depreciation factor for state taxes is the same as that computed for Federal tax purposes.

The depreciation schedule has the form $D_1, D_2, \ldots, D_M$

where D_i = the ratio of depreciation allowance to first cost in year i (i = 1, 2, ..., M), and

M = the number of years in the study period, or the depreciation period, whichever is shorter.

Cumulative depreciation factors are calculated both in present value (i.e., discounted) and nominal (i.e., non-discounted) terms as follows:

$$DA = \sum_{i=1}^{M} D_i \cdot DF_i, \text{ and} \qquad (5.27)$$

$$DD = \sum_{i=1}^{M} D_i, \qquad (5.28)$$

where DA = the present-value cumulative depreciation factor, and

DD = the nominal cumulative depreciation factor.

In addition, a straight-line cumulative depreciation factor (SC) must be calculated if depreciation recapture rule 3 is used and the resale value of the investment is greater than the remaining basis (SP > FC-DD) at the end of the study period. This is calculated as

$$SL = 1 \quad \text{for } N \geq M, \text{ or} \qquad (5.29a)$$

$$SL = N/DL \quad \text{for } N < DL, \qquad (5.29b)$$

where N = the length of the study period, and

DL = the actual length of the depreciation period for a given class of assets.

5.3.2 Financing Factors

All of the conservation measures evaluated in SOLCOM are considered to have the same financing terms, if any. Three different financing alternatives can be specified in SOLCOM:

(1) fully amortized loan with equal payments in each time period,

(2) interest-only payments at periodic intervals (of equal length) but not less than one per year); principal paid back at end of loan life, and

(3) principal and interest deferred to end of loan period.

While a longer loan life than the time horizon can be specified, any unpaid principal is assumed to be paid back at the end of the study period. A down payment factor (DP), the ratio of initial payment to actual first cost (including sales tax) for a given conservation measure is specified in the input data file (see data sheet 5.) The loan amount factor is then computed as (1-DP).

Computation procedures to find the present value factor for principal and interest payments are as follows:

(1) <u>Loan Type 1 (Amortized)</u>

(a) Loan payment factor (CR):

$$CR = \frac{LI/LN \cdot (1+LI/LN)^{LN \cdot LL}}{(1 + LI/LN)^{LN \cdot LL} - 1} \tag{5.30}$$

where LI = annual interest rate (nominal),

LN = number of payments per year, and

LL = loan life (in years).

(b) Present-value factor for loan payments discounted from time of payment (L1):

$$L1 = (1-DP) \cdot \sum_{i=1}^{LM} CR \cdot \frac{(1+DR_i'/LN)^{LN}-1}{DR_i'/LN \cdot (1+DR_i'/LN)^{LN}} \cdot DF_{i-1} \tag{5.31}$$

where $DR_i' = LN \cdot (1+DR_i)^{1/LN} - LN$, and (5.32)

LM = LL or study period, whichever is shorter.

(DR_i' is the nominal equivalent of the effective discount rate in year i, DR_i. If LN = 1, DR_i' and DR_i are equivalent.)

(c) Present-value factor for interest payments discounted from end of year (L2):

$$L2 = \sum_{i=1}^{LM} \cdot DF_i \sum_{k=1}^{LN} I_{i,k} \tag{5.33}$$

where $I_{i,k} = P_{i,k-1} \cdot LI/LN$, $i=1, 2, ..., LM$ (5.34)

$k=1, 2, ..., LN$

$$P_{1,o} = 1-DP, \tag{5.35}$$

$$P_{i,o} = P_{i-1,LN}, \qquad i = 2, 3, ..., LM \tag{5.36}$$

$$P_{i,k} = P_{i,k-1} + I_{i,k} - CR(1-DP), \qquad k=1, 2, ..., LN \tag{5.37}$$

(d) If the loan life is greater than the study period (LL > N) then the present value of the remaining principal (L3) must be calculated:

$$L3 = P_{LM,LN} \cdot DF_N \tag{5.38}$$

(2) Loan Type 2 (Interest Only)

(a) Present-value factor for interest payments discounted from time of payment (L1):

$$L1 = (1-DP) \sum_{i=1}^{LM} \frac{LI}{LN} \cdot \frac{(1+DR_i'/LN)^{LN}-1}{DR_i'/LN \cdot (1+DR_i'/LN)^{LN}} \cdot DF_{i-1} \tag{5.39}$$

(b) Present-value factor for interest payments discounted from end of year (L2):

$$L2 = (1-DP) \sum_{i=1}^{LM} LI \cdot DFi \tag{5.40}$$

(c) Present-value for remaining principal at end of loan period (L3):

$$L3 = (1-DP) \cdot DF_{LM} \tag{5.41}$$

(3) Loan Type 3 (Interest and Principal Deferred)

(a) Present-value factor for interest payments made at end of loan period (L1):

$$L1 = (1-DP)\left[(1 + LI)^{LM} - 1\right] \cdot DF_{LM} \tag{5.42}$$

(b) Present-value factor for remaining principal at end of loan period (L3):

$$L3 = (1-DP) \cdot DF_{LM} \tag{5.43}$$

6. SUMMARY

This report provides a methodology, algorithms, and a computer program to determine simultaneously the lowest life-cycle cost combination of energy-conserving envelope modifications, equipment efficiencies, and size of an active solar heating system for a new commercial building. These three competing approaches to energy conservation in a new building design must be analyzed simultaneously because they are functionally interdependent. That is, a change in any one will significantly affect the energy savings attributable to each of the others. The computer program, called SOLCOM, can be used by design professionals on a microcomputer. Considerable financial analysis and thermal performance data is required to run the program. The thermal performance data will require extensive engineering analysis of the appropriate conservation modifications and of the active solar heating system design prior to the use of the SOLCOM program.

This report represents a significant advance over previous studies which evaluated solar heating systems and other energy conservation methods in buildings in a systematic manner. The economic optimization algorithm for determining the size of a solar heating system, based on the Newton-Raphson method of successive approximation, greatly decreases the amount of computer time needed to converge on an optimal collector size. This algorithm makes the use of a microcomputer to solve the simultaneous optimization problem a practical choice.

However, only a hypothetical building is used in this report to demonstrate the application of the SOLCOM program. In order to demonstrate the usefulness of this program to professionals engaged in commercial building design, actual building and system performance data are needed. As active solar heating systems become more attractive to commercial building developers during the next decade, an expansion of this report to include realistic examples of design problems and their solutions would greatly increase the value of the SOLCOM program.

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APPENDIX A

SOLCOM DATA SHEETS

1. PROJECT IDENTIFICATION AND ECONOMIC PARAMETERS
2. DISCOUNT RATES AND PRICE ESCALATION RATES BY TIME INTERVALS
3. ENERGY PRICE ESCALATION RATES BY TIME INTERVAL Y(I)
4. ENERGY COST DATA
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7. NON-ANNUALLY RECURRING O&M COSTS - ENVELOPE MODIFICATIONS
8. DEPRECIATION DATA FOR ENVELOPE MODIFICATIONS
9. SPACE HEATING EQUIPMENT DATA
10. NON-ANNUALLY RECURRING O&M COSTS - SPACE HEATING PLANT IMPROVEMENTS
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13. SPACE HEATING SYSTEM DATA
14. DEPRECIATION SCHEDULE FOR CONVENTIONAL HEATING AND COOLING PLANTS
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16. DEPRECIATION DATA FOR SOLAR HEATING EQUIPMENT
17. BASIC ENVELOPE PERFORMANCE DATA, WATER HEATING REQUIREMENTS, AND INCIDENT SOLAR RADIATION
18. REDUCTIONS IN HEATING AND COOLING LOADS DUE TO ENVELOPE MODIFICATIONS

DATA SHEET 1

PROJECT IDENTIFICATION AND ECONOMIC PARAMETERS

```
01001 DATA _________,
             F1$
01002 DATA ____________________________________________
                                  N$
01003 DATA _________, _________, _________, _________, _________
              MM         YO         TH         TT         TG
01004 DATA _________, _________, _________, _________, _________
              TS         TX        CG(1)      CG(2)       TP
```

Variable	Description
F1$	File name
N$	Project title
MM	Measurement base: MM = 1: conventional units (e.g. Btu, gallons), MM = 2: SI units (e.g., J(oules), liters).
YØ	First year of occupancy Occupancy is assumed to occur on January 1 and all initial costs are incurred on that date. January 1 of year YØ is the base time to which all future costs are discounted.
TH	Time horizon, or the length of the study period in years ($0 < TH \leq 50$).
TT	Tax status of owner: TT = 1: tax paying, TT = 2: tax exempt. If TT = 1, all initial costs (except sales tax) are depreciated; all future costs, sales tax, and interest payments are tax deductible in the year of occurrence. Tax credits are computed as of the end of the first year. If TT = 2, no tax deductions, depreciation, or tax credits are allowed; no property taxes are paid.
TG	Federal income tax rate (%).
TS	State income tax rate (%).
TX	Sales tax rate (%).
CG(1)	Percent of capital gains subject to income taxation at ordinary income tax rate - Federal taxes (currently 40%).
CG(2)	Same as CG(1) but for state taxes.
TP	Property tax rate (%). The property tax rate is applied to the assessed value of each conservation measure. The assessment rate is specified individually for each measure.

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DATA SHEET 2

DISCOUNT RATES AND PRICE ESCALATION RATES
BY TIME INTERVAL

02001 DATA ________
IN

Line Number	Y(I)	R1(I)	R2(I)	R3(I)	"IN" entries only ↓
02101 DATA					I = 1
02102 DATA					I = 2
02103 DATA					I = 3
02104 DATA					I = 4
02105 DATA					I = 5
02106 DATA					I = 6
02107 DATA					I = 7
02108 DATA					I = 8
02109 DATA					I = 9
02110 DATA					I = 10

continue as needed

02150 DATA					I = 50

Variable	Description
IN	Number of time intervals for which a discount rate and price escalation rates are entered (see lines 2101-2150 and 3101-3150). $(0 < IN \leq 50.)$ The discount rate and price escalation rates for certain cost elements can be varied from time interval to time interval.
Y(I)	Length of the I^{th} time interval (in whole years) for which a discount rate and price escalation rates are given. The sum of all Y(I), I = 1, 2, ..., IN, must be at least as great as the length of the study period (TH).
R1(I)	Discount rate in the I^{th} time interval (%).
R2(I)	Annual rate of increase in operating and maintenance costs in I^{th} time interval (%).
R3(I)	Annual rate of increase in the cost of conservation measures, including solar equipment, in the I^{th} time interval (%).

DATA SHEET 3

ENERGY PRICE ESCALATION RATES
BY TIME INTERVAL Y(I)

3001 DATA ________
EN

EN entries only* →

Line Number	R4(I,1)	R4(I,2)	R4(I,3)	R4(I,4)	R4(I,5)	R4(I,6)	IN entries only** ↓
03101 DATA							I = 1
03102 DATA							I = 2
03103 DATA							I = 3
03104 DATA							I = 4
03105 DATA							I = 5
03106 DATA							I = 6
03107 DATA							I = 7
03108 DATA							I = 8
03109 DATA							I = 9
03110 DATA							I = 10

continue as needed

03150 DATA							I = 50

Variable	Description
EN	Number of energy types to be entered. The same energy types with different unit prices (e.g., electricity for space heating at winter rates and electricity for cooling at summer rates) are counted separately. $(0 < EN \leq 6)$
R4(I,K)	Annual rate of increase in the K^{th} energy type price in I^{th} time interval (%).

* EN entries corresponding to number of energy types specified in line 3001.
** IN entries corresponding to number of time intervals used in Data Sheet 2.

DATA SHEET 4

ENERGY COST DATA

Line Number	KE(K)	TU(K)	EN$(K)	EM$(K)	EN entries only* ↓
04101 DATA					K = 1
04102 DATA					K = 2
04103 DATA					K = 3
04104 DATA					K = 4
04105 DATA					K = 5
04106 DATA					K = 6

Variable	Description
KE(K)	Cost per unit of energy type K (in base-time dollars).
TU(K)	Thermal units per unit of energy type K, in KJ (Btu); e.g. 3,600KJ/kWh (3,412 Btu/kWh).
EN$(K)	Name of K^{th} energy type.
EM$(K)	Name of unit used for K^{th} energy type (e.g. kWh, liter, gallon).

* EN entries corresponding to number of energy types entered in Data Sheet 3.

DATA SHEET 5

MORTGAGE DATA

```
05101 DATA ________
              LT

Skip the following if LT = 0

05002 DATA ________, ________, ________, ________
              LL        LN        LI        DP
```

Variable	Description
LT	Loan type designator: LT = 0: no loan LT = 1: amortized loan, LT = 2: interest only loan, LT = 3: interest and principal deferred loan.
LL	Life of loan (years)
LN	Number of payments per year.
LI	Nominal interest rate per year (%)
DP	Down payment as a percent of initial cost (including sales tax).

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DATA SHEET 6

ENVELOPE MODIFICATION IDENTIFICATION DATA

06001 DATA ____________
N1

Line Number	EN(I)	E$(I)	EC(I,1)	EA(I)	NE(I)	N1 entries only ↓
06101 DATA						I = 1
06102 DATA						I = 2
06103 DATA						I = 3
06104 DATA						I = 4
06105 DATA						I = 5
06106 DATA						I = 6
06107 DATA						I = 7
06108 DATA						I = 8
06109 DATA						I = 9
06110 DATA						I = 10

Line Number	EP(I)	ET(I)	ER(I,1)	EG(I)	ES(I)	N1 entries only ↓
06201 DATA						I = 1
06202 DATA						I = 2
06203 DATA						I = 3
06204 DATA						I = 4
06205 DATA						I = 5
06206 DATA						I = 6
06207 DATA						I = 7
06208 DATA						I = 8
06209 DATA						I = 9
06210 DATA						I = 10

Variable	Description
N1	Number of envelope modifications to be entered ($0 < N1 \leq 10$).
EN(I)	Code number for I^{th} modification ($0 < EN(I) \leq 100$). This code number is used again in data sheet 18-I to match thermal performance data to the appropriate modification.
E$(I)	Name of I^{th} envelope modification.
EC(I,1)	Initial cost of the I^{th} envelope modification.
EA(I)	Annual recurring O&M (AROM) cost for the I^{th} envelope modification (in base time dollars).* Enter actual cost ($EA(I) \geq 1$) or the ratio of AROM cost to EC(I,1) ($EA(I) < 1$).
NE(I)	Number of non-annually recurring (NAROM) costs (e.g., repair or replacement costs) to be entered for the I^{th} envelope modification.
EP(I)	Assessment rate for property tax computation purposes for the I^{th} envelope modification (percent of actual value). If the conservation measure is not expected to increase property taxes, set EP(I) = 0.
ET(I)	Percent of EC(I,1) which is subject to sales tax.
ER(I)	Resale value of the I^{th} envelope modification at end of study period, as a percent of EC(I,1), unadjusted for inflation. This resale value is the value this measure would add to the selling price of the building at the end of the study period, whether or not the building is to be sold.
EG(I)	Federal investment or energy tax credit for the I^{th} modification, as a percent of EC(I,1).
ES(I)	Same as EG(I), but for a state tax credit.

* Annual recurring O&M costs do not include energy costs in this report.

DATA SHEET 7-I

NON-ANNUALLY RECURRING O&M COSTS - ENVELOPE MODIFICATIONS

Separate data sheet required for each envelope modification I for which NE(I) > 0
No data needed if NE(I) = 0

Line Number*	YI(I,K)	Y2(I,K)	NE(I) entries only ↓
07X01 DATA			K = 1
07X02 DATA			K = 2
07X03 DATA			K = 3
07X04 DATA			K = 4
07X05 DATA			K = 5
07X06 DATA			K = 6
07X07 DATA			K = 7
07X08 DATA			K = 8
07X09 DATA			K = 9
07X10 DATA			K = 10
07X11 DATA			K = 11
07X12 DATA			K = 12
07X13 DATA			K = 13
07X14 DATA			K = 14
07X15 DATA			K = 15
	continue as needed		
07X99 DATA			K = 99

* Note - use the following schedule to assign line numbers:

I	line numbers	I	line numbers
1	07101 - 07199	6	07601 - 07699
2	07201 - 07299	7	07701 - 07799
3	07301 - 07399	8	07801 - 07899
4	07401 - 07499	9	07901 - 07999
5	07501 - 07599	10	08001 - 08099

Variable	Description
Y1(I,K)	Year of occurrence of K^{th} NAROM cost to I^{th} envelope modification (base year = 1). NAROM is assumed to occur on the last day of year Y1(I,K).
Y2(I,K)	Amount of K^{th} NAROM cost (in base-time dollars). Enter actual cost ($Y2(I,K) \geq 1$) or ratio of K^{th} NAROM cost to EC(I,1) ($Y2(I,K) < 1$). Note: Use ratio, not percent.

DATA SHEET 8

DEPRECIATION DATA FOR ENVELOPE MODIFICATIONS

08001 DATA ________, ________
DG ED

Skip lines 08002 - 08141 if DG = 0.

08002 DATA ________
RR(G)

Line Number	DY(Fed, Env.) DG entries only →					
08101 DATA						years 1-5
08106 DATA						years 6-10
08111 DATA						years 11-15
08116 DATA						years 16-20
08121 DATA						years 21-25
08126 DATA						years 26-30
08131 DATA						years 31-35
08136 DATA						years 36-40
08141 DATA						years 41-45

Skip lines 08198 - 08241 if ED = 0.

08198 DATA ________
DS

Skip lines 08199 - 08241 if DS = 0.

08199 DATA ________
RR(S)

Line Number	DY(State, Env.) DS entries only →					
08201 DATA						years 1-5
08206 DATA						years 6-10
08211 DATA						years 11-15
08216 DATA						years 16-20
08221 DATA						years 21-25
08226 DATA						years 26-30
08231 DATA						years 31-35
08236 DATA						years 36-40
08241 DATA						years 41-45

Variable	Description
DG	Number of years over which any envelope modification is to be depreciated - Federal schedule.
ED	Depreciation code for state tax purposes: ED = 0: state depreciation schedule is same as Federal, ED = 1: state depreciation schedule is different from Federal.
RR(G)	Depreciation recapture rule code - Federal tax*: RR = 1 any positive difference between the actual selling price at the end of the study period and the remaining basis (first cost less cumulative depreciation) is taxed as ordinary income. RR = 2 The same positive difference is taxed as capital gains. RR = 3 Any positive difference between the actual selling price and the remaining basis computed using straight-line depreciation is taxed as capital gains. The difference between cumulative depreciation computed using the depreciation schedule entered and the straight-line method is taxed as ordinary income.
DY(fed,env.)	Percent of initial envelope modification cost to be depreciated in each year (1, 2, ..., DG) - Federal tax. DY is entered for each year in the depreciation schedule. Any type of depreciation schedule can be entered (e.g. straight-line, sum-of-years digits, etc).
DS	Same as DG, but for state depreciation schedule.
RR(S)	Depreciation recapture rule for state tax (see above).
DY(state, env.)	Same as DY(fed,env.) but for state depreciation schedule.

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* The Economic Recovery Tax Act of 1981 is fairly explicit about which of these methods to use for different building classes. Even if the building is not to be sold at the end of the study period, there is still a potential liability of this amount that may partially offset the resale value. However, depreciation recapture and capital gains liability at the end of the study period can be set to zero by setting RR(G) = 2, CG(1) = 0, RR(S) = 2, and CG(2) = 0.

DATA SHEET 9

SPACE HEATING EQUIPMENT DATA

09001 DATA ________, ________, ________, ________, ________
N2, HB, DB(1), HO, DE(1)

09011 DATA ________, ________, ________, ________, ________
HE(1), HF, HV, HA(1), NH(1)

Line Number	HE(J)	HC(J,1)	HA(J)	NH(J)	N2-1 entries only ↓
09012 DATA					J = 2
09013 DATA					J = 3
09014 DATA					J = 4
09015 DATA					J = 5

Line Number	HP(J)	HT(J)	HR(J)	HG(J)	HS(J)	N2 entries only ↓
09021						J = 1
09022						J = 2
09023						J = 3
09024						J = 4
09025						J = 5

Variable	Description
N2	Number of alternative space heating plants to be entered ($0 < N2 \le 5$).
HB	Index of energy type used by space heating plant. HB corresponds to K in data sheet 4, i.e., HB = 1 for energy type designated as EN$(1), etc.
DB(1)	Index of energy type used by distribution system for space heating. This energy type will always be electricity, but the proper index number (K in data sheet 4) must be designated.
HO	Oversizing ratio for space heating plant (nominal capacity/design heating load).
DE(1)	kWh consumed per GJ (10^6Btu) of heating output by fans and/or pumps in distribution system.
HE(1)	Seasonal energy efficiency (output/input) of base space heating plant, measured before entering distribution system (percent).
HF	Initial fixed cost of base space heating plant (i.e., that portion of the total cost not sensitive to output capacity).
HV	Initial variable cost of base space heating plant, in dollars per MJ (10^3Btu) nominal output capacity.
HA(1)	AROM cost for base heating plant (in base-time dollars). Enter actual cost ($HA(1) \ge 1$) or ratio of AROM cost to total initial cost ($HA(1) < 1$).
NH(1)	Number of NAROM entries for base space heating plant.
HE(J)	Seasonal energy efficiency of the J^{th} space heating plant (percent) $HE(J) > HE(J-1)$, i.e., each new plant is more efficient than the one before (using the same energy type).
HC(J,1)	Additional initial cost of J^{th} space heating plant relative to the $(J-1)^{th}$ plant. Enter actual cost ($HC(J,1) \ge 1$) or ratio of additional cost to base plant cost ($HC(J,1) < 1$).
HA(J)	AROM cost (in base-time dollars) due only to the improvement in efficiency from HE(J-1) to HE(J).
NH(J)	Number of NAROM entries for the increase in efficiency from HE(J-1) to HE(J).
HP(J)	Assessment rate for property tax computation purposes for the base space heating plant (J=1) or the J^{th} modification (J>1), as a percent of actual value.
HT(J)	Percent of the initial cost of the base space heating plant (J=1) or J^{th} modification (J>1) subject to sales tax.
HR(J)	Resale value of the base plant (J=1) or J^{th} modification (J>1) at end of the study period as a percent of its initial cost, unadjusted for inflation.
HG(J)	Federal investment or energy tax credit for base heating plant (J=1) or J^{th} modification (J>1) as a percent of its initial cost.
HS(J)	Same as HG(1), but for state tax credits.

DATA SHEET 10-J

NON-ANNUALLY RECURRING O&M COSTS - SPACE HEATING PLANT IMPROVEMENTS

Separate data sheet required for each space heating plant improvement for which NH(J) > 0. No data needed if NH(J) = 0.

Line Numbers*	Y3(J,K)	Y4(J,K)	NH(J) entries only ↓
10X01 DATA			K = 1
10X02 DATA			K = 2
10X03 DATA			K = 3
10X04 DATA			K = 4
10X05 DATA			K = 5
10X06 DATA			K = 6
10X07 DATA			K = 7
10X08 DATA			K = 8
10X09 DATA			K = 9
10X10 DATA			K = 10
	continue as needed		
10X99 DATA			K = 99

* Note: Use the following schedule to assign line numbers:

J	line numbers
1	10101 - 10199
2	10201 - 10299
3	10301 - 10399
4	10401 - 10499
5	10501 - 10599

Variable	Description
Y3(J,K)	Year of occurrence of K^{th} NAROM cost to base space heating plant (J=1) or J^{th} modification (J>1). Base year = 1. NAROM is assumed to occur on last day of year Y3(J,K).
Y4(J,K)	Amount of K^{th} NAROM cost (in base-time dollars). Enter actual cost ($Y4(J,K) \geq 1$) or ratio of K^{th} NAROM cost to incremental cost of J^{th} plant ($Y4(J,K)<1$). Note: When J=1, incremental cost is cost of base plant, i.e., incremental cost = HF + HV • CAP, where CAP = nominal output capacity in MJ (10^3 Btu).

DATA SHEET 11

WATER HEATING PLANT DATA

11001 DATA ________ , ________
Q1 Q2

Skip all the following unless Q1=2 and Q2 = 2.

11002 DATA ________ , ________
N3 WB

Line Number	WE(W)	WC(W,1)	WA(W)	NW(W)	N3 entries only* ↓
11011 DATA					W = 1
11012 DATA					W = 2
11013 DATA					W = 3
11014 DATA					W = 4
11015 DATA					W = 5

Line Number	WP(W)	WT(W)	WR(W)	WG(W)	WS(W)	N3 entries only* ↓
11021 DATA						W = 1
11022 DATA						W = 2
11023 DATA						W = 3
11024 DATA						W = 4
11025 DATA						W = 5

* N3 entries corresponding to water heating plant numbers.

Variable	Description
Q1	Water heating plant code: Q1 = 1 if space heating and water heating are provided by the same plant; Q1 = 2 if space heating and water heating are provided by separate plants. If Q1 = 1, no entries are needed for water heating plant. In either case, solar heating equipment provides both space and water heating. (If Q2 = 1, Q1 is ignored; use Q1 = 0.)
Q2	Solar equipment code: If Q2 = 1, solar equipment does not provide service hot water; If Q2 = 2, solar equipment provides both space and water heating. When Q2 = 1, there is no need to evaluate the water heating plant or water heating requirements because they are functionally independent from the simultaneous optimization problem.
N3	Number of alternative water heating plants to be entered ($0 < N3 \leq 5$).
WB	Index of energy type used by water heating plant. WB corresponds to K in data sheet 4, i.e., WB = 1 for EN$(1), etc.
WE(W)	Seasonal energy efficiency of the W^{th} water heating plant (W=1 for base plant), percent (WE(W) > WE(W-1)).
WC(W,1)	For W = 1, initial cost of the base plant. For W > 1, additional initial cost due to increase in efficiency from WE(W-1) to WE(W).
WA(W)	AROM cost for the base plant (W=1) or the improvement in energy efficiency from WE(W-1) to WE(W). Enter actual cost ($WA(W) \geq 1$) or ratio of AROM to WC(W,1) ($WA(W) < 1$).
NW(W)	Number of NAROM entries for W^{th} plant.
WP(W)	Assessment rate for property tax computation purposes for the base water heating plant (W=1), or W^{th} modification (W>1), as a percent of actual value.
WT(W)	Percent of the initial cost of the base water heating plant (W=1), or W^{th} modification (W>1), subject to sales tax.
WR(W)	Resale value of base plant (W=1), or W^{th} modification (W>1), at the end of the study period as a percent of its initial cost, unadjusted for inflation.
WG(W)	Federal investment or energy tax credit for base water heating plant (W=1), or W^{th} modification (W>1), as a percent of its initial cost.
WS(W)	Same as WG(W), but for state tax credits.

DATA SHEET 12-W

NON-ANNUALLY RECURRING O&M COSTS - WATER HEATING PLANT IMPROVEMENTS

Separate data sheet required for each water plant improvement for which NW(W) > 0. No data needed if NW(W) = 0.

Line Number*	Y5(W,K)	Y6(W,K)	NW(W) entries only ↓
12X01 DATA			K = 1
12X02 DATA			K = 2
12X03 DATA			K = 3
12X04 DATA			K = 4
12X05 DATA			K = 5
12X06 DATA			K = 6
12X07 DATA			K = 7
12X08 DATA			K = 8
12X09 DATA			K = 9
12X10 DATA			K = 10
	continue as needed		
12X99 DATA			K = 99

* Note: Use the following schedule to assign line numbers

W	line numbers
1	12101 - 12199
2	12201 - 12299
3	12301 - 12399
4	12401 - 12499
5	12501 - 12599

Variable	Description
Y5(W,K)	Year of occurrence of K^{th} NAROM cost to base water heating plant (W=1) or W^{th} modification (W>1). Base year = 1. NAROM is assumed to occur on last day of year Y5(W,K).
Y6(W,K)	Amount of K^{th} NAROM cost (in base-time dollars). Enter actual cost (Y6(W,K)$\geq$1) or ratio of K^{th} NAROM cost to incremental cost of W^{th} water heating plant (WC(W,1)), (Y6(W,K)<1).

DATA SHEET 13

SPACE COOLING PLANT DATA

13001 DATA	______,	______,	______,	______,	______
	CB	DB(2)	CE	CO	DE(2)
13002 DATA	______,	______,	______,	______	
	CF	CV	CA	NC	
13003 DATA	______,	______,	______,	______,	______
	CP	CT	CR	CG	CS

Skip the following if NC = 0:

Line Number	Y7(K)	Y8(K)	NC entries only ↓
13101 DATA			K = 1
13102 DATA			K = 2
13103 DATA			K = 3
13104 DATA			K = 4
13105 DATA			K = 5
13106 DATA			K = 6
13107 DATA			K = 7
13108 DATA			K = 8
13109 DATA			K = 9
13110 DATA			K = 10

continue as needed

13199 DATA			K = 99

Variable	Description
CB	Index of energy type used by space cooling plant. CB corresponds to K in data sheet 4, i.e., CB = 1 for EN$(1), etc.
DB(2)	Index of energy type used by distribution system for space cooling. This energy type will always be electricity, but the proper index number (K in data sheet 4) must be designated.
CE	Seasonal efficiency (or coefficient of performance) for space cooling plant (before entering distribution system, (%)).
CO	Oversizing ratio for space cooling equipment (nominal capacity/design cooling load). (Note: Use ratio, not percent.)
DE(2)	kWh consumed per GJ (10^6Btu) of cooling output by fans and/or pumps in the distribution system.
CF	Initial fixed cost of space cooling plant (i.e., that portion of total cost not sensitive to output capacity).
CV	Initial variable cost of space cooling plant in dollars per MJ (10^3 Btu) nominal output capacity.
CA	AROM cost for space cooling plant (in base-time dollars). Enter actual cost or ratio of AROM to total initial cost.
NC	Number of NAROM entries for space cooling plant.
CP	Assessment rate for property tax computation purposes for the space cooling plant as a percent of actual value.
CT	Percent of the initial cost of the space cooling plant subject to sales tax. Note: Initial cost = CF + CV• CAP, where CAP = nominal output capacity in MJ (10^3Btu).
CR	Resale value of space cooling plant at end of study period as a percent of its initial cost, unadjusted for inflation.
CG	Federal investment or energy tax credit for space heating plant, as a percent of its initial cost.
CS	Same as CG, but for state tax credits.
Y7(K)	Year of occurrence of K^{th} NAROM cost to space cooling plant. Base year = 1. NAROM is assumed to occur on last day of year Y7(K).
Y8(K)	Amount of K^{th} NAROM cost (in base-time dollars). Enter actual cost ($Y8(K) \leq 1$) of ratio of K^{th} NAROM cost to initial cost of space cooling plant ($Y8(K)<1$).

DATA SHEET 14

DEPRECIATION SCHEDULE FOR CONVENTIONAL HEATING AND COOLING PLANTS

14001 DATA __________, __________
DG HD

Skip lines 14002 - 14111 if DG = 0.

14002 DATA __________
RR(G)

DY(fed., plant)

Line Number — DG entries only →

14101 DATA						years 1-5
14106 DATA						years 6-10
14111 DATA						years 11-15

Skip lines 14198 - 14211 if HD = 0.

14198 DATA __________
DS

Skip lines 14199 - 14211 if DS = 0.

14199 DATA __________
RR(S)

DY(state, plant)

Line Number — DS entries only →

14201 DATA						years 1-5
14206 DATA						years 6-10
14211 DATA						years 11-15

Variable	Description
DG	Number of years over which any plant or plant modification is to be depreciated - Federal schedule.
HD	Depreciation code for state tax purposes: HD = 0: state depreciation schedule is same as Federal. HD = 1: state depreciation schedule is different from Federal.
RR(G)	Depreciation recapture rule code - Federal tax (See data sheet 8 for codes).
DY(fed, plant)	Percent of initial plant cost (or plant modification cost) to be depreciated in each year (1, 2, ..., DG) - Federal schedule.
DS	Same as DG, but for state depreciation schedule.
RR(S)	Depreciation recapture rule for state income tax.
DY(state, plant)	Same as DY(fed, plant), but for state depreciation schedule.

DATA SHEET 15

SOLAR HEATING SYSTEM DATA

15001 DATA ________, ________, ________, ________, ________
SF SV SB SO DE(3)

15002 DATA ________, ________, ________, ________
M1 M2 SA NS

15003 DATA ________, ________, ________, ________, ________
SP ST SR SG SS

Skip the following if NS = Ø:

Line Number	Y9(K)	YØ(K)	NS entries only ↓
15101 DATA			K = 1
15102 DATA			K = 2
15103 DATA			K = 3
15104 DATA			K = 4
15105 DATA			K = 5
15106 DATA			K = 6
15107 DATA			K = 7
15108 DATA			K = 8
15109 DATA			K = 9
15110 DATA			K = 10
	continue as needed		
15199 DATA			K = 99

Variable	Description
SF	Initial fixed cost of solar heating equipment.
SV	Initial variable cost of solar heating equipment, in dollars per m^2 (ft^2) of collector area.
SB	Index of energy type used by fans and/or pumps in solar heating equipment. Electricity is always used but the proper index (with appropriate kWh price) must be designated. SB corresponds to K in data sheet 4, i.e., SB = 1 for EN$(1), etc.
SO	Solar heating system code. Coefficients for six different solar heating systems which can provide space heating and service hot water are stored in the SOLCOM program. The system code designates which of these are to be used. The user must be sure that the cost data entered into SOLCOM1 for the solar heating system is consistent with the system type designated here. SO = 1: liquid system, 1 - cover, selective. SO = 2: liquid system, 1 - cover, non-selective. SO = 3: liquid system, 2 - cover, non-selective. SO = 4: air system, 1 - cover, selective. SO = 5: air system, 1 - cover, non-selective. SO = 6: air system, 2 - cover, non-selective.
DE(3)	kWh consumed per GJ (10^6Btu) of useful heat provided by the solar heating system to run fans and/or pumps.
M1	Minimum permissible collector size in m^2 (ft^2).
M2	Maximum permissible collector size in m^2 (ft^2).
SA	AROM cost for solar equipment (in base-time dollars). Enter actual cost ($SA \geq 1$) or ratio of AROM to total first cost ($SA<1$).
NS	Number of NAROM entries for solar heating equipment.
SP	Assessment rate for property tax computation purposes for the solar heating equipment as a percent of actual value.
ST	Percent of the initial cost of the space cooling plant subject to sales tax. Note: Initial cost = SF + SV • AREA, where AREA = collector area in m^2 (ft^2).
SR	Resale value of solar heating equipment at end of study period as a percent of its initial cost, unadjusted for inflation.
SG	Federal investment or energy tax credit for solar heating equipment, as a percent of its initial cost.
SS	Same as SG, but for state tax credits.
Y9(K)	Year of occurrence of K^{th} NAROM cost to solar heating equipment. Base year = 1. NAROM is assumed to occur on last day of year Y9(K).
YØ(K)	Amount of K^{th} NAROM cost (in base-time dollars). Enter actual cost ($YØ(K) \geq 1$) or ratio of K^{th} NAROM cost to initial cost of solar heating equipment ($YØ(K)<1$).

DATA SHEET 16

DEPRECIATION DATA FOR SOLAR HEATING EQUIPMENT

16001 DATA __________, __________
DG SD

Skip lines 16002 - 16113 if DG = 0.

16002 DATA __________
RR(G)

Line Number	DY(fed, solar) DG entries only →					
16101 DATA						years 1-5
16106 DATA						years 6-10
16111 DATA						years 11-15

Skip lines 16201 - 16213 if SD = 0.

16198 DATA __________
DS

Skip lines 16202 - 16213 if DS = 0.

16199 DATA __________
RR(S)

Line Number	DY(state, solar) DS entries only →					
16201 DATA						years 1-5
16206 DATA						years 6-10
16211 DATA						years 11-15

Variable	Description
DG	Number of years over which solar heating equipment is to be depreciated - Federal schedule.
SD	Depreciation code for state tax purposes SD = 0: state depreciation schedule is same as Federal. DD = 1: state depreciation schedule is different from Federal.
RR(G)	Depreciation recapture sale code - Federal tax. (See data sheet 8 for codes.)
DY(fed, solar)	Percent of initial solar equipment cost to be depreciated in each year (1, 2, ... DG) Federal schedule.
DS	Same as DG, but for state depreciation schedule.
RR(S)	Depreciation recapture rule for state income tax.
DY(state, solar)	Same as DY(fed, solar), but for state depreciation schedule.

DATA SHEET 17

BASIC ENVELOPE PERFORMANCE DATA,
WATER HEATING REQUIREMENTS, AND INCIDENT SOLAR RADIATION

Line Number	HL(Ø,M), M = 1 to 12				
17101 DATA					Jan., Feb., Mar., Apr.
17105 DATA					May, June, July, Aug.
17109 DATA					Sept., Oct., Nov., Dec.

17113 DATA __________, __________, __________
MH(Ø) CL(Ø) MC(Ø)

Line Number	WL(M), M = 1 to 12				
17201 DATA					Jan., Feb., Mar., Apr.
17205 DATA					May, June, July, Aug.
17209 DATA					Sept., Oct., Nov., Dec.

Line Number	IR(M), M = 1 to 12				
17301 DATA					Jan., Feb., Mar., Apr.
17305 DATA					May, June, July, Aug.
17309 DATA					Sept., Oct., Nov., Dec.

Variable	Description
HL(Ø,M)	Monthly space heating requirements (output) for base building (before the envelope modifications are brought in), M = 1, 2, ..., 12, in GJ (10^6Btu).
MH(Ø)	Maximum hourly space heating load for the year, in MJ (10^3Btu).
CL(Ø)	Annual cooling requirements (output) for the base building, in GJ (10^6Btu).
MC(Ø)	Maximum hourly space cooling load for the year, in MJ (10^3Btu).
WL(M)	Monthly water heating requirements, in GJ (10^6Btu), M = 1, 2, ..., 12.
IR(M)	Daily average incident solar radiation on tilted collector surface in M^{th} month, in KJ/m^2 (Btu/ft^2), M = 1, 2, ..., 12.

DATA SHEET 18-I

REDUCTIONS IN HEATING AND COOLING LOADS
DUE TO ENVELOPE MODIFICATIONS

Separate data sheet required for each envelope modification.

18X00 DATA ________
EI(I)

Line Number — DH(I,M), M = 1 to 12

18X01 DATA					Jan., Feb., Mar., Apr.
18X05 DATA					May, June, July, Aug.
18X09 DATA					Sept., Oct., Nov., Dec.

18X13 DATA ________, ________, ________
D1(I), DC(I), D2(I)

Note: Use the following schedule to assign line numbers:

I	line numbers	I	line numbers
1	18101 - 18113	6	18601 - 18613
2	18201 - 18213	7	18701 - 18713
3	18301 - 18313	8	18801 - 18813
4	18401 - 18413	9	18901 - 18913
5	18501 - 18513	10	19001 - 19013

Variable	Description
EI(I)	Code number for the I^{th} envelope modification, corresponding to EN(I) in data sheet 6. Every envelope modification on data sheet 6 must have a corresponding data sheet here.
DH(I,M)	Reduction[1] in monthly space heating requirements due to the I^{th} envelope modification, in GJ (10^6Btu), M = 1, 2, ..., 12.
D1(I)	Reduction[1] in maximum space heating load due to the I^{th} envelope modification, in MJ/hr (10^3Btu/hr).
DC(I)	Reduction[1] in annual cooling requirements due to the I^{th} envelope modification, in KJ (10^3Btu).
D2(I)	Reduction[1] in maximum space cooling load due to the I^{th} envelope modification, in KJ/hr (10^3Btu/hr).

[1] Reductions in heating or cooling requirements are entered as positive numbers. If an increase in heating or cooling requirements results from any envelope modifications, use a negative sign. (Some modifications, e.g. solar screening, may reduce cooling requirements but increase heating requirements, and vice versa.)

APPENDIX B. SOLAR LOAD RATIO COEFFICIENTS

Solar load ratio coefficients for six different "standard" solar heating systems that can provide both space and water heating in commercial buildings are referenced in the SOLCOM optimization program. The use of these coefficients is explained in section 3.2. These coefficients are as follows[1]:

System Type	B1	B2	B3	B4
Liquid Systems				
1. 1-cover, selective	0.317	1.478	1.314	0.613
2. 1-cover, non-selective	0.291	1.581	1.298	0.555
3. 2-cover, non-selective	0.287	1.605	1.302	0.550
Air Systems				
1. 1-cover, selective	0.415	1.187	1.360	0.830
2. 1-cover, non-selective	0.426	1.177	1.392	0.872
3. 2-cover, non-selective	0.371	1.314	1.353	0.739

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[1] Source: Powell, Jeanne W. and Rodgers, Jr., Richard C., FEDSOL: Program User's Manual and Economic Optimization Guide for Solar Federal Buildings Projects, NBSIR 81-2342, U.S. Department of Commerce, National Bureau of Standards, Washington, D.C., August 1981.

APPENDIX C LISTING OF SOLCOM PROGRAM

```
20000 REM PROGRAM NAME:SOLCOM1
20010 DIM D3(50),DF(50),DR(50),IE(3,50),IM(50),IV(50),I(50)
20020 DIM E$(10),EC(10,4),EA(10),EP(10),ET(10),ER(10),EN(10),ES(10),EG(10)
20030 DIM HE(5),HC(5,4),HA(5),HP(5),HT(5),HR(5),HF(5),HG(5),HS(5),H1(5),H2(5)
20040 DIM ZC(20),P(30,12)
20050 DIM WE(5),WC(5,4),WA(5),WP(5),WT(5),WR(5),WG(5),WS(5),W1(5),W2(5)
20060 DIM CC(4),SC(4),DA(2,3),DD(2,3),SL(2,3),RR(2,3),DB(2),CG(2)
20070 DIM R1(50),R2(50),R3(50),R4(50,6),KE(6),KM(6),TU(6),EN$(6),EM$(6)
20080 DIM DH(10,12),DC(10),D1(10),D2(10),CL(1),MH(1),MC(1),WL(12),IR(12),HL(1,12),EI(10)
20090 READ F1$
20100 READ N$,MM,Y0
20110 READ TH,TT,TG,TS,TX,CG(1),CG(2),TP,IN
20115 TG=TG/100:TS=TS/100:TX=TX/100:CG(1)=CG(1)/100:CG(2)=CG(2)/100:TP=TP/100
20120 IF TT=1 THEN 20140
20130 TG=0:TS=0:TP=0:CG(1)=0:CG(2)=0
20140  DF(0)=1:IM(0)=1:IV(0)=1
20150 Y=0
20160 FOR I=1 TO IN
20170 READ IY,DR,IM,IV
20175 DR=DR/100:IM=IM/100:IV=IV/100
20180 Y(I)=IY:R1(I)=DR:R2(I)=IM:R3(I)=IV
20190 FOR J=1 TO Y(I)
20200 Y=Y+1
20210 DF(Y)=DF(Y-1)/(1+DR)
20220 DR(Y)=DR
20230 IM(Y)=IM(Y-1)*(1+IM)
20240 IV(Y)=IV(Y-1)*(1+IV)
20250 NEXT J
20260 NEXT I
20270 READ EN
20280 FOR K=1 TO EN
20290 IE(K,0)=1
20300 NEXT K
20305 Y=0
20310 FOR I=1 TO IN
20320 FOR K=1 TO EN
20330 READ R4(I,K)
20335 R4(I,K)=R4(I,K)/100
20340 NEXT K
20345 FOR J=1 TO Y(I)
20350 Y=Y+1
20355 FOR K=1 TO EN
20360 IE(K,Y)=IE(K,Y-1)*(1+R4(I,K))
20365 NEXT K
20370 NEXT J
20380 NEXT I
20390 IF Y=>TH THEN 20420
20400 PRINT "NEED TO ADD MORE INFLATION/DISCOUNT FACTORS TO BE CONSISTENT WITH TIME HORIZON."
20410 STOP
20420 FOR K=1 TO EN
20430 READ KE(K),TU(K),EN$(K),EM$(K)
20440 IF MM=2 THEN 20470
20450 KM=10[6/TU(K)*KE(K)
20460 GOTO 20480
20470 KM=10[6/TU(K)*KE(K)
20480 KM(K)=0
20490 FOR Y=1 TO TH
20500 KM(K)=KM(K)+KM*IE(K,Y)*DF(Y)*(1-(TG+TS*(1-TG)))
20510 NEXT Y
20520 NEXT K
```

```
20530 REM READ MORTGAGE LOAN DATA
20540 READ LT
20550 IF LT=0 THEN 20590
20560 READ LL,LN,LI,DP
20565 LI=LI/100:DP=DP/100
20570 GOSUB 23810
20580 GOTO 20600
20590 L$(0)="NO LOAN"
20600 REM READ ENVELOPE COST DATA
20610 READ N1
20620 FOR I=1 TO N1
20630 READ EN(I),E$(I),EC(I,1),EA(I),NE(I)
20635 NEXT I
20637 FOR I=1 TO N1
20640 READ EP(I),ET(I),ER(I),EG(I),ES(I)
20645 EP(I)=EP(I)/100:ET(I)=ET(I)/100:ER(I)=ER(I)/100:EG(I)=EG(I)/100:ES(I)=ES(I)/100
20650 IF EA(I)>=1 THEN 20670
20660 EA(I)=EA(I)*EC(I,1)
20670 NEXT I
20680 FOR I=1 TO N1
20690 IF NE(I)=0 THEN 20770
20695 EC(I,2)=0
20700 FOR Y=1 TO NE(I)
20710 READ Y1,Y2
20720 IF Y1>TH THEN 20760
20730 IF Y2>=1 THEN 20750
20740 Y2=Y2*EC(I,1)
20750 EC(I,2)=EC(I,2)+Y2*IM(Y1)*DF(Y1)
20760 NEXT Y
20770 NEXT I
20780 REM READ DEPRECIATION SCHEDULE FOR ENVELOPE
20790 READ DG,ED
20800 IF DG=0 THEN 20870
20810 DN=DG
20820 GOSUB 24630
20830 DA(1,1)=DA
20840 DD(1,1)=DD
20850 SL(1,1)=SL
20860 RR(1,1)=RR
20870 IF ED=0 THEN 20960
20880 READ DS
20890 IF DS=0 THEN 20960
20900 DN=DS
20910 GOSUB 24630
20920 DA(2,1)=DA
20930 DD(2,1)=DD
20940 SL(2,1)=SL
20950 RR(2,1)=RR
20960 REM READ CONVENTIONAL SPACE HEATING EQUIPMENT COST AND EFFICIENCY DATA
20970 READ N2
20980 READ HB,DB(1),HO,DE(1)
20990 KH=KM(HB):KD(1)=KM(DB(1))
21000 H1(1)=0:H2(1)=0
21010 READ HE(1),HF,HV,HA(1),NH(1)
21015 HE(1)=HE(1)/100
21020 IF HA(1)>1 THEN 21050: REM HA(1) IS ACTUAL COST
21030 H2(1)=1: REM HA(1) IS RATIO OF AN. RECUR. O&M COST TO HC(1,1)
21050 IF N2=1 THEN 21135
21060 FOR J=2 TO N2
21070 H1(J)=0:H2(J)=0
```

```
21080 READ HE(J),HC(J,1)
21085 HE(J)=HE(J)/100
21090 IF HC(J,1)>1 THEN 21110: REM HC(J,1) IS ACTUAL ADDITIONAL FIRST COST
21100 H1(J)=1: REM HC(J,1) IS RATIO OF ADDITIONAL COST TO HC(1,1)
21110 READ HA(J),NH(J)
21120 IF HA(J)>1 THEN 21133: REM HA(J) IS ACTUAL AN. RECUR. O&M COST
21130 H2(J)=1: REM HA(J) IS RATIO OF AN. RECUR. O&M COST TO HC(J,1)
21133 NEXT J
21135 FOR J=1 TO N2
21140 READ HP(J),HT(J),HR(J),HG(J),HS(J)
21145 HP(J)=HP(J)/100:HT(J)=HT(J)/100:HR(J)=HR(J)/100:HG(J)=HG(J)/100:HS(J)=HS(J)/100
21150 NEXT J
21160 FOR J=1 TO N2
21170 IF NH(J)=0 THEN 21270
21175 FOR Y=1 TO NH(J)
21180 READ Y1,Y2
21190 IF Y1>TH THEN 21260
21200 IF H2(J)=1 THEN 21240
21210 IF Y2>1 THEN 21250
21220 PRINT "NAR O&M COST IN YEAR "Y1" MUST BE IN UNITS CONSISTENT WITH AR O&M COST FOR SPACE HTG EQUIP #"J
21230 STOP
21240 IF Y2>1 THEN 21220
21250 HC(J,2)=HC(J,2)+Y2*IM(Y1)*DF(Y1)
21260 NEXT Y
21270 NEXT J
21280 READ Q1,Q2
21290 IF Q2=1 THEN 21600
21300 IF Q1=2 THEN 21310
21302 KW=KH:WB=HB
21305 GOTO 21600
21310 REM READ CONVENTIONAL HOT WATER HEATING EQUIPMENT COST AND EFFICIENCY DATA
21320 READ N3,WB
21330 KW=KM(WB)
21340 FOR W=1 TO N3
21350 READ WE(W),WC(W,1)
21355 WE(W)=WE(W)/100
21360 W1(W)=0
21370 IF W=1 THEN 21400
21380 IF WC(W,1)>2 THEN 21400
21390 W1(W)=1:REM WC(W,1) IS RATIO OF ADDITIONAL 1ST COST OF WTH EFF IMPROVEMENT TO WC(1,1)
21400 READ WA(W),NW(W)
21402 W2(W)=0
21403 IF WA(W)>=1 THEN 21405
21404 W2(W)=1: REM WA(W) IS RATIO OF AROM FOR IMPROVEMENT W TO INCREMENTAL FIRST COST
21405 NEXT W
21406 FOR W=1 TO N3
21410 READ WP(W),WT(W),WR(W),WG(W),WS(W)
21415 WP(W)=WP(W)/100:WT(W)=WT(W)/100:WR(W)=WR(W)/100:WG(W)=WG(W)/100:WS(W)=WS(W)/100
21420 NEXT W
21430 FOR W=1 TO N3
21440 IF NW(W)=0 THEN 21590
21480 FOR Y=1 TO NW(W)
21490 READ Y1,Y2
21500 IF Y1>TH THEN 21580
21510 IF W2(W)=1 THEN 21550
21520 IF Y2>1 THEN 21570
21530 PRINT "NON-RECURRING COSTS IN YEAR "Y1" ARE NOT CONSISTENT WITH RECURRING O&M COSTS FOR WATER HEATING EQUIPMENT "J
21540 STOP
21550 IF Y2<1 THEN 21570
21560 GOTO 21530
```

```
21570 WC(W,2)=WC(W,2)+Y2*IM(Y1)*DF(Y1)
21580 NEXT Y
21590 NEXT W
21600 REM READ CONVENTIONAL COOLING EQUIPMENT COST AND EFFICIENCY DATA
21610 READ CB,DB(2),CE,CO,DE(2)
21615 CE=CE/100
21620 KC=KM(CB):KD(2)=KM(DB(2))
21630 C2=0
21640 READ CF,CV,CA,NC
21650 IF CA>1 THEN 21670
21660 C2=1
21670 READ CP,CT,CR,CG,CS
21675 CP=CP/100:CT=CT/100:CR=CR/100:CG=CG/100:CS=CS/100
21680 IF NC=0 THEN 21790
21690 FOR Y=1 TO NC
21700 READ Y1,Y2
21710 IF Y1>TH THEN 21780
21720 IF C2=1 THEN 21760
21730 IF Y2>1 THEN 21770
21740 PRINT "NON AN. RECUR. O&M COSTS FOR COOLING EQUIP MUST BE CONSISTENT WITH AN. RECUR O&M COSTS"
21750 STOP
21760 IF Y2>1 THEN 21740
21770 CC(2)=CC(2)+Y2*IM(Y1)*DF(Y1)
21780 NEXT Y
21790 REM DEPRECIATION SCHEDULE FOR CONVENTIONAL EQUIP
21800 READ DG,HD
21810 IF DG=0 THEN 21880
21820 DN=DG
21830 GOSUB 24630
21840 DA(1,2)=DA
21850 DD(1,2)=DD
21860 SL(1,2)=SL
21870 RR(1,2)=RR
21880 IF HD=0 THEN 21960
21890 READ DS
21895 IF DS=0 THEN 21960
21900 DN=DS
21910 GOSUB 24630
21920 DA(2,2)=DA
21930 DD(2,2)=DD
21940 SL(2,2)=SL
21950 RR(2,2)=RR
21960 REM READ SOLAR HEATING SYSTEM COST DATA
21970 READ SF,SV,SB,SO,DE(3)
21980 KS=KM(SB)
21990 REM READ MIN AND MAX COLLECTOR AREA
22000 READ M1,M2
22010 S9=0
22020 READ SA,NS
22030 IF SA>1 THEN 22050
22040 S9=1
22050 READ SP,ST,SR,SG,SS
22055 SP=SP/100:ST=ST/100:SR=SR/100:SG=SG/100:SS=SS/100
22060 IF NS=0 THEN 22170
22070 FOR Y=1 TO NS
22080 READ Y1,Y2
22090 IF Y1>TH THEN 22160
22100 IF S9=1 THEN 22140
22110 IF Y2>1 THEN 22150
22120 PRINT "NON AN. RECUR. O&M COSTS FOR SOLAR EQUIP MUST BE CONSISTENT WITH AN. RECUR. O&M COSTS "
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```
22130 STOP
22140 IF Y2>1 THEN 22120
22150 SC(2)=SC(2)+Y2*IM(Y1)*DF(Y1)
22160 NEXT Y
22170 REM READ DEPRECIATION SCHEDULE FOR SOLAR HEATING SYSTEM
22180 READ DG,SD
22190 IF DG=0 THEN 22260
22200 DN=DG
22210 GOSUB 24630
22220 DA(1,3)=DA
22230 DD(1,3)=DD
22240 SL(1,3)=SL
22250 RR(1,3)=RR
22260 IF SD=0 THEN 22350
22270 READ DS
22280 IF DS=0 THEN 22350
22290 DN=DS
22300 GOSUB 24630
22310 DA(2,3)=DA
22320 DD(2,3)=DD
22330 SL(2,3)=SL
22340 RR(2,3)=RR
22350 FOR M=1 TO 12
22360 READ HL(0,M)
22370 NEXT M
22380 READ MH(0),CL(0),MC(0)
22385 IF Q2=1 THEN 22420
22390 FOR M=1 TO 12
22400 READ WL(M)
22410 NEXT M
22420 FOR M=1 TO 12
22430 READ IR(M)
22440 NEXT  M
22450 FOR I=1 TO N1
22460 READ EI(I)
22470 FOR K=1 TO N1
22480 IF EN(K)=EI(I) THEN 22520
22490 NEXT K
22500 PRINT "ENVELOPE MOD CODE "EI(I)"USED FOR REDUCTIONS IS H&C LOADS DOES NOT HAVE COUNTERPART COST DATA."
22510 STOP
22520 FOR M=1 TO 12
22530 READ DH(K,M)
22540 NEXT M
22550 READ D1(K),DC(K),D2(K)
22560 NEXT I
22570 GOTO 23400
22580 REM
22590 ZC(2)=ZC(1)*ZT*TX:REM SALES TAX
22600 ZC(3)=ZC(1)+ZC(2) :REM TOTAL INITIAL COST
22610 IF TT=1 THEN 22640
22620 Z4=0:Z5=0:REM NO TAX CREDITS FOR TAX EMEMPT STATUS
22630 GOTO 22660
22640 ZC(4)=ZC(3)*ZS*(1-TG)*DF(1):REM NET STATE INVESTMENT TAX CREDIT
22650 ZC(5)=ZC(3)*ZG*DF(1): REM FEDERAL INVESTMENT TAX CREDIT
22660 IF LT<>0 THEN 22700
22670 ZC(6)=ZC(3)
22680 ZC(7)=0
22690 GOTO 22720
22700 ZC(6)=ZC(3)*DP: REM DOWN PAYMENT
22710 ZC(7)= ZC(3)*(1-DP)*(L1+L3): REM P.V. OF MORTGAGE PAYMENTS + REMAINING PRINCIPAL, IF ANY
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22720 ZC(8)=0
22730 FOR Y=1 TO TH
22740 ZC(8)=ZC(8)+ZA*IM(Y)*DF(Y):REM P.V. ANNUALLY RECURRING O&M
22750 NEXT Y
22760 ZC(9)=ZC(9): REM P.V. NON-AN. RECURRING O&M
22770 ZC(10)=0:ZC(11)=0
22780 FOR Y=1 TO TH
22790 D8=ZC(1)*(1-ZR)*(Y-1)/TH
22800 D9=(ZC(1)-D8)*IV(Y-1)*ZP*TP: REM PROPERTY TAX LIABILITY AT BEGINNING OF YEAR Y
22810 ZC(10)=ZC(10)+D9*DF(Y-1): REM P.V. OF PROPERTY TAX PAYMENTS
22820 ZC(11)=ZC(11)+D9*(TG+TS*(1-TG))*DF(Y): REM P.V. OF INCOME TAX SAVINGS DUE TO PROPERTY TAX PAYMENTS
22830 NEXT Y
22840 ZC(12)=ZC(1)*ZR*IV(TH)*DF(TH): REM P.V. OF RESALE VALUE AT END OF TIME HORIZON
22850 IF ZD=1 THEN 22880
22860 ZC(13)=ZC(1)*DA(1,A)*(TG+TS*(1-TG))
22870 GOTO 22890
22880 ZC(13)=ZC(1)*(DA(1,A)*TG+DA(2,A)*TS*(1-TG)): REM INCOME TAX SAVINGS FROM DEPRECIATION
22890 ZC(14)=(ZC(8)+ZC(9))*(TG+TS*(1-TG)): REM INCOME TAX SAVINGS FROM O&M EXPENDITURES
22900 ZC(15)=ZC(2)*(TG+TS*(1-TG))*DF(1): REM P.V. OF INCOME TAX SAVINGS DUE TO SALES TAX EXPENDITURE
22910 IF L1<>0 THEN 22940
22920 ZC(16)=0
22930 GOTO 22950
22940 ZC(16)=ZC(7)/(L1+L3)*L2*(TG+TS*(1-TG)): REM P.V. OF INCOME TAX SAVINGS FROM INTEREST
22950 REM P.V. OF CAPITAL GAINS AND DEPRECIATION RECAPTURE TAXES
22960 IF TT=1 THEN 22990
22970 ZC(17)=0
22980 GOTO 23120
22990 B=1:REM FEDERAL CAP GAINS AND DEPR. RECAP. TAX COMPUTATION
23000 PS=ZC(1)*ZR*IV(TH): REM ACTUAL SELLING PRICE
23010 IF ZD=0 THEN 23040
23020 TR=TG
23030 GOTO 23050
23040 TR=TG+TS*(1-TG)
23050 GOSUB 23180
23060 ZC(17)=RT*DF(TH): REM P.V. OF CAPITAL GAINS AND RECAPTURE TAXES
23070 IF ZD=0 THEN 23120
23080 B=2:REM STATE CAP GAINS AND DEPR. RECAP TAX COMPUTATION
23090 TR=TS*(1-TG)
23100 GOSUB 23180
23110 ZC(17)=ZC(17)+RT*DF(TH)
23120 REM
23130 ZC(19)=ZC(6)+ZC(7)-ZC(4)-ZC(5)
23140 ZC(18)=ZC(8)+ZC(9)-ZC(14)
23150 ZC(19)=ZC(19)+ZC(10)-ZC(11)-ZC(13)-ZC(15)-ZC(16)
23160 ZC(19)=ZC(19)-ZC(12)+ZC(17)
23170 RETURN
23180 REM: SUBROUTINE TO CALCULATE CAPITAL GAINS AND DEPRECIATION RECAPTURE TAXES AT END OF STUDY PERIOD
23190 IF RR(B,A)=0 THEN 23390
23200 IF RR(B,A)=2 THEN 23240
23210 IF RR(B,A)=3 THEN 23260
23220 T8=TR:T9=TR
23230 GOTO 23270
23240 T8=TR*CG(B):T9=TR*CG(B)
23250 GOTO 23270
23260 T8=TR:T9=TR*CG(B)
23270 REM
23280 IF PS=>ZC(1)*(1 -SL(B,A)-.001) THEN 23330
23290 IF PS=>ZC(1)*(1 -DD(B,A)-.001) THEN 23380
23300 PRINT "WARNING: RESALE PRICE OF MODIFICATION #"EI" TO "Z$" IS LESS THAN REMAINING BASIS AT END OF STUDY PERIOD."
23310 PRINT "   DEPRECIATION RATE SHOULD PROBABLY BE INCREASED.  CAPITAL LOSS NOT COMPUTED."
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23320 GOTO 23390
23330 IF PS>ZC(1) THEN 23360
23340 RT=PS-(ZC(1)*(1-SL(B,A)))*T9+ZC(1)*(SL(B,A)-DD(B,A))*T8
23350 GOTO 23390
23360 RT=(PS-ZC(1))*TR*CG(B)+ZC(1)*SL(B,A)*T9+ZC(1)*(DD(B,A)-SL(B,A))*T8
23370 GOTO 23390
23380 RT=PS-(ZC(1)*(1-DD(B,A)))*T8
23390 RETURN
23400 REM ENVELOPE COST CALCULATIONS
23410 FOR I=1 TO N1
23420 ZC(1)=EC(I,1)
23430 ZC(9)=EC(I,2):ZT=ET(I):ZS=ES(I):ZG=EG(I)
23440 ZA=EA(I):ZR=ER(I):ZP=EP(I):A=1:ZD=ED
23450 GOSUB 22580
23460 EC(I,4)=ZC(18)+ZC(19)
23470 NEXT I
23480 REM SPACE HEATING EQUIPMENT COST CALCULATIONS
23490 FOR J=1 TO N2
23500 ZC(1)=1
23510 ZC(9)=HC(J,2):ZT=HT(J):ZS=HS(J):ZG=HG(J)
23520 ZA=HA(J):ZR=HR(J):ZP=HP(J):A=2:ZD=HD
23530 GOSUB 22580
23540 HC(J,3)=ZC(18)
23550 HC(J,4)=ZC(19)
23560 NEXT J
23570 REM WATER HEATING EQUIPMENT COST CALCULATIONS
23580 FOR W=1 TO N3
23590 ZC(1)=1:ZC(9)=WC(W,2)
23600 ZT=WT(W):ZS=WS(W):ZG=WG(W)
23610 ZA=WA(W):ZR=WR(W):ZP=WP(W):A=2:ZD=HD
23620 GOSUB 22580
23630 WC(W,3)=ZC(18)
23640 WC(W,4)=ZC(19)
23650 NEXT W
23660 REM SPACE COOLING COST CALCULATIONS
23670 ZC(1)=1
23680 ZC(9)=CC(2):ZT=CT:ZS=CS:ZG=CG
23690 ZA=CA:ZR=CR:ZP=CP:A=2:ZD=HD
23700 GOSUB 22580
23710 CC(3)=ZC(18)
23720 CC(4)=ZC(19)
23730 REM
23740 ZC(1)=1
23750 ZC(9)=SC(2):ZT=ST:ZS=SS:ZG=SG
23760 ZA=SA:ZR=SR:ZP=SP:A=3:ZD=SD
23770 GOSUB 22580
23780 SC(3)=ZC(18)
23790 SC(4)=ZC(19)
23800 GOTO 24770
23810 REM SUBROUTINE TO CALCULATE PRESENT VALUE FACTORS RELATED TO FINANCING:
23820 REM    L1=P.V. FACTOR FOR PERIODIC MORTGAGE PAYMENTS
23830 REM    L2=P.V. FACTOR FOR INTEREST PAYMENTS, DISCOUNTED FROM END OF YEAR (FOR TAX DEDUCTION PURPOSES)
23840 REM    L3=P.V. FACTOR FOR PRINCIPAL REPAYMENT (IF ANY) AT END OF LOAN PERIOD (OR END OF TIME HORIZON IF FIRST)
23850 REM    THREE LOAN TYPES:
23860 L$(1)=" FULLY AMORTIZED IN EQUAL PAYMENTS"
23870 L$(2)=" INTEREST ONLY PAYMENTS WITH PRINCIPAL REPAID AT END OF LOAN PERIOD"
23880 L$(3)=" INTEREST AND PRINCIPAL DEFERRED TO END OF LOAN PERIOD"
23890 REM
23900 LM=LL
23910 IF TH>LL THEN 23930
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23920 LM=TH
23930 IF LT=3 THEN 24580
23940 FOR I=1 TO LM
23950 IF LN>1 THEN 23980
23960 D3(I)=DR(I)
23970 GOTO 23990
23980 D3(I)=LN*(1+DR(I))[(1/LN)-LN: REM D3(I)=NOMINAL DISCOUNT RATE,DR=EFFECTIVE DISCOUNT RATE
23990 NEXT I
24000 IF LT=2 THEN 24360
24010 REM: LOAN TYPE 1 COMPUTATIONS
24020 IF LI=0 THEN 24060
24030 CR=LI/LN*(1+LI/LN)[(LN*LL)
24040 CR=CR/((1+LI/LN)[(LN*LL)-1)
24050 GOTO 24065
24060 CR=1/(LN*LL)
24065 L1=0
24070 FOR I=1 TO LM
24080 IF LN>1 THEN 24110
24090 L1=L1+CR*DF(I)
24100 GOTO 24160
24110 IF D3(I)=0 THEN 24150
24120 L1=L1+CR*((1+D3(I)/LN)[LN-1)/(D3(I)/LN*(1+D3(I)/LN)[LN)*DF(I-1)
24140 GOTO 24160
24150 L1=L1+CR*LN*DF(I-1)
24160 NEXT I
24170 L1=L1*(1-DP)
24180 P(1,0)=1
24190 L2=0
24200 FOR I=1 TO LM
24210 L9=0
24220 FOR K=1 TO LN
24230 L9=L9+P(I,K-1)*LI/LN
24240 P(I,K)=P(I,K-1)*(1+LI/LN)-CR
24250 NEXT K
24260 L2=L2+L9*DF(I)
24270 P(I+1,0)=P(I,LN)
24280 NEXT I
24290 L2=L2*(1-DP)
24300 IF LL>TH THEN 24330
24310 L3=0
24320 GOTO 24350
24330 L3=P(LM,LN)*DF(TH)
24340 L3=L3*(1-DP)
24350 GOTO 24620
24360 REM: LOAN TYPE 2 COMPUTATIONS
24365 L1=0
24370 IF LI=0 THEN 24490
24380 FOR I=1 TO LM
24390 IF LN>1 THEN 24420
24400 L1=L1+LI*DF(I)
24410 GOTO 24460
24420 IF D3(I)=0 THEN 24450
24430 L1=L1+LI/LN*((1+D3(I)/LN)[LN-1)/((D3(I)/LN*(1+D3(I)/LN)[LN)*DF(I-1))
24440 GOTO 24460
24450 L1=L1+LI*DF(I-1)
24460 NEXT I
24470 L1=L1*(1-DP)
24480 GOTO 24510
24490 L1=0:L2=0
24500 GOTO 24550
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24510 FOR I=1 TO LM
24520 L2=L2+LI*DF(I)
24530 NEXT I
24540 L2=L2*(1-DP)
24550 L3=(1-DP)*DF(LM)
24560 GOTO 24620
24570 REM
24580 REM: LOAN TYPE 3 COMPUTATIONS
24590 L1=((1-DP)*(1+LI)[LM-(1-DP))*DF(LM)
24600 L2=L1
24610 L3=(1-DP)*DF(LM)
24620 RETURN
24630 REM SUBROUTINE TO READ AND CALCULATE DEPRECIATION FACTORS
24640 DA=0:DD=0
24650 READ RR
24660 FOR Y=1 TO DN
24670 READ DY
24675 DY=DY/100
24680 IF Y>TH THEN 24710
24690 DA=DA+DY*DF(Y)
24700 DD=DD+DY
24710 NEXT Y
24720 IF TH<DN THEN 24750
24730 SL=1
24740 GOTO 24760
24750 SL=TH/DN
24760 RETURN
24770 INPUT "ENTER DATA FILE NAME FOR TRANSFER TO SOLCOM2";A$
24780 OPEN "O",1,A$
24790 PRINT #1, F1$
24800 PRINT #1,N$
24810 PRINT #1,Y0;TH;TT;TG;TS;TX;CG(1);CG(2);TP;IN;MM;EN
24820 FOR I=1 TO IN:PRINT #1,Y(I);R1(I);R2(I);R3(I)
24830 FOR K=1 TO EN:PRINT #1,R4(I,K);:NEXT K:PRINT #1,
24840 NEXT I
24850 FOR K=1 TO EN:PRINT #1,KE(K);TU(K);EN$(K);",";EM$(K):NEXT K
24860 PRINT #1,KH;KW;KC;KS;KD(1);KD(2)
24870 PRINT #1,LT;LL;LN;LI;DP;L$(LT)
24880 PRINT #1,N1;N2;N3
24890 FOR I=1 TO N1
24900 PRINT #1,E$(I)
24910 PRINT #1,EN(I);EC(I,1);EC(I,4);EG(I);ES(I);ET(I)
24920 NEXT I
25110 PRINT #1,HB;DB(1)
25120 PRINT #1,HE(1);HO;HF;HV;HC(1,3);H2(1);HC(1,4);HG(1);HS(1);HT(1)
25130 IF N2=1 THEN 25170
25140 FOR J=2 TO N2
25150 PRINT #1,HE(J);H1(J);HC(J,1);HC(J,3);H2(J);HC(J,4);HG(J);HS(J);HT(J)
25160 NEXT J
25170 PRINT #1,Q1,Q2
25180 IF Q2=2 AND Q1=2 THEN 25200
25185 IF Q2=1 THEN 25240
25190 PRINT #1,WB:REM THIS IS THE SAME AS HB SINCE SPACE AND WATER HEATING ARE COMBINED
25195 GOTO 25240
25200 PRINT #1,WB
25210 FOR W=1 TO N3
25220 PRINT #1, WE(W);W1(W);WC(W,1);WC(W,3);W2(W);WC(W,4);WG(W);WS(W);WT(W)
25230 NEXT W
25240 PRINT #1,CB;DB(2);CE;CO;CF;CV;CC(3);C2;CC(4);CG;CS;CT
25250 PRINT #1,SB;SF;SV;SC(3);S9;SC(4);M1;M2;SG;SS;ST
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25260 PRINT #1,DE(1);DE(2);DE(3);SO
25270 FOR M=1 TO 12:PRINT #1,HL(Ø,M);:NEXT M:PRINT #1,
25271 PRINT #1,MH(Ø),CL(Ø),MC(Ø)
25272 FOR M=1 TO 12:PRINT #1,WL(M);:NEXT M:PRINT #1,
25273 FOR M=1 TO 12:PRINT #1,IR(M);:NEXT M:PRINT #1,
25274 FOR I=1 TO N1
25275 FOR M=1 TO 12:PRINT #1,DH(I,M);:NEXT M:PRINT #1,
25276 PRINT #1,D1(I),DC(I),D2(I)
25277 NEXT I
25279 CLOSE 1
25280 INPUT "DO YOU WANT TO RUN 'SOLCOM2' ('Y' OR 'N')";Q$
25290 IF LEFT$(Q$,1)="Y" THEN 25320
25300 IF LEFT$(Q$,1)="N" THEN 25340
25310 GOTO 25280
25320 PRINT "LOADING SOLCOM2...."
25330 RUN "SOLCOM2"
25340 END
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```
10 REM PROGRAM NAME:SOLCOM2
20 CLEAR 200
30 DIM DH(10,13),DK(10),DC(10),D1(10),D2(10),E$(10),EI(10)
40 DIM HL(11,13),CL(11),MH(11),MC(11),     WL(13),TL(11,13),IR(12),N(12)
50 DIM G(12,3),G1(13),AO(11,5),AX(11),FT(11,5)
60 DIM FH(11,5),FW(11,5),F1(3),F2(3),F3(3),DE(3),DB(3),KD(2)
70 DIM TE(11),SK(11),EK(11),TK(11),EG(10),ES(10),ET(10)
80 DIM BO(11),EN(10),EJ(5,10),EW(5,10),TC(11,5),TX(11),RA(13)
90 DIM EC(10,4),HC(5,4),WC(5,4),CC(4),SC(4),SF(1),SV(1)
100 DIM Y(50),R1(50),R2(50),R3(50),R4(50,6),KE(6),TU(6),EN$(6),EM$(6)
110 DIM HE(5),H1(5),H2(5),HF(5),HG(5),HS(5),HT(5)
120 DIM WE(5),W1(5),W2(5),WG(5),WS(5),WT(5),WK(5,2),WM(5,2),HK(5,4),CK(2)
130 DIM QT(3),QH(3),QW(3)
140 DIM EO(5),HJ(5,2),CJ(5,2),HW(5,2),CW(5,2),R(10)
145 DIM AA(5),FF(5,3),IO(5),TT(5),JO(5)
150 INPUT "ENTER DATA FILE NAME FROM SOLCOM1";A$
160 OPEN "I",1,A$
170 INPUT #1,F1$,N$
180 INPUT #1,Y0,TH,TT,TG,TS,TX,CG(1),CG(2),TP,IN,MM,EN
190 EM=10[6
200 IF MM=2 THEN 230
210 EE=0.003412:REM ENGLISH UNITS
220 GOTO 240
230 EE=0.0036:REM SI UNITS
240 FOR I=1 TO IN:INPUT #1,Y(I),R1(I),R2(I),R3(I)
250 FOR K=1 TO EN:INPUT #1,R4(I,K):NEXT K
260 NEXT I
270 FOR K=1 TO EN:INPUT #1,KE(K),TU(K),EN$(K),EM$(K):NEXT K
280 INPUT #1,KH,KW,KC,KS,KD(1),KD(2)
285 PRINT "KW="KWQ
290 INPUT #1,LT,LL,LN,LI,DP,L$
300 INPUT #1,N1,N2,N3
310 FOR I=1 TO N1
320 INPUT #1,E$(I),EN(I),EC(I,1),EC(I,4),EG(I),ES(I),ET(I)
330 DK(I)=EC(I,4)
340 NEXT I
350 N(1)=31:N(2)=28:N(3)=31:N(4)=30:N(5)=31:N(6)=30
360 N(7)=31:N(8)=31:N(9)=30:N(10)=31:N(11)=30:N(12)=31
370 INPUT #1,HB,DB(1)
380 INPUT #1,HE(1),HO,HF,HV,HC(1,3),H2(1),HC(1,4),HG(1),HS(1),HT(1)
390 IF N2=1 THEN 430
400 FOR J=2 TO N2
410 INPUT #1,HE(J),H1(J),HC(J,1),HC(J,3),H2(J),HC(J,4),HG(J),HS(J),HT(J)
420 NEXT J
430 INPUT #1,Q1,Q2
440 IF Q2=2 AND Q1=2 THEN 460
445 IF Q2=1 THEN 500
450 INPUT #1,WB
455 GOTO 500
460 INPUT #1,WB
470 FOR W=1 TO N3
480 INPUT #1,WE(W),W1(W),WC(W,1),WC(W,3),W2(W),WC(W,4),WG(W),WS(W),WT(W)
490 NEXT W
500 INPUT #1,CB,DB(2),CE,CO,CF,CV,CC(3),C2,CC(4),CG,CS,CT
510 INPUT #1,SB,SF,SV,SC(3),S9,SC(4),M1,M2,SG,SS,ST
520 INPUT #1,DE(1),DE(2),DE(3),SO
525 HL(0,13)=0
530 FOR M=1 TO 12:INPUT #1,HL(0,M):HL(0,M)=HL(0,M)*(1-EE*DE(1)):HL(0,13)=HL(0,13)+HL(0,M):NEXT M
540 INPUT #1,MH(0):MH(0)=MH(0)*(1-EE*DE(1))
542 INPUT #1,CL(0):CL(0)=CL(0)*(1+EE*DE(2))
544 INPUT #1,MC(0):MC(0)=MC(0)*(1+EE*DE(2))
548 WL(13)=0
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550 FOR M=1 TO 12:INPUT #1,WL(M):WL(13)=WL(13)+WL(M):NEXT M
560 FOR M=1 TO 12:INPUT #1,IR(M):NEXT M
570 FOR I=1 TO N1
575 DH(I,13)=0
580 FOR M=1 TO 12:INPUT #1,DH(I,M):DH(I,M)=DH(I,M)*(1-EE*DE(1)):DH(I,13)=DH(I,13)+DH(I,M):NEXT M
590 INPUT #1,D1(I):D1(I)=D1(I)*(1-EE*DE(1))
592 INPUT #1,DC(I):DC(I)=DC(I)*(1+EE*DE(2))
594 INPUT #1,D2(I):D2(I)=D2(I)*(1+EE*DE(2))
600 NEXT I
610 CLOSE 1
620 GOSUB 2460
630 GOSUB 6910
640 GOSUB 7110
650 A5=0
660 INPUT "COMPLETE OPTIMIZATION (1) OR SOLAR COLLECTOR OPTIMIZATION ONLY (2)?";Q9
670 IF Q9=1 THEN 5420
672 IF Q2=2 AND Q1=2 THEN 680
674 INPUT "ENTER INDEX FOR SPACE HEATING EQUIPMENT (J)";J
676 W=1:WE(W)=HE(J)
678 GOTO 690
680 INPUT "ENTER INDEXES FOR SPACE HEATING (J) AND WATER HEATING (W) EQUIPMENT";J,W
690 GOSUB 2610
700 LPRINT " SOLAR COLLECTOR SIZE OPTIMIZATION ANALYSIS FOR "N$
710 LPRINT USING A6$;HE(J)*100,WE(W)*100,CE*100
720 LPRINT USING A7$;SF(1),SV(1),M$
725 LPRINT B1$
730 LPRINT USING B2$;KH,KW,KC
735 LPRINT USING B3$;KD(1),KD(2),KS
737 LPRINT
740 LPRINT A1$:LPRINT A2$
750 IF MM=2 THEN 780
760 LPRINT A3$
770 GOTO 790
780 LPRINT A5$
790 FOR I=0 TO N1
800 IF I>0 THEN 820
810 PRINT "ENTER FIRST GUESS FOR OPTIMAL COLLECTOR AREA FOR BASE BUILDING";
812 IF MM=2 THEN 816
814 PRINT " (SQ. FT)";
815 GOTO 818
816 PRINT " (SQ M)";
818 INPUT A5
819 GOTO 830
820 A5=AO(I-1,J)*(HL(I,13)*KH/HE(J)+WL(13)*KW/WE(W))/(HL(I-1,13)*KH/HE(J)+WL(13)*KW/WE(W))
830 GOSUB 870
840 NEXT I
850 END
860 REM SUBROUTINE TO FIND OPTIMAL COLLECTOR AREA AND FRACTIONS CORRESPONDING TO I,J,W
870 M3=M1:M4=M2
880 FA=0:FB=0
890 IF A5>M1 THEN 1050
900 GOSUB 930
910 IF FA=1 THEN 1050 :REM OPT AREA > MIN AREA
920 GOTO 1760
930 REM SUBROUTINE TO DETERMINE IF OPT AREA =0,=MIN AREA,OR > MIN AREA
940 A9=M1
950 GOSUB 1930
960 F(1)=F1(1):A(1)=M1
970 IF D1>=0 THEN 1000 :REM OPTIMAL AREA <= MIN AREA IF D1 >= 0.
980 FA=1:A5=(M3*2+M4)/3:REM IF FA=1, TEST 1 HAS BEEN MADE AND OPT AREA > MIN AREA.
```

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990 GOTO 1040
1000 IF NS>0 THEN 1030 :REM OPTIMAL COLLECTOR AREA =M1 (MIN AREA)
1010 AO(I,J)=0:FT(I,J)=0:FH(I,J)=0:FW(I,J)=0:A5=0
1020 GOTO 1040
1030 AO(I,J)=M1:FT(I,J)=F1(1):FH(I,J)=F2(1):FW(I,J)=F3(1):A5=M1
1040 RETURN
1050 REM USE FOLLOWING ONLY IF MAX COLLECTOR AREA MIGHT <OPTIMAL COLLECTOR AREA
1060 F(2)=0
1070 IF A5<M2 THEN 1220
1080 GOSUB 1100
1090 IF FB=1 THEN 1220 :REM OPT AREA < MAX AREA
1095 GOTO 1760
1100 REM SUBROUTINE TO DETERMINE IF OPTIMAL AREA =0,=MAX AREA, <MAX AREA
1110 A9=M2
1120 GOSUB 1930
1130 F(2)=F1(1):A(2)=M2
1140 IF D1=<0 THEN 1170 :REM OPT AREA >= MAX AREA
1150 FB=1: A5=(M3+M4*2)/3: REM IF FB=1, TEST 2 HAS BEEN MADE AND OPT AREA < MAX AREA.
1160 GOTO 1210
1170 IF NS>0 THEN 1200 :REM OPT AREA = M2 (MAX AREA)
1180 AO(I,J)=0:FT(I,J)=0:FH(I,J)=0:FW(I,J)=0:A5=0
1190 GOTO 1210
1200 AO(I,J)=M2:FT(I,J)=F1(1):FH(I,J)=F2(1):FW(I,J)=F3(1):A5=M2
1210 RETURN
1220 REM
1230 REM A5 IS NOW FIRST GUESS
1240 IF A5>M3 THEN 1270
1250 A5=M3
1260 GOTO 1290
1270 IF A5<M4 THEN 1290
1280 A5=M4
1290 A9=A5
1300 GOSUB 1930
1320 IF D2>0 THEN 1360
1330 A5=A5+Z9*2
1340 REM: ADJUST A5 TO MOVE OUT OF KINK IN SOLAR FRACTION CURVE
1350 GOTO 1290
1360 IF D1>0 THEN 1430 :REM A5 IS < OPT AREA
1370 IF D1<0 THEN 1450 :REM A5 IS > OPT AREA
1380 IF NS>0 THEN 1410 :REM A5=OPT AREA
1390 AO(I,J)=0:FT(I,J)=0:FH(I,J)=0:FW(I,J)=0
1400 GOTO 1760
1410 AO(I,J)=A5:FT(I,J)=F1(1):FH(I,J)=F2(1):FW(I,J)=F3(1)
1420 GOTO 1760
1430 M4=A5
1440 GOTO 1460
1450 M3=A5
1460 A6=A5
1470 A5=A6-D1/D2
1490 IF A5>M4 THEN 1710
1500 IF A5<M3 THEN 1640
1510 IF MM=2 THEN 1540
1520 Z7=10
1530 GOTO 1550
1540 Z7=1.0
1550 IF A5<A6-Z7 THEN 1290
1560 IF A5>A6+Z7 THEN 1290
1570 A9=A5
1580 GOSUB 1930
1590 IF NS>0 THEN 1620
```

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1600 AO(I,J)=0:FT(I,J)=0:FH(I,J)=0:FW(I,J)=0
1610 GOTO 1760
1620 AO(I,J)=A5:FT(I,J)=F1(1):FH(I,J)=F2(1):FW(I,J)=F3(1)
1630 GOTO 1760
1640 IF FA=1 THEN 1690
1650 IF A5>M1 THEN 1690
1660 GOSUB 930
1670 IF FA=1 THEN 1700
1680 GOTO 1760
1690 A5=(M3+M4)/2
1700 GOTO 1290
1710 IF FB=1 THEN 1690
1720 IF A5<M2 THEN 1690
1730 GOSUB 1100
1740 IF FB=1 THEN 1700
1760 IF Q9=1  THEN 1920
1770 REM: PRINTING INSTRUCTIONS FOR SOLAR-ONLY OPTIMIZATION
1780 IF AO(I,J)>0 THEN 1810
1790 SK(I)=0
1800 GOTO 1820
1810 SK(I)=SF(1)+SV(1)*AO(I,J)
1820 W9=WK(W,1)
1830 H9=HK(J,1)+HK(J,2)*HO*MH(I)
1840 H5=HL(I,13)/(1-EE*DE(1))
1850 C9=CK(1)+CK(2)*CO*MC(I)
1860 C5=CL(I)/(1+EE*DE(2))
1870 TE(I)=KH/HE(J)*HL(I,13)*(1-FH(I,J))+KD(1)*EE*H5*DE(1)+HL(I,13)*FH(I,J)*DE(3)*KS*EE
1880 TE(I)=TE(I)+KW/WE(W)*WL(13)*(1-FW(I,J))+WL(13)*FW(I,J)*DE(3)*KS*EE
1890 TE(I)=TE(I)+KC/CE*CL(I)+KD(2)*EE*C5*DE(2)
1900 TK(I)=TE(I)+SK(I)+EK(I)+H9+C9+W9
1905 IF MM=1 THEN 1915
1910 LPRINT USING A4$;H5,C5,WL(13),AO(I,J),FT(I,J)*100,FH(I,J)*100,FW(I,J)*100,TE(I),EK(I),SK(I),H9,C9,W9,TK(I)
1911 GOTO 1920
1915 LPRINT USING A8$;H5,C5,WL(13),AO(I,J),FT(I,J)*100,FH(I,J)*100,FW(I,J)*100,TE(I),EK(I),SK(I),H9,C9,W9,TK(I)
1920 RETURN
1930 REM SLR SUBROUTINE TO FIND FRACTION CORRESPONDING TO COLLECTOR AREA, TOTAL HEATING AND COLLECTOR COSTS,
1935 REM AND 1ST AND 2ND DERIVATIVES OF TOTAL COST CURVE
1940 IF MM=1 THEN 1970
1950 Z9=0.5:REM Z9 IS AREA INTERVAL TO FIND 1ST AND 2ND DERIVATIVES OF TOTAL COST CURVE (SQ. METERS)
1960 GOTO 1980
1970 Z9=5:REM Z9 IS AREA INTERVAL USED TO FIND 1ST AND 2ND DERIVATIVES OF TOTAL COST CURVE (SQ. FT.)
1980 Z8=Z8+1: REM Z8= COUNTER TO KEEP TRACK OF NUMBER OF TIMES THIS SUBROUTINE IS ENTERED
1990 FOR L=1 TO 3
2000 QT(L)=0:QH(L)=0:QW(L)=0
2010 NEXT L
2020 IF A9<Z9 THEN 2450
2030 FOR M=1 TO 12
2040 IF TL(I,M)=0 THEN 2250
2050 TL=EM*TL(I,M)
2060 X=IR(M)*N(M)/TL
2070 X1=X*A9
2080 IF X1<B2 THEN 2130
2090 G(M,1)=1-B3*EXP(-B4*X1)
2100 G(M,2)=1-B3*EXP(-B4*X*(A9-Z9))
2110 G(M,3)=1-B3*EXP(-B4*X*(A9+Z9))
2120 GOTO 2160
2130 G(M,1)=B1*X1
2140 G(M,2)=B1*X*(A9-Z9)
2150 G(M,3)=B1*X*(A9+Z9)
2160 QT(3)=QT(3)+G(M,3)*TL(I,M)
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2170 QH(3)=QH(3)+G(M,3)*HL(I,M)
2180 QW(3)=QW(3)+G(M,3)*WL(M)
2190 QT(2)=QT(2)+G(M,2)*TL(I,M)
2200 QH(2)=QH(2)+G(M,2)*HL(I,M)
2210 QW(2)=QW(2)+G(M,2)*WL(M)
2220 QT(1)=QT(1)+G(M,1)*TL(I,M)
2230 QH(1)=QH(1)+G(M,1)*HL(I,M)
2240 QW(1)=QW(1)+G(M,1)*WL(M)
2250 NEXT M
2260 F1(1)=QT(1)/TL(I,13)
2270 F2(1)=QH(1)/HL(I,13)
2280 IF Q2=2 THEN 2290
2285 F3(1)=0: GOTO 2300
2290 F3(1)=QW(1)/WL(13)
2300 EK=K2+K3*A9
2310 T1#=KH/HE(J)*HL(I,13)*(1-F2(1))+KW/WE(W)*WL(13)*(1-F3(1))+QT(1)*DE(3)*KS*EE +EK
2320 NS=KH/HE(J)*HL(I,13)*F2(1)+KW/WE(W)*WL(13)*F3(1)-EK-QT(1)*DE(3)*KS*EE
2330 F1(2)=QT(2)/TL(I,13)
2340 F2(2)=QH(2)/HL(I,13)
2342 IF Q2=2 THEN 2350
2345 F3(2)=0:GOTO 2360
2350 F3(2)=QW(2)/WL(13)
2360 EK=K2+K3*(A9-Z9)
2370 T2#=KH/HE(J)*HL(I,13)*(1-F2(2))+KW/WE(W)*WL(13)*(1-F3(2))+QT(2)*DE(3)*KS*EE+EK
2380 F1(3)=QT(3)/TL(I,13)
2390 F2(3)=QH(3)/HL(I,13)
2392 IF Q2=2 THEN 2400
2395 F3(3)=0:GOTO 2410
2400 F3(3)=QW(3)/WL(13)
2410 EK=K2+K3*(A9+Z9)
2420 T3#=KH/HE(J)*HL(I,13)*(1-F2(3))+KW/WE(W)*WL(13)*(1-F3(3))+QT(3)*DE(3)*KS*EE+EK
2430 D1=(T3#-T2#)/(2*Z9)
2440 D2=(T3#-2*T1#+T2#)/Z9[2
2450 RETURN
2460 REM SLR COEFFICIENTS FOR SOLAR HEATING SYSTEMS
2470 REM SYSTEM 1: LIQUID, 1 COVER, SELECTIVE
2480 B(1,1)=.317:B(1,2)=1.478:B(1,3)=1.314:B(1,4)=.613
2490 REM SYSTEM 2: LIQUID, 1 COVER, NON-SELECTIVE
2500 B(2,1)=.291:B(2,2)=1.581:B(2,3)=1.298:B(2,4)=.555
2510 REM SYSTEM 3: LIQUID, 2 COVER, NON-SELECTIVE
2520 B(3,1)=.287:B(3,2)=1.605:B(3,3)=1.302:B(3,4)=.550
2530 REM SYSTEM 4: AIR, 1 COVER, SELECTIVE
2540 B(4,1)=.415:B(4,2)=1.187:B(4,3)=1.360:B(4,4)=.830
2550 REM SYSTEM 5: AIR, 1 COVER, NON-SELECTIVE
2560 B(5,1)=.426:B(5,2)=1.177:B(5,3)=1.392:B(5,4)=.872
2570 REM SYSTEM 6: AIR, 2 COVER, NON-SELECTIVE
2580 B(6,1)=.371:B(6,2)=1.314:B(6,3)=1.353:B(6,4)=.739
2590 B1=B(SO,1):B2=B(SO,2):B3=B(SO,3):B4=B(SO,4)
2600 RETURN
2610 A1$="  AHR     ACR     AWR      OPTIMAL    OPTIMAL FRACTION    ENERGY    SHELL    SOLAR  SP.HT EQ.  CL. EQ.  W.H. EQ.    TOTAL"
2620 A2$="                           COL. AREA  TOTAL  SPACE  WATER   COST      COST     COST     COST      COST     COST       COST"
2630 A3$="(MMBTU)(MMBTU)(MMBTU) (SQ.FT.)      (%)    (%)    (%)     ($)       ($)      ($)      ($)       ($)      ($)        ($)"
2640 A5$=" (GJ)    (GJ)    (GJ)     (SQ.M.)      (%)    (%)    (%)     ($)       ($)      ($)      ($)       ($)      ($)        ($)"
2650 A4$="###.#  ###.#  ###.#   #####.#       ##.#  ##.#   ##.# ######   #######  ######  ######    ######    ######  ########"
2655 A8$="###.#  ###.#  ###.#   ######        ##.#  ##.#   ##.# ######   #######  ######  ######    ######    ######  ########"
2660 A6$="SPACE HTG PLANT EFF = ##.#%; WATER HTG PLANT EFF = ##.#%; SPACE CLG PLANT EFF = ###.#%"
2670 A7$="PRESENT-VALUE SOLAR HTG SYSTEM COSTS: FIXED = $#######; VARIABLE = $#####/%   %"
2680 IF MM=2 THEN 2710
2690 M$="SQ FT"
2700 GOTO 2720
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2710 M$="SQ M"
2720 B1$= "LIFE-CYCLE COST PER MILLION BTU PURCHASED ANNUALLY:"
2722 B2$= "SPACE HEATING = $$###.##  WATER HEATING = $$###.##  SPACE COOLING = $$###.##"
2724 B3$="SP HGT DIST = $$###.##  SP CLG DIST = $$###.##   SOLAR FANS/PUMPS = $$###.##"
2725 RETURN
2730 REM SUBROUTINE TO FIND APPROXIMATE OPTIMUM I FOR GIVEN J,W
2740 FOR Y=0 TO N1:TX(Y)=0:NEXT Y
2750 IF TX(I)=1 THEN 2790
2760 GOSUB 3090
2770 GOSUB 4100 :TX(I)=1
2780 TC(I,J)=T1
2790 I=I-1:IF TX(I)=1 THEN 2810
2800 GOSUB 4100 :TX(I)=1:TC(I,J)=T1
2810 I=I+1
2820 DT=TC(I,J)-TC(I-1,J): PRINT "I="I,TC(I,J),T1,DT
2830 IF DT>0 THEN 2870
2840 IF I=N1 THEN 3030
2850 I=I+1
2860 GOTO 2760
2870 IF I<>I2 THEN 2900
2880 IF I>1 THEN 2920
2890 GOTO 3030
2900 I=I-1
2910 GOTO 3030
2920 I=I-1
2930 GOSUB 3090
2940 IF TX(I)=1 THEN 2970
2950 GOSUB 4100 :TX(I)=1
2960 TC(I,J)=T1
2970 I=I-1
2980 IF TX(I)=1 THEN 3000
2990 GOSUB 4100 :TX(I)=1:TC(I,J)=T1
3000 I=I+1
3010 DT=TC(I,J)-TC(I-1,J)
3020 IF DT>0 THEN 2880
3030 PRINT "1ST APPROX OPT I FOR J="J"AND W="W"IS "I
3040 IF AX(I)=1 THEN 3080
3050 A5=BO(I)
3060 PRINT "A5="A5
3070 GOSUB 870  :AX(I)=1:REM CALCULATE OPT AREA AND FRACTIONS CORRESPONDING TO APPROX OPT I
3080 RETURN
3090 BO(I)=AO(I2,J)*(HL(I,13)*KH/HE(J)+WL(13)*KW/WE(W)+FT*TL(I,13)*DE(3)*KS*EE)
3100 BO(I)=BO(I)/(HL*KH/HE(J)+WL(13)*KW/WE(W)+FT*TL*DE(3)*KS*EE)
3110 BO(I-1)=AO(I2,J)*(HL(I-1,13)*KH/HE(J)+WL(13)*KW/WE(W)+FT*TL(I-1,13)*DE(3)*KS*EE)
3120 BO(I-1)=BO(I-1)/(HL*KH/HE(J)+WL(13)*KW/WE(W)+FT*TL*DE(3)*KS*EE)
3130 RETURN
3140 REM: THIS SUBROUTINE FINDS OPTIMAL I GIVEN J,W
3150 FOR Y=1 TO N1:AX(Y)=0:NEXT Y
3160 IF I>0 THEN 3180
3170 I=1
3180 GOSUB 870  :AX(I)=1:REM GET INITIAL FRACTIONS AND COLLECTOR AREA FOR INITIAL GUESS OF I,J, AND W
3190 I2=I
3200 HL=HL(I2,13):FT=FT(I2,J):TL=TL(I2,13)
3210 GOSUB 6490 :REM RANK ENVELOPE MODIFICATIONS BY DECREASING B-C RATIO AND COMPUTE NEW HEATING LOADS
3220 GOSUB 2740 :REM FIND APPROXIMATE OPTIMAL I AND CORRESPONDING AREA AND FRACTIONS
3230 IF I=I2 THEN 3390
3240 IF I=0 THEN 3260
3250 R5=HL(I-1,13)
3260 R6=HL(I,13)
3270 IF I=N1 THEN 3290
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3280 R7=HL(I+1,13)
3290 GOSUB 6490 :REM RERANK ENVELOPE MODIFICATIONS WITH FRACTIONS BASED ON APPOXIMATE OPTIMAL I
3300 IF I=0 THEN 3320
3310 IF HL(I-1,13)<>R5 THEN 3360
3320 IF HL(I,13)<>R6 THEN 3360
3330 IF I=N1 THEN 3350
3340 IF HL(I+1,13)<>R7 THEN 3360
3350 GOTO 3390
3360 AX(I2)=0
3370 GOSUB 2740 :REM IF ANY CHANGE IN SPACE HEATING REQUIREMENTS AROUND OPTIMAL I DUE TO CHANGE IN RANKING OF EVELOPE
3375 REM MODIFICATIONS, REPEAT OPTIMIZATION PROCESS
3380 PRINT "MODS WERE REORDERED"
3390 GOSUB 3450
3410 HJ(J,1)=HL(I,13):HJ(J,2)=MH(I)
3420 CJ(J,1)=CL(I):CJ(J,2)=MC(I)
3430 REM: TC(I,J),AO(I,J),EO(J),FH(I,J),FW(I,J),FT(I,J) HAVE ALL BEEN DETERMINED FOR J - I AT THIS POINT IS OPTIMAL GIVEN J.
3440 RETURN
3450 REM: SUBROUTINE TO FIND ACTUAL OPTIMUM I FOR SHELL FOR JTH EQUIPMENT EFFICIENCY (EO(J)) AND CORRESPONDING
3455 REM OPTIMAL COLLECTOR AREA (AO(EO(J),J)).
3460 FOR Y=0 TO N1:TX(Y)=0:NEXT Y
3470 BO(I)=AO(I,J)
3480 I=I-1
3490 IF AX(I)=1 THEN 3530
3500 I9=I+1:GOSUB 4070
3510 A5=A5*AO(I+1,J):PRINT "A5="A5
3520 GOSUB 870  :AX(I)=1
3530 BO(I)=AO(I,J)
3540 I=I+1
3550 I4=I:REM I4=STARTING I
3560 IF TX(I)=1 THEN 3600
3570 I2=I
3580 GOSUB 4100 :TX(I)=1:REM GET TC(I,J)
3590 TC(I,J)=T1
3600 I=I-1:I2=I
3610 IF TX(I)=1 THEN 3640
3620 GOSUB 4100 :TX(I)=1:REM GET TC(I-1,J)
3630 TC(I,J)=T1
3640 I=I+1
3650 DT=TC(I,J)-TC(I-1,J):PRINT "DT("I")="DT
3660 IF DT>0 THEN 3790
3680 IF I=N1 THEN 3760
3690 I=I+1
3700 IF AX(I)=1 THEN 3740
3710 I9=I-1:GOSUB 4070
3720 A5=A5*AO(I-1,J)
3730 GOSUB 870  :AX(I)=1
3740 BO(I)=AO(I,J)
3750 GOTO 3570
3760 IF I<>I4 THEN 4060
3770 GOSUB 4560
3780 GOTO 4060
3790 I=I-1
3800 GOSUB 4240
3810 IF I=0 THEN 4060
3820 IF I+1=I4 THEN 3840
3830 GOTO 4060
3840 I=I-1
3850 IF AX(I)=1 THEN 3900
3860 I9=I+1
```


3870 GOSUB 4070

```
3870 GOSUB 4070
3880 A5=A5*AO(I+1,J)
3890 GOSUB 870  :AX(I)=1
3900 BO(I)=AO(I,J)
3910 I=I+1
3920 IF TX(I)=1 THEN 3950
3930 I2=I:GOSUB 4100 :TX(I)=1
3940 TC(I,J)=T1
3950 I=I-1
3960 IF TX(I)=1 THEN 4000
3970 I2=I
3980 GOSUB 4100 :TX(1)=1
3990 TC(I,J)=T1
4000 I=I+1
4010 DT=TC(I,J)-TC(I-1,J)
4020 IF DT<=0 THEN 4050
4030 I=I-1
4040 IF I=0 THEN 4060
4045 GOTO 3840
4050 GOSUB 4560
4060 EO(J)=I:RETURN
4070 A5=HL(I,13)*KH/HE(J)+WL(13)*KW/WE(W)+FT(I9,J)*TL(I,13)*DE(3)*KS*EE
4080 A5=A5/(HL(I9,13)*KH/HE(J)+WL(13)*KW/WE(W)+FT(I9,J)*TL(I9,13)*DE(3)*KS*EE)
4090 RETURN
4100 REM COMPUTE TOTAL COST OF I,J,W AND I-1,J,W OPTIONS
4110 H5=HL(I,13)/(1-EE*DE(1))
4120 C5=CL(I)/(1+EE*DE(2))
4130 T1=HL(I,13)*KH/HE(J)*(1-FH(I2,J))+HL(I,13)*FH(I2,J)*DE(3)*KS*EE
4140 T1=T1+WL(13)*KW/WE(W)*(1-FW(I2,J))+WL(13)*FW(I2,J)*DE(3)*KS*EE
4150 T1=T1+CL(I)*KC/CE
4160 T1=T1+H5*DE(1)*KD(1)*EE
4170 T1=T1+C5*DE(2)*KD(2)*EE
4180 IF BO(I)>0 THEN 4210
4190 K4=0
4200 GOTO 4220
4210 K4=SF(1)+SV(1)*BO(I)
4220 T1=T1+EK(I)+K4+HK(J,1)+HK(J,2)*MH(I)*HO+CK(1)+CK(2)*MC(I)*CO+WK(W,1)
4230 RETURN
4240 REM CHECKING ROUTINE - INCREMENT I ONCE MORE
4250 IF I>=N1-1 THEN 4550
4260 I=I+2
4270 IF AX(I)=1 THEN 4310
4280 I9=I-1:GOSUB 4070
4290 A5=A5*AO(I-1,J)
4300 GOSUB 870  :AX(I)=1
4310 BO(I)=AO(I,J)
4320 IF TX(I)=1 THEN 4360
4330 I2=I
4340 GOSUB 4100 :TX(I)=1
4350 TC(I,J)=T1
4360 I=I-1
4370 IF TX(I)=1 THEN 4410
4380 I2=I
4390 GOSUB 4100 :TX(I)=1
4400 TC(I,J)=T1
4410 I=I-1
4420 DT=TC(I+2,J)-TC(I+1,J):PRINT "DT("I"+2)="DT
4430 IF DT>0 THEN 4550
4440 I=I+1
4450 GOSUB 4880
```

```
4460 I9=I-1:GOSUB 4070
4470 A5=A5*AO(I-1,J)
4480 GOSUB 870  :AX(I)=1
4490 BO(I)=AO(I,J)
4500 I2=I:GOSUB 4100 :TX(I)=1
4510 TC(I,J)=T1
4520 DT=TC(I,J)=TC(I-1,J)
4530 IF DT<=0 THEN 4240
4540 I=I-1
4550 RETURN
4560 REM CHECKING ROUTINE - DECREMENT I ONCE MORE
4570 IF I<2 THEN 4870
4580 I=I-2
4590 IF AX(I)=1 THEN 4630
4600 I9=I+2:GOSUB 4070
4610 A5=A5*AO(I+2,J)
4620 GOSUB 870  :AX(I)=1
4630 BO(I)=AO(I,J)
4640 IF TX(I)=1 THEN 4670
4650 I2=I:GOSUB 4100 :TX(I)=1
4660 TC(I,J)=T1
4670 I=I+1
4680 IF TX(I)=1 THEN 4720
4690 I2=I
4700 GOSUB 4100 :TX(I)=1
4710 TC(I,J)=T1
4720 I=I+1
4730 DT=TC(I-1,J)-TC(I-2,J):PRINT "DT("I"-2)="DT
4740 IF DT<=0 THEN 4870
4750 I=I-1
4760 GOSUB 4880
4770 I9=I-1:GOSUB 4070
4780 A5=A5*AO(I-1,J)
4790 GOSUB 870  :AX(I)=1
4800 BO(I)=AO(I,J)
4810 I2=I:GOSUB 4100 :TX(I)=1
4820 TC(I,J)=T1
4830 DT=TC(I,J)-TC(I-1,J)
4840 IF DT<=0 THEN 4560
4850 I=I-1
4860 GOTO 4560
4870 RETURN
4880 REM SWITCH I AND I+1 MODIFICATIONS
4890 FOR M=1 TO 13:G1(M)=DH(I,M):NEXT M
4900 G2=DC(I):G3=D1(I):G4=D2(I)
4910 G5=DK(I):G6=EN(I):G$=E$(I)
4920 FOR M=1 TO 13:DH(I,M)=DH(I+1,M):NEXT M
4930 DC(I)=DC(I+1):D1(I)=D1(I+1):D2(I)=D2(I+1)
4940 DK(I)=DK(I+1):EN(I)=EN(I+1):E$(I)=E$(I+1)
4950 FOR M=1 TO 13:DH(I+1,M)=G1(M):NEXT M
4960 DC(I+1)=G2:D1(I+1)=G3:D2(I+1)=G4
4970 DK(I+1)=G5:EN(I+1)=G6:E$(I+1)=G$
4980 GOSUB 6910
4990 RETURN
5000 REM THIS SUBROUTINE FINDS OPTIMAL J FOR SPACE HEATING EQUIPMENT GIVEN W FOR WATER HEATING EQUIPMENT
5010 REM
5020 IF Q1=2 AND Q2=2 THEN 5040
5030 WE(1)=HE(J)
5040 GOSUB 3140 :REM FIND OPTIMAL AO AND I GIVEN J AND W
5050 PRINT "OPT I FOR J="J" IS "EO(J)"; CORRESPONDING OPT AREA = "AO(EO(J),J)
```

```
5060 IF J=1 THEN 5210
5070 J=J-1
5080 IF Q1=2 THEN 5100
5090 WE(1)=HE(J)
5100 IF AO(I,J)=0 THEN 5130
5110 A5=AO(I,J)
5120 GOTO 5140
5130 A5=AO(I,J+1)
5140 GOSUB 3140
5150 PRINT "OPT I FOR J="J" IS "EO(J)";CORRESPONDG OPT AREA = "AO(EO(J),J)
5160 IF TC(EO(J),J)>TC(EO(J+1),J+1) THEN 5190
5170 IF J=1 THEN 5345
5180 GOTO 5070
5190 J=J+1
5200 IF J<>J1 THEN 5345
5210 IF J=N2 THEN 5345
5220 J=J+1
5230 IF Q2=1 THEN 5260
5240 IF Q1=2 THEN 5260
5250 WE(1)=HE(J)
5260 IF AO(I,J)=0 THEN 5290
5270 A5=AO(I,J)
5280 GOTO 5300
5290 A5=AO(I,J-1)
5300 GOSUB 3140
5310 PRINT "OPT I FOR J="J" IS "EO(J)";CORRESPONDG OPT AREA = "AO(EO(J),J)
5320 IF TC(EO(J),J)>TC(EO(J-1),J-1) THEN 5340
5330 GOTO 5210
5340 J=J-1
5345 JO(W)=J
5350 FOR L=1 TO EO(J):EW(W,L)=EJ(J,L):NEXT L
5360 HW(W,1)=HJ(J,1):HW(W,2)=HJ(J,2)
5370 CW(W,1)=CJ(J,1):CW(W,2)=CJ(J,2)
5372 IO(W)=EO(J)
5374 AA(W)=AO(EO(J),J)
5376 FF(W,1)=FH(EO(J),J):FF(W,2)=FW(EO(J),J):FF(W,3)=FT(EO(J),J)
5378 TT(W)=TC(EO(J),J)
5380 PRINT "OPTIMAL J="J,"OPT I="EO(J)
5390 RETURN
5420 REM THIS SUBROUTINE FINDS OPTIMAL W
5430 IF Q1=2 AND Q2=2 THEN 5510
5470 INPUT "ENTER SEARCH STARTING POINT INDEXES (I,J) FOR ENVELOPE AND HEATING EQUIPMENT";I1,J1
5480 W1=1
5490 N3=1
5500 GOTO 5520
5510 INPUT "ENTER SEARCH STARTING POINT INDEXES (I,J,W) FOR ENVELOPE, SPACE HEATING EFF, WATER HEATING EFF";I1,J1,W1
5520 PRINT "ENTER FIRST GUESS FOR OPTIMAL COLLECTOR AREA FOR THE STARTING POINTS USED";
5522 IF MM=2 THEN 5226
5524 PRINT " (SQ. FT.)";
5525 GOTO 5528
5526 PRINT " (SQ M)";
5528 INPUT A5
5530 IF A5>M1 THEN 5560
5540 A5=(2*M1+M2)/3
5550 GOTO 5570
5560 IF A5>M2 THEN 5540
5570 IF I1>1 THEN 5590
5580 I1=1
5590 IF N1>I1 THEN 5610
5600 I1=N1
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```
5610 IF J1<=N2 THEN 5630
5620 J1=N2
5630 IF W1<=N3 THEN 5650
5640 W1=N3
5650 I=I1:J=J1:W=W1
5660 GOSUB 5010 : REM FIND OPTIMAL AO, I, AND J GIVEN W
5700 IF Q2=1 THEN 5920
5710 IF Q1=1 THEN 5920
5720 IF W=1 THEN 5830
5725 A5=AA(W)
5730 W=W-1
5770 GOSUB 5010
5780 IF TT(W+1)<TT(W) THEN 5810
5790 IF W=1 THEN 5920
5800 GOTO 5730
5810 W=W+1
5820 IF W<>W1 THEN 5920
5830 IF W=N3 THEN 5920
5835 A5=AA(W)
5840 W=W+1
5880 GOSUB 5010
5890 IF TT(W)>=TT(W-1) THEN 5910
5900 GOTO 5830
5910 W=W-1
5915 REM W IS OPT W AT THIS POINT
5920 WO=W:IO=IO(W):JO=JO(W):AO=AA(W):TC=TT(W)
5930 FH=FF(W,1):FW=FF(W,2):FT=FF(W,3)
5940 PRINT "IO="IO
5950 PRINT "JO="JO
5960 PRINT "WO="WO
5970 PRINT "AO="AO
5980 PRINT "TC="TC
5990 PRINT "FT="FT;"FH="FH;"FW="FW
6000 INPUT "ENTER TRANSFER FILE NAME TO MOVE RESULTS TO SOLCOM3";B$
6010 OPEN "O",1,B$
6020 PRINT #1,F1$
6030 PRINT #1,N$
6040 PRINT #1,Y0,TH,TT,TG,TS,TX,CG(1),CG(2),TP,IN,MM,EN
6050 PRINT #1,EM,EE
6060 FOR I=1 TO IN:PRINT #1,Y(I),R1(I),R2(I),R3(I)
6070 FOR K=1 TO EN:PRINT #1,R4(I,K):NEXT K
6080 NEXT I
6090 FOR K=1 TO EN:PRINT #1,KE(K),TU(K),EN$(K),",",EM$(K):NEXT K
6100 PRINT #1,KH,KW,KC,KS,KD(1),KD(2)
6110 PRINT #1,LT,LL,LN,LI,DP,L$
6120 PRINT #1,N1,N2,N3
6130 FOR I=1 TO N1
6140 PRINT #1,E$(I);",";EN(I);EC(I,1);EC(I,4);EG(I);ES(I);ET(I)
6150 NEXT I
6160 PRINT #1,HB,DB(1)
6170 PRINT #1,HO
6180 FOR J=1 TO N2
6190 PRINT #1,HE(J);HG(J);HS(J)
6200 NEXT J
6210 PRINT #1,Q1,Q2
6220 IF Q2=2 AND Q1=2 THEN 6240
6225 IF Q2=1 THEN 6280
6230 PRINT #1,WB
6235 GOTO 6280
6240 PRINT #1,WB
6250 FOR W=1 TO N3
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6250 FOR W=1 TO N3
6260 PRINT #1,WE(W);WG(W);WS(W)
6270 NEXT W
6280 PRINT #1,CB;DB(2);CE;CO;CF;CV;CG;CS;CT
6290 PRINT #1,SB;SF;SV;SG;SS;ST
6300 PRINT #1,IO,JO,WO,AO,FH,FW,FT
6310 PRINT #1,HW(WO,1),HW(WO,2),CW(WO,1),CW(WO,2)
6320 PRINT #1,HK(JO,1),HK(JO,2)
6330 FOR J=1 TO JO
6340 PRINT #1,HK(J,3),HK(J,4)
6350 NEXT J
6360 IF Q1=1 THEN 6420
6370 IF Q2=1 THEN 6420
6380 PRINT #1,WK(WO,1)
6390 FOR W=1 TO WO
6400 PRINT #1,WK(W,2)
6410 NEXT W
6420 PRINT #1,CK(1),CK(2),SF(1),SV(1)
6430 PRINT #1,DE(1),DE(2),DE(3),WL(13)
6440 FOR L=1 TO IO
6450 PRINT #1,EW(WO,L)
6460 NEXT L
6470 CLOSE 1
6480 GOTO 8320
6490 REM:SUBROUTINE TO RANK ENVELOPE MODIFICATIONS
6500 PRINT "AT 14005"
6510 FOR L=1 TO N1
6520 R(L)=KH/HE(J)*(1-FH(I2,J))*DH(L,13)+DE(3)*KS*EE*FH(I2,J)*DH(L,13)
6530 R(L)=R(L)+DH(L,13)/(1-EE*DE(1))*DE(1)*KD(1)*EE
6540 R(L)=R(L)+KC/CE*DC(L)
6550 R(L)=R(L)+DC(L)/(1+EE*DE(2))*DE(2)*KD(2)*EE
6560 R(L)=R(L)+D1(L)*HO*HK(2,J)
6570 R(L)=R(L)+D2(L)*CO*CK(2)
6580 R(L)=R(L)/DK(L)
6590 NEXT L
6600 FOR K=1 TO N1-1
6610 FOR L=1 TO N1-1
6620 IF R(L)=>R(L+1) THEN 6840
6630 FOR M=1 TO 13
6640 RA(M)=DH(L,M)
6650 NEXT M
6660 R2=DC(L)
6670 R3=D1(L):R4=D2(L)
6680 R5=DK(L):R6=EN(L)
6690 R$=E$(L)
6700 FOR M=1 TO 13
6710 DH(L,M)=DH(L+1,M)
6720 NEXT M
6730 DC(L)=DC(L+1)
6740 D1(L)=D1(L+1):D2(L)=D2(L+1)
6750 DK(L)=DK(L+1):EN(L)=EN(L+1)
6760 E$(L)=E$(L+1)
6770 FOR M=1 TO 13
6780 DH(L+1,M)=RA(M)
6790 NEXT M
6800 DC(L+1)=R2
6810 D1(L+1)=R3:D2(L+1)=R4
6820 DK(L+1)=R5:EN(L+1)=R6
6830 E$(L+1)=R$
6840 NEXT L
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6850 NEXT K
6860 FOR L=1 TO N1
6870 EJ(J,L)=EN(L):REM EJ(J,L) KEEPS TRACK OF ECONOMIC RANKING OF ENVELOPE MODIFICATIONS CORRESPONDING TO HE(J), GIVEN W
6880 NEXT L
6890 GOSUB 6910
6900 RETURN
6910 REM SUBROUTINE TO CALCULATE HEATING AND COOLING LOADS CORRESPONDING TO EACH ADDITIONAL MODIFICATION
6920 FOR M=1 TO 13
6930 TL(0,M)=HL(0,M)+WL(M)
6940 NEXT M
6950 FOR L=1 TO N1
6960 HL(L,13)=0
6970 TL(L,13)=0
6980 EK(0)=0
6990 FOR M=1 TO 12
7000 HL(L,M)=HL(L-1,M)-DH(L,M)
7010 TL(L,M)=HL(L,M)+WL(M)
7020 HL(L,13)=HL(L,13)+HL(L,M)
7030 TL(L,13)=TL(L,13)+TL(L,M)
7040 NEXT M
7050 MH(L)=MH(L-1)-D1(L)
7060 CL(L)=CL(L-1)-DC(L)
7070 MC(L)=MC(L-1)-D2(L)
7080 EK(L)=EK(L-1)+DK(L)
7090 NEXT L
7100 RETURN
7110 REM SUBROUTINE TO FIND FIXED AND VARIABLE COSTS RELATED TO SPACE HEATING, WATER HEATING,  AND COOLING EQUIPMENT
7120 HF(1)=HF*HC(1,4)
7130 HV(1)=HV*HC(1,4)
7140 IF H2(1)=1 THEN 7170
7150 HF(1)=HF(1)+HC(1,3)
7160 GOTO 7190
7170 HF(1)=HF(1)+HF*HC(1,3)
7180 HV(1)=HV(1)+HV*HC(1,3)
7190 IF N2=1 THEN 7420
7200 FOR J=2 TO N2
7210 IF H1(J)=1 THEN 7250
7220 HF(J)=HC(J,4)*HC(J,1)
7230 HV(J)=0
7240 GOTO 7270
7250 HF(J)=HF*HC(J,1)*HC(J,4)
7260 HV(J)=HV*HC(J,1)*HC(J,4)
7270 IF H2(J)=1 THEN 7310
7280 HF(J)=HF(J)+HC(J,3)
7290 HV(J)=HV(J)
7300 GOTO 7370
7310 IF H1(J)=1 THEN 7350
7320 HF(J)=HF(J)+HC(J,1)*HC(J,3)
7330 HV(J)=HV(J)
7340 GOTO 7370
7350 HF(J)=HF(J)+HC(J,1)*HF*HC(J,3)
7360 HV(J)=HV(J)+HC(J,1)*HV*HC(J,3)
7370 NEXT J
7380 J=2
7390 R(J)=(1/HE(J-1)-1/HE(J))*1000/(HF(J)+HV(J)*MH(0)*HO)
7400 IF J=2 THEN 7510
7410 IF R(J)<=R(J-1)THEN 7510
7420 HE(J-1)=HE(J):HF(J-1)=HF(J-1)+HF(J):HV(J-1)=HV(J-1)+HV(J)
7430 N2=N2-1
7440 IF J<N2 +1 THEN 7460
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7450 HE(N2+1)=0:HF(N2+1)=0:HV(N2+1)=0:GOTO 7530
7460 FOR Y=J TO N2
7470 HE(Y)=HE(Y+1):HF(Y)=HF(Y+1):HV(Y)=HV(Y+1)
7480 NEXT Y
7490 HE(N2+1)=0:HF(N2+1)=0:HV(N2+1)=0
7500 GOTO 7390
7510 J=J+1
7520 IF J<=N2 THEN 7390
7530 GOTO 7540
7540 HK(0,1)=0:HK(0,2)=0
7550 FOR J=1 TO N2
7560 HK(J,1)=HK(J-1,1)+HF(J): REM TOTAL FIXED COST OF SPACE HEATING EQUIP J (LCC)
7570 HK(J,2)=HK(J-1,2)+HV(J): REM TOTAL VARIABLE COST (PER 1000 BTU OUTPUT) OF SPACE HEATING EQUIPMENT J(LCC)
7580 NEXT J
7590 HK(1,3)=HF*(1+TX*HT(1)):HK(1,4)=HV*(1+TX*HT(1))
7600 IF N2=1 THEN 7690
7610 FOR J=2 TO N2
7620 IF H1(J)=1 THEN 7660
7630 HK(J,3)=HK(J-1,3)+HC(J,1)*(1+TX*HT(J))
7640 HK(J,4)=HK(J-1,4)
7650 GOTO 7680
7660 HK(J,3)=HK(J-1,3)+HC(J,1)*HF*(1+TX*HT(J)):REM TOTAL FIXED COST OF JTH S.H.PLANT (FIRST COST)
7670 HK(J,4)=HK(J-1,4)+HC(J,1)*HV*(1+TX*HT(J)):REM TOTAL VARIABLE COST (PER 1000 BTU OUTPUT) OF JTH S.H.PLANT  (FIRST COST)
7680 NEXT J
7690 REM COOLING EQUIPMENT COST
7700 CK(1)=CF*CC(4)
7710 CK(2)=CV*CC(4)
7720 IF C2=1 THEN 7760
7730 CK(1)=CK(1)+CC(3)
7740 CK(2)=CK(2)
7750 GOTO 7780
7760 CK(1)=CK(1)+CF*CC(3)
7770 CK(2)=CK(2)+CV*CC(3)
7780 REM FIND FIXED AND VARIABLE ($/SQ.FT.) SOLAR COSTS
7790 SF(1)=SF*SC(4)
7800 SV(1)=SV*SC(4)
7810 IF S9=1 THEN 7850
7820 SF(1)=SF(1)+SC(3)
7830 SV(1)=SV(1)
7840 GOTO 7870
7850 SF(1)=SF(1)+SF*SC(3)
7860 SV(1)=SV(1)+SV*SC(3)
7870 K2=SF(1)
7880 K3=SV(1)
7890 REM WATER HEATING EQUIPMENT COSTS
7895 IF Q1=1 OR Q2=1 THEN 8310
7900 FOR W=1 TO N3
7910 IF W1(W)=1 THEN 7940
7920 WM(W,2)=WC(W,1)
7930 GOTO 7950
7940 WM(W,2)=WC(W,1)*WC(1,1)
7950 IF W2(W)=1 THEN 8040
7960 IF W1(W)=0 THEN 7990
7970 WM(W,1)=WC(W,4)*WC(W,1)*WC(1,1)+WC(W,3)
7980 GOTO 8050
7990 WM(W,1)=WC(W,4)*WC(W,1)+WC(W,3)
8000 GOTO 8050
8010 IF W1(W)=0 THEN 8040
8020 WM(W,1)=WC(W,4)*WC(W,1)*WC(1,1)+WC(W,3)*WC(W,1)*WC(1,1)
8030 GOTO 8050
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8040 WM(W,1)=WC(W,4)*WC(W,1)+WC(W,3)*WC(W,1)
8050 NEXT W
8060 IF N3=1 THEN 8240
8070 W=2
8080 R(W)=(1/WE(W-1)-1/WE(W))*1000/WM(W,1)
8090 IF W=2 THEN 8210
8100 IF R(W)=<R(W-1) THEN 8210
8110 WE(W-1)=WE(W):WM(W-1,1)=WM(W-1,1)+WM(W,1):WM(W-1,2)=WM(W-1,2)+WM(W,2)
8120 N3=N3-1
8130 IF W<N3+1 THEN 8160
8140 WE(N3+1)=0:WM(N3+1,1)=0:WM(N3+1,2)=0
8150 GOTO 8240
8160 FOR Y=W TO N3
8170 WE(Y)=WE(Y+1):WM(Y,1)=WM(Y+1,1):WM(Y,2)=WM(Y+1,2)
8180 NEXT Y
8190 WE(N3+1)=0:WM(N3+1,1)=0:WM(N3+1,2)=0
8200 GOTO 8080
8210 W=W+1
8220 IF W<=N3 THEN 8080
8230 REM
8240 WK(1,1)=WM(1,1):REM LCC OF BASE W.H.PLANT
8250 WK(1,2)=WM(1,2)*(1+TX*WT(1)):REM FIRST COST OF BASE W.H. PLANT
8260 IF W=1 THEN 8310
8270 FOR W=2 TO N3
8280 WK(W,1)=WK(W-1,1)+WM(W,1):REM LCC OF WTH W.H.PLANT
8290 WK(W,2)=WK(W-1,2)+WM(W,2)*(1+TX*WT(W)):REM FIRST COST OF WTH W.H. PLANT
8300 NEXT W
8310 RETURN
8320 INPUT "DO YOU WANT TO RUN 'SOLCOM3' ('Y' OR 'N')";Q$
8330 IF LEFT$(Q$,1)="Y" THEN 8360
8340 IF LEFT$(Q$,1)="N" THEN 8380
8350 GOTO 8320
8360 PRINT "LOADING SOLCOM3....."
8370 RUN "SOLCOM3"
8380 END
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100 REM NAME OF PROGRAM IS SOLCOM3
15000 CLEAR 400
16000 DIM Y(50),R1(50),R2(50),R3(50),R4(50,6)
16005 DIM KE(6),TU(6),EN$(6),EM$(6),KD(2)
16010 DIM E$(10),EN(10),EC(10,20),EG(10),ES(10),DB(3)
16015 DIM HE(5),HG(5),HS(5)
16020 DIM WE(5),WG(5),WS(5)
16030 DIM HW(5,2),CW(5,2),HK(5,4),WK(5,2)
16035 DIM CK(2),SF(1),SV(1),DE(3),WL(13),EW(5,10)
16040 DIM F$(50)
16090 INPUT "ENTER TRANSFER FILE NAME FROM SOLCOM2";B$
16100 OPEN "I",1,B$
16105 INPUT #1,F1$
16110 INPUT #1,N$
16120 INPUT #1, Y0,TH,TT,TG,TS,TX,CG(1),CG(2),TP,IN,MM,EN
16125 INPUT #1, EM,EE
16130 FOR I=1 TO IN:INPUT #1,Y(I),R1(I),R2(I),R3(I)
16140 FOR K=1 TO EN:INPUT #1,R4(I,K):NEXT K
16150 NEXT I
16160 FOR K=1 TO EN:INPUT #1,KE(K),TU(K),EN$(K),EM$(K):NEXT K
16170 INPUT #1,KH,KW,KC,KS,KD(1),KD(2)
16180 INPUT #1,LT,LL,LN,LI,DP,L$
16190 INPUT #1,N1,N2,N3
16200 FOR I=1 TO N1
16210 INPUT #1,E$(I),EN(I),EC(I,1),EC(I,4),EG(I),ES(I),ET(I)
16220 NEXT I
16230 INPUT #1,HB,DB(1)
16240 PRINT HB
16250 INPUT #1,HO
16270 FOR J=1 TO N2
16280 INPUT #1,HE(J),HG(J),HS(J)
16290 NEXT J
16300 INPUT #1,Q1,Q2
16310 IF Q2=2 AND Q1=2 THEN 16330
16315 IF Q2=1 THEN 16370
16320 INPUT #1,WB
16325 GOTO 16370
16330 INPUT #1,WB
16340 FOR W=1 TO N3
16350 INPUT #1,WE(W),WG(W),WS(W)
16360 NEXT W
16370 INPUT #1,CB,DB(2),CE,CO,CF,CV,CG,CS,CT
16390 INPUT #1,SB,SF,SV,SG,SS,ST
16400 INPUT #1,IO,JO,WO,AO,FH,FW,FT
16401 IF MM=2 THEN 16404
16402 SZ=1 :REM ROUNDING FACTOR FOR COLLECTOR AREA (SQ FT.)
16403 GOTO 16405
16404 SZ=.1 :REM ROUNDING FACTOR FOR COLLECTOR AREA (SQ M)
16405 AO=INT(AO/SZ+.5)*SZ
16410 INPUT #1,HW(WO,1),HW(WO,2),CW(WO,1),CW(WO,2)
16420 INPUT #1,HK(JO,1),HK(JO,2)
16430 FOR J=1 TO JO
16440 INPUT #1,HK(J,3),HK(J,4)
16450 NEXT J
16455 IF Q1=2 AND Q2=2 THEN 16460
16456 IF Q2=1 THEN 16500
16457 WE(1)=HE(JO)
16458 GOTO 16500
16460 INPUT #1,WK(WO,1)
16470 FOR W=1 TO WO
```

```
16480 INPUT #1,WK(W,2)
16490 NEXT W
16500 INPUT #1,CK(1),CK(2),SF(1),SV(1)
16510 INPUT #1,DE(1),DE(2),DE(3),WL(13)
16520 FOR L=1 TO IO
16530 INPUT #1,EW(WO,L)
16540 NEXT L
16600 CLOSE 1
16750 REM
16900 M1$(1)="SQ.FT.":     M1$(2)=" SQ. M"
16910 M2$(1)="MMBTU/YR":   M2$(2)=" GJ/YR"
16920 M3$(1)="MBTU/HR":    M3$(2)=" MJ/HR"
16930 M4$(1)="BTU":        M4$(2)="KJ"
17900 EU$(1)="SPACE HEATING"
17910 EU$(2)="WATER HEATING"
17920 EU$(3)="SPACE COOLING"
17930 EU$(4)="FANS/PUMPS: SOLAR"
17940 EU$(5)="DISTRIBUTION: HTG"
17950 EU$(6)="DISTRIBUTION: CLG"
17960 TT$(1)="TAX-PAYING BUSINESS"
17962 TT$(2)="TAX EXEMPT"
17965 BB(1)=HB
17967 BB(2)=WB
17969 BB(3)=CB
17971 BB(4)=SB
17973 BB(5)=DB(1)
17975 BB(6)=DB(2)
18010 GOSUB 19000
18025 LPRINT
18030 LPRINT "              * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *"
18040 LPRINT "              *                                                              *"
18050 LPRINT USING F$(1);N$
18060 LPRINT F$(2);TIME$;:LPRINT "                                  *"
18070 LPRINT USING F$(3);TH,Y0,Y0+TH-1
18090 LPRINT USING F$(4);TT$(TT)
18100 IF TT=2 THEN 18120
18110 LPRINT USING F$(5);TG*100,TS*100
18120 LPRINT USING F$(6);TP*100,TX*100
18125 IF TT=2 THEN 18135
18130 LPRINT USING F$(7);CG(1)*100,CG(2)*100
18132 LPRINT USING F$(45);F1$
18135 LPRINT "              *                                                              *"
18136 LPRINT "              * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *"
18140 LPRINT
18142 LPRINT F$(8)
18144 LPRINT "                   * * * * * * * * * * * * * * * * * * * * * * * * *"
18150 LPRINT F$(9);
18160 P(0)=Y0:AB=0
18170 FOR I=1 TO IN
18180 P(I)=P(I-1)+Y(I)
18190 IF P(I)>=Y0+TH+1 THEN 18210
18200 LPRINT USING F$(11);P(I-1),:AB=AB+1
18210 NEXT I
18220 LPRINT
18230 LPRINT F$(10);
18240 FOR I=1 TO IN
18250 IF I>AB THEN 18270
18260 LPRINT USING F$(11);P(I)-1,
18270 NEXT I
18275 LPRINT
```

```
18280 LPRINT "                              ************** ";
18282 FOR I=1 TO IN
18284 IF I>AB THEN 18288
18286 LPRINT " ****** ";
18287 NEXT I
18288 LPRINT
18290 LPRINT USING F$(13);"DISCOUNT RATE",
18300 FOR I=1 TO IN
18310 LPRINT USING F$(12);R1(I)*100,
18320 NEXT I
18325 LPRINT
18330 LPRINT "                                AVERAGE ANNUAL"
18340 LPRINT "                                COST INCREASE:"
18350 LPRINT USING F$(13);"MAINTENANCE",
18360 FOR I=1 TO IN
18370 IF I>AB THEN 18390
18380 LPRINT USING F$(12);R2(I)*100,
18390 NEXT I
18395 LPRINT
18400 LPRINT USING F$(13);"BLDG VALUE",
18410 FOR I=1 TO IN
18420 IF I>AB THEN 18440
18430 LPRINT USING F$(12);R3(I)*100,
18440 NEXT I
18450 LPRINT
18460 FOR K=1 TO EN
18470 LPRINT USING F$(13);EN$(K),
18480 FOR I=1 TO IN
18490 IF I>AB THEN 18510
18500 LPRINT USING F$(12);R4(I,K)*100,
18510 NEXT I
18520 LPRINT
18530 NEXT K
18540 LPRINT:LPRINT
18550 LPRINT "                                   BASE YEAR UNIT ENERGY COSTS
18555 LPRINT "                                  * * * * * * * * * * * * * * *"
18560 LPRINT
18570 LPRINT USING F$(14);M4$(MM)
18575 LPRINT "                         *************       ***********   ******    ********       *********"
18580 FOR I=1 TO 6
18582 IF Q2=2 THEN 18590
18584 IF I=2 THEN 18600
18590 LPRINT USING F$(15);EU$(I),EN$(BB(I)),EM$(BB(I)),TU(BB(I)),KE(BB(I))
18600 NEXT I
18610 LPRINT:LPRINT
18620 REM
18630 IF LT=0 THEN 18720
18640 LPRINT "                                   FINANCING ASSUMPTIONS"
18645 LPRINT "                                  * * * * * * * * * * * *
18650 LPRINT USING F$(16);DP*100
18660 LPRINT USING F$(17);L$
18670 LPRINT USING F$(18);LL
18680 LPRINT USING F$(19);LN
18690 LPRINT USING F$(20);LI*100
18700 LPRINT
18710 REM
18720 LPRINT:LPRINT
18730 LPRINT "              * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *"
18740 LPRINT
18750 LPRINT "                                  OPTIMIZATION ANALYSIS"
```

```
18755 LPRINT "                              * * * * * * * * * * *"
18760 LPRINT
18770 LPRINT "       (1) OPTIMAL ENVELOPE MODIFICATIONS (IN DECREASING ORDER OF COST EFFECTIVENESS):"
18780 LPRINT "                                                         FIRST    LIFE-CYCLE"
18785 LPRINT "                                                          COST       COST*"
18787 T0=0:T2=0:T3=0
18790 FOR L=1 TO IO
18800 FOR I=1 TO N1
18810 IF EN(I)=EW(WO,L) THEN 18840
18820 NEXT I
18840 LPRINT USING F$(21);E$(I),EC(I,1)*(1+TX*ET(I)),EC(I,4)
18845 T0=T0+EC(I,1)*(1+TX*ET(I)):REM TOTAL ENVELOPE MODS COST (FIRST COST)
18846 T2=T2+EC(I,4):REM TOTAL ENVELOPE MOD COST (LCC)
18847 IF TT=2 THEN 18850
18848 T3=T3+EC(I,1)*(1+TX*ET(I))*(EG(I)+ES(I)*(1-TG)): REM TOTAL TAX CREDITS FOR ENVELOPE MODS
18850 NEXT L
18855 LPRINT USING F$(22);T0,T2
18856 LPRINT USING F$(23);T3
18857 LPRINT USING F$(24);T0-T3
18858 T6=0:HK(0,3)=0:IF TT=2 THEN 18869
18859 FOR J=1 TO JO:REM COMPUTE TAX CREDITS FOR SPACE HEATING EQUIP
18860 H1=HK(J,3)+HK(J,4)*HW(WO,2)*HO
18861 H0=HK(J-1,3)+HK(J-1,4)*HW(WO,2)*HO
18862 T6=T6+(H1-H0)*(HG(J)+HS(J)*(1-TG)):PRINT J,T6
18863 NEXT J
18864 FOR W=1 TO WO
18865 T6=T6+(WK(W,2)-WK(W-1,2))*(WG(W)+WS(W)*(1-TG)):PRINT W,T6
18866 NEXT W
18867 T6=T6+(CF+CV*CW(WO,2)*CO)*(1+TX*CT)*(CG+CS*(1-TG)):PRINT T6
18869 LPRINT
18870 LPRINT "       (2) OPTIMAL CONVENTIONAL EQUIPMENT EFFICIENCY:"
18874 LPRINT "                         OUTPUT CAP.    SEASONAL      FIRST    LIFE-CYCLE"
18875 LPRINT USING "                          (%      %)    EFFICIENCY      COST       COST*";M3$(MM)
18876 H1=HK(JO,3)+HK(JO,4)*HW(WO,2)*HO:REM TOTAL FIRST COST OF HEATING EQUIP
18877 H2=HK(JO,1)+HK(JO,2)*HW(WO,2)*HO:REM TLLC OF HEATING EQUIP
18880 LPRINT USING F$(25);"SPACE HEATING",HW(WO,2)*HO,HE(JO)*100,H1,H2
18885 IF Q2=1 THEN 18895
18890 LPRINT USING F$(43);"WATER HEATING",WE(WO)*100,WK(WO,2),WK(WO,1)
18895 C3=(CF+CV*CW(WO,2)*CO)*(1+TX*CT):REM TOTAL FIRST COST OF COOLING EQUIP
18896 C4=CK(1)+CK(2)*CW(WO,2)*CO:REM TLLC OF COOLING EQUIP
18900 LPRINT USING F$(25);"SPACE COOLING",CW(WO,2)*CO,CE*100,C3,C4
18901 T4=H1+WK(WO,2)+C3
18902 T5=H2+WK(WO,1)+C4
18904 LPRINT USING F$(26);T4,T5
18906 LPRINT USING F$(23);T6
18907 LPRINT USING F$(24);T4-T6
18910 LPRINT
18920 LPRINT "                                                         FIRST    LIFE-CYCLE"
18930 LPRINT "                                                          COST       COST*"
18931 IF AO=0 THEN 18939
18932 T7=(SF+SV*AO)*(1+TX*ST):REM SOLAR FIRST COST
18933 T8=0
18935 IF TT=2 THEN 18940
18937 T8=T7*(SG+SS*(1-TG)):REM  SOLAR TAX CREDIT
18938 GOTO 18940
18939 T7=0:T8=0
18940 LPRINT USING F$(27);T7,SF(1)+SV(1)*AO
18942 LPRINT USING F$(23);T8
18944 LPRINT USING F$(24);T7-T8
18950 LPRINT
```

```
18960 LPRINT USING F$(28);AO,M1$(MM)
18970 LPRINT "                SOLAR FRACTION(S):"
18975 IF Q1=1 THEN 18990
18980 LPRINT USING F$(29);"SPACE HEATING",FH*100
18982 IF Q2=1 THEN 18992
18985 LPRINT USING F$(29);"WATER HEATING",FW*100
18990 LPRINT USING F$(29);"COMBINED",FT*100
18992 LPRINT USING F$(41);SF
18994 LPRINT USING F$(42);M1$(MM),SV
18995 LPRINT:LPRINT
18999 GOTO 19600
19000 REM
19010 F$(1)="                 *  PROJECT NAME: %                                   %       *"
19020 F$(2)="                 *  RUN DATE:"
19030 F$(3)="                 *  STUDY PERIOD: ## YEARS (#### TO ####)                       *"
19040 F$(4)="                 *  TAX STATUS: %                            %                  *"
19050 F$(5)="                 *  INCOME TAX RATE:  FEDERAL=##.##%, STATE=##.##%               *"
19060 F$(6)="                 *  PROPERTY TAX RATE: ##.##%  STATE SALES TAX RATE: ##.##%     *"
19070 F$(7)="                 *  CAPITAL GAINS MULTIPLIER: FEDERAL=##.##%, STATE=##.##%     *"
19075 F$(45)="                 *  SUPPORTING FILE: %         %                                 *"
19080 F$(8)="                        ANNUAL DISCOUNT RATE AND COST ESCALATION RATES"
19090 F$(9)="                                   FROM: "
19100 F$(10)="                                    TO:  "
19110 F$(11)=" ####    "
19120 F$(12)="##.##%  "
19130 F$(13)="                       %              %"
19140 F$(14)= "                     END USE           ENERGY TYPE    UNIT     % %/UNIT      UNIT COST
19150 F$(15)="              %                  %  %            %  %    %  ########        $$#.###"
19160 F$(16)="                             DOWN PAYMENT:  ###.##%"
19170 F$(17)="                             LOAN TYPE:%                                                  %"
19180 F$(18)="                             LOAN LIFE: ## YEARS"
19190 F$(19)="                             PAYMENTS/YEAR: ##"
19200 F$(20)="                             INTEREST RATE: ##.##%"
19210 F$(21)="          %                  %                       $$,#####  $$,######"
19215 F$(22)="             TOTAL ENVELOPE MODIFICATION COST          $$,##### $$,#######"
19216 F$(23)="             APPLICABLE TAX CREDITS                     $$,#####"
19217 F$(24)="             NET FIRST COST                             $$,#####"
19220 F$(25)="          %                  %#####        ###.##%     $$,#####  $$,######"
19223 F$(43)="          %                  % N/A         ###.##%     $$,#####  $$,######"
19225 F$(26)="             TOTAL CONVENTIONAL EQUIPMENT COST          $$,##### $$,#######"
19230 F$(27)="        (3) SOLAR HEATING SYSTEM                          $$,##### $$,#######"
19240 F$(28)="          OPTIMAL COLLECTOR SIZE  ##,##.# %         %"
19250 F$(29)="              %              %   ###.#%"
19260 F$(30)="        (4)  ENERGY REQUIREMENTS AND COST:"
19270 F$(31)="             OUTPUT ENERGY REQUIREMENTS         ANNUAL    PEAK LOAD"
19280 F$(32)="                                               (%      %)  (%     %)"
19290 F$(33)="               %                        %   ###,###     ###,###
19300 F$(44)="               %                        %   ###,###       N/A"
19310 F$(35)="            INPUT ENERGY REQUIREMENTS  ******ANNUAL****** FIRST-YR  LIFE-CYCLE"
19320 F$(36)="                                                           COST        COST*"
19330 F$(37)="              %                   %###,### %    % %   %$$,####  $$,######"
19340 F$(38)="              DISTRIBUTION SYSTEM:"
19350 F$(39)="                  TOTAL ENERGY COST                   $$,####### $$,#######"
19360 F$(40)="        (5) TOTAL LIFE CYCLE COST                              $$,########"
19370 F$(41)="          FIXED COST                                   $$,#####"
19380 F$(42)="          COST PER %          %                        $$,#####"
19500 RETURN
19600 LPRINT F$(30)
19610 LPRINT
19620 LPRINT F$(31)
```

```
19630 LPRINT USING F$(32);M2$(MM),M3$(MM)
19640 LPRINT USING F$(33);"SPACE HEATING",HW(WO,1)/(1-EE*DE(1)),HW(WO,2)/(1-EE*DE(1))
19645 IF Q2=1 THEN 19660
19650 LPRINT USING F$(44);"WATER HEATING",WL(13)
19660 LPRINT USING F$(33);"SPACE COOLING",CW(WO,1)/(1+EE*DE(2)),CW(WO,2)/(1+EE*DE(2))
19670 LPRINT
19690 LPRINT F$(35)
19700 LPRINT F$(36)
19705 TR=1
19710 U1=HW(WO,1)*(1-FH)*EM/(TU(HB)*HE(JO))
19715 TT(1)=U1*KE(HB)*TR:TT(2)=U1*KH*TU(HB)/EM
19720 LPRINT USING F$(37);"SPACE HEATING PLANT",U1,EM$(HB),EN$(HB),U1*KE(HB)*TR,U1*KH*TU(HB)/EM
19725 IF Q2=1 THEN 19750
19730 U2=WL(13)*(1-FW)*EM/(TU(WB)*WE(WO))
19735 TT(1)=TT(1)+U2*KE(WB)*TR:TT(2)=TT(2)+U2*KW*TU(WB)/EM
19740 LPRINT USING F$(37);"WATER HEATING PLANT",U2,EM$(WB),EN$(WB),U2*KE(WB)*TR,U2*KW*TU(WB)/EM
19750 U3=CW(WO,1)*EM/(TU(CB)*CE)
19755 TT(1)=TT(1)+U3*KE(CB)*TR:TT(2)=TT(2)+U3*KC*TU(CB)/EM
19760 LPRINT USING F$(37);"SPACE COOLING PLANT",U3,EM$(CB),EN$(CB),U3*KE(CB)*TR,U3*KC*TU(CB)/EM
19770 U4=(HW(WO,1)*FH+WL(13)*FW)*DE(3)
19775 TT(1)=TT(1)+U4*KE(SB)*TR:TT(2)=TT(2)+U4*KS*TU(SB)/EM
19780 LPRINT USING F$(37);"SOLAR FANS/PUMPS",U4,EM$(SB),EN$(SB),U4*KE(SB)*TR,U4*KS*TU(SB)/EM
19790 LPRINT F$(38)
19800 U5=HW(WO,1)/(1-EE*DE(1))*DE(1)
19805 TT(1)=TT(1)+U5*KE(DB(1))*TR:TT(2)=TT(2)+U5*KD(1)*TU(DB(1))/EM
19810 LPRINT USING F$(37);"  SPACE HEATING",U5,EM$(DB(1)),EN$(DB(1)),U5*KE(DB(1))*TR,U5*KD(1)*TU(DB(1))/EM
19820 U6=CW(WO,1)/(1+EE*DE(2))*DE(2)
19825 TT(1)=TT(1)+U6*KE(DB(2))*TR:TT(2)=TT(2)+U6*KD(2)*TU(DB(2))/EM
19830 LPRINT USING F$(37);"  SPACE COOLING",U6,EM$(DB(2)),EN$(DB(2)),U6*KE(DB(2))*TR,U6*KD(2)*TU(DB(2))/EM
19840 LPRINT USING F$(39);TT(1),TT(2)
19850 LPRINT
19860 LPRINT USING F$(40);T2+H2+WK(WO,1)+C4+SF(1)+SV(1)*AO+TT(2)
19870 LPRINT
19880 LPRINT "  * * * * * * * * * * * * * * * * * * * "
19890 IF TG*TS=0 THEN 19910
19900 LPRINT "   * AFTER-TAX LIFE-CYCLE COST
19910 IF MM=2 THEN 19999
19920 LPRINT "     NOTE: MBTU = 1,000 BTU; MMBTU = 1,000,000 BTU"
19999 END
```

FEDERAL INFORMATION PROCESSING STANDARD SOFTWARE SUMMARY

01. Summary date (Yr. Mo. Day)	8 2 0 9 3 0
02. Summary prepared by (Name and Phone)	Stephen R. Petersen (301) 921-3701
03. Summary action	New [X] Replacement [ ] Deletion [ ]
Previous Internal Software ID	
04. Software date (Yr. Mo. Day)	8 2 0 9 3 0
05. Software title	SOLCOM
06. Short title	SOLCOM
07. Internal Software ID	None

08. Software type
- [ ] Automated Data System
- [X] Computer Program
- [ ] Subroutine/Module

09. Processing mode
- [X] Interactive
- [ ] Batch
- [ ] Combination

10. Application area

General:
- [ ] Computer Systems Support/Utility
- [ ] Scientific/Engineering
- [ ] Bibliographic/Textual
- [X] Management/Business
- [ ] Process Control
- [ ] Other

Specific: Economic optimization of energy-related building designs.

11. Submitting organization and address

Center for Applied Mathematics
National Engineering Laboratory
National Bureau of Standards
Washington, D.C. 20234

12. Technical contact(s) and phone

Stephen R. Petersen
(301) 921-3701

13. Narrative

The SOLCOM program was written to demonstrate the use of economic optimization algorithms for integrating solar and other energy conservation features into new commercial building designs. These algorithms will be useful to design engineering teams who must determine the proper size of an energy conservation budget in a new building and its allocation among competing solar and conservation investments. It is intended to be used on a microcomputer with 48K memory, one disk drive, and 132 character line printer.

14. Keywords building design; commercial buildings; energy conservation; engineering economics; heating and cooling equipment; heating and cooling loads; life-cycle cost analysis; optimization algorithms; solar heating

15. Computer manuf'r and model	16. Computer operating system	17. Programing language(s)	18. Number of source program statements
Radio Shack TRS-80 Model III	TRSDOS	BASIC	1800
19. Computer memory requirements	**20. Tape drives**	**21. Disk/Drum units**	**22. Terminals**
48K Ram	0	1	1

23. Other operational requirements

Line printer

24. Software availability
- [ ] Available
- [X] Limited
- [ ] In-house only

25. Documentation availability
- [X] Available
- [ ] Inadequate
- [ ] In-house only

26. FOR SUBMITTING ORGANIZATION USE

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1974 July
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5. AUTHOR(S)

Stephen R. Petersen

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

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WASHINGTON, D.C. 20234

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8. Type of Report & Period Covered

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Office of Solar Heat Technologies
Department of Energy
Washington, D.C. 20545

10. SUPPLEMENTARY NOTES

[XX] 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 methodology, algorithms and a computer program for determining the least life-cycle cost combination of three interdependent conservation strategies in new commercial buildings. These three strategies include (1) envelope modifications to reduce seasonal and peak load heating and cooling requirements, (2) heating and cooling plant modifications to increase their seasonal efficiency, and (3) the use of an active solar space and water heating system. The resulting computer program, called SOLCOM, can be run on a microcomputer in three stages.

The SOLCOM program performs a complete life-cycle cost analysis for the active solar system and for each envelope and plant modification to be considered, include tax and mortgage effects. The program then determines the optimal combination of envelope modifications and the resulting seasonal and peak load heating and cooling requirements; the optimal space heating, water heating, and space cooling plant efficiencies; and the optimal collector size for the active solar heating system.

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

building design; commercial buildings; energy conservation; engineering economics; heating and cooling equipment; heating and cooling loads; life-cycle cost analysis; optimization algorithms; solar heating

13. AVAILABILITY

[XX] Unlimited
[ ] For Official Distribution. Do Not Release to NTIS
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