Manual and Programmable Calculator Methods for Sizing Solar Energy Systems

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ABSTRACT

This report describes the important characteristics, features, and limitations of manual methods and programmable calculator software for sizing active or passive solar energy systems and predicting their performance. The intent is to provide utilities with useful information that will facilitate sound choices of solar calculation methods to be used in responding to the National Energy Act.

The report begins with a discussion of the major issues relating to manual solar calculation methods. General information on each method is given in easily used matrices. Critical reviews, as well as sources and costs, are given in a one-page summary for each method. Throughout the text, an effort is made to identify those methods that will be most useful, and overall conclusions regarding this concern are included.

FOREWORD

This report is the result of an "in-house" study completed during the summer of 1979 to provide a review of the available manual and hand-held calculator methods for sizing solar energy systems. The purpose of this work is to provide the electric utility industry with a document summarizing the various characteristics of these methods so that the utilities may be more responsive to their customers' or contractors' needs with regard to decisions about solar energy as called for by the National Energy Act (NEA) or public regulatory commissions.

Because of the current state of interests and developments in solar energy, the manual methods reviewed for "active" solar systems are more clearly defined than for "passive" solar systems. The state of development of passive solar calculation methods in 1979 provided the reviewer a moving target as more and more of the methods came into being. We expect to repeat this review in approximately a year, when we will concentrate on a more complete review of passive methods.

If the reader is looking for computer solar simulation methods to be used as research tools, then EPRI report number ER-1146 provides a reference manual that may be used for that purpose. Report ER-1146 was the result of research project 1269. A final report for RP1269 will be available in the first quarter of 1980.

Gary G. Purcell, Project Manager
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SUMMARY

To provide customers with information on solar energy measures as required by the National Energy Act (NEA), utilities will have to choose appropriate tools to perform solar calculations. Many simplified methods, which rely on manual computations or hand-held programmable calculators (PC) in predicting the performance of solar energy systems, have been developed over the past few years. Until now, no single document has described them. This report gives critical reviews of all the major manual and PC methods for sizing active and passive solar systems, identifies their applications through easily used matrices, points out their advantages and disadvantages, and lists their sources and costs. The information presented will aid utilities in making informed choices of solar calculation methods to be used in their customer information services.

Calculation methods for active and passive solar systems are treated separately in this report. Methods for sizing active solar space-heating and water-heating systems on a residential scale appear to be fairly well established. The most widely accepted method for sizing such systems is F-Chart, which was developed at the University of Wisconsin. Until validation studies using long term data from actual systems are completed, F-Chart and its offshoots will probably remain the methods of choice. All the commercially available PC software for sizing active solar systems uses the F-Chart method or a simplification of it. PC programs offered by the University of Wisconsin and by Scotch Programs, Inc., were found to be most convenient for the complete month-by-month F-Chart calculation. Either program set can predict the performance of a system and carry out a life-cycle cost analysis in a matter of minutes. Of the many manual methods for sizing active systems, only the fastest ones seem appropriate for repetitive use. Particularly notable are: the Relative Areas Method, developed at Colorado State University; the GFL Method from the Solar Energy Research Institute; and the Solar Load Ratio (SLR) Method, developed at Los Alamos Scientific Laboratories (LASL). In this report, all the manual and PC methods for active systems are presented in the approximate order of their overall usefulness.

Performance prediction methods for passive solar-heated buildings are less well established because of the more recent involvement of solar investigators in this area. All the passive design methods reviewed in this report have appeared within the past two years, and further rapid developments can be expected. Methods for analyzing passive solar-heated buildings were found to fall into two categories: those that predict average annual performance and those that predict temperature excursions and/or auxiliary heating requirements on selected design days. The latter category is primarily intended for use by architects and designers in fine tuning a particular passive building design. This category includes several PC programs that actually simulate the thermal response of a passive building on an hour-by-hour basis. LASL's SLR Method was found to be the most thoroughly researched and well documented technique for predicting the average annual performance of passive solar-heated buildings. This method can be applied manually or by using commercially available PC software. PASCALC, offered by Total Environmental Action, Inc., was found to be the most complete and versatile PC program using the SLR method.

Experience with the methods described in this report has shown that the most widely used methods provide powerful yet quick and simple tools for obtaining information about solar energy systems. They require a minimum of technical training and are quite inexpensive to use, yet they represent the current state of the art in simplified methods for analyzing solar systems. Consequently, many utilities are likely to find these methods useful.

Section 1

INTRODUCTION

PURPOSE AND SCOPE

The National Energy Act (NEA) provides for a program that will require utilities to "offer energy audits to their customers that would identify appropriate energy conservation and solar energy measures and estimate their likely cost and savings." To provide this service, the utilities or their contractors will have to choose appropriate tools to perform solar calculations. Most solar calculations for residential or small commercial applications can be performed by hand or with the aid of programmable hand-held calculators that use commercially supplied software. Many such methods exist, but until now there has been no single document describing them. This project was undertaken to provide the utilities with a reference manual for all the major manual and programmable calculator (PC) methods for sizing and predicting the performance of both active and passive solar systems; to provide detailed information on the important characteristics, features, limitations, sources, and costs of each method; and to identify those methods that are of greatest potential use to the utilities. This information will assist utilities in making sound choices of calculation methods to use in responding to the NEA.

APPROACH

A list of manual and PC methods for solar-sizing calculations was compiled by Arthur D. Little, Inc., as part of EPRI Research Project 1269 on computer simulation programs. That list was updated and expanded for the preparation of this report, and after an initial screening, promising methods were obtained for detailed review. In most cases, test problems were run to accurately gauge the data requirements and working time of the procedure and the technical background that the user would need to apply the method effectively.

Final selection of the methods included in this manual was made according to the following criteria:

- The method deals specifically with predicting the performance of active or passive solar systems;
- The method has general applicability (e.g., it is not for use with individual products or in small regions of the United States);
- The method does not require any unusual information or data that is not generally available or cannot be calculated with reasonable ease;
- The method is readily available to the electric utilities and their customers;
- Complete documentation was received in time for the preparation of this reference manual.

Brief descriptions of the methods eliminated from the detailed listing by the above criteria are included in Section 6.

HOW TO USE THIS MANUAL

The structure of this reference manual is outlined in the Table of Contents and in Figure 1-1. Manual and PC methods that satisfy the selection criteria are divided into active and passive solar applications, Sections 3 and 4, respectively. For each group, the capabilities and restrictions of individual methods are outlined through summary matrices and one-page reviews.

The summary matrices are designed to allow quick reference to the important characteristics, applications, and requirements of each method. In most cases, the features of a method are described by the presence of a bullet (•) in the appropriate column. The one page reviews follow the same order as the matrices and are intended to elaborate on important features that cannot be fully described by the matrices. Detailed information is given on the major assumptions, technical complexity, quality of documentation, advantages and/or disadvantages, and convenience of each method. An effort has been made to identify those methods that will be most useful to the utilities.

The introductions to Sections 3 and 4 explain the order of the listings and outline the content of the matrices and reviews. A separate section (Section 6) provides a list of methods that were reviewed during the preparation of this manual, but were eliminated from the detailed listings by the selection criteria outlined above. Overall conclusions are given in Section 5.

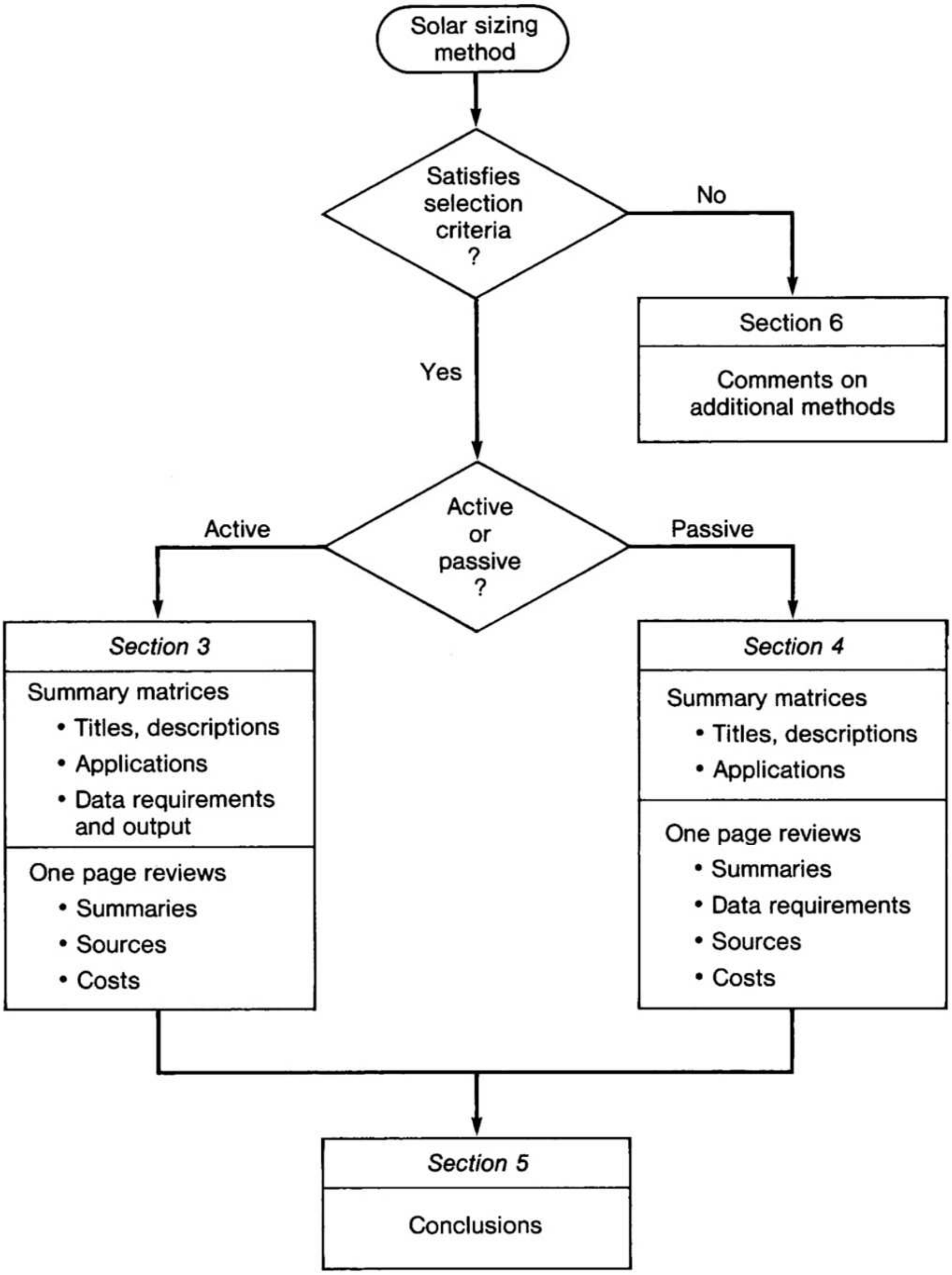

Figure 1-1. Structure and Use of Reference Manual

Section 2

BACKGROUND

TYPES OF METHODS AND APPLICATIONS

Sizing and performance prediction procedures for solar systems, which rely on manual calculations or programmable calculators, are a compromise between detailed computer simulations and rough rules of thumb for solar design. They have been developed to reduce the time, cost, and technical background required for solar calculations while retaining generality and accuracy sufficient for design decisions and economic evaluation. To accomplish this, simplifying assumptions and restrictions on the system design have been incorporated into each method. Degrees of simplification and restriction vary greatly from method to method, and some assumptions are more valid than others. The better of these methods provide convenient yet powerful tools for analyzing either active or passive solar systems. However, with any of these methods, the user should be familiar with the limits of applicability and avoid overstepping them.

METHODS FOR ACTIVE SOLAR SYSTEMS

Most of the manual and PC methods for active solar systems are for use in sizing and predicting the performance of space-heating and/or domestic hot water (DHW) systems for residences or small commercial buildings. Performance, in this context, is the percentage of the annual heating load that is supplied by solar, often referred to as the annual solar fraction. These simplified methods began to appear in the solar literature in about 1975. Several similar methods, which are based on correlations of many detailed computer simulations, have been published since then. One, the F-Chart method, has dominated and is currently the most widely accepted method for sizing solar space- and water-heating systems. It was developed by S. A. Klein, et al. at the University of Wisconsin, using correlations of results from the TRNSYS simulation program, and it is available in three forms: an interactive computer program, hand calculator programs, and handbooks for manual calculation.

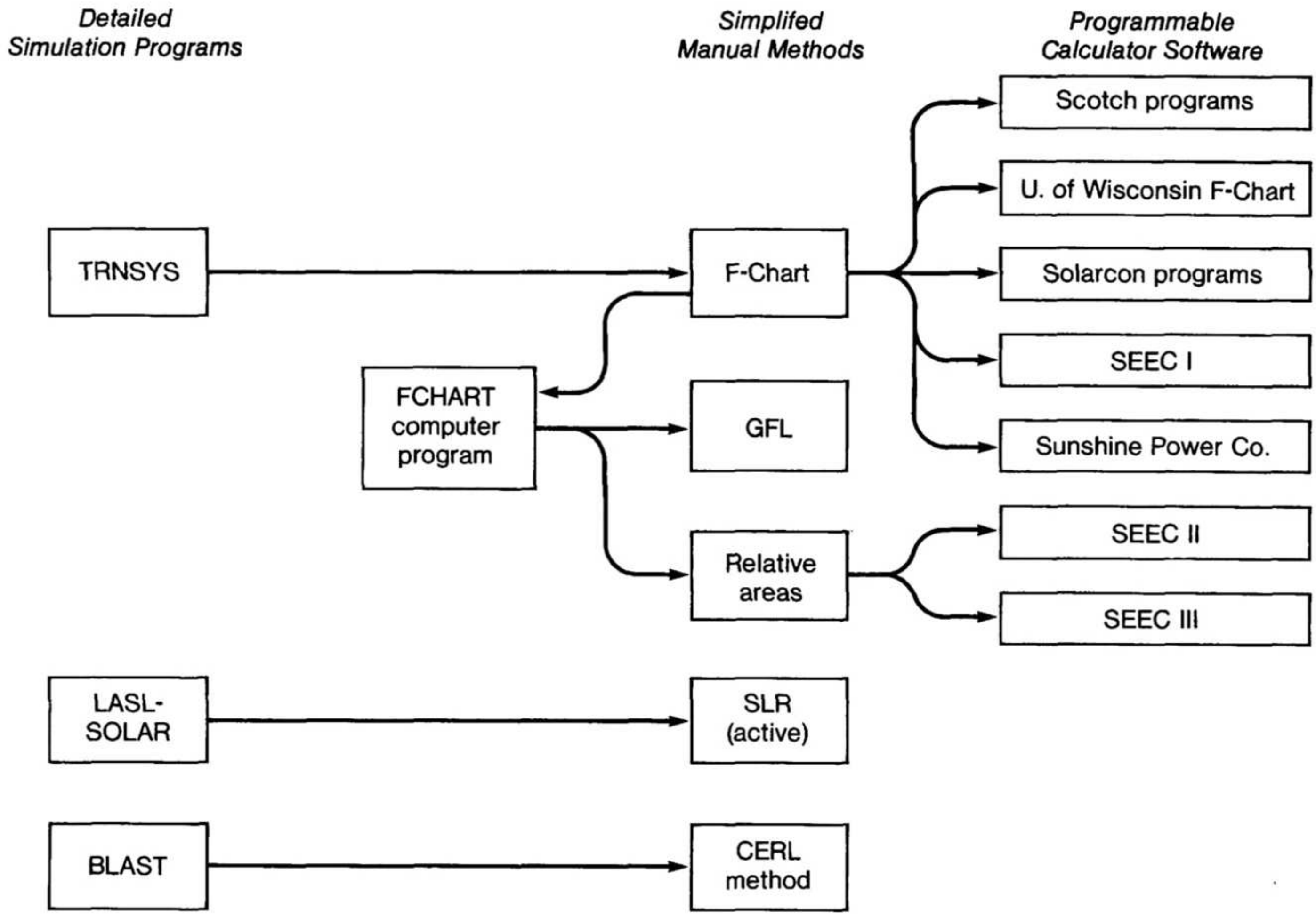

Figure 2-1. Historical Developments of Major Manual and PC Methods for Active Solar Systems

All of the PC programs for sizing active solar systems that were identified in this project are based on F-Chart or simplifications of it. The major differences between these programs lie in their convenience and the completeness of the documentation provided. These differences can be significant even though most of the programs perform similar calculations. Other manual methods range from simple charts or formulas, which use preprocessed, location-dependent data in determining the solar fraction, to laborious calculations of monthly performance that can take several hours to complete. Typically, the shorter methods incorporate more restrictive assumptions about the system design. A summary of the historical development of F-Chart and some of the other major methods is presented in Figure 2-1.

It is important to note that many manufacturers and distributors of solar equipment have used F-Chart or some other method to develop simple charts or sizing rules for their own products or specific locations. Such information may be useful to the utilities, but the basis and limitations of the information should be fully understood.

METHODS FOR PASSIVE SOLAR SYSTEMS

Calculation methods for predicting the performance of passive solar-heated buildings are not as well established as those for active systems. This is due to the more recent involvement of solar investigators in the analysis of passive designs. It can be expected that new methods and improvements on current methods will appear in the next few years.

Two types of calculations are important for passive solar-heated buildings. First, the ability to determine maximum and minimum indoor temperatures on selected typical days allows the designer to deal with problems of over- or underheating, and thus, provide comfort control. Second, the ability to estimate the auxiliary energy requirements over an average year allows the determination of the energy saved or annual thermal performance. Hence, the life-cycle economics of the design can be evaluated.

As with active systems, some of the current passive design methods were derived using detailed computer simulations. Much of this work has been done at the Los Alamos Scientific Laboratory (LASL), publishers of the Solar Load Ratio (SLR) methods for estimating the annual performance of "standard" direct gain and thermal storage wall buildings. Mazria has used computer simulations to develop charts for sizing passive systems and estimating indoor temperature swings.

Results from experimental buildings and test cells have also been used to generate and check simplified methods.

PC software is available for both types of passive calculations. The programs that calculate yearly performance are based on the SLR method and are easy to use. Programs for daily comfort calculations are more numerous and varied. These programs actually simulate the thermal response of a passive design on an hourly basis for a single selected day. Depending on the program and the detail of the model, execution can take from two minutes to over half an hour. The amount of time required to set up the input data also varies considerably and can be longer than the execution time. These simulation programs are intended to be used primarily by architects and designers in the final stages of designing passive buildings. They generally require a fairly thorough knowledge of heat transfer fundamentals, overall passive design considerations, and the specific building plan, and they cannot be used to supply quick answers or general information about passive design procedures.

ACCURACY AND UNCERTAINTY

The level of accuracy that can be expected from these methods depends on several factors, including the validity of the assumptions of the method, the accuracy of the input data, the proper application of the method to problems for which it was intended, the detail of the model, and the experience of the user. The better manual or PC methods can give substantially the same results as detailed computer simulations for certain problems. However, this does not ensure that the performance of an actual solar system will be predicted correctly. Very little long-term performance data for actual systems is available to validate prediction methods. Consequently, the accuracy of any prediction method is not well-defined with respect to individual installations and one must be aware that there is a range of uncertainty associated with the results.

Uncertainty is a topic that is almost entirely neglected by the authors of the various sizing methods. Ward (see Method No. 8) has pointed out this inadequacy and claims that the range of uncertainty in the long-term performance of a typical installation is on the order of ±10 to ±15%. This figure is affected most by the uncertainties inherent in determining heating loads, but there are also uncertainties of ±5 to ±10% or greater associated with available solar radiation and weather data. Ward's conclusion is that long-term predictions of the solar fraction can only be accurate to one significant figure. Uncertainties involved in life-cycle cost analysis are even greater because of the difficulty of correctly predicting inflation rates and various costs. Thus values for the solar fraction, which are expressed to tenths of a percent, and life-cycle costs, which are calculated to the last dollar, cannot be taken literally.

Uncertainties do not negate the usefulness of these methods, however. Design decisions should be based on the best information available, and this information can be provided by the better methods in this reference manual.

PROGRAMMABLE CALCULATORS

Rapid advances in the electronics industry over the past few years have made available hand-held calculators that are capable of accepting and storing sequences of calculation steps. Long calculations, which used to require hundreds of keystrokes, can now be initiated with a single key, which greatly reduces the time required for calculation and eliminates the possibility of errors. More advanced calculators, such as the Texas Instruments TI-59 and Hewlett-Packard HP67 or 97, can read magnetic cards. Programs, and the data or conversion factors required to run them, can be stored on these cards and quickly loaded into the calculator memories when needed. The commercially available software reviewed in this manual comes on such cards. As an added feature, the calculator can be connected to a desk top printing unit that will automatically record and even label results.

A programmable calculator with card-reading capability and a printer can be purchased for as little as $400. The software for solar calculations is also relatively inexpensive. For instance, a complete set of programs to do all the calculations of the F-Chart method, including economic analysis, can be obtained for $150, and there are no additional costs associated with running the programs. Most solar energy calculations for residential and small commercial buildings can be done on these calculators, and no experience with programming is required to use the commercially available software. Many utilities will find these powerful yet simple and inexpensive tools useful in their solar information programs.

Section 3

CHARACTERISTICS OF SELECTED METHODS FOR ACTIVE SYSTEMS

ORDER OF UTILITY OF THE METHODS FOR ACTIVE SYSTEMS

Manual and PC methods for active solar systems are listed separately. Within each group, the methods have been listed roughly in order of their overall utility. This ordering is based on a subjective evaluation in which the following characteristics were considered:

- The level of detail and the engineering completeness of the analytical model;
- The scope of the problems to which the method can be applied;
- Convenience and speed of the application;
- Quality of the documentation;
- The availability of the required data.

SUMMARY MATRICES

The major characteristics and features of the selected methods for sizing and predicting the performance of active solar energy systems are described in four matrices:

- Table 3-1: Titles and Descriptions of Manual Methods
- Table 3-2: Titles and Descriptions of PC Methods
- Figure 3-1: Applications
- Figure 3-2: Data Requirements and Output

Information contained in these matrices was obtained through direct examination of the documentation for each method and through actual use of the methods. In Figure 3-1 in most cases, a particular feature or requirement is marked by a bullet (•) in the appropriate column. Bullets in the "Other" Columns are discussed further in the one-page reviews. An asterisk (*) indicates that the particular feature cannot be completely described by the matrix and is explained in the one-page review.

Table 3-1

TITLES AND DESCRIPTIONS OF MANUAL METHODS FOR ACTIVE SYSTEMS

Number	Title	Authors	Date	Description	Summary Page
1	"Optimal Sizing of Solar Collectors by the Method of Relative Areas"	C. D. Barley C. B. Winn	1977	Simplification of F-Chart. Optimal collector area, life-cycle economics, and F[a] for heating or DHW systems	3-8
2	"The GFL Method for Sizing Solar Energy Space and Water Heating Systems"	G. F. Lameiro P. Bendt (SERI)	1978	Simplification of F-Chart, F for combined space heating, and DHW systems	3-9
3	"A Simplified Method for Calculating Required Solar Collector Array Size for Space Heating," ERDA's Pacific Regional Solar Heating Handbook	J. D. Balcomb J. C. Hedstrom Los Alamos Scientific Laboratory	1976	Solar Load Ratio (SLR) method for sizing standard solar heating systems. ERDA's handbook shows effects of varying system parameters	3-10
4	"Solar Heating Design by the F-Chart Method"	W. A. Beckman S. A. Klein J. A. Duffie	1977	Most complete documentation of the F-Chart method. Monthly and annual F, and life-cycle savings	3-11
5	"Copper Brass Bronze Design Handbook: Solar Energy Systems"	Copper Development Association	1978	Includes manual method for calculating useful energy gain per ft^2 collector. Liquid space heat, and DHW	3-13
6	"Predicting the Performance of Solar Energy Systems"	Construction Engineering Research Laboratory	1977	Monthly and annual F for space heating, annual F for DHW and heating/cooling systems	3-14

[a]Solar fraction.

Table 3-1 (continued)

Number	Title	Authors	Date	Description	Summary Page
7	<u>Designing and Building a Solar House</u>	D. Watson	1977	Includes appendix on methods to calculate energy gains through windows and solar collectors	3-15
8	"A General Design Method For Closed-Loop Solar Energy Systems"	S. A. Klein W. A. Beckman	1978	ϕ,f-chart. Similar to F-Chart, but extended to allow user definition of the minimum useful application temperature	3-16
9	"Prediction of the Performance of Solar Heating Systems Over a Range of Storage Capacities"	D. J. Lunde	1978	Similar to F-Chart. Monthly and annual F for systems with any minimum useful storage temperature	3-17
10	"Realistic Sizing of Residential Solar Heating and Cooling Systems"	D. S. Ward	1978	Simplification of F-Chart using only January data. F and optimum collector area	3-18
11	"An Averaging Technique for Predicting the Performance of a Solar Energy Collector System"	G. H. Stickford	1976	Based on simplified energy balance equations. Monthly F	3-19
12	"Calculation of Long Term Solar Collector Heating System" Performance	S. R. Swanson R. F. Boehm	1977	For calculating monthly useful energy gain to storage	3-20

Table 3-2

TITLES AND DESCRIPTIONS OF PC METHODS FOR ACTIVE SYSTEMS

Number	Title	Authors	Date	Description	Summary Page
13	Scotch Programs SE-1, SE-2	McClintock	1977	Condensed F-Chart program. Detailed economics program	3-22
14	F-Chart (University of Wisconsin Programs)	W. A. Beckman S. A. Klein J. A. Duffie	1977	Programs for all calculations of the F-Chart method, including economics	3-24
15	Solar Environmental Engineering Company SEEC III (SEEC II)	C. B. Winn D. Barley G. Johnson J. Leflar	1978	Building design and solar system optimization programs using the Relative Areas method. (Program for Relative Areas method.)	3-26
16	Solarcon ST355, ST365	W. Graeff	1977	F-Chart programs for air and liquid systems. Includes simplified economic analysis	3-28
17	Solar Environmental Engineering Company SEEC I	C. B. Winn	1976	F-Chart, economics, simplified ASHRAE building load calculation	3-30
18	Sunshine Power Company T-33, T-34	G. R. Shramek	1979	Partial F-Chart calculations for air and liquid systems. No economics	3-31

	Applications				Fluid		Life-cycle Economics			Based On			Tools Required							Interval		Units	
Number	Space heating	DHW	Combined	Other	Liquid	Air	Detailed	Simplified	None	Detailed simulation	F-Chart	Other	Tables	Graphs	4 function calculator	Scientific calculator	Programmable calculator	PC with printer	Program protected	Month	Year	English	SI
1	●	●	*		●	●	●	*			●		●			●					●		●
2			●		●	●			●		●		●			●					●		●
3	●				●	●				●			●		●					*	●	●	
4	●	●	●		●	●				●			●	●		●				●			●
5	●	●	●		●				●		●		●	●	●					●		●	
6	●	●	●	●	●				●	●			●	●		●				*		●	
7	●	●	●		●	●		●				●	●	●	●					●		●	
8	●			●	●				●	●	●		●	●		●				●			●
9	●				●				●	●			●	●		●				●		●	●
10	●				●	●		●					●			●					●	●	●
11	●	●	●		●	●			●			●	●			●				●			●
12	●				●				●	●	●			●		●						●	●
13	●	●	●		●	●	●				●			*			●	●	●	●	●	●	●
14	●	●	●		●	●	●				●						●	●		●	●	●	●
15	●	●	*		●	●	●					●					●	●			●	●	●
16	●	●	●		●	●	*	●			●							●	●	●	●	●	
17	●	●	●		●	●	●				●						●			●	●	●	●
18	●	*	●		●	●			●		●							●		●		●	

Figure 3-1. Applications of Methods for Active Systems

	User Supplied System Data								User Supplied Load Data					Environmental Data							Supplied By				Output					
Number	Collector area	Collector tilt	Collector efficiency parameters	Storage capacity	Minimum useful temperature	Storage H.X. size	Load H.X. size	Other	Building UA	Btu/DD	Monthly or annual DHW load	Monthly or annual total load	Method includes load calculation	Latitude	Horizontal surface radiation	Tilted surface radiation	Average ambient temperature	Degree days	Clearness factor (K_T)	Other	User	Method (number of cities)	Supplier's data cards	User cannot supplement data	Monthly F	Annual F	Useful energy gain	Life-cycle cost/savings	Optimum collector area	Other
1	●		●						●		●							●		●		170		●		●		●	●	
2	●		●									●								●		151		●		●				
3	●									●					*		*	*		●	*	85			*	●				
4	●	●	●	●		●	●	●	●		●			●	●	●	●	●	●		●	170			●	●		●		
5	●	●	●							●	●	●		●	●			●		●	●	177								●
6	●							●			●	●		●	●	●					●				●	●				
7	●	●						●		●	●		●	●				●		●	●	130				●	●	●		●
8	●		●	●	●							●				●	●		●		●				●	●				
9	●	●	●	●	●			●				●				●	*					8		●	●	●				
10	●							●				*				●				●	●					●		●	●	
11	●	●						●						●	●		●			●	●						●			
12	●	●		●	●					●				●	●		●	●		●	●	4			●		●			
13	●	●	●	*		*	*			●	●									●	●	261	●		●	●	●	●	●	●
14	●	●	●	●		●	●		●		●			●	●		●	●	●		●	170			●	●		●		●
15	*		●						●		●		●	●				●	●			200		●		●		●		●
16	●	●		●		●	●		●		●			●	●		●	●	●		●	122	●		●	●	●			●
17	●	●								●	●		●	●	●		●	●		●	●	170			●	●				●
18	●							●				●		●		●	●				●				●		●			●

Figure 3-2. Data Requirements on Output of Methods for Active Systems

ONE-PAGE REVIEWS

For each method, a brief summary is given to elaborate on the information provided by the matrices and to give specific information regarding the overall usefulness of the method. We have tried to present the information that will be most helpful in making a sound choice among the methods described in this report. This includes: general information on form, basis, and applications; special features and/or shortcomings; unusual data requirements; technical background required; working time; source; and cost. PC programs for the Texas Instruments TI-59 were obtained for these reviews, and some of the information regarding the running of the programs may vary with other calculators.

Optimal Sizing of Solar Collectors by the Method of Relative Areas

No. 1

The Relative Areas method, which was developed at Colorado State University, is a simplification of the F-Chart procedure (see Method No. 4) based on correlations of many runs of the FCHART computer program. Additional assumptions beyond those of the F-Chart method are: due south orientation, a collector tilt equal to latitude plus 15° for space-heating systems and latitude for DHW systems, the standard F-Chart load heat exchanger size, and specific water or rock storage capacities per unit collector area. The article includes preprocessed data for 170 cities, which allows a straightforward calculation of the annual solar fraction for a given collector type and area. This data cannot be supplemented by the user. Calculation of the solar fraction takes less than 5 min once the building UA and/or annual water-heating load is specified. The authors claim agreement within 1 to 4% of F-Chart results, depending on the location. Caution should be used, however, in applying the method to combined space-heating and DHW systems. The authors recommend using results for space heating alone. However, this may not always be accurate, and results should be tested against the complete F-Chart calculation. The Relative Areas method may not be appropriate for sizing combined systems in mild climates where the hot water load is a large portion of the total load.

A detailed economic analysis is also presented in this paper. The nature of the curve fit used for calculation of the solar fraction allows a direct calculation of the economic optimum collector area, which eliminates the need for iteration. Here the optimum is defined by maximizing the life-cycle savings of the solar system over a conventional system. The economic calculation can take from about 20 min for residential property to about 30 min for commercial property once all the economic parameters have been defined.

The Relative Areas method provides a good combination of speed and a wide scope of problems to which it can be applied. This method is used in the SEEC II and SEEC III PC programs (see No. 15).

Source: C. D. Barley and C. B. Winn. Solar Energy. Vol. 21, 1978, pp. 279-289.

Cost: None

The GFL Method for Sizing Solar Energy Space and Water Heating Systems

No. 2

The GFL method, like the Relative Areas method (No. 1), is based on correlations of numerous runs of the FCHART computer program. In addition to the assumptions of the F-Chart method (No. 4), the GFL method assumes: a collector tilt equal to latitude, storage capacity, heat exchanger sizes equal to the standard values recommended in the F-Chart method, and a specific water heating load corresponding to an average household. Data are provided for 151 locations, and the calculations lead to the annual solar fraction for a given collector area. The GFL curve fit includes second-order terms, giving agreement within 2% of the FCHART results using the above assumptions. Calculations can be carried out in about 10 min by hand, or the formulas can be programmed easily on a hand calculator. No economic analysis is included.

On the whole, the GFL method is somewhat less convenient to use than the Relative Areas method. However, the GFL method may be more appropriate for sizing combined space-heating and DHW systems in mild climates, and in this way the two methods complement each other.

Source: G. F. Lameiro and P. Bendt
SERI-30
Solar Energy Research Institute
1536 Cole Boulevard
Golden, Colorado 80401

Cost: None

a) A Simplified Method for Calculating Required Solar Collector Array Size for Space Heating

and

b) ERDA's Pacific Regional Solar Heating Handbook — No. 3

Both of these sources contain the Solar Load Ratio (SLR) method for sizing active solar space-heating systems, which was developed at the Los Alamos Scientific Laboratory using correlations of LASL's detailed simulation program. The first source gives data for 85 locations, which allows calculation of the collector areas required to give solar fractions of 25, 50, and 75%. Only a few seconds are required to perform the simple calculations once the heat load in Btu/degree day units is specified. If the location is not among those listed, a longer monthly procedure is required. The major drawback of the method is that a standard system design is assumed. All aspects of the system are specified by values that are not easily translated into terms that a nonthermal specialist can understand. This severely restricts the range of applicability of the method and makes it easy to misuse. The collector specified corresponds to a typical single-glazed, nonselective design which would probably not be used in colder climates. When corresponding collector parameters were used in F-Chart calculations, the SLR method tended to predict lower performance for a given collector area (see Appendix A). Use of more efficient collectors would accentuate this difference.

ERDA's handbook presents the SLR method with data for 18 cities in Arizona, California, Oregon, and Washington. In addition to the SLR method, the handbook includes charts showing the effects of varying individual system parameters and general information on DHW systems, pool-heating systems, and passive solar designs. A simple nomograph for determining life-cycle economics is also given.

Source: a) J. D. Balcomb, et al. Sharing the Sun: Proceedings of the 1976 Joint Conference of the American Section of ISES and the Solar Energy Society of Canada, Winnipeg, Vol. 4, 1976.

b) U.S. Government Publication, Los Alamos Scientific Laboratory, Solar Energy Group, Los Alamos, N.M. 87545

Cost: None

This book, by W. A. Beckman, S. A. Klein, and J. A. Duffie, summarizes the results of many years of government-funded research at the University of Wisconsin that used correlations of TRNSYS computer simulations to develop a simplified solar heating system-sizing technique, and it is the most complete documentation of the F-Chart method. The basic assumptions of F-Chart are: 1. Long-term collector performance can be described by the collector parameters $F_R(ta)_n$ and F_RU_L and the incident angle modifier $(ta)/(ta)_n$. 2. System schematics are as shown in Figure 3-3. 3. System loads can use energy down to room temperature (70°F). 4. 212°F is the maximum liquid storage temperature. 5. The demand distribution is for residential application. 6. The use of conventional furnace backup (no heat pumps, etc.) where the furnace only tops off the solar contribution. 7. In-air systems, the rock bin is designed such that NTU > 10 and air flow is vertical and reversing to maintain the hot end up.

Two dimensionless parameters are used to describe the solar system and are combined in an empirical expression for the monthly solar fraction (F). Alternatively, the monthly F can be read from a chart, the actual "F-Chart."

F-Chart appears to be the most complete and flexible manual method currently available in a form that can be used by the nonsolar specialist. It has a wide range of applicability in that any collector type for which the performance parameters are known can be analyzed. Also, variations in the storage capacity, and the sizes of the heat exchangers in the system can be accounted for. The book is simply written, each step in the calculation procedure is demonstrated fully with examples, and a complete set of worksheets is included. Discussions of basic solar energy theories and life-cycle economic analysis as well as general design recommendations for liquid and air systems are given. Environmental data for 170 locations are tabulated in an appendix, and updated data for 261 locations can be obtained from the report cited below. This report would be a useful data source for many of the methods in this manual.

The major disadvantage of the F-Chart method in its manual form is that a complete calculation takes several hours, which makes it entirely impractical for repetitive use. It is recommended, however, that those who use any of the other manuals of PC methods based on F-Chart, use this book to become familiar with the details of its uses and restrictions. The F-Chart method appears in several government publications as well as the sources below (see Section 6).

Source: Wiley and Sons, New York, N.Y.

Cost: $15

Original Articles: S. A. Klein, et al. "A Design Procedure for Solar Heating Systems." Solar Energy. Vol. 18, 1976, pp. 113-127.

S. A. Klein, et al. "A Design Procedure for Solar Air Heating Systems." Solar Energy. Vol. 19, 1977, pp. 509-512.

Updated Data: Report EE-44-2
Engineering Experiment Station
University of Wisconsin
Madison, WI 53705

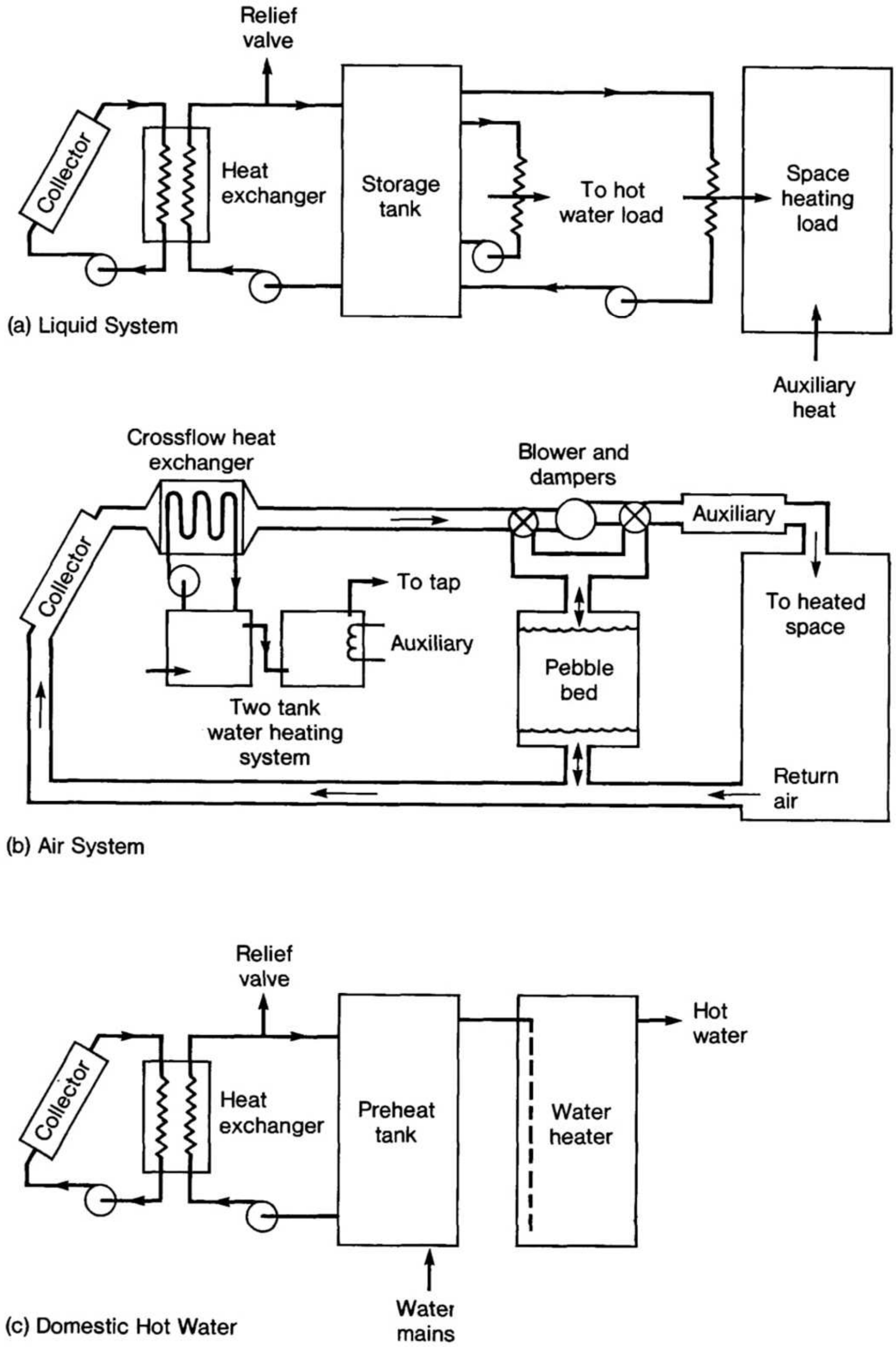

Figure 3-3. Systems Schematics for F-Chart

Copper Brass Bronze Design Handbook: Solar Energy Systems

No. 5

This is a 35-page primer on active solar systems with a section on hand calculations for sizing systems. Several system schematics are discussed with an emphasis on practical design considerations. The handbook includes a great deal of useful information for those with little or no background in solar energy. The last section presents the Copper Development Association (CDA) Sun-Chart Hand Calculations for determining space- and water-heating loads, collector performance, and recommended collector area. The basic assumptions of the method are: a collector orientation within 15° of due south, liquid in the collectors, 1-1/2 to 2 gallons of storage water per square foot of collector, and solar fractions of 60 to 70% for space heating and 70 to 80% for water heating. The method implicitly assumes that collector efficiency is independent of the solar fraction, so it should not be used for solar fractions outside these recommended ranges. The result of the calculation is the average useful heat produced each month by 1 square foot of collector. These figures are then combined with heating loads to determine the required collector area. A tabulation chart is provided, and the handbook supplies all the necessary data for 177 locations, with the exception of the monthly average daytime temperature. The Climatic Atlas of the United States, or a similar source, is required to estimate these values. The whole procedure is fairly time-consuming--1 to 1-1/2 h depending on practice and the detail used when interpolating in the tables provided.

Source: Copper Development Association, Inc.
1101 High Ridge Road
Stamford, CN 06905

Cost: $3

The method described in this report was developed by the United States Army Construction Engineering Research Laboratory (CERL) using the BLAST computer simulation program. The method uses universal performance curves, which relate the solar fraction to the ratio of incident radiation on the collector array and the energy requirements of the building. Separate curves are given for hot water, space heating, and combined heating and cooling. These curves are based on the use of a single-glazed, selective surface collector, but correction factors are given for other types of collectors. Collector tilts are assumed to be latitude plus 10° for space heating, latitude for hot water, and latitude minus 10° for combined heating and cooling. Other basic assumptions about the system design and control strategies are not included in the report, which leaves the user unsure of what systems the method can be applied to or what restrictions must be observed. Calculations are done on an annual basis for hot water and combined heating and cooling systems, but on a monthly basis for space-heating systems. The heating calculation takes 20 to 30 min. Reprints of the monthly and annual mean daily horizontal surface radiation maps from the Climatic Atlas of the United States are provided, but any more complete radiation data source may be used.

Source: CERL Interim Report E-98
U.S. Army Construction Engineering Research Laboratory
P.O. Box 4005
Champaign, IL 61820

Cost: None

Designing and Building a Solar House is a 200-page book by Donald Watson that discusses both active and passive solar designs. Greater emphasis is given to active systems, and much of the text is concerned with examples of existing solar buildings. Discussions of general principles of solar design are also included. Appendix II, "Solar Design Calculations," contains manual procedures, worksheets, and examples for calculating monthly heating requirements, solar contribution, auxiliary fuel requirements, and simplified life-cycle cost. The space-heating load calculation uses simplified charts for the overall loss coefficient of standard building designs with selected values of average wall insulation, infiltration rate, and percent window area. The assumptions of these charts are somewhat restrictive compared with a simplified ASHRAE procedure. The monthly solar contribution through south facing glass is calculated by multiplying clear day insolation through a vertical window, percent possible sunshine, days in the month, window area, a shading factor, and a correction factor to account for the passive efficiency of the building. The monthly solar contribution from collectors is obtained by multiplying average clear day radiation on the tilted surface, percent possible sunshine, days per month, collector area, a correction factor for off-south orientation, and the monthly average collection efficiency. This last value is taken to be 20% less than the instantaneous efficiency of the specific collector, which can be read from the manufacturer's test curve at set values of the fluid parameter. The method involves several major assumptions that are not fully justified by the author, and a novice could easily be confused by or misuse the method.

Source: Garden Way Publishing
Charlotte, VT 05445

Cost: $9

A General Design Method for Closed-Loop Solar Energy Systems (ϕ,f-chart Method) No. 8

The method presented in this paper is similar to F-Chart and is being developed by the same authors. The major difference is that the new ϕ,f-chart method allows the user to specify a minimum useful application temperature, whereas F-Chart assumes a minimum of 70°F. The ϕ,f-chart method consists of two steps. First, the maximum possible energy collection is determined using collector utilizability charts. This maximum value corresponds to a very large storage capacity, no storage losses, and no resistance to heat transfer to the load. The second step in the calculation is to account for these factors. The ϕ,f-chart method is still in the process of being refined. It is more difficult to apply than the F-Chart method, has considerable potential for misuse in its present form, and a thorough understanding of solar engineering is required for its use. Further development of this method can be expected.

Source: S. A. Klein and W. A. Beckman. Solar Energy. Vol. 22, 1979, pp. 264-282.

Cost: None

Prediction of the Performance of Solar Heating Systems Over a Range of Storage Capacities — No. 9

Numerous calculations using a detailed simulation program were correlated to produce an analytical expression for the monthly solar fraction and charts that look very similar to the F-Chart. Peter Lunde, the author of the method, defines his dimensionless parameters differently, however, from the parameters of F-Chart, and he uses three dimensionless groups to describe the system rather than two. Unlike F-Chart, this method allows the user to define the minimum useful storage temperature. Input data are essentially the same as for F-Chart but also include values for minimum useful storage temperature, average daytime temperature, and average daily operating time of the collectors. Unfortunately, the paper does not clearly state how these last values should be chosen. Other drawbacks to the method are that it can only be applied to liquid space-heating systems and documentation is not complete enough to allow the nonsolar specialist to use the method. Furthermore, the correlation is based on tilted surface radiation data calculated using the cloud cover model, which predicts lower winter insolation values than the commonly used Liu and Jordan method. The author claims that this method is more accurate. However, data processed in this way is not currently available for a large number of locations. On the whole, Lunde's method offers potential as a competitor to F-Chart, but it is still being developed and refined, and is not yet ready for widespread application.

Source: Proceedings of the 1978 Conference of the American Section of ISES, Denver, pp. 154-160.

Cost: None

Original article: Peter Lunde. Solar Energy. Vol. 20, 1978, pp. 283-287.

Realistic Sizing of Residential

Solar Heating and Cooling Systems No. 10

The major part of this article by Dan Ward deals with the various uncertainties involved in predicting the performance of solar heating systems. Uncertainties inherent in heating load calculations, solar radiation and weather data, solar fraction calculations, and life-cycle cost predictions are evaluated. The thesis of the article is that the solar fraction for a given system can only be predicted to one significant figure, and therefore, detailed analyses cannot be justified. Ward presents a simple performance prediction procedure, which uses only January radiation and load data and two curve fit parameters. These parameters were developed using the F-Chart method and are given for 13 specific collector models. Test problems showed that the correspondence between the results of this method and F-Chart is location-dependent. Other shortcut versions of F-Chart appear to give more consistent results.

Source: Proceedings of the 1978 Conference of the American Section of ISES, Denver, Vol. 2.

Cost: None

An Averaging Technique for Predicting the Performance of a Solar Energy Collector System — No. 11

Published by George Strickford soon after F-Chart appeared, this method is an averaging technique based on energy balance principles rather than detailed simulations. It applies the generalized long-term collector utilizability curves developed by Liu and Jordan to determine the long-term average daily energy gain of a collector system. Monthly average weather and radiation data are used, and separate calculations are made for each month. Important characteristics of the system design, such as limited storage capacity, a minimum useful temperature, control strategies, and system losses are not addressed. The method also requires an estimate of the monthly average collector plate operating temperature. Stickford suggests using the ambient temperature plus 45°C, but this leads to an inaccurate independence of collector efficiency and the solar fraction. On the whole, the method appears to have a considerable potential for misuse.

Source: Sharing the Sun: Proceedings of the Joint Conference of the American Section of ISES and the Solar Energy Society of Canada. Winnipeg, pp. 295-315.

Cost: None

Calculation of Long Term Solar Collector Heating System Performance

No. 12

The Liu and Jordan procedures are used to calculate tilted surface radiation for an average day of each month and to predict the monthly heat gain of the collectors. Charts are then used to correct this value for effects of the storage capacity of the system giving the daily total useful energy gain of the storage system. The storage temperature at the end of the day must be calculated using an iterative procedure. This makes the method very inconvenient to use. Furthermore, documentation is not complete enough to allow the nonsolar specialist to use the method.

Source: S. R. Swanson and R. F. Boehm. Solar Energy. Vol. 19, 1977, pp. 129-138.

Cost: None

METHODS FOR PROGRAMMABLE CALCULATORS
(ACTIVE SYSTEMS)

A great deal of effort has been invested to make these programs compact and easy to use. The SE-1 performs F-Chart calculations for liquid or air space-heating, DHW, or combined systems. The program and the environmental data for a given location are contained on just two magnetic cards (with the TI system). To allow for this compact form, the program has built-in values for storage capacity and load heat exchanger size. Simple charts are provided to correct for variations in these parameters and to correct for off-south collector orientation. Environmental data are available in two forms: basic data for use at any collector angle, and preprocessed data given for four specific angles at each location. Both data forms for one location are included in the program price and come on prerecorded magnetic cards. Additional prerecorded cards are available for a total of 261 locations at $20 for each location. Basic and preprocessed data in tabular form for all 261 locations come with the program, and the user can prepare his own data cards in less than 5 min. Instructions on how to convert any F-Chart type data to the proper form for the SE-1 program are included. Because of the compacting and rounding of data, the results of SE-1 may be slightly different from those of the FCHART computer program. However, in view of the overall uncertainties in solar calculations (see Section 2), this is not a significant drawback. Run time is about 3 min for each collector area using preprocessed data.

The SE-2 performs detailed life-cycle cost calculations. Collector areas and annual F values for two runs of SE-1 are automatically stored for use by this program. A convenient feature of SE-2 compared with other economics programs in this reference manual is that the economic parameters are entered by simply identifying the item number and then specifying its value. The program has an option to automatically calculate the optimum collector area based on the minimum payout, where payout equals initial cash investment/(net savings minus initial investment)/year. Other methods define the optimum by maximizing life-cycle savings, which can be done using the SE-2 results for life-cycle savings.

Documentation is clear and concise, which makes the programs easy to use by the nonsolar specialist. Furthermore, complete documentation and user instructions are included with sales literature. Having the major input parameters printed with the results and having all output of the programs labeled make the Scotch Programs SE-1 and SE-2 very appropriate for information services.

Source: Scotch Programs, Inc.
8107 S. W. 72nd Avenue 321
Box 430734
Miami, FL 33143
Tel. No. (305) 665-1251

Cost: SE-1 $165, SE-2 $95, Both $195

Calculators: TI-59, SR-52, HP-67, HP-97 (printer required with SE-2)

Sample Printout From SE-1 on the TI-59/PC-100

```
SOLAR F-CH
SCOTCH SE1
NASHVILLE

   46.00     ANG ———— Collector tilt
    0.75     F'TA }
    1.15     F'UL }——— Collector performance parameters
13680.00     HTG ———— Heating load in Btu/degree day
    0.00     WTR ———— Water heating load in Btu/month


   LIQ SYST

   70.00      F² ———— Collector area

    0.08    FR S ———— Monthly solar fraction
   10.60    MBTU ———— Monthly heating load
    0.84    MBTU ———— Energy supplied by solar

    0.14    FR S
    8.89    MBTU
    1.25    MBTU
     •        •
     •        •
     •        •
    0.10    FR S
    9.92    MBTU
    0.97    MBTU

   48.91    MBTU ———— Annual heating load
    9.68    MBTU ———— Annual energy supplied by solar
    0.20    FR S ———— Annual solar fraction
```

Sample Printout From SE-2

```
    300.     FT² ———— Collector area
   3089.    COST ———— Total initial cost
    618.    CASH ———— Down payment
  15019.    PWSV ———— Present worth of net life-cycle savings
     1.6     P O ———— Pay-out in years
    0.52       F ———— Solar fraction
    403.    FUEL ———— Annual dollar fuel savings
             OPT ———— Indicates optimum based on minimum pay-out
    160.     FT²
   1881.    COST
    376.    CASH
  11358.    PWSV
     1.3     P O
    0.39       F
    300.    FUEL
```

Written by the originators of the F-Chart method, S. A. Klein, W. A. Beckman, and J. A. Duffie, these programs closely follow the procedures of Solar Heating Design (see Method No. 4); this book is included with the software. Separate program sets, which will operate in either English or SI units, are provided for:

1. Calculation of the monthly average daily radiation on south-facing tilted surfaces.
2. Permanent storage of weather data for later use.
3. Determination of the storage heat exchanger penalty, F_R'/F_R.
4. Prediction of monthly and annual solar fraction for air or liquid space-heating systems.
5. The F value for water-heating systems.
6. Life-cycle savings.

The user must prepare his own data cards, and separate cards must be prepared for each collector tilt at each location. (Different cards can be prepared for collectors having 1 or 2 covers, but it is adequate in most cases to simply use data cards for 1 cover, and multiply the F_R'(ta)n input for a two-cover collector by 0.98.) Each data card takes about 30 min to prepare, and two to four cards are needed for each location. However, once these are prepared, the F-Chart thermal calculations are almost as convenient as with the Scotch programs. Run time for the performance calculation is about 5 min for the first area, and 4 min for each additional area. (Times can be reduced to 4 and 3 min when using a printer by changing the 4 "pause" steps to "NOP" steps.)

An advantage of this version of F-Chart is that (ta)/(ta)n, F_R'/F_R, and the effects of storage capacity, load heat exchanger size, and monthly ground reflectance can be calculated automatically. Thus, this program is somewhat more versatile than the SE-1, and may be more appropriate for use by solar designers and engineers. Documentation and user instructions are also clear enough for the non-solar specialist.

Source: F-Chart
P.O. Box 5562
Madison, WI 53705

Cost: $150

Calculators: TI-59, HP-67, HP-97 (printer optional)

1.		Month number
0.59		Solar fraction
2.		•
0.69		•
3.		•
0.88		
4.		
1.00		
5.		
1.00		
6.		
1.00		
7.		
1.00		
8.		
1.00		
9.		
1.00		
10.		
1.00		
11.		
0.70		
12.		
0.59		

13.		Indicates yearly totals
107.		Collector area (m^2 or ft^2)
110.42 09		Total load (J/year or Btu/year)
0.75		Solar fraction

20.	M YR	Mortgage years
20.	E YR	Period of economic analysis
20.	D YR	Depreciation years
0.	SALV	Salvage value
0.46	I TX	Income tax bracket
0.0133	P TX	Property tax rate
0.01	I M	First year insurance and maintenance cost
0.1	DOWN	Fractional down payment
0.08	DISC	Discount rate
0.09	INT	Mortgage rate
0.06	GINF	General inflation rate
0.1	FINF	Fuel inflation rate
200.	DL/A	Installed collector area dependent costs
1000.	DLFX	Fixed costs
201.8	LOAD	Annual load
8.33	FUEL	First year fuel cost ($/GJ or $/MMBtu)
0.27	FRAC	Solar fraction
25.	AREA	Collector area
3734.768858	RSAV	Life cycle savings for residential property (life cycle saving for commercial property can also be printed)

SEEC III is a multipurpose design optimization package containing four separate programs to be run in a sequence. A detailed life-cycle economics program calculates factors that are used in determining: optimum choices of the collector type, degrees of insulation or weatherproofing that should be used in each portion of the building envelope (with solar and conventional heating systems considered separately), and the collector area that will yield the maximum life-cycle savings. The solar fraction and optimum collector area are calculated by the Relative Areas method (No. 1), and an article on "Optimization of Space Heating Loads," as calculated by SEEC III, can be found in the 1978 American Section, ISES Proceedings (pp. 163-167).

SEEC III is primarily intended for use by architects and designers. The programs are somewhat cumbersome, and effective use of the thermal design optimization option requires detailed information on the construction or installation costs of the various options considered. However, this feature may be very useful when energy conservation measures are being investigated. Furthermore, it is not necessary to use all the optimization options. For example, the loads program can be used simply to calculate the heat loss coefficient of a single building design, or a predetermined UA value can be entered directly. Run time depends on the number of design options considered.

SEEC III is inconvenient to use for simple calculations of the solar fraction, life-cycle cost, and optimum areas as prescribed in the Relative Areas method. If optimization of the building design is not a desired feature, the SEEC II program can be purchased. This program performs the calculations described in review No. 1, is simple to use, and may be very appropriate for utility customer information services.

Documentation for SEEC III is excellent. The 95-page user's manual contains complete program listing, explanations of the theories and formulas, and several worked examples. Convenient tabulation sheets are provided for recording all data and results. Documentation for SEEC II is equally good.

Source: Solar Environmental Engineering Company
2524 East Vine Drive
Fort Collins, CO 80524
Tel. No. (303) 221-5166

Cost: SEEC III $125, SEEC II $95

Calculators: TI-59, HP-67, HP-97

Sample Printouts From the SEEC III Programs*

7

SEEC III Worksheet
TI-59

Job Title: Example 1 (with printer)   Location: Boulder, CO

UNITS(side 3)   SI UNITS

ECONOMICS(1,2

00	n	20.
01	i	0.09
02	α	0.1
03	m	25.
04	d	0.07
05	g	0.06
06	rfc	0.1
07	rfs	0.[illegible]
08	ro	0.1
09	t	0.25
10	β	0.2
11	p	0.
12	h	0.005
13	Dep	0.
14	k	10.
15	δ	1.5
16	Bus	0.
17	σ	0.02
18	Sal	1.
19	S1	0.
20	S2	10.
21	S3	0.

press "Run" ("

COLLECTORS(1,4

01	Z	0.03464
02	n	0.45
03	time	1945.
	Celec	0.05

press "Ready"

#1	FR'(τα)	0.7
	FR'UL	2.
	Cmod	319.
	Amod	1.8[illegible]
	[Δp]	199.
	[G]	0.9[illegible]
or	[Co]	0.

press 1 "Run"

#2	FR'(τα)	0.5
	FR'UL	3.
	Cmod	205.
	Amod	1.81
	[Δp]	119.
	[G]	0.61
or	[Co]	0.

press 2 "Run"

#3 etc.

LOADS(1,4)

01	DD	73867.
02	AS or AD	9.0[illegible]
03	C1	0.544
04	C2	0.334
05	CFs	7.5
06	CFc	7.5
07	CLs	0.
08	CLc	0.
09	D	302.
10	ΔT	50.
11	Cb	2400.
12	Cm	50.
13	CHc	2600.
14	CHs	2600.

press "Ready"

U or V	Cu or Cv	Option	Area
.41	1.72	1	Walls
.26	2.69	2 } 2.3	
.21	4.94	3	232
.25	2.26	1	Ceiling
.13	4.52	2 } 2.3	
.09	6.74	3	139
6.94	129	1	Windows
3.24	144	2 } 2.2	
8.68	97.5	3	23.2
8.07	27.8	1	Doors
6.05	65.2	2 } 2.2	
3.07	530	3	3.72

SIZING(1,(2))

Solar System:

$(UA)_s$	177.22
Aopt	25.3[illegible]
F	0.8[illegible]
CT_s	14885.3[illegible]

Conventional:

$(UA)_c$	160.06
CT_c	19112.46

Savings   4227.0[illegible]

(press "Print")

*Reproduced by permission from the SEEC III user's manual

8

NOMENCLATURE

ECONOMICS

n = period of economic analysis, yrs
i = annual loan interest rate
α = loan downpayment fraction
m = period of mortgage, yrs
d = annual discount rate
g = general inflation rate
rfc = annual rate of conventional system fuel price inflation
rfs = annual rate of solar system auxiliary fuel price inflation
ro = annual rate of operating cost (electricity) inflation
t = net (federal and state) marginal income tax rate
β = investment tax credit fraction
p = annual property tax rate, as fraction of actual first cost
h = annual insurance rate
Dep = depreciation type = 0 for none, 1 for SL, 2 for DB, 3 for SOYD.
k = depreciation lifetime, yrs
δ = declining balance multiplier
Bus = 1 for business, 0 for residence
σ = fractional salvage value
Sal = 1 if salvage cash flow is to be included at last year, 0 if not
S1, S2, S3 = Expected service lives of collector #1, #2, and #3, respectively. All must be divisible into n. Default value of 0 means S = n.

COLLECTORS

Z = location dependent parameter from Table 3 or 4.
n = collector loop pump or blower efficiency
time = collector pump or blower operating time, hrs/yr
Celec = cost of electricty, $/kwh
FR' = collector and heat exchanger heat removal factor
(τα) = collector transmittance - absorptance product at normal incidence
UL = collector heat loss coefficient, W/°Cm^2(Btu/°F-hr-ft^2)
Cmod = installed cost of one collector module, including associated storage
Amod = collector module effective (i.e., absorber) area, m^2(ft^2)
Δp = pressure rise across pump or blower, nt/m^2(in. W.G.)
G = collector fluid flow rate, m^3/min m^2(ft^3/min ft^2)
Co = annual operating cost, $/m^{2}yr ($/ft^{2}yr)

LOADS

DD = annual degree days, from Table 3 or 4, °C-hr/yr(°F-hr/yr)
AS, AD, C1, C2 = location dependent parameters, from Table 3 or 4.
CFs = cost of solar auxiliary fuel, $/GJ($/MMBtu) delivered by furnace
CFc = cost of conventional fuel, $/GJ($/MMBtu) delivered by furnace
CLs = load-dependent cost of solar auxiliary equipment, $yr/GJ($yr/MMBtu)
CLc = load-dependent cost of conventional system equipment, $yr/GJ($yr/MMBtu)
D = daily hot water demand, liters/day (gal/day)
ΔT = hot water temperature rise, °C(°F)
Cb = solar system fixed cost, $
Cm = annual solar system maintenance cost, $/yr
CHc = conventional system fixed cost
CHs = solar auxiliary system fixed cost, $
U = net conductance of building surface option, W/°Cm^2(Btu/°F-hr-ft^2)
Cu = cost per unit area of building surface option, $/m^2($/ft^2)
V = infiltration rate, m^3/hr(ft^3/hr)
Cv = cost of infiltration option, $

SIZING

(UA) = over-all heat loss factor for building, W/°C(Btu/°F-hr)
Aopt = optimal collector area, m^2(ft^2)
F = fraction of annual heat load supplied by solar energy
CT = present worth of life cycle heating expenses, $

Solarcon offers two sets of programs for F-Chart performance calculations. ST355 and ST365, for air and liquid systems respectively, include a Liu and Jordan calculation of the radiation on a tilted surface. ST35/36 require tilted surface insolation data as input. Separate programs are available for calculating these values from horizontal insolation data and average atmospheric transmission (K_T) figures. Both ST355/365 and ST35/36 sets include simplified calculations of annual dollar savings for four different fuel costs. The ST369 is a detailed economics program based on the economy methods described in Solar Heating Design (No. 4).

The Solarcon programs are less convenient to use than the Scotch or University of Wisconsin F-Chart programs. System parameters must be entered manually into storage registers rather than by the simpler use of user-defined keys. The correction factor for DHW systems must be calculated by hand, and the run time is longer, about 6 min per collector area. Documentation and user instructions are neither as simple nor as clear as for the three previous methods and may be confusing to those without an engineering background or previous exposure to the F-Chart method. Solarcon does offer prerecorded data cards, which is an advantage. An important feature of the ST369 detailed economics program is that year-by-year cash flow figures can be printed, as well as the present worth of the net life-cycle savings. If year-by-year cash flow figures are desired, this program could be used in conjunction with an F-Chart thermal program from another vendor.

The handbook, Solar Energy Calculations, contains documentation and user instructions for all the Solarcon programs and can be used as a shopping guide.

Source: Solarcon
607 Church
Ann Arbor, MI 48104
Tel. No. (313) 769-6588

Cost: ST355 $142; ST365 $142; Total $239
ST35 $127; ST36 $127; Total $215
Data cards $15 each
ST369 $95
Solar Energy Calculations $25 (Includes coupon for $20 off the price of any programs purchased)

Calculators: TI-59, HP-67, HP-97

Sample Printout of Solarcon ST365 on the TI-59/PC-100

1.	Month number
1097.32	Isolation (Btu/ft^2 day)
27122384.00	Total load (Btu/mo)
200.00	Collector area
3077117.45	Energy supplied by solar (Btu/mo)
0.11	Monthly solar fraction

```
          2.
    1288.83
23702294.00

     200.00
 3834549.63
       0.16

          3.
    1561.48
20927504.00

     200.00
 4883887.96
       0.23
          •
          •
          •
         12.
    1027.09
24657338.00

     200.00
 2821503.32
       0.11
```

200.00	Collector area
0.27	Annual solar fraction
5.00	Auxiliary fuel cost ($/MBtu)
-29.08	Yearly savings
10.00	
184.04	•
15.00	•
397.17	•
20.00	(for four fuel costs)
610.30	

The SEEC I package includes a simplified thermal building load analysis program, programs for F-Chart space heating and DHW performance prediction, and a detailed life-cycle economics program. In its present form, SEEC I has two major shortcomings. First, the programs are not written for use with a printer, so the calculations of monthly F, annual F, total heating load, and economic maximum first cost must each be initiated with a keystroke, and all results must be recorded by hand. Second, the programs do not account for variations in the storage capacity or load heat exchanger size, and no discussion of these effects is included in the documentation. The standard values of these parameters are built into the program, but this, also, is not documented. SEEC I is currently being rewritten to include printing capability, but there are no plans to include corrections for variation in storage capacity and load heat exchanger size.

Documentation is excellent, aside from the above omission. A 100-page user's manual includes complete program listings, explanations of the calculations, many sample problems, and data for 170 locations. Data cards take about 10 min to prepare, and only one is needed for each location. Run time is about 6 min plus the time to record each result.

Source: Solar Environmental Engineering Company, Inc.
P.O. Box 1914
Fort Collins, CO 80522
Tel. No. (303) 221-5166

Cost: $125

Calculators: TI-59, SR-52, HP-67, HP-97,HP-65, SR-60 ($200)

Sunshine Power Company

T-33, T-34 No. 18

These programs, for air and liquid systems respectively, perform only parts of the calculations of the F-Chart method. Correction factors for storage size and load heat exchanger size must be determined by hand, and no economic analysis is included. The programs analyze only one month at a time, and monthly data for average ambient temperature, radiation on the tilted collector, and total load must be entered by hand prior to each monthly calculation. This makes the programs very inconvenient to use compared with the other F-Chart software reviewed in this report.

Source: Sunshine Power Company
1018 Lancer Drive
San Jose, CA 95124
Tel. No. (408) 446-2446

Cost: T-33 \$40; T-34 \$40
Solar Heating Design by the F-Chart Method \$15

Calculators: TI-59/PC-100, HP-67 (printer required), HP-97

Section 4

CHARACTERISTICS OF SELECTED METHODS FOR PASSIVE SYSTEMS

SUMMARY MATRICES

The major characteristics and features of the selected methods for sizing passive solar heating systems and predicting their performance are described in three matrices:

Table 4-1: Titles and Descriptions of Manual Methods
Table 4-2: Titles and Descriptions of PC Methods
Figure 4-1: Applications

Information contained in these matrices was obtained through direct examination of the documentation provided with each method and through actual use of the methods. In Figure 4-1, in most cases, a particular feature or requirement is marked by a bullet (•) in the appropriate column. An asterisk (*) indicates that a further explanation is contained in the one-page review of the method.

Manual and PC methods are listed separately in alphabetical order of authors and program titles, respectively. The methods for analyzing passive systems have not been ranked, because they cover a wide range of applications, and ranking criteria are not easily defined.

Table 4-1

TITLES AND DESCRIPTIONS OF MANUAL METHODS FOR PASSIVE SYSTEMS

Number	Title	Authors	Date	Description	Summary Page
19	"A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type"	J. D. Balcomb R. D. McFarland	1978	Los Alamos Scientific Laboratory's Solar Load Ratio (SLR) method for Trombe wall and water wall designs. Predicts annual solar fraction, auxiliary energy requirements	4-6
20	"A Semi-Empirical Method for Estimating the Thermal Performance of Direct Gain Passive Solar Buildings"	J. D. Balcomb R. D. McFarland W. O. Wray	1979	SLR method for predicting annual solar heating fraction carried by direct gain systems	4-7
21	"A Proposed Simplified Thermal Load Analysis Technique for Trombe Wall Passive Solar Heating Systems"	D. Kelbaugh J. Tichy	1979	Gives "dynamic" U-factors for analyzing Trombe walls through standard ASHRAE heat loss calculations	4-8
22	The Passive Solar Energy Book	E. Mazria	1979	Comprehensive source book on passive solar design. Simple rules of thumb	4-9
23	"A Simple Direct Gain Passive House Performance Prediction Model"	W. B. Niles	1979	Proposed method using charts to analyze direct gain buildings	4-10

Table 4-2

TITLES AND DESCRIPTIONS OF PC METHODS FOR PASSIVE SYSTEMS

Number	Title	Authors	Date	Description	Summary Page
24	PASCALC	J. T. Kohler	1979	SLR method for storage wall, direct gain, and combined passive systems. Solar fraction and life-cycle economics	4-12
25	PDP	R. M. Lebens	1978	Predicts maximum room air temperature in direct gain buildings at the equinox	4-13
26	PEGFIX/PEGFLOAT	W. L. Glennie Princeton Energy Group	1978	Design day simulation of direct gain buildings. Temperature fluctuations and daily auxiliary energy requirements	4-15
27	SEEC VI	K. Sharp C. D. Barley C. B. Winn J. A. Leflar	1978	SLR method for Trombe walls and water walls. Annual performance and life-cycle economics	4-17
28	Solarcon ST 33	R. W. Graeff	1979	Trombe wall simulation	4-18
29	Solarcon ST 34	R. W. Graeff	1979	Direct gain simulation	4-20
30	TEANET	J. T. Kohler P. W. Sullivan	1979	General thermal network analyzer for passive system simulation	4-22

	Applications					Purpose					Based On				Tools Required						Interval			
Number	Trombe wall	Water wall	Direct gain	Attached sunspace	Combinations	Rules-of-thumb	Design day performance	Simulation	Annual performance	Life-cycle economics	Computer simulation	Test cell data	Building data	Simplified analytical model	Tables	Graphs	4 function calculator	Scientific calculator	Programmable calculator	PC with printer	Year	Month	Day	Hour
19	●	●							●		●				●		●	*			●	*		
20			●						●		●	●			●		●	*			●	*		
21	●						●		●				●			●		●				●	●	
22	●	●	●	●		●	●				●				●	●							●	
23			●				●							●		●	●						●	
24	●	●	●	●	●				●	●	●								●	●		●		
25			●				*				●								●					●
26			●	●			●	●						●					●	●				●
27	●	●							●	●	●								●	●		●		
28	●						●	●						●						●				●
29			●				●	●						●						●				*
30	●	●	●	●	●		●	●						*						●				●

Figure 4-1. Applications of Methods for Passive Systems

ONE-PAGE REVIEWS

For each method, a brief review is given to elaborate on the information included in the matrices. These include: general information on the form, basis, and applications of the method; special features and/or shortcomings; data requirements and outputs; technical background required; sources; costs; and additional references. PC programs for the Texas Instruments TI-59 calculator were obtained for these reviews, and some of the information regarding the running of the program may vary with other calculators.

A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type — No. 19

Similar to the SLR method for active solar systems (Method No. 3), this simplified procedure is based on correlations of the results of many hour-by-hour computer simulations of passive building performance. Trombe walls or water walls of standard design, with or without night insulation and with or without a reflector, can be sized, and auxiliary energy requirements can be calculated. The method has two options for application. First, if the location of interest is one of the 84 listed cities, the south-facing vertical storage wall area required to supply the desired annual solar-heating fraction can be calculated directly. The only data required from the user for this simple procedure is an estimate of the building loss coefficient in Btu/degree-day. (Losses through the storage wall should not be included in this figure.) Second, if the location is not listed or if the user wishes month-by-month information, a longer procedure is used. Step-by-step instructions for all the necessary calculations along with a sample problem are included in the article.

The monthly Solar Load Ratio curves were developed using the specific reference system described below:

Assumptions for both methods:

- Thermal Storage = 45 Btu/°F-ft^2 of glazing
- Trombe wall has vents with backdraft dampers
- Double glazing (normal transmittance = .747)
- Temperature range in building is 65 to 75°F
- Building mass is negligible
- Night insulation (when used) is R9, 5:00 p.m. to 8:00 a.m.
- Wall-to-room conductance = 1.0 Btu/hr-°F-ft^2
- Trombe wall properties:
  --Conductance = 1.0 Btu/hr-°F-ft^2
  --Heat capacity = 30 Btu/ft^3-°F

Additional assumptions for method A:

- Vertical, south-facing glass
- Wall absorptance = 1.0
- Ground reflectance = 0.3
- No shadings

Source: J. D. Balcomb and R. D. McFarland. Proceedings of the 2nd National Passive Solar Conference, Philadelphia, 1978, or Los Alamos Scientific Laboratory Report LA-UR-78-1159.

Cost: None

Additional Reference: R. D. McFarland and J. D. Balcomb. "The Effect of Design Parameter Changes on the Performance of Thermal Storage Wall Passive Systems." Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979.

A Semi-Empirical Method for Estimating the Performance of Direct Gain Passive Solar Heated Buildings — No. 20

Here, the SLR technique (see also Methods Nos. 3 and 19) has been extended to cover performance prediction for direct gain buildings. As with the SLR method for storage wall designs, data for 84 cities are given for direct calculation of the south-facing, vertical window area (with or without night insulation) required to provide the desired solar-heating fraction. Step-by-step instructions for a monthly calculation of the solar-heating fraction in any location are also given. The method is based on a "reference" design matching the one described in the review of Method No. 19, except that the storage mass is assumed to be 6-inch concrete distributed over the floor and north, east, or west walls with an absorptance of 0.8 and a surface area three times that of the glazing area. Correlations are given to convert monthly horizontal insolation data to transmitted solar flux through the south-facing, vertical, double-glazed aperture and to account for the use of a reflector on the ground in front of the aperture. The method is quite simple to apply, and little technical background in solar design is required. Another article from the same source gives a method of correcting monthly SLR values to account for internal heat generation and thermostat-set temperatures other than 65°F.

Source: J. D. Balcomb, et al.
Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979, pp. 395-402.

Cost: None

Additional Reference: J. D. Balcomb. "Performance Simulation and Prediction." Proceedings of the 3rd National Passive Conference, San Jose, 1979.

A Proposed Simplified Thermal Load Analysis Technique for Trombe Wall Passive Solar Heating Systems — No. 21

This method gives a correlation for a monthly "dynamic" U-factor for Trombe walls that allows the calculation of the building thermal performance and auxiliary energy needs in the same manner as the familiar ASHRAE procedures. The dynamic U-factor, which was developed by analyzing data from the Kelbaugh house in New Jersey, depends on the monthly average ambient temperature and the average daily solar radiation transmitted through south-facing, vertical double glazing. All formulas necessary for determining this factor and the annual solar fraction are clearly outlined, and the paper includes a sample problem. The only data that the user must supply, other than that for standard heat loss analysis of the rest of the building, are the monthly average values of ambient temperature, degree days, and daily horizontal insolation. This approach to passive design analysis offers considerable potential because it is a simple extension of the standard ASHRAE methods. However, the authors note that the method awaits further testing against performance data from actual buildings.

Source: D. Kelbaugh and J. Tichy. Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979.

Cost: None

Written by Edward Mazria, this book is probably the most comprehensive source of information on the design of passive solar buildings available. The emphasis is on general design rules of thumb that are relatively simple to apply and can be useful to anyone from the do-it-yourselfer to the experienced architect. The book includes: an introduction to the basic concepts of solar energy, heat transfer, and thermal comfort; descriptions of various passive solar systems with examples of existing buildings; design "patterns" comprising a step-by-step process for designing and sizing passive solar heating systems; suncharts for determining insolation and shading effects; and appendices giving calculation procedures. The design patterns move from the general (e.g., choosing the building site) to the specific (e.g., appropriate paint colors to use in direct gain buildings). Charts, which are based on a two-year research effort using computer simulations, can be used to predict the heat gain through a variety of passive systems, the average indoor temperature, and the indoor temperature swing on a daily basis.

The paper cited below contains information that was excerpted and condensed from this book. It presents simple design rules of thumb for direct gain and thermal storage wall passive buildings.

Source: Rodale Press
Emmaus, PA 18049

Cost: $11 (Expanded professional edition $25 hardcover price)

Additional Reference: E. Mazria. "A Design and Sizing Procedure for Passive Solar Heated Buildings." Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979.

A Simple Direct Gain Passive House Performance Prediction Model

No. 23

Two simplified mathematical models were used to develop the design charts presented in this paper. These charts, which apply to direct gain buildings with south-facing, double-glazed windows and heavyweight concrete storage mass, are used for estimating the window area required to maintain a given average indoor temperature and to predict the indoor temperature swing during the selected day. Simplifying assumptions of the mathematical models include sinusoidal variation of insolation and ambient temperature, consideration of a single zone heated space, no auxiliary heating, no night insolation, and no exhausting of excess heat. The user must supply data for average outdoor temperature; clear day radiation transmitted through south-facing windows; surface area, surface conductivity, and thickness of the concrete storage mass; building thermal loss coefficient; and outdoor temperature swing. The method has yet to be thoroughly tested against more detailed simulations or data from actual buildings, and it should be regarded with due caution until such comparisons have been made.

Source: W. B. Niles. Proceedings of the 2nd National Passive Solar Conference, Philadelphia, 1978.

Cost: None

METHODS FOR PROGRAMMABLE CALCULATORS
(PASSIVE SYSTEMS)

PASCALC calculates monthly and annual auxiliary energy consumption and the solar fraction for passive solar-heated buildings on a TI-59 programmable calculator using the Solar Load Ratio method which was developed at the Los Alamos Scientific Laboratory (see Method Nos. 19 and 20). The program can be used to analyze direct gain, Trombe wall, water wall, and sunspace passive systems, with or without night insulation. Applications are limited to systems with the general design specifications listed under the SLR manual methods, but performance of any combination of up to three of these designs can be evaluated in a single run of the program. Correction factors for orientation, tilt, number of glazing layers, transmittance, absorptance, shading, and reflector augmentation may be entered for each subsystem. The program can also compensate for thermostat setbacks and internal heat generation. The PASCALC user's manual is a 50-page document giving brief explanations of the input requirements (listed below), a worksheet for organizing these data, a discussion of the applications of the program, a sample problem, and weather data for 266 locations. A separate program is supplied to use in preparing weather data cards. These cards (one for each location of interest) take just a few minutes to prepare. Running PASCALC, also, takes only a few minutes. The PASCALC economics program is an adaptation of the University of Wisconsin F-Chart economics program and is based on Chapter 6 of Solar Heating Design (Method No. 4). It calculates the net life-cycle savings of the passive building as compared with a conventional building and can be used to optimize the size of the passive system.

Source: Total Environmental Action, Inc.
Church Hill
Harrisville, NH 03450
Tel. No. (603) 827-3374

Cost: PASCALC $75, PASCALC Economics $20

Calculator: TI-59 (PC-100 required with economics program)

Required inputs for PASCALC:

- Overall heat loss coefficient excluding the south face of the building
- Area of the south wall, including conventional wall and the passive system
- Heat loss coefficient from the conventional south wall
- Thermostat setting (time-weighted)
- Internal heat generation
- Number of different passive systems up to three
- Ratio of each system area to the total south wall area
- Heat loss coefficient through each system calculated by ASHRAE methods (time-weighted if night insulation is used)
- Monthly correction factors for each system to account for: transmittance of glazing, tilt, orientation, absorptance, shading, and reflector enhancement

PDP, the Passive Design Program written by Ralph Lebens, is a TI-59 program that calculates the maximum room air temperature in a direct gain passive solar-heated building on a clear day at the equinox (March 21st or September 23rd). Its purpose is to allow the designer to check a proposed building plan to ensure that overheating will not occur during these critical periods of the year, thereby eliminating the need for venting excess heat from the building. The program does not do an actual simulation. Rather, it uses correlations derived from a more complex analytical modeling program written at MIT. R. Lebens indicates that the results of PDP are in close agreement ($\pm$2°F) with this MIT computer program and with data from actual buildings. However, detailed information about the building design, weather conditions, and solar angles is needed to properly use PDP, and the program itself is somewhat inconvenient to run. PDP has several documentation sources. R. Lebens' self-published book, A Design Handbook for Direct Heat Transfer Passive Solar Systems, which is available through Louis Weitzman, includes a listing of PDP, explanations of the input parameters, discussions of the basis and applications of the program, and a lengthy sample problem involving conversion of an English row house to passive solar heating. Explanations of the derivation of PDP, concise user instructions, and a program listing can also be found in the published articles cited below.

Source: Louis M. Weitzman
20 St. Charles Street
Boston, MA 02118

Cost: $30 (includes R. Lebens' book and PDP on prerecorded magnetic cards)

Calculator: TI-59

Additional References: R. M. Lebens. "A Design Tool to Assess Room Air Temperature of a Passively Heated Space." Proceedings of the 2nd National Passive Solar Conference, Philadelpha, 1978.

R. M. Lebens and L. M. Weitzman. "A User Manual for PDP." Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979.

Required inputs for PDP:

- Average outdoor temperature at night and outdoor temperatures from hour 1 to hour 8 (8:00 a.m. to 4:00 p.m.)
- Actual volume of noon target, area of noon target, and fraction of noon target hit from hour 1 to hour 8
- Floor area, U-value, and temperature of space below
- Convective and radiative heat transfer resistances from storage to room air
- Vertical and horizontal components of insolation from hour 1 to hour 8
- Internal heat generation and gains from east or west windows from hour 1 to hour 8 and at night
- Area of unshaded south glass
- Density and specific heat of target
- U-values and areas of building envelope
- Number of air changes per hour

Both these programs use the simple two-node thermal network shown below and perform hour-by-hour simulation of the response of direct gain passive solar-heated buildings to prescribed weather conditions over a 24-h period. With PEGFIX, the user specifies minimum and maximum allowable temperatures in the space, and the program predicts auxiliary heat requirements and the excess heat available in the space, as well as the hourly temperature of the room air and storage surface. It is intended for use in sizing system components, backup heating, and ventilating equipment. With PEGFLOAT, no heat is added or removed, and the program predicts the hourly temperature excursions in a completely solar-dependent operating mode. The input data required for the two programs are listed below. The 70-page user's manual includes complete explanations of these inputs and sample problems. Worksheets are provided for organizing inputs and results.

These programs are the simplest to apply of the simulation programs included in this report. Very little background in thermal analysis is necessary, and less time is required to set up the input data and run the program.

Source: PEG Programs
Princeton Energy Group
729 Alexander Road
Princeton, NJ 08540
Tel. No. (609) 452-8235

Cost: PEGFIX/PEGFLOAT $75
Handbook only $25 (includes $20 credit toward purchase of programs)

Calculators: TI-59, HP-67, HP-97 (printers optional)

Additional Reference: W. L. Glennie. "Hand-Held Calculator Aids for Passive Design." Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979. (A paper describing the PEGFIX/PEGFLOAT programs.)

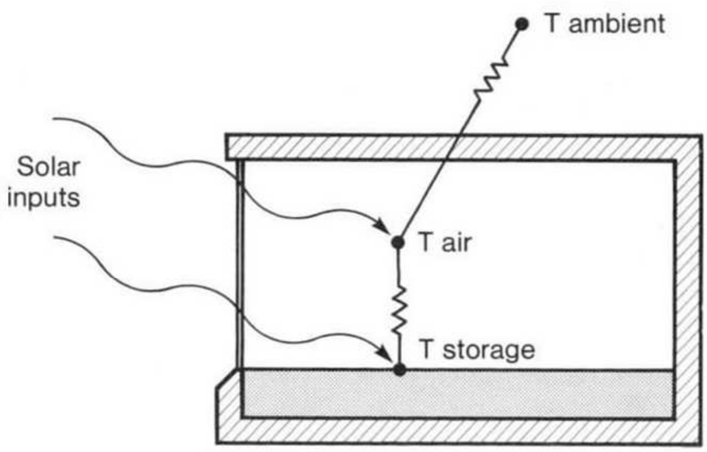

Figure 4-2. Thermal Network for PEGFIX/PEGFLOAT

Required inputs for PEGFLOAT:

- Area of collector glazing, ft^2
- Total daytime heat loss coefficient of the space
- Total nighttime heat loss coefficient
- Total effective heat capacity of storage; this value can be used to include shaded and directly illuminated areas of storage, and to account for thickness of storage
- Total heat transfer coefficient between storage and the space being heated
- The fraction of incoming solar radiation that is absorbed by the storage mass
- The fraction of solar radiation that strikes lightweight objects and thus transfers most of its energy immediately to the air
- The initial temperature of the storage mass
- The total daily solar radiation transmitted to the sunspace through all solar glazing, <u>or</u> the hourly solar radiation values
- Length of the day, sunrise to sunset; a chart is provided in the handbook
- Daily average outdoor temperature
- Outdoor daily temperature swing obtained from the <u>Climatic Atlas of the United States</u> or a similar source

Additional inputs for PEGFIX:

- The minimum temperature to be maintained by auxiliary heat
- The temperature at which venting will occur, or maximum allowable temperature
- The temperature of the space from which air is drawn during venting; can default to outdoor temperature

SEEC VI uses the Solar Load Ratio method to predict the performance of thermal storage wall passive solar heating systems (see Method No. 19). The SEEC VI package consists of three programs. The data entry program facilitates the recording of weather data cards for the locations of interest. The thermal analysis program predicts the monthly and annual solar fraction, and the economics program, which uses a detailed life-cycle cost analysis, calculates the maximum investment that should be made in a system providing a given solar fraction, or the net savings of the passive solar design over a conventional design. Documentation includes program listings, several sample problems, concise user instructions, and data for 174 locations. The programs are easy to use and take only a few minutes to run. However, the PASCALC programs (No. 24), which also use the SLR method, are more versatile.

Source: Solar Environmental Engineering Co., Inc.
2524 East Vine Drive
Fort Collins, CO 80524
Tel. No. (303) 221-5166

Cost: $125

Calculators: TI-59, HP-67, HP-97 (printer optional)

The Solarcon ST33 is a simulation program for vented or nonvented Trombe wall systems. The program solves energy balance equations for the thermal network shown in Figure 4-3 using a finite difference scheme. Hourly results are printed for the temperature at each node, heat flows from the wall to the room and through the vents to the room, and the auxiliary energy required to maintain the room at the thermostat setting. To increase accuracy, the number of calculation steps per hour can be increased from 1 to any value (only hourly results are printed). A fairly thorough understanding of the fundamentals of heat transfer and thermal analysis is recommended for the use of this program. As with all the simulation programs, setting up the input data and running the program can be fairly time-consuming, and the program is primarily intended for use by architects and engineers in the final stages of designing passive solar-heated buildings. Most of the documentation for this fairly sophisticated program concerns the input requirements, which are listed below. A sample problem, user instructions, and tabulation sheets for inputs and results are also included. Documentation for all the Solarcon programs can be found in the book Solar Energy Calculations, which can be purchased separately.

Source: Solarcon, Inc.
607 Church
Ann Arbor, MI 48104
Tel. No. (313) 769-6588

Cost: ST33 $138
Solar Energy Calculations $25 (includes $20 coupon for any Solarcon programs)

Calculators: TI-59/PC-100, HP-67 (printer required), HP-97

Required inputs for Solarcon ST33:

- Radiation heat transfer coefficient from the Trombe wall to the inner window
- Average daily ambient temperature and temperature swing (Climatic Atlas of the United States or similar source)
- Maximum hourly solar radiation striking the window surface. (The program uses sine function used to model variation during the day; hourly weather data can be entered manually as an option)
- Sunrise hour (formula given)
- Heat loss coefficient from the inner window to the environment (graph given)
- Surface area of the sunspace and window area
- Absorptivity--average transmissivity product for the Trombe wall
- Heat capacitances of the sunspace and the shadowed room
- Heat transfer coefficient from the wall to the sunspace

- Infiltration rates and U-values for the sunspace and the shadowed room
- Density, specific heat, conductivity, surface area, and thickness of the wall
- Heat transfer coefficient from the wall to the shadowed room
- Thermostat-set temperature
- Blower control differential temperature setting and heat transfer coefficient from the wall to the sunspace under forced flow conditions
- Fraction of radiation absorbed by lightweight materials in the sunspace
- Initial temperature distribution
- Starting hour, number of time steps per hour, and number of hours to be calculated

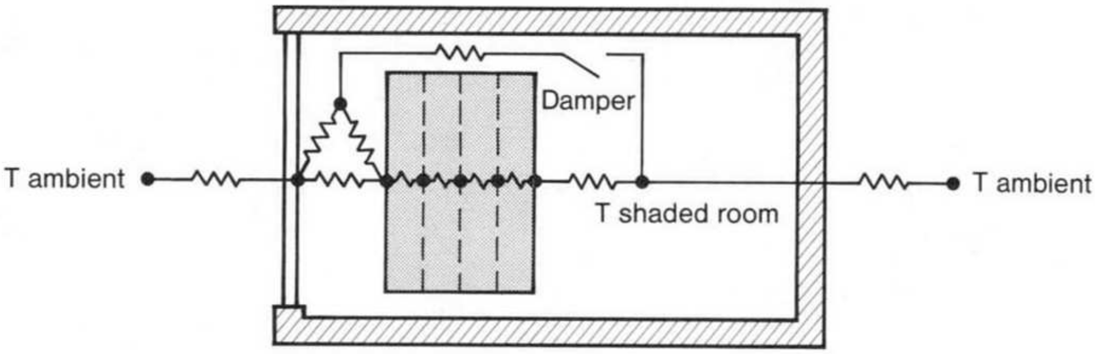

Figure 4-3. Thermal Network for Solarcon ST33

This Solarcon program simulates a direct gain passive solar-heated building. A thermal network such as the one shown to the right is typical, and the user has the option of dividing the storage wall in one to seven sections. As with the ST33 program, the energy balance equations are solved using a finite difference scheme. Several program options are possible: for more accuracy, the number of calculation steps per hour can be increased from one to any number; the storage wall can be massive or filled with liquid; new weather data for successive days can be entered automatically for up to eight days; varying ambient temperature and insolation can be modeled by the program or entered manually at preselected intervals; and auxiliary heating or cooling required to keep the space at the thermostat setting can be calculated. The program prints out the temperature at each node, the heat flow from the storage mass to the room, and the auxiliary heating or cooling requirements at a user-defined frequency. About 15 pages of documentation explaining the input data and program options are included in the book Solar Energy Calculations, along with a sample problem, user instructions, and tabulation sheets for input data and results.

ST34 is a fairly powerful simulation program. It is intended primarily for use by solar architects and designers, and a fairly thorough knowledge of the fundamentals of heat transfer and thermal analysis is required. The run time of the program depends on the number of calculation steps per hour and the number of sections used to model the storage mass. A typical one day simulation may take half an hour. The option to automatically enter new weather data for successive days makes it possible to start the calculator on a large problem (i.e., several days of simulation using a 10 to 15 min time step) and leave it unattended for several hours or even over night.

Source: Solarcon, Inc.
607 Church
Ann Arbor, MI 48104
Tel. No. (313) 769-6588

Cost: ST34 $95
Solar Energy Calculations $25 (includes $20 coupon for any Solarcon programs)

Calculators: TI-59/PC-100, HP-67 (printer required), HP-97

Required inputs for Solarcon ST34:

- Average daily ambient temperature and the ambient temperature swing
- Maximum hourly solar radiation striking the south-facing windows. (The program uses sine functions to model variation of insolation and temperature; hourly weather data can be entered manually as an option.)
- Surface area and average transmissivity of the window
- Heat loss coefficient from the inner window to the environment
- Absorptivity and heat capacity of the sunspace
- Infiltration and U-value for the sunspace

- Heat transfer coefficient from the window to the sunspace
- Surface area, thickness, density, specific heat, and conductivity of the storage mass
- U-value behind the mass and heat transfer coefficient from the mass to the sunspace
- Number of sections in the storage mass
- Initial temperature distribution
- Thermostat-set temperature
- The fraction of solar radiation that is absorbed by lightweight objects in the sunspace
- Startup time, number of hours to be calculated, and number of calculation steps per hour
- Frequency of printout

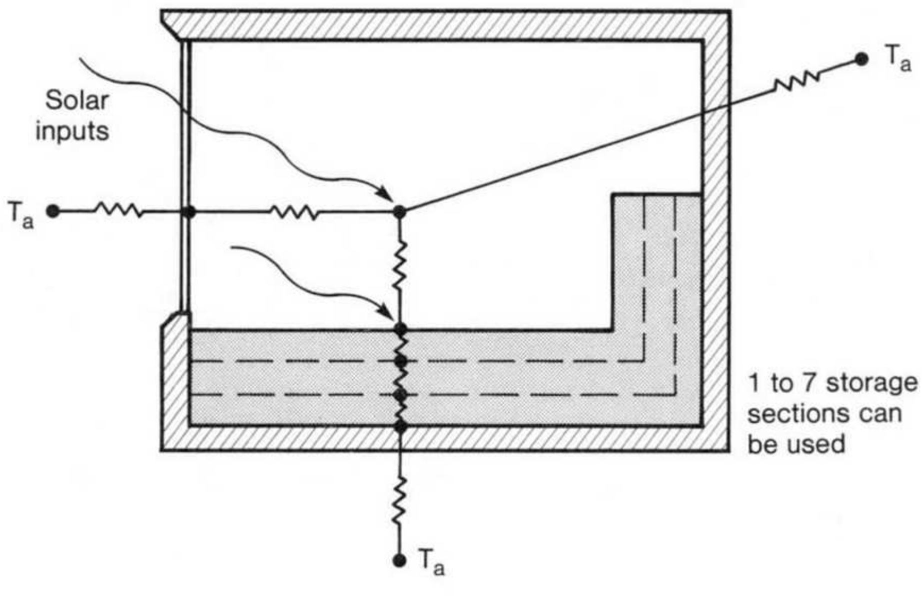

Figure 4-4. Thermal Network for Solarcon ST34

TEANET is a general thermal network analyzer for one-day simulation of passive solar buildings on an hour-by-hour basis. The user defines the thermal network, and up to seven thermal nodes inside the building can be used to model a variety of passive solar designs, including direct gain, vented or nonvented Trombe walls, water walls, greenhouses, attached sunspaces, roof ponds, and combinations of these. TEANET uses an implicit finite difference technique to solve transient heat conduction problems. The system of linear equations describing the energy balances at each node in the network is solved using the matrix inversion subroutine in the TI-59 master library module. Variation in insolation and ambient temperatures are modeled using trigonometric functions. For each hour, the program prints out the ambient temperature, insolation, auxiliary energy use, cumulative auxiliary use, and the temperature at each thermal node. Because the user specifies the thermal network rather than having the network built into the program, TEANET is more flexible than the other simulation programs, particularly if combinations of passive systems are involved. However, this requires the user to have a more thorough background in thermal analysis. The TEANET user's manual includes explanations of the inputs, worksheets to organize input data, concise user instructions, two example problems, and reprints of the two papers cited below. The Automatrix program, which is also explained in the user's manual, facilitates data entry and is particularly useful for parametric studies. Run time for TEANET depends on the number of nodes used in the thermal network. A 24-hour simulation using all seven nodes takes about half an hour.

Source: Total Environmental Action, Inc.
Church Hill
Harrisville, NH 03450
Tel. No. (603) 827-3374

Cost: TEANET and user manual $95
Automatrix option $40

Calculator: TI-59/PC-100

Additional References: J. T. Kohler. "A Procedure for Evaluating the Performance of Passive Buildings Based on Programmable Calculator Simulations." Proceedings of the 3rd National Passive Solar Conference, San Jose, 1979.

J. T. Kohler et al. "Simulation of Direct Gain Buildings with Active Rockbeds on a TI-59 Programmable Calculator Using TEANET." Proceedings of the 3rd National Passsive Solar Conference, San Jose, 1979.

Required inputs for TEANET:

- Number of nodes used
- Matrices containing all the conductances and capacitances of the thermal network
- Maximum hourly solar radiation input (at solar noon). (Solar inputs can be directed to any node, and the program uses a sine curve to model insolation between 8:00 a.m. and 4:00 p.m.)
- Average ambient temperature and daily temperature swing
- Start and stop times for the simulation
- Heating and cooling thermostat set points
- Internal heat gains
- Hourly insolation and ambient temperature values can be entered manually as an option

Section 5

CONCLUSIONS

GENERAL CONCLUSIONS

- Most calculations for sizing residential or small commercial solar systems and evaluating their economic feasibility are simple enough to be done by hand or with the aid of a programmable hand-held calculator using commercially available software.

- Experience with the methods contained in this report has shown that the better methods provide powerful, yet quick and simple tools to obtain information about solar energy systems.

- These methods, particularly the PC methods, can give many of the same answers as computer programs, such as FCHART or SOLCOST, at a much lower cost. Consequently, they should be very useful in the utility customer information programs that are required by the National Energy Act.

- An effort has been made to include in this reference manual accurate, critical, and useful information that will allow utilities to make sound choices of solar calculation methods. However, it is possible that existing methods will be modified and that new methods will appear. Hence, it is recommended that the reader use this manual to make a preliminary selection of methods and then rely on an in-depth review of available documentation or sales literature for a final selection.

CONCLUSIONS ON METHODS FOR ACTIVE SOLAR SYSTEMS

- The most widely accepted method for sizing active solar space-heating and water-heating systems is the F-Chart method. Until validation studies using long-term data from actual systems are completed, F-Chart and its offshoots will probably remain the methods of choice for manual and PC applications.

- Only the fastest manual methods seem useful for repeated applications. The Relative Areas method (No. 1) and the GFL method (No. 2), which are both based on F-Chart, allow hand calculation of the predicted solar fraction for a given active system in less than ten minutes.

- The SLR method (No. 3) is the fastest manual method available. However, it is more restrictive and often disagrees with the predictions of the above methods (see Appendix A).

- Most of the remaining nine manual methods (Nos. 4-12) were found to be less convenient and/or less complete than the above methods based on the experience of this investigator.

- All the commercially available PC programs for sizing active solar systems are based on F-Chart or a simplification of it.

- The Scotch programs (No. 13) and the University of Wisconsin programs (No. 14) for programmable calculators were found to be the most convenient programs for the month-by-month F-Chart procedure. Both of these programs perform monthly and annual solar fraction calculations in less than five minutes, and they both are capable of detailed life-cycle cost analyses.

- The Scotch programs are easy to use and incorporate features such as labeling of results, which may make them especially appropriate for use by information services.

- The University of Wisconsin programs are less convenient than the Scotch programs, but they are somewhat more thorough and may be more appropriate for use by solar designers, engineers, and contractors.

- SEEC II and SEEC III (No. 15), offered by the Solar Environmental Engineering Company, are based on the Relative Areas method, which is a simplification of F-Chart. SEEC II can be used to provide quick results for annual solar fraction and optimum collector area. SEEC III is valuable in designing new buildings or in evaluating energy conservation measures.

- The remaining three PC programs (Nos. 16, 17, and 18) perform F-Chart calculations but were found to be either less convenient or less complete than the Scotch or University of Wisconsin programs.

CONCLUSIONS ON METHODS FOR PASSIVE SOLAR SYSTEMS

- Techniques for predicting the performance of passive solar-heated buildings are not as well established as those for active systems. Consequently, new methods and improvements on existing methods can be expected to appear in the near future.

- The SLR methods (Nos. 19 and 20) appear to be the most thorough manual methods available at this time for predicting the annual performance of passive buildings.

- PASCALC (No. 24), which is based on the SLR methods, is the more versatile of the two PC programs for predicting annual performance and life-cycle economics of passive buildings.

- The most comprehensive, currently available source of information on passive design appears to be The Passive Solar Energy Book (No. 22) by Edward Mazria.

- Several methods for daily comfort calculations are available, including four PC programs that actually simulate the thermal response of passive buildings. These programs are intended to be used primarily by architects and designers to fine tune a passive design that is already in its final stages. They are relatively difficult and time-consuming to apply, and further study is needed to compare them and evaluate their usefulness.

Section 6

COMMENTS ON OTHER METHODS

Methods included in this section were identified in the preparation of this report but were not included in the detailed listings in accordance with the criteria given in Section 1. Sources and summary comments, which briefly describe the methods and cite reasons for their exclusion from Sections 3 and 4, are listed below.

Method Name and Source	Comments
Copper Brass Bronze Technical Report: How to Design and Build a Solar Swimming Pool Heater. Copper Development Association 405 Lexington Avenue New York, NY 10017	Contains technical information on collector design, pool heat loss calculation, economics of pool heating, system installation, etc. Method is limited to pool heating applications.
Domestic Hot Water Manual Using Sunearth Solar Collector Systems. Sunearth Solar Products Corporation Technical Services R.D. 1 Box 337 Green Lane, PA 18054	For use with Sunearth products only. Based on F-Chart.
Energy Conservation for the Home. EES Series Report No. 45 Engineering Experiment Station University of Arizona Tucson, AZ 85721	Concerned with evaluating energy conservation measures and direct gain passive solar contributions/load in the Tucson area.
Intermediate Minimum Property Standards for Solar Heating. NBS/HUD, 1976	Contains a version of the F-Chart method (see Method No. 4).
MESH Dr. John Clark University of Michigan Ann Arbor, MI	Adaptation of work by Balcomb, et al. (see Method No. 3). Not available to the general public.
PCTS Central States Energy Research Corporation Box 2623 Iowa City, IA 52240	These F-Chart programs for hand calculators are not available to the public.

PSLR Fuller Moore Associate Professor of Architecture Miami University Oxford, OH 45056	These TI-59/PC-100 programs for the SLR method for passive solar heating systems (see Methods Nos. 19 and 20) could not be obtained in time for review.
Solar Applications Notebook Pacific Sun, Inc. 540 Santa Cruz Avenue Menlo Park, CA 94025	Contains simplified, region-specific calculating procedures for building loads, active system sizing, and economic evaluation.
Solar Heating of Buildings and Domestic Hot Water, E. J. Beck, R. L. Field U.S. Government Technical Report R835	Contains a version of F-Chart (see Method No. 4).

APPENDIX A

TEST PROBLEMS ON MANUAL METHODS

Test problems were worked out using the three fastest manual methods to allow comparison of their results. These problems involved predicting the solar collector area (ft^2) required to supply 25, 50, and 75% of the heating load for a 13,680 Btu/degree day house in eight representative locations in the continental United States. Results are given in Table A-1.

Methods Tested:

- Relative Areas (No. 1)
- GFL (No. 2) adding a fictitious water-heating load equal to that assumed in the derivation of the method
- GFL (No. 2) using the heating load only
- SLR (No. 3)

Assumptions:

$F_R'(\tau\alpha) = .75$, $F_R'U_L = 1.15$ Btu/ft^2-hr-°F for the Relative Areas and GFL methods, corresponding to a single-glazed, nonselective collector design. (This type of collector is assumed by the SLR method.)

Table A-1

PREDICTED COLLECTOR AREAS
(ft^2)

City	F = 25%				F = 50%				F = 75%			
	R.A.	GFL + H_2O	GFL	SLR	R.A.	GFL + H_2O	GFL	SLR	R.A.	GFL + H_2O	GFL	SLR
Albuquerque	55	55	45	85	135	140	100	215	270	320	240	440
Atlanta	75	70	50	90	190	190	120	230	420	480	320	470
Boston	190	200	160	160	510	520	410	420	1200	1300	1000	850
Brownsville	21	23	6	26	53	57	16	63	110	130	36	125
Madison	180	200	170	180	500	540	440	490	1150	1350	1100	1050
Nashville	120	110	80	120	320	300	215	310	770	830	590	650
Reno	70	80	65	110	170	200	160	290	340	440	350	620
Santa Maria	28	40	27	40	70	100	62	100	140	190	120	200

The following conclusions can be drawn:

1. Agreement between the methods depends on the location, with large discrepancies occurring in some locations.

2. The GFL method should not be used for sizing space-heating systems unless a fictitious water-heating load equal to that assumed in the method is added. With this water-heating load added, the GFL method gives results consistent with the Relative Areas method for the lower solar fractions. However, the GFL method predicts larger required collector areas for F = 75%.

3. In the majority of locations, the SLR method predicts poorer system performance than do the two methods based on F-Chart.