IEA

SOLAR R&D

INTERNATIONAL ENERGY AGENCY
program
to develop and test
solar heating
and cooling systems

task I

investigation of the performance of solar heating and cooling systems

modelling and simulation

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MODELLING AND SIMULATION

Ove Jørgensen

The following persons and groups have contributed to this report:

Tom Freeman
Altas Corporation, Ca., U.S.A.

S.A. Klein
University of Wisconsin, Madison, U.S.A.

James C. Hedstrom
Los Alamos Scientific Laboratory, N.M., U.S.A.

Tatsuo Inooka
Nikken Sekkei, Tokyo, Japan

Ove Jørgensen
Thermal Insulation Laboratory, Lyngby, Denmark

Richard Bruno
Philips Research Laboratory, Aachen, Germany

P.B. Anderson
Faber Computer Operations Ltd., St. Albans, United Kingdom

Federico Butera
Istituto Di Fisica Tecnica, Palermo, Italy

Eduardo Mezquida
Instituto Nacional De Tecnica Aeroespacial, Madrid, Spain

PREFACE

INTERNATIONAL ENERGY AGENCY

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organization for Economic Cooperation and Development (OECD) to administer that agreement. Nineteen countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Program, the participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat, coordinates the energy research, development, and demonstration program.

SOLAR HEATING AND COOLING PROGRAM

Solar Heating and Cooling was one of the technologies selected by the IEA for a collaborative effort. The objective was to undertake cooperative research, development, demonstrations and exchanges of information in order to advance the activities of all Participants in the field of solar heating and cooling systems. Several sub-projects or "tasks" were developed in key areas of solar heating and cooling. A formal Implementing Agreement for this Program, covering the contributions, obligations and rights of the Participants, as well as the scope of each task, was prepared and signed by 15 countries and the Commission of the European Communities. The overall program is managed by an Executive Committee, while the management of the sub-projects is the responsibility of Operating Agents who act on behalf of the other Participants.

The tasks of the IEA Solar Heating and Cooling Program and their respective Operating Agents are:

I. Investigation of the Performance of Solar Heating and Cooling Systems - Technical University of Denmark
II. Coordination of R & D on Solar Heating and Cooling Components - Agency of Industrial Science and Technology, Japan
III. Performance Testing of Solar Collectors - Kernforschungsanlage Jülich, Federal Republik of Germany
IV. Development of an Insolation Handbook and Instrumentation Package - United States Department of Energy
V. Use of Existing Meteorological Information for Solar Energy Application - Swedish Meteorological and Hydrological Institute

Collaboration in additional areas is likely to be considered as projects are completed or fruitful topics for cooperation identified.

TASK I - INVESTIGATION OF THE PERFORMACE OF SOLAR HEATING AND COOLING SYSTEMS

In order to effectively assess the performance of solar heating and cooling systems and improve the cost-effectiveness of these systems, the Participants in Task I have undertaken to establish common procedures for predicting, measuring, and reporting the thermal performance of systems and methods for designing economical, optimized systems. The results will be an increased understanding of system design and performance as well as reports and/or recommended formats on each of the task activities.

The subtasks of this project are:

A. Assessment of modelling and simulation for predicting the performance of solar heating and cooling systems
B. Development of recommended procedures for measuring system thermal performance
C. Development of a format for reporting the performance of solar heating and cooling systems
D. Development of a procedure for designing economical optimized systems
E. Validation of simulation programs by comparison with measured data.

The Participants in this Task are: Belgium, Denmark, Germany, Italy, Japan, the Netherlands, New Zealand, Spain, Sweden, Switzerland, United Kingdom, United States, and the Commission of the European Communities.

This report documents work carried out under subtask A of this Task. The cooperative work and resulting report is described in the following section.

Table of Contents

INTRODUCTION

This report presents the work carried out in subtask (A) of Task I within the International Energy Agency Solar Heating and Cooling Programme. The objectives of Task I are given in the preface. Subtask (A) Modelling and Simulation, is one of five subtasks established in this Task to accomplish these objectives.

The purpose of this subtask was to establish a common understanding and basis for the modelling and simulation of solar heating and cooling systems.

The work has been performed according to the work plan set up in the Implementing agreement as given in section 1.1 of this report. The essence of this is comparison of the results of computer-runs with the simulation codes on two different solar systems (a liquid and an air based system, see Annex I) and hourly weather data for a one-year period from three different places (Madison, Santa Maria and Hamburg).

At the sixth experts meeting it was decided that each program should be designated by the country and the "name of the program" in a paranthesis; the eight programs are:

USA (TRNSYS)
USA (LASL)
J (NIKKEN)
DK (SVS)
D (PHILIPS)
GB (FABER)
I (FTP)
E (INSOL)

All simulation programs have been used to predict the performance of the liquid system with the Madison weather and load data, seven with the Santa Maria and Hamburg data, (I (FTP) missing) and four have been used with the Madison data for the air system: USA(TRNSYS), USA(LASL), DK(SVS) and D(PHILIPS).

The main results of these simulations are presented and compared in chapter 5 on a yearly, monthly and hourly basis.

CHAPTER I

PROCEDURE FOR EVALUATION OF SYSTEM SIMULATION PROGRAMS.

1.1 Comment on the evaluation procedure

The foundation for the selected procedure is that many research groups have developed their own solar simulation programs. An obvious possibility therefore is to compare these programs by using them on the same system and with the same input data. The legitimacy of this is based upon the assumption that all programs are individually developed to solve simular problems.

This is a very quick way of evaluating programs compared to comparisons with measured data, which takes a long time to collect and which up to now has not been available over a longer period. It is also an excellent way of finding dissimilarities in the modelling of components in systems.

There is of course the risk that all have made the same errors because they have based their models on the same ideas.

If a certain uniformity can be obtained it will help programmers to know the value of the programs when the results of just one program have been compared with the measured data for an actual system.

The final thing to do, when measured data for systems are available, will be to compare these with the results of the simulation programs. This is the purpose of the new subtask recently initiated within this agreement, subtask (~~e~~ F) Validation of simulation programs.

1.2 Subtask description according to the implementing agreement.

In the implementing agreement the extent of the work for comparison of solar simulation programs is set up under subtask (a).

Modelling and simulation.

A common understanding and basis for the modelling and simulation of solar heating and cooling systems will be established.

A reporting format for system simulation programs was established and distributed by the Operating Agent on the basis of recommendations from the participants. The participants provide information on their programs for the Operating Agent, according to the format, and this will then be distributed to the rest of the participants. The Operating Agent will organize an expert panel to specify the characteristics of two solar heating systems - a liquid system and an air system which will be used for performance prediction comparisons. Detailed information on these two systems will be distributed by the Operating Agent to all participants. Weather records from Denmark (Copenhagen), Germany (Hamburg), Japan (Tokyo) and the United States (Madison and Santa Maria) will be used initially. These weather records will be put on magnetic tape according to an agreed format. The magnetic tapes will be prepared by the Danish, German, Japanese and United States participants respectively and will be sent to the United States participant.

The United States participant will determine hourly loads using the NBSLD-program[1] and the five weather records for a particular single family house. Initially that house will be the NBS Solar House[2]. The calculated loads will be put on magnetic tape with the weather data by the United States Participant and distributed to all participants. The participants will use their own system simulation programs with the four weather and load records to predict the performance of the two solar heating systems. The output data and monthly system performance will be distributed to the participants. The description of the computer programs will be included. A meeting or meetings will be held to evaluate the results of these systems performance calculations and discrepancies will be resolved. A summary report will be prepared by the Operating Agent and distributed to all participants. A subsequent meeting will be held to evaluate the results of additional system performance simulation made in accordance with agreed-to changes in the above details.

1. NBSIR 74-575, NBSLD, Computer Program for Heating and Cooling Loads in Buildings.
2. ISES-Congress 1975, Paper 41/9.

1.3 Brief description of involved system simulation programs.

In this report of comparison of simulation programs the following codes are described and have been used to solve some standardized systems to determine the effect of code assumptions and approximations.

USA (TRNSYS)
USA (LASL SOLAR) named USA (LASL)
JAPAN (NIKKEN) named J(NIKKEN)
DK (SVS)
D (Philips finite element) named D (PHILIPS)
GB (FABER)
I (FTP)
E (INSOL)

USA (TRNSYS) - University of Wisconsin

A computer simulation program that interconnects each mathematical component subroutine in any desired manner to solve the simultaneous algebraic and differential equations describing the system. With this program, the problem of transient systems simulation reduces to one of formulating mathematical models for each of the components in the system. TRNSYS contains general mathematical models of many (~30) components commom in solar energy systems.

TRNSYS is well documented and supported by a full time computer service engineer at the University of Wisconsin.

USA (LASL SOLAR) - Los Alamos Scientific Laboratory

A computer simulation program to determine collector sizing and parameters sensitivity studies of active liquid and air systems. Used internally by LASL for a guide to collector design, and design of mobile home projects.

J(NIKKEN) - Nikken Sekkei, Ltd, Tokyo

The program is purposed to simulate solar heat cooling, heating and domestic hot water supply. Cooling is made by an absorption refrigerator, of which model is based on the performance data of a manufacturer. Models of other components are theoretically represented by use of algebraic expressions and differential equations. In order to shorten calculation time, these models are simplified, yet are designed to insure reasonable accuracy to serve practical purpose.

The program is of quasi-stationary calculation which can be made assuming an arbitrary interval within one hour.

DK (SVS)- Technical University of Denmark.

The SVS solar heating simulation program consists of a number of subroutines, which each either model components or have mathematical functions. The program is quasi-stationary, meaning that the energy flows within the time steps are supposed to be stationary.

A control routine for the energy flows has to be programmed for each system to be simulated. When a whole year is calculated, the program continues month by month until the same mean storage temperature is obtained. In this way the start up effect is avoided.

D (PHILIPS) - Philips Research Laboratory Aachen

The Philips simulation code is based upon a Finite element approach. The system is broken down into segments (finite elements) of a given capacity and/or thermal responce. These finite elements are defined in such a way that the most important temperature gredients, heat and mass transfers are properly accounted for. It was found for solar energy systems that only a two dimensional finite element treatment (in the mass flow direction and perpendicular to it) was necessary for most components.

GB (FABER) - Faber Computer Operations Ltd.

This code was developed for design and optimisation purposes. The program is of the modular type using a time step of one hour.

I (FTP) - Istituto di Fisica Tecnica, Palermo

I(FTP) is an interactive program prepared for a desk-computer to fulfil the need for a reliable tool for the consulting engineer. The time-step used is 1 hour and the computing time on a Hewlett-Packard 9830 desk-computer is 3.5 hrs.

E (INSOL) - Instituto Nacional De Tecnica Aerospacial, Madrid

This is also a program of the modular type. It was basically made to investigate the behaviour of solar systems and has been specially prepared for direct application to a wide range of possible configurations. Secondary objectives were the development of simplified methods and design purposes.

A review of the programs and their capacity is given in table 1.3.1.

Computer program information table

Table 1.3.1

Programs	USA (TRNSYS)	USA (LASL)	J(NIKKEN)	DK (SVS)	D(PHILIPS) Finite Element	GB(FABER)	I(FTP)	E(INSOL)
Objective	Research	R & D	Research & Design	Research	Research, Design, Studies and Evaluation	Research and Design	Design	Research and Design
User Technology	High (Engineer)	Engineer	Engineer	High (Engineer)	High	Engineer	Low	
Type Building	Any	Residential. Simple Commercial	Any	Any	-	Any	Residential	
Math. Model	Alg. & Diff.	Algebraic	Alg. & Diff.	Alg. & Diff.	Alg.&Finite Diff.	Algebraic	Algebraic	
Load Calculation	Transfer Func. Degree Days External Calc.	Degree-Hour	RF & WF Method	Another Program	Another Program	Another Program	Degree-hour/ external calc.	
System Type	All	Liquid, Air DHW	Liquid Cooling/ Heating/ Hot Water	Heating H.W.	All	Liquid	Liquid heating H.W.	Liquid Cooling/ Heating/H.W.
Data Input	Cards, Tape Interactive	Terminal	Cards	Tape Cards	Cards/Tape	Terminal interactive	Key board, magn. cass., p. tape	
Units	SI	English	MKH	SI	SI	SI	SI	SI
Weather Data	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly
Computer Size	Large		50 K Bytes	Large >80 Bytes	64 K Bytes	64 K	8 K Bytes	64 K Bytes
Language	ASA Fortran IV	Fortran IV	Fortran IV	Fortran IV	Fortran IV	ANS: Fortran IV	Basic	
Output Options	Plot Print Histograms	Print & Plot	Prints/Cards/ Plot	Printer	Printer, Cards	Printer/ Disk File	Prints, Plot	
Availability	Tape, Cards Documents	Yes, Not Documented		Yes	No	No	Yes	
Run Time	Long	Low 10 Sec. CDC 7600	6 min. (IBM 370)138)	1-2 min. (IBM 370/165)	7-15 min. CDC 7600	4-7 min. (Prime 300)	2.5-3.5 hours (H.P. 9830A)	(H.P. 2100)
Active/Passive	Active	Active	Active	Active	Active/Passive	Active	Active	Active

CHAPTER II

MODELLING OF SOLAR ENERGY SYSTEMS

(WHICH MODELS FOR WHAT)

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WHICH MODELS FOR WHAT

R. BRUNO
PHILIPS GMBH FORSCHUNGSLABORATORIUM AACHEN, 5100 AACHEN, WEST-GERMANY

I Introduction

The total heat and mass transfer problem of a building and its energy system (see Fig 1) can be evaluated experimentally or numerically. Both methods are important. Experiments serve as the final check on the consistency of particular numerical simulations, and simulation programs using numerical modelling methods can quickly and inexpensively give results which assist in defining the thermal consequences of choosing between various building codes, system component types, system designs and general operating strategies. Such programs also form the basis of any parameter sensitivity studies or optimization calculations.

As shown in Fig 1 the total problem encountered for a building and its energy system in the low grade heat energy use sector, is made up of two parts: a demand area (eg. heating and cooling demand of a building) and an energy supply system. If the supply system is a solar energy system then both the building, for its demand, and the energy system, for its supply, depend upon the ambient weather. Moreover, the building's thermal demands are also dependant on the inhabitants' user profile. Both weather data and user profiles are stochastic in nature and have no intuitive simple and general representations which could lead to closed form solutions for this total problem.

In almost all cases this total problem is solved by dividing it up into two independent parts: a demand and a supply area program. The demand area program provides the thermal energy demand as input data for the supply area program. The supply area program then calculates the thermal performance of the energy system in terms of the alternative energy used and the auxilliary energy required. Below the various methods of determining the performance of the energy supplying system are identified and compared for solar energy systems in buildings. The evaluation of computer based simulation programs is done by:

a. qualitatively comparing existing simulation programs
b. quantitatively comparing specific simulation programs on the basis of results found from yearly simulations.

The numerical and analytical techniques for the simulation of thermal energy systems are well known [1, 2]. These techniques can be classified into the following categories (see Table 1):

1. first principles approaches
2. component 'black box' approaches
3. simplified approaches.

First principles approaches take into account all the basic physical processes which occur in an energy system. Component 'black box' approaches use the fact that energy systems are arranged in one dimensional acyclic or recyclic circuits and made up of component parts (i.e. solar collectors, pipes, heat exchangers etc.). For each of these component parts the dynamics are defined by taking into account the net gain and loss mechanisms, in a quasi-stationary sense, and identifying one or more capacitive terms related to each component. The circuit is defined by setting outlet and inlet temperatures of neighbouring components equal to each other. As indicated by Table 1 simplified approaches can be divided into two basic subcategories:

a. dynamic simplified approaches
b. semi-empirical simplified approaches.

In the former subcategory the boundary conditions as defined by the weather and load demand data and/or the real time-ordered physical processes are simplified. However, certain information referring to the dynamic response of the energy system is still retained. The latter subcategory either uses simplifying rules without retaining any information on the dynamics, or uses relationships between systems and performance parameters which have been established by fitting to the results of more detailed approaches.

Each of these approaches to solving the underlying thermal processes can be based on a variety of mathematical solution procedures some of which are given in Table 1. Moreover, each category has certain system limits (ie. one cannot simulate components in a system if the allowable time step $\tau_M \sim \tau_C$ the components' response time) and critical time periods below which no physically valid information can be obtained. These two points as well as the user area, where each category of programs are of most use, are given in Table 1.

As for weather and load data the first two categories require hour-by-hour data for calculations. The simplified methods mentioned here require at most daily and at the least monthly data. These requirements are listed for existing energy system programs in Tables 2 and 3. Table 2 gives a list of the R and D systems analysis programs which have been developed in the USA and at the Philips Research Laboratories in Aachen (PFA). This table indicates the user technology required to handle such programs as well as the reduced core space needed and typical run times required on a CDC 6700 for a year's run. Table 2 also gives a rough ordering of the methods in degree of complexity and accuracy. A similar ordering is given for simplified methods in Table 3. Here, however, the accuracy of the methods, relative to the first principles models, decreases considerably. It can be seen from these two tables that, in going from finite element models to the fastest simplified methods, computation time may be reduced by over four orders of magnitude. A detailed account of the accuracy of these classes of simulation programs is given below.

II Modeling of Energy Systems

1. First Principles Approach

Such methods are exact in their physical description of all the thermal processes which determine the dynamics and detailed performance of an energy system. One such approach is the finite element method. Below, this method is discussed and is then used as a master program for the comparison of various other methods.

The finite element method |2| is based on a nodal analysis where each component is broken up into finite elements. These elements are arranged in such a way that the most important temperature gradients, heat and mass flows, are accounted for. It was found that a dimensionality of two, as indicated by the temperature gradients in the fluid flow direction and perpendicular to it [1], is sufficient for determining the detailed dynamics of most energy systems.

To assess transient effects in the direction perpendicular to the flow direction it was found that the maximum element size may be estimated by the heat wave penetration depth, d, | 8 | given by:

$$d \approx \left(\frac{\lambda\tau}{\pi\rho C}\right)^{1/2}$$

where λ is the heat conductivity,
τ is the time period of typical temperature changes (e.g. the cycling time of the solar collector circuit),
ρ is the density and C the heat capacity.

The subelements of the i^{th} element of a component are shown schematically in Fig 2. Here, the mass transport is given by $\dot{m}C_f$ with a mean fluid temperature $T_w(i)$ and a heat capacity $C_w(i)$. In Fig 2 the superscripts U and L indicate the upper and lower set of subelements. The dynamics in this approach are governed by the specific capacities $C^U_{C_j}$ and $C^L_{C_j}$, the loss mechanisms (e.g. conduction processes) and the possible energy gains (e.g. solar) which may occur.

This finite element approach has the following features:

(a) The typical error [2] for a year's run is no larger than 0.1%.

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[1] for elements with cylindrical symmetry the flow direction and the radial are taken while for plane elements the flow direction and the normal to the flow plane are taken.

[2] sum of round-off, element size and time step errors.

(b) It may be used to simulate any experimental situation; thus this approach lends itself to being a master program.

(c) If the dimensionality 2 is sufficient, it is straight forward to program an energy system.

(d) Its major drawback is long computer run times, e.g. 25 min/year on a CDC 6700 for 50 elements each divided into three subelements and 300 time steps per hour . Such a program has a reduced program size of not more than 30 K words.

2. Component 'Black Box' Approach

2a Total Solution

Mathematically an exact form for solving the first order differential equations which define each component of a system (ie. the 'black box' equations) is a total analytic solution over a basic time step.
In this method, which is one step away from the finite element method, each component is considered as a 'black box' (see Fig 3). In a simple solar energy system, e.g. Fig 4, there are five such components, namely the solar collector, two pipes, the heat exchanger and the storage tank. As indicated in Fig 3 for each component j, the power balance can be written as a differential equation [9 , 10] in terms of:

the fluid heat flow

$$\dot{m}C_f \cdot (T_{C_{in}}^{(j)} - T_{C_{out}}^{(j)})$$

gain and loss mechanisms,

and the capacitive effect $C_C^{(j)} \frac{dT_C^{(j)}}{dt}$ for the j^{th} component. Since a circuit, even with branching, is a one dimensional sequence of components, the inlet and outlet temperatures of neighbouring components are equal (e.g. $T_{C_{in}}^{(j+1)} = T_{C_{out}}^{(j)}$). Moreover, the component reference temperatures $T_C^{(j)}$ are not independent of the other temperatures, that is, $T_C^{(j)}$ may be expressed by algebraic equations in terms of the $T_{C_{in}}^{(j)}$ and $T_{C_{out}}^{(j)}$ and possibly also certain ambient temperatures. Connecting all the components together one has a set of coupled linear differential equations in terms of the independent reference temperatures $T_C^{(j)}$, where the inhomogeneous parts of the differential equations contain the actual ambient loads. These equations can be solved exactly by the usual methods of linear differential equations assuming a constant or analytic load over any given time step.

With this method, the more components used the more complex it is to set up and define the solution of the coupled differential equations and thus to develop and test the corresponding computer program. Experience has shown that if the number of components in this method exceeds about 5 then this method offers no advantage over a finite element approach with about 50 elements.

3b Modular Program: a Numerical Method

This type of program is essentially a component 'black box' approach even though at times one or more components may be handled by finite element methods. Two such programs in current use are TRNSYS [4] and SIMSHAC [5]. Each of these simulation programs is a general dynamic model which can be used for any energy system configuration in analyzing the solar hot water, heating and/or cooling contribution to buildings. In each of these programs the various components are described by subroutines or subprograms. The user of such a program must specify the components included in the system, the manner in which they are interconnected and the basic control strategy. The program then generates the computer program structure required to analyze the specific system.

In general, a modular program consists of three levels with the following functions:

(a) The input level. This reads the system layout description, control function, component and subsystem variables, as well as the initial conditions of the system state variables.
(b) The output level. This produces the system state variables at given time intervals or under certain prescribed conditions.
(c) The executor level. This is the main part of the program, which connects the set of subsystem modules and components together as a sequential set of differential and algebraic equations and uses an integrator function to converge cyclically to the solution of the state variables over a given time step.

In the case of non-convergence the time step must be reduced. This results in absolute convergence (1) of the solution with the same boundary conditions. However, this also increases the round-off errors and so the total accumulative error.

At first it appears that such a program has the possibility of being user oriented as well as multi-system oriented. However, in such a versatile program the operation's language, the system's definition, the punching of input information and checking for consistency often take as long as writing a program oneself for the same system.

Such a modular program was constructed on the basis of equations similar to those given in |6| and calculations were performed on solar heating and hot water systems. Some of these results were presented in [7| for Hamburg. The typical reduced program size was 35 K words and yearly run times of the order of 1 - 10 minutes on a CDC 6700 were found.

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(1) but not necessarily onto convergence

The problems encountered while using this type of program were as follows:

(a) Setting up the right input data for components and controls, as well as checking and testing, was time consuming.
(b) Erroneous convergence occurred often.
(c) When 10^{-5} convergence was reached in the integrator the total accumulated error for a year's run was of the order of 1%.
(d) The run times for system optimization, where a whole parameter space must be scanned, were too long.
(e) No information could be obtained on the system's dynamic performance at time intervals below a couple of heat transport fluid cycle times. This relates most directly to an experimental situation.

2c Lumped Circuit Separation: a Reduced Method

In this method the number of differential equations is further reduced to one for each closed loop (e.g. the solar collector circuit in Fig 4) and each acyclic circuit. In each case only one reference temperature T (see Fig 4) is required. If the temperature profile is linear between the inlet and outlet of a component (indicated by large dots in Fig 4) then the reference temperature T is directly related to the average component temperature. However, for strongly nonlinear temperature profiles (eg. heat exchanger) the reference temperature $T = (T_{in} + T_{out})/2$ can be related to the average component temperature via a renormalization equation [11]. Considering the simple solar collector system in Fig 4 the problem is then reduced to only two coupled linear differential equations with an average loop temperature T_L and an average storage tank temperature T_S as independent variables. All the specific gain and loss mechanisms as well as capacity effects are now considered in terms of these common reference temperatures. The coupling of the differential equations here is due to the quasi-stationary relation between any two interacting circuits (eg. via a heat exchanger). This reduction in the number of equations used in the other 'black box' methods allows for an exact solution assuming a constant or analytic load over any given time step.

The advantage of this approach, apart from the ease in programming, is its comparatively short run time of about 5-15 sec/year run on a CDC 6700. This run time is still, however, too long for large scans of a system's parameter space and/or direct inputs to optimization routines. As for the modular method, and the total solution mentioned above, no information can be obtained about the system's performance over time periods less than several fluid cycle times. Since these cycle times are normally of the order of a few minutes, all weather-dependent switching effects for hour-to-hour data are correctly evaluated to within one hour. However, switching effects due to start-ups where thermal waves persist can only be fully accounted for by a first principles approach. In the above mentioned total solution and reduced method no convergence problems are encountered as an exact solution to the defining equations is always found.

4. Simplified Approaches

4a General Discussion

Basically simplified methods can be placed into two groups:

(a) Dynamic methods [6, 15, 16] which exactly solve a set of differential equations over longer time periods (eg. a day or month) and thus reduce computing time.

(b) Stationary and semi-empirical methods [12,13, 14], which either use simple relations or functional forms to describe the effect of the system's parameters on performance measures.

The latter of these methods requires at least spot scans from an exact program to establish the value of certain constants contained in the semi-empirical equation for a given system type. The former method, on the other hand, requires that the boundary conditions as defined by loads be for example, integrable over time. Semi-empirical methods do not allow accounting for system design variations whereas the dynamic simplified methods do.

In the dynamic simplified model considered here an energy system is defined by a set of first order differential equations, one for each recyclic and acyclic circuits, similar to the lumped circuit method of section 3c. In addition, the loads are reduced to a sequence of simple integrable functions with a minimum of input data required over a year. This saves computer time. However, it also reduces the number of possible on/off switchings.

4b Load Data

The load data, as mentioned above, are simple analytic functions. In the program version considered here the insolation $H_T(t)$ is given by

$$H_T(t) = S_T \quad \frac{\cos\frac{\pi}{12}t - \cos w'}{1 - \cos w'}$$

where

$$w' = F_{AC} \frac{\pi}{12} \quad \frac{\tau_d(o) + \tau_d(s)}{4}$$

S_T = the effective insolation (amplitude) defined such that the integral of $H_T(t)$ over a day equals the total incident energy during that day

$\tau_d(s)$ = the day length (beam component) for a surface tilted at s towards the south

and

F_{AC} = the day length reduction constant.

The day length reduction constant is used to adjust $H_T(t)$ to the local weather statistics relevant to a solar energy system. For most locations and energy systems it is sufficient to take an F_{AC} per year between 0.9 and 0.95. The ambient temperature, $T_{amb}(t)$, is defined here by

$T_{amb}(t) = T_{amb} + \Delta T_{amb} \cos\left(\frac{\pi}{12}(t-\delta)\right)$ where

$$T_{amb} = \frac{1}{24} \int_{0}^{24} T_{amb\ data}(t)\, dt, \quad \Delta T_{amb} = \left(\frac{1}{12} \int_{0}^{24} (T_{amb\ data} - T_{amb})^2\, dt\right)^{1/2}$$

and δ is the time phase shift in hours. The wind velocity, V_{amb}, used here for the collector is given by

$$V_{amb}(t) = V_{amb}$$

$$= \frac{1}{\tau_d} \int_{-\tau_d/2}^{\tau_d/2} V_{amb\ data}(t)\, dt$$

where

$$\tau_d' = F_{AC} \left(\frac{\tau_d(o) + \tau_d(s)}{2}\right) .$$

The hot water, heating and/or cooling loads can be defined, like the insolation, as the first term of a fourier series or as the amount of the loads existing between three basic time intervals:

0 - 7 hours
7 - 17 hours
17 - 24 hours

during the day.

It was found that the heating and cooling load can in most cases be simulated as averages over these three time periods, while the hot water load can be simulated by a pointwise demand at 7, 12 and 20 hours.

As input data, only five constants (S_T , τ'_d , V_{amb} , ΔT_{amb}) per day are required by this method to define the weather data and at most three constants per day to define any one of the load demands.

3c The Program

A program built in the aforementioned way was found capable of simulating four different energy system designs as either air or water systems under several operation modes. These modes are hot water production only, heating only, or cooling only or any combination of these three basic modes. The reduced size of this program is not larger than 26 K words. Typical run times found for this program are from about 0.5 sec for hot water only to 1.5 sec for a combined heating-cooling and hot water system per year's run on a CDC 6700. Because of this short computer time, the start-off initialization conditions used in this program were taken to be such that the values of all temperatures on January 1st at 0 hours are the same as those on December 31st at 24 hours. That is to say the program is self-consistent. Such short run times also make this program suitable for optimization runs.

The major disadvantage of this and other such programs is that no information can be obtained on the system's performance for times less than one day.

4. Comparison of Finite Element, Lumped Circuit and Simplified Models

The above title gives the methods which are compared below in order of decreasing number of equations (or independant variables) used to define the energy system. Also, this ordering is given in increasing resolution time allowable. Either way, this ordering indicates what needs to be done to reduce computer run time for parameter space scans. In doing so, the accuracy of the results is affected. To assure that the accuracy of each method is sufficient for the purpose it is used for, an error analysis was performed.

Table 4 shows three sets of yearly results referring to the three methods, namely the finite element, the lumped circuit and the dynamic simplified method discussed above. The modular (numerical method) and exact (total solution) 'black box' methods are not considered here as their errors are comparable 1) to those of the lumped circuit model. Basic system 1 in Table 4 is, in brief, definable by the following system parameters:

collector area = $5\ m_c^2$
transmission-absorption factor = 0.86
average front loss factor = $1.22\ W/m_c^2K$
back loss factor = $0.47\ W/m_c^2K$
total collector heat capacity = $4.0\ Wh/m_c^2K$
piping length = 40 m
heat loss factor of piping = 0.2 W/Km
total heat capacity of piping = 0.25 Wh/Km
storage tank volume = 400 l (water equivalent)
storage tank heat los factor = $0.2\ W/Km^2$
fluid flow rate = 300 W/K
heat exchanger rating = 300 W/K
average hot water demand = 350 l/day (12°C inlet, 45°C outlet).

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1) with the exception of the convergence and round-off error problems encountered in methods using cyclic convergence (e.g. modular method). In this case, the time step Δt_s used cannot be made smaller than Δt_c, the heat transport fluid circulation time, and so a solution which reduces these errors can only be found "in principle" i.e. by neglecting the physical basis used.

This is a normal hot water system with a high efficiency collector. The results presented here were calculated for Hamburg 1973 [17] with a collector surface facing 45° south. Columns 2 and 3 of Table 4 are some system variations used as a check for extreme effects. Here, column 2 takes a high collector heat capacity of 20 Wh/m^2K and column 3 takes a low flow rate of 72 W/K while all other parameters are the same as in case 1. The last system investigated, system 4, whose results are not shown in Table 4, considers a standard one pane non-selective collector with an average front loss coefficient of 6 W/m^2K. All other parameters of system 4 are the same as in case 1.

The reasons for these choices are that:

system 1 does not see the details of the weather structure,
system 2 decouples the 'black box' equations and has an effective pumping cycle time of the order of a half hour,
system 3 has a pumping cycle time of the order of a half hour, and
system 4 sees the details of the weather structure because of its high front loss coefficient.

As seen from the yearly results of Table 4, the differences of all energies calculated are within the percent range. However, the difference in pumping hours, which are related to on/off switching effects, is as high as 4% for the lumped circuit and 8% for the dynamic simplified method. This was to be expected on the basis of the resolution time for each of these methods compared to the finite element approach. From this table it is seen that all three methods are accurate enough for the analysis of systems on a yearly basis. In fact, the dynamic simplified method is the best choice for yearly runs (which are the basis for optimization procedures) because of its short computer run times.

The detailed error distributions, on a day-to-day basis, relative to the finite element model, are shown for basic systems 1 to 4 in Figs 5 to 8 respectively. In these figures the error channel is given on the x-axis and is defined as the percentage difference of the system's gains between two models over a day relative to the daily average system's gain found by the finite element model over a month. The y-axis gives the number of days in each error channel. Fig 5 shows that for system 1 a sharp distribution was found with respect to (a) the lumped circuit and (b) the dynamic simplified model. The average error over a year and month is always less than ~ 1% and the typical full width at half maximum errors (ε_{FWHM}) are 2% for the lumped circuit and 3.5% for the dynamic simplified method. Thus, there is about a 65% chance that the day-to-day errors are not larger than $\pm (\varepsilon_{FWHM}/2.)$ and a ~ 90% chance that they are no larger than $\pm \varepsilon_{FWHM}$. This good agreement was to be expected. In going from basic system 1 to system 2 (Fig 6), ε_{FWHM} of the dynamic simplified method is ~ 8% or about a percent larger than that for the lumped circuit method. However, the average monthly error is only ~ 1% for the former and ~ -4% for the latter. This is due to the fact that the equations, in this case, tend to be decoupled for both models. The dynamic simplified model, however, due to the choice of F_{AC}, has the effect of distributing the errors, in a least square sense, normally about zero. Fig 7 shows the errors for system 3, where the definition of the 'black box' equations becomes less valid for use on an hour-by-hour basis since these equations are defined as an integral over several pumping cycle times. Here it is observed that ε_{FWHM} is twice that of system 1 whereas the average monthly and yearly errors remain at about ± 1%. Fig 7 shows the errors for system 4 which, due to the high collector top loss coefficient, 'see' the details of the weather structure more than system 1. The effect of this higher loss coefficient is observed in that ε_{FWHM} ~ 2% for the lumped circuit model while ε_{FWHM} ~ 10% for the dynamic simplified model. The reason for this difference is that the lumped circuit model uses the actual hr-hr data while the dynamic simplified model uses daily data with a cosine function fit for the dynamics over the day. The monthly and yearly errors are ~ 1.5% for the lumped circuit and ~ 2.5% for the dynamic simplified method.

A comparison has also been made [15] between the finite element program and F-chart |12' , a semi-empirical simple method. The results of this comparison are shown in Figs 9 and 10. The x-axis of these figures gives the parameters which were varied for the comparison and the y-axis gives the percentage difference between the performance predicted by F-Chart and the finite element method relative to the finite element results. The first of these comparisons was made for the energy system given in |12| and |15| for Hamburg 1973, with heating only. This was done for one house design [15] built according to three different building codes:

1. Normal house
   (a house built according to the German DIN 4108. This house has a high internal heat capacity and a yearly heating requirement of 35000 kWh)

2. Swedish Standards house
   (a house built according to the 1978 Swedish Standards. This is a well insulated light wood frame construction with a yearly heating requirement of 9100 kWh)

and 3. Experimental Standards house
   (a house built according to the standards of the Philips experimental house [18]. This house has a yearly heating requirement of 1300 kWh)

as a function of solar collector area.

It is observed from Fig 9 that the deviations using F-chart for a heavy European house are about 30% and almost independant of collector area. This is so as the demand profile, for such a house, has another time sequence (relative to the supply profile) than that used to define F-chart. The Swedish Standards house, although well insulated, has a dynamic response similar to the house on which F-chart was based. This is also reflected in the deviations found for the Swedish Standards house. As seen from Fig 9 they don't exceed 15% for reasonable collector areas. The final code considered is for the Experimental Standards house. It has a very low heating demand and a relatively high internal heat capacity. The maximum deviation observed here is over 100%. This is due to the fact that with this house type we are now out of the range of validity of F-chart |12|.

Fig 10 considers deviations due to changes in the collector parameters such as the average transmittance-absorptance product $(\alpha\tau)$, the average collector loss coefficient U_L and the total effective collector heat capacity C_c . This comparison is done for a solar augmented heating system as given by |12| for a Swedish Standards house in Hamburg 1973. The results indicate that differences as high as 12% can be anticipated by varying any one of these collector parameters in a plausible range. Varying two or more of these parameters simultaneously within joint plausible ranges gives differences no greater than 15%.

III Concluding Remarks

1. Energy Systems Programs

The above results show that care must be exercised when using simplified semi-empirical methods, especially those based on regression procedures. Not only can considerable errors occur when using such methods but of greater importance is the fact that the user of such methods may unwittingly use the method beyond its range of validity. As for the other approaches, typically, in going from a first principles to a component 'black box' approach yearly errors of a couple of percent and daily errors of several percent may be expected. In going from a first principles to a simplified dynamic approach, errors no greater than a few percent occur on a yearly or monthly basis for the calculation of energy balances; however, more than a few percent error can occur in defining the pumping times or on-off switching. For real systems the input weather data, load data, or data defining the physical parameters of a system are never known to closer than a few percent. Thus, it seems only sensible to use simplified dynamic methods for calculations where yearly or monthly results are required and creative engineering work, from a systems design point of view, are needed.

For supply area programs, in short, it can be said that as long as information over time periods greater than one day is needed simplified dynamic methods are the most useful tools. This is especially the case for the optimization of existing and new alternative energy systems. However, to observe the influence of, for example, control strategies, whose primary influence occurs at times less than a day or to develop other simpler methods, component 'black box' or first principles approaches should be used. Finally, as a master program or for checks with experiment a first principles approach is necessary. The actual choice of one program or another is determined by the purpose for which it is to be used as well as by the trade-off between the time required for setting up and running the program on the one hand and the accuracy which may be expected and needed on the other.

2. An Open Question

The above discussion and the results shown in this paper were based on the assumption that the total heat and mass transfer problem of a building and its energy system could be treated by two independant programs. The validity of such an assumption, over a wide range of energy systems designs available today and building codes which are or will be implemented, has yet to be investigated.

It is well known that a demand defined by a two point thermostat setting can lead to overshooting of indoor temperatures with hydronic systems in wood frame houses. This indicates from a control point of view a dependant dynamic behaviour which may lead to additional systems losses. Sensitive buildings where both heating and cooling loads can occur simultaneously define a situation where the demand area is an integral part of the supply area. Also, if the response and storage times of an energy system are of the same order as those of a zone in a building and these, in turn, are of the order of one to a few hours then, intuitively, the effects due to dynamic interaction between the demand and supply areas via a control strategy may lead to different results for the total (building)-(energy system) problem. From these and other examples it seems that the range of validity and usefulness of this simplification (i.e. dividing the total (building)-(energy system) problem into two independant parts) requires some investigation.

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Table 1

CLASSES OF SYSTEM ANALYSIS PROGRAMS

Class	Mathematical Models Usable	Critical Time Period (τ_M)	System^{++} Limits	User Area
1st Prin: First Principles Approach	Finite Element Finite Difference	Maximum Time Step: Fourier Limit	None	(a) Research (b) Validation
BB: 'Black Box'	a. Total Solution Operator Methods	Minimum Time Step$^+$: τ_f	$\tau_M \sim \tau_c$	(a) Research (b) Validation
	b. Numerical Methods Cyclic Convergence of Coupled Diff./Alg.Equ. (e.g Euler, R-K)	(a) a couple τ_f (b) step size where roundoff error ~ num. Accum. error	$\tau_M \sim \tau_c$	(a) Research (b) Validation (c) User Prog.
	c. Reduced Methods (i) Network (ii) Response Factor (iii) Lumped Circuit (iv) Energy Balance	Several τ_f	(a) $\tau_M \sim \tau_c$ (b) on/off	(a) Research (b) Validation (c) User Prog. (d) Sizing
S: Simplified a. Dynamic (Dyn)	(a) Simple Network (b) Analytic Loads (c) Recursion (d) Stochastic	Minimum Time Step$^+$: Several τ_f/Day/Mo/Yr Several τ_f/Day/Mo/Yr Several Days/Mo/Yr Mo/Yr	(a) on/off (b) critical ranges (e.g. stagnation effect)	(a) Research (b) User Prog. (c) Sizing (d) Optimization
b. Semi-Empirical (Emp)	(a) Regression (b) Functional Form	Mo/Yr Mo/Yr	Range of validity	(a) User Prog. (b) Sizing (c) Optimization

\+ Below this time interval information not physically valid (τ_f = fluid cycle time)

++ Programs cannot be used with certain components or for accurate estimation of certain performance parameters (τ_c = component's response time)

Table 2

R & D SYSTEM ANALYSIS PROGRAMS[+]

Prog.Name (Institution)	Class	User Techn.	Load Calc. Data	System Type	Weather Data	Computer Size	Run Time (Min.) (CDC 6700)
PFA-FE	1st Prin	High	Input	All	HR	40 K	20-45
PFA-BB	BB-a	High	Input	All	HR	40 K	1-5
SIMSHAC (CSU)	BB-b	High-Med.	Ashrae	HT/CL	HR	80 K	10-20
TRNSYS (U of Wisconsin)	BB-b	High-Med.	DD/Input	All	HR	200 K	5-15
SDLAR ADL	BB-b	High	00/1 Cap[++]	3-Liq.	HR	200 K	10-20
TAF LASL	BB-b	Med	20 Node[++]	All	HR	200 K	10-20
PFA-LC	BB-c	High-Med	Input	All	HR	30 K	0.15
CAL-ERDA	BB-c	High	Res.Fac.[++]	All	HR	200 K	10-30
SDLSIM MM	BB-c	High	Network[++]	5 Sys.	HR	50 K	15-30
LASL SOL	BB-c	Med	D.HR.[++]	Liq.-Air	HR	20 K	0.4

[+] for a more detailed list see [3]

[++] not interactively coupled

Table 3

SIMPLIFIED SYSTEM ANALYSIS PROGRAMS +

Prog.Name (Institution)	Class	User Tech.	Load Calc. Data	System Type	Weater Data	Computer Size	Run Time (Min) (CDC 6700)
PFA-SIN	S-DYN	High-Med	Input	60 Sys.	Day/Mo	30 K	0.02
OFVLR-Stochastic	S-DYN	High-Med	Input	3 Sys.	Mo (Stochastic)	16 K	$1.5 \cdot 10^{-3}$
Solcost MM	S-DYN	Low	Network	5 Sys.	Mo	50-120 K	0.3
SAT-Func ++ (PFA,LASL)	S-EMP	Low	Input	6 Sys.	Mo/Yr	1 K	10^{-4}
MINI-SHAC IBM	S-EMP	Med	OD	HT/HW	Mo	32 K	0.2
F-CHART (U of Wisconsin)	S-EMP	Low	DD/Input	1 Air/1 LQ	Mo	4 K	0.02

+ for a more detailed list see [3]

++ see [24]

Table 4

COMPARISON OF METHODS

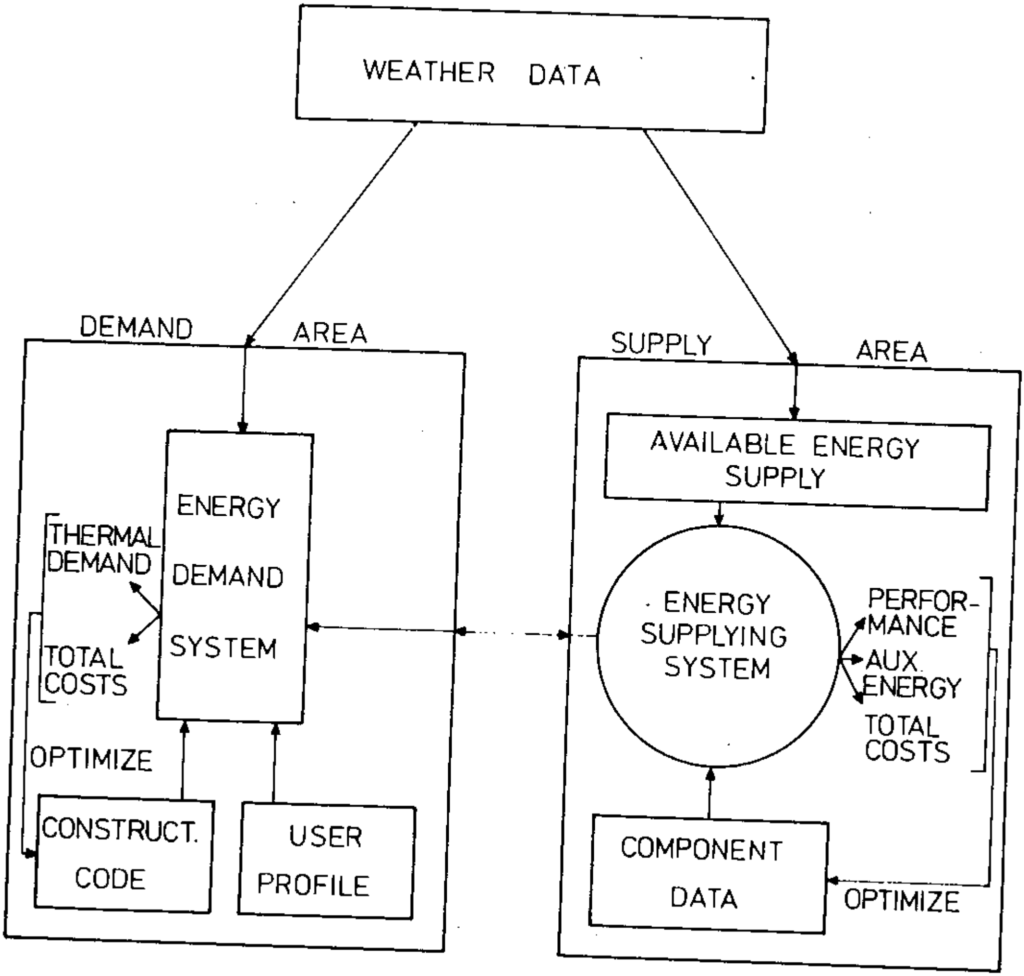
Quantity	FINITE ELEMENT			LUMPED CIRCUIT			DYNAMIC SIMPLIFIED		
	1	2	3	1	2	3	1	2	3
Yearly Insolation on Solar Collector (kWh)	5264	5264	5264	5264	5264	5264	5264	5264	5264
Solar Collector Gain (kWh/year)	3475	3200	3456	3478	3281	3453	3517	3216	3415
For $T_c > 95$ Energy still recoverable (kWh)	17	0	5	9	0	4	9	0	4
Storage Tank Gain (kWh/year)	2876	2654	2791	2878	2726	2804	2881	2644	2819
Solar Hot Water (kWh/year)	2799	2596	2725	2794	2655	2727	2805	2600	2750
Auxiliary Energy (kWh/year)	2104	2307	2178	2109	2248	2176	2098	2303	2153
Total Energy for Hot Water (kWh/year)	4903	4903	4903	4903	4903	4903	4903	4903	4903
Percent Solar	57.1	52.9	55.6	57.0	54.2	55.6	57.2	53.0	56.1
Pumping Hours (hr/year)	2961	3178	3083	3069	3214	3181	3200	3165	3207

Table 5

DIMENSIONS AND STATIC PHYSICAL PROPERTIES OF THE REFERENCE HOUSE

Surface	Length (m)	Width (m)	Total Heat Trans. Coefficient (W/m^2K)	Surface Area (m^2)	Wall Abs. (α_w)	U-Value Glass (W/m^2K)	Window Area (m^2)	Trans. Glass (τ)	Door Heat Trans.Coef. (W/m^2K)	Door Area (m^2)	Door Abs. (α_d)
South	12.53	4.27	.374	51.8	.8	2.62	1.67	.8	-	-	-
West	5.87	4.27	.374	16.9	.8	2.62	8.18	.8	-	-	-
North	12.53	4.27	.374	51.1	.8	2.62	2.42	.8	-	-	-
East	5.87	4.27	.374	19	.8	2.62	4.95	.8	1.99	1.12	.8
Roof	12.53	5.87	.258	73.6	.87	-	-	-	-	-	-
Floor	12.53	5.87	.185	73.6	-	-	-	-	-	-	-

Temperature Setting Heating:	21.1 °C
Temperature Setting Cooling:	23.9 °C
Maximum Lighting Load:	6 W/m^2
Maximum Equipment Load:	18.9 W/m^2
Maximum Occupation Number:	5.5 persons
Total Internal Load:	24.8 kWh/day



THE TOTAL SIMULATION PROBLEM

FIG. 1

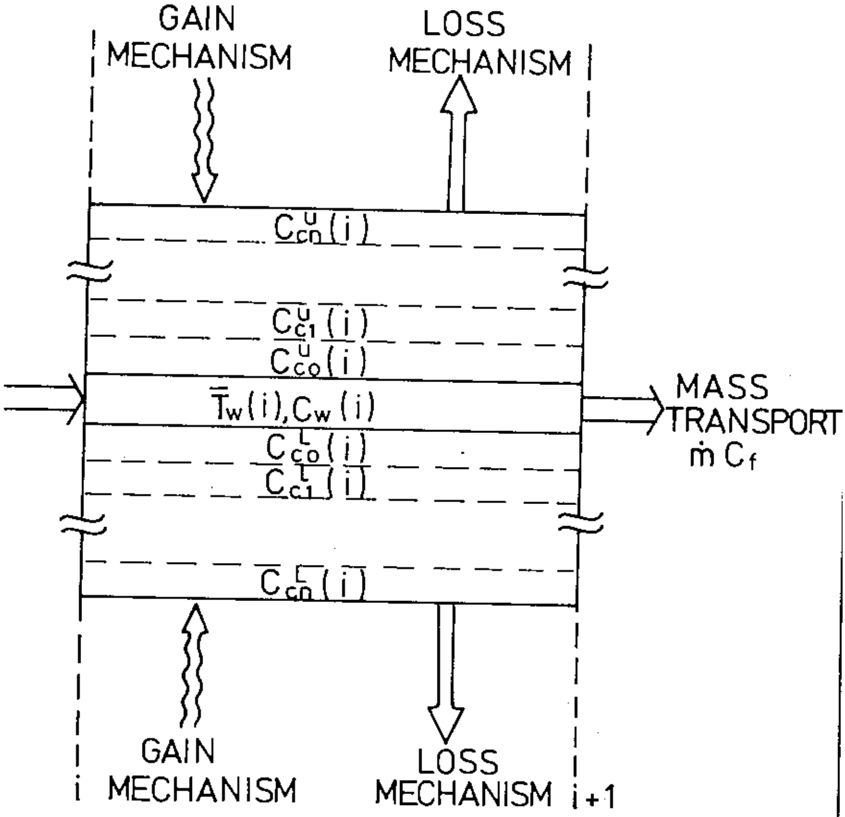


Fig. 2 FINITE ELEMENT METHOD ELEMENT i WITH SUBELEMENTS

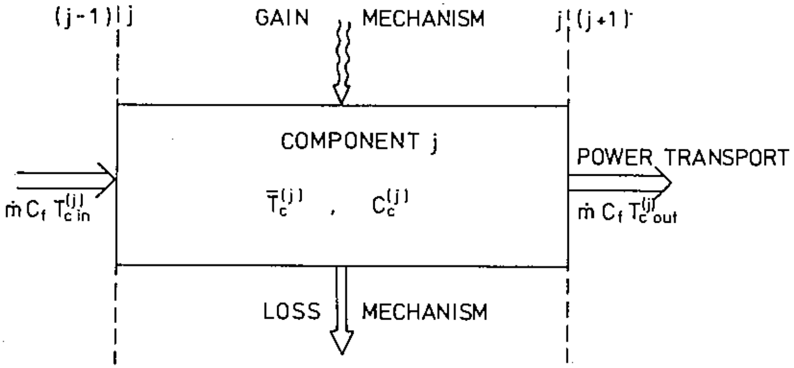


Fig. 3 COMPONENT j IN THE BLACK BOX MODEL

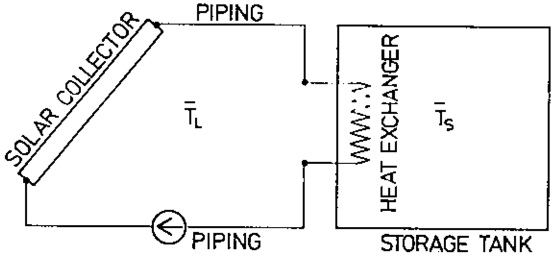


Fig. 4 LUMPED CURCUIT SEPARATION MODEL
SIMPLE SOLAR HOT WATER SYSTEM

Fig. 6 b

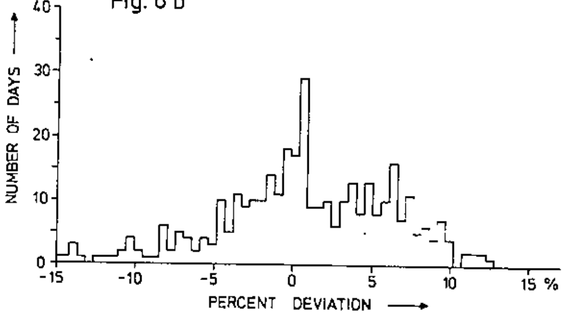
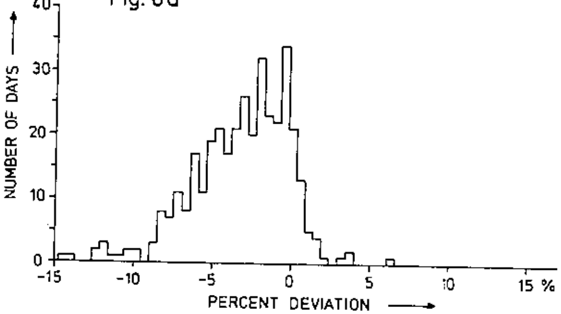


Fig. 6 a



STORAGE COLL.

Fig. 5 b

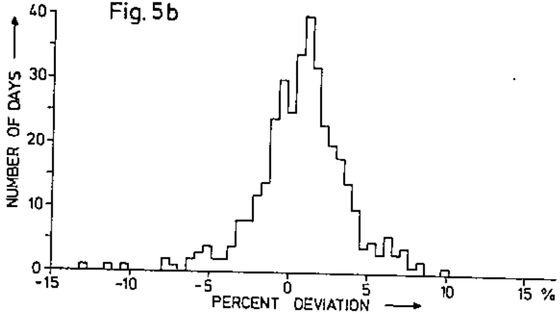
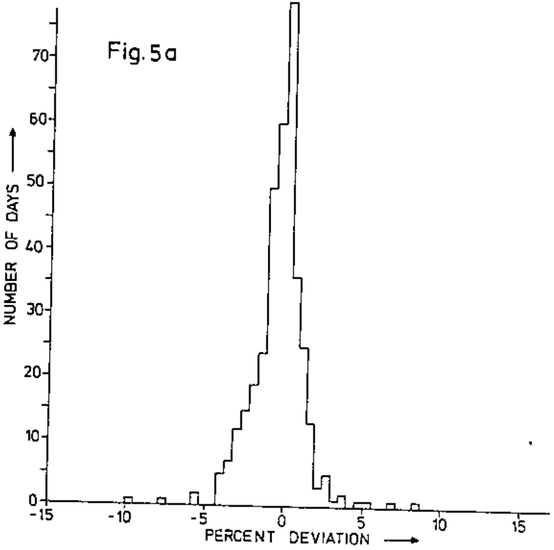
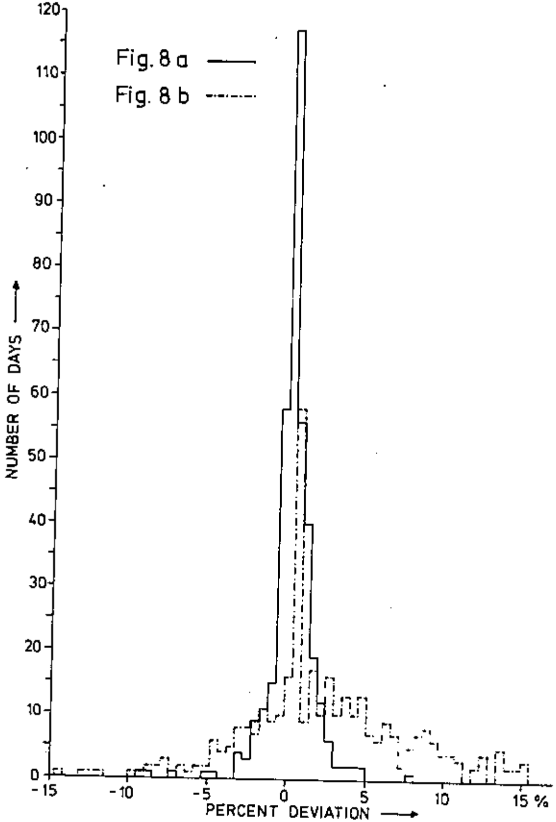


Fig. 5 a



NORMAL SYSTEM



STANDARD COLL.

Fig. 7 b

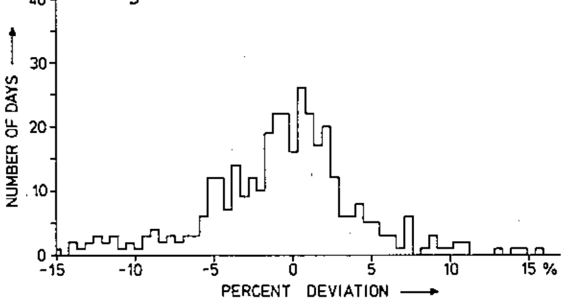
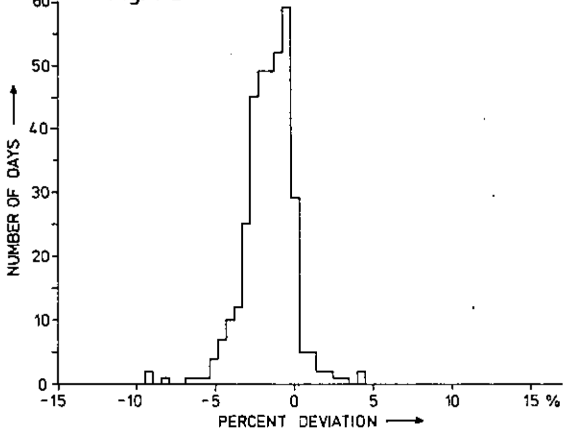


Fig. 7 a



SMALL FLOW RATE

Fig.9

Comparison of F-Chart and Exact Dynamic Calculation (Hamburg 1973)

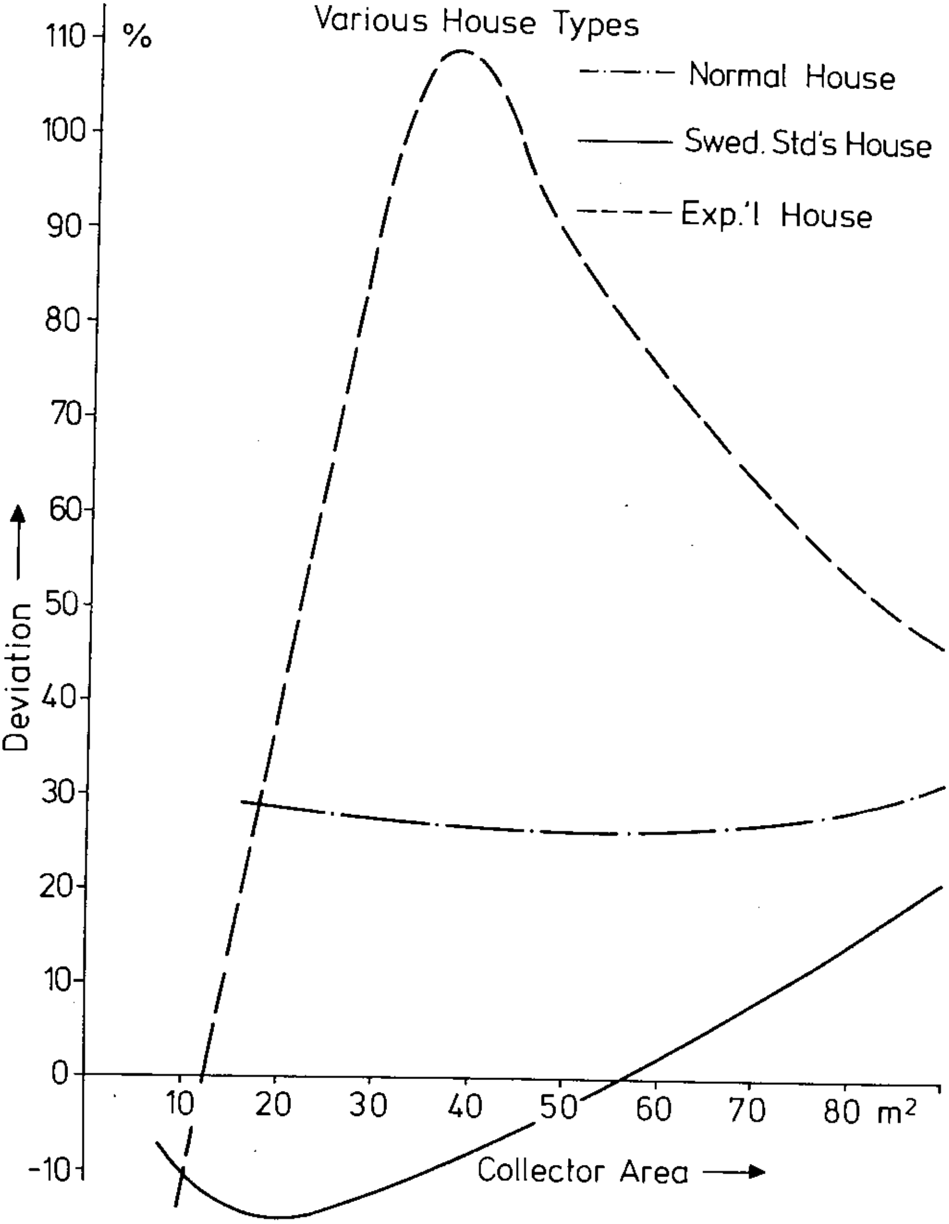
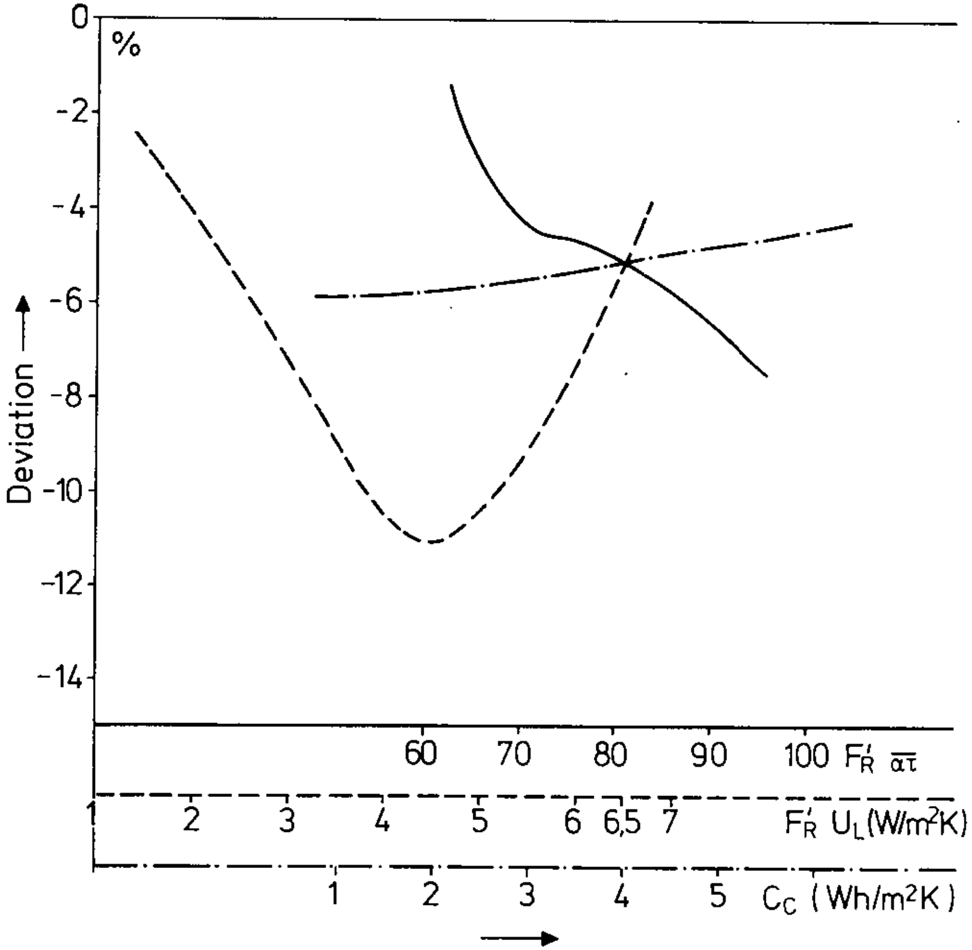


Fig. 10

Comparison of F-Chart and Exact Dynamic Calculation (Swed. Std's House; Hamburg 1973)

Collector Parameters



CHAPTER III

DESCRIPTIONS OF SIMULATION PROGRAMS

ASHRAE Transactions, *vol. 82, part 1, (1976).*

1.1 TRNSYS–A TRANSIENT SIMULATION PROGRAM

SANFORD A. KLEIN DR. WILLIAM A. BECKMAN DR. JOHN A. DUFFIE

A solar energy system is a group of interacting pieces of equipment designed to collect solar radiation, store the collected energy in one form or another, and distribute the energy as needed for some specific purpose. The performance of all solar energy systems is dependent upon weather. In a solar heating/cooling system, for example, both the energy collected and the energy demand are functions of the solar radiation, the ambient temperature, and other meteorological variables. These forcing functions are unique in that they are neither completely random, nor deterministic; they are best described as irregular functions of time, both on a small (e.g. hourly or daily) and large (e.g. seasonally or yearly) time scale.

It is this irregular behavior of the forcing functions which complicates the analyses of solar energy systems. In general, these systems exhibit a nonlinear dependence upon the weather which is further complicated by the time lags introduced from thermal capacitance effects. It is thus not possible to analyze these systems by observing their response to average weather conditions. Because the forcing functions are time variable on both small and large time scales, the analyses of these systems require an examination of their performance at small increments of time over a large time period.

Solar energy systems are characteristically capital-intensive. Thus the economic feasibility of these systems is critically dependent upon their design. The determination of an optimum design requires a comparative analysis of many different designs. If possible at all, comparative experiments are very costly and time-consuming.

In theory, mathematical models can be formulated which, when supplied with sufficient meteorological data, simulate the transient performance of these systems. In practice, however, the formulation of such varied models is complex. Because a system consists of components, a mathematical description of system performance can be developed by combining the mathematical models of all of the system components. This modular approach reduces the complexity involved in the formulation of a system model because each of the components can be mathematically described with little regard for the description of other components. In addition, many components are common to several systems, and thus the mathematical models of these components can often be used in different simulations with little or no modification, provided that they are formulated in a general manner. Once all of the components of a system have been identified and a mathematical model for each has been formulated, the models must be connected together in the desired manner and information must be transferred among them. This information transfer can be schematically represented by an information flow diagram of the system which identifies the input and output variables of each of the component models and indicates their interrelationship.

A transient simulation formulated from component models requires a simultaneous solution of a system of algebraic and differential equations which describe the component models. Solar energy systems in particular often exhibit several recycles in the information flow among component models; thus an iterative scheme (in addition to that which may be used to solve the differential equations of the system) is needed to obtain a simultaneous solution of these equations. This paper describes TRNSYS, a computer program designed specifically to connect

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Sanford A. Klein is Research Assistant; William A. Beckman is Professor of Mechanical Engineering; John A. Duffie is Professor of Chemical Engineering, Solar Energy Laboratory, University of Wisconsin, Madison, Wisconsin.

component models in a specified manner, solve the simultaneous equations of the system model, and display the results.

COMPONENT MODELING

Solar energy system components are described by individual FORTRAN subroutines. These subroutines, as listed in Table 1, comprise a growing library of equipment models available to the user for system simulation. If a particular component is not available in the library, the user can supply his own. These subroutines may be fairly complex, as in the case for the multinode storage tank, or they may be very simple, which is the case for a constant flow-rate pump. For some hardware, analytical mathematical modeling is impractical as an analytic model may be very difficult to develop or expensive to use in a lengthy simulation. In addition, a user may want to simulate a system that includes a particular piece of hardware for which he has actual performance data. In these cases, the component model may be empirically defined by transfer functions obtained from curve-fitting theoretical or actual performance characteristics. An example of such an empirical model is the TRNSYS absorption air conditioner subroutine (TYPE 7).

TABLE 1
Current TRNSYS Library

Type	Name	Description
1	Collector	Uses Hottel-Whillier-Bliss equations for collector performance. Mode 1: all collector parameters are assumed constant. Mode 2: loss coefficient is calculated as function of conditions. Mode 3: cover transmission is calculated as founction of angle. Mode 4: combination of Modes 2 and 3.
2	Differential Controller	Outputs 0 or 1 depending upon difference in two input signals.
3	Pump	Fixed flow rate pump (on or off).
4	Liquid Storage Tank	N-section model of liquid thermal storage tank.
5	Heat Exchanger	Counter, parallel or cross-flow heat exchanger.
6	Auxiliary Heater	On-off heater with set temperature and deadband.
7	Space Load and Air Conditioner	Simple house load calculated by energy per unit time per unit temperature difference method, with built in absorption air conditioner and cooling tower.
8	Three Stage Room Thermostat	For use in controlling combined heating and air conditioning systems.
9	Card Reader	Reads data from cards or mass storage (usually weather data).
10	Packed Bed Energy Storage Tank	N-section model of packed bed thermal storage unit.
11	Tee, Flow Mixer, Damper	Flow controllers for air or water.
12	Space Heating Load	Simple energy per unit time per unit temperature difference load, with Mode 1: parallel auxiliary. Mode 2: series auxiliary. Mode 3: no auxiliary. Mode 4: no auxiliary with thermal lag.
13	Relief Valve	"Dumps" energy to maintain temperature below specified maximum.
14	Time Dependent Forcing Functions	Permits time varying data to be introduced into simulation (usually periodic).

TABLE 1 (Cont.)

Type	Name	Description
15	Algebraic Operations	Permits algebraic operation using Reverse Polish notation.
16	Solar Radiation Processor	Estimates beam and diffuse radiation on surface of any orientation from total radiation on horizontal surface.
17	Wall	Components that can be used to model buildings, which include the effects of thermal capacity, infiltration, fenestration, etc.
18	Roof	
19	Room and Basement	
20	Heat Pump	Water or air source using manufacturers performance data.
24	Integrator	Integrates any quantity with respect to time (not used to solve differential equations).
25	Printer	Prints desired information in easy-to-read format.
26	Plotter	Plots information on line printer.

Each TRNSYS component is described either by algebraic or differential equations. The collector model (TYPE 1) is an example of component with only algebraic equations while the storage tank (TYPE 4) is a component with algebraic and differential equations.

As an illustration of an algebraic component, we will use the Hottel-Whillier-Bliss equations, as presented by Duffie and Beckman[1], for a flat plate collector.

$$\dot{Q}_u = AF_R[H_T(\tau\alpha)-U_L(T_{in}-T_a)] \tag{1}$$

$$\dot{Q}_u = \dot{m}C_p(T_{out}-T_{in}) \tag{2}$$

$$F_R/F' = (1-e^{-\phi})/\phi \tag{3}$$

$$\phi = AF'U_L/\dot{m}C_p \tag{4}$$

$$U_L = f_1 \text{ (collector design, } T_a, T_{plate}, \text{ wind, tilt)} \tag{5}$$

$$F' = f_2 \text{ (collector design)} \tag{6}$$

$$(\tau\alpha) = f_3 \text{ (collector design, angle of incidence of solar radiation)} \tag{7}$$

For preliminary design purposes, U_L, F' and $(\tau\alpha)$ can often be considered as constants throughout the simulation and therefore can be entered into the program as parameters. The collector component receives "information" such as H_T, $\dot{m}$, T_{in}, and T_a from other components and must calculate T_{out} and $\dot{Q}_u$ to be transmitted to other components. This transfer of information into and out of a subroutine is shown in Fig. 1, which indicates the ordering of INPUTS, OUTPUTS and PARAMETERS. (The TRNSYS Users Manual[2] contains complete documentation for each component in the library.) Note that the mass flow rate, $\dot{m}$, is an OUTPUT but is never changed by the collector subroutine; it is an OUTPUT so that TRNSYS systems can be constructed which resemble the flow of material in real systems.

If more detail is required than is given by this simple collector model with constant parameters, another subroutine could be written to include as much detail as desired. For example, the dependence of U_L on ambient conditions can be included. This would require an additional INPUT corresponding to the wind speed and additional parameters for the number of covers, cover spacing, plate infrared emittance and the back and edge coefficients. TRNSYS has, in effect, four collector models giving the user four choices as to level of detail (more detail is almost always associated with higher computer costs). Instead of having four different subroutines, a single subroutine was written which has four modes of operation. The first parameter of the collector model is the MODE (1,2,3, or 4) which determines the level of detail. Each mode has a different set of INPUTS, PARAMETERS and OUTPUTS.

Communication between each component subroutine and TRNSYS is through the calling arguments. For any TYPEn model, the appropriate FORTRAN statement is

```
SUBROUTINE TYPEn (TIME, XIN, OUT, T, DTDT, PAR, INFO)
```

where

TIME = integration time

XIN = an array containing the INPUTS

OUT = an array which the subroutine fills with the appropriate OUTPUTS

T = an array containing the dependent variables of any differential equations

DTDT = an array which the subroutine fills with the time dependent derivatives

PAR = an array containing the PARAMETERS

INFO = an array containing TRNSYS control information

For MODE 1 of the collector model, the array XIN corresponds to T_{in}, $\dot{m}$, T_a and H_T; the array OUT corresponds to T_o, and $\dot{Q}_u$ as calculated from Eq. 1 and 2 and $\dot{m}$, which was an input; the T array and the DTDT array are not used since no differential equations are involved, the PAR array contains MODE, A, F', C_p, α, U_L and τ.

The tank model is an example of a component described by differential equations. A fully mixed tank is described by the following differential equation which relates the rate of temperature rise of the tank to the net energy into the tank from the collector, the load and the surroundings[1].

$$(MC_p)_s \frac{dT_s}{dt} = (\dot{m}C_p)_c\ (T_o-T_s) + (\dot{m}C_p)_L\ (T_L-T_s) + (UA)_s\ (T_a-T_s) \tag{8}$$

TRNSYS handles component differential equations with its own internal integrator. Through the T array, TRNSYS supplies the subroutine with values of the dependent variables. TIME is always the independent variable. The component subroutine calculates values of the time derivatives and puts them in the DTDT array. For the one node tank model, a single differential equation is involved so that T(1) is T_s and DTDT(1) is dT_s/dt.

The internal TRNSYS integrator uses the modified-Euler integration algorithm which predicts new values of the dependent variable using simple Euler and corrects using the trapezoid rule. The advantage of this integration scheme for systems of combined algebraic and differential equations is that the iterations occur at a constant value of time. As the differential equations converge (by successive substitution).

"Black-box" component models are identical to algebraic models although the relationship between independent and dependent variables may be in the form of tables rather than analytical equations.

SYSTEMS AND INFORMATION FLOW DIAGRAMS

Once all of the components of a system are available in the TRNSYS library the next step is to construct a system information flow diagram. An information flow diagram is a schematic representation of the flow of information between each of the system components. In the diagram, each component is represented by a component diagram like Fig. 1. Each piece of information required to completely describe the component is represented as an arrow directed into the box.* Each piece of information calculated by the algebraic or differential equations describing the component can be represented as an arrow directed out of the box.

---

*A component must receive values for all its INPUTS, but it is not necessary to use all of the OUTPUTS.

It is often helpful to think of the arrows connecting component inputs and outputs as information exchanged via pipes and wires in a real system. A collector outlet flowstream temperature and flowrate connected to the inlet of some other piece of hardware is "information" transmitted through a pipe. A controller on-off output connected to a pump is information transmitted through a wire. The analogy between information flow and pipes and wires is, however, not perfect. In a real system a pipe may carry a flowstream through some component which does not affect one or more variables that characterize the flow. In these cases it is not necessary to route those particular pieces of information through the component.

In order to demonstrate the construction of an information flow diagram, consider a very simple solar water-heating system consisting of a solar collector and an auxiliary energy heater as shown in Fig. 2. Cold water, at a fixed temperature T_{in}, is circulated at a constant rate $\dot{m}$, to the collector. If the outlet temperature from the collector is less than T_{set}, the water is heated from T_o to T_{set} by the auxiliary heater. The problem is to determine Q_B, the total auxiliary energy required over a specified time period using the collector model of Fig. 1. The system information flow diagram is assembled from the collector component diagram and from the component diagrams described below.

Time dependent solar radiation on the plane of the collector and the ambient temperature are assumed to be available on punched cards. The card reader (TYPE 9) is shown in Fig. 3.

The instantaneous auxiliary energy required, $\dot{Q}_B$, is described by the following equation:

$$Q_B = \begin{cases} \dot{m}c_p[T_{set}-T_o]; \ T_r = T_{set}, T_o \leq T_{set} \\ 0; \ T_r = T_o \qquad \text{otherwise} \end{cases} \tag{9}$$

The information flow diagram for the heater is shown in Fig. 4.

In order to determine the total auxiliary energy required, Q_B, the instantaneous auxiliary energy must be summed or integrated over the period of operation. For this purpose, it is necessary to include a "quantity integrator" as one of the system components. Note that a quantity integrator component is used only to integrate some calculated OUTPUT quantity over a period of time; it is distinct from the internal integrator used to solve first-order differential equations which are part of the mathematical description of differential components. A quantity integrator is treated as any other system component. The equation describing it is

$$Q_B = \int^{TIME} \dot{Q}_B \, dt \tag{10}$$

The diagram for the quantity integrator is shown in Fig. 5.

One more component is needed to allow the results of the simulation to be made available to the user. For this purpose, TRNSYS has both printer and plotter components. The analogous pieces of equipment in a physical system would perhaps be a multichannel digital display and/or strip chart recorders, which would monitor, record, and display various quantities.

It is necessary to include either a printer or a plotter component (or both) in the system information flow diagram; otherwise no output will occur. In fact, TRNSYS recognizes this and unless it detects either of these component models in the system information flow diagram, it will not execute and the appropriate error message will be displayed.

In the example being considered, the user may wish to print Q_B and T_o as the integration progresses with time. The Printer is shown in Fig. 6.

The information flow diagram of a system is constructed by joining all of the diagrams of the system components. TRNSYS recognizes the position of each component in the information flow diagram by the user assigning to each component a unique UNIT number. The component UNIT number should not be confused with its TYPE number; the two numbers are unrelated. The UNIT number is nothing more than a reference number which will aid in conveying the information flow diagram of the system to TRNSYS. The user is free to select any unit number he chooses. The only restriction imposed on the UNIT number selection is that no two system component can have the same UNIT number. The information flow diagram of the solar water heating system is shown in Fig. 7 with UNIT and TYPE numbers.

A TRNSYS PROGRAM

In order to convey the information of Fig. 7 to TRNSYS, a simple language has been developed that is based essentially upon seven key-words*. The first card of a TRNSYS deck must be of the form

SIMULATION t_o t_f Δt

where t_o is the time at the start of the simulation

t_f is the time at the end of the simulation

Δt is the timestep to be used by the integrator.

The final card of a deck must be an END card. Between these two cards, there is a set of cards for each component of the general form.

UNIT n TYPE m Comment

PARAMETERS j

$p_1, p_2, \cdots p_j$

INPUTS k

$u_1, 0_1\ u_2, 0_2, \cdots u_k, 0_k$

$v_1, v_2, \cdots v_k$

DERIVATIVES ℓ

$i_1, i_2, \cdots i_\ell$

where

n is a unique unit number

m is a type number from the TRNSYS library

j is the number of parameters for TYPE m

$p_1, p_2, \cdots p_j$ are the j values of the parameters, listed in order indicated in the manual, e.g. as shown for TYPE 1 in Fig. 1.

k is the number of INPUTS for TYPE m

$u_1, 0_1\ u_2, 0_2 \cdots u_k, 0_k$ are the UNIT numbers and corresponding OUTPUT numbers for the first, second ··· and kth INPUT to this UNIT n.

$v_1, v_2, \cdots v_k$ are the initial values of the k INPUT variables. A special notation is used whenever an INPUT is to be a constant. When both u_i and 0_i are set to zero, v_i is then the value of the ith input throughout the simulation.

ℓ is the number of derivatives used to describe TYPE m. For an algebraic component this is zero and this and the following cards are not used.

$i_1, i_2 \cdots i_\ell$ are the ℓ initial values of the dependent variables for TYPE m.

If a particular component does not have INPUTS, PARAMETERS or DERIVATIVES, the corresponding cards are not necessary.

---

*The seven key-words are SIMULATION, UNIT, TYPE, PARAMETERS, INPUTS, DERIVATIVES and END. Other key-words exist in TRNSYS but their use is optional and will not be discussed here.

In order to illustrate the TRNSYS language, the following deck would be required to simulate the water heater problem for 100 hr. beginning at time zero. The numerical values of some of the PARAMETERS were selected to be representative of current practice. The units in this example are S.I.

```
SIMULATION 0, 100, 1
UNIT 17 TYPE 9 CARD READER
PARAMETERS 2
2, 1
UNIT 14 TYPE 1 MODE 1 COLLECTOR
PARAMETERS 7
1, 2, 0.95, 4,2, 0.9, 15.0, 0.8
INPUTS 4
0,0 0,0 17,1 17,2
15.0 100. 20.0 0.0
UNIT 32 TYPE 6 HEATER
PARAMETERS 4
1.E6, 60, 2, 4.2
INPUTS 2
14,1 14,2
20.0 0.0
UNIT 43 TYPE 24 INTEGRATOR
INPUTS 1
32,3
0.0
UNIT 25 TYPE 25 PRINTER
PARAMETERS 1
1
INPUTS 2
14,1 43,1
TO, QB*
END
```

(Data to be read in by CARD READER must be placed after the END card. It was assumed here that each data card contains two pieces of information, and each card represents one hour.)

---

*The initial values of INPUTS to the printer are nmeumonics which identify the printed output.

Klein, et al.[3] have presented the detailed results of several heating simulations using TRNSYS.

CONCLUSIONS

TRNSYS is a compiler for a high level computer language designed specifically to connect component models of transient systems and solve the resulting simultaneous algebraic and differential equations describing the system. TRNSYS has the following desirable features:

1. Each component model is formulated as a separate FORTRAN subroutine. The requirements for compatibility of the component subroutine with TRNSYS are minimal. Components which provide the capability to print, plot or integrate various quantities as the simulation progresses are built into TRNSYS and need not be formulated.

2. TRNSYS is general in the sense that it can be used to simulate any transient system for which the system component models are expressible in FORTRAN statements. TRNSYS is particularly applicable to solar energy system simulations because a library of component subroutines modeling the components common in these systems has been established.

3. The input data to TRNSYS is essentially the information flow diagram of the system. This information is communicated to TRNSYS in a very simple manner requiring only seven keywords. An error-checking facility is provided to diagnose most data input errors.

4. The computation scheme incorporated into TRNSYS recognizes the existence of information recycles, and it will provide the iterative calculations needed to solve the simultaneous algebraic and differential equations of the system model. An important part of the TRNSYS computation scheme is that only those component subroutines involved in the recycles are recalled for additional iterative calculations. In this manner, TRNSYS requires a minimum of computational effort to achieve a simultaneous solution to the equations describing the system.

5. The user need not concern himself with the order in which the component subroutines are called during the simulation since the computation scheme built into TRNSYS will solve the system equations, within a specified accuracy, regardless of the calculation order. However, since the calculation order may affect computation time, it may be optionally specified by the user.

6. The entire TRNSYS program is written in ASA standard FORTRAN IV. It requires relatively small storage space; it is thus usable on most modern computers.

NOMENCLATURE

A	Collector area
C_p	Heat capacity
F_R	Collector heat removal factor
F'	Collector plate efficiency factor
H_T	Total solar radiation on plane of collector per unit area
M	Mass of water in the storage tank
$\dot{m}$	Mass flow rate
$\dot{Q}_u$	Useful energy output of collector
Q_B	Total auxiliary energy
$\dot{Q}_B$	Auxiliary energy rate
T_a	Ambient temperature
T_{in}	Fluid temperature at collector inlet
T_o	Fluid temperature at collector outlet

T_{set}	Set temperature for auxiliary heater
U_L	Collector loss coefficient
UA	Product of loss coefficient and area
α	Solar absorptance of collector plate
τ	Solar transmittance of collector cover system

SUBSCRIPTS

c	Collector
L	Load
s	Storage

REFERENCES

[1] J.A. Duffie and W.A. Beckman, Solar Energy Thermal Processes, Wiley, New York (1974).

[2] TRNSYS - A Transient Simulation Program, Report #38, University of Wisconsin, Engineering Experiment Station (Nov. 1975).

[3] S.A. Klein, et al., "A Method of Simulation of Solar Processes and its Application," Solar Energy 17, p 29 (1975).

ACKNOWLEDGMENTS

The financial assistance of the National Science Foundation under its RANN program through Grant GI34029 and later, the Energy Research and Development Administration through Contract E(11-1)-2588 is gratefully acknowledged.

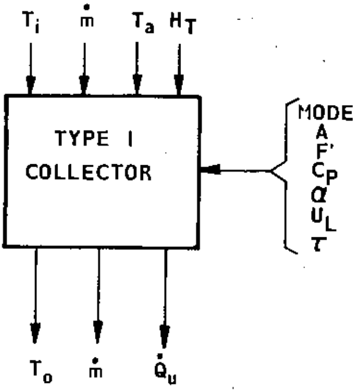


Fig. 1 Component diagram for simple collector

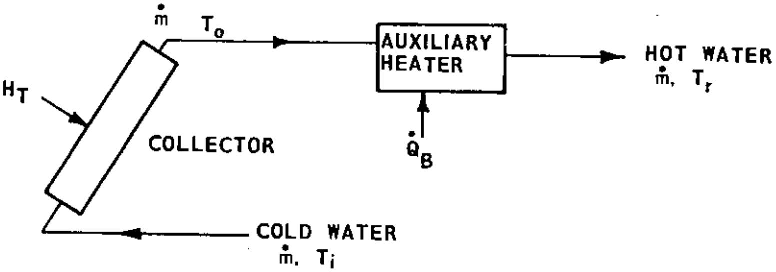


Fig. 2 Simple solar water heating system

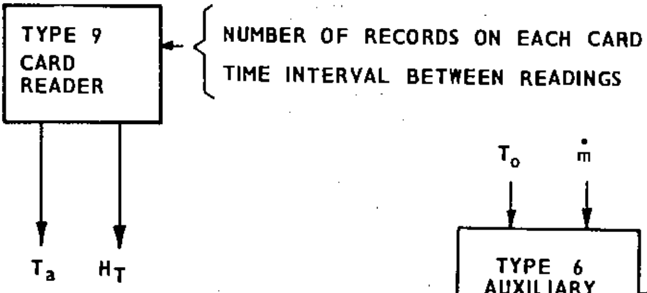


Fig. 3 Component diagram for card reader

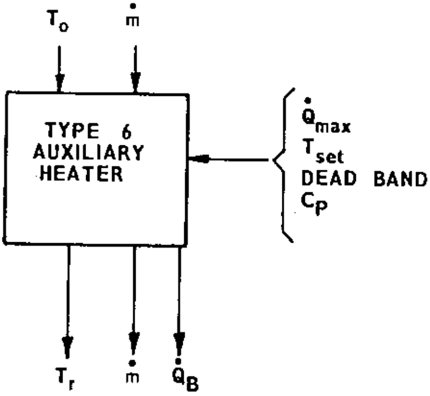


Fig. 4 Component diagram for auxiliary heater

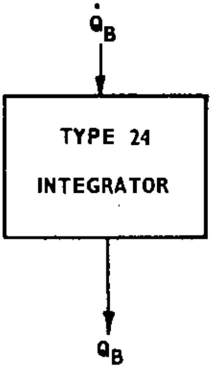


Fig. 5 Component diagram for integrator

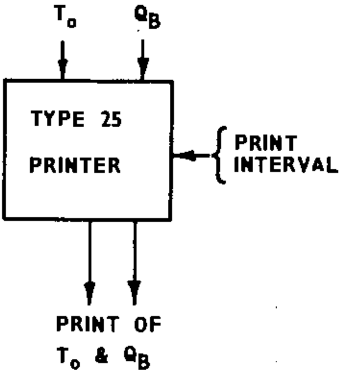


Fig. 6 Component diagram for printer

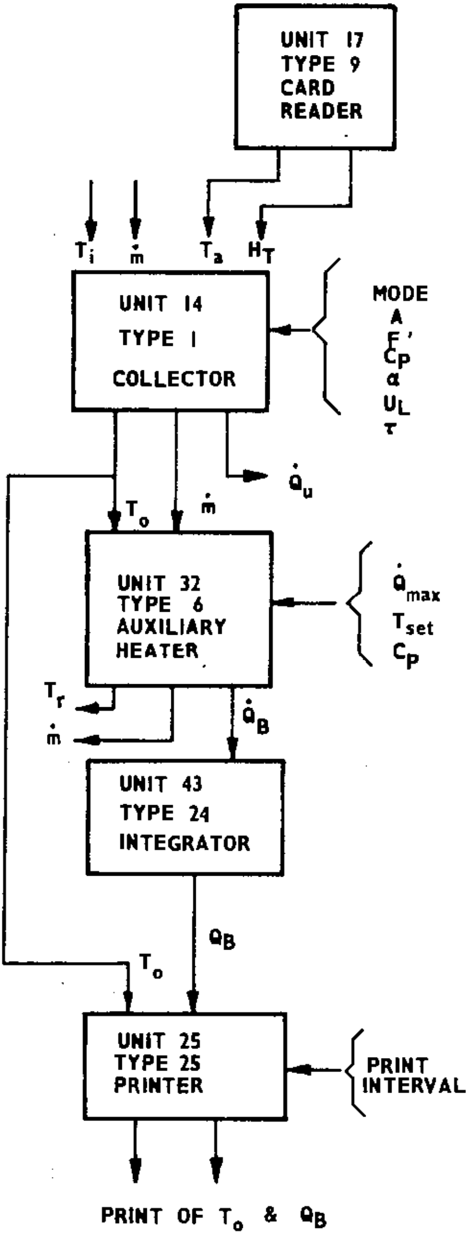


Fig. 7 Information flow diagram for solar water heater

.2 DESCRIPTION OF LASL SOLAR ENERGY SYSTEM SIMULATION CODE

I. General description of the system.

a) Objective. The strategy was to write streamlined special-purpose codes which could be used to study the effect of parameter changes on overall system performance. Two codes have been written -- one for a system consisting of liquid heating collectors, a heat exchanger, water tank thermal storage, and forced air heat distribution. -- the second for air heating collectors, rock bed thermal storage, and forced air heat distribution. Since the objective of the code was to study the solar heating system, the details of the load calculation were bypassed by assuming a simple "degree-day" load directly proportional to the room-to-ambient temperature difference.

b) Main Components:

Liquid System -- collector -- one or two glazings
-- absorber surface
-- back and side heat loss
-- heat exchange to coolant
-- thermal storage
piping -- heat loss to ambient
heat exchanger --
thermal storage -- mixed tank
-- heat loss to ambient
distribution -- heat exchange to a finned tube coil upstream of auxillary
-- auxillary as required to raise air temperature to required level
hot water -- preheater tank coupled to main tank

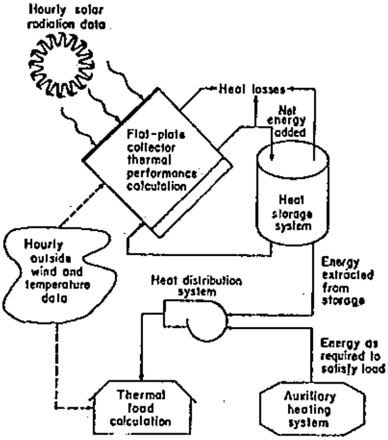
Air System -- collector -- same as above
ducting -- heat loss to ambient
thermal storage-- one dimensional
-- air-to-rock heat transfer
-- reversable flow direction
-- heat loss to room
distribution -- auxillary as required to raise rock bed exit air temperature to required level

hot water -- preheater tank heated by finned-tube coil in collector exit duct.

Input data -- solar radiation on horizontal surface
-- ambient temperature

II. Computer Model

a) <u>Schematic</u>



SIMULATION SCHEMATIC

At each hour the net energy which can be extracted from the collector is calculated. This is determined from the solar radiation, the collector design, the outside temperature and wind condition, and the inlet fluid temperature from storage. If this energy is positive it is added to storage. The thermal load is calculated either from the outside temperature (for space heating) or a fixed schedule (for water heating). This energy is extracted from storage by the heat distribution system to satisfy the load. If the load cannot be totally satisfied from storage then auxiliary heat is added as required to make up the difference. The change in storage temperature over the hour is the net energy added from the collector minus storage heat losses minus the energy extracted by the thermal load, divided by the storage heat capacity.

This calculation is repeated for each of the 8760 hours of the year. All energy flows are summed hour-by-hour and both monthly and yearly summaries are printed out. A typical year-long calculation requires only 34 seconds on the Los Alamos COC 6600 computer and thus it is feasible to study the effect of changes in many design parameters.

b) Input data -- hourly values of solar radiation on a horizontal or tilted surface and ambient temperature.

Load (AL) -- BTU/hr - °F - ft_c^2 for temperature below 68°F

Liquid System:

SCPM - Thermal Storage Mass, BTU/°F ft_c^2
TILT - Collector tilt from horizontal, degrees
GL - number of collector glazings
EC - collector surface emittance
ALF - collector surface absorptance (normal)
EG - collector glass emittance (hemispheric)
CPM - collector heat capacity, BTU/°F - ft_c^2
EX - glass extinction coefficient
TCONV - design convection temperature, °F

TCONV = Trm + CEFF (Tdw-Trm)

$$CFM = \frac{(LOAD)\ (Design\ \Delta T)}{(24)\ (1.08)\ (Tconv-Trm)}$$

Trm = room temperature, °F
Tdw = design water temperature
CEFF= coil effectiveness

WCP - collector coolant flow rate, BTU/hr-°F-ft_c^2
H - collector heat transfer coefficient, surface-to-coolant (average), BTU/hr-°F-ft_c^2
UHX - heat exchanger heat transfer coefficient, collector coolant-to-water (averages), BTU/hr-°F-ft_c^2
UPIPE - piping heat loss coefficient, BTU/hr-°F-ft_c^2
UBACK - collector back and side loss coefficient, BTU/hr-°F-ft_c^2
DIR - collector orientation, degrees east of due south
ALAT - latitude, degrees

Air System;

SCPM, TILT, GL, EC, ALF, EG, CPM, EX,
UPIPE, UBACK, DIR, ALAT: same as above

HA - collector heat transfer coefficient, collector surface-to-air (averages), BTU/hr-°F-ft_c^2

L/LAM - thermal storage length in units of heat exchange relaxation length (dimensionless) (same as NTU)

Note: the domestic hot water feature was specially coded for the IEA runs and is not a normal feature.

Output:

MON - month of year (1 to 12)

EBLDG - building thermal load, BTU/ft_c^2 (based on Σ(68°F-ambient temperature) x AL, when the quantity is greater than zero.)

ECOLL - energy collected by collector, BTU/ft_c^2

EAUX - auxiliary energy required, BTU/ft_c^2

EHORZ - solar radiation incident on horizontal surface, BTU/ft_c^2

EINC - solar radiation incident on collector, BTU/ft_c^2

DEG DAY - heating degree-days, °F-days (based on daily median temperatures)

% SOL - percent of solar heating, 1 - EAUX/EBLDG

III. Description of individual components and subroutines

a) Solar Collector -

A heat flow balance is achieved for each (one or two) glass surfaces and the absorber surface accounting for radiation, convection, and conduction, by numerical iteration using a Newton-Raphson technique. The heat capacity term is accounted for as an equivalent heat flow from the surface averaged over the previous hour.

b) Energy Storage Unit -

The change in storage temperature over the hour is equal to the net energy from the collector minus the piping losses minus the heat extracted to heat the space minus the heat losses from the storage container surface divided by the storage thermal capacity. For the air system the situation is somewhat more complex.

The governing differential equations for the rock bed storage model are:

$$WC_p \frac{dT}{dx} = \frac{hA_s}{L} (T_s - T)$$

$$M_s \; C_{ps} \frac{dT_s}{dt} = hA_s \; (T - T_s)$$

which after rearrangement become:

$$\frac{dT}{d(\frac{x}{L})} = \frac{L}{\lambda} \; (T_s - T)$$

$$\frac{dT_s}{d(\frac{t}{\tau})} = \frac{L}{\lambda} (T - T_s)$$

where

$$\lambda = \frac{WC_pL}{hA} = \text{Rock bed relaxation length}$$

$$\tau = \frac{M_s \; C_{ps}}{WC_p}$$

In the numerical form these equations become:

$$T_{i+1} - T_i = \alpha(T_{si+1} + T_{si} - T_{i+1} - T_i)$$

$$T_{si} - T'_{si} = \beta(T_i + T'_i - T_{si} - T'_{si})$$

$$T_{i+1} = \frac{\alpha\beta(T'_{i+1} + T'_i) + (1-\alpha+\beta)T_i + \alpha(1-\beta) (T'_{si+1} + T'_{si})}{1 + \alpha + \beta}$$

$$T_{si+1} = \frac{(1-\beta) \; T'_{si+1} + \beta(T_{i+1} + T'_{i+1})}{1 + \beta}$$

where

$$\alpha = \frac{1}{2N} \cdot \frac{L}{\lambda}$$

$$\beta = \frac{\Delta t}{2\tau} \cdot \frac{L}{\lambda}$$

Dec. 12th, 1977
Revised: May 29th, 1978
Revised: Mar. 1st, 1979

SOLAR HEATING AND COOLING PROGRAM

(TASK 1 SUBTASK A)

MODELING AND SIMULATION RESULTS

Reported by Japanese Group

Y. Matsuo, Chairman
T. Noguchi
K. Kimura
S. Tanaka
E. Maki
M. Udagawa
T. Inooka

1. Description of the Computer Program

The authors have since 1974 developed simulation programs for solar heating, cooling and hot water supply systems, and investigated the problems of energy saving and economy in the systems.

These programs have a number of parameters by which effects from many factors can be clarified. Computation can be made at one-hour or shorter intervals which have been arbitrarily determined. Where summation is called for by the month or year, the intervals can be elongated so as to reduce computing time. On the other hand, where the results of simulation is compared with data actually measured, the intervals can be shortened to enhance the accuracy of simulation.

The present simulation was made at 20-minute intervals. Computing time was 6 minutes per case per year. The computer system used was IBM S/370 M/138.

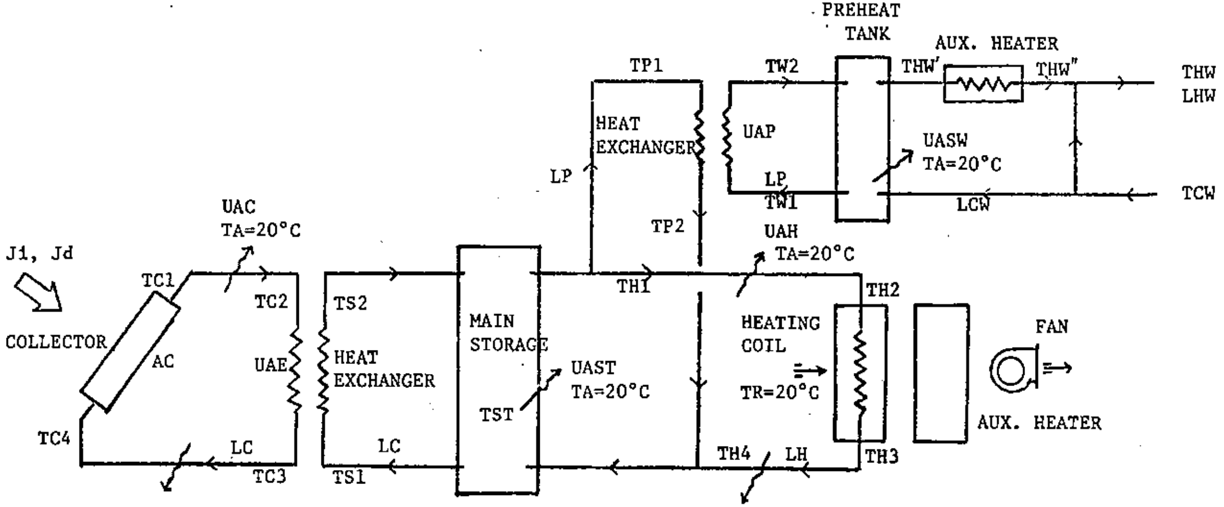
2. Input Data

Weather and load data furnished in magnetic tapes by NBS contained those for the following three cities.

Madison, Wisc., U.S.A.
Santa Maria, Calif., U.S.A.
Hamburg, Germany

The data of magnetic tapes contained hourly values of the following items:

a.	Solar radiation on horizontal surface (Total)	(W/M^2)
b.	Wind speed	(M/SEC)
c.	Dry bulb temperature	(°C)
d.	Wet bulb temperature	(°C)
e.	Dew point temperature	(°C)
f.	Total cloud cover	(0 to 10)
g.	Sensible load	(KW)



AC : Collector area
J : Solar radiation intencity
T : Temperature (°C)
L : Fluid flow rate (ℓ/n)
UA : Heat transfer
↯ : Heat loss

Fig. 1 Liquid Solar System

3. Description of the Individual Components

3.1 Parameters

* : Parameters not described in Annex I

Δ : Parameters described in Annex I, but not used in the present simulation

Other parameters are as indicated in Annex I.

For symbols see Fig. 1.

(a) Collector

Area	AC = 50 M^2 (Madison and Hamburg) = 20 M^2 (Santa Maria)
Tilt (Latitude + 10°)	ϕ = 53° (Madison) = 45° (Santa Maria) = 65.6° (Hamburg)
Orientation	South
* Front loss (See 3.3 (b) below)	KO = 3.23 W/M^2·°C
Back and side loss	KU = 0.42 W/M^2·°C
* Heat transfer coefficient from collector to circulating water	rKW (Determined by KO, KU and F')
Collector surface	a = 0.95
Δ	ε = 0.9 (taken into account in KO above)
* Shade coefficient of glass (See 3.3 (a) below)	SCT = 0.915
Heat transfer coefficient	F' = 0.95
Δ Heat capacity	Disregarded
Glazing spacing	0.04 M

(b) Piping (Collector – Heat Exchanger : Each Side)

Fluid flow rate	LC = 1 /MIN·M^2_c
Heat loss	UAC = 0.1 W/M^2_c·°C

Ambient temperature	TA = 20°C
Δ Heat capacity	Disregarded

(c) Piping (Heat Exchanger – Main Storage Tank : Each Side)

Δ Fluid flow rate	LS = 1 ℓ/MIN·$M^2{}_c$
Heat loss	Disregarded
Δ Heat capacity	Disregarded

(d) Collector – Main Storage Heat Exchanger

Heat transfer coefficient	UAE = 60 W/$M^2{}_c$·°C
Heat capacity	Disregarded

(e) Main Storage Tank

Volume	V = 80 ℓ/$M^2{}_c$ (Madison) (Santa Maria) (Humburg Case 1)
	= 40 ℓ/$M^2{}_c$ (Humburg Case 2)
	= 20 ℓ/$M^2{}_c$ (Humburg Case 3)
Shape (Cylinder)	H/D = 1
Heat loss	U = 0.42 W/$M^2{}_{ST}$·°C
Ambient temperature	TA = 20°C
No stratification	

(f) Preheat Exchanger

Heat transfer coefficient	UAP = 1000 W/°C
Heat capacity	Disregarded
Fluid flow rate (both sides)	LP = 10 ℓ/MIN

(g) Preheat Tank

Volume	VP = 350 ℓ

Shape (Cylinder)	$H/D = 1$
Heat loss	$U = 0.42\ W/M^2{}_p \cdot {}^\circ C$
Hot water use	$LHW = 350\ \ell/day$
Ambient temperature	$TA = 20^\circ C$
Cold water inlet temperature	$TCW = 10^\circ C$
Set point for hot water	$THW = 50^\circ C$

(h) <u>House Heating Unit</u>

Fluid flow rate	$LH = 0.25\ \ell/MIN \cdot M^2{}_c$
Piping length	20 M
Heat loss	$UAH = 0.15\ W/M \cdot {}^\circ C$
Ambient temperature	$TA = 20^\circ C$
Air flow rate	G = 1364 KG/H (Madison) = 496 KG/H (Santa Maria) = 745 KG/H (Hamburg)
Air inlet temperature	$TR = 20^\circ C$
Heat unit capacity	Disregarded
Coil effectiveness	$\eta = 0.8$

(i) <u>Controls</u>

Collector

Off → On When $TC1 > TST + 5^\circ C$

On → Off When $TC1 > 95^\circ C$

On → Off When $TC1 \leq TC4$

D.H.W. circuit Always on

Heating unit

On When $QAC > 0$

Off When $QAC \leq 0$

Where, QAC: House heating requirement

(j) Initial Condition

Main storage tank $TST = 30°C$

Preheat tank $TSW = 30°C$

3.2 Basic Formulae

For symbols see 3.1 and Fig. 1.

(a) Collector

Equivalent heat transfer coefficient (KE) and equivalent temperature (TE) are obtained by the use of equation of heat balance for heat collecting:

$$KE = \frac{KO + KU}{KO + KU + rKW} \cdot rKW = F' \cdot (KO + KU) \quad \text{----------} \ (1)$$

$$TE = TO + \frac{Ji \cdot Gi + Jd \cdot Gd}{KO + KU} \cdot SCT \cdot a - \frac{KU}{KO + KU} \cdot (TO - TA) \quad \text{----} \ (2)$$

Where,

Solar radiation	(Direct)	Ji	W/M^2
	(Diffused)	Jd	W/M^2
Radiation gain coefficient of glass (See 3.3 (a) below)			
	(Direct)	Gi	
	(Diffused)	$Gd = 0.808$	
Outdoor temperature		TO	

Temperature at inlet and outlet of coolant (TC4, TC1):

$$TC1 = TE - (TE - TC4)\ EXP\ (-KE \cdot AC/LC) \quad \text{----------} \ (3)$$

Heat collected:

$$QSC = LC \cdot (TC1 - TC4) \quad \text{----------} \ (4)$$

(b) Heat Exchanger (Collector - Storage)

Heat exchanged:

$$QEX = UAF \cdot ETD \quad \text{----------} \ (5)$$

Where,

$$ETD = \frac{\Delta 1 - \Delta 2}{\ell n(\Delta 1/\Delta 2)} = \frac{(TC2 - TS2) - (TC3 - TS1)}{\ell n(TC2 - TS2)/(TC3 - TS1)} \quad \text{----------} \ (6)$$

(c) Piping

$TS1 = TST$

Heat loss:

$$TC4 = TA - (TA - TC3)\ EXP\ (-UAC/LC) \qquad \text{----------- (7)}$$

$$TC2 = TA - (TA - TC1)\ EXP\ (-UAC/LC) \qquad \text{----------- (8)}$$

Solar heat to storage:

$$QST = LS\cdot(TS2 - TS1)\cdot 0.86 \qquad \text{----------- (9)}$$

(d) Preheat Exchanger

Heat exchanger:

$$QP = UAP\cdot ETD \qquad \text{---------- (10)}$$

Where,

$$ETD = \frac{\Delta 1 - \Delta 2}{\ell n(\Delta 1/\Delta 2)} = \frac{(TP1 - TW2) - (TP2 - TW1)}{\ell n(TP1 - TW2)/(TP2 - TW1)} \qquad \text{---------- (11)}$$

(e) Hot Water Supply

Hot water requirement:

$$QHW = LHW\cdot(THW - TCW)\cdot 0.86 \qquad \text{---------- (12)}$$

$TSW \geq THW$

Flow rate of cold water:

$$LCW = LHW\cdot(THW - TCW)/(TSW - TCW) \qquad \text{---------- (13)}$$

Auxiliary heat:

$$QA\cdot HW = 0 \qquad \text{---------- (14)}$$

$TSW < THW$

Flow rate of cold water:

$$LCW = LHW \qquad \text{---------- (15)}$$

Auxiliary heat:

$$QA\cdot HW = LHW\cdot(THW - TSW) \qquad \text{---------- (16)}$$

(f) House Heating

$TH1 = TST$

Coil inlet water temperature:

$$TH2 = TA - (TA - TH1)\ EXP\ (-UAH/LH) \qquad \text{---------} \ (17)$$

Heating capacity of coil (Q):

$$Q = G \cdot (TH2 - TR)\eta \qquad \text{---------} \ (18)$$

$Q \geqq QAC$ (QAC: House heating load)

Aux. heat: $QA \cdot AC = 0$ --------- (19)

$Q > QAC$

Aux. heat: $QA \cdot AC = QAC - Q$ --------- (20)

Coil outlet water temperature:

$$TH3 = TH2 - (QAC - QA \cdot AC)/LH \qquad \text{---------} \ (21)$$

Temperature of return water:

$$TH4 = TA - (TA - TH3)\ EXP\ (-UAH/LH) \qquad \text{---------} \ (22)$$

Storage load for house heating (QSOUT)

$$QSOUT = LH \cdot (TH1 - TH4) \qquad \text{---------} \ (23)$$

(g) Main Storage Tank

Heat loss:

$$QLOSS = UAST \cdot (TA - TST) \qquad \text{---------} \ (24)$$

Heat balance:

$$\begin{aligned} \Sigma Q = {} & LS \cdot (TS4 - TST) + LP \cdot (TP2 - TST) \\ & + LH \cdot (TH4 - TST) + QLOSS \end{aligned} \qquad \text{---------} \ (25)$$

Water temperature of thermal storage:

$$TST_{(K)} = TST_{(k-1)} + \Sigma Q/V \cdot \Delta \qquad \text{---------} \ (26)$$

Where,

K : Time

Δ : Interval to be used for simulation

3.3 Remarks

(a) Gain Ratio and Shade Coefficient of Glass

Solar radiation passing through glass (including emission after absorbed by glass) was calculated in the following procedure:

Therefore, by calculating resistance at the outside surface, resistance of glasses and resistance by 40mm air gaps, KO was obtained as 3.23 $W/M^2{}_c \cdot °C$.

(c) Solar Radiation Processor

Solar radiation on the tilted surface was obtained by the use of LASL Method described in Annex 3 of July 7th, 1977 (revised on Sept. 27th, 1977).

4. Simulation Results

Output data as to punched output, hourly solar performance summary, monthly solar performance summary and yearly solar performance summary are explained in the attachment.
(The left sides are shown by the symbols described in Annexes of July 7th, 1977, and the right sides are represented by those in Fig. 1.)

Gain ratio (Gi) of glass (standard type, 3mm thick) is determined on the basis of obtained incident angles (i) on a collector.

Thus,

$$Gi = 2.3920 \cos i - 3.8636 (\cos i)^3 + 3.7568 (\cos i)^5 - 1.3952 (\cos i)^7 \quad \text{---------} \quad (29)$$

Since diffused gain of solar radiation is regarded as nondirectional, ratio of diffused gain (Gd) can be described as:

$$Gd = 2 \int_0^{\pi/2} Gi \cdot \sin i \cdot \cos i \cdot di = 0.808 \quad \text{---------} \quad (30)$$

For arbitrary types of glass, Gi is corrected by the use of shade coefficient (SCT). So, SCT of the collector of "NBS Solar House" was assumed on the basis of data indicating that the collector is composed of two panes of glass being 0.037 in glass absorptance per sheet and 1.526 in refractive index.

Thus,

Gain ratio of two paned glass (as normal incidence)

$Gi' = 0.8133$

Gain ratio of 3mm thick standard glass (as normal incidence)

$Gi = 0.889$

Therefore,

$$SCT = \frac{Gi'}{Gi} = 0.915$$

(b) Heat Transmission Coefficient of Collector Surface

For heat loss through the collector of "NBS Solar House," that through the back and side walls of collector ($KU = 0.42\ W/M^2c \cdot {}^\circ C$) only has been indicated. For the purpose of this simulation, however, heat loss through the glass surface, i.e., the front loss (KO), must also be computed.

MONTHLY SOLAR PERFORMANCE SUMMARY

Unit = kWh

Collector

1.	Collector input	$QCIN = (Ji + Jd) \cdot A$
2.	Collector output	$QCOUT = LC \cdot (TC1 - TC4)$

Storage

3.	Storage input	$QSIN = LC \cdot (TS4 - TS1)$
4.	Storage loss	$QSL = UAST \cdot (TST - TA)$

House

5.	Storage output	$QSOUT = LH \cdot (TH1 - TH4)$
6.	Auxiliary required	$QAUX = QD - QSOUT$
7.	Demand load	QD = House heating load (from tape)

DHW

8.	Storage output	$QSOUT = LCW \cdot (THW' - TCW)$
9.	Storage loss	$QSL = UASW \cdot (TSW - TA)$
10.	Auxiliary required	$QAUX = LCW \cdot (THW'' - THW')$
11.	Demand load	$QD = LHW \cdot (THW - TCW)$

Percent Solar = $(QD - QAUX)/QD$ (%)

YEARLY SOLAR PERFORMANCE SUMMARY

1. Collector area = A
2. Horizontal insolation = Jh (from tape)
3. Collector input = (Ji + Jd)·A
4. Collector output = LC·(TC1 - TC4)
5. Main storage input = LC·(TS4 - TS1)
6. Main storage loss = UAST·(TST - TA)
7. Main storage output to house = LH·(TH1 - TH4)
8. House auxiliary = (House demand) - LH·(TH2 - TH3)
9. House demand (from tape)
10. DHW storage input = LPH·(TP1 - TP2)
11. DHW storage loss = UASW·(TSW - TA)
12. DHW storage output = LCW·(THW' - TCW)
13. DHW auxiliary = LCW·(THW'' - THW')
14. DHW demand = LHW (THW - TCW)
15. House percent solar
16. DHW percent solar
17. Total percent solar

Table 4

COMPARISON OF METHODS

Quantity Measured	FINITE ELEMENT			LUMPED CIRCUIT			SIMPLIFIED		
	1	2	3	1	2	3	1	2	3
Yearly Insolation on Solar Collector (kWh)	5264	5264	5264	5264	5264	5264	5264	5264	5264
Solar Collector Gain (kWh/year)	3475	3200	3456	3478	3281	3453	3517	3216	3415
For T_c 95 Energy still recoverable (kWh)	17	0	5	9	0	4	9	0	4
Storage Tank Gain (kWh/year)	2876	2654	2791	2878	2726	2804	2881	2644	2819
Solar Hot Water (kWh/year)	2799	2596	2725	2794	2655	2727	2805	2600	2750
Auxiliary Energy (kWh/year)	2104	2307	2178	2109	2248	2176	2098	2303	2153
Total Energy for Hot Water (kWh/year)	4903	4903	4903	4903	4903	4903	4903	4903	4903
Percent Solar	57.1	52.9	55.6	57.0	54.2	55.6	57.2	53.0	56.1
Pumping Hours (hr/year)	2961	3178	3083	3069	3214	3181	3200	3165	3207

3.4 Description of the S.V.S. simulation code.

Introduction.

This program, which is developed at the Thermal Insulation Laboratory at the Technical University of Denmark, is based upon programs developed for the Zero-Energy-House by T. Esbensen and for solar heating systems by H. Lawaetz.

The program consists of a number of subroutines, which either model components or have mathematical functions. The program is quasi-stationary, meaning that energy flows within the timestep are supposed to be stationary.

Description of the computer model.

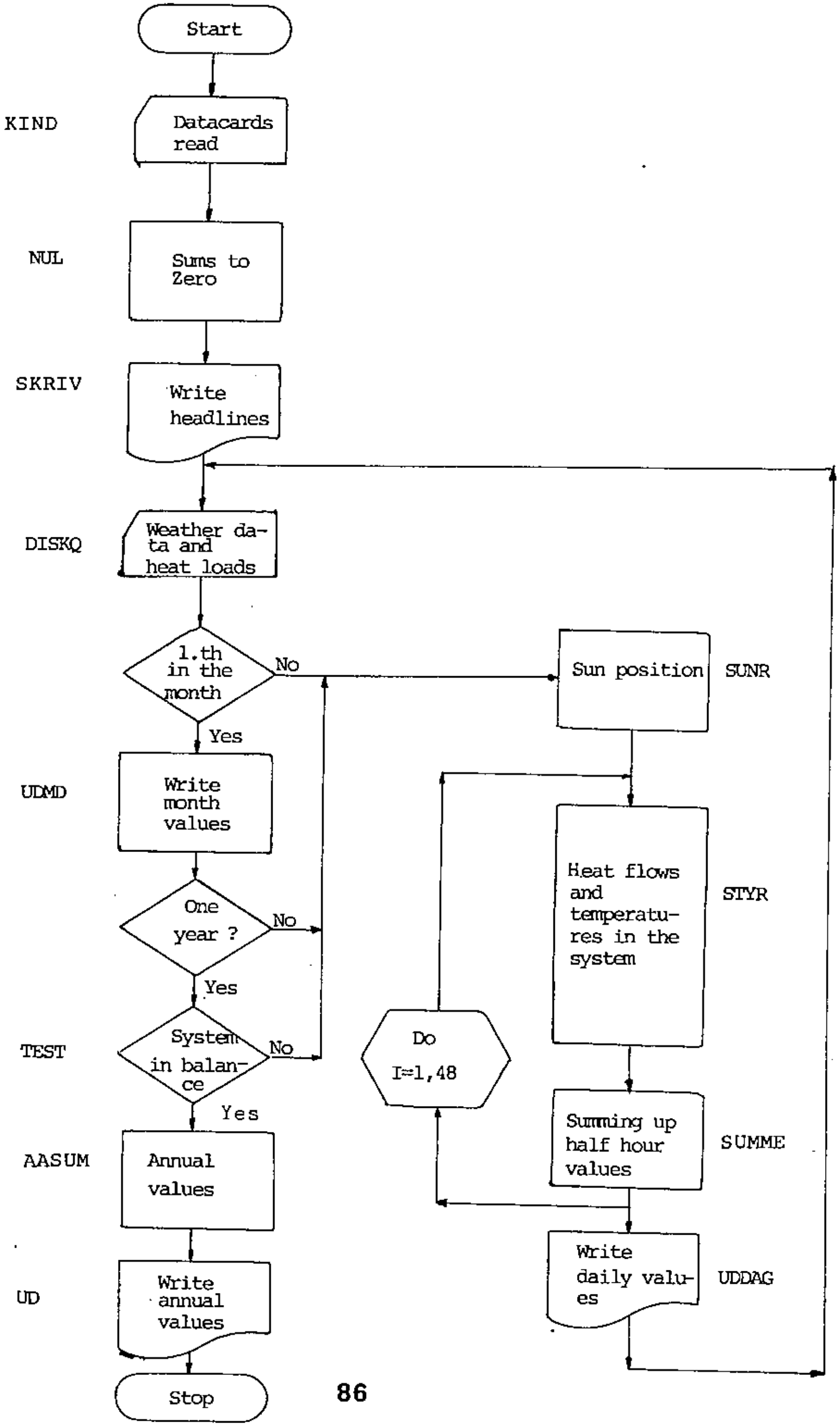
The program calculates the entire system every hour or half hour in a year, and after that a test is made upon the storage temperature. If it deviates less than 1°C from the start storage temperature the computation is stopped. Otherwise the calculation continues month by month until the storage temperature deviates less than 1°C from the temperature at the same time last year. The system in that way is in balance with the climatic data and the heat loads, so a continued calculation does not give results which differ from those last year.

The computing time will be about 1 min. for the solar water system and about 2 min. for the solar air system.

The computation is carried out by an IBM 370/165 system, compiled by a FORTG compiler. Core needed approx. 58 k + input-output buffers, total 82 k.

Depending how the climatic data and house loads are available (explained in section "Input data") the structure of the programs ready for computation may look as shown in the flowchart.

Flowchart for MAIN



The subroutine STYR controls the energy transports (heat flows) and calculates the temperatures of the system. At the moment four different STYR-subroutines exist at the laboratory for as many different solar heating systems:

1) Combined heating and PHW liquid system.
2) Combined heating and DHW air system.
3) Combined solar heating and heat pump system.
4) Liquid DHW system.

A special subroutine for calculating the pebble bed storage has been developed for the air system.

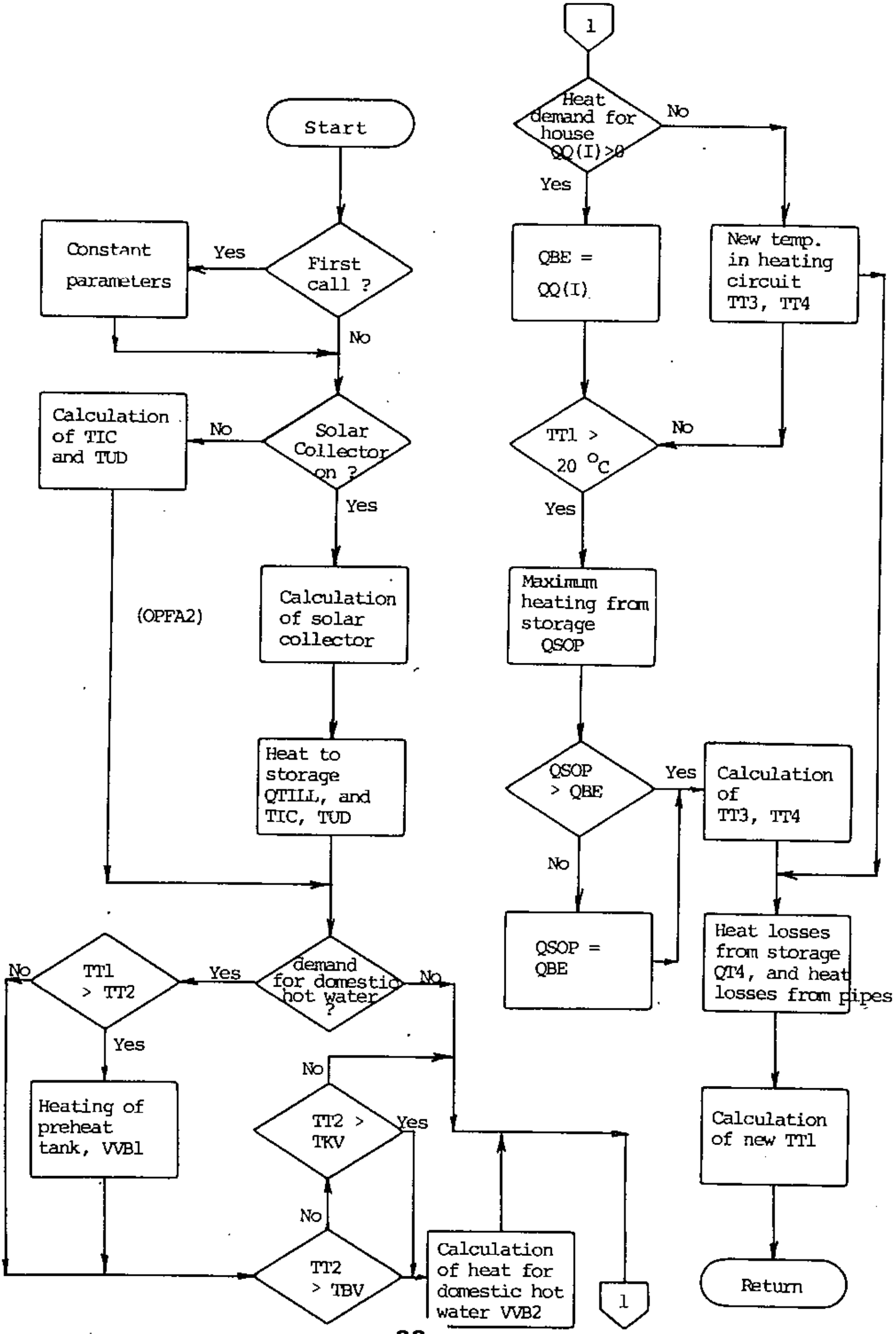
The subroutine OPFA calculates the energy gain by the solar collector. Five different subroutines exist at the laboratory, two for a one glazed water-based collector, two for a two glazed water-based collector and one for a two glazed air based collector.

Only the key subroutines used in the IEA-simulations will be described here.

Subroutine STYR for a water system.

1) At the first call the geometric parameters, the heat contents in the tanks and the heat loss coefficient are calculated.
2) The collector is calculated by calling the collector the collector subroutine.
3) The heat transported to the storage and the new temperatures of the collector circuit pipings are calculated.
4) Calculations of heat moved from storage to preheat tank by a heat exchanger and heat needed for domestic hot water from the preheat tank.
5) Calculation of heat needed for house heating from storage to house air through the coil.
6) Calculations of heat losses from the system and new temperatures in the heating circuit pipings.
7) Calculations of the new temperatures of the storage tank and the preheat tank.

Flowchart for STYR (water system)



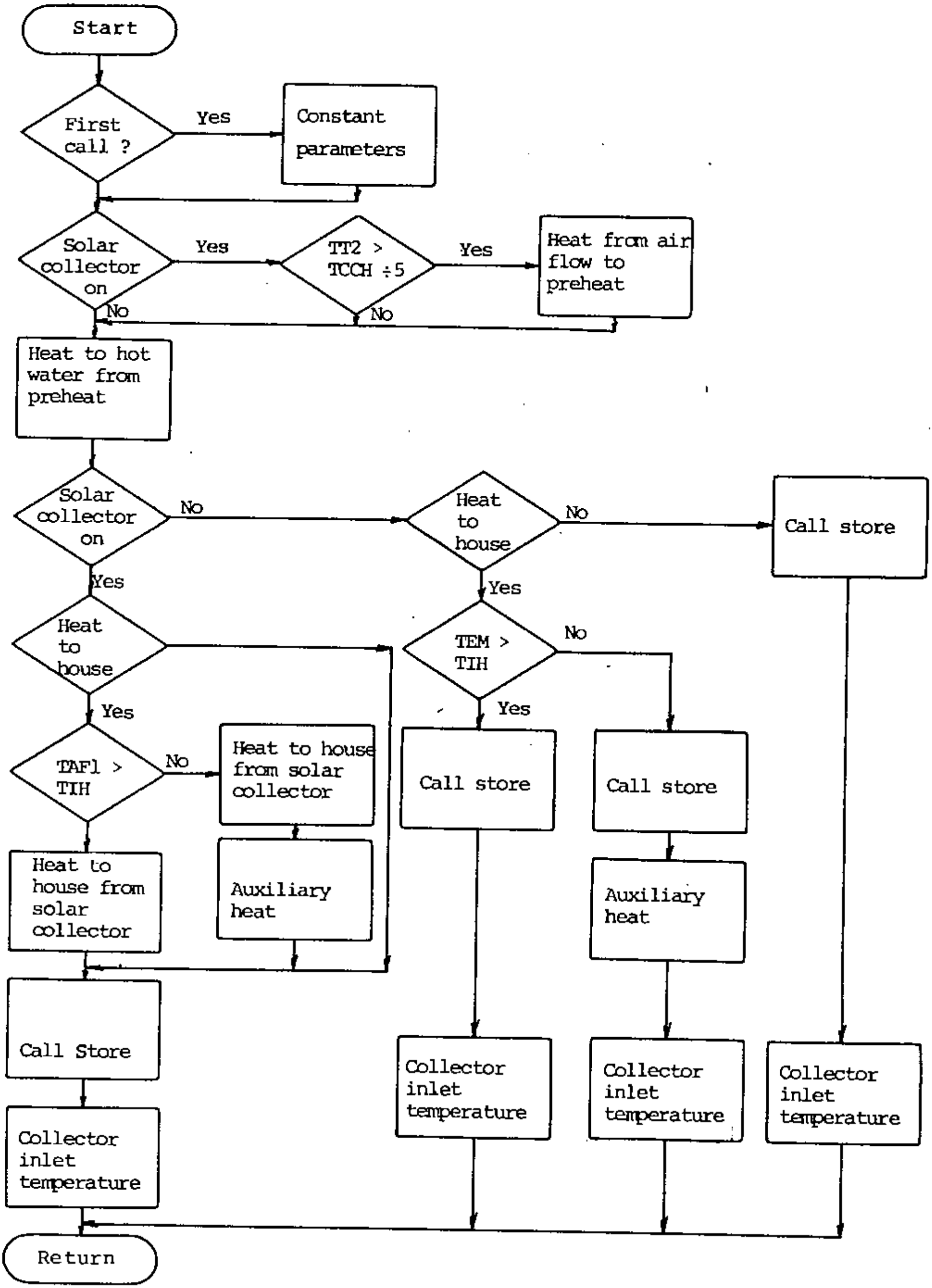
TBV	Needed temperature for domestic hot water.
TT2	Temperature of preheat tank.
TT1	Temperature of storage tank.
TIC	Inlet temperature to collector.
TUD	Outlet temperature from collector.
QTILL	Solar heat to storage.
VVB1	Heat from storage to preheat tank.
VVB2	Heat from preheat tank to domestic hot water.
QQ(I)	= QBE, Heating demand of the house.
TT4	Temperature in the heating circuit from storage.
TT3	Temperature in the heating circuit to storage.
QSOP	Maximum heating from storage.
QT4	Heat losses.
TKV	Temperature of cold water from mains.

Subroutine STYR for the air system.

1) As for the water solar system the geometric parameters, the heat contents and the heat loss coefficients are calculated at the first call.
2) The solar collector is calculated by calling the collector subroutine.
3) If the air temperature after the solar collector is 5 °C higher than the temperature in the preheat tank, heat is transported from the heat exchanger to the preheat tank.
4) Heat for hot water from the preheat tank is calculated.
5) Depending on the heat loads for the house the heat transported to the house and to or from the storage is calculated.
6) The heat losses from preheat tank and storage are calculated.

The new average temperatures of the storage and the preheat tank are calculated.

Flowchart for STYR (air system)



TT2	Temperature in preheat tank.
TCCH	Air temperature after solar collector.
TAF1	Air temperature after heat exchanger.
TIH	Demand temperature for air flow into the house.
TEM	Temperature in top of store.
Call STORE	heat losses temperatures in storage.

Subroutine STORE (Energy storage unit for air)

Assuming that Q "infinite NTU model (8) is adequate since NTU_c 10, the storage can be divided up into N sections.

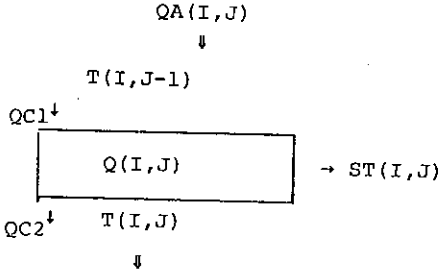
It is assumed that there are infinite heat conductions in the sections in the radial direction, but normal conduction between the elements in the axial direction. With this in mind the heat balance for each element can be calculated.

Parameter list:

T(I,J):	Temperature of element J at the time I	°C
Q(I,J):	Accumulated heat in the storage at the time I for element J	J
QTS:	Accumulated heat in half an hour	J
QA(I,J):	Heat loss from air to storage at the time I for element J	J
QAS:	Heat loss from air in half an hour	J
ST(I,J):	Heat loss to earth at the time I for element J	J
QTAK:	Heat loss to earth in half an hour	J
QC1(I,J) and QC2(I,J):	Heat conducted to and from the element J at the time I	J
MCR:	Heat capacity for an element	J/°C
MCL:	Heat capacity of the air in a time element	J/°C
KA:	The effective axial thermal conductivity during non-flow conditions for an element in a time element.	J/°C
UP:	Thermal loss coefficient for an element in a time element	J/°C
TJORD:	Temperature of the surroundings	°C
N:	Number of elements in the storage.	

a) <u>For heat entering the storage.</u>

Element nr. J at a time I:



$$(1)\quad Q(I,J) = QA(I,J) - ST(I,J) + QC1(I,J) - QC2(I,J)$$

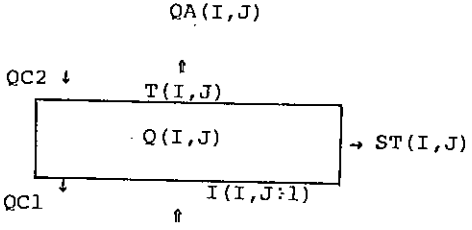
where

$$Q(I,J) = MCR\cdot(T(I,J) - T(I-1,J))$$
$$QA(I,J) = MCL\cdot(T(I,J-1) - T(I,J))$$
$$ST(I,J) = UP\cdot(T(I,J) - TJORD)$$
$$QC1(I,J) = KA\cdot(T(I,J-1) - T(I,J))$$
$$QC2(I,J) = KA\cdot(T(I,J) - T(I,J+1))$$

The only unknown in equation (1) is now T(I,J)

$$(2)\quad T(I,J) = [MCL\cdot T(I,J-1) + MCR\cdot T(I-1,J) + KA\cdot(T(I,J-1) + T(I-1,J+1))\cdot UP\cdot TJORD] / (MCL + 2KA + UP + MCR)$$

b) Heat out of the storage.



Heat balance.

Q(I,J) = QA(I,J) - ST(I,J) + QC1(I,J) - QC2(I,J)

The index J is now switch (N → 1 and 1 → N) so the air flow still enters element number 1 first. This means that T(I,J) can be calculated with the same equation (2) as before.

When equation (2) is written for each element, it is possible to form a matrix equation which can be solved by matrix-inversion. The outlet air temperature is found from

TUS = TIS - QAS/TMCL

Subroutine OPFA

This subroutine calculates the solar collector and is called every half hour from STYR.

Mathematical description.

The principles of the calculation are with a few corrections the same as those used by Lawaetz (1) and Esbensen (2).

Depending on the sun's position the incidence angle of beam radiation on the collector surface can be determined as (5)

$$\cos(I) = \cos(HD) \cdot \cos(AZ-AF) \cdot \cos(T) + \sin(HD) \cdot \sin(T)$$

The transmittance for a single glass cover is (3)

$$TR = e^{-KL} \cdot (1-RE)/(1+RE)$$

where K is the extinction coefficient and L is the thickness of the glass, and the reflection factor RE is determined of Fresnels formular (5)

$$RE = \tfrac{1}{2} [\sin^2(I-IB)/\sin^2(I+IB) + \tan^2(I-IB)/\tan^2(I+IB)]$$

where $\sin(IB) = \sin(I)/N$

That part of the beam radiation which is absorbed by the collector with the absorptance α is (3)

$$FE = 1.012 \cdot TR^2 \cdot \alpha + 0.17(1-e^{-KL}) + 0.63 \cdot TR \cdot (1-e^{-KL})$$

That means that out of the total amount of beam radiation hitting the outside of the collector the absorbed amount is

$$QDIR = FE \cdot (1-D) \cdot (1-S) \cdot DIR$$

Where D is the correction for dirt on the cover glass and S the correction for the shadow on the absorber. D is found to be between 0 and 4% (3), and are in these calculations 2% as an average.

The diffuse radiation comes from different directions and therefore the transmittance is calculated with an average incidence angle in these calculations. This angle is estimated to 50 degrees (from 3).

The heat removed by the water is calculated as the difference between the absorbed heat and the heat losses

$Q = QTOT - QLOSS$

The heat loss UP through the cover glasses is a combination of radiation, convection and conduction, and is rather complicated to calculate. It is necessary to use an iteration to find the heat balances between the air and glasses.

The coefficient of heat losses are calculated in (5), and will not because of their complexity be reproduced here. However, it shall be mentioned, that the convective coefficient between the top cover and the outside air is calculated as:

$HW = (1 + 0.3W) \cdot 5.67 \quad W/m_e^2 \cdot {}^{o}C$

where W is the windspeed in miles/h and 5.67 the ratio between $Btu/ft^2 \cdot h \cdot {}^{o}F$ and $W/m^2\ {}^{o}C$.

The heat loss through the side edges is also difficult to calculate and is therefore estimated to be 5% of the front heat losses (2).

The heat transfer coefficient for the backside can be found as

$UR = \lambda/e$

Where λ is the isolation heat conductivity and e the thickness of the isolation.

The total heat loss coefficient therefore is:

$Ul = UP \cdot (1 + 0.05) + UR$

Calculations of the utilized heat.

The heat exchanger factor is here called F3. And it forms together with the solar collector efficiency factor (F1) and the fluid flow factor (F2), the solar collector equation:

$$q = F1 \cdot F2 \cdot F3 \cdot (QA2 - UL2(TT1 - TA)) \qquad (1)$$

In this equation:

QA2 is the collection rate of solar radiation in W/m^2.

q is the final collection rate of heat in the solar collector.

UL2 is the heat loss coefficient of the collector in $W/{}^{o}C$.

TT1 is the storage temperature.
TA is the ambient temperature.

F2 is given by: $F2 = \frac{1-e^{-H}}{H}$

where $H = \frac{F1 \cdot UL2}{FLOW}$, and FLOW is the capacity flow of the fluid in W/°C.

There are two parameters, which determine the heat exchanger. That is the heat exchanger effectiveness, ϵ, and the number of tranfer unit, NTU.

The definition of NTU is $NTU = \frac{UAx}{FLOW}$

where UAx is the UA product of the heat exchanger, and the definition of the heat exchanger effectiveness is:

$$\epsilon = \frac{TUD - TIC}{TUD - TTI} \qquad (2)$$

TUD is the outlet temperature of the solar collector, and TIC is the inlet temperature.

A presumption of the two above equations is that the capacity flow of the collector loop is lower than the capacity flow of the storage loop (FLOC).

In the program we are now able to calculate the heat exchanger effectiveness, ϵ, as a function of NTU and R, by the help of the heat exchanger equation:

$$\epsilon = \frac{1 - EXP(- NTU \cdot (1 - R))}{1 - R \cdot (EXP(- NTU \cdot (1-R)))} \qquad (3)$$

$$R = \frac{FLOW}{FLOC}$$

for $FLOC = \infty : \epsilon = 1 - EXP(- NTU)$

$FLOC = FLOW: \epsilon = NTU/(1 + NTU)$

For the solar collector we have the heat balance

$$q = FLOW(TUD - TIC) \qquad (4)$$

Combined equations (1), (2) and (4) yield

$$q = \left[\frac{F1 \cdot F2}{1 + \frac{UL2 \cdot F1 \cdot F2}{FLOW}\left[\frac{1}{\epsilon} - 1\right]}\right] \cdot (QA2 - UL2(TT1 - TA))$$

Comparing this equation whith equation (1) the heat exchanger factor is given by:

$$F3 = \frac{1}{1 + \frac{UL2 \cdot F1 \cdot F2}{FLOW}\left[\frac{1}{\epsilon} - 1\right]}$$

The product F2 · F3 is now given as a function of only $H = \frac{F1 \cdot UL2}{FLOW}$, and ϵ :

$$F2 \cdot F3 = \frac{1-e^{-H}}{H} \cdot \left[\frac{1}{1 + H \cdot \left[\frac{1-e^{-H}}{H}\right] \cdot \left[\frac{1-\epsilon}{\epsilon}\right]}\right]$$

$$= \underline{\underline{\frac{1-e^{-H}}{H(1+(1-e^{-H}) \cdot \left(\frac{1-\epsilon}{\epsilon}\right)}}}$$

The program will now calculate F3 as:

$$\underline{\underline{F3 = \frac{F2 \cdot F3}{F2}}}$$

Subroutine SUNR. (Sun radiation processor)

Algorithms.

This subroutine calculates the time SO and SN for sunrise and sunset, the sun's altitude H and azimuth AS for each half-hour, and the day number DN in the year. Simplified, the longer duration of the summer half than the one of the winter half, the refraction, and the equation of the time are counted in. Then the normal, diffuse, and the total radiation are calculated for clear weather conditions, and depending on the fraction between the measured total radiation and the calculated total radiation, the actual diffuse and normal radiation can be calculated.

Procedure and definitions.

DN 1 to 365.

Calculation of the equation of time TEQ, in minutes:

$1 \leq DN < 21 \qquad TEQ = -2.6 - 0.44 \cdot DN$

$21 \leq DN < 136 \qquad TEQ = -5.2 - 9.0 \cdot \cos((DN-43) \cdot 0.0357$

$136 \leq DN < 241 \qquad TEQ = -1.4 + 5.0 \cdot \cos((DN-135) \cdot 0.0449)$

$241 \leq DN < 336 \qquad TEQ = 6.3 + 10.0 \cdot \cos(DN-306) \cdot 0.0360)$

$336 \leq DN = 365 \qquad TEQ = -0.45 \cdot (DN-359)$

The local time (-9.7 min. for Copenhagen), is added, and TEQ is converted into angle of time:

$TET = (TEQ + LOCALT)/60$

$TEQ = TET \cdot \pi/12$

The declination of the sun VA:

$$DF = DN \cdot \pi/182.5$$

$$VA = 0.33 - 22.96 \cdot \cos DF + 4.0 \cdot \sin DF - 0.37 \cdot \cos 2DF - 0.15 \cdot \cos 3DF$$

Sunrise and sunset:

$$TON = 12/\quad \cdot \arccos(\sin BR \cdot \sin VA + 0.01)/(\cos BR \cdot \cos VA))$$

$$SO = TON - TET \quad \text{(sunrise)}$$

$$SN = 24. - TON - TET \quad \text{(sunset)}$$

Half-hour angle, $I = 1$ to 48

$$TP = I \cdot \pi/24 + TEQ$$

Altitude of the sun:

$$\sin H = \sin VA \cdot \sin BR - \cos VA \cdot \cos BR \cdot \cos TP$$

Azimuth:

$$\cos AS = AN = (\sin BR \cdot \cos VA \cdot \cos TP + \cos BR \cdot \sin VA)/\cos H$$

Refraction (when $H > -0.005$, corresponding to about -0.3°)

$$H = H + 0.000225/(H + 0.023)$$

If the refraction and the longer duration of the summer half are neglected, it will give the length of the day an error of up to 12 - 13 min. at equinoxes.

Subroutine DISKQ

The subroutine is called once for every day from MAIN, and following list gives the variables and the arrangement of data in the card picture.

		Unit	Format	col
NMD	Month	-	12	11-12
NGD	Day	-	12	14-15
IHOUR	Hour	-	12	17-18
ISOLAR	Global radiation	W/m^2	14	20-23
IWS	Wind speed	m/s	12	25-26
(converted to FF		knots)		
DB	Temperature	^oC	F5.1	28-32
ITC	Cloud cover	1/10	13	46-48
(converted to NN		1/8)		
ISOLD	Diffuse radiation	W/m^2	14	50-53
(converted to IDIFF		W/m^2)		
QLOAD	House load	kW	F6.2	55-60
(converted to QQ		W)		

Subroutine TEST

With this a test is made upon the storage temperature. If the temperature deviates more than 1^oC from the value it had last year the sum counter of the next month is put to zero position and the calculation continued for the next month. If not the calculation is stopped. The subroutine is called from MAIN once a month.

Some program problems.

1) As described earlier the program is built up for calculating the IEA water system. If these systems do not describe the user's actual system, a new control routine STYR has to be written. An important thing to remember is to use the common blocks right, because they are the key in connecting the subroutines. Also the user has to remember that subroutine OPFA is called from STYR.

2) If the input data are not available in the expected form the routine DISKQ has to be changed.

3) Some of these problems will be solved in the coming editions and some of the routines will be split up in two or three, so they become simpler and easier to understand and change.

4) Routines for calculation of a solar system with a heatpump are existing at the laboratory and can be added if wanted.

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3.5 Philips Research Laboratory Aachen (PFA)

R. Bruno and V. Brombach

Finite Element Method

Introduction

In the finite element approach an energy system is broken down into segments of a given heat capacity and/or thermal response. These finite elements are defined in such a way that the most important temperature gradients, heat and mass transfers are properly accounted for. It was found for solar energy systems that only a two dimensional finite element treatment (in the mass flow direction and perpendicular to it) was necessary for most components. The determining criteria for this being that the total calculation error is less than about 10^{-4} over the time periods (day, month, year) considered.

IEA study,it was found that with element sizes of

(i) Water System: 10 Wh/°C fluid capacity for Madison, Aachen, Denmark, Tokyo
and 5 Wh/°C fluid capacity for Santa Maria.
(ii) Air System: 10 Wh/°C blown air volume element for Madison, Aachen, Denmark, Tokyo
and 5 Wh/°C blown air volume for Santa Maria.

the various errors did not exceed:

(i) round-off error $\epsilon_{rd} < 1/25000$
(ii) element size error $\epsilon_{ez} < 4/10000$
(iii) time step error $\epsilon_{ts} < 1/10000$

over a day, month or year.

Two basic approaches are available in this method for calculating the effect of fluid flow. The first considers laminar flow and the second turbulent flow. For all cases considered here only turbulent flow was taken.

This program also takes as input data two constants related to temperature measurements. First, the heat capacity of a measuring device (C_{TEMP}) and second its measurement accuracy ($\epsilon_{TEMP.}$). By using the appropriate values of C_{TEMP} and ϵ_{TEMP} comparison can be made directly with experiment. In the calculations made here C_{TEMP} was taken to be 0.1 Wh/^oC and ϵ_{TEMP} had two values depending on the measurement position and program run. The two values used were $\epsilon_{TEMP} = \pm 0.01^oC$ and $\epsilon_{TEMP} = \pm \epsilon_{COMP.\ RD.-OFF}$. It should be mentioned that in all runs made here temperature differences were considered as differences between two absolute temperatures.

The reduced finite element program sizes are not larger than 31 K bytes.

3.1 b Conditional Transfers

Three conditional transfer constants are read by these programs which enable one or another segment of the program to be activated. They are constants indicating whether:

(i) to cool or not to cool
(ii) a short circuit start should be activated or not
(iii) a set of pipes/ducts are used in common for both heating and cooling modes or not.

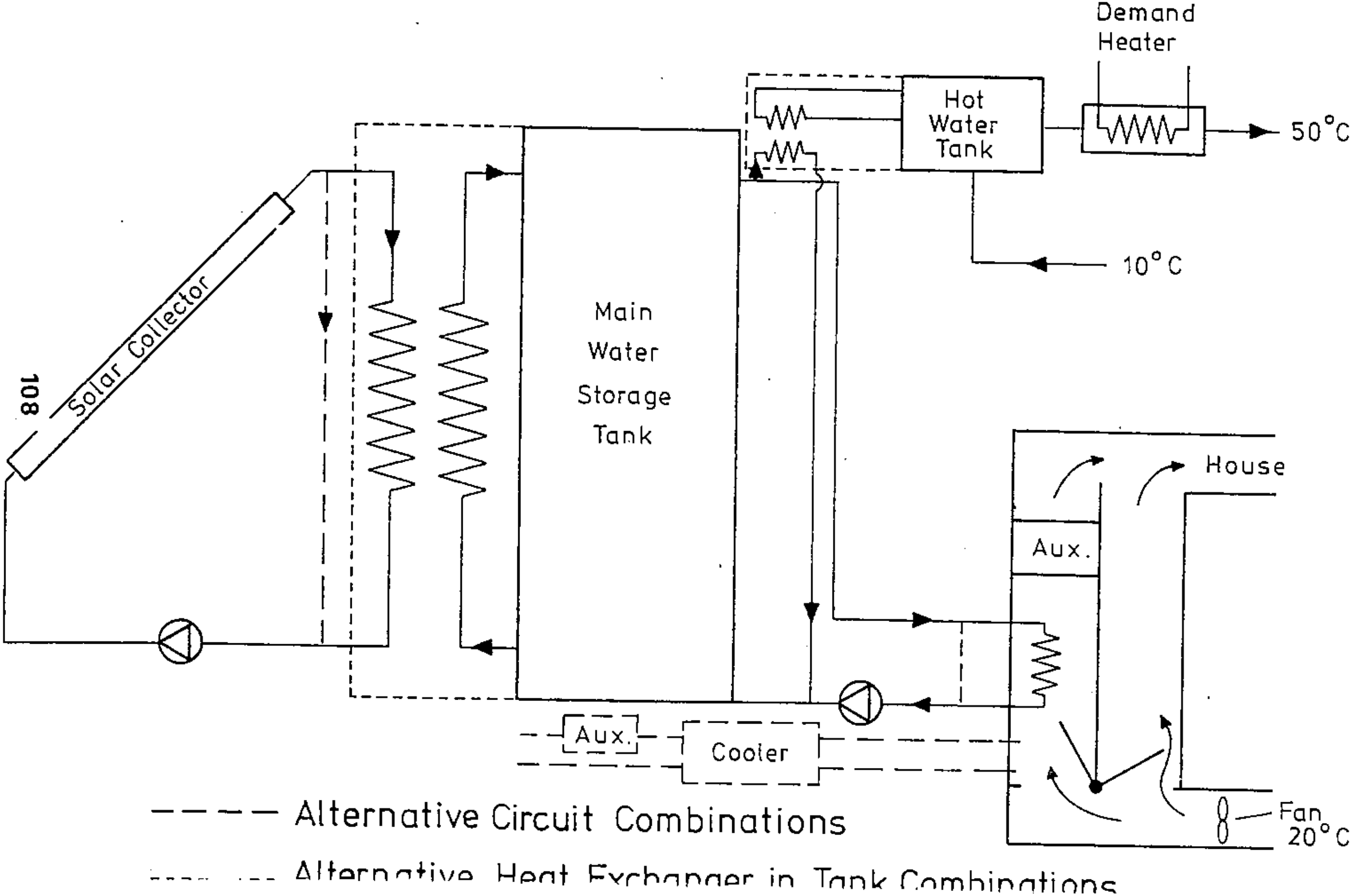
Since these finite element programs took about 13 hours computime per year's run on the P880 the start-off initialization considered here was to have all temperatures at hour 1 on January 1st set at 20^oC. That is to say the program is not self-consistent.

In both programs all energy circuits had ON delays (see Tables 2.1 e and 2.2 e). The reason for this was that otherwise too many ON/OFF switchings occurred in the circuits. This is also an approach which is used experimentally.

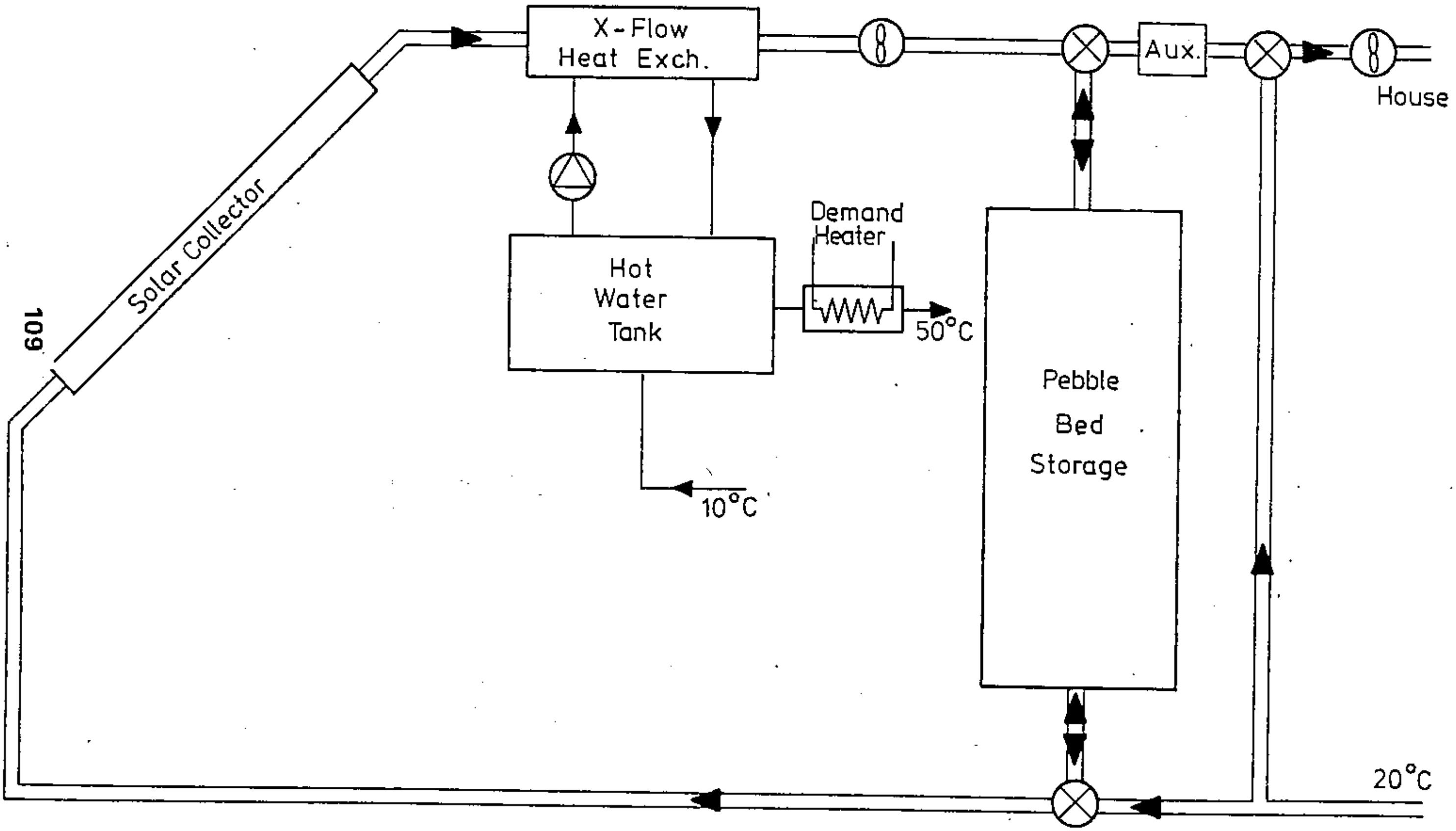
Energy Systems

The two energy systems and their variants considered are given in Figures A 1 and A 2. Fig. A 1 gives the water system where for the finite element model short circuit delays were tried out as well as containing heat exchangers within the storage tanks. Fig. A 2 shows the circuits used in the air system. It should be mentioned that the simplified method did not use two tanks for the water system but assumed that both tanks were effectively combined. This is a sensible assumption as seen from the finite element results for the average tank temperatures over a month. This is so since a large enough heat exchanger and fluid flow was used. For the air system an effective main storage tank was set for the simplified method that had the same effective heat loss as both tanks together and also their combined heat capacity. The stratification effect as well as the hot water heat exchanger in the simplified method were then simulated by an effective heat exchanger in the main storage tank. These values are contained in the input data (e.g. Fig. D 7) for the simplified method.

A 1 Liquid Solar System



A 2 Air Solar System



2. Hot Water Circuit Table

PREH TKGN = The energy gain of the hot water storage tank in kWh.

SOLAR HW = The amount of solar energy given to the hot water produced in kWh.

AUX HOTW = The auxilliary energy required for hot water production in kWh.

TOT HOTW = Total energy required for hot water production in kWh.

AV PTK TEMP = The average temperature of the hot water storage tank.

3. Table for Heating and Cooling Loops

TK HTL = The energy drawn from the main tank to satisfy the heat load in kWh.

SOL HT = The amount of solar energy given to the heating coil in kWh.

AUX HT = The auxilliary energy required for heating in kWh.

TOT HT = The total energy required for heating in kWh.

AV $TEMP_1$ = The average temperature of the main storage tank in ^oC.

TK CLL = The energy drawn from the main tank to satisfy the cooling load in kWh.

SOL CL = The amount of solar cooling energy given to the house in kWh.

AUX CL = The amount of auxilliary cooling energy given to the house in kWh.

TOT CL = The total cooling demand of the house in kWh.

For the air system two additional results are written, they are:

Hot Water Circuit Table

TK HEAT LOSS = The total heat loss of the hot water storage tank in kWh.

Table for Heating and Cooling Loops

AV TEMP$_2$ = The average of the temperature difference between the top and bottom of the main storage tank in ^{o}C.

J9430/1/PBA/FCO

3.6 Faber

FABER COMPUTER
OPERATIONS LIMITED

UPPER MARLBOROUGH ROAD
ST ALBANS HERTS AL1 3UT
TELEPHONE: ST ALBANS 61222
TELEX: 889072

Date : 19th May 1978

Name : **P B Anderson**

Title : Solar Simulation System - Liquid

Project : I.E.A. Study on Solar Heating and Cooling

Contents :

I General Description

a) Objectives

The objectives of writing a computer program to simulate solar heating and cooling systems were:

to assist engineers in their designs.

to study various systems and find the minimum economic cost.

to vary installation parameters of a particular system and find its optimal running characteristics.

b) Main Components

Collector
- single or double glazing
- absorber surface
- wind, back and side losses
- heat exchange to transport medium
- heat capacity

Plumbing
- heat loss to surroundings
- heat capacity of pipes

Collector/Storage Heat Exchanger

Thermal Storage
- mixed tank
- heat loss to ambient

House Distribution	- heat exchange to finned tube coil - auxiliary as required
Domestic Hot Water Supply	- preheat tank coupled to main storage tank through heat exchanger - auxiliary as required
Input Data	- collector, storage and preheat tank, domestic hot water and house distribution load specification - weather data horizontal radiation, dry bulb temperature, wind speed, house loads

II Computer Model

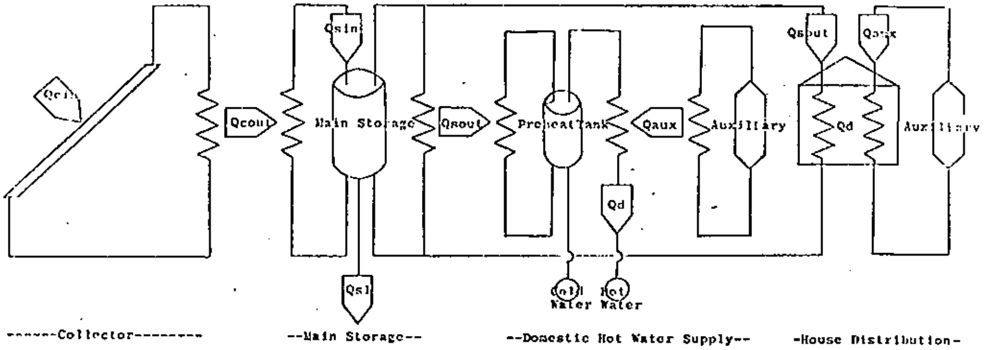


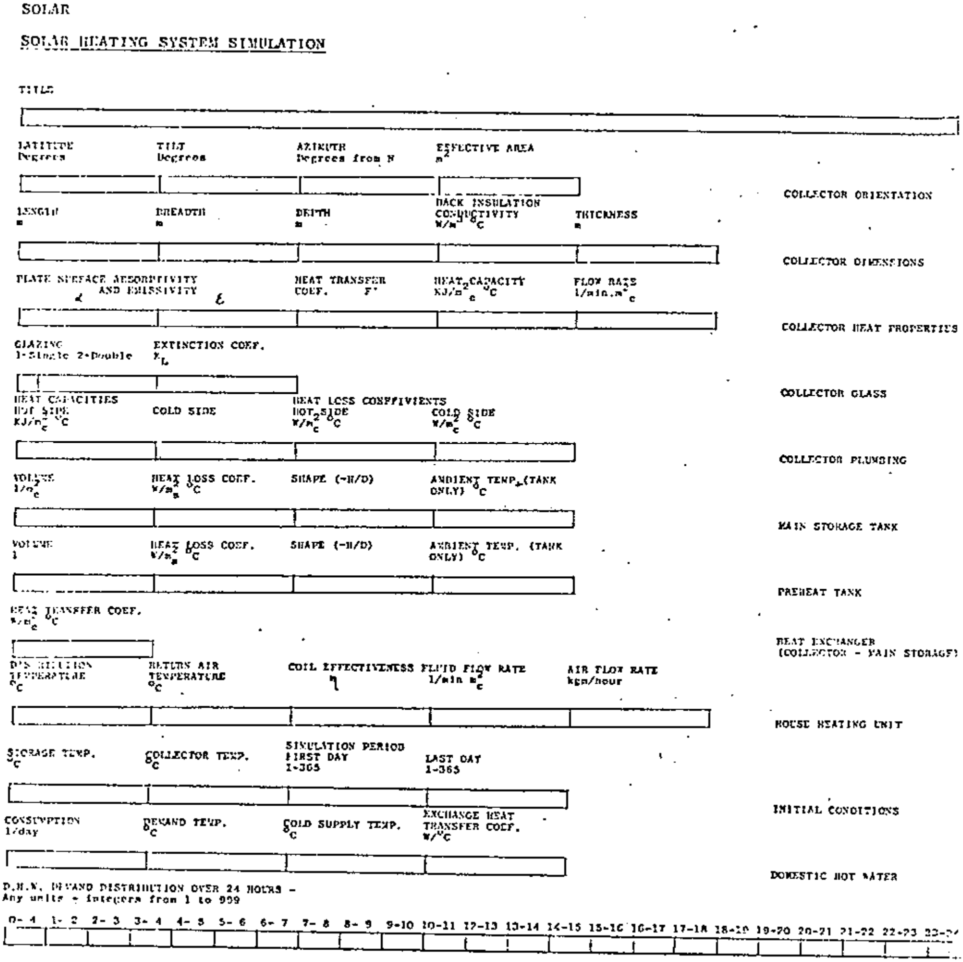
Figure 1 : Solar Model Diagram

a) System

The schematic drawing of the solar system model is given in Figure 1. The simulation period is initially for a year, but shorter intervals can be analysed. The time step is at discrete hourly intervals. For a yearly run the central processing time is four minutes.

b) Input Data

The input data is divided into two distinct pieces of information; Solar System Specification, outlined in Figure 2; Weather data, as supplied from the operating agent, in particular horizontal radiation, dry bulb temperature, wind speed, and house loads.



SOLAR

SOLAR HEATING SYSTEM SIMULATION

TITLE

COLLECTOR ORIENTATION

LATITUDE Degrees	TILT Degrees	AZIMUTH Degrees from N	EFFECTIVE AREA m^2

COLLECTOR DIMENSIONS

LENGTH m	BREADTH m	DEPTH m	BACK INSULATION CONDUCTIVITY $W/m^2\,°C$	THICKNESS m

COLLECTOR HEAT PROPERTIES

PLATE SURFACE ABSORPTIVITY AND EMISSIVITY α	ε	HEAT TRANSFER COEF. F'	HEAT CAPACITY $KJ/m^2_c\,°C$	FLOW RATE $l/min.m^2_c$

COLLECTOR GLASS

GLAZING 1=Single 2=Double	EXTINCTION COEF. K_L

COLLECTOR PLUMBING

HEAT CAPACITIES HOT SIDE $KJ/m^2_c\,°C$	COLD SIDE	HEAT LOSS COEFFIVIENTS HOT SIDE $W/m^2_c\,°C$	COLD SIDE $W/m^2_c\,°C$

MAIN STORAGE TANK

VOLUME l/m^2_c	HEAT LOSS COEF. $W/m^2_s\,°C$	SHAPE (=H/D)	AMBIENT TEMP. (TANK ONLY) °C

PREHEAT TANK

VOLUME l	HEAT LOSS COEF. $W/m^2_s\,°C$	SHAPE (=H/D)	AMBIENT TEMP. (TANK ONLY) °C

HEAT EXCHANGER (COLLECTOR - MAIN STORAGE)

HEAT TRANSFER COEF. $W/m^2_c\,°C$

HOUSE HEATING UNIT

DISTRIBUTION TEMPERATURE °C	RETURN AIR TEMPERATURE °C	COIL EFFECTIVENESS η	FLUID FLOW RATE $l/min\ m^2_c$	AIR FLOW RATE kgm/hour

INITIAL CONDITIONS

STORAGE TEMP. °C	COLLECTOR TEMP. °C	SIMULATION PERIOD FIRST DAY 1-365	LAST DAY 1-365

DOMESTIC HOT WATER

CONSUMPTION l/day	DEMAND TEMP. °C	COLD SUPPLY TEMP. °C	EXCHANGE HEAT TRANSFER COEF. W/°C

D.H.W. DEMAND DISTRIBUTION OVER 24 HOURS -
Any units - integers from 1 to 999

0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24

Figure 2 : Solar System Computer Specification

c) Output

Month - month of the year (1 to 12)
Qcin - Collector Input
Qcout - Collector Output
Qsin - Storage Input
Qsout - Storage Output
Qsl - Storage Loss
Qaux - Auxiliary Supplied
Qd - Demand Load
% House - Percentage Solar for House Distribution
% DHW - Percentage Solar for Domestic Hot Water
% Total - Percentage Solar of Total

III Individual Components & Subroutines

The general discription of the program is given in Figure 3.

a) Solar Collector

At discrete hourly intervals; horizontal solar radiation is converted into total incident radiation on the collector surface using the specified 'LASL' routine, this energy is transferred into the energy transport medium which in turn is supplied to the collector-storage heat exchanger. The energy input to the collector system simulator and the net energy output being 'Qcin' and 'Qcout' respectively. The theory used in the collector simulator is the Klein formula (1973) using Hottel and Woertz methods, and in the collector heat balances converging iterative procedures which take into account capacities, losses, heat exchange rates, and the storage temperature.

b) Energy Storage Unit

The storage energy balance, measured by the varying temperature, is calculated from; the hourly net gain from the collector circuit 'Qsin', and the hourly net loss to the space heating and hot water supply 'Qsout' and 'Qsl'. The auxiliary and demand load are given by 'Qaux' and 'Qd' respectively.

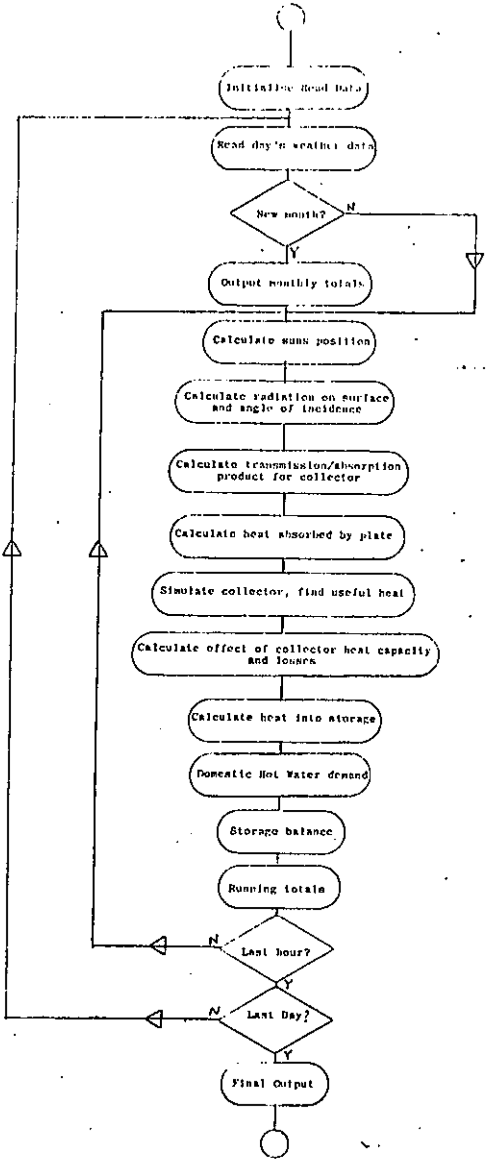


Figure 3. Flowchart of Simulation Program

IV Programming Problems

a) Weather Data

The weather data for Madison had to be modified to correct missing data. To overcome the problem, the weather data was modified by taking the average from the preceding hour and the next hour.

b) Controls

The controls have been slightly modified, so that the maximum amount of energy is transferred from the collector to the storage medium.

c) Ambient Temperature for Calculating Heat Loss

The ambient temperature has replaced the dry bulb temperature for the calculation of heat losses. The dry bulb temperature is still used for calculating losses on the collector. i.e. top, side and back losses.

d) Incident Insolation

The incident insolation on the collector was calculated by the Boes correlation from the horizontal insolation provided on the weather tape. For the Hamburg simulation runs the incident insolation calculated by the Boes correlation method was higher than the actual data supplied. For the final Hamburg simulation run, the diffuse radiation from the weather tape was used to calculate the total incident radiation on the collector.

V Discussion of Results

The results for the three locations are similar to the other participants, but slightly biased on the lower side. The reason for the results being slightly biased may be due to many factors which will only be shown up in the validation subtask.

3.7 DESCRIPTION OF FTP SOLAR ENERGY SYSTEM SIMULATION PROGRAM

Federico Butera-Istituto di Fisica Tecnica-Palermo-Italy.

1. General description of the system

a) Objective.

Many small consultant firms or small factories beginning to deal with solar energy do not find it convenient to work with big computers and very often own small desk-computers. On the other hand up to now the simulation models available have been prepared for big computers.

For this reason a simulation model has been developed at the Istituto di Fisica Tecnica of Palermo University to be used with a Hewlett Packard 9830 desk-computer.

The FTP Solar Energy Simulation program is a versatile and reasonably reliable tool for evaluating the effect of parameter changes on the overall system performance.

The code written is only for water systems, and can be used also by unqualified personnel, because once the program is loaded, the input data are requested one by one on the computer's display, and given through the key-board.

b) Main components.

The flat plate collectors are connected to the storage tank via a heat exchanger.

The main tank is fully mixed, and the water flows from it to the heating coil.

Two types of connection between tank and HVAC system are possible.

- The auxiliary heat is given by means of a second water-to-air heat exchanger (IEA system).

- The auxiliary heat is given in alternative to the solar with a three-way valve which excludes the tank and activates the furnace. Only one heating coil is therefore provided.

The same storage tank is used for the DHW system. Feed water enters the tank in a separate coil. Preheating of DHW is therefore always provided.

The controls are:

- on-off for the collector pump
- mixing valve for the HVAC system

The main input data used are:

- horizontal solar radiation (hourly)
- wind speed (hourly, if available)
- d.b. temperature (hourly)
- heating load (hourly, if available. If not, the heating load is calculated hour by hour on the basis of the inside-outside temperature difference).

2. Description of the computer model

The calculations are performed with a time-step of 1 hour, for all the 8760 hours of a year.

The computing time is 3.5 hrs.

a) <u>Input data.</u>

-Weather data

-Latitude of location

-Collector tilt

-Transmission-absorbtion product (normal incidence)

-Absorber efficiency factor

-Overall loss coefficient U_L (or five matrixes, as explained in the next paragraph)

- -Collector coolant flow rate
- -Collector area
- -Storage tank volume
- -Heat exchanger (collector-tank) effectiveness
- -Inlet water temperature (DHW)
- -Required water temperature (DHW)
- -DHW daily usage pattern
- -Daily hot water requirement
- -Overall building heat losses (if hourly load is not available)
- -Water-to-air coil efficiency
- -Inside temperature profile

b) Output data.

For each month the following outputs are given:

- -Mean daily horizontal solar radiation
- -Mean daily solar radiation incident on the tilted collector surface.
- -Collector output
- -DHW solar
- -DHW auxiliary
- -DHW demand
- -House solar
- -House auxiliary
- -Total heating load
- -Collector efficiency
- -DHW percent solar
- -House percent solar
- -Total percent solar
- -Average tank temperature

The same outputs are provided on yearly basis.

3. Description of the individual components and subroutine.

a) Solar collector

Energy gain E which -hour by hour - is transferred to the coolant fluid in the collector is calculated with the Hottel-Willier-Bliss equation, modified according to De Winter to include the heat exchanger between collectors loop and tank:

$$E = F_R\, F''\, A\, [H_T\, (\tau\alpha)_e - U_L\, (t_s - t_a)] \qquad 1)$$

where

$F_R = [(Gc_p)/U_L]\ [1-\exp(-F'U_L/Gc_p)]$

c_pG=capacitance rate

F' =plate efficiency factor

U_L =overall heat loss coefficient

$F'' = 1/[1+(F_R\, U_L/Gc_p)(1/\varepsilon-1)]$

ε =heat exchanger efficiency

A =collector area

$(\tau\alpha)_e$=effective transmission-absorbtion product

H_T =total solar radiation incident on the tilted surface

ts =storage tank temperature(no stratification)

ta =ambient temperature

$\underline{c_pG, F', \varepsilon, A}$ are given, for each system simulated,as input.

$\underline{H_T}$ is generally (not for IEA runs) calculated with the Liu and Jordan procedure for evaluating diffuse radiation.

$(\tau\alpha)_e$ is a function of the angle of incidence of solar radiation.The value at normal incidence $(\tau\alpha)_n$ requires to be known (either from tests or from calculations).

$\underline{F'}$ is given as input

U_L can be either constant (as input) or variable as a function of ta,ti H_t and V (wind speed) as follows: before the hourly calculations begin, a subroutine builds up-by numerical iteration- a set of five matrices (10x10), containing values of U_L. In each matrix the 100 values of U_L are calculated for a given value of $H_T\ (\tau\alpha)_e$ (200W/m^2 the first matrix,400 W/m^2 the second, up to 1000 W/m^2 the fifth), for 10 values (10 to 100 °C of ti and for 10 values (1 to 9 m/sec) of V. The value of ta is considered constant for all the matrices and equal to 0 °C.

Each hour, when the value of U_L is required as a function of the operating conditions of the collector, the appropriate U_L is calculated with linear interpolation from the values contained in the matrices.

With this procedure is avoided the need to proceed to a numerical iteration each time step, saving computing time.

The subroutine for the U_L matrices requires as input the collector tilt, fluid flow rate, number of covers, F', plate absorbance and emittance, glazing transmittance.

Collectors control is based on the conditions:

$E = 0$ if $H_T\ (\tau\alpha)_e < U_L\ (ts-ta)$

$E = 0$ if $ts \geq 100\ ^{o}C$

otherwise E has the value given bu eqn. 1).

Heat capacity of the collector and piping losses are neglected.

b) Energy storage unit.

Only one storage tank is considered, and each hour the new temperature is found with the simple heat balance

$$ts^{new} = ts^{old} + (E-Q_L-Q_A-Q_D)/Mc_p$$

where:

E = collectors energy gain

Q_L = solar heating load

Q_A =solar DHW load

Q_D =tank losses

Mc_p=thermal capacity

c) Solar heating load calculations

Solar heating load is calculated as follows:

Mode 1) $Q_L = 0$ if $q(ts-ti) < Q'_L$

$Q_L = Q'_L$ otherwise, where

q = design load/(coil design temp.-air temp.)

Q'_L = heating load (required)

ti = air temperature (ambient, internal)

Mode 2) $Q_L = q(ts-ti)$ if $Q_L \leq Q'_L$

$Q_L = Q'_L$ otherwise

4. Discussion of the major programming problems and comparison.

a) The basic need of a computer model to be used with a desk-computer is to optimize the running time and the accuracy. Because of the running time the time step cannot be chosen smaller than 1 hour.

With such a time-step it is impossible to introduce in the program the required condition

$E > 0$ (Tcoll.out-Tcoll.in.) $> 5\ ^{o}C$

$E = 0$ otherwise

because most the useful energy at the beginning and at the end of the day would be lost.

b) In order to avoid time consuming iterative processes all the parameters are supposed to be constant within each hour. This leads to errors, that anyway are very small, as the comparative runs show.
The larger difference appears to be in the evaluation of H_T. This is attributable to the fact that all the radiation falling on the collector in the period between sunrise (sunset) and the next (previous) hour is supposed to be zero. Nevertheless the performance of the system is little affected by this inaccuracy because the values of solar radiation lost are not high enaugh to produce useful gain for the collector.

c) All the requirements of the "working plan for IEA task 1" of July 7th, 1977 including revised version of Annex 2) have been met in the computer runs performed, with the exception of what follows:

1) piping heat losses have been ignored
2) only one storage tank of (80xA+350) liters has been considered
3) storage losses have not been printed out, but are included in the calculations
4) The yearly calculation has been performed only for one location (Madison) because to trasfer data from the tape to the cassette of the Hewlett Packard desk-computer revealed to be a very time consuming task.
5) The hourly outputs are plotted and printed out, not transferred to cards because this is impossible with the equipment used.

3.8

DESCRIPTION OF THE INTASOL SIMULATION PROGRAM AND REPORT ON SIMULATION RESULTS

I. GENERAL DESCRIPTION

The INTASOL method is one of the programs carried out at the Instituto Nacional de Têcnica Aeroespacial (INTA), Spain, for performance calculation of hot water and central heating solar systems.

The program is basically aimed to investigate the behaviour of solar systems and has been specially prepared fór direct application to a wide range of possible configurations. The INTASOL method can also be used in the development of simplified methods of calculation as well as in the design of solar installations.

The equations that define the behaviour of each system component constitute independent sub-routines. In this way the INTASOL program allows for the determination of the discrepancies that occur in the calculations when the components are simulated by means of mathematical models by more or less complexity or when the design parameters are changed.

The method, in its general version, has been prepared to utilize, as input data, the diffused and total radiation hourly standard local values, the ambient temperature and the wind velocity, that are being recorded at the moment for different Spanish places according to statistical data of actual measurements.

Hot water, heating or refrigeration loads can be introduced in the programme either by recorded hourly data or by fixed and statistically defined sub-routines.

In this paper the INTASOL is applied for the solution of domestic water heating and refrigeration proposed by IEA. The input data are the ones recorded for different climates and loads by NBS at Madison (USA), Santa María (USA) and Hamburg (Germany).

II DESCRIPTION OF THE COMPUTER MODEL

II.1 Schematic Drawings of Entire System

The whole system is shown in Fig. 1.

II.2 Simulation Period and Time Step

The simulation period is a complete year with calculation intervals of 30 minutes. The computer system used was Hewlet Packard 2100 (64 KBYTS).

II.3 Computing Time

The computing time was long, due to the conversion time needed in EBCDIC and ASCII format and line printer.

II.4 Input Data

The program was processed with the data recorded at Madison (USA), Santa María (USA) and Hamburg (Germany) as has been mentioned above.

III DESCRIPTION OF THE INDIVIDUAL COMPONENTS AND SUBROUTINES

III.1 Solar Collector

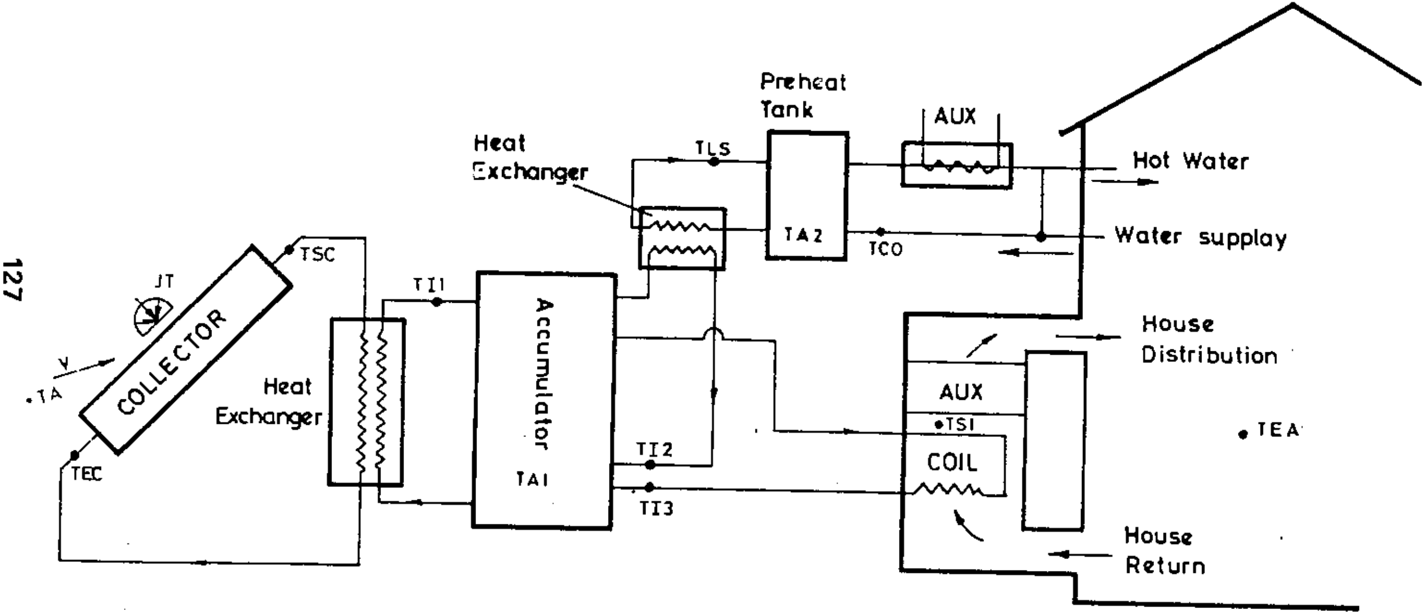
The collector model used corresponds basically to the equations given by Hottel, Whiller and Bliss.

$$QGC = AC \cdot FR \cdot \{JT \cdot \alpha \cdot \tau - UC(TEC-TA)\}$$

$$QGC = GMC \cdot CP\{TSC-TEC\}$$

$$FR = \frac{GMC \cdot CP}{AC \cdot UC}\{i-e^{-FP \cdot UC \cdot AC/GMC \cdot CP}\}$$

A-4/60.7.3. Imprenta del INTA



LIQUID SOLAR SYSTEM
FIG.1

Where the collector overall loss coefficient UC is obtained as a function of the collector design factor the ambient temperature, the wind velocity, the collector tilt an the plate temperature.

III.2 Main Storage Unit

The model used in the program concern to a non-stratified storage tank. The differential equation that defines the behaviour of the accumulator unit constitutes the center of the system and controls the calculation process throughout the functions F_1, F_2 and F_3.

$$\frac{dT}{dt'} = F_1\cdot GMC\cdot \frac{CP}{AUA}\,(TI1-T)+F_2\cdot GM2\cdot \frac{CP}{AUA}\,(TI2-T)+F_3\cdot GM3\cdot \frac{CP}{AUA}(TI3-T)-$$

$$-(T-TEA)$$

Where:

T = TA1 = main storage tank temp.

$t' = t/ta$; $ta = C/AUA$

Controls

$F_1 = 0$ when $TSC \leq TEC$
$F_1 = 0$ when $TSC > 95°C$
$F_1 = 1$ when $TSC > T+5$

$F_2 = 0$ when $T \leq TA2$
$F_2 = 1$ when $T > TA2$

$F_3 = 0$ when $QLC \leq 0$
$F_3 = 1$ when $QLC > 0$

The value of the functions F_1, F_2, F_3 is determined by the corresponding sub-routines.

The accumulator differential equation is integrated by one integration algorithm which used the trapezoid rule to predict more exact values of tank temperature.

III.3 Preheat Tank

The corresponding subroutine is that of the main storage tank, particularized for the hot water tank parameters.

$$\frac{dT'}{dt''} = F_2 \cdot GM2 \cdot \frac{CP}{AUL}(TLS-T') + F_4 \cdot GM4 \cdot \frac{CP}{AUL}(TCO-T') - (T'-TEA)$$

where:

$T' = TA2$ = preheat tank temperature
$t'' = t/tl$ ' $te = CL/AUL$

Controls:

$F_2 = 0$ when $TA1 \leq T'$
$F_2 = 1$ when $TA1 > T'$

$F_4 = 40/(T'-10)$ when $T' > 50$
$F_4 = 1$ when $T' \leq 50$

The calculation of functions F_2 and F_4 is carried out by independent subroutines.

III.4 Heat Exchanges

The basic equations are:

$NUT = UACC/CP \cdot GM$
$REC = NUT/(NUT+1)$
$TSF = TIF+REC(TIC-TIF)$
$TSC = TIC-REC(TIC-TIF)$
$QT = GM \cdot CP(TIC-TSC)$
TSF = cold fluid outlet temp.
TSC = hot " " "
TIF = cold fluid inlet temp.
TIC = hot " " "

III.5 Fan-Coil Heat Exchanger

The basic equations are:

$CC1 = GA \cdot CPA \cdot F_3$
$CC2 = GM3 \cdot CP \cdot F_3$

CMI = CC1/CC2

TS3 = TA1-EFEC(CMI/CC2)(TA1-TEA)

TS1 = TA1+EFEC(TA1-TEA)

QIE = EFEC·(CMI/CC1)(TA1-TEA)

QCR = QLC-QIE

III.6 Pipings

TS = TA+(TE-TA)/EXP(AU/GM·CP)

TS = fluid onlet temperature

TE = fluid inlet temperature

III.7 Subroutine DECET (DN, DECL, TEQ)

Subroutine DECET affords the determination of both declination and time equation, the subroutine is called once for every day.

$DECL = 23.45 \cdot \sin(2 \cdot \pi \cdot (284+DN)/365) \cdot \pi/180$

TEQ = f(DN)

TEQ = (TEQ+LOC)/60

III.8 Subroutine HORAR (HOUR, TEQ, W, GC)

It determines the value of the hour angle and the hot water load.

$W = \pi/12((HOUR-(DT/2)+TEQ)-12)$

GC = f(HOUR)

III.9 Subroutine LASL

It includes the determination of the direct and diffused radiation in accord with program LASL and also the calculation of product $\tau \cdot \alpha$.

IV CONCLUSIONS

IV.1 Subroutine for collector calculation constitutes the longer calculation time program part. Therefore, to start with, the subroutine is simplified by taking the plate temperature as an experimental function of the inlet fluid temperature. For this reason high values of the collected energy have been obtained. In the following calculations the whole subroutine will be used.

IV.2 Some difficulties have arised in timing the program with the corresponding recorded values.

IV.3 It would be desirable to have measured values for the diffused radiation as well as a better definition of the house heating unit functioning conditions.

NOMENCLATURE

DN = Day number of the year
TEQ = Time equation
LOC = Local time
$\tau \cdot \alpha$ = Transmittance-absorptance product
AC = Collector area
GMC = Collector flow rate
GM2 = Storage-preheat tank heat exchanger flow-rate
GM3 = Storage fan coil flow rate
GM4 = Preheat tank-hot water load flow rate
GM = Fan coil air flow rate
UC = Collector overall loss coefficient
AUA = Accumulator loss coefficient
AUL = Preheat tank loss coefficient
UACC= Heat exchanger coefficient
AU = Piping loss coefficient
CPA = Air heat capacity
CP = Water heat capacity
EECC= Fan coil effectiveness
REC = Heat exchanger coefficient
TA = Outdoor temperature
TRA = Indoor ambient temperature
TCO = Cold water supply temperature
JT = Total radiation on glass collector
QGC = Energy collected
QI = Energy transferred in the heat exchangers
QIE = " " " " fan coil

PARAMETER	INSOL Nomenclature	I.E.A. Nomenclature	UNITS
-MONTHLY SOLAR PERFORMANCE SUMMARY-			
Total solar radiation on collector	QINC	qcin	KWH
Collectors output	QGC	qcout	KWH
Main storage input	QEA1	qsin	KWH
Main storage loss	QPA1	qsl	KWH
House heating storage output	QSCR	qsout	KWH
House heating auxiliary required	QACR	qaux	KWH
House heating load	QLC	qd	KWH
Preheat tank input	QEA2	qsin	KWH
Preheat tank loss	QPA2	qsl	KWH
Preheat tank output	QSAC	qsout	KWH
Hot water auxiliary required	QAAC	qaux	KWH
Hot water load	QLA	qd	KWH
House percent solar	SC	H	-
Domestic hot water percent solar	SAC	DW	-
Total percent solar	TOT	TOT	-
-HOURLY SOLAR PERFORMANCE SUMMARY-			
Main storage tank temperature	TA1	TNK	DEG.C
Hot water tank temperature	TA2	T HWT	DEG.C
Collector inlet temperature	TEC	-	DEG.C
Collector output temperature	TSC	-	DEG.C
Total solar radiation on collector	QINC	-	WATT/M
Absorbed on collector surface	QPC	-	WATT/M
Collector output	QGC	QCOL	WATT
Main heat exchanger input/output	QI	-	WATT
Main storage input	QEA1	QIN	WATT
Main storage loss	QPA1	-	WATT
Energy delivered to house by solar	QSCR	QCOIL	WATT
Hot water tank input	QEA2	-	WATT
Hot water tank loss	QPA2	-	WATT
Energy output form DHW preheat tank	QSA2	QDHW	WATT
Total energy required	QNECTC	-	WATT

CHAPTER IV

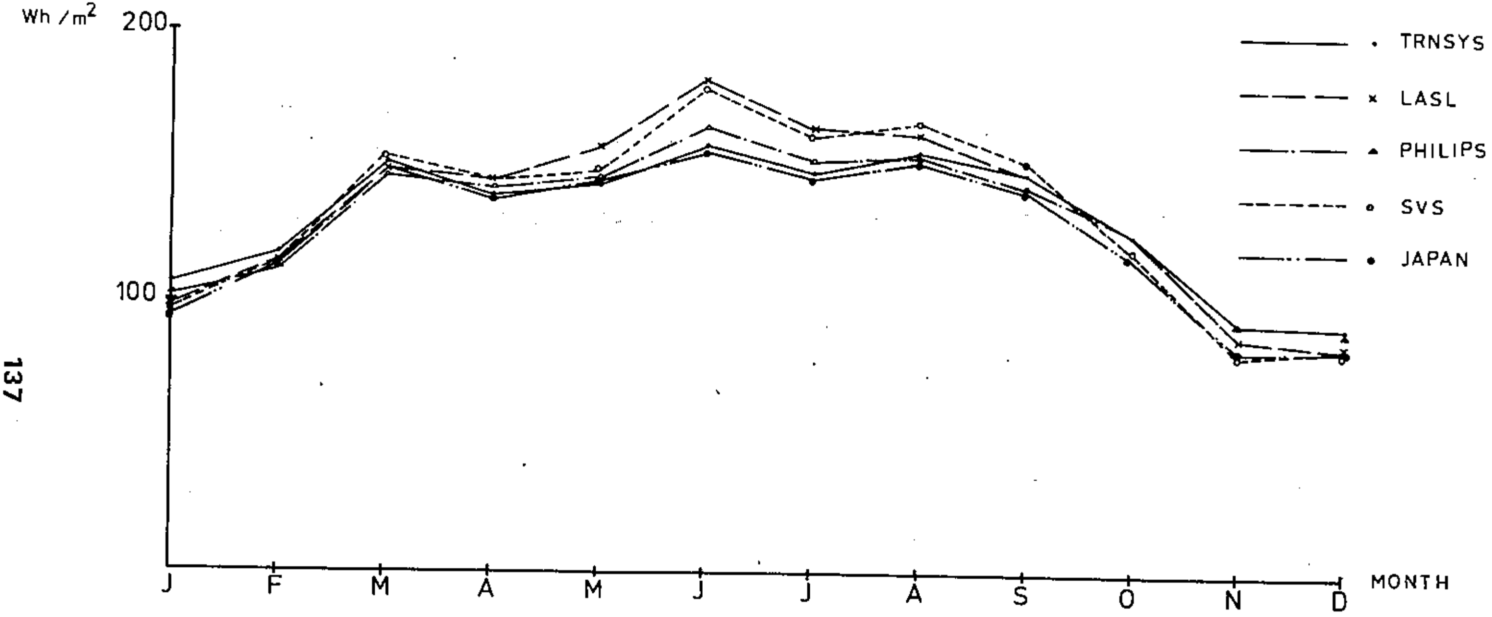
DIFFERENT APPROACHES - DIFFERENT RESULTS

4.1 Calculation of radiation on tilted surfaces

At the meeting in Los Alamos where the results were first presented there was a very significant difference in the yearly percent of solar energy predicted. The main reason for that was different methods for calculation of the hourly solar radiation on tilted surfaces using horizontal radiation data.

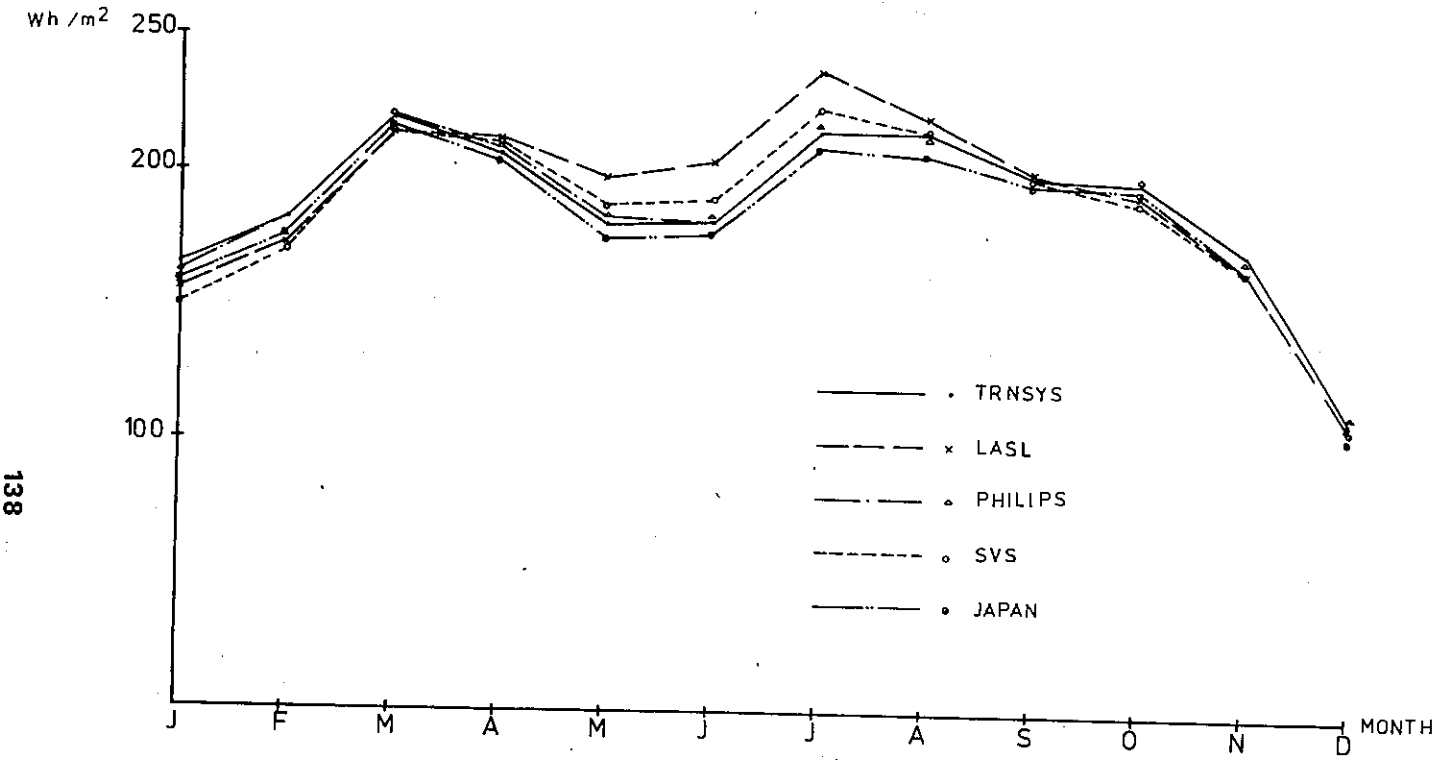
The figures 4.1 - 4.3 show the monthly solar radiation on a tilted surface calculated by each group using their own method.

A short report made by S.A. Klein, University of Wisconsin gives a description of the methods used in the different programs and a suggested solution of the problem. The participants agreed on using the LASL method for future calculations. All results presented in this report are from calculations where this method has been used.



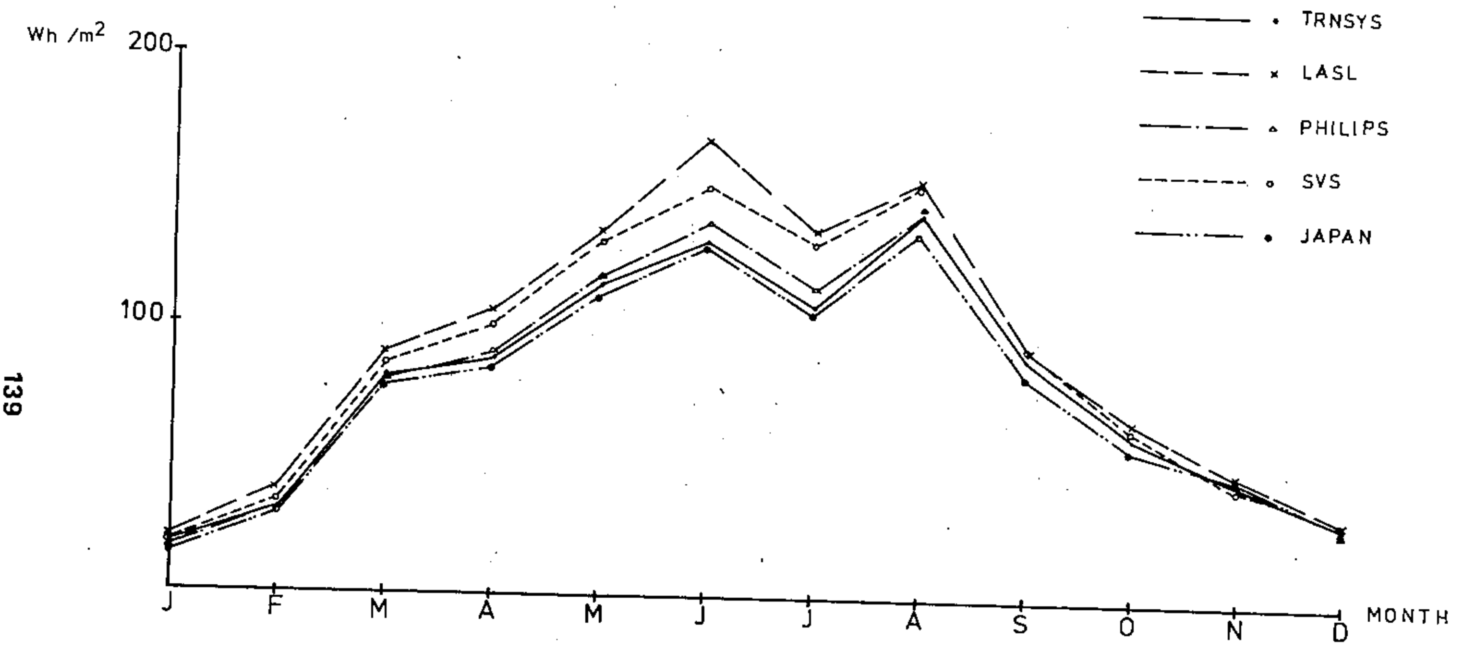
COMPARISON OF CALCULATED SOLAR RADIATION ON A TILTED SURFACE.
MADISON WEATHER DATA.

Fig. 4.1



COMPARISON OF CALCULATED SOLAR RADIATION ON A TILTED SURFACE.
SANTA MARIA WEATHER DATA.

Fig. 4.2



COMPARISON OF CALCULATED SOLAR RADIATION ON A TILTED SURFACE, HAMBURG WEATHER DATA.

Fig. 4.3

CALCULATION OF RADIATION ON TILTED SURFACES

I Introduction

Each of the groups which submitted solar heating system simulation results has a preferred method of calculating hourly solar radiation on tilted surfaces using horizontal radiation data. The methods are not completely in agreement, as seen in Table 4.1, in which monthly total radiation on a 53° surface in Madison, Wisc. (lat. 43° N) is presented. The purpose of this report is to summarize the methods used by each group and to identify points of discrepancy and sources of concern.

II Summary of Each Group's Methods

There are several problems involved in calculating hourly radiation on tilted surfaces using radiation data on a horizontal surface. First, all of the groups require a knowledge of diffuse radiation on a horizontal surface. Since diffuse (or beam) radiation is not available for Madison or Santa Maria, empirical methods are used to estimate the diffuse component from a knowledge of the total radiation. Second, there are some discrepancies in how the diffuse and reflected radiation on the tilted surface are calculated once the diffuse and beam components on the horizontal surface are known. Finally, problems occur at times near sunrise or sunset (as will be explained), and each group handles these problems somewhat differently.

Table 4.1 Radiation on 50 m^2 of Collector Surface (kWhr)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
UW	5361	5944	7556	7042	7208	7958	7472	7875	7431	6361	4722	4667	79600
LASL	4967	5834	7533	7314	7919	9166	8260	8233	7416	6174	6484	4312	81512
PHILIPS SIMPL. FINITE ELEMENT	(5266) 5080	(5848) 5698	(7439) 7463	(6870/ 7078	(7165) 7365	(8005) 8266	(7448) 7711	(7704) 7944	(7282) 7397	(6225) 6226	(4635) 4780	(4672) 4686	(78557) 79690
Denmark	4979	5749	7742	7252	7498	9042	8129	8426	7706	6092	4079	4268	80962
Japan	4800	5645	7355	6980	7125	7875	7380	7720	7720	5980	4205	4175	76455

II.1 University of Wisconsin

$$I_T = (I - I_d)R_B + I_d\left(\frac{1+\cos s}{2}\right) + \rho I\left(\frac{1-\cos s}{2}\right) \qquad (1)$$

I_T is hourly radiation on tilted surface
I is hourly total radiation on horizontal surface
I_d is hourly diffuse radiation on horizontal surface
R_B is ratio of radiation (beam) on a tilted surface to that on a horizontal surface

$$R_B = \cos \theta_T / \cos \theta_H \qquad (2)$$

θ_T is solar incidence angle on tilted surface
θ_H is solar incidence angle on horizontal surface

s is collector slope (from horizontal, facing equator)
ρ is ground reflectance (assumed to be 0.2)

I_d was determined empirically from a knowledge of I using Liu and Jordan's correlation, shown in Figure 1.10. (Note, Liu and Jordan's correlation is defined on a daily basis, but it was used here on an hourly basis).

At times near sunrise and sunset during the winter, R_B becomes very large. Ordinarily, the radiation on the horizontal surface would tend towards zero at these times. However, as a result of interpolation, time shifts, the simulation time and the horizontal solar radiation data may not be in phase, and large errors in the calculated beam radiation on the tilted surface may result. This problem is treated by limiting the value of R_B to be its value at ½ hour from sunrise or sunset.

$$0 \leqslant R_B < R_B'$$

$R_B' = R_B$ at ½ hour or less from sunrise or sunset

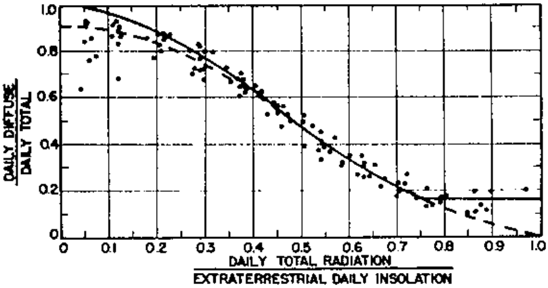


Figure 3.5.2 The ratio of the daily diffuse radiation to the daily total radiation as a function of cloudiness index. From Liu and Jordan (1960).

Figure 1.10

II.2 LASL

LASL also uses equation (1). However, I_d, the hourly diffuse radiation on a tilted surface is calculated using the relationship of Boes:

$$I_{DN} = \begin{cases} 0.0 & PP < 0.3 \\ 1.19\ PP - 0.55 & 0.3 < PP < 0.85 \\ 1.0 & PP > 0.85 \end{cases} \qquad (4)$$

where

I_{DN} is the hourly direct normal radiation in units of kW/m^2

PP is the % possible or K_T

$$PP = K_T = \frac{\text{horizontal radiation}}{\text{extraterrestrial radiation}} = \frac{I}{I_o}$$

Diffuse radiation is then given by

$$I_d = -I_{DN} \cos \theta_H + I \qquad (5)$$

To solve the problems encountered near sunrise or sunset, R_B is restricted to be between 0 and 5.

$$0 \leqslant R_B \leqslant 5 \qquad (6)$$

Ground reflectance, ρ , is constant at 0.2.

II.3 Germany: Schreitmuller, Stuttgart

The German group also uses equation (1) with ρ, the ground reflectance set to 0.2. The relationship between diffuse and total radiation on a horizontal surface is similar to that of Liu & Jordan, it is given as follows.

$$I_{DN} = \begin{cases} 0 & \text{if} \quad I \leqslant 0.2\ I_o \\ I(I - 0.2\ I_o)/.7\ I_o \sin h & .2\ I_o < I < .85\ I_o \\ .4\ I_o/\sin h & I > 0.85\ I_o \end{cases} \qquad (7)$$

where

h is the solar attitude

I_o is the extraterrestrial radiation

At times near sunrise or sunset, I_{DN} is restricted to be less than 1100 W/m^2:

$$0 < I_{DN} < 1100\ \text{W/m}^2 \quad \text{near sunset} \qquad (8)$$

II.4 Denmark

Diffuse radiation, if it is not available from the meteorological data is calculated as follows.

$$I_d = \begin{cases} 0.94\ I & 0 \leqslant E < 0.4 \\ I(1.29 - 1.19\ F)/(1 - 334\ E) & 0.4 \leqslant E \leqslant 1.0 \\ 0.15\ I & E > 1 \end{cases} \qquad (9)$$

where

E is the ratio of measured radiation on the horizontal surface to the clear day radiation at the same time,

$$E = \frac{I}{I_{\substack{\text{clear}\\\text{day}}}} \qquad (10)$$

The radiation on the tilted surface, I_T, is calculated as the sum of beam, diffuse, and reflected components, as in equation (1). The beam component is as given in equation 1. However, the diffuse and reflected components are handled somewhat differently. The diffuse radiation on the tilted surface is given by the following algorithm.

$$\text{Diffuse}_{\text{tilted}} = I_d \cdot F$$

where

$$F = (F'' - R) * \frac{(8-N)}{8} + (1 + \cos s)/2$$

$$N = \text{cloud cover} \qquad 1 < N < 8$$

$$F'' = F'(1 - \cos \phi_I) + \cos \phi_I$$

$$\phi_I = \text{incidence angle on tilted surfaces}$$

$$F' = \begin{cases} 0.55 + 0.437 \cos \phi_I + 0.313 \cos^2 \phi_I & \text{for } \cos \phi_I \geqslant 0.2 \\ 0.45 \quad \text{for } \cos \phi_I < -0.2 & \end{cases} \tag{11}$$

The reflected radiation is given as follows.

$$\text{Reflected}_{\text{tilted}} = \rho\left(\frac{1-\cos s}{2}\right)(I_d \sin h + I_d)$$

where $\rho = 0.25$

Presumably, these algorithms assume a distribution of diffuse radiation intensity over the sky, whereas equation (1) assumes diffuse radiation is isotropic.

II.5 Philips: Germany

Where diffuse radiation is not given, it is estimated from global radiation by the following algorithm.

$$I_d = (I_o)(K_d)$$

$$K_d = \bar{K}_d + (1-f)\,\sigma$$

$$\bar{K}_d = 0.31\, K_t + 0.139 \sin(4.62\, K_t)$$

$$K_t = I/I_o \tag{12}$$

$$\sigma = (0.81\, \bar{K}_d)(K_t)\left(\frac{K_t - 0.942}{K_t - 1.09}\right)$$

$0 \leqslant f \leqslant 1$ is a stochastic variable.

Radiation on tilted surfaces is calculated in one of two manners. In the more simplified method, equation (1) is employed. In the more detailed method, an attempt is made to describe the distribution of diffuse radiation over the sky by a detailed algorithm (see Bruno).

II.6 Japan

Measured total radiation (I) on horizontal surface is separated into direct radiation and diffuse one by the use of Bouguer's Formula and Berlage's Formula, taking atmospheric transmittance (P) a parameter.

$$I_{DN} = I_0 \cdot P^{\mathrm{cosec}(h)} \quad \text{------------ (Bouguer's Formula) ---- (1)}$$

$$I_d = \frac{1}{2} \cdot I_0 \cdot \sin(h) \, \frac{1 - P^{\mathrm{cosec}(h)}}{1 - 1.4 \cdot \ln P} \quad \text{— (Berlage's Formula) ---- (2)}$$

$$I' = I_{DN} \cdot \sin(h) + I_d \quad \text{-------------------------------- (3)}$$

Where,

I_0 : Extraterrestrial radiation

I_{DN} : Normal direct radiation

I_d : Diffuse radiation on horizontal surface

I' : Total radiation on horizontal surface

h : Solar incidence angle on horizontal surface

Thus, appropriate atmospheric transmittance can be found out in the case I' obtained through Equation (3) is equal to the measured I. In this, since error may occur at the time around sunrise or sunset, limitation of $0 < P < 0.85$ is given.

The measured radiation is represented by hourly integrated values. However, the sun changes its position considerably in an hour, particulary during an hour after sunrise or before sunset. So, errors in computation can be greatly reduced if, in Equations (1), (2) and (3), the solar positions are determined at every ten minutes and total radiation is separated into direct radiation and diffuse one on the basis of hourly integrated values.

III Discussion

There are several points of discrepancy between the various methods described in section II. These will be discussed here.

Diffuse radiation

Each group used a different algorithm to estimate diffuse radiation on a horizontal surface from global radiation measurements when diffuse radiation measurements were not available. It is impossible for this group to decide which of the various methods is best. However, we recommend a study and comparison of these methods, so that further simulation results will agree (at least in terms of the solar radiation). All groups are to use the method recommended by LASL.

Distribution of Diffuse Radiation

Once the diffuse radiation on a horizontal surface is determined, it is necessary to assume a distribution of the diffuse radiation over the sky, in order to calculate the diffuse radiation on a tilted surface.

The simplest assumption is that diffuse radiation is uniformily distributed across the sky. This assumption was used by all groups except the Danish and the more complicated model of the Philips group. One point in favor of the isotropic distribution assumption is that it yields conservative result.

Radiation on surface having tilt (s) is obtained as follows:

$$I_T = I_{DN} \cdot \sin(\theta_T) + I_d \cdot \frac{1 + \cos(s)}{2} + \rho \cdot I \cdot \frac{1 - \cos(s)}{2} \quad \text{--------} \quad (4)$$

Where,

θ_T : Solar incidence angle on tilted surface

ρ : Ground reflectance (assumed to be 0.2)

Time

There is discrepancy on how the horizontal radiation data is synchronized to solar time. For example, the radiation recorded at 12:00 noon on the data tape could be interpreted to be the integrated total radiation from 11:00 to 12:00, from 12:00 to 1:00 p.m. or 11:30 to 12:30 p.m. Also, some groups, notably, the Philips group, considered the correction of local time to solar time. This subject is treated in more detail in the report by Bruno. The participating groups have agreed to treat the time shift consistent with Bruno.

Times Near Sunrise or Sunset

All algorithms for calculating radiation on tilted surfaces experience diffuculty at times near sunrise or sunset. The reason for this is that R_B, the ratio of beam radiation on a tilted surface to that on a horizontal surface, tends to infinity during the winter months. The horizontal beam radiation, which should, in reality, become very small as (sunrise or) sunset approaches may be out of phase with the measured radiation data. This causes a calculated value of beam radiation on the horizontal surface which is very large.

To eliminate this problem, all groups have agreed to use the method of LASL with the correction that $R_B = 0$ if the sin(Altitude) is < 0.017.

Ground Reflectance

Most groups have set the ground reflectivity to 0.2. Bruno has suggested the use of a ground reflectance which changes daily. For further simulations, ρ will be set to 0.2.

4.2 Comparison of solar collector models.

A main reason for differences in the results of solar heating system computer simulation programs is likely to be differences in the modelling of the solar collector. To investigate that point the participants agreed that comparison plots of the steady state efficiencies should be drawn.

The input data for calculating the instantaneous efficiency were:

1) $I = 800\ W/m^2$, $i = 0^o$, pct. diffuse = 0%
   $t_a = 20^oC$, $g = 1.2\ kg/m^2min$, $v = 4\ m/s$
   $t_s = 0^oC$, $t_i = 0, 20, 40, 60, 80^oC$
2) as 1), but with $i = 60^o$
3) as 1), but with $v = 8\ m/s$
4) as 1), but with $v = 0\ m/s$
5) as 1), but with $t_s = 20^oC$
6) as 1), but with pct. diffuse = 30%
7) as 1), but with $I = 100\ W/m^2$

where I is total radiation on the collector surface
i is angle of incidence
pct. diffuse is percent of diffuse radiation on the collector surface
t_a is ambient temperature
g is coolant flow
v is windspeed
t_s is sky temperature
t_i is inlet temperature of coolant flow

It was decided to plot the efficiencies using the collector inlet temperature in the collector parameter.

The average fluid temperature can be used in this parameter by using the following equation:

$$(T_F - T_A)/I = (T_{IN} - T_A)/I + \eta/(2\ \dot{m}\ Cp)$$

For our given conditions this equation reduces to:

$$(T_F - T_A)/I = (T_{IN} - T_A)/I + .006 \cdot \eta$$

As the possibility of calculating the solar collector efficiency using a sky temperature, t_s different from the ambient temperature, t_a does not exist in all the programs, two series of plots were made. Fig. 4.2.1 - 4.2.7 are made using $t_s = 0\ ^{o}C$ and fig. 4.2.8 - 4.2.12 using $t_s = 20\ ^{o}C$.

It is impossible to show how the differences between the calculated steady state efficiences influence the yearly and monthly results of the programs because of the negative feed back mechanism of the solar systems and because these steady state efficiences and the results are rather close. The differences only show up in the plot of the hour values of energy collected given in section 5.3. The J(NIKKEN) and D(PHILIPS) programs calculate in general a bit higher steady state collector efficiencies than the USA(TRNSYS), USA(LASL) and DK(SVS) programs, and this is in complete agreement with what is seen from the hour value plot.

4.3 Program differences and specialities

Of the eight modelling and simulation programs presented in this report one is of the finite element approach D(PHILIPS), and the rest modularized. Of these seven two have a built in integrator for the governing differential equations using the euler-trapezoid principle, USA(TRNSYS) and E(INSOL). The five other programs calculate the heat flows as steady state within each timestep (quasi-stationary). The chosen timesteps range between 20 minutes and 1 hour.

The USA(LASL) program calculates the influence of collector heat capacity by calculating the change in collector temperature and subtracting the energy stored from the collector output each hour.

The J(NIKKEN) program uses a constant collector top loss coefficient of 2.02 $W/^{o}C\ m_c^2$.

The DK(SVS) and I(FTP) programs both use the De Winter method for calculating the heat exchanger between solar collector and main storage.

The GB(FABER) program uses Klein's formula (1973) using the Hottel and Woertz method (1942).

In calculating the predictions presented in this report the E(INSOL) program uses a simplified collector model.

The I(FTP) program is the only low user technology program of the eight. It is programmed for a desk computer and thus has some simplifications: only one tank, DHW is preheated in a coil in the big tank. A matrix of U_L values are generated in the beginning of the program to avoid iteration. There are no piping losses and the controls are changed from $T_o > T_{in} + 5$ to $T_o > T_{in}$ because of the use of 1 hour as timestep.

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

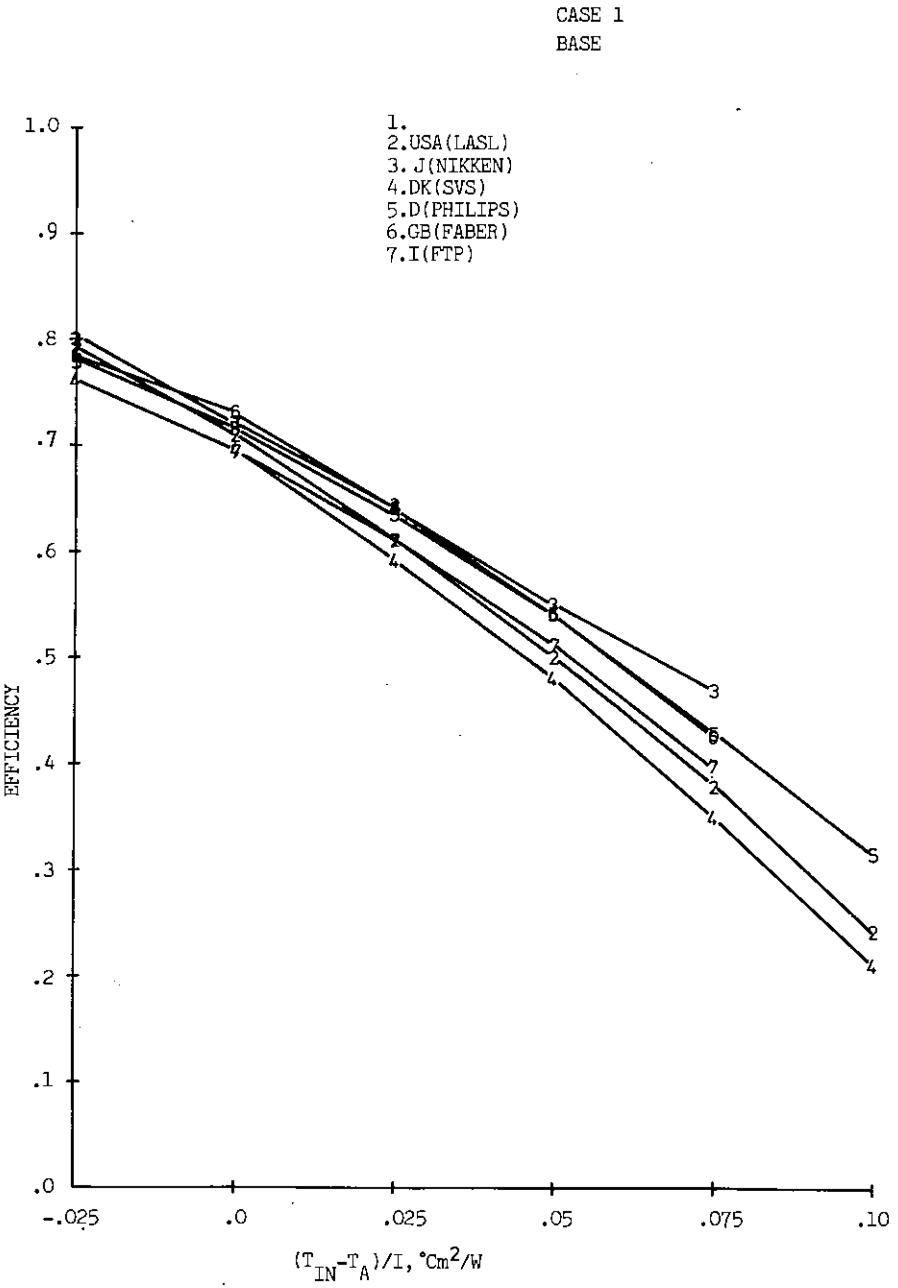


Fig. 4.2.1

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

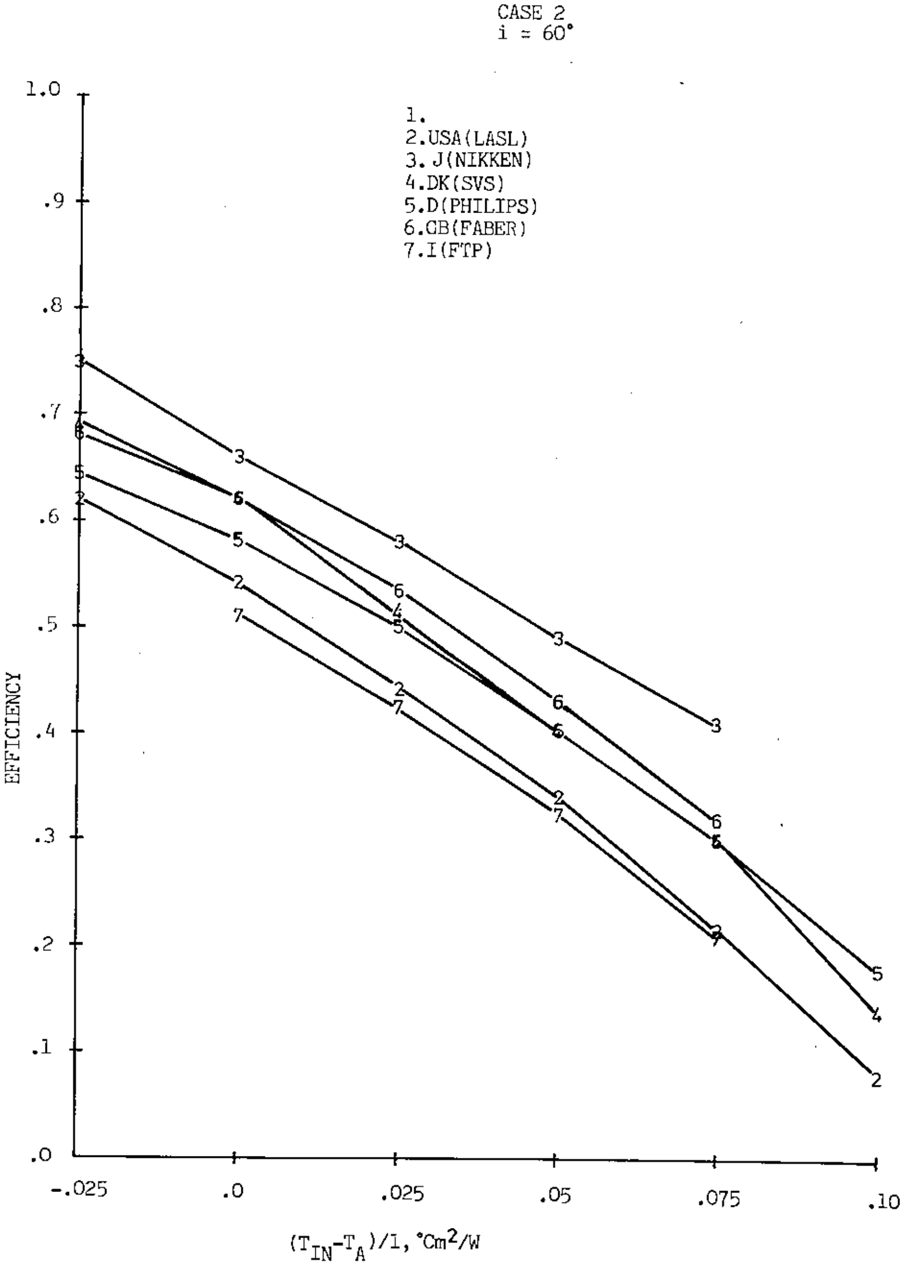


Fig. 4.2.2

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

CASE 3

V = 8 m/s

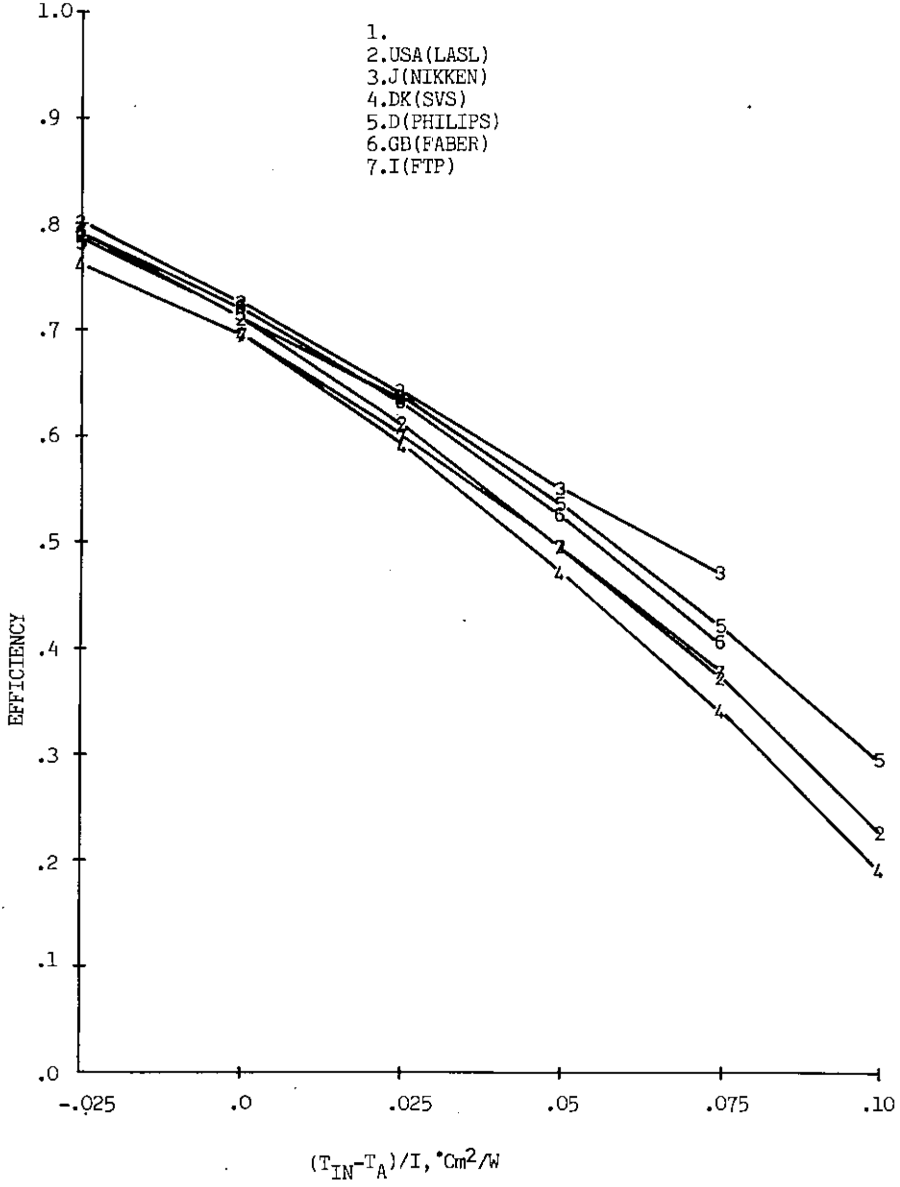


Fig. 4.2.3

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

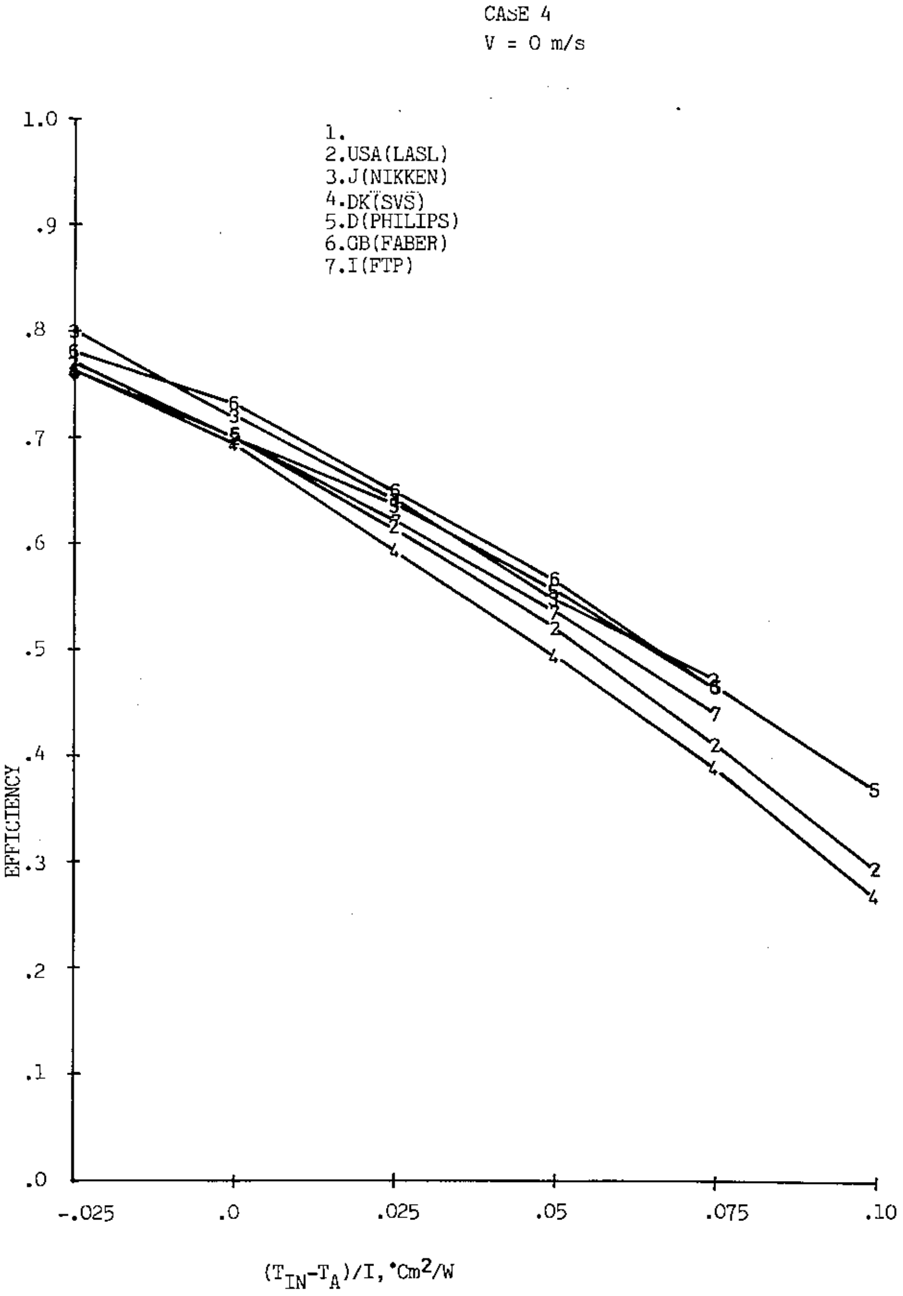


Fig. 4.2.4

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

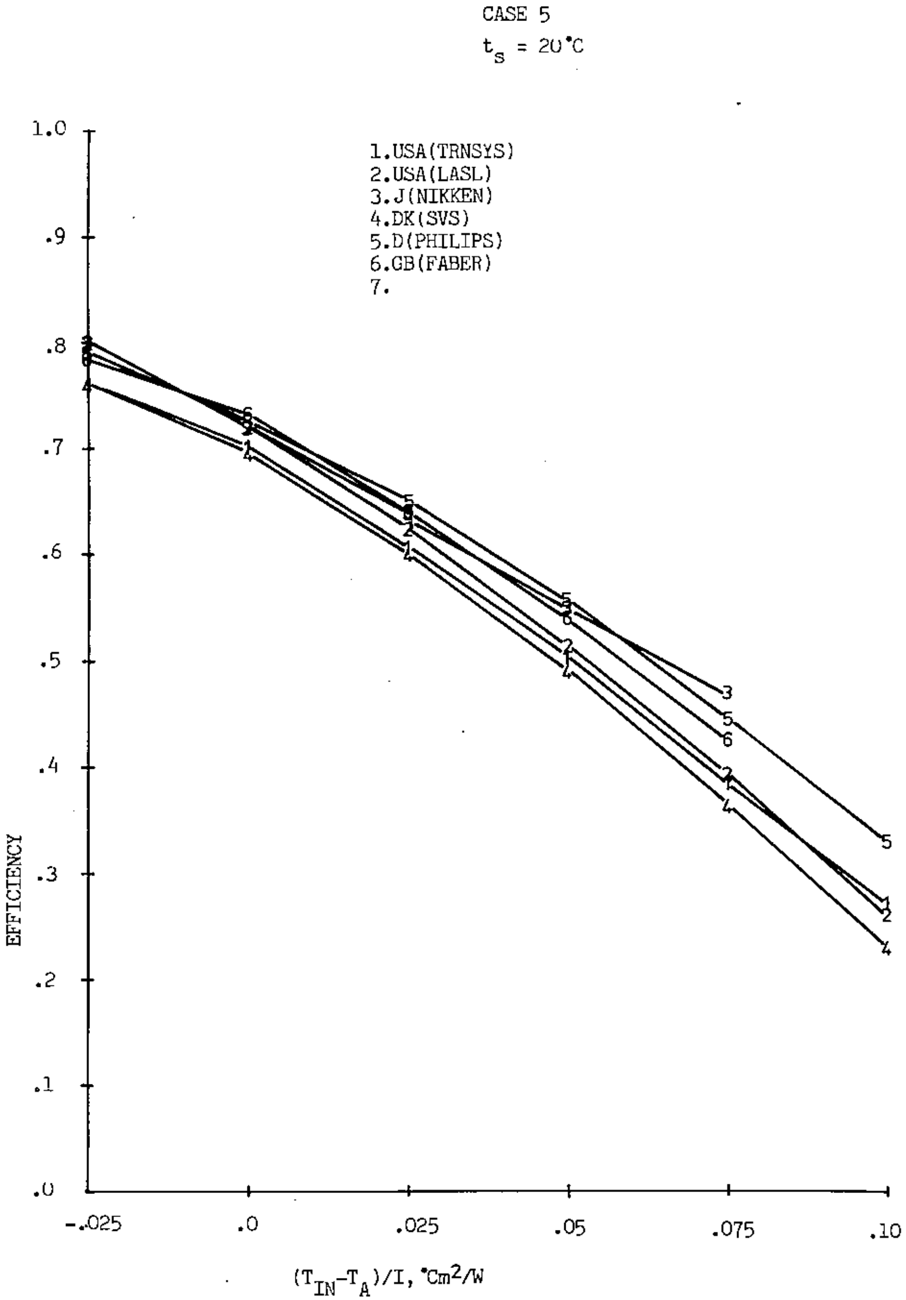


Fig. 4.2.5

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

CASE 6
DIFFUSE = 30%

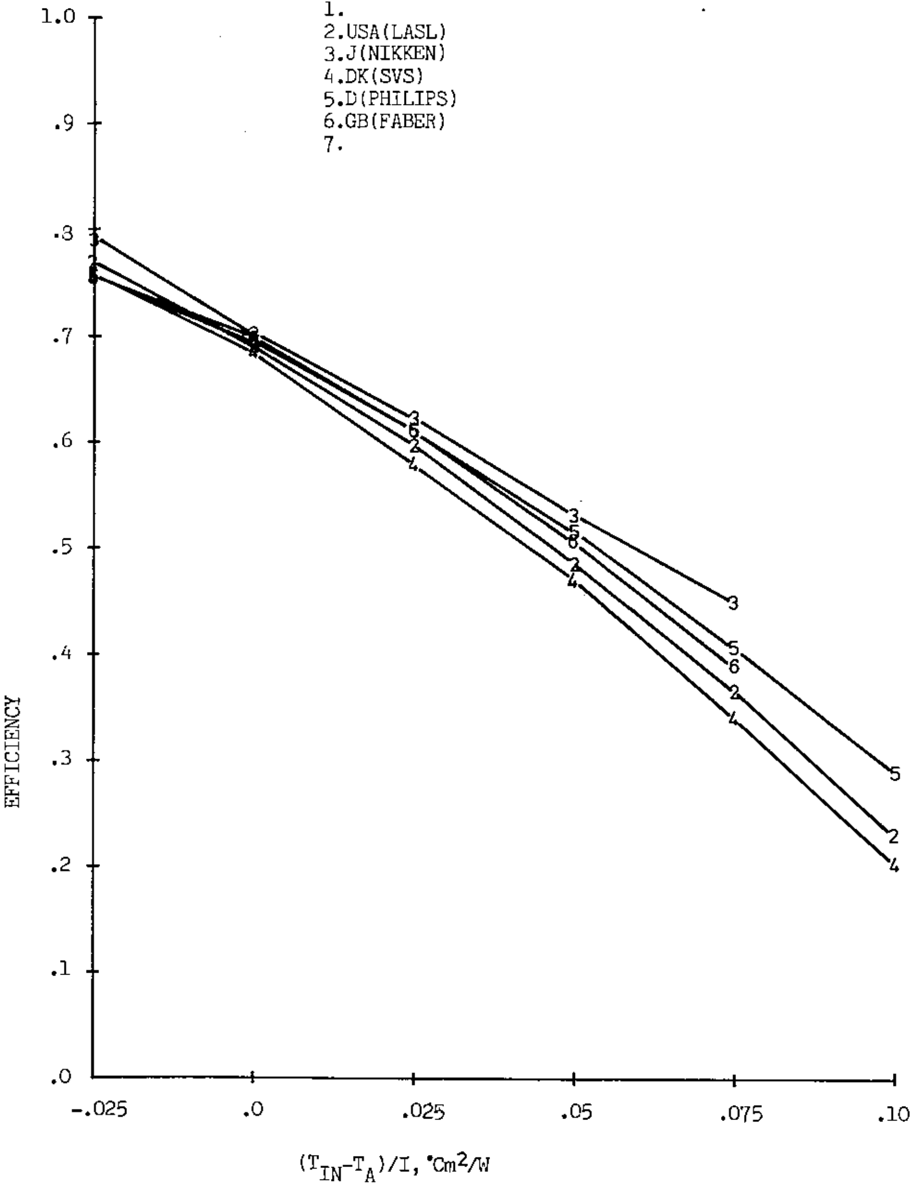


Fig. 4.2.6

COMPARISON OF CALCULATED COLLECTOR EFFICIENCIES

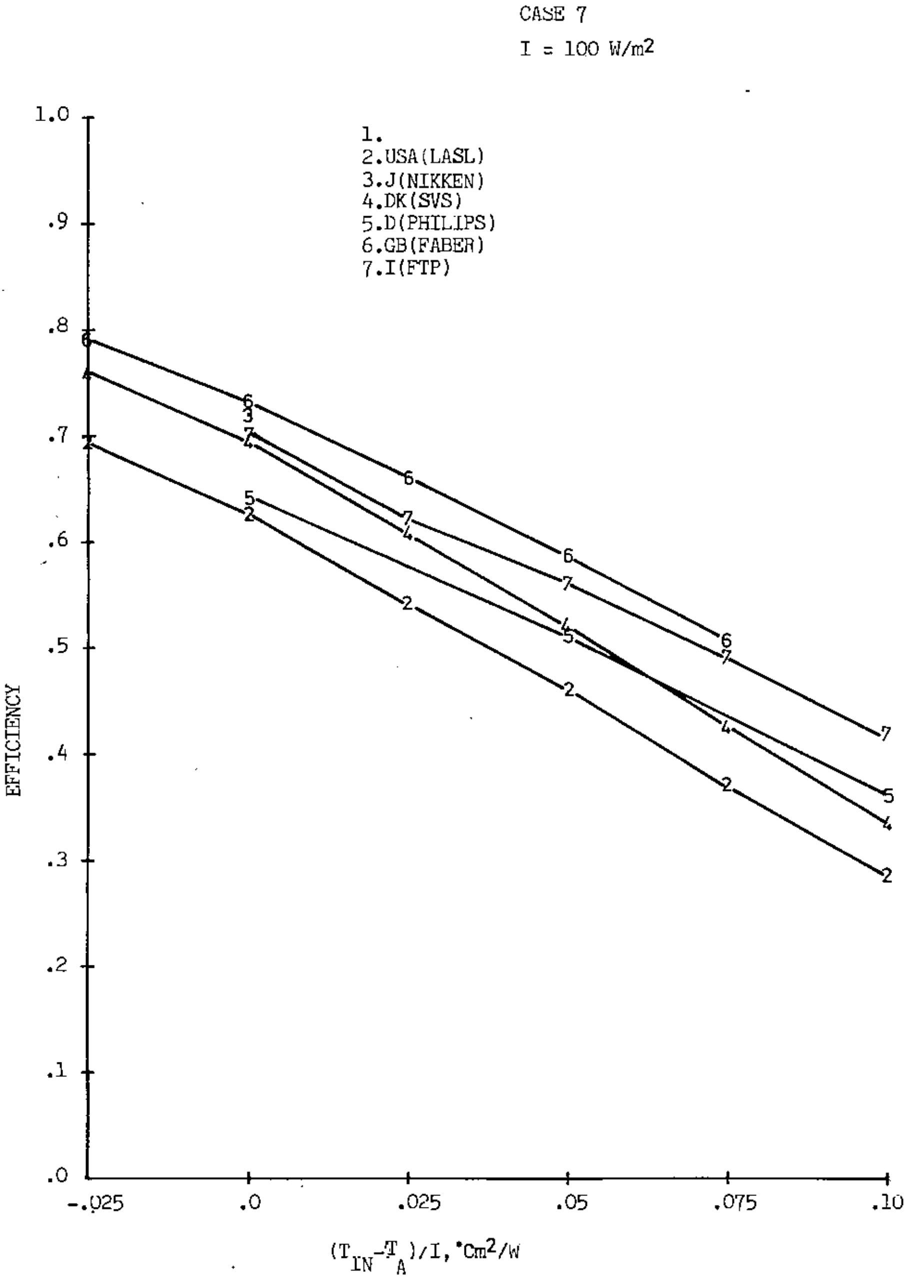


Fig. 4.2.7

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

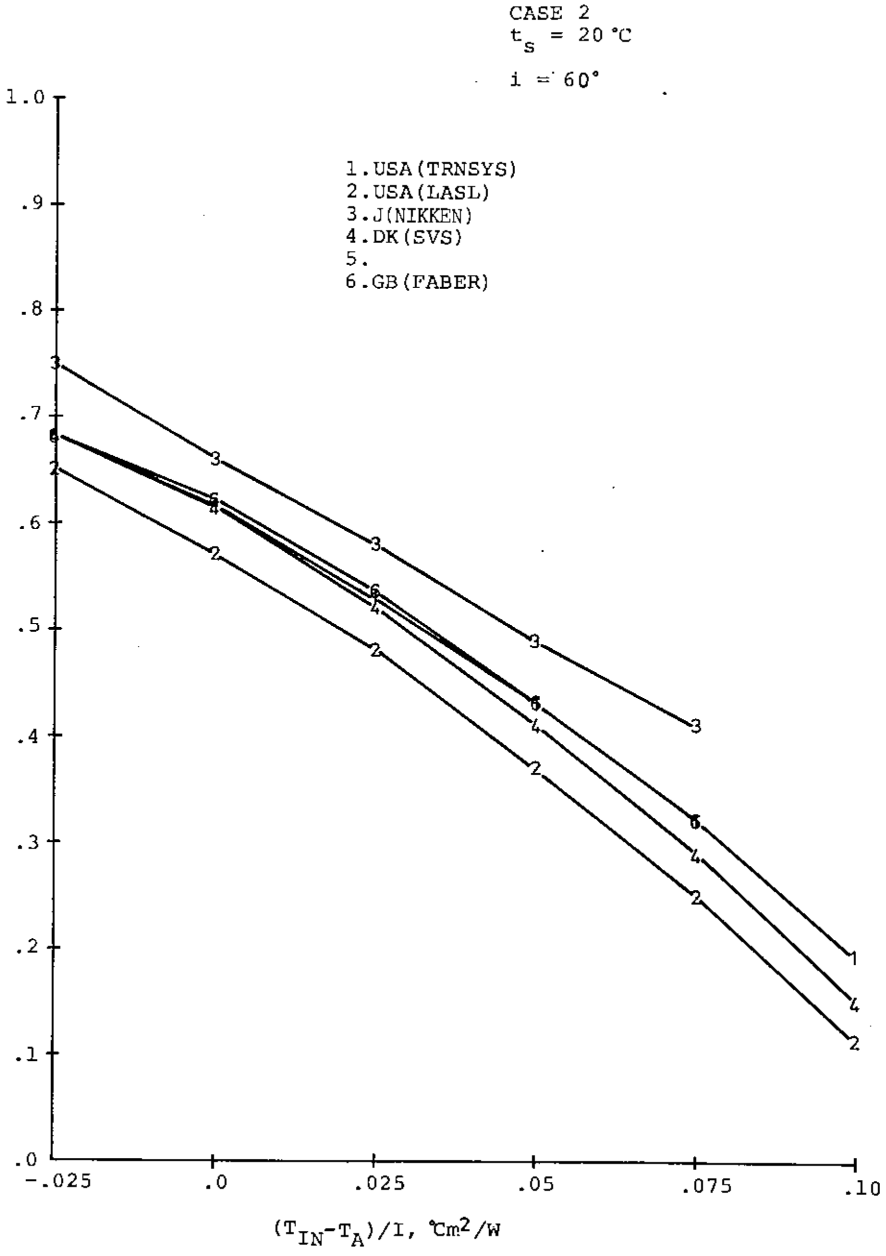


Fig. 4.2.8

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

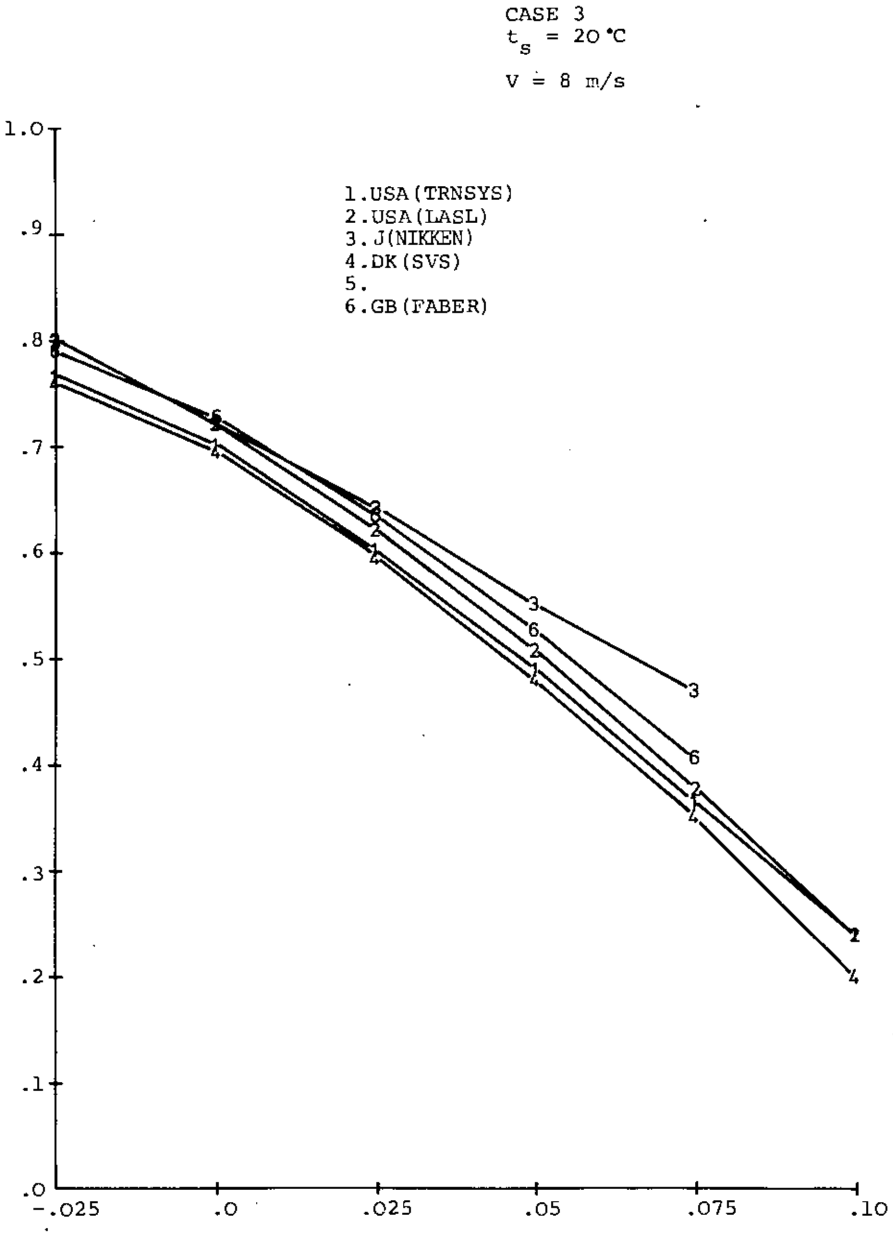


Fig. 4.2.9

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

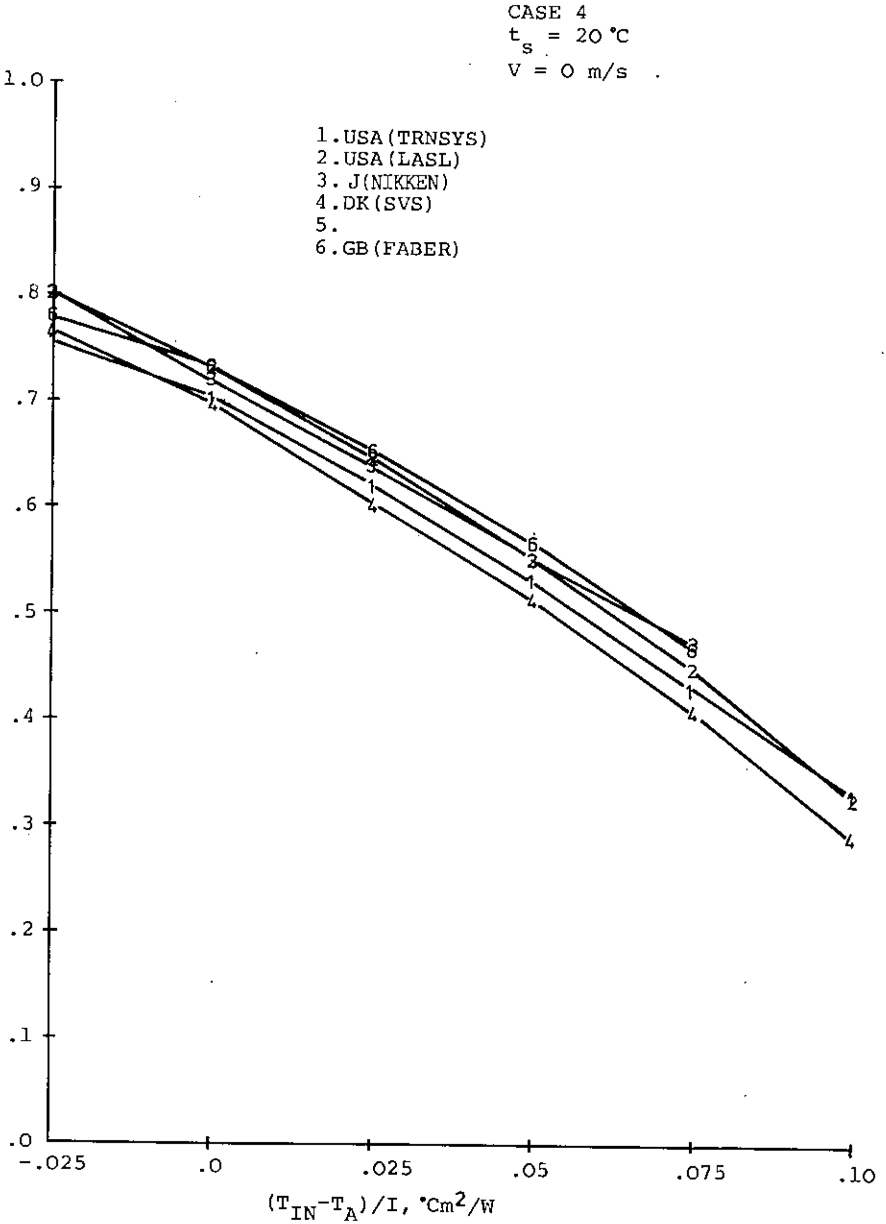


Fig. 4.2.10

COMPARISON OF CALCULATED COLLECTOR EFFICIENCIES

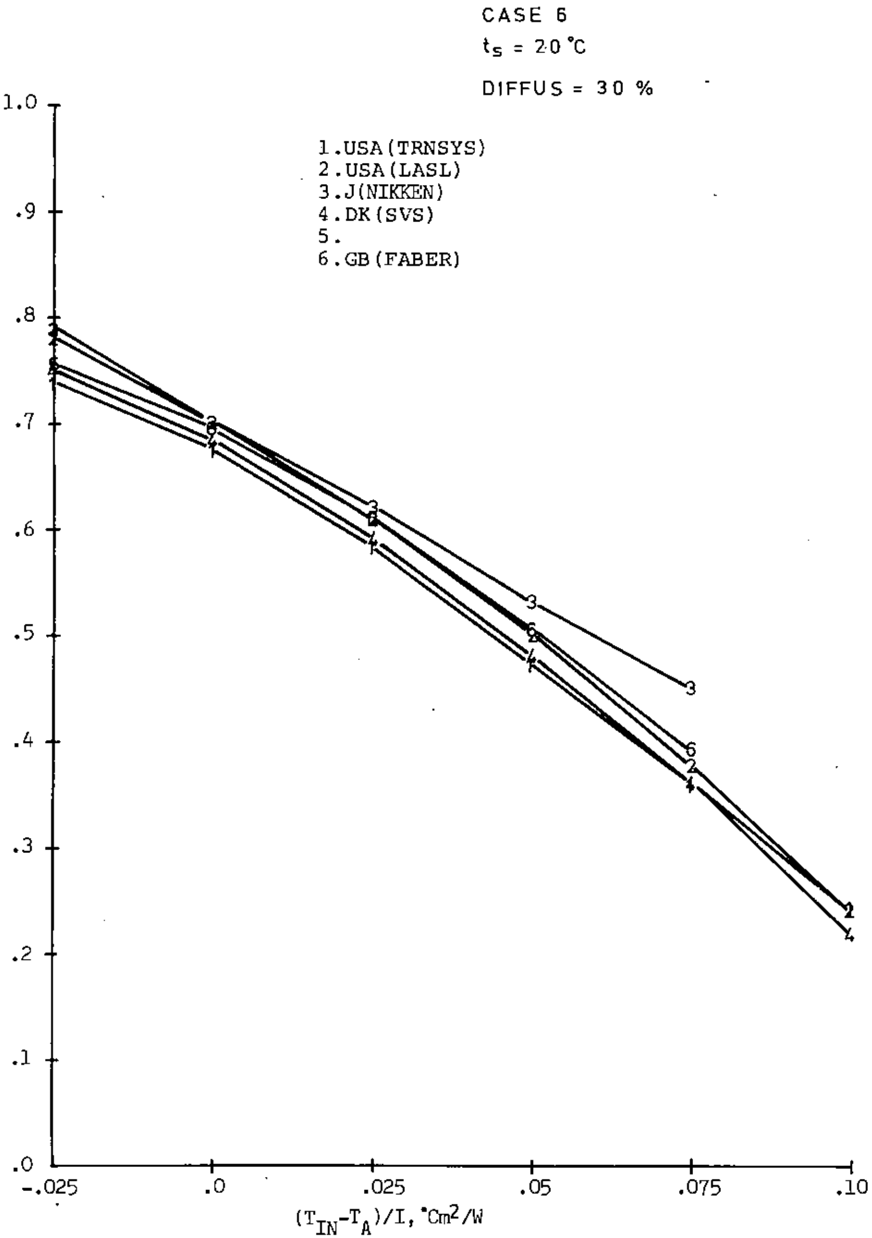


Fig. 4.2.11

COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

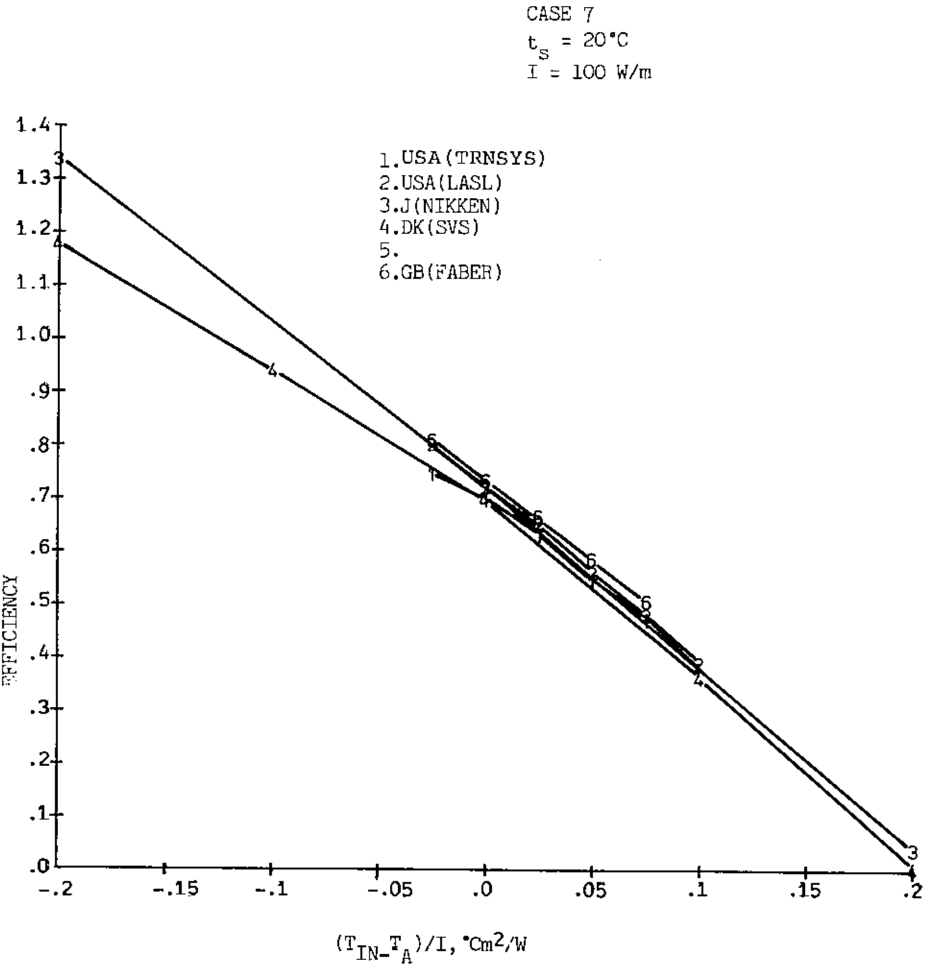


Fig. 4.2.12

CHAPTER V

COMPARISON OF RESULTS

5.1 Yearly results

With the purpose of making the comparison between the different program results for each location and type of system more easy the tables 5.1.1 - 5.1.6 are made. These tables are based upon the "Yearly Solar Performance Summary" tables (Annes II). The principle upon which the tables are made is that in a solar heating system, there are three sums that can be used to test the calculation. The sum of demands has to be equal to the sum of Solar Supply and Auxiliary Energy, and the sum of Solar Supply and Losses from tanks and pipings has to be equal to the Collector Output.

From the "Yearly Solar Performance Summary" tables it is seen that there are some confusion about whether "Main Storage Output to House" includes Heating Circuit Pipings Losses D(PHILIPS) or not (DK(SVS), USA(LASL), JAPAN, GB(FABER)), or even includes input to the DWH storage tank USA(TRNSYS). The House Solar Supply is therefore calculated as the difference between House Demand and House Auxiliary for the PHILIPS and TRNSYS programs.

The Heating Circuit Pipings Loss is easily calculated for the PHILIPS program as the difference between Main Storage Output to House and House Solar Supply. For USA(TRNSYS) one has to subtract one more figure, namely the DWH Storage Input.

The Collector Circuit Pipings Loss is calculated as the difference between Collector Output and Main Storage Input.

Table 5.1.6 for the air system is made in exactly the same way.

The maximum differences observed in the yearly tables in calculated collector input and predicted total solar supply are summarized in table 5.1.7.

Demand

All codes calculate the same yearly heating demand and the variations in the calculated hot water demand are very small and must be due to different assumptions of the density of water and/or the temperature dependency of the density.

Collector Input

Although it was agreed to use the same correlation to split up the global radiation into direct and diffuse insolation (see paragraph 4.1) there are still differences in the calculated collector input. On the Madison weather data the relative difference between the highest and lowest values is 7-8%, on the Santa Maria data it is 3-4%. The Hamburg weather data contain the diffuse radiation, and the programs therefore are very close in calculating the collector input on these data.

Total Solar Supply

First it is interesting to investigate whether the above mentioned differences in calculated collector input show up in the predicted total percentages of solar - which is not the case. The relative difference between the total solar supply predicted by D(PHILIPS) and I(FTP) on the Madison data is only 2.3%. This because D(PHILIPS) calculates a lower collector efficiency and higher losses than I(FTP). The relative difference between USA(LASL) and E(INSOL) on the Santa Maria data is -1.9%, because USA(LASL) calculates a lower collector efficiency. The relative difference on the Hamburg data between D(PHILIPS) and E(INSOL) is -6.2%, because D(PHILIPS) calculates much higher piping losses than does E(INSOL).

Secondly the reasons for maximum differences on each set of weather data are sought. On the Madison data the relative difference between GB(FABER) and E(INSOL) is 10% which obviously is due to the much higher collector efficiency calculated by E(INSOL). The maximum relative difference between the predicted results on the Santa Maria data is only 2.5% (E(INSOL), USA(TRNSYS)) because this system is somewhat oversized which causes all programming differences to smear out. The difference is due to the higher collector efficiency calculated by E(INSOL) and the 518 kWh not accounted for by that program. The highest relative difference between the predicted percentages of total solar supply is observed on the Hamburg data. The E(INSOL) program predicts 17.6% more than the GB(FABER) program. Again the main reason for the difference is the difference between the calculated collector efficiencies.

It is seen that in the last cases the main reason for the difference is the high collector efficiency predicted by the E(INSOL) program. This is in complete agreement with what is stated in the description of this code (paragraph 3.8), that the collector subroutine is simplified and therefore high values of the collected energy have been obtained.

"Old" Programs

As some of the groups have run their programs from the very beginning of this research programme, they have had a lot more time to "tune in" their programs on the problems (see chapter 6). Therefore one could expect a better agreement among the results predicted by the programs (USA(TRNSYS), USA(LASL), J(NIKKEN), DK(SVS) and D(PHILIPS). This is in fact the case. The maximum relative difference between the calculated collector input range between 1.5% and 1.9% for all three sets of weather data and the maximum relative differences between predicted percentages of total solar supply are 4.9%, 1.4% and 8.2% for the Madison, Santa Maria and Hamburg data respectively. Again the differences are due to differences in collector efficiences and piping losses. The absolute differences in the predicted percentages by these five programs range between ± .7 and ± 1.8%

% DHW Solar Supply - % House Solar Supply Ratio

This ratio ranges between 1.22 and 1.33 for the Madison data and between 1.67 and 2.04 for the Hamburg data. It has not been possible to find the reasons for these differences, they might be due to different modelling assumptions of the preheat heat exchanger.

Piping Losses

Four of the programs calculate the losses from the heating circuit pipings. USA(TRNSYS) and J(NIKKEN) agree very closely on all the data sets and so do DK(SVS) and D(PHILIPS) but the two latter predict from 18% (on the Madison data set) to 31% (on the Santa Maria and Hamburg data sets) higher losses from the heating circuit pipings. The most likely reason for this is that DK(SVS) and D(PHILIPS) also take into account night losses (when there is no circulation in the pipes).

Collector piping losses are calculated by all the programs, but the variations are quite high. In general for all three weather data sets DK(SVS) and D(PHILIPS) predict the highest losses, USA(TRNSYS) and E(INSOL) a little less and the rest lower losses. This pattern is violated for the Santa Maria data where E(INSOL) predicts the highest.

The differences between the predicted piping losses most likely have two main reasons: One is that some of the programs take into account night losses when there is no circulation, and the others do not. Second user errors, such as forgetting to change the length of the pipings when changing the collector area from 50 to 20 m^2 (Madison to Santa Maria) and forgetting that the lenght given is for each side and not both sides of the pipings, can explain some of the differences.

Storage losses

All the programs agree to a reasonable degree on the DHW storage and the Main storage losses. As they should both closely correspond to the predicted collector output, the higher the collector output the greater the storage losses.

Effect of storage size

The results of the USA(LASL) program show a stronger dependency of storage volume than the results of the other programs doing the sensitivity analysis, table 5.1.3 - 5.1.5. Figuring that this might be because of the collector heat capacity being used in the USA(LASL) program (and not in the other programs) US participant J. Hedstrom ran his program with no collector heat capacity, the results shown in the last column of the three tables. This raises the prediction of the total solar supply of that program with 3, 3.3 and 3.7%, still showing a higher dependency of storage volume than the other programs. This is very clearly seen on figure 5.1.1, showing the percent solar versus storage size (J. Hedstrom). The curves of the USA(TRNSYS), DK(SVS) and J(NIKKEN) programs are more flat than the two curves of the USA(LASL) program.

It is interesting that the DHW solar supply calculated by the USA(TRNSYS), DK(SVS) and J(NIKKEN) programs increase as the storage decreases whereas it decreases calculated by the USA(LASL) program. The net result of that being a closer agreement on DHW supply and a higher discrepancy in House solar supply.

Air system

Four programs have been used to run the air system on the Madison weather data. The results are shown in table 5.1.6. The agreement is excellent. Not only are the predicted percentages of solar within ± 0.25%, also the piping losses and the storage losses are very close.

Table: 5.1.1 Location: Madison System: Liquid Coll. area: 50 m^2
Storage vol.: 80 l/m_c^2

kWh	USA (TRNSYS)	USA (LASL)	J (NIKKEN)	DK (SVS)	D (PHILIPS)	GB (FABER)	I (FTP)	E (INSOL)
DHW Demand	5947	5936	5942	5893	5943	5933	6099	5942
House Demand	16480	16484	16482	16484	16484	16479	16475	16484
Total Demand	22427	22420	22424	22377	22427	22412	22574	22426
DHW Auxiliary	1258	1056	1080	966	998	1090	1094	883
House Auxiliary	5797	6265	5481	734	5695	6260	5991	4835
DHW Solar Supply	4689	4880	4862	4927	4945	4844	5007	5059
House Solar Supply	10683	10219	10993	10750	10789	10220	10484	11649
DHW Storage Loss	385	419	392	509	392	300	4904	414
Main Storage Loss	2171	2146	2062	2544	1998	1489		2162
Heat.Circ.pip.Loss	598	0	659	779	745	0		0
Coll.Circ.Pip.Loss	1270	635	600	1963	2401	395		1510
Not accounted for	-26	-46	-47	0	-44	-45		111
Collector Output	19770	18253	19521	21471	21226	17203	20395	20905
Collector Input	78500	78863	78176	78141	79351	75110	73500	74188
Collector Eff. %	25.2	23.1	25.0	27.5	26.7	22.9	27.7	28.2
DHW Solar Supply %	78.8	82.2	81.8	83.6	83.2	81.6	82.1	85.1
House Solar Supply %	64.8	62.0	66.7	65.2	65.5	62.0	63.6	70.6
Total Solar Supply %	68.5	67.3	70.7	70.1	70.2	67.2	68.6	74.5

Table: 5.1.2 Location: Santa Maria System: Liquid Coll. area: 20 m^2 Storage vol.: 80 l/m_c^2

kWh	USA (TRNSYS)	USA (LASL)	J (NIKKEN)	DK (SVS)	D (PHILIPS)	GB (FABER)		E (INSOL)
DHW Demand	5943	5936	5942	5893	5943	5933		5943
House Demand	4826	4827	4826	4827	4827	4823		4825
Total Demand	10769	10763	10768	10720	10770	10756		10768
DHW Auxiliary	274	224	216	181	168	132		116
House Auxiliary	212	199	142	205	181	111		111
DHW Solar Supply	5669	5712	5726	5713	5774	5801		5826
House Solar Supply	4614	4627	4684	4622	4646	4712		4716
DHW Storage Loss	498	524	492	621	499	534		511
Main Storage Loss	1478	1075	1404	1656	1372	1429		1441
Heat.Circ.pip.Loss	845	0	899	1295	1237	0		0
Coll.Circ.Pip.Loss	760	478	461	1068	1111	296		1518
Not accounted for	36	32	42	0	0	96		118
Collector Output	13900	12448	13708	14975	14639	12868		14130
Collector Input	44880	45598	45323	45110	45395	44404		44060
Collector Eff. %	31.0	27.3	30.2	33.2	32.2	29.0		32.1
DHW Solar Supply %	95.4	96.2	96.4	96.9	97.2	97.8		98.0
House Solar Supply %	95.6	95.9	97.1	95.8	96.3	97.7		97.7
Total Solar Supply %	95.5	96.1	96.7	96.4	96.8	97.7		97.9

Table: 5.1.3 Location: Hamburg System: Liquid Coll. area: 50 m^2 Storage vol.: 80 $1/m_c^2$

kWh	USA (TRNSYS)	USA (LASL)	J (NIKKEN)	DK (SVS)	D (PHILIPS)	GB (FABER)	E (INSOL)	USA (LASL)
DHW Demand	5948	5936	5942	5893	5943	5933	5942	No coll. heat capacity
House Demand	12590	12587	12585	12586	12587	12582	12587	
Total Demand	18538	18523	18527	18479	18530	18515	18529	18523
DHW Auxiliary	2307	1939	2110	1919	1909	2193	1725	1820
House Auxiliary	7973	8403	8395	8154	7935	8697	7537	7975
DHW Solar Supply	3641	3997	3832	3975	4034	3740	4215	4117
House Solar Supply	4617	4181	4190	4433	4652	3885	5050	4612
DHW Storage Loss	234	268	254	313	277	195	307	219
Main Storage Loss	1418	1371	1345	1572	1371	981	1618	1489
Heat.Circ.pip.Loss	258	0	288	385	401	0	0	9
Coll.Circ.Pip.Loss	820	411	368	1268	1561	305	885	479
Not accounted for	22	6	12	0	- 7	- 9	100	0
Collector Output	11010	10234	10289	11946	12289	9097	12175	10997
Collector Input	48260	47973	47399	47559	48326	47219	47209	47973
Collector Eff. %	22.8	21.3	21.7	25.1	25.4	19.3	25.8	22.9
DHW Solar Supply %	61.2	67.3	64.5	67.5	67.9	63.0	70.9	69.3
House Solar Supply %	36.7	33.2	33.3	35.2	37.0	30.9	40.1	36.6
Total Solar Supply %	44.5	44.2	43.3	45.5	46.9	41.2	50.0	47.1

Table: 5.1.4 Location: Hamburg System: Liquid Coll. area: 50 m^2 Storage vol.: 40 l/m_c^2

kWh	USA (TRNSYS)	USA (LASL)	J (NIKKEN)	DK (SVS)	USA (LASL)			
DHW Demand	5948	5936	5942	5893	No coll. heat capacity			
House Demand	12590	12587	12585	12586				
Total Demand	18538	18523	18527	18479	18523			
DHW Auxiliary	2268	1968	2089	1893	1831			
House Auxiliary	8285	8836	8754	8425	8356			
DHW Solar Supply	3680	3968	3853	4000	4105			
House Solar Supply	4305	3751	3831	4161	4231			
DHW Storage Loss	237	268	253	327	292			
Main Storage Loss	903	864	845	1018	943			
Heat.Circ.pip.Loss	195	0	291	405	0			
Coll.Circ.Pip.Loss	863	415	347	1180	468			
Not accounted for	7	3	16	1	8			
Collector Output	10190	9269	9436	11092	10047			
Collector Input	48260	47973	47399	47559	47973			
Collector Eff. %	21.1	19.3	19.9	23.3	20.9			
DHW Solar Supply %	61.9	66.8	64.9	67.9	69.2			
House Solar Supply %	34.2	29.8	30.4	33.1	33.6			
Total Solar Supply %	43.0	41.7	41.5	44.2	45.0			

Table: 5.1.5 Location: Hamburg System: Liquid Coll. area: 50 m^2 Storage vol.: 20 l/m_c^2

kWh	USA (TRNSYS)	USA (LASL)	J (NIKKEN)	DK (SVS)	USA (LASL)			
DHW Demand	5948	5936	5942	5893	No coll. heat capacity			
House Demand	12590	12587	12585	12586				
Total Demand	18538	18523	18527	18479	18523			
DHW Auxiliary	2219	2061	2108	1828	1902			
House Auxiliary	8841	9527	9264	8878	9004			
DHW Solar Supply	3727	3876	3834	4065	4034			
House Solar Supply	3749	3060	3321	3708	3583			
DHW Storage Loss	238	257	248	343	287			
Main Storage Loss	572	527	523	639	589			
Heat.Circ.pip.Loss	226	0	291	409	0			
Coll.Circ.Pip.Loss	966	419	339	1012	467			
Not accounted for	14	-2	9	1	0			
Collector Output	9492	8137	8565	10177	8960			
Collector Input	48260	47973	47399	47559	47973			
Collector Eff. %	19.7	17.0	18.1	21.4	18.7			
DHW Solar Supply %	62.7	65.3	64.5	69.0	68.0			
House Solar Supply %	29.8	24.3	26.4	29.5	28.5			
Total Solar Supply %	40.3	37.4	38.6	42.1	41.1			

Table: 5.1.6 Location: Madison System: Air Coll. area: 50 m^2 Storage vol.: 12.5 m^3

kWh	USA (TRNSYS)	USA (LASL)	DK (SVS)	D (PHILIPS)				
DHW Demand	5940	5936	5905	5943				
House Demand	16480	16484	16484	16483				
Total Demand	22420	22420	22389	22426				
DHW Auxiliary	1680	1618	1547	1654				
House Auxiliary	6417	6594	6623	6521				
DHW Solar Supply	4260	4318	4357	4289				
House Solar Supply	10063	9890	9861	9962				
DHW Storage Loss	295	302	299	298				
Main Storage Loss	2670	2753	2545	2754				
Heat.Circ.pip.Loss	1186	1053	1358	1281				
Coll.Circ.Pip.Loss								
Not accounted for	-34	-161	-1	-216				
Collector Output	18440	18155	18419	18368				
Collector Input	78500	78858	78141	79351				
Collector Eff. %	23.5	23.0	23.6	23.1				
DHW Solar Supply %	71.7	72.7	73.8	72.2				
House Solar Supply %	61.0	60.0	59.8	60.4				
Total Solar Supply %	63.9	63.4	63.5	63.5				

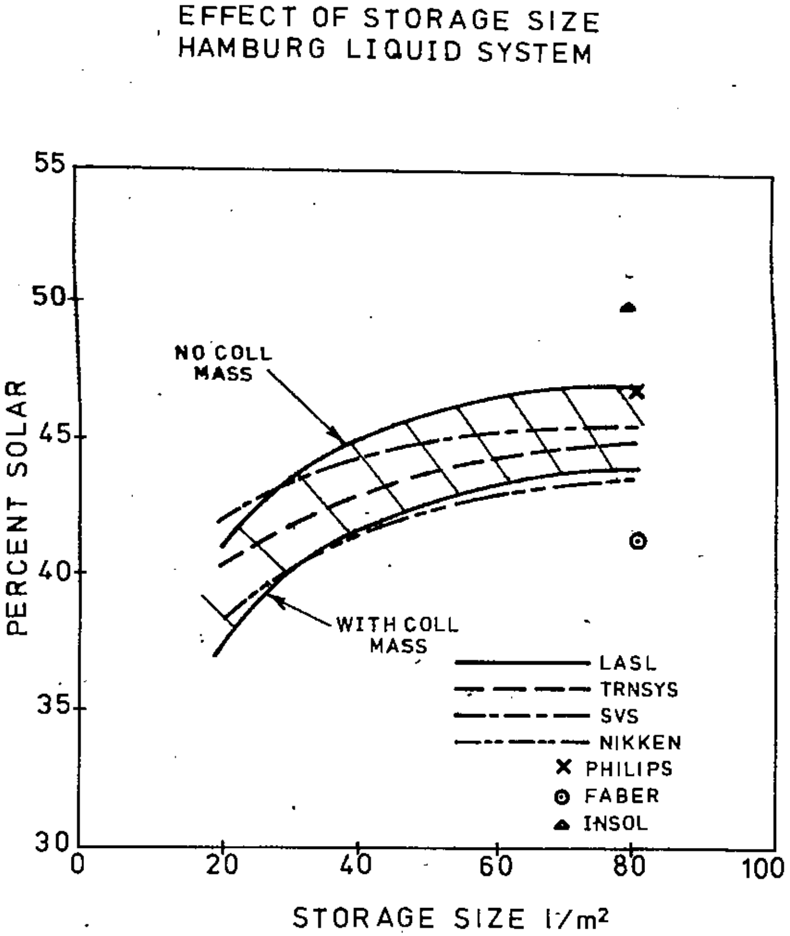

EFFECT OF STORAGE SIZE
HAMBURG LIQUID SYSTEM
PERCENT SOLAR
55
50
45
40
35
30
0
20
40
60
80
100
STORAGE SIZE l/m²
NO COLL MASS
WITH COLL MASS
LASL
TRNSYS
SVS
NIKKEN
× PHILIPS
⊙ FABER
▲ INSOL

Fig. 5.1.1

5.2 Monthly results

The results of the yearly tables are reflected in the histograms, fig. 5.2.1 - 5.2.8 showing the monthly total solar supply and for Madison weather data also the DHW solar supply and house solar supply. For some reason the USA(TRNSYS) program calculates a somewhat smaller DHW solar supply than the others, this shows up in fig. 5.2.3, Nov. and Dec.. Also it is very clear from the histograms 5.2.2 and 5.2.3 that the USA(LASL) is in complete agreement with the others on the DHW solar supply, but calculates a somewhat lower house solar supply in November and December. The J(NIKKEN) program results shoe the opposite, a higher house solar supply and a little less DHW solar supply.

Generally it must be said that the histograms show a fine agreement among the programs. This agreement is excellent on the results of the air system, fig. 5.2.8.

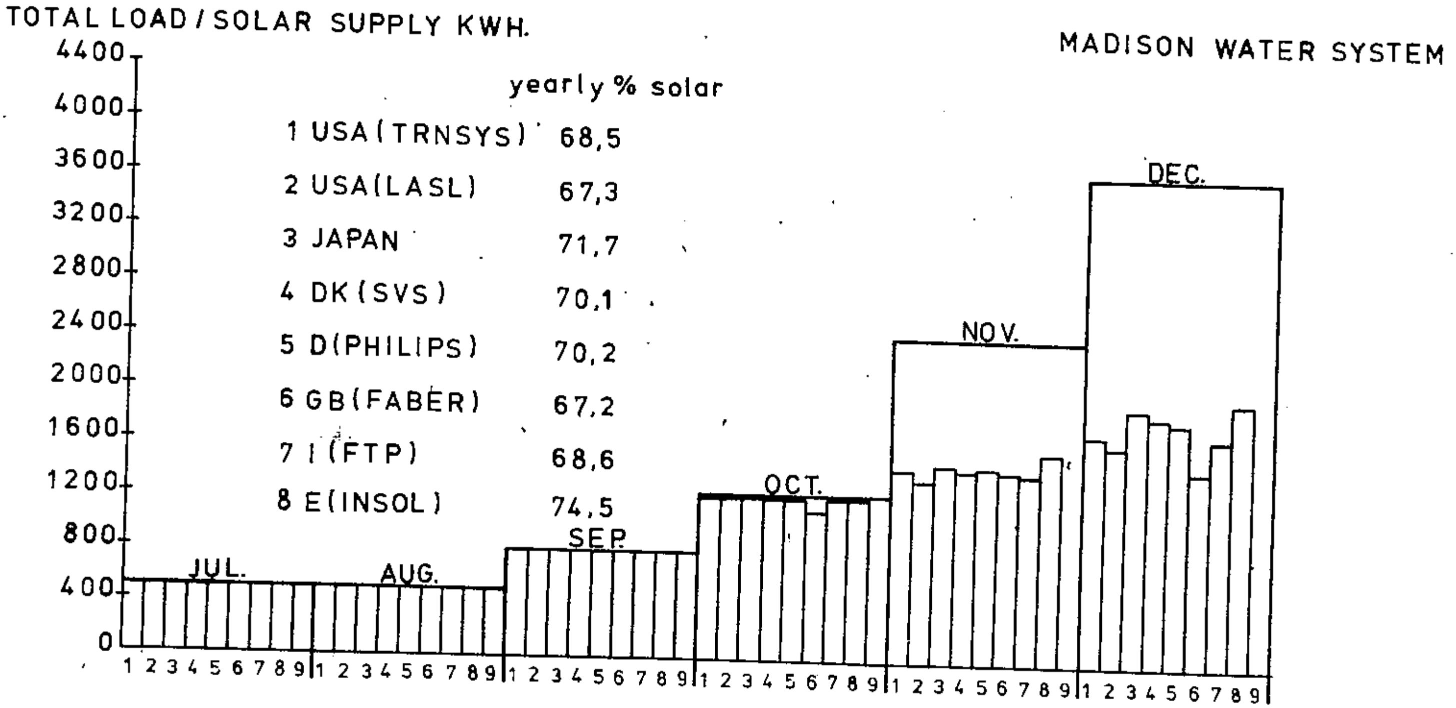

TOTAL LOAD / SOLAR SUPPLY KWH.
MADISON WATER SYSTEM
yearly % solar
1 USA(TRNSYS) 68,5
2 USA(LASL) 67,3
3 JAPAN 71,7
4 DK(SVS) 70,1
5 D(PHILIPS) 70,2
6 GB(FABER) 67,2
7 I (FTP) 68,6
8 E(INSOL) 74,5
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6 7 8 9

Fig. 5.2.1

MADISON WATER SYSTEM

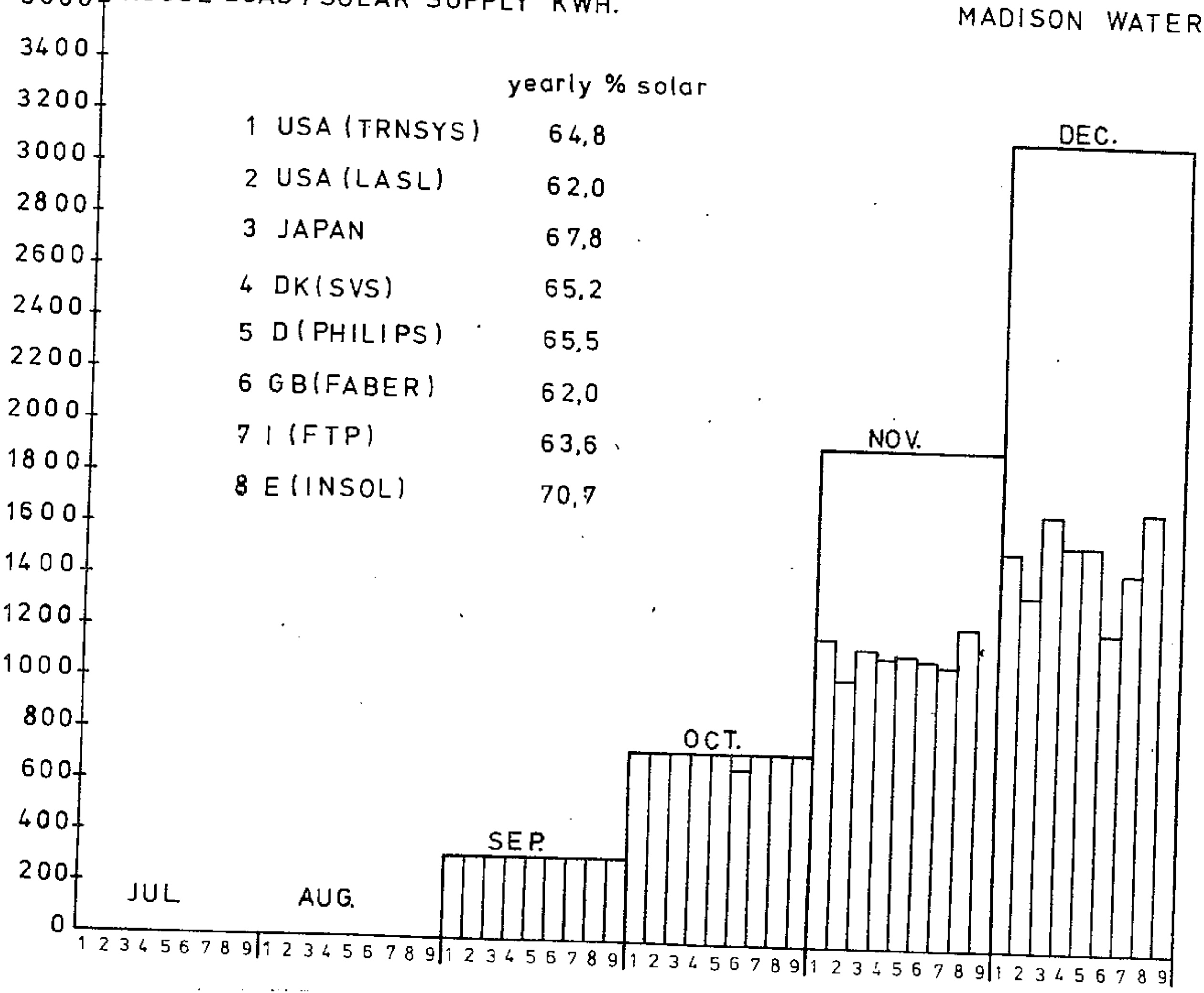


Fig. 5.2.2

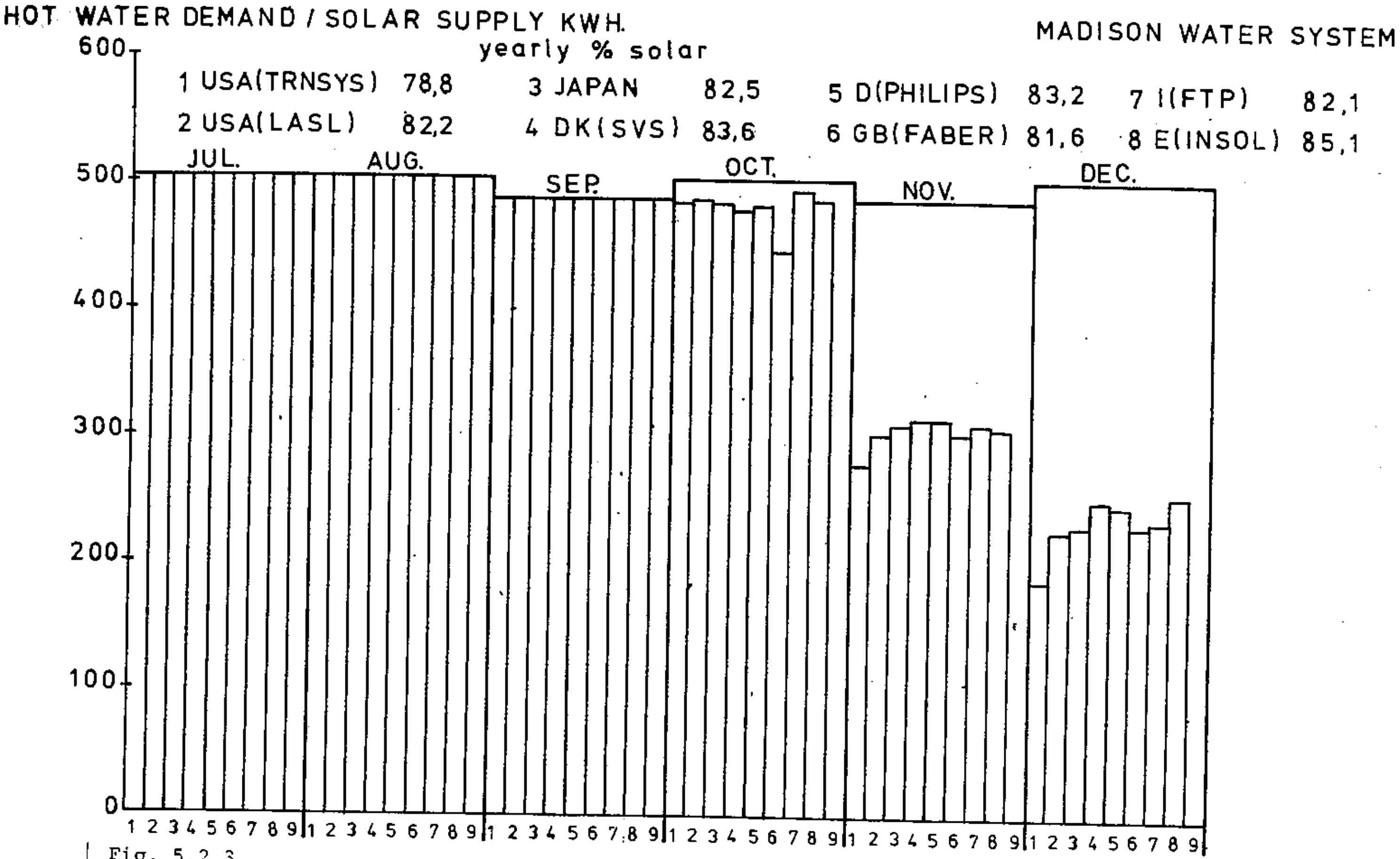

HOT WATER DEMAND / SOLAR SUPPLY KWH.
yearly % solar
1 USA(TRNSYS) 78,8
2 USA(LASL) 82,2
3 JAPAN 82,5
4 DK(SVS) 83,6
5 D(PHILIPS) 83,2
6 GB(FABER) 81,6
7 I(FTP) 82,1
8 E(INSOL) 85,1
MADISON WATER SYSTEM
600
500
400
300
200
100
0
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9

Fig. 5.2.3

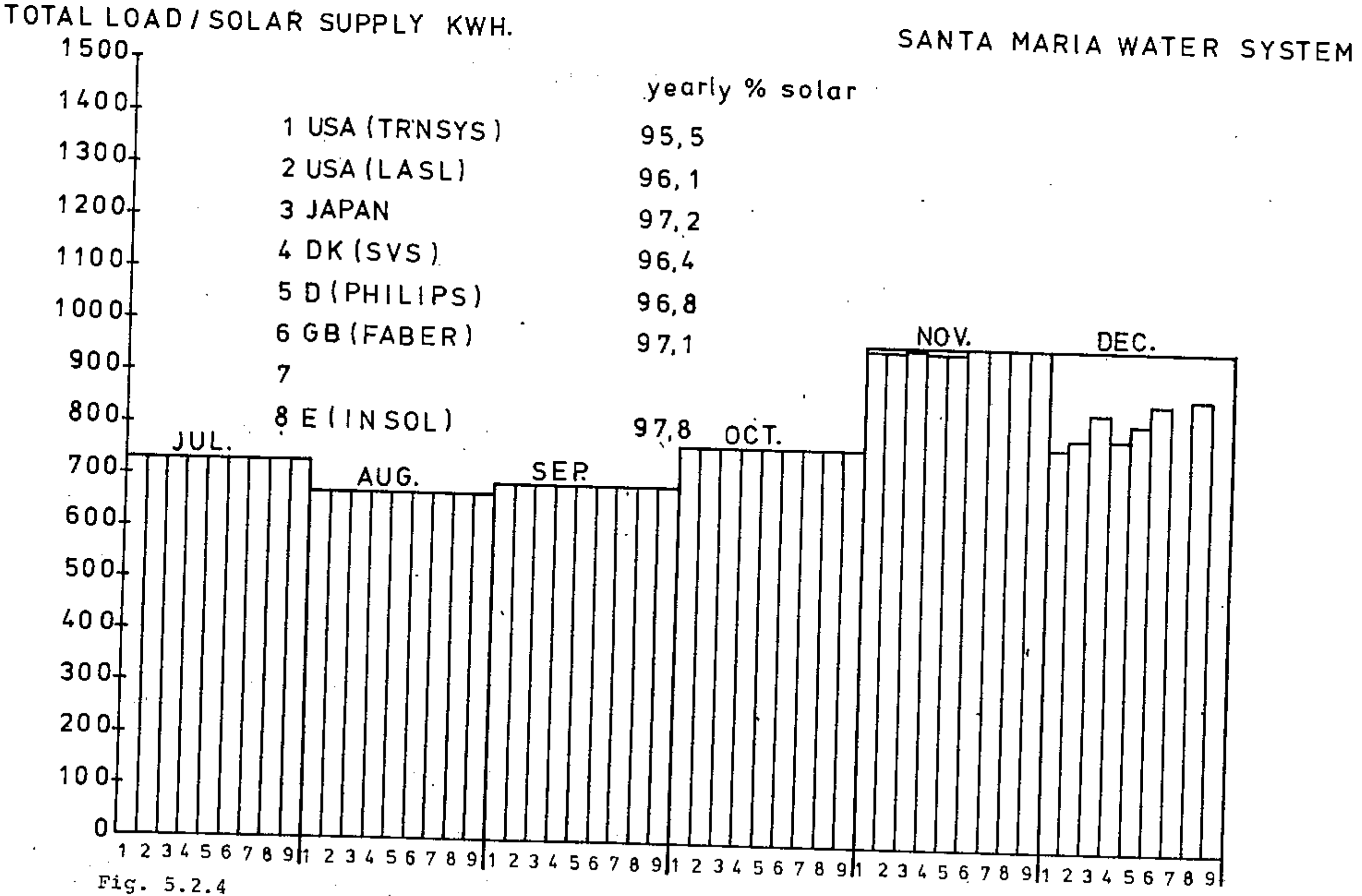

TOTAL LOAD / SOLAR SUPPLY KWH.
SANTA MARIA WATER SYSTEM
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
yearly % solar
1 USA (TR'NSYS) 95,5
2 USA (LASL) 96,1
3 JAPAN 97,2
4 DK (SVS) 96,4
5 D (PHILIPS) 96,8
6 GB (FABER) 97,1
7
8 E (INSOL) 97,8
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9

Fig. 5.2.4

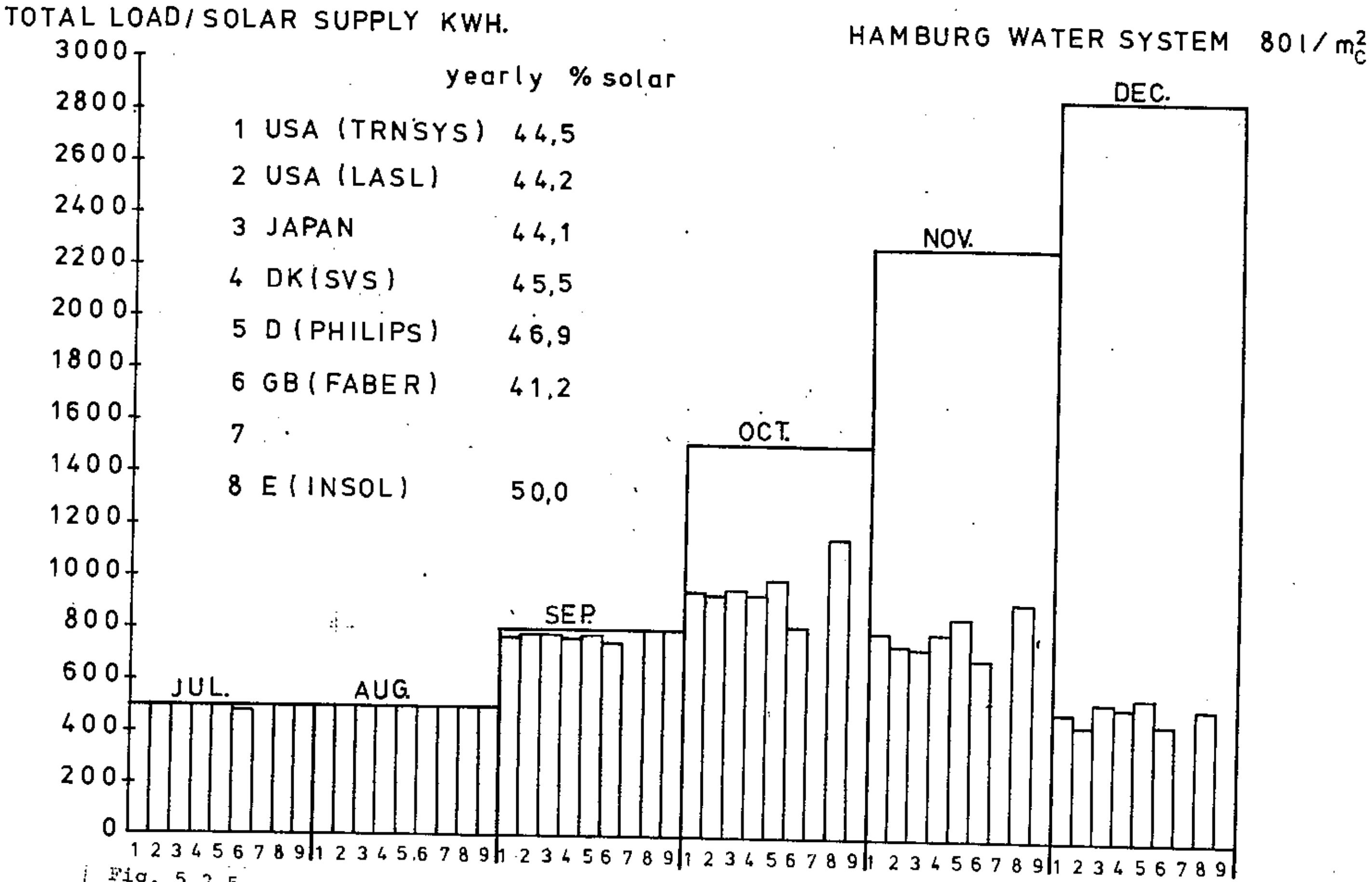

TOTAL LOAD/SOLAR SUPPLY KWH.
HAMBURG WATER SYSTEM 80l/m_C^2
yearly % solar
1 USA (TRNSYS) 44,5
2 USA (LASL) 44,2
3 JAPAN 44,1
4 DK(SVS) 45,5
5 D (PHILIPS) 46,9
6 GB (FABER) 41,2
7
8 E (INSOL) 50,0
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9

Fig. 5.2.5

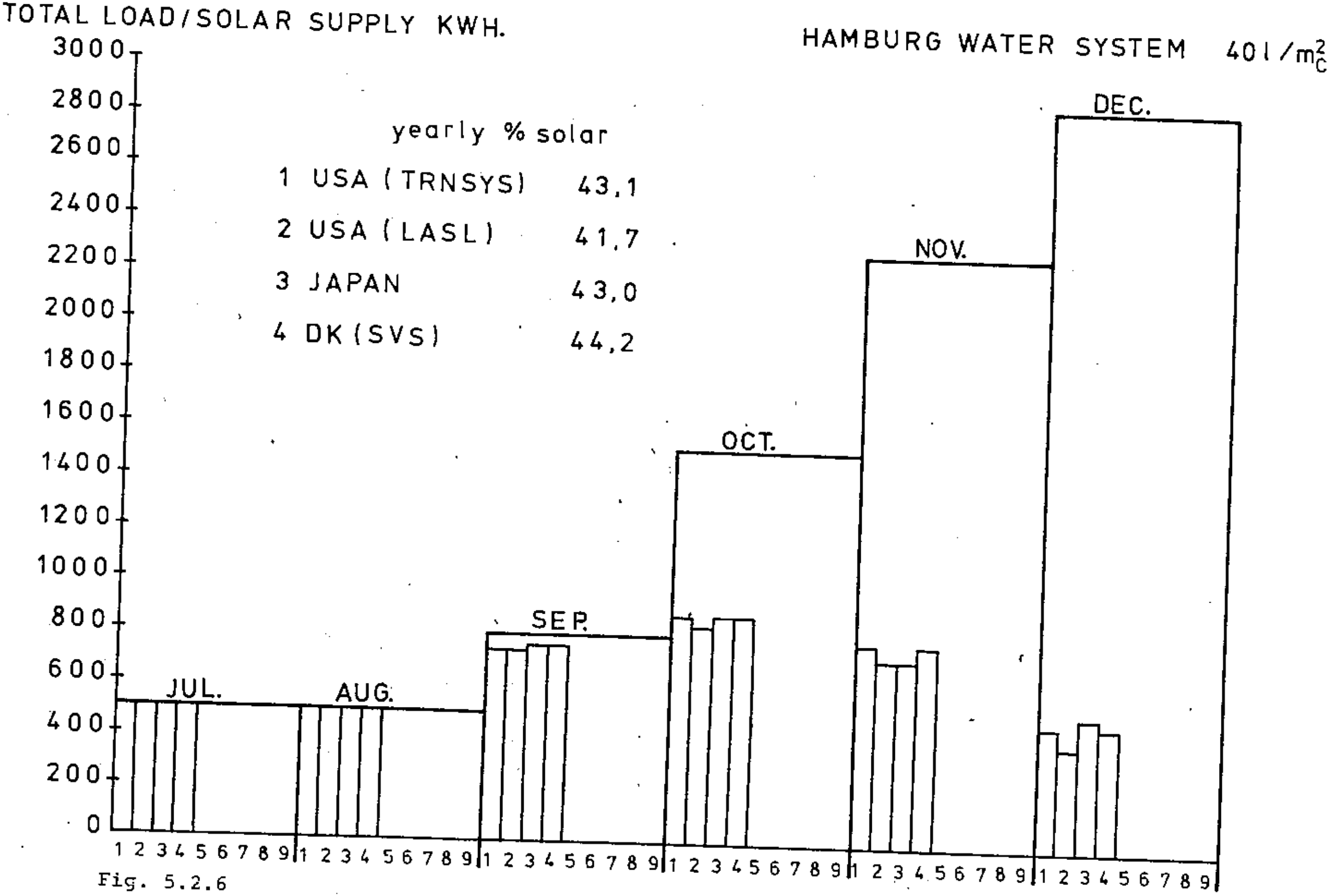

TOTAL LOAD/SOLAR SUPPLY KWH.
HAMBURG WATER SYSTEM 40 l/m_c^2
yearly % solar
1 USA (TRNSYS) 43,1
2 USA (LASL) 41,7
3 JAPAN 43,0
4 DK (SVS) 44,2
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6 7 8 9

Fig. 5.2.6

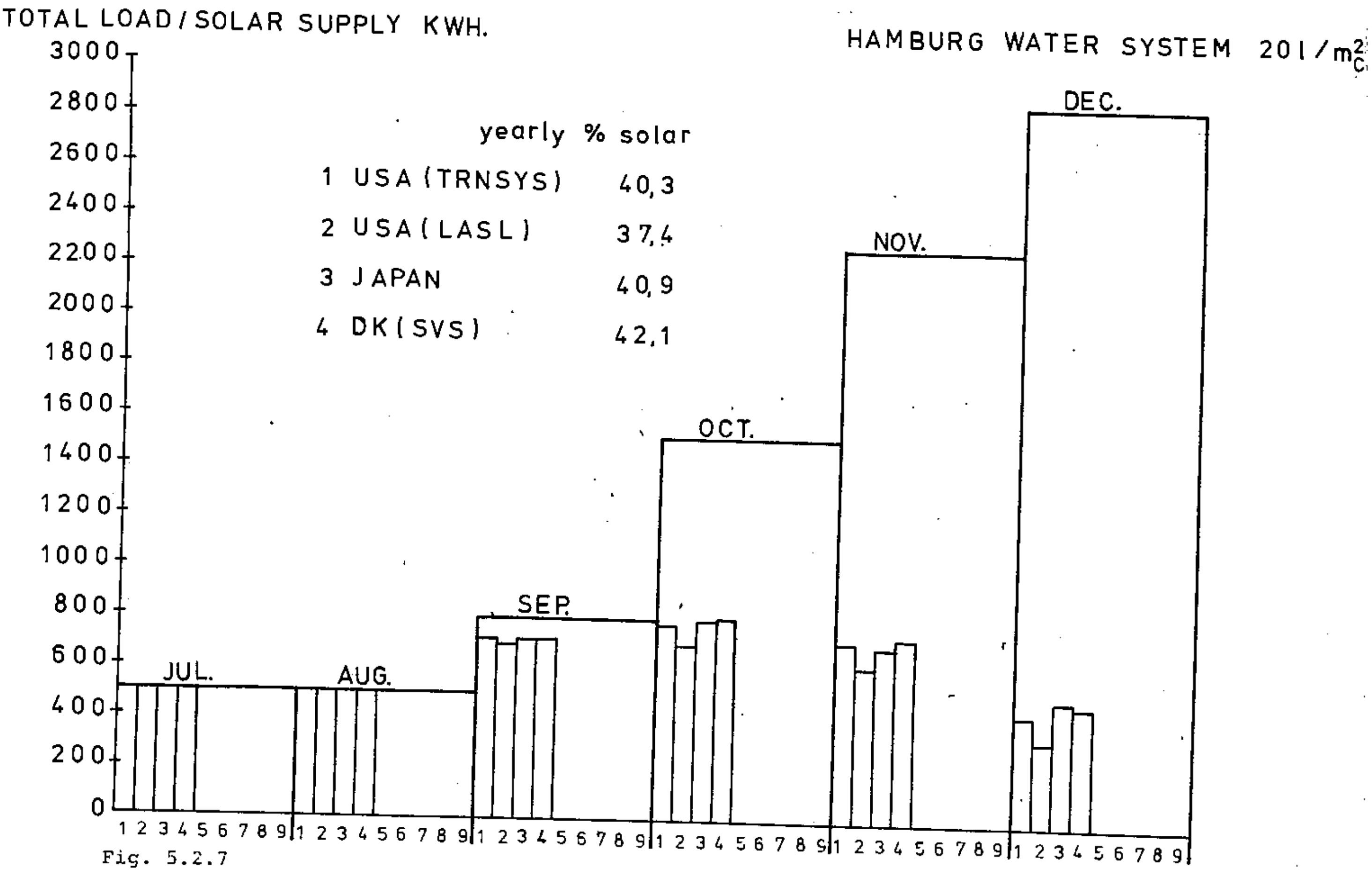

TOTAL LOAD / SOLAR SUPPLY KWH.
HAMBURG WATER SYSTEM 20l / m_C^2
yearly % solar
1 USA (TRNSYS) 40,3
2 USA (LASL) 37,4
3 JAPAN 40,9
4 DK (SVS) 42,1
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6 7 8 9

Fig. 5.2.7

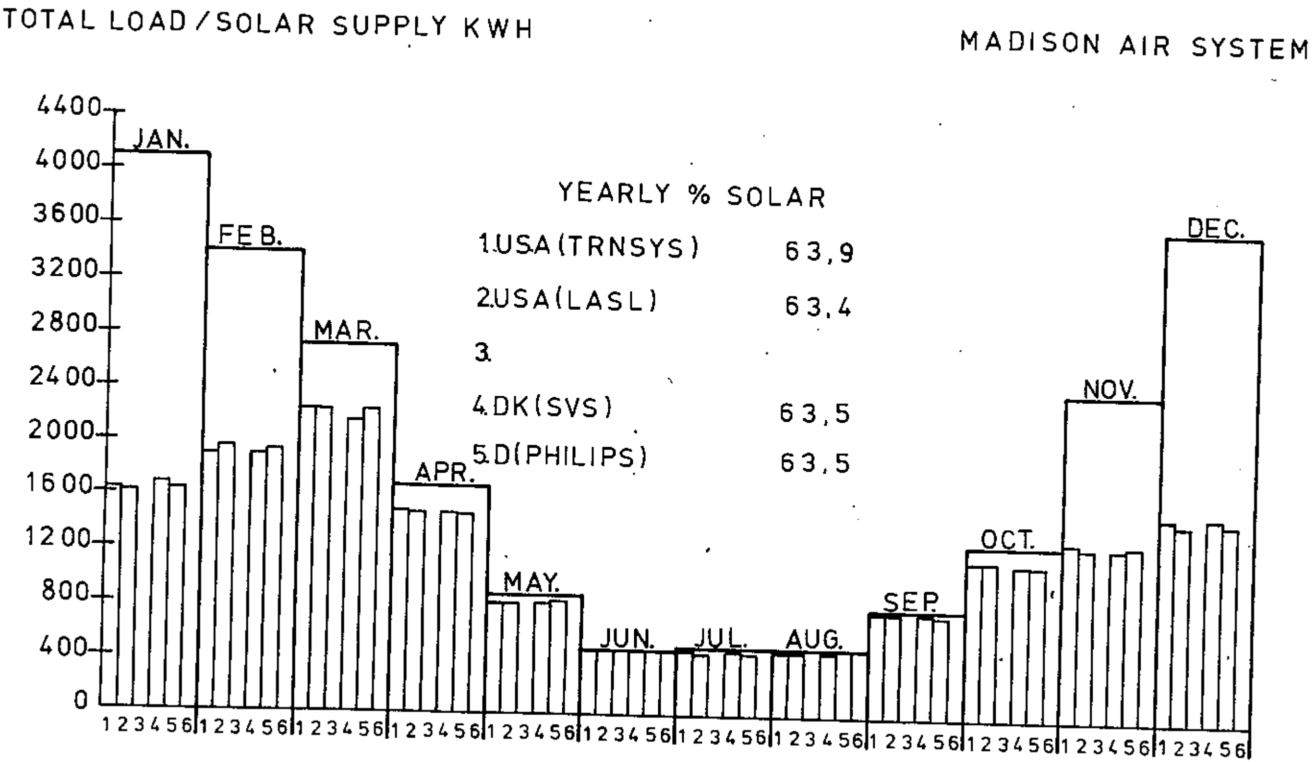

TOTAL LOAD / SOLAR SUPPLY KWH
MADISON AIR SYSTEM
YEARLY % SOLAR
1.USA (TRNSYS) 63,9
2.USA (LASL) 63,4
3.
4.DK (SVS) 63,5
5.D (PHILIPS) 63,5
4400
4000
3600
3200
2800
2400
2000
1600
1200
800
400
0
JAN.
FEB.
MAR.
APR.
MAY.
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
1 2 3 4 5 6

Fig. 5.2.8

Table 5.1.7 Maximum Differences from Yearly Tables

Weather data	Maximum Relative Difference, %					"Old" Programs Total Solar Supply	
	Collector Input			Total Solar Supply			
	Collector Input	Total Solar Supply	Programs	Total Solar Supply	Programs	Max. Relative Diff., %	Abs. Difference %
Madison	7 - 8	2.3	D(PHILIPS) I(FTP)	10	GB(FABER) E(INSOL)	4.9	±1.7
Santa Maria	3-4	-1.9	USA(LASL) E(INSOL)	2.5	USA(TRNSYS) E(INSOL)	1.4	±.7
Hamburg	2	-6.2	D(PHILIPS) E(INSOL)	17.6	GB(FABER) E(INSOL)	8.2	±1.8

5.3 Short Term Results

Short segments from the Madison, Hamburg and Santa Maria weather &load tapes were identified for the purpose of making more detailed comparisons of results. The segments of approximately one week duration, were selected for their inclusion of randomly distributed "good" and "bad" days. The periods selected were:

Hamburg	3/12 to 3/21 inclusive
Santa Maria	1/2 to 1/8 inclusive
Madison	3/10 to 3/16 inclusive

The participants were asked to simulate the liquid system in all three locations and the air system in Madison only. Later, they were asked to simulate the liquid system in Hamburg with smaller storage tanks (20 and 40 l/m^2 collector). In all cases storage temperatures were initialized at 30°C and pipe and duct temperatures to 20°C. The requested output was punched cords consisting of hourly values of the following:

QCOL----total energy collected [Kwh]
QIN------energy input to main tank [Kwh]
QSTO----energy output from tank to house [Kwh]
QCOIL---energy delivered to house by solar [Kwh]
QDHW ---energy output from domestic hot water tank [Kwh]
TTNK-----main tank temperature

This data was sent to a central site for plotting so that it could be presented together on composit graphs. A huge number of graphs were generated but not all participants furnished output for each system and location. Figures 1 through 8 were selected for inclusion in this report since they are representative of all results and illustrate the major points to be made in the short term comparisions.

Discussion

In general the agreement among the programs is very good. The differences are the result of a wide variety of factors including the method of solution of system equations, component modeling, parameter selection, program anomalies,and user input error. The importanceof this last factor is difficult to over state. Nearly every participant had several opportunties to find and correct errors in his input through comparisons with the other participants as their work progressed. Still, due to the large amount of data required to describe these systems and the need to transform it in one way or another to fit the particular format of each program , there are many opportunities for user error.

As evident from Fig. 1,the energy collected by the liquid system in Madison, all programs calculate similar collector performance in Madison. Small differences seen in the long term results of table 4.2.1 are reflected in Fig. 1. Japan, Germany and Denmark have the highest annual collector output and their hourly collector outputs consistantly peak higher than those of USA-TRNSYS and USA-LASL in Fig.1. This is partially due to these three having slightly high January incident radiation on the collector but is also due to differences in collector modeling. The programs differ slightly in their treatment of the heat transfer to the collector fluid, the losses, and the capacitance. Only on the second and fourth days (hours 35 and 85) do appreciable discrepancies occur. In these intermittantly cloudy periods the Japanese collector output is 0 and the other programs predict varying amounts of collected energy. The explanation here may be differences in modeling the no-flow collector temperature which of course is critical to the collector turn on control strategy.

The plots of the energy delivered to the house heating coil by the solar storage tank in the Madison liquid system (figure2) are also in very good agreement. They are nearly exact when the load can be fully met by the tank as in hours 20 to 40 and 140 to 160. At other times the heat transfer across the load heat exchanger is rate limited as in hours 0 to 10, 60 to 80, and 90 to 105. At these times discrepancies occur because the tanks start out at slightly different temperatures and because the house piping & coil systems are modeled slightly differently. The difference in the time constant of decay of QCOIL between hours 60 and 80 is probably an indication that the Japanese have modeled a slightly higher performance coil. Their lower values of QCOIL between hours 90 and 105 is a result of their lower tank temperature caused by lack of energy collection in the immediately preceding cloudy period as discussed earlier.

Heat transfer to and from the domestic hot water system has been modeled nearly identically as shown in figure 3. A phase advance error in the German results is apparent however. It has been verified that the domestic hot water load profile was mistakenly shifted one hour ahead when input to their program. Aside from that problem it is evident from figure 3 that no significant errors in time synchronization exist among the programs. It was previously believed that small time shifts caused by different interpretations of "hourly" input and output, synchronization of solar and local time, and numerical integration error might cause greater differences. These effects could cancel each other out but their net effect is insignificant on the scale of these plots.

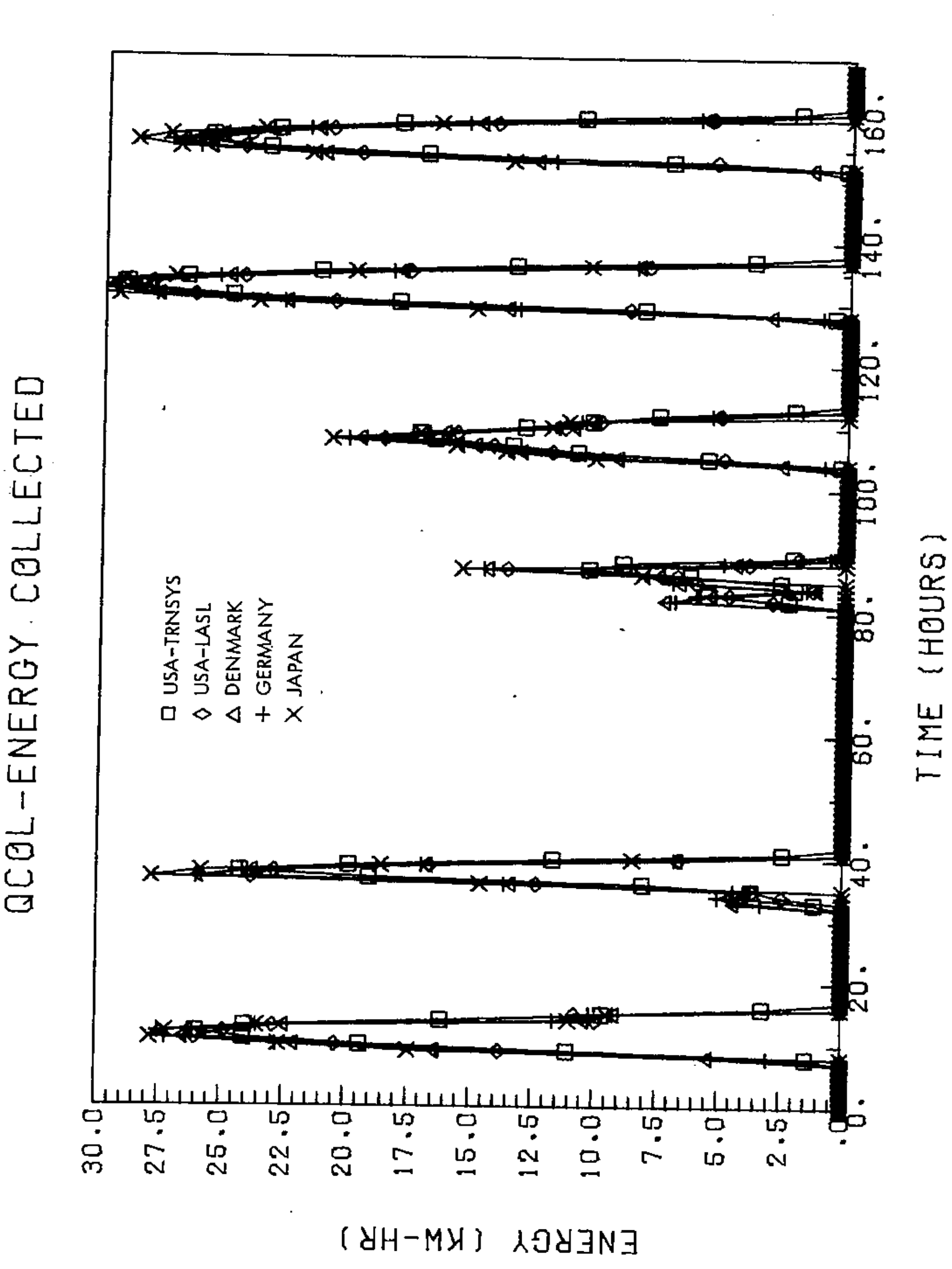
Figure 4 shows the excellent agreement in the Madison liquid system main storage tank temperatures. Storage temperature plots are the single most informative for any system-location combination since the dynamics of the collector, storage, and load subsystems are all evident. Any gross modeling errors would be apparent by comparison of tank temperature plots, either with experiments or other analytical techniques. However, it should be recognized that many "negative feedback" mechnisms act to diminish differences between "real" and modeled storage temperatures. At high tank temperature, collector efficiency, and hence tank energy input, decreases. At still higher temperatures, the relief valve opens or the controller turns the collector pump off. At low tank temperatures little energy can be extracted to meet the load. As a result, even when temperature predictions diverge for awhile, they are often forced back together in a short time.

The liquid system specified for Santa Maria meets about 95% of the annual load with solar and thus is probably "oversized". The tank temperatures are considerably higher on the average than in Madison and therefore some differences in collector and control performance noted earlier are exaggerated. It is not suprising, then, that the Santa Maria tank temperature plots of Figure 5 show poorer agreement than those for Madison. The English tank temperature predictions are consistantly lower than the others, indicating a basic systematic difference in their model. Refering to the long term results in Table 4.2.2 it is clear that their collector predicts consistantly lower performance.

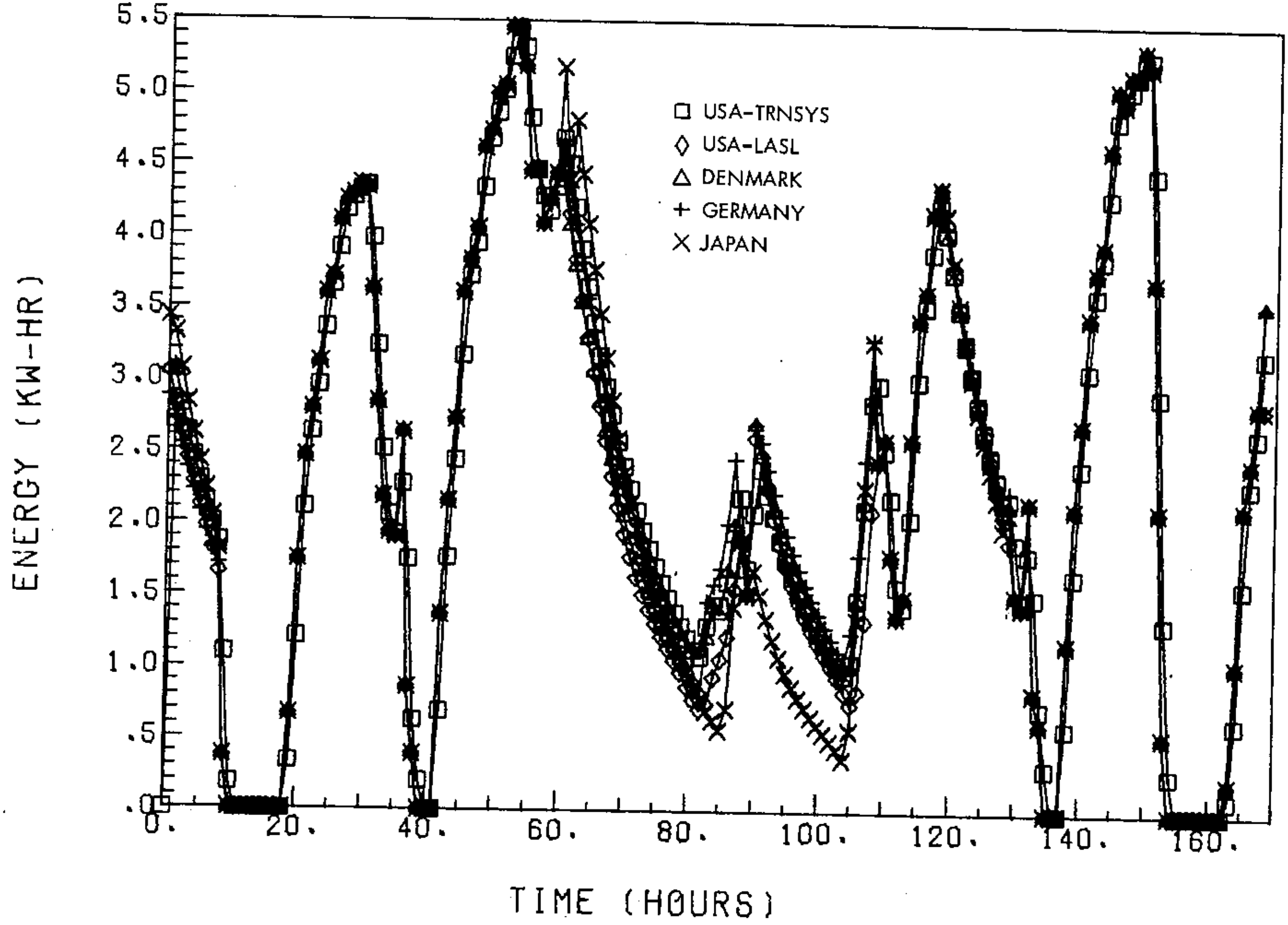
Figure 6 shows the Hamburg liquid system storage temperature plots. Again agreement is good but not as good as in Madison. In Hamburg the day length is short and it is often cloudy. In these cases differences in collector and control models are more evident.

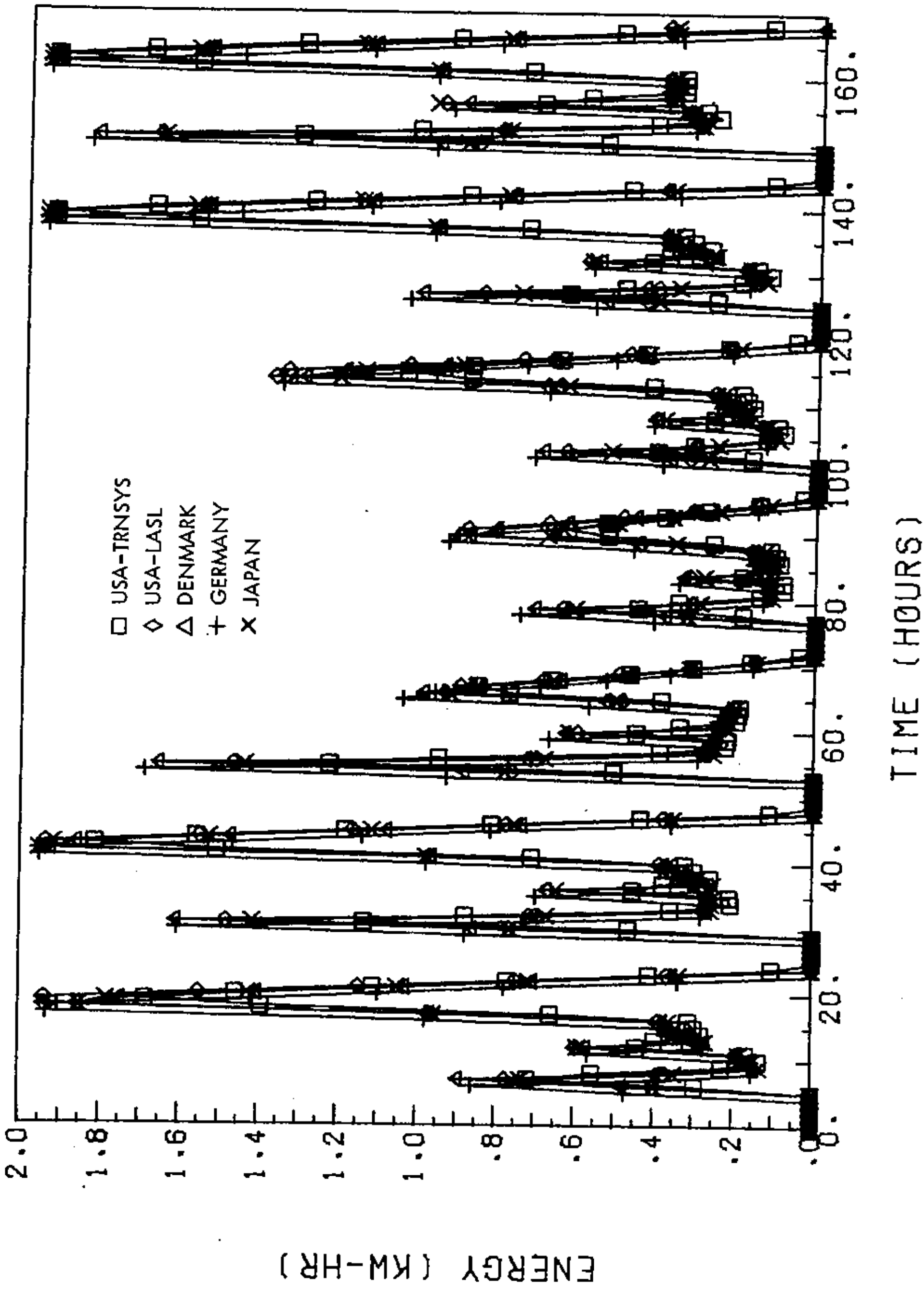
In order to investigate the extent to which the storage tank dampens out differences in the rest of the system, the Hamburg liquid system tank size was reduced from 80 l/m^2 of collector to 40 and then to 20. Figure 7 shows the storage temperature for the Hamburg liquid system with 20 l/m^2 storage. The daily swings in tank temperature are predictably greater in the small tank simulation but the discrepancies of results when expressed as percent of total temperature range, are not much different from those seen in the large tank system. The sixth day (hours 125 to 150) is obviously a marginal day for solar collection. Going into this day, the Japanese and Italians seem to over-predict the tank temperature, which is a contributing factor to their collectors not turning on while the others did. If storage size were decreased toward zero, differences of this kind would become more apparent. Short time step, finite element type models of solar components, pipes, etc. would be required to model accurately systems having little or no storage tanks.

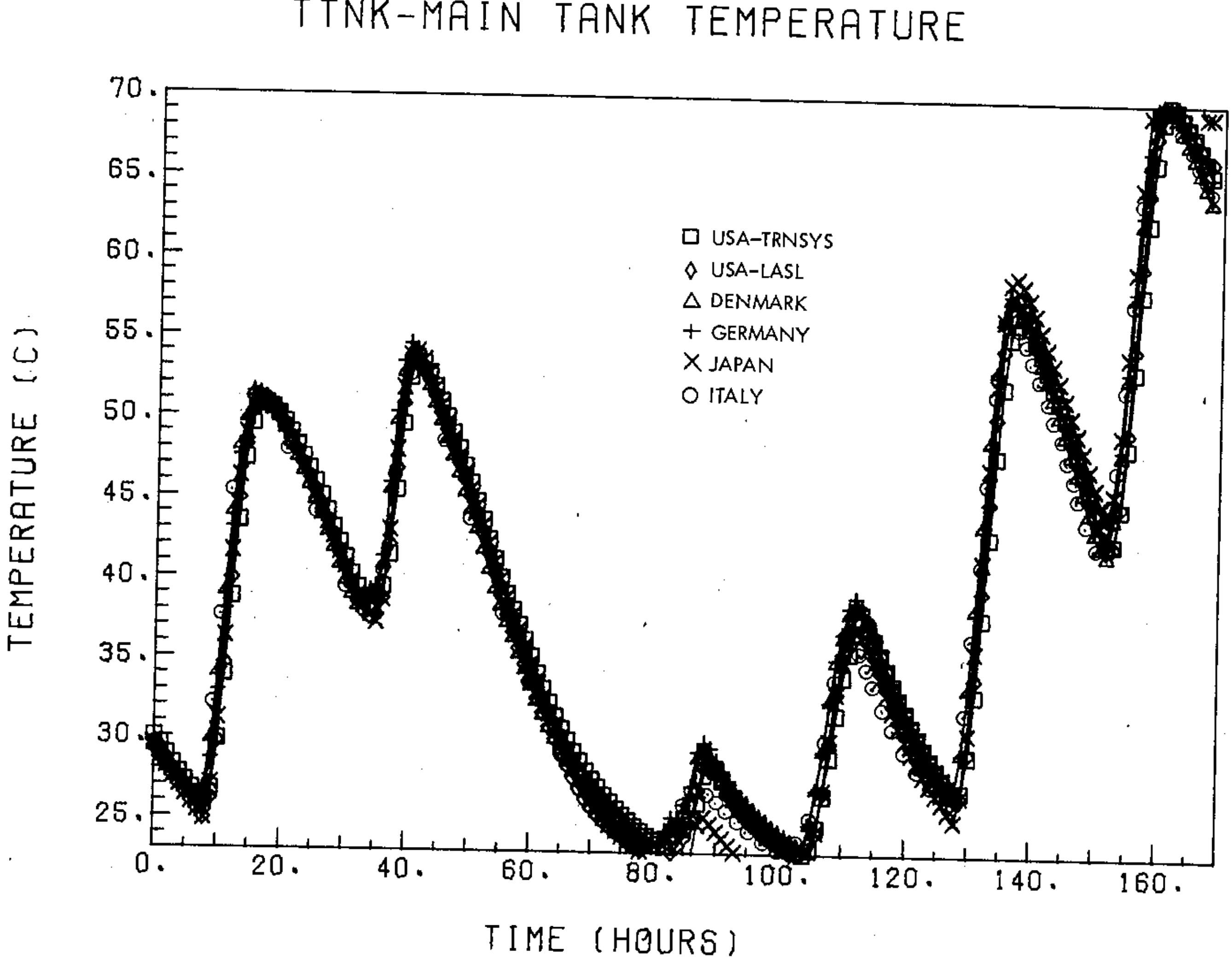
The average spacial temperatures of the Madison air system pebble bed are shown in figure 8. The agreement here is excellent in view of the added complications in simulating the air based system. While the liquid system storage tanks were all modeled as fully mixed, the air system pebble beds were modeled as 5 stratified nodes. Another complicating factor is the air system control strategy which must allow heat to be delivered to the load either from storage or from the collectors. This requires each of the programs to make an approximating assumption regarding the delivery of energy when the load is smaller than the collection rate. The programs must either divide the timestep into 2 or more operational modes in such timesteps (eg collector to load and collector to storage), or generally over or under-supply the load in a given timestep. The latter approach requires the use of some kind of programming or modeling "trick" to compensate for the over or under supply in subsequent timesteps. One such trick is the use of a fluctuating "room" temperature. It is gatifying that the variety of approaches leads to very nearly the same results.


QCOL-ENERGY COLLECTED
ENERGY (KW-HR)
TIME (HOURS)
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
.0
0.
20.
40.
60.
80.
100.
120.
140.
160.
□ USA-TRNSYS
◇ USA-LASL
△ DENMARK
+ GERMANY
× JAPAN

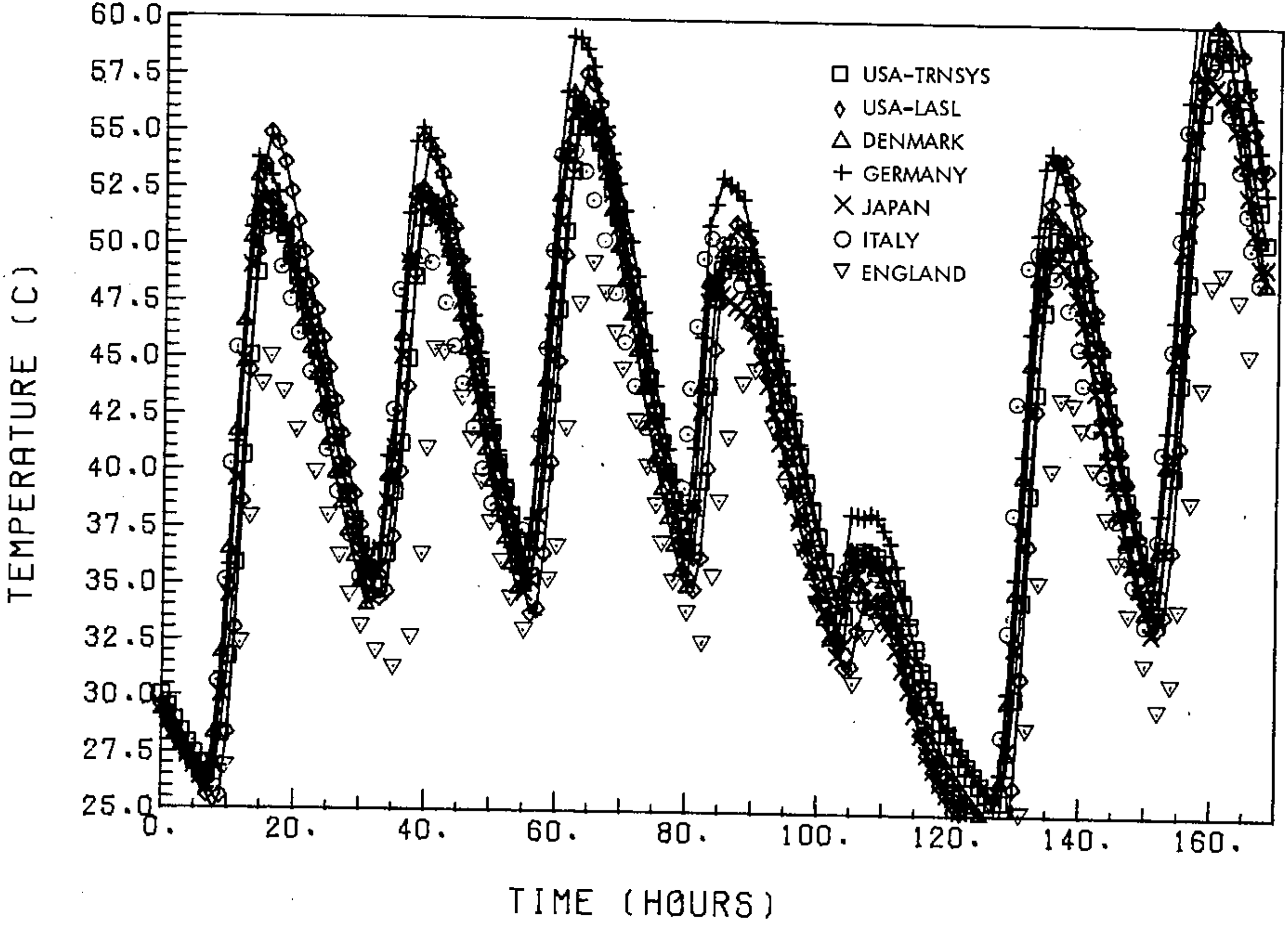
QC0IL-S0LAR ENERGY DELIVERED T0 H0USE



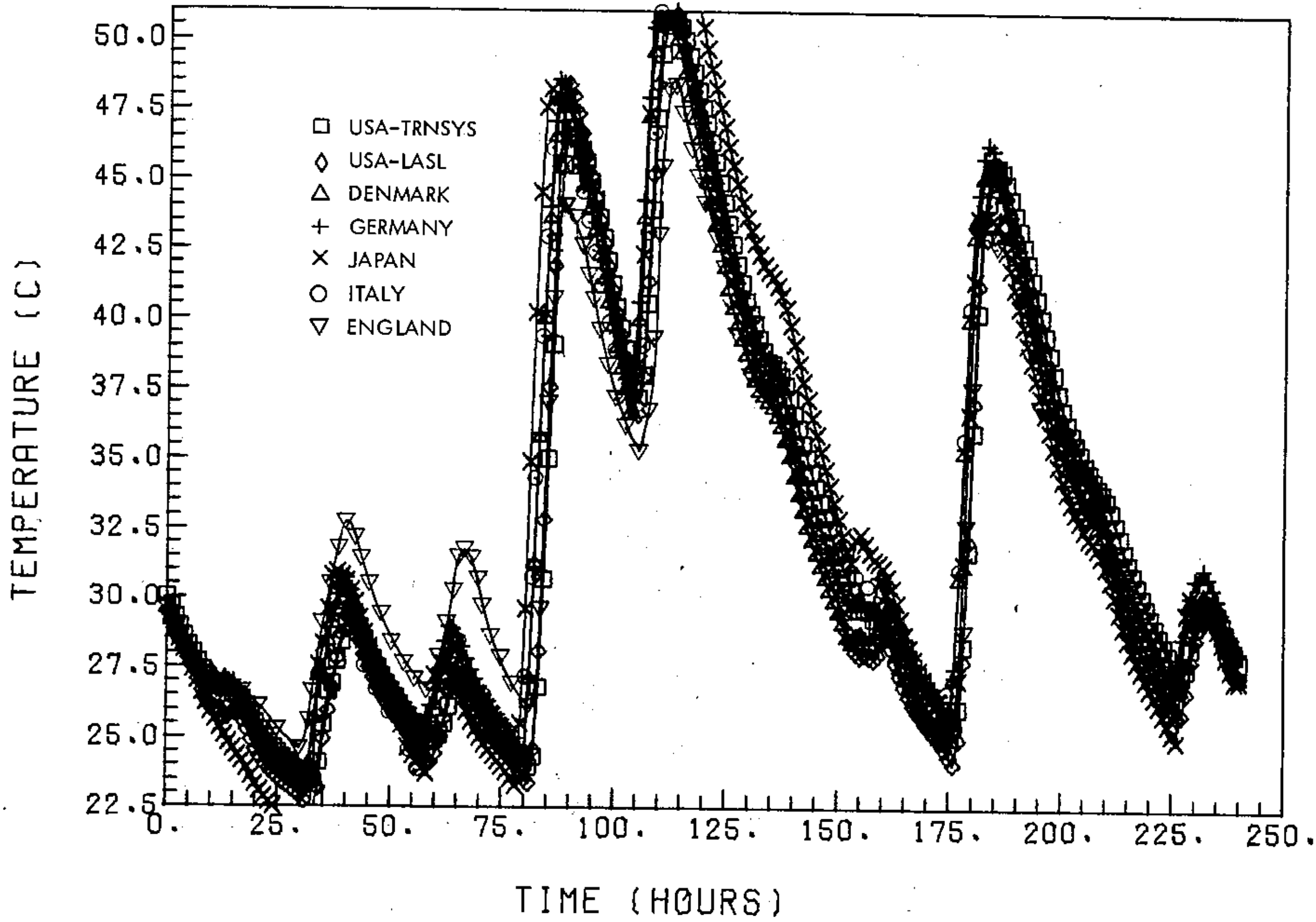

QDHW-DHW TANK ENERGY OUTPUT
□ USA-TRNSYS
◇ USA-LASL
△ DENMARK
+ GERMANY
× JAPAN
ENERGY (KW-HR)
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0.
TIME (HOURS)
0.
20.
40.
60.
80.
100.
120.
140.
160.


TTNK-MAIN TANK TEMPERATURE
TEMPERATURE (C)
70.
65.
60.
55.
50.
45.
40.
35.
30.
25.
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (HOURS)
□ USA-TRNSYS
◊ USA-LASL
△ DENMARK
+ GERMANY
× JAPAN
○ ITALY

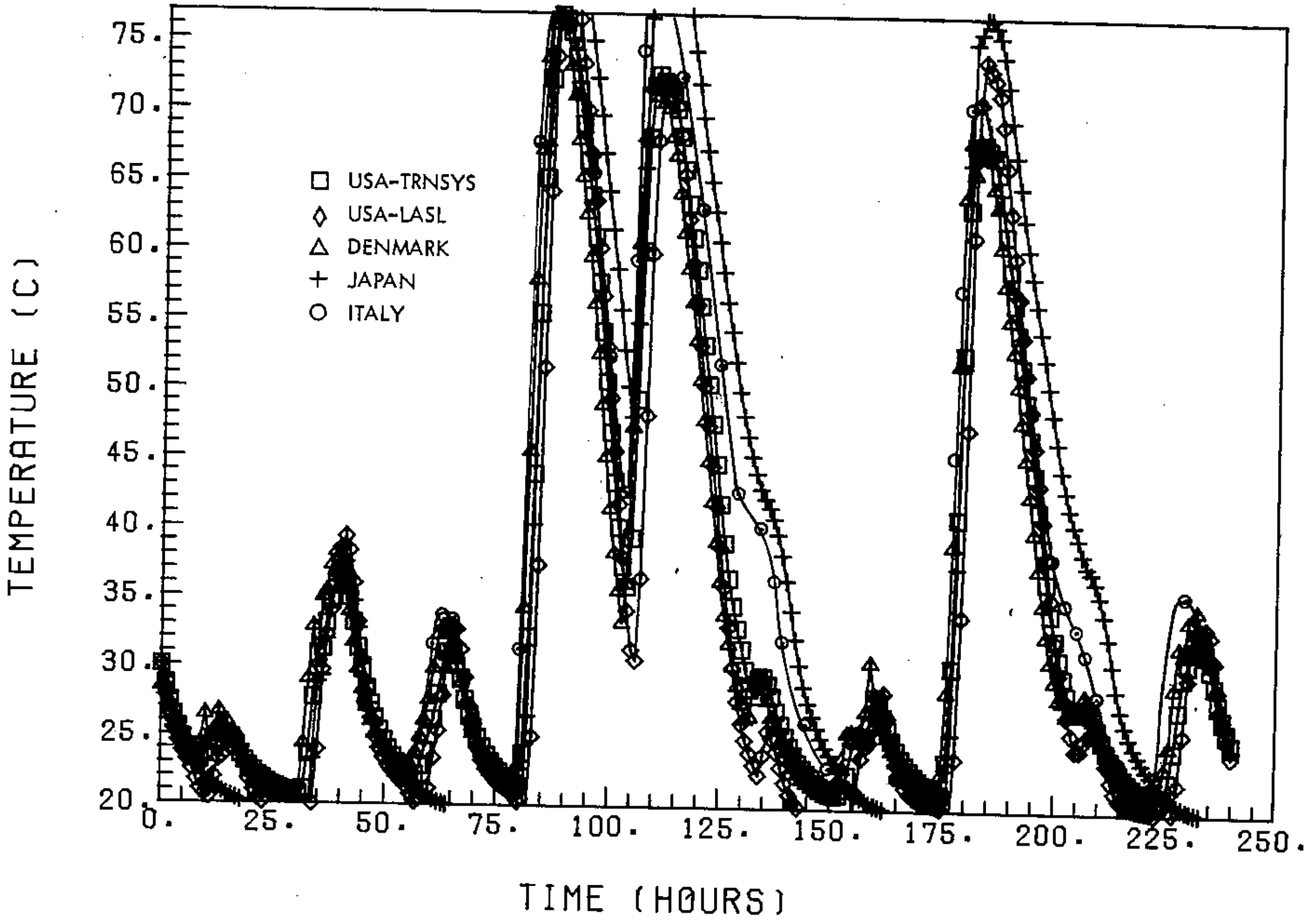
TTNK-MAIN TANK TEMPERATURE

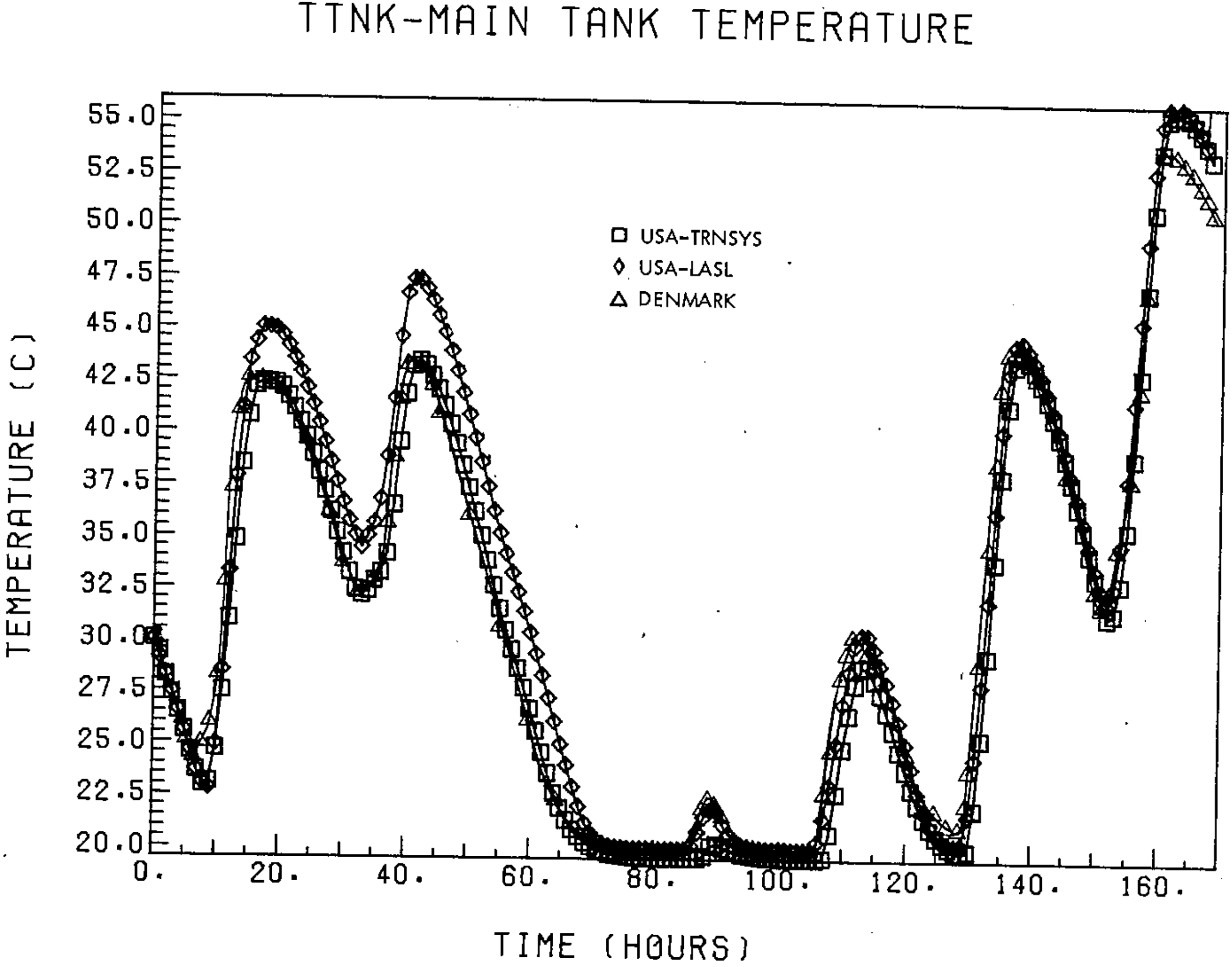


TTNK-MAIN TANK TEMPERATURE



TTNK-MAIN TANK TEMPERATURE




TTNK-MAIN TANK TEMPERATURE
□ USA-TRNSYS
◇ USA-LASL
△ DENMARK
TEMPERATURE (C)
55.0
52.5
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
0.
20.
40.
60.
80.
100.
120.
140.
160.
TIME (HOURS)

CHAPTER VI

CONCLUSION

6.1 Conclusion

A significant improvement in the agreement among the programs has been obtained since the first draft report was made in October 1977. When the results of the five programs USA(TRNSYS), USA(LASL), J(NIKKEN), DK(SVS) and D(PHILIPS) were compared for the first time, the predicted yearly percentage of total solar supply on the Madison weather data ranged from 66.1% to 77.9%; now this range is from 67.3% to 70.7%. This improvement is mainly due to the choice of a common solar processor as mentioned in section 4.1. Second the system parameters were redefined to avoid misunderstandings and limit the possibilities of making user errors. Also quite clearly some of the researchers have corrected user errors and modified their programs in order to model the two solar systems as accurately as possible. Referring to the results presented in this final report it must be concluded that this process has been succesful. Since this joint programmes was established, three more groups have contributed with the results of their programs GB(FABER), I(FTP) and E(INSOL). These groups have not had as much time to "fine-tune" their programs as the others, but still they predict results within a narrow band.

The percent total solar supply predicted by each program for the liquid system on the Madison data agree within +4% (see table 6.1).

Table 6.1
Total solar supply pct.
Location: Madison System: Liquid

Program	%
USA(TRNSYS)	68.5
USA(LASL)	67.3
J(NIKKEN)	71.7
DK(SVS)	70.1
D(PHILIPS)	70.2
GB(FABER)	67.2
I(FTP)	68.6
E(INSOL)	74.5

Considering the wide variety in the modelling approaches (section 4.3) and the many opportunities for input error caused by the very large amount of data required to describe the systems, the differences between the percentages in table 6.1 are small.

On the other hand the relatively large differences between the program in calculating the pipings losses as stated in chapter 5 must lead to the conclusion that when modelling these losses one has to be extremely careful.

The overall conclusion is that this evaluation of the programs has been succesful, and that as far as this evaluation procedure is valid all the programs model a solar energy system in an acceptable way.

ANNEX I

SYSTEM SPECIFICATIONS ON THE TWO SOLAR SYSTEMS SET UP FOR PERFORMANCE PREDICTION COMPARISONS.

Annex I

Information on the two solar systems set up for performance prediction comparisons.

Data for the Liquid Solar Heating System.

See the schematic diagram of the system, Figure 1.1

Collector,

Area (m_c^2) =	50 m^2	Madison Hamburg Copenhagen
	20 m^2	Tokyo Santa Maria

Tilt	Latitude + 10°C
Orientation	South
Number of glazings	2
Glass absorptance (per sheet)	0.037
Refractive index	1.526
Absorber surface α	0.95
Absorber surface ε	0.90
Overall effective Heat transfer coefficient (F^1)	0.95
Back and side losses	0.42 W/°C m_c^2
Back and side temperature	20°C
Total heat capacity	10 kJ/°C m_c^2
Fluid flow rate	1 L/min m_G^2
Glazing spacing	0.04 m.

Pipings.

The collector circuit piping and the heating circuit piping are divided into a cold side and a hot side, and the following data are the same for both sides.

Collector circuit pipe: (each side)

Heat loss: = 0.1 W/m_c^2 ^oC
Total Heat Capacity = 5 $kJ/^oC$ m_c^2
Ambient temperature = 20 ^oC

Heating circuit pipe: (each side)

Length (m_H) = 20 m
Heat loss = 0.15 W/m_H ^oC
Total heat capacity = 2.16 kJ/m_H ^oC
Ambient temperature = 20 ^oC

Thermal Storage Tank.

Volume		80.1 L/m_c^2
Shape	cylinder	H/D = 1
Thermal loss		0.42 W/m_{st}^2 ^oC

m_{st}^2 = Storage surface

No stratification

Collector-storage heat exchanger.

U·A =	60 $W/^oC$ m_c^2
Capacity	0 kJ/m_c^2 ^oC
Fluid flowrate (heat exchanger - storage)	1 $L/min.m_c^2$

Preheat tank

Volume	350 l
Thermal loss	$0.42\ W/m_p^2\ {}^{\circ}C$
m_p^2 = Preheat surface	
Shape	H/D = 1
Cold water inlet temp.	$10^{\circ}C$
Hot water use (see figure 1.2)	350 L/day
Ambient temperature	$20^{\circ}C$
Set point for hot water	$50^{\circ}C$

Preheat heat exchanger

U·A	$1000\ W/{}^{\circ}C$
Heat Capacity	$0\ kJ/{}^{\circ}C$
Fluid flowrate (both sides)	10 L/min

House heating unit

Fluid flow rate		$0.25\ L/min.\ m_c^2$
Maximum air flow rate	Madison	1364 kg/h
	Santa M.	496 kg/h
	Denmark	867 kg/h
	Hamburg	745 kg/h
	Tokyo	621 kg/h
Air inlet temperature (to coil)		$20^{\circ}C$
Heating unit capacity		$0\ kJ/{}^{\circ}C$

Controls

Collector	On when $T_{coll(out)} > T_{storage} + 5^{o}C$
	Off when $T_{coll(out)} > 95^{o}C$
	Off when $T_{coll(out)} \leq T_{coll(in)}$
D.H.W. circuit:	always on Hot water from taps is mixed with cold water when preheat tank temperature is higher than $50^{o}C$
Heating unit:	ON: QLoad > 0.0
	OFF: QLoad < 0.0

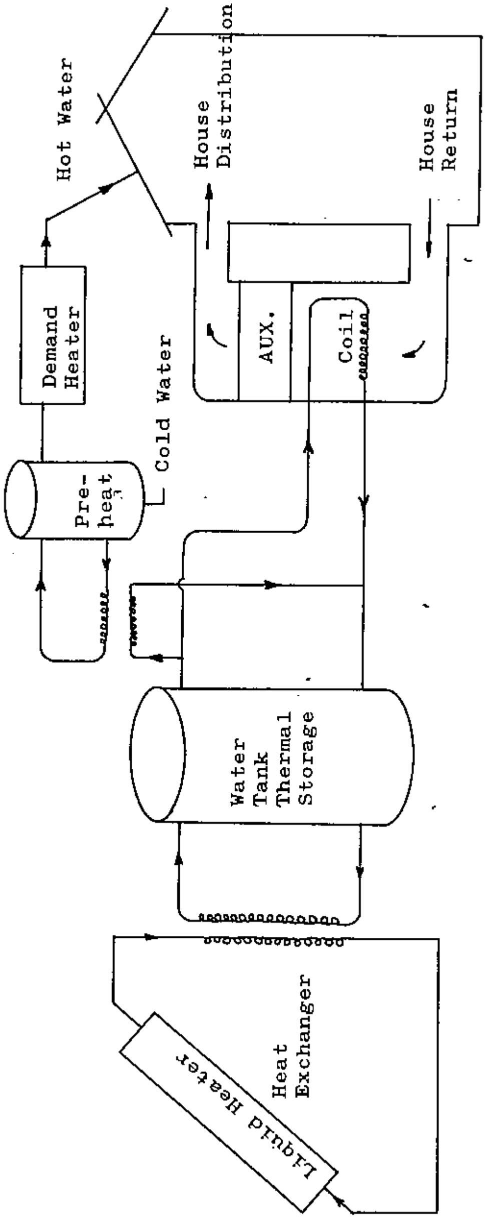


Figure 1.1

LIQUID SOLAR SYSTEM

Use Profile for Domestic Hot Water

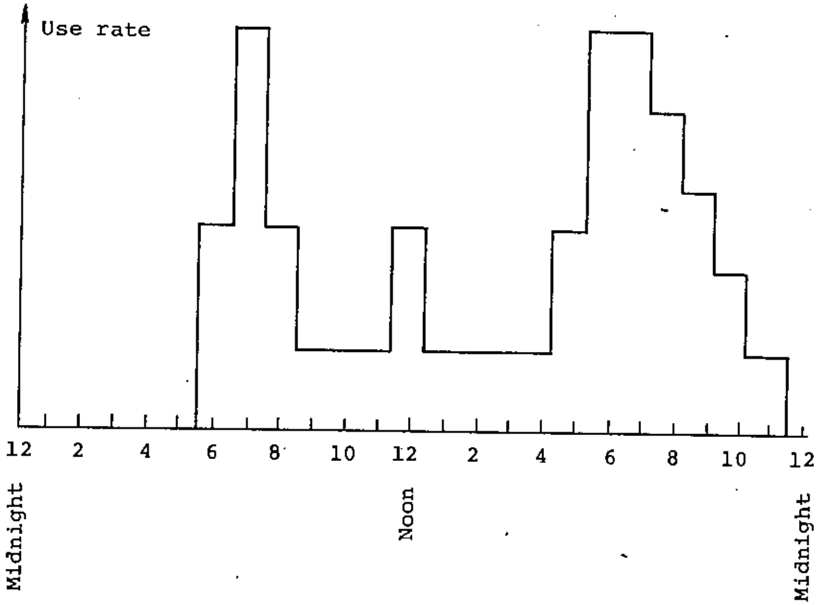


Fig. 1.2

Coil effectiveness:

The coil and air circulation are sized to meet the building load with an outside temperature of -2°F with 133°F water and an air flow rate adequate to make up the space heat losses at an air discharge temperature of 120°F. This corresponds to a finned-tube coil effectiveness of 80%.

Data for the Air Solar Heating System

See the schematic diagram of the system. 1.3

Collector

Area (m_c^2)	50 m^2	Madison Hamburg Copenhagen
	20 m^2	Tokyo Santa Maria
Tilt		Latitude + 10°
Orientation		Due South
Number of glazing		2
Glass absorptance pr. sheet		0.037
Refractive index		1.526
Absorber surface α		0.95
Absorber surface ε		0.90
Collector efficiency factor (F^1)		0.70
Back and side losses		0.42 W/°C m_c^2
Back side temperature		20 °C
Total heat capacity		1.8 kJ/°C m_c^2
Fluid flow rate		44 kg/h·m_c^2
Glazing spazing		0.04 m.

Storage: (pebble bed)

Volume	.25 m^3/m_c^2
Shape	1.83 m high with square cross section.
Effective density (including voids)	1600 kg/m^3
Specific heat of pebbles	.84 kJ/kg °C
Thermal loss coefficient	.42 W/°C m_s^2
m_s^2 = storage surface	
Axial conductivity (no flow)	.125 W/°C m
Ambient temperature	20 °C

Storage is modeled with an "infinite" NTU model 1)

D.H.W. heat exchanger.

Type =	cross flow (water mixed, air not mixed)
U·A =	1000 W/°C
Fluid flow rate (water)	0.1764 L/min m_c^2

Preheat tank

Thermal loss	.42 $W/m_p^2 \cdot °C$
Volume	350 L
Shape	H/D = 1
Cold water inlet	10°C
Hot water use (see figure 1.2)	350 L/day
Ambient temperature	20 °C
Set point for hot water	50 °C

Use profile (see water system)

Ducts

The collector circuit pipings and the heating circuit pipings are divided up into a cold and a hot side, and the following data are the same for both sides.

Collector circuit (each side)

Heat loss	0.1 W/°C m_c^2
Heat capacity	5 kJ/°C m_c^2
Ambient temperature	20 °C

Heating circuit (each side)

length (m_H)	20 m
Heat loss	0.15 W/°C m_H
Heat capacity	1.44 kJ/°C m_H
Ambient temperature.	20 °C

House heating unit.

Maximum air flow rate	Madison	1364 kg/h
	Santa M.	496 kg/h
	Denmark	867 kg/h
	Hamburg	745 kg/h
	Tokyo	621 kg/h
House temperature		20°C

Controls

Collector	$\Delta t_{on} = 5^{o}C$, $\Delta t_{off} = 0^{o}C$ between collector outlet and cold end of pebles.
Preheat tank	$\Delta t_{on} = 5^{o}C$, $\Delta t_{off} = 0^{o}C$ between collector outlet and preheat tank.
Heating unit	on Qload >0 $(T_{house} < 20^{o}C)$ off Qload $\leq$ 0.

1) P.J. Hughes, S.A. Klein, D.J. Close,
"Packed Bed Thermal Storage Models for Solar Air Heating and Cooling Systems"
ASME Journal of Heat Transfer, May 1976.

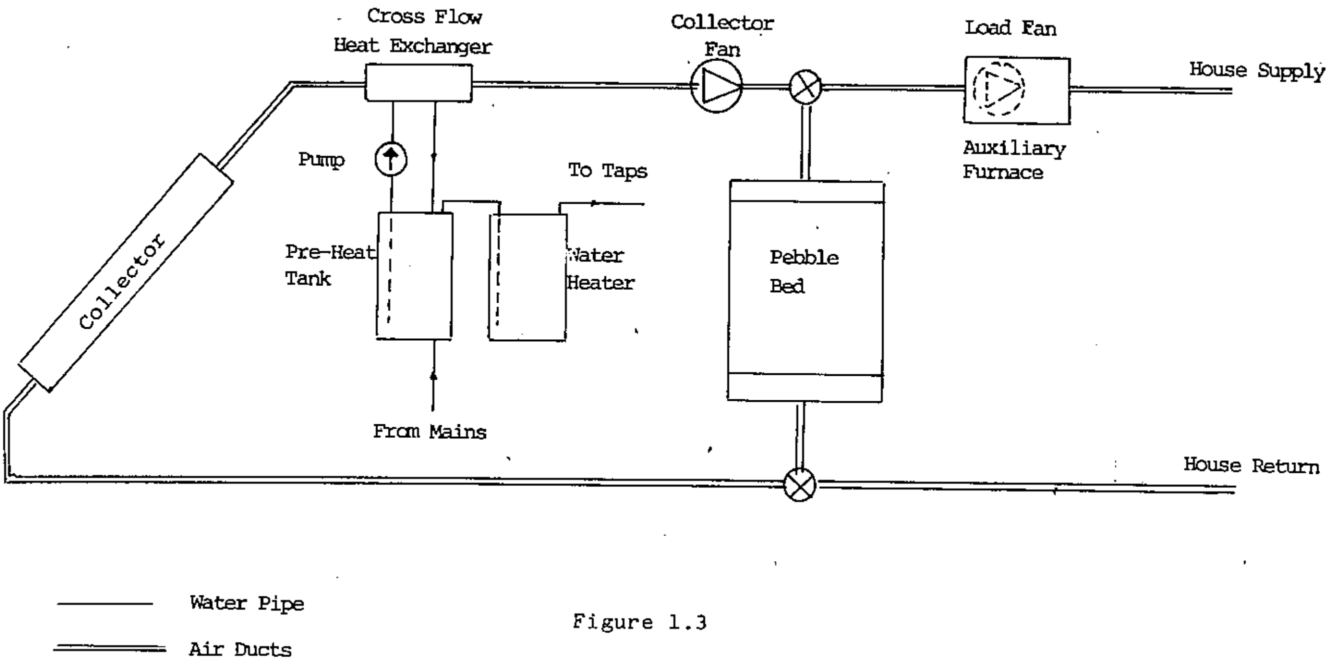


Figure 1.3

Solar Air Heating System

ANNEX II

YEARLY SOLAR PERFORMANCE AND MONTHLY SOLAR PERFORMANCE TABLES

IEA RESULTS

YEARLY SOLAR PERFORMANCE
SUMMARY, TRNSYS

City (location)	SANTA MARIA LIQUID	MADISON LIQUID	MADISON AIR	
Collector Area m^2	20	50	50	
Horizontal Insolation kWh/m^2	2079	1431	1431	
Collector Input	48,880	78,500	78,500	
Collector Output	13,900	19,770	18,440	
Main Storage Input	13,140	18,500	10,410	
Main Storage Loss	1,478	2,171	2,670	
Main Storage Output to House	11,630	16,350	7,767	
House Auxiliary	212	5,797	6,417	
House Demand	4,826	16,480	16,480	
DHW Storage Input	6,171	5,069	4,548	
DHW Storage Loss	498	385	295	
DHW Storage Output	5,669	4,689	4,260	
DHW Auxiliary	274	1,258	1,680	
DHW Demand	5,943	5,947	5,940	
House Percent Solar	95.6	64.8	61.0	
DHW Percent Solar	95.4	78.8	71.7	
Total Percent Solar	95.5	68.5	63.9	

Units: kWh

IEA RESULTS

TRNSYS Results

YEARLY SOLAR PERFORMANCE

SUMMARY

SYSTEM: LIQUID (STORAGE SIZE TEST)

City (location)	HAMBURG (80 ℓ/m^2)	HAMBURG (40 ℓ/m^2)	HAMBURG (20 ℓ/m^2)
Collector Area m^2	50	50	50
Horizontal Insolation kWh/m^2	977.4	977.4	977.4
Collector Input	48260	48260	48260
Collector Output	11010	10190	9492
Main Storage Input	10190	9327	8526
Main Storage Loss	1418	9033	572
Main Storage Output	8749	8416	7940
House Auxiliary	7973	8285	8841
House Demand	12590	12590	12590
DHW Storage Input	3874	3916	3965
DHW Storage Loss	234	237	238
DHW Storage Output	3641	3680	3727
DHW Auxiliary	2307	2268	2219
DHW Demand	5948	5948	5948
House Percent Solar	36.7	34.2	29.8
DHW Percent Solar	61.2	61.9	62.7
Total Percent Solar	44.5	43.0	40.3

Units: kWh

IEA RESULTS

YEARLY SOLAR PERFORMANCE

SUMMARY , LASL

System	------------ Liquid---			--Air--
City (location)	Madison	Santa Maria		Madison
Collector Area m^2	50	20		50
Horizontal Insolation kWh/m^2	1434	2082		1434
Collector Input	78863	45598		78858
Collector Output	18253	12448		18155
Main Storage Input	17618	11970		10471
Main Storage Loss	2146	1075		2753
Main Storage Output to House	10219	4627		7955
House Auxiliary	6265	199		6594
House Demand	16484	4827		16484
DHW Storage Input	5300	6236		4696
DHW Storage Loss	419	524		302
DHW Storage Output	4880	5712		4400
DHW Auxiliary	1056	224		1618
DHW Demand	5936	5936		5936
House Percent Solar	62.0	95.9		60.0
DHW Percent Solar	82.2	96.2		72.7
Total Percent Solar	67.3	96.1		63.4

Units: kWh

IEA RESULTS

TABLE I
LASL
YEARLY SOLAR PERFORMANCE
SUMMARY
SYSTEM: LIQUID

City (location)	HAMBURG	HAMBURG	HAMBURG		
Storage Size ℓ/m^2	80	40	20		
Horizontal Insolation kWh/m^2	979	979	979		
Collector Input	47973	47973	47973		
Collector Output	10234	9269	8137		
Main Storage Input	9823	8854	7718		
Main Storage Loss	1371	864	527		
Main Storage Output to House	4181	3751	3060		
House Auxiliary	8403	8836	9527		
House Demand	12587	12587	12587		
DHW Storage Input	4266	4236	4133		
DHW Storage Loss	268	268	257		
DHW Storage Output	3997	3968	3876		
DHW Auxiliary	1939	1968	2061		
DHW Demand	5936	5936	5936		
House Percent Solar	33.2	29.8	24.3		
DHW Percent Solar	67.3	66.8	65.3		
Total Percent Solar	44.2	41.7	37.4		

Units: kWh

TABLE IV
LASL
YEARLY SOLAR PERFORMANCE
SUMMARY
SYSTEM: LIQUID

City (location)	HAMBURG	HAMBURG	HAMBURG		
Storage Size ℓ/m^2	80	40	20		
Horizontal Insolation kWh/m^2	979	979	979		
Collector Input	47973	47973	47973		
Collector Output	10997	10047	8960		
Main Storage Input	10518	9579	8493		
Main Storage Loss	1489	943	589		
Main Storage Output to House	4612	4231	3583		
House Auxiliary	7975	8356	9004		
House Demand	12587	12587	12587		
DHW Storage Input	4408	4397	4321		
DHW Storage Loss	291	292	287		
DHW Storage Output	4117	4105	4034		
DHW Auxiliary	1820	1831	1902		
DHW Demand	5936	5936	5936		
House Percent Solar	36.6	33.6	28.5		
DHW Percent Solar	69.3	69.2	68.0		
Total Percent Solar	47.1	45.0	41.1		

Units: kWh

No Collector Mass

YEARLY SOLAR PERFORMANCE SUMMARY

NIKKEN, JAPAN

System: Liquid solar system

Items City (Location)		Madison	Santa Maria	Hamburg (Case 1)	Hamburg (Case 2)	Hamburg (Case 3)
Collector area	(m^2)	50	20	50	50	50
Storage size	(ℓ/m^2)	80	80	80	40	20
Horizontal insolation	(kWh/m^2)	1431	2079	977	977	977
Collector input	(kWh)	78176	45323	47399	47399	47399
Collector output	(kWh)	19521	13708	10289	9436	8565
Main storage input	(kWh)	18921	13247	9921	9089	8226
Main storage loss	(kWh)	2062	1404	1345	845	523
Main storage output to house	(kWh)	11652	5583	4478	4122	3612
House auxiliary	(kWh)	5481	142	8395	8754	9264
House demand	(kWh)	16482	4826	12585	12585	12585
DHW storage input	(kWh)	5248	6224	4085	4108	4084
DHW storage loss	(kWh)	392	492	254	253	248
DHW storage output	(kWh)	4862	5726	3832	3853	3834
DHW auxiliary	(kWh)	1080	216	2110	2089	2108
DHW demand	(kWh)	5942	5942	5942	5942	5942
House percent solar	(%)	66.7	97.1	33.3	30.4	26.4
DHW percent solar	(%)	81.8	96.4	64.5	64.9	64.5
Total percent solar	(%)	70.7	96.7	43.3	41.5	38.6

IEA RESULTS

YEARLY SOLAR PERFORMANCE
SUMMARY

SYSTEM: S.V.S., liquid

City (location)	Madison	St. Maria	Hamburg	Hamburg	Hamburg
Collector Area m^2	50	20	50	50	50
Storage size l/m_c^2	80	80	80	40	20
Horizontal Insolation kWh/m^2					
Collector Input	78438	45109	47556	47556	47556
Collector Output	22113	152o5	12214	11480	10703
Main Storage Input					
Main Storage Loss	2559	1661	1580	1019	634
Main Storage Output to House	10843	4626	4466	4161	3662
House Auxiliary	5641	201	8121	8426	8925
House Demand	16484	4827	12587	12587	12587
DHW Storage Input					
DHW Storage Loss	490	593	299	309	315
DHW Storage Output	4869	5685	3895	3920	3962
DHW Auxiliary	1024	208	1998	1973	1931
DHW Demand	5893	5893	5893	5893	5893
House Percent Solar	65.8	95.8	35.5	33.1	29.1
DHW Percent Solar	83.2	96.5	66.1	66.5	67.2
Total Percent Solar	70.3	96.2	45.2	43.7	41.3

Units: kWh

IEA RESULTS

YEARLY SOLAR PERFORMANCE
SUMMARY

SYSTEM: Air, DK(SVS)

City (location)	Madison				
Collector Area m^2	50				
Storage size $1/m_c^2$	12.5				
Horizontal Insolation kWh/m^2					
Collector Input	78141				
Collector Output	18234				
Main Storage Input	2617				
Main Storage Loss	2617				
Solar to house	9439				
House Auxiliary	7028				
House Demand	16467				
DHW Storage Input					
DHW Storage Loss	293				
DHW Storage Output	4261				
DHW Auxiliary	1644				
DHW Demand	5905				
House Percent Solar	57.3				
DHW Percent Solar	72.1				
Total Percent Solar	61.2				

Units: kWh

IEA RESULTS

YEARLY SOLAR PERFORMANCE
SUMMARY

SYSTEM: Philips, liquid

City (location)	Madison	Santa Maria	Hamburg		
Collector Area m^2	50	20	50		
Storage size l/m_c^2	80	80	80		
Horizontal Insolation kWh/m^2					
Collector Input	79351	45395	48326		
Collector Output	21226	14639	12289		
Main Storage Input	18825	11311	10728		
Main Storage Loss	1998	1372	1371		
Main Storage Output to House	11534	4646	5053		
House Auxiliary	5695	181	7935		
House Demand	16484	4827	12587		
DHW Storage Input	5333	6282	4301		
DHW Storage Loss	392	499	277		
DHW Storage Output	4945	5774	4034		
DHW Auxiliary	998	168	1909		
DHW Demand	5943	5943	5943		
House Percent Solar	65.5	96.3	40,0		
DHW Percent Solar	83.2	97.2	67.9		
Total Percent Solar	70.2	96.8	46.9		

Units: kWh

IEA RESULTS

YEARLY SOLAR PERFORMANCE, UK (FABER)
SUMMARY

SYSTEM:

City (location)	HAMBURG	MADISON	SANTA MARIA		
Collector Area m^2	50	50	20		
Storage size $1/m_c^2$	80	80	80		
Horizontal Insolation kWh/m^2					
Collector Input	47219	75110	44404		
Collector Output	9097	17203	12868		
Main Storage Input	8792	16808	12572		
Main Storage Loss	981	1489	1429		
Main Storage Output to House	3885	10220	4712		
House Auxiliary	8697	6260	111		
House Demand	12582	16479	4823		
DHW Storage Input	3935	5143	6335		
DHW Storage Loss	195	300	534		
DHW Storage Output	3740	4844	5801		
DHW Auxiliary	2193	1090	132		
DHW Demand	5933	5933	5933		
House Percent Solar	30.9	62.0	97.7		
DHW Percent Solar	63.0	81.6	97.8		
Total Percent Solar	41.2	67.2	97.7		

Units: kWh

IEA RESULTS

YEARLY SOLAR PERFORMANCE, I(FTP)
SUMMARY

SYSTEM: LIQUID

City (location)	MADISON				
Collector Area m^2	50				
Storage size $1/m_c^2$	80				
Horizontal Insolation kWh/m^2	1430				
Collector Input	73,500				
Collector Output	20,395				
Main Storage Input	--				
Main Storage Loss	--				
Main Storage Output to House	10,484				
House Auxiliary	5,991				
House Demand	16,475				
DHW Storage Input	--				
DHW Storage Loss	--				
DHW Storage Output	5,007				
DHW Auxiliary	1,094				
DHW Demand	6,099				
House Percent Solar	63.6				
DHW Percent Solar	82.1				
Total Percent Solar	68.6				

Units: kWh

IEA RESULTS

YEARLY SOLAR PERFORMANCE
SUMMARY

SYSTEM: INSOL, liquid

City (location)	Sta. María	Madison	Hamburg		
Collector Area m^2	20	50	50		
Horizontal Insolation kWh/m^2					
Collector Input	44060	74188	47209		
Collector Output	14130	20905	12175		
Main Storage Input	12612	19395	11290		
Main Storage Loss	1441	2162	1618		
Main Storage Output to House	4716	11649	5050		
House Auxiliary	111	4835	7537		
House Demand	4825	16484	12587		
DHW Storage Input	5819	5462	4523		
DHW Storage Loss	511	414	307		
DHW Storage Output	5826	5059	4215		
DHW Auxiliary	116	883	1725		
DHW Demand	5943	5942	5942		
House Percent Solar	97,70	70,6	40,12		
DHW Percent Solar	98,00	85,1	70,9		
Total Percent Solar	97,89	74,5	50,0		

Units: kWh

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SUMMARY, TRNSYS

SYSTEM: LIQUID

CITY: MADISON

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	--collector--		house					dwh					-percent solar-		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot
1	4868	1959	1901	38	1824	1990	3599	200	4	194	311	505	44.7	38.4	43.9
2	5573	2213	2141	56	2163	1041	2927	242	8	241	215	456	64.4	52.8	62.8
3	7449	2746	2630	120	2430	296	2217	422	20	395	110	505	86.6	78.2	85.1
4	7065	2056	1939	175	1699	79	1198	477	31	441	48	489	93.4	90.2	92.5
5	7371	1565	1431	236	1002	4	389	538	43	478	27	505	99.1	94.7	96.6
6	8251	993	849	301	545	0	0	544	55	489	0	489	100	100	100
7	7718	976	844	308	560	0	0	559	56	505	0	505	100	100	100
8	7951	1041	900	306	565	0	0	564	56	505	0	505	100	100	100
9	7396	1277	1152	281	959	0	325	532	52	489	0	489	100	100	100
10	6123	1538	1427	234	1374	0	748	513	42	486	18	505	100	96.3	98.5
11	4412	1658	1590	82	1493	780	1935	293	13	279	210	489	59.7	57.0	59.1
12	4324	1752	1699	36	1739	1607	3147	185	4	188	317	505	48.9	37.2	47.3
Total	78,500	19,770	18,500	2171	16,350	5797	16,480	5069	385	4689	1258	5947	64.8	78.8	68.5

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                                     solar performance summary

                                        liquid system ,LASL

                                     madison, wisc.  1/54 to 12/54

                   - - - - - - - - - house - - - - - - - - -        - - - - - - - - dwh - - - - - - - -     h    dwh   tot

 mon   qinc   qcout    qsin     qsl    qsout    qaux      qd     qsin     qsl   qsout    qaux     qd    - percent solar -
   1   4970.   1355.   1335.     37.   1511.   2086.   3597.    248.      7.    241.    264.    504.   42.0  47.7  42.7
   2   5311.   2143.   2115.     58.   1849.   1078.   2927.    294.     11.    283.    172.    455.   63.2  62.2  63.0
   3   7470.   2557.   2510.    117.   1871.    346.   2217.    438.     23.    415.     89.    504.   84.4  82.4  84.0
   4   7133.   1867.   1827.    172.   1100.     99.   1199.    485.     34.    452.     36.    488.   91.7  92.6  92.0
   5   7404.   1414.   1330.    228.    385.      5.    390.    529.     45.    485.     19.    504.   98.7  96.1  97.3
   6   8261.    925.    854.    304.      0.      0.      0.    548.     60.    488.      0.    488.  100.0 100.0 100.0
   7   7752.    914.    838.    308.      0.      0.      0.    565.     61.    504.      0.    504.  100.0 100.0 100.0
   8   7964.    983.    905.    302.      0.      0.      3.    563.     59.    504.      0.    504.  100.0 100.0 100.0
   9   7339.   1108.   1040.    284.    324.      0.    324.    544.     56.    488.      0.    488.  100.0 100.0 100.0
  10   6107.   1371.   1313.    225.    747.      0.    747.    532.     44.    488.     16.    504.  100.0  96.9  98.7
  11   4371.   1492.   1466.     76.   1045.    889.   1934.    319.     15.    305.    183.    488.   54.0  62.4  55.7
  12   4260.   1603.   1586.     33.   1386.   1762.   3148.    234.      6.    228.    277.    504.   44.0  45.1  44.2

total 78863.  18253.  17618.   2146.  10219.   6265.  16484.   5300.    419.   4880.   1056.   5936.   62.0  82.2  67.3


               qinc  - collector input
               qcout - collector output
               qsin  - storage input
               qsl   - storage loss
               qsout - storage output
               qaux  - auxiliary required
               qd    - demand load

units: kwh
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                                  ==== NIKKEN (JAPAN) ====

                                  MONTHLY SOLAR PERFORMANCE SUMMARY                          MON...     MONTH OF THE YEAR
UNITS.(KWH)                                                                                  QCIN...    COLLECTOR INPUT
                                  SYSTEM...  LIQUID SOLAR SYSTEM                             QCOUT...   COLLECTOR OUTPUT
                                                                                             QSIN...    STORAGE INPUT
                                  CITY...    MADISON                                         QSL...     STORAGE LOSS
                                                                                             QSOUT...   STORAGE OUTPUT
                                                                                             QAUX...    AUXILIARY REQUIRED
                                                                                             QD...      DEMAND LOAD

        ===COLLECTOR===   ====STORAGE====   ======== HOUSE ========   ================ DHW ================   =====PERCENT SOLAR=====
 MON     QCIN    QCOUT     QSIN     QSL      QSOUT    QAUX     QD      QSIN     QSL    QSOUT    QAUX      QD        H      DW     TOT
 JAN    5097.7  2063.6    2036.8    36.7    1718.4  1910.2  3597.1    238.8     6.6   228.6   276.1   504.7      46.9   45.3    46.7
 FEB    5625.9  2297.4    2262.4    58.2    2019.3   960.1  2926.8    274.2    10.7   271.4   184.4   455.8      67.2   59.5    66.2
 MAR    7431.2  2822.8    2760.0   135.3    2080.2   243.4  2217.0    458.2    25.4   425.3    79.3   504.7      89.0   84.3    88.1
 APR    7009.3  2020.0    1955.4   177.3    1223.4    81.4  1199.2    489.3    33.6   450.5    37.9   488.4      93.2   92.2    92.5
 MAY    7304.4  1446.1    1375.0   230.7     457.7     4.0   389.5    538.8    44.0   482.1    22.5   504.7      99.0   95.5    97.0
 JUN    8116.9   886.8     830.0   272.3       0.0     0.0     0.0    541.8    52.1   488.4     0.0   488.4       0.0  100.0   100.0
 JUL    7666.3   859.5     807.5   279.0       0.0     0.0     0.0    555.6    53.4   504.7     0.0   504.7       0.0  100.0   100.0
 AUG    7812.0   895.4     839.1   277.4       0.0     0.0     0.0    557.9    53.1   504.7     0.0   504.7       0.0  100.0   100.0
 SEP    7245.6  1209.3    1154.7   253.7     409.0     0.0   323.6    533.2    48.5   488.4     0.0   488.4     100.0  100.0   100.0
 OCT    5952.1  1430.1    1371.1   217.9     851.3     0.0   747.0    506.4    41.5   482.5    22.2   504.7     100.0   95.6    98.2
 NOV    4438.0  1691.2    1656.0    84.8    1201.6   792.1  1934.0    324.6    15.8   304.9   183.4   488.4      59.0   62.4    59.7
 DEC    4476.2  1898.7    1873.3    38.2    1691.4  1489.5  3147.8    229.5     6.9   230.2   274.4   504.7      52.7   45.6    51.7

TOTAL  78175.6 19521.1   18921.1  2061.5   11652.3  5480.8 16481.9   5248.3   391.5  4861.6 -1080.3  5941.9      66.7   81.8    70.7
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                                   MONTHLY SOLAR PERFORMANCE SUMMARY                    MON:    MONTH OF THE YEAR
                                                                                        QCIN:   COLLECTOR INPUT
                                   SYSTEM: LIQUID                                       QCOUT:  COLLECTOR OUTPUT
                                                                                        QSIN:   STORAGE INPUT
                                   CITY:  MADISON                                       QSL:    STORAGE LOSS
                                                                                        QSOUT:  STORAGE OUTPUT
                                                                                        QAUX:   AUXILIARY REQUIRED
                                                                                        QD:     DEMAND LOAD
         -COLLECTOR-    ---------------HOUSE----------------   ---------------DHW-----------------   --PERCENT SOLAR--
  MON   QCIN   QCOUT    QSIN    QSL   QSOUT   QAUX     QD      QSIN    QSL   QSOUT   QAUX     QD      H    DWH    TOT
    1   5104    2156    2123     42    1686   1913   3599       276      9     260    241    501     47     52     47
    2   5628    2279    2229     52    1899   1027   2927       300     17     294    158    452     65     65     65
    3   7341    2768    2666    131    1895    322   2217       457     27     423     78    501     85     94     85
    4   6977    2138    1979    196    1101     96   1198       494     40     449     35    484     92     93     92
    5   7325    1720    1493    269     383      5    388       552     53     482     19    501     99     96     97
    6   8179    1226     933    376       0      0      0       559     74     484      0    484      0    100    100
    7   7641    1184     908    375       0      0      0       571     74     501      0    501      0    100    100
    8   7906    1294     992    371       0      0      0       578     73     501      0    501      0    100    100
    9   7266    1454    1213    336     325      0    325       541     67     484      0    484    100    100    100
   10   6074    1673    1492    257     748      0    748       519     51     452     18    501    100     96     99
   11   4346    1706    1645     87    1130    805   1935       336     19     315    160    494     58     65     50
   12   4372    1874    1945     41    1582   1564   3146       255      9     253    248    501     50     51     50
TOTAL  78141   21471   19508   2544   10750   5734  16484      5436    509    4927    966   5893     65     84     70
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SYMMARY

SYSTEM: PHILIPS, finite element, liquid

CITY: Madison

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	-collector--		house					dhw					---percent solar---		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dhw	tot
1	4939	2103	2027	39	1644	1954	3597	264	8	251	254	504			
2	5632	2348	2251	59	1929	999	2927	298	12	294	162	456			
3	7477	2855	2689	121	1920	298	2217	458	24	426	78	505			
4	7100	2152	1944	165	1114	86	1199	489	32	452	37	488			
5	7383	1663	1400	223	386	3	390	542	43	486	19	505			
6	8253	1128	817	267	0	0	0	541	52	488	0	488			
7	7729	1106	801	275	0	0	0	556	53	505	0	505			
8	7986	1156	842	270	0	0	0	558	53	505	0	505			
9	7440	1438	1171	248	324	0	324	532	48	488	0	488			
10	6199	1612	1391	209	747	0	747	508	41	485	20	505			
11	4652	1782	1678	81	1147	787	1934	337	16	317	171	489			
12	4562	1883	1815	39	1579	1569	3148	247	8	247	258	505			
total	79351	21226	18825	1998	10789	5695	16484	5333	392	4945	998	5943	65.5	83.2	70.2

```
FABER COMPUTING (RESEARCH AND DEVELOPMENT) - U.K.                                          Faber

Job number : 9430/FBA

I.E.A. Project On Solar Heating And Cooling

Location .......................... Madison - U.S.A.

Results  .......................... Yearly Units (kwh)


          -Collector -     ------------ House ------------     ------------ DHW --------------    --- Percent Solar -----
Month     Qcin   Qcout     Qsin   Qsl   Qsout   Qaux    Qd     Qsin   Qsl   Qsout   Qaux   Qd     %House   %DHW   %Total
  1       4691   2062      2014    39   1637    1960  3597     277     9    268     236   504      46       53     46
  2       5297   2313      2260    60   1986     940  2927     323    13    310     145   455      68       68     68
  3       6903   2494      2436   103   1825     392  2217     433    22    412      92   504      82       82     82
  4       6776   1707      1668   121   1019     180  1199     432    25    408      80   488      85       84     85
  5       7198   1145      1118   157    384       5   389     510    31    478      26   504      99       95     97
  6       8149    738       721   195      0       0     0     526    38    488       0   488     100      100    100
  7       7474    715       699   200      0       0     0     543    39    504       0   504     100      100    100
  8       7675    820       801   197      0       0     0     542    39    503       0   504     100      100    100
  9       7037    974       951   189    323       0   323     524    37    486       1   488     100      100    100
 10       5833   1163      1136   138    681      65   747     476    28    448      56   504      91       89     90
 11       4244   1549      1513    63   1124     810  1934     319    13    306     182   488      58       63     59
 12       3834   1524      1489    28   1240    1907  3148     238     6    232     272   504      39       46     40

Total    75110  17203     16808  1489  10220    6260 16479    5143   300   4844    1090  5933     62.0     81.6   67.2


Qcin    ............. Collector Input
Qcout   ............. Collector Output
Qsin    ............. Storage Input
Qsout   ............. Storage Output
Qsl     ............. Storage Loss
Qaux    ............. Auxillary Required
Qd      ............. Demand Load
%House  ............. % Solar House
%DHW    ............. % Solar DHW
%Total  ............. % Solar Total
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SYMMARY, I(FTP)

SYSTEM: LIQUID

CITY: MADISON

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	-collector--		house					dhw					---percent solar---		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dhw	tot
1	4396	1858	---	---	1548	2046	3594	---	---	242	263	504	43.1	47.9	43.7
2	5095	2069	---	---	1841	1080	2921	---	---	280	177	457	63.0	61.2	62.8
3	6787	2506	---	---	1919	298	2217	---	---	423	91	513	86.5	82.3	85.8
4	6776	1891	---	---	1145	57	1202	---	---	462	56	518	95.2	89.1	93.3
5	7178	1448	---	---	382	1	383	---	---	488	35	523	99.6	93.4	96.0
6	8044	1513	---	---	0	0	0	---	---	508	0	508	100	100	100
7	7475	1379	---	---	0	0	0	---	---	525	0	525	100	100	100
8	7663	1532	---	---	0	0	0	---	---	525	0	525	100	100	100
9	6835	1565	---	---	316	0	316	---	---	508	0	508	100	100	100
10	5571	1472	---	---	742	0	742	---	---	495	26	522	100	94.8	97.9
11	3761	1489	---	---	1109	823	1932	---	---	314	178	492	57.4	63.4	58.7
12	3919	1673	---	---	1482	1686	3168	---	---	237	268	504	46.7	47.0	46.8
total	73500	20395	---	---	10484	5991	16475	---	---	5007	1094	6099	63.6	82.1	68.6

```
                                                                                                  mon:  month of the year
                                    ** SUMARIO ACTUACIONES SOLARES MENSUALES **                   qcin: collector input
   UNITS: KWh                                                                                     qcout:collector output
                                       SYSTEM: INSOL,  LIQUID                                     qsin: storage input
                                                                                                  qsl:  storage loss
                                                                                                  qsout:storage output
                                       CIUDAD .....  MADISON                                      qaux: auxiliary required
            ---- collector--  -------------------- house ----------                               qd:   demand load
                                                                  ---------------- dwh --------------
                                                                                                     percent solar
  mon    qcin     qcout    qsin     qsl     qsout    qaux     qd      qsin     qsl    qsout    qaux      qd      h    dwh   tot
  MES    QINC     QGC      QEA1     QPA1    QSCR     QACR     QLC     QEA2     QPA2   WSHC     WHAL      QLA     SC   SHC   TCT

    1   4752.4   2339.8   2246.4    46.0   1824.6   1772.9   3597.5   277.7     8.9   262.4    242.3    504.7   50 7  52.0  50.9
    2   5444 7   2625.8   2505.0    79.4   2190.5    736.7   2927.2   332.4    15.5   326.7    129.1    455.8   74 8  71.7  74.4
    3   7041.1   3026.0   2844 4   168.3   2062.6    154.8   2217.3   504.4    32.4   463.9     40.8    504.7   93.0  91.9  92 8
    4   6667.9   2062 8   1914.0   139.8   1149.9     49.5   1199.4   503.5    36 3   462.8     25.6    458.4   95.9  94.8  95.6
    5   6957.7   1479.8   1321.2   279 6    365.7      3.8    389.6   543.3    45.7   486.0     18.6    504.7   99 0  96.3  97.5
    6   7754.1    945.8    814 9   269.6       .0       .0      .0   538.5    51.6   488.4       .0    488.4   $$$$  100   100.
    7   7188 5    930 8    814.7   273.6       .0       .0      .0   553.7    52.3   504.7       .0    504.7   $$$$  100.  100.
    8   7524 1    985.3    854.0   276.0       .0       .0      .0   557.1    52.8   504.7       .0    504.7   $$$$  100.  100
    9   6953.1   1219.1   1086.7   252.9    323.6      -.0    323.6   532.9    48.4   488.4       .0    488.4   100.  100.  100.
   10   5836.0   1413.1   1289.9   226.0    747.1      -.0    747.1   513.2    43.2   468.6     16.0    504.7   100.  96.6  98.7
   11   4085 1   1839.3   1746.9    95.8   1248.5    685.8   1934.3   349.0    18.2   327.8    160.6    488 4   64 5  67 1  65.1
   12   3983.0   2039.0   1956.8    44.9   1716.4   1431.8   3148.3   256.4     9.7   255.0    249.7    504 7   54 5  50.5  54.0

Total 74187,7  20905,6  19394,9  2161,9  11648,9   4835,3  16484,3  5462,1   414   5059,4    882,7   5942,3  70,69 85,14 74,5
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SUMMARY, TRNSYS

SYSTEM: Liquid

CITY: Santa Maria

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	--collector--		--house--					--dwh--					-percent solar-		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot
1	3154	1370	1314	69	1192	160	852	447	22	414	91	505	81.2	82.0	81.5
2	3585	1358	1295	99	1190	1	637	483	34	448	7	456	99.9	98.4	99.3
3	4383	1398	1321	142	1131	0	480	563	48	505	0	505	100	99.9	99.9
4	4191	1253	1184	131	1104	0	495	520	45	487	1	488	100	99.7	99.9
5	3645	1095	1039	117	922	0	324	530	39	490	14	505	100	97.2	98.3
6	3693	1054	997	122	832	0	247	526	41	475	13	489	99.9	97.3	98.2
7	4370	1103	1032	160	863	0	222	561	55	505	0	505	100	100	100
8	4306	1039	965	163	802	0	165	560	55	505	0	505	100	100	100
9	4065	1026	957	149	809	0	198	539	51	488	0	489	100	99.9	99.9
10	3978	1124	1053	152	901	0	265	556	52	505	0	505	100	100	100
11	3351	1157	1096	115	1053	1	479	501	39	477	11	488	99.8	97.8	98.8
12	2162	919	884	57	834	51	462	385	18	369	136	505	89.1	73.1	80.7
Total	44,880	13,900	13,140	1475	11,630	212	4826	6171	498	5669	274	5943	95.6	95.4	95.5

```
                                    solar performance summary

                                      liquid system  , LASL

                                 santa maria, calif.  1/55 to 12/55

              - - - - - - - - - - house - - - - - - - - -      - - - - - - - - dwh - - - - - - - - -     h    dwh    tot

 mon   qinc   qcout   qsin    qsl   qsout   qaux     qd    qsin    qsl   qsout   qaux     qd   - percent solar -
   1   3362.  1310.   1252.    53.   710.   141.    851.   458.    25.   433.    71.    504.   83.4   85.9   84.3
   2   3728.  1241.   1203.    75.   635.     1.    636.   487.    36.   451.     5.    455.   99.9   99.0   99.5
   3   4440.  1233.   1185.   104.   481.     0.    481.   555.    51.   504.     0.    504.  100.0  100.0  100.0
   4   4237.  1109.   1063.    93.   495.     0.    495.   532.    45.   486.     1.    488.  100.0   99.7   99.9
   5   3665.   976.    938.    83.   324.     0.    324.   532.    40.   492.    12.    504.  100.0   97.6   98.6
   6   3714.   928.    888.    84.   248.     1.    249.   516.    41.   475.    13.    488.   99.7   97.3   98.1
   7   4395.   964.    909.   111.   223.     0.    223.   558.    54.   504.     0.    504.  100.0  100.0  100.0
   8   4212.   901.    853.   121.   165.     0.    165.   563.    59.   504.     0.    504.  100.0  100.0  100.0
   9   4066.   892.    858.   112.   197.     0.    197.   543.    55.   488.     0.    488.  100.0  100.0  100.0
  10   3997.   979.    936.   112.   265.     0.    265.   559.    55.   504.     0.    504.  100.0  100.0  100.0
  11   3432.  1040.   1005.    85.   478.     0.    478.   518.    41.   477.    11.    488.   99.9   97.8   98.8
  12   2247.   875.    857.    42.   406.    57.    463.   414.    20.   394.   111.    504.   87.8   78.1   82.7

total 45598. 12448.  11970.  1075.  4627.   199.   4827.  6236.   524.  5712.   224.   5936.   95.9   96.2   96.1


              qinc  - collector input
              qcout - collector output
              qsin  - storage input
              qsl   - storage loss
              qsout - storage output
              qaux  - auxiliary required
              qd    - demand load

    units: kwh
```

```
                              **** NIKKEN (JAPAN) ****

                              MONTHLY SOLAR PERFORMANCE SUMMARY                         MON...    MONTH OF THE YEAR
                                                                                        QCIN...   COLLECTOR INPUT
UNITS.(KWH)                   SYSTEM...  LIQUID SOLAR SYSTEM                            QCOUT...  COLLECTOR OUTPUT
                                                                                        QSIN...   STORAGE INPUT
                              CITY...    SANTA MARIA                                    QSL...    STORAGE LOSS
                                                                                        QSOUT...  STORAGE OUTPUT
                                                                                        QAUX...   AUXILIARY REQUIRED
                                                                                        QD...     DEMAND LOAD

       ***COLLECTOR===  ====STORAGE====  ======== HOUSE ========  ================ DHW ================  =====PERCENT SOLAR=====
MON     QCIN    QCOUT     QSIN     QSL    QSOUT    QAUX      QD     QSIN    QSL   QSOUT    QAUX     QD      H      DW     TOT

JAN    3328.1  1455.8   1422.5    75.1    812.5   106.4   850.6    468.6   25.9   428.5    76.2   504.7    87.5    84.9    86.5

FEB    3657.9  1367.5   1325.3   106.0    723.2     0.0   636.0    490.5   37.1   452.1     3.7   455.8   100.0    99.2    95.7

MAR    4423.8  1326.7   1280.5   132.1    571.5     0.0   481.2    555.4   46.4   504.7     0.0   504.7   100.0   100.0   100.0

APR    4182.2  1258.9   1214.0   125.3    589.3     0.0   495.4    526.2   44.0   488.1     0.3   488.4   100.0    99.9   100.0

MAY    3623.4  1077.2   1038.9   116.4    398.3     0.0   323.9    534.2   40.7   495.7     9.0   504.7   100.0    98.2    98.9

JUN    3678.4  1035.9    996.2   120.0    311.1     0.3   248.5    524.6   42.1   474.0    14.4   488.4    99.9    97.1    98.0

JUL    4356.8  1044.0    999.8   145.2    298.5     0.0   222.6    555.7   51.1   504.7     0.0   504.7   100.0   100.0   100.0

AUG    4267.5   965.0    926.2   143.1    235.0     0.0   164.8    553.7   50.4   504.7     0.0   504.7   100.0   100.0   100.0

SEP    4040.7   967.9    931.0   132.1    264.1     0.0   197.5    534.2   46.4   487.7     0.7   488.4   100.0    99.9    99.9

OCT    3966.5  1066.3   1027.8   134.4    340.5     0.0   264.8    552.0   47.2   504.7     0.0   504.7   100.0   100.0   100.0

NOV    3461.2  1168.8   1132.2   111.1    560.3     0.0   478.2    510.4   38.9   482.3     6.0   488.4   100.0    98.8    99.4

DEC    2336.2   974.0    952.0    62.8    478.8    35.6   462.7    418.8   21.6   398.9   105.8   504.7    92.3    79.0    85.4

TOTAL 45322.9 13707.8  13246.5  1403.6   5583.1   142.3  4826.3   6224.2  492.1  5725.8   216.1  5941.9    97.1    96.4    96.7
```

```
                                      MONTHLY SOLAR PERFORMANCE SUMMARY          MON:    MONTH OF THE YEAR
                                                                                 QCIN:   COLLECTOR INPUT
                                      SYSTEM: LIQUID                             QCOUT:  CCLLECTOR OUTPUT
                                                                                 QSIN:   STORAGE INPUT
                                      CITY:    SANTA MARIA                       QSL:    STORAGE LOSS
                                                                                 QSOUT:  STCRAGE OUTPUT
                                                                                 QAUX:   AUXILIARY REQUIRED
                                                                                 QD:     DEMANO LOAD

          -COLLECTOR-     -------------HOUSE--------------     ---------------DHW---------------     --PERCENT SOLAR--

   MON    QCIN   QCOUT    QSIN    QSL  QSOUT   QAUX     QD   QSIN    QSL  QSOUT   QAUX     QD     H    DWH    TOT
     1    3255    1433    1384     78    711    141    852    487     30    452     49    501    83     90     96
     2    3523    1393    1328    104    634      3    637    486     40    446      6    452   100     99     99
     3    4317    1471    1371    154    480      0    480    568     58    500      0    501   100    100    100
     4    4156    1329    1236    140    495      0    495    525     53    483      1    484   100    100    100
     5    3673    1171    1089    126    324      0    324    538     47    491     10    501   100     98     99
     6    3740    1134    1044    132    247      1    247    531     49    473     12    484   100     98     98
     7    4411    1221    1102    177    222      0    222    569     66    501      0    501   100    100    100
     8    4324    1192    1064    194    165      0    165    574     72    501      0    501   100    100    100
     9    4045    1143    1035    180    198      0    198    549     67    484      0    484   100    100    100
    10    3952    1244    1134    175    264      0    264    567     65    500      0    501   100    100    100
    11    3437    1243    1166    133    477      2    479    513     50    479      6    494    99     99     99
    12    2277     995     954     63    403     58    462    427     24    404     97    501    87     81     84
 TOTAL   45110   14975   13907   1656   4622    205   4827,  6334    621   5713    191   5893    96     97     96
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SYMMARY

SYSTEM: PHILIPS, finite element, liquid

CITY: Santa Maria

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	-collector--		------------house------------					------------dhw------------					---percent solar---		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dhw	tot
1	3253	1563	1206	76	720	140	851	495	28	452	52	505			
2	3653	1419	1119	103	635	1	636	492	38	453	3	456			
3	4415	1401	1084	129	481	0	481	555	47	505	0	505			
4	4214	1330	1035	121	495	0	495	527	44	488	0	488			
5	3658	1157	893	114	324	0	324	538	41	499	6	505			
6	3700	1134	867	118	248	1	249	532	42	478	10	488			
7	4385	1149	859	145	223	0	223	555	52	505	0	505			
8	4330	1081	807	140	165	0	165	556	50	505	0	505			
9	4094	1043	787	126	197	0	197	532	46	488	1	488			
10	4027	1172	890	130	265	0	265	554	47	505	0	505			
11	3449	1222	952	106	478	1	478	510	38	483	5	488			
12	2223	1019	813	63	415	47	463	436	23	414	91	505			
total	45395	14639	11311	1372	4646	181	4827	6282	499	5774	168	5943	96.3	97.2	96.8

```
FABER COMPUTING (RESEARCH AND DEVELOPMENT) - U.K.

Joh number : 9430/PBA

I.E.A. Project On Solar Heating And Cooling

Location ......................... Santa Maria - California U.S.A.                Faber

Results  ......................... Yearly Units (kwh)


        -Collector-    ------------ House ------------    ------------ DHW --------------    --- Percent Solar -----
Month   Qcin   Qcout   Qsin   Qsl  Qsout  Qaux   Qd      Qsin  Qsl  Qsout  Qaux   Qd     %House   %DHW  %Total
  1     3171    1493   1458    86   767    83   850      502   33   469    35    504      90      93     91
  2     3453    1301   1271   110   636     0   636      496   42   454     1    455     100     100    100
  3     4308    1206   1179   132   481     0   481      553   49   504     0    504     100     100    100
  4     4149    1140   1114   125   495     0   495      535   47   488     0    488     100     100    100
  5     3624     984    961   114   324     0   324      541   42   499     5    504     100      99     99
  6     3670     948    926   111   248     1   248      514   41   473    15    488     100      97     98
  7     4346     947    925   142   222     0   222      556   52   504     0    504     100     100    100
  8     4233     895    874   145   165     0   165      557   53   504     0    504     100     100    100
  9     3988     884    863   134   197     0   197      537   50   487     0    488     100     100    100
 10     3865     983    960   139   265     0   265      555   52   504     0    504     100     100    100
 11     3296    1096   1071   118   478     0   478      530   44   486     2    488     100     100    100
 12     2302     993    970    72   435    27   462      458   27   430    74    504      94      85     90

 Total 44404   12868  12572  1429  4712   111  4823     6335  534  5801   132   5933    97.7    97.8   97.7


 Qcin   .............  Collector Input
 Qcout  .............  Collector Output
 Qsin   .............  Storage Input
 Qsout  .............  Storage Output
 Qsl    .............  Storage Loss
 Qaux   .............  Auxillary Required
 Qd     .............  Demand Load
 %House .............  % Solar House
 %DHW   .............  % Solar DHW
 %Total .............  % Solar Total
```

```
                                                                                                       mon:     month of the year
                                    ** SUMARIO ACTUACIONES SOLARES MENSUALES **                        qcin:    collector input
      UNITS: KWh                       SYSTEM: INSOL,  LIQUID                                           qcout:   collector output
                                                                                                       qsin:    storage input
                                                                                                       qsl:     storage loss
                                       CIUDAD .....  SANTA MARIA                                        qsout:   storage output
           ---collector--   ------------------- house ----------                                      qaux:    auxiliary required
  mon      qcin     qcout     qsin     qsl     qsout     qaux      qd     ---------------- dwh ----------------  qd:      demand load
  MES      QIHC     QCC       QEA1     QPA1    QSCR      GACR      QLC      qsin     qsl     qsout     qaux      qd        percent solar
                                                                            QEA2     QPA2    QSAC      QAAC      QLA      h      dwh     tot
                                                                                                                          SC     SAC     TOT

    1    3202.4    1586.9    1458.1     88.4    762.5     88.3    850.8    515.0    31.7    464.5     39.7     504.7    89.6    92.1    90.6
    2    3567.1    1379.5    1240.4    109.2    636.1     -.0     636.1    493.7    39.2    455.3       .5     455.8   100.     99.9   100.
    3    4318.7    1319.8    1177.4    131.3    481.3     -.0     461.3    552.2    46.7    504.7       .0     504.7   100.    100.    100.
    4    4094.8    1285.1    1138.9    126 5    495.5     -.0     495.5    529.4    45.1    488.4       .0     488.4   100.    100.    100.
    5    3464.4    1105.3     980.5    121.5    323.9     -.0     323.9    542.6    42.9    502.8      1.9     504.7   100.     99.6    99.8
    6    3514.8    1064.1     936.9    121.7    248.4      .2     248.5    530.1    42.9    480.9      7.5     489.4    99.9    98.5    99 0
    7    4167.3    1055.6     922.5    140.8    222.6     -.0     222.6    553.8    49.7    504.7       .0     504.7   100.    100.    100.
    8    4174.2     983.1     861.2    139.1    164.8     -.0     164.8    552.7    49.0    504.7       .0     504.7   100.    100.    100.
    9    3992.7     973.3     863.0    129.5    197.5     -.0     197.5    532.6    45.6    488.0       .4     488.4   100.     99.9    99.9
   10    3951.6    1079.6     957.5    133.4    264.8     -.0     264.8    551.6    47.1    504.7       .0     504.7   100.    100.    100.
   11    3399.2    1223.1    1092.0    119.3    478.2     -.0     478.2    522.5    42.4    487.6       .8     488.4   100.     99.6    99.9
   12    2222.7    1075.0     983.3     80.7    440.3     22.4    462.7    465.7    28.5    439.3     65.4     504.7    95.2    87.0    90.9

 Total  44059,9   14130,4   12611,7   1441,4   4715,9    110,9   4826,7   5819,4   510,8   5826      116,2    5942,3   97,7    98,0    97,8
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SUMMARY , US (TRNSYS)

SYSTEM: Liquid System (80 $1/m^2$)

CITY: Hamburg

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	--collector--		-------house-------					-------dwh-------					-percent solar-		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot.
1	777	192	185	4	228	2082	2240	73	-3	81	424	505	7.1	16.1	8.7
2	1573	469	452	11	416	1682	2000	97	-1	96	360	456	15.9	21.0	16.8
3	4036	1324	1259	66	1070	586	1341	280	9	260	246	505	56.3	51.4	54.9
4	4500	1372	1297	71	1248	217	1135	287	11	279	210	489	80.9	57.0	73.7
5	5968	1387	1283	172	960	0	404	489	30	446	59	505	99.9	88.3	93.5
6	6963	958	836	274	541	0	0	540	50	489	0	489	100	100	100
7	5788	800	703	228	540	0	0	538	41	503	2	505	100	99.6	99.6
8	7250	1069	926	282	565	0	0	564	51	505	0	505	100	100	100
9	4497	920	836	206	866	0	306	482	37	466	22	489	100	95.4	97.1
10	3112	1157	1105	60	995	307	1012	260	8	248	257	505	69.7	49.0	62.8
11	2324	845	810	31	818	1142	1790	158	2	159	330	489	36.2	32.4	35.4
12	1471	513	494	13	502	1959	2359	105	-1	109	397	505	16.9	21.5	17.7
Total	48260	11010	10190	1418	8749	7973	12590	3874	234	3641	2307	5948	36.7	61.2	44.5

solar performance summary

liquid system LASL

hamburg germany 1/73 to 12/73 . 80 L/m_c^2

```
            - - - - - - - - - - house - - - - - - - - - -    - - - - - - - - - dwh - - - - - - - - -      h    dwh    tot

 mon   qinc   qcout   qsin    qsl   qsout   qaux     qd     qsin    qsl   qsout   qaux    qd    - percent solar -
   1    744.    164.    163.     3.     76.  2164.   2240.   135.     1.   134.   370.   504.     3.4  26.6    7.7
   2   1553.    434.    430.    10.    252.  1748.   2000.   146.     2.   144.   312.   455.    12.6  31.6   16.1
   3   4024.   1268.   1242.    65.    720.   613.   1341.   317.    13.   305.   200.   504.    54.3  60.4   56.0
   4   4533.   1343.   1311.    71.    921.   216.   1137.   344.    14.   330.   158.   488.    81.0  67.7   77.0
   5   6000.   1273.   1214.   171.    404.     0.    404.   505.    34.   471.    33.   504.   100.0  93.5   96.4
   6   7016.    892.    819.   263.      0.     0.      0.   540.    52.   488.     0.   488.   100.0 100.0  100.0
   7   5816.    766.    704.   210.      0.     0.      0.   547.    43.   504.     0.   504.   100.0 100.0  100.0
   8   7249.    994.    917.   278.      0.     0.      0.   559.    55.   504.     0.   504.   100.0 100.0  100.0
   9   4420.    819.    774.   200.    305.     0.    305.   511.    39.   472.    16.   488.   100.0  96.7   98.0
  10   3015.   1081.   1064.    55.    656.   355.   1012.   298.    11.   288.   217.   504.    64.9  57.0   62.3
  11   2217.    755.    745.    26.    550.  1238.   1788.   204.     5.   199.   289.   488.    30.8  40.2   32.9
  12   1385.    445.    441.    11.    292.  2069.   2360.   160.     2.   158.   346.   504.    12.4  31.4   15.7

total 47973.  10234.   9823.  1371.   4184.  8403.  12587.  4266.   268.  3997.  1939.  5936.    33.2  67.3   44.2
```

qinc - collector input
qcout - collector output
qsin - storage input
qsl - storage loss
qsout - storage output
qaux - auxiliary required
qd - demand load

units: kwh

```
                                        ==== NIKKEN (JAPAN) ====

                                        MONTHLY SOLAR PERFORMANCE SUMMARY                  MON...      MONTH OF THE YEAR
                                                                                           QCIN...     COLLECTOR INPUT
UNITS.(KWH)                             SYSTEM...  LIQUID SOLAR SYSTEM                     QCOUT...    COLLECTOR OUTPUT
                                                                                           QSIN...     STORAGE INPUT
                                        CITY...    HAMBURG  LST=80 L/SM                    QSL...      STORAGE LOSS
                                                                                           QSOUT...    STORAGE OUTPUT
                                                                                           QAUX...     AUXILIARY REQUIRED
                                                                                           QD...       DEMAND LOAD

       ===COLLECTOR===   ====STORAGE====   ======== HOUSE ========   ================ DHW ================   =====PERCENT SOLAR=====
MON     QCIN    QCOUT     QSIN     QSL     QSOUT    QAUX     QD       QSIN     QSL    QSOUT    QAUX      QD        H      DW     TOT

JAN     768.6   118.6    117.5     1.4     47.6   2193.5   2239.9    117.9    -0.1    122.4   382.2    504.7      2.1    24.3     6.2

FEB    1550.3   382.6    378.0     7.0    221.6   1784.4   1999.6    130.5     1.0    127.8   328.0    455.8     10.8    26.0    14.0

MAR    4014.8  1258.3   1231.0    61.8    727.6    653.2   1340.6    304.4    11.3    281.3   223.4    504.7     51.3    55.7    52.5

APR    4474.1  1352.7   1323.1    66.0    983.7    199.5   1136.4    308.5    12.2    299.6   188.8    488.4     82.4    61.3    76.1

MAY    5822.9  1327.7   1274.8   170.2    462.0      0.1    404.0    491.1    32.2    445.9    56.8    504.7    100.0    88.4    93.5

JUN    6682.8   873.5    811.0   265.0      0.0      0.0      0.0    539.5    50.7    488.4     0.0    488.4      0.0   100.0   100.0

JUL    5696.0   760.1    713.2   222.2      0.0      0.0      0.0    539.2    42.3    501.3     3.4    504.7      0.0    99.3    99.3

AUG    7106.1   961.2    895.4   269.3      0.0      0.0      0.0    561.6    51.5    504.7     0.0    504.7      0.0   100.0   100.0

SEP    4387.6   843.8    802.5   196.0    373.7      0.0    305.0    481.7    37.3    465.9    22.5    488.4    100.0    95.4    97.2

OCT    3005.7  1100.4   1081.5    50.3    691.2    355.3   1011.5    275.0     9.2    260.2   244.5    504.7     64.9    51.6    60.4

NOV    2261.2   744.1    733.1    23.3    559.9   1249.0   1787.8    182.1     4.1    180.7   307.6    488.4     30.1    37.0    31.6

DEC    1628.5   566.1    560.0    12.0    410.6   1960.2   2359.9    154.0     1.9    153.5   351.1    504.7     16.9    30.4    19.3


TOTAL 47398.6 10289.0   9921.2  1344.7   4478.0   8395.2  12584.7   4085.4   253.5   3831.7  2110.2   5941.9     33.3    64.5    43.3
```

```
                         MONTHLY SOLAR PERFORMANCE SUMMARY                MON:     MONTH OF THE YEAR
                                                                          QCIN:    COLLECTOR INPUT
                         SYSTEM: LIQUID, 80 l/m²                          QCOUT:   COLLECTOR OUTPUT
                                                                          QSIN:    STORAGE INPUT
                         CITY:  HAMBURG                                   QSL:     STORAGE LOSS
                                                                          QSOUT:   STORAGE OUTPUT
                                                                          QAUX:    AUXILIARY REQUIRED
                                                                          QD:      DEMAND LOAD

       -COLLECTOR-    -------------HOUSE--------------   ---------------DHW----------------   --PERCENT SOLAR--

MON    QCIN  QCOUT    QSIN   QSL  QSOUT   QAUX     QD    QSIN   QSL  QSOUT   QAUX     QD      H   DWH   TOT
  1     769    226     223     0    152   2088   2240     118     0    122    378    501      7    24    10
  2    1502    493     484     9    295   1705   2000     145     2    141    311    452     15    31    18
  3    3943   1377    1321    70    747    594   1341     332    14    307    194    501     56    61    57
  4    4449   1454    1386    77    919    216   1135     352    16    338    147    484     81    70    78
  5    5976   1439    1324   193    403      0    403     517    38    468     32    501    100    94    96
  6    7034   1132     884   317      0      0      0     549    63    484      0    484      0   100   100
  7    5778    985     738   253      0      0      0     545    50    500      0    501      0   100   100
  8    7223   1255     990   337      0      0      0     574    67    501      0    501    100   100   100
  9    4362   1030     873   219    305      1    306     488    44    465     19    484    100    96    97
 10    2953   1157    1113    59    657    355   1013     305    12    288    212    501     65    58    63
 11    2158    841     814    29    593   1197   1790     205     6    203    281    484     33    42    35
 12    1409    538     528    11    361   1997   2358     158     2    157    344    501     15    31    18
TOTAL 47559  11946   10676  1572   4433   8154  12586    4285   313   3975   1919   5393     35    67    45
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SYMMARY

SYSTEM: PHILIPS, finite element, liquid

CITY: Hamburg

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	-collector--		house					dhw					percent solar		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dhw	tot
1	778	235	228	0	154	2087	2240	119	0	123	382	505			
2	1568	542	522	10	325	1675	2000	147	2	143	313	456			
3	4038	1447	1357	69	772	569	1341	336	13	311	193	505			
4	4505	1525	1418	77	947	190	1337	357	15	344	145	488			
5	5972	1518	1317	174	0	0	404	521	34	475	30	505			
6	6972	1080	811	259	0	0	0	540	50	488	0	488			
7	5794	955	711	220	0	0	0	543	43	505	0	505			
8	7264	1184	889	265	0	0	0	562	52	505	0	505			
9	4507	1046	863	193	305	0	305	491	38	473	16	488			
10	3115	1256	1183	61	704	308	1012	316	12	299	205	505			
11	2332	926	880	31	647	1141	1788	213	6	210	278	488			
12	1481	573	551	12	394	1966	2360	158	2	158	347	505			
total	48326	12289	10728	1371	4652	7935	12587	4301	266	4034	1909	5943	37.0	67.9	46.9

```
FABER COMPUTING (RESEARCH AND DEVELOPMENT) - U.K.

Job Number : 9430/PBA

I.E.A. Project on Solar Heating and Cooling

Location ............................ Hamburg - Germany (80 l/m**2)

Results ............................. Yearly Units (kwh)


       Collector       -------------- House ----------------   -------------- DHW --------------    ---- Percent Solar ----
Month  Qcin    Qcout   Qsin    Qsl   Qsout  Quax   Qd      Qsin   Qsl   Qsout  Qaux   Qd      %House  %DHW   %Total
 1     763     188     187     -1    127    2112   2240    118    0     118    386    504     6       23     9
 2     1548    419     416     6     247    1753   1999    136    1     135    320    455     12      30     16
 3     4022    1063    1045    46    627    713    1340    275    9     265    239    504     47      53     48
 4     4495    1147    1124    54    788    348    1136    296    11    285    203    488     69      58     66
 5     5810    1103    1061    120   396    8      404     448    24    424    80     504     98      84     90
 6     6539    780     726     185   0      0      0       523    36    487    0      488     100     100    100
 7     5641    649     606     152   0      0      0       513    30    483    21     504     100     96     96
 8     7088    895     829     207   0      0      0       544    41    504    0      504     100     100    100
 9     4489    751     718     142   300    5      305     476    28    477    40     488     98      92     94
10     3102    934     921     41    570    441    1011    258    8     250    254    504     56      50     54
11     2298    718     711     22    516    1271   1787    194    5     189    298    488     29      39     31
12     1425    451     448     8     313    2046   2360    154    2     152    351    504     13      30     16

Total  47219   9097    8792    981   3885   8697   12587   3935   195   3740   2193   5933    30.9    63.0   41.2

Qcin   ............... Collector Input
Qcout  ............... Collector Output
Qsin   ............... Storage Input
Qsout  ............... Storage Output
Qsl    ............... Storage Loss
Qaux   ............... Auxillary Required
Qd     ............... Demand Load
%House ............... %Solar House
%DHW   ............... %DHW
%Total ............... %Solar Total
```

Faber

```
                                                                                                           mon:     month of the year
                                  ** SUMARIO ACTUACIONES SOLARES MENSUALES **                              qcin:    collector input
                                                                                                           qcout:   collector output
UNITS: KWh                            SYSTEM: INSOL,  LIQUID                                               qsin:    storage .input
                                                                                                           qsl:     storage loss
                                                                                                           qsout:   storage output
                                      CIUDAD ...    HAMBURGO                                               qaux:    auxiliary required
                                                                                                           qd:      demand load
        ---collector---   --------------------- house --------   ---------------- dwh ---------------        percent solar
mon     qcin      qcout     qsin     qsl      qsout    qaux      qd      qsin     qsl      qsout    qaux      qd      h     dwh   tot
NES     OINC      OGC       QEHI     QPHI     QSCR     QACR      QLC     QEAZ     QPAZ     QSAC     QAAC      QLA     SC    SAC   TOT

  1     862.3     257.8     251.2      1.3    175.6   2064.7   2240.3    118.5     - 0     123.0    381.7     504.7   7.8  24.4  10.9
  2    1717.8     632.6     612.7     13.3    403.1   1596.9   2000.0    151.5     2.3     145.8    310.0     455.8  20.2  32.0  22.3
  3    4164.7    1582.3    1498.9     96.8    823.7    517.2   1340.5    373.8    18.2     338.4    166.3     504.7  61.4  67.0  63.0
  4    4489.9    1620.5    1529.4    110.1   1062.5     74.2   1136.7    419.9    20.8     405.2     83.2     488.4  93.5  83.0  90.3
  5    5673 9    1397.7    1282.1    203.2    404.0       .0    404.0    542.4    38.6     493.0     11.6     504.7  100.  97.7  98 7
  6    6527.2     953.9     840.1    269.7       .0       .0       .0    541.7    51.6     488.4       .0     488.4  ****  100.  100.
  7    5461.7     923.8     813.0    265.4       .0       .0       .0    553.9    50 7     504.7       .0     504.7  ****  100.  100.
  8    6950.4     975.5     854.8    280.8       .0       .0       .0    558.9    53.7     504.7       .0     504.7  ****  100.  100.
  9    4415.8    1011.6     906.1    235.7    305.0       .0    305.0    518.5    45.0     487.6       .8     488.4  100.  99.8  99.9
 10    3202.1    1356.4    1292.9     93.1    807.3    204.5   1011.8    375.0    17.5     356.4    148.3     504.7  79.8  70.6  76.7
 11    2324.5     953.5     913.0     39.0    696.5   1091.7   1788.2    223.8     7 2     221.1    267.3     488.4  38.9  45.3  40.3
 12    1420.3     509.5     495.8      9.9    372.5   1987.8   2360.3    145.4     1.6     147.3    357.4     504.7  15.8  29.2  18.1

Total 47209,7  12175,1  11289,9   1618,3   5050,2   7537    12587,2   4523,3   307,2    4215,6   1725,8    5942,3 40,12 70,94 50,00
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SUMMARY, **US (TRNSYS)**

SYSTEM: Liquid System (40 l/m^2)

CITY: Hamburg

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

mon	--collector--		---house---					---dwh---					-percent solar-		
	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot
1	777	186	182	1	206	2096	2240	65	-3	75	430	505	6.5	14.9	8.0
2	1573	444	427	7	411	1689	2000	99	-1	99	357	456	15.6	21.7	16.7
3	4036	1224	1147	46	1020	652	1341	299	11	273	232	505	51.3	54.1	52.1
4	4500	1309	1230	47	1190	294	1135	313	12	303	186	489	74.1	61.9	70.4
5	5968	1223	1114	115	951	4	404	494	32	453	52	505	98.9	89.9	93.8
6	6963	838	714	172	534	0	0	540	49	489	0	489	100	100	100
7	5788	754	658	144	532	0	0	539	40	501	4	505	100	99.2	99.2
8	7250	903	763	181	556	0	1	561	52	505	0	505	100	100	100
9	4497	906	815	122	821	534	303	461	34	449	40	489	98.2	91.9	94.3
10	3112	1094	1029	41	928	391	1012	281	9	261	244	505	61.3	51.7	58.1
11	2324	811	771	20	791	1169	1790	161	3	165	324	489	34.7	33.7	34.5
12	1471	495	477	7	476	1984	2359	104	-1	107	398	505	15.7	21.2	16.8
Total	48260	10190	9327	903	8416	8285	12590	3916	237	3680	2268	5948	34.1	61.9	43.1

TABLE III
LASL RESULTS
Storage Size, 40 ℓ/m^2

```
                                   solar performance summary

                                         liquid system

                                hamburg germany  1/73 to 12/73

                  - - - - - - - - - house - - - - - - - - - .     - - - - - - - - dwh - - - - - - - -      h    dwh   tot

mon   qinc    qcout   qsin     qsl    qsout    qaux     qd      qsin     qsl   qsout    qaux     qd     - percent solar -
 1     744.    152.    151.      1.     44.    2197.    2240.    132.     0.    132.    372.    504.     2.0  26.2    6.4
 2    1553.    393.    388.      6.    229.    1771.    2000.    148.     2.    146.    309.    455.    11.4  32.1   15.3
 3    4024.   1117.   1087.     45.    638.     703.    1341.    315.    14.    301.    203.    504.    47.6  59.7   50.9
 4    4533.   1247.   1214.     46.    830.     307.    1137.    344.    14.    330.    158.    488.    73.0  67.7   71.4
 5    6000.   1104.   1047.    113.    399.       6.     404.    503.    35.    468.     36.    504.    98.6  92.8   95.4
 6    7016.    765.    713.    165.      0.       0.       0.    540.    52.    488.      0.    488.   100.0 100.0  100.0
 7    5816.    728.    664.    137.      0.       0.       0.    545.    43.    502.      2.    504.   100.0  99.6   99.6
 8    7249.    839.    767.    176.      0.       0.       0.    559.    55.    504.      0.    504.   100.0 100.0  100.0
 9    4420.    814.    770.    115.    296.       9.     305.    488.    36.    452.     35.    488.    97.2  92.7   94.5
10    3015.    971.    952.     37.    552.     460.    1012.    298.    11.    287.    217.    504.    54.5  56.9   55.3
11    2217.    703.    691.     17.    513.    1275.    1788.    204.     5.    199.    289.    488.    28.7  40.8   31.3
12    1385.    415.    410.      6.    251.    2109.    2360.    159.     2.    157.    347.    504.    10.6  31.2   14.3

total 47973.  9269.   8854.    864.   3751.    8836.  12587.   4236.   268.   3968.   1968.   5936.    29.8  66.8   41.7


              qinc  - collector input
              qcout - collector output
              qsin  - storage input
              qsl   - storage loss
              qsout - storage output
              qaux  - auxiliary required
              qd    - demand load

units: kwh
```

```
                          ==== NIKKEN (JAPAN) ====

                          MONTHLY SOLAR PERFORMANCE SUMMARY                   MON...     MONTH OF THE YEAR
                                                                              QCIN...    COLLECTOR INPUT
UNITS.(KWH)               SYSTEM...  LIQUID SOLAR SYSTEM                      QCOUT...   COLLECTOR OUTPUT
                                                                              QSIN...    STORAGE INPUT
                          CITY...    HAMBURG  LST=40 L/SM                     QSL...     STORAGE LOSS
                                                                              QSOUT...   STORAGE OUTPUT
                                                                              QAUX...    AUXILIARY REQUIRED
                                                                              QD...      DEMAND LOAD

       ===COLLECTOR===   ====STORAGE====   ======== HOUSE ========   ================= DHW =================   =====PERCENT SOLAR=====
MON     QCIN    QCOUT     QSIN     QSL     QSOUT    QAUX      QD       QSIN     QSL    QSOUT   QAUX      QC        H      DW     TOT

JAN     768.6   131.8     130.2     0.7     37.1  2203.8  2239.9      117.6    -0.1    122.3   382.3   504.7      1.6    24.2     5.8
FEB    1550.3   368.4     362.6     5.3    218.9  1788.5  1999.6      134.5     1.3    132.6   323.3   455.8     10.6    29.1    14.0
MAR    4014.8  1140.7    1109.5    45.8    650.1   735.3  1340.6      319.2    13.4    289.2   215.4   504.7     45.2    57.3    48.5
APR    4474.1  1284.9    1252.4    45.0    901.9   283.3  1136.4      321.4    13.2    311.5   176.9   488.4     75.1    63.8    71.7
MAY    5822.9  1144.2    1096.4   107.6    457.2     4.3   404.0      489.0    32.3    449.5    55.2   504.7     98.9    89.1    93.5
JUN    6682.8   764.1     711.7   162.1      0.0     0.0     0.0      539.3    49.2    488.4     0.0   488.4      0.0   100.0   100.0
JUL    5696.0   720.7     674.9   139.7      0.0     0.0     0.0      537.2    42.2    495.5     9.1   504.7      0.0    98.2    98.2
AUG    7106.1   793.0     741.5   166.6      0.0     0.0     0.0      558.0    50.6    504.6     0.0   504.7      0.0   100.0   100.0
SEP    4387.6   828.4     791.9   113.0    356.1     8.6   305.0      457.5    34.1    446.6    41.7   488.4     97.2    91.5    93.7
OCT    3005.7  1020.5     998.9    35.6    604.0   445.0  1011.5      294.0    10.3    272.3   232.4   504.7     56.0    54.0    55.3
NOV    2261.2   696.5     683.3    15.9    522.2  1288.8  1787.8      183.0     4.5    185.0   303.4   488.4     27.9    37.9    30.1
DEC    1628.5   543.1     535.6     7.7    374.5  1996.6  2359.9      157.1     2.0    155.9   348.8   504.7     15.4    30.9    18.1

TOTAL 47398.6  9436.3    9089.0   845.2   4122.1  8754.1 12584.7     4107.9   252.9   3853.4 -2088.5  5941.9     30.4    64.9    41.5
```

```
                         MONTHLY SOLAR PERFORMANCE SUMMARY                    MON:    MONTH OF THE YEAR
                                                                              QCIN:   COLLECTOR INPUT
                         SYSTEM: LIQUID, 40l/m²                               QCOUT:  COLLECTOR OUTPUT
                                                                              QSIN:   STORAGE INPUT
                         CITY:  HAMBURG                                       QSL:    STORAGE LOSS
                                                                              QSOUT:  STORAGE OUTPUT
                                                                              QAUX:   AUXILIARY REQUIRED
                                                                              QD:     DEMAND LOAD

        -COLLECTOR-    -------------HOUSE------------   -------------DHW--------------   --PERCENT SOLAR-
 MON   QCIN   QCOUT    QSIN   QSL  QSOUT  QAUX     QD    QSIN  QSL  QSOUT  QAUX     QD      H  DWH  TOT
   1    769     221     220    -2    140  2100   2240     107    0    112   389    501      6   22    9
   2   1592     473     469     5    293  1707   2000     146    2    142   310    452     15   32   18
   3   3943    1270    1219    51    684   657   1341     345   17    314   187    501     51   63   54
   4   4443    1325    1298    52    842   297   1135     373   18    357   127    484     74   74   74
   5   5979    1277    1179   131    399     5    403     521   42    472    29    501     99   94   96
   6   7034    1092     765   204      0     0      0     550   64    484     0    484      0  100  100
   7   5776     992     635   164      0     0      0     549   51    499     1    501      0  100  100
   8   7223    1271     815   216      0     0      0     577   48    501     0    501    100  100  100
   9   4362    1013     873   132    259     8    706     475   42    454    31    484     97   94   95
  10   2953    1022    1050    41    583   430   1013     395   14    301   200    501     58   60   58
  11   2158     911     759    13    573  1218   1790     210    7    211   274    484     32   43   34
  12   1309     521     513     6    745  2013   2759     155    2    153   347    501     15   31   17
TOTAL 47559   11092    9912  1018   4161  8475  12596    4329  327   4000  1893   5893     33   68   44
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SUMMARY, US (TRNSYS)

SYSTEM: Liquid System (20 $1/m^2$)

CITY: Hamburg

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	--collector--		house					dwh					-percent solar-		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot
1	777	179	171	0	184	2115	2240	62	-4	72	433	505	5.6	14.2	7.2
2	1573	412	388	4	380	1730	2000	109	-1	108	348	456	13.5	23.7	15.4
3	4036	1100	1016	32	937	751	1341	313	14	283	222	505	44.0	56.0	47.3
4	4500	1220	1130	32	1090	429	1135	343	14	328	160	489	62.3	67.1	63.7
5	5968	1120	994	73	921	21	404	484	32	452	53	505	94.7	89.6	91.9
6	6963	788	655	106	534	0	0	534	46	483	6	489	100	98.9	98.8
7	5788	725	616	92	533	0	0	534	40	497	8	505	100	98.4	98.4
8	7250	843	691	114	561	0	0	560	50	504	1	505	100	100	100
9	4497	891	789	74	780	23	307	441	32	432	57	488	92.5	88.4	89.9
10	3112	989	920	28	850	502	1012	305	12	278	227	505	50.4	55.1	51.9
11	2324	761	715	13	734	1240	1790	171	4	177	312	489	30.7	36.3	31.9
12	1471	465	442	4	378	2030	2359	110	-1	113	392	505	13.9	22.4	15.4
Total	48260	9492	8526	571	7940	8841	12590	3965	238	3727	2219	5948	29.8	62.7	40.3

TABLE II
LASL RESULTS
Storage Size 20 ℓ/m^2

solar performance summary

liquid system

hamburg germany 1/73 to 12/73

	house							dwh					h	dwh	tot
mon	qinc	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	- percent solar -		
1	744.	136.	134.	0.	17.	2223.	2240.	131.	0.	130.	374.	504.	0.8	25.9	5.4
2	1553.	329.	323.	4.	170.	1830.	2000.	148.	2.	146.	309.	455.	8.5	32.1	12.9
3	4024.	928.	895.	30.	512.	829.	1341.	302.	14.	288.	216.	504.	38.2	57.1	43.4
4	4533.	1085.	1049.	29.	676.	461.	1137.	336.	14.	322.	166.	482.	59.4	66.1	61.4
5	6000.	968.	914.	69.	375.	29.	404.	485.	34.	451.	53.	504.	92.8	89.5	91.0
6	7016.	705.	641.	90.	0.	0.	0.	528.	49.	480.	8.	488.	100.0	98.3	98.3
7	5816.	677.	610.	83.	0.	0.	0.	539.	41.	498.	6.	504.	100.0	93.7	98.7
8	7249.	751.	685.	107.	0.	0.	0.	555.	53.	502.	2.	504.	100.0	99.7	99.7
9	4420.	777.	732.	67.	270.	35.	305.	459.	33.	427.	61.	488.	88.7	87.5	37.9
10	3015.	814.	789.	25.	428.	583.	1012.	289.	12.	278.	226.	504.	42.4	55.1	46.6
11	2217.	607.	593.	10.	419.	1369.	1788.	201.	5.	196.	292.	488.	23.4	40.2	27.0
12	1385.	361.	354.	4.	193.	2168.	2360.	158.	2.	156.	348.	504.	8.2	31.0	12.2
total	47973.	8137.	7718.	527.	3060.	9527.	12587.	4133.	257.	3876.	2061.	5936.	24.3	65.3	37.4

419

qinc - collector input
qcout - collector output
qsin - storage input
qsl - storage loss
qsout - storage output
qaux - auxiliary required
qd - demand load

units: kwh

```
                             ==== NIKKEN (JAPAN) ====

                             MONTHLY SOLAR PERFORMANCE SUMMARY                     MON...     MONTH OF THE YEAR
                                                                                   QCIN...    COLLECTOR INPUT
UNITS.(KWH)                  SYSTEM...  LIQUID SOLAR SYSTEM                        QCOUT...   COLLECTOR OUTPUT
                                                                                   QSIN...    STORAGE INPUT
                             CITY...   HAMBURG  LST=20 L/SM                        QSL...     STORAGE LOSS
                                                                                   QSOUT...   STORAGE OUTPUT
                                                                                   QAUX...    AUXILIARY REQUIRED
                                                                                   QD...      DEMAND LOAD

       ===COLLECTOR===  ====STORAGE====  ======== HOUSE ========  ================ DHW ================  =====PERCENT SOLAR=====
MON     QCIN    QCOUT     QSIN     QSL    QSOUT    QAUX      QD     QSIN     QSL   QSOUT    QAUX     QD        H      DW     TOT

JAN    768.6    124.3    122.4     0.3     17.7  2222.9  2239.9    117.1    -0.2   121.9   382.7  504.7      0.8    24.2     5.1

FEB   1550.3    336.6    329.6     3.8    187.5  1821.1  1999.6    137.9     1.5   136.3   319.6  455.8      8.9    29.9    12.8

MAR   4014.8    983.5    948.2    31.7    540.1   846.4  1340.6    318.6    14.9   283.0   221.7  504.7     36.9    56.1    42.1

APR   4474.1   1188.6   1150.9    30.9    788.7   397.5  1136.4    331.2    14.4   317.4   170.9  488.4     65.0    65.0    65.0

MAY   5822.9   1023.4    978.8    67.6    440.6    18.7   404.0    476.1    32.2   446.0    58.6  504.7     95.4    88.4    91.5

JUN   6682.8    687.2    643.9    96.4      0.0     0.0     0.0    535.5    46.4   485.0     3.4  488.4      0.0    99.3    99.3

JUL   5696.0    653.3    611.9    84.7      0.0     0.0     0.0    531.0    40.6   491.9    12.7  504.7      0.0    97.5    97.5

AUG   7106.1    710.5    667.3    99.8      0.0     0.0     0.0    555.3    48.0   503.2     1.5  504.7      0.0    99.7    99.7

SEP   4387.6    791.8    758.6    65.7    326.4    31.3   305.0    434.2    31.4   426.2    62.2  488.4     89.7    87.3    88.2

OCT   3005.7    916.5    890.5    25.5    508.7   542.9  1011.5    305.6    11.8   275.7   229.0  504.7     46.3    54.6    49.1

NOV   2261.2    657.5    641.6    11.2    484.6  1329.4  1787.8    182.3     5.1   189.9   296.4  488.4     25.6    38.9    28.5

DEC   1628.5    491.8    462.7     4.9    317.7  2053.6  2359.9    159.3     2.0   157.1   347.6  504.7     13.0    31.1    16.2

TOTAL 47398.6  8565.0   8226.4   522.6   3612.1  9263.8 12584.7   4083.9   248.1  3833.6  2108.3 5941.9     26.4    64.5    38.6
```

```
MONTHLY SOLAR PERFORMANCE SUMMARY                        MON:    MONTH OF THE YEAR
                                                         QCIN:   COLLECTOR INPUT
SYSTEM: LIQUID, 20 l/m²                                  QCOUT:  COLLECTOR OUTPUT
                                                         QSTIN:  STORAGE INPUT
CITY:   HAMBURG                                          QSL:    STORAGE LOSS
                                                         QSOUT:  STORAGE OUTPUT
                                                         QAUX:   AUXILIARY REQUIRED
                                                         QD:     DEMAND LOAD

      -COLLECTOR-    -------------HOUSE--------------   ---------------DHW---------------   --PERCENT SOLAR--
MON   QCIN  QCOUT   QSTIN  QSL  QSOUT  QAUX     QD      QSTIN  QSL  QSOUT  QAUX    QD       H    DHW   TOT
  1    749    211     212   -3    126  2113   2240        101    0    109   393   501        6    22     8
  2   1502    447     433    7    262  1738   2000        154    2    151   301   452       13    33    17
  3   3043   1147    1105   76    600   741   1341        301   21    322   179   501       45    64    50
  4   4442   1281    1245   36    777   402   1179        305   22    337   147   484       65    70    67
  5   5679   1102    1260   82    383    21    403        515   44    475    26   501       95    95    95
  6   7074    917     638  134      0     0      0        547   63    479     5   484        0    99    99
  7   6772    979     642  104      0     0      0        647   63    498     3   501        0    99    99
  8   7223    955     723  133      0     0      0        577   60    500     1   501      100   100   100
  9   4362    966     848   31    280    26    306        465   43    444    40   484       92    92    92
 10   2037    351     561   22    433   880   1313        341   17    317   184   501       33    63    40
 11   2158    762     751   12    518  1272   1790        204    9    227   257   484       29    47    33
 12   1402    464     422    3    312  2046   2358        155    7    172   329   501       17    33    17
TOTAL 47559 10177    9165  639   3708  8873  12586'      4409  343   4065  1323  5893       29    69    42
```

UNITS: kWh

MONTHLY SOLAR PERFORMANCE SUMMARY, TRNSYS

SYSTEM: AIR

CITY: MADISON

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	collector		house					dwh					percent solar		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot
1	4868	1648	797	12	809	2158	3599	203	5	199	307	505	40.0	39.3	39.9
2	5576	1936	1100	24	1102	1233	2927	216	7	216	241	456	57.7	47.3	56.2
3	7449	2511	1742	96	1600	296	2217	334	13	316	189	505	86.9	62.5	82.4
4	7065	1911	1356	193	1101	67	1198	395	21	372	116	488	94.5	76.2	89.3
5	7371	1508	879	279	378	0	389	481	30	435	69	504	99.5	86.3	92.1
6	8251	1143	458	428	0	0	0	528	48	479	8	488	100	98.3	98.3
7	7718	1080	431	432	0	0	0	508	45	477	26	504	100	94.8	94.8
8	7951	1137	443	432	0	0	0	544	45	482	21	504	100	95.8	95.8
9	7896	1228	615	394	334	0	325	481	42	454	34	488	100	93.1	96.7
10	6123	1420	857	291	739	0	748	433	28	412	92	504	99.1	81.7	92.1
11	4412	1445	946	76	888	838	1935	240	8	232	257	489	56.7	47.5	54.9
12	4324	1476	781	13	817	1825	3147	185	4	186	319	505	41.8	36.8	41.1
Total	78,500	18,440	10,410	2,670	7,767	6,417	16,480	4,548	295	4,260	1,680	5,940	61.0	71.7	63.9

```
                              solar performance summary

                                  air system , LASL

                             madison, wisc.  1/54 to 12/54

          - - - - - - - - - - house - - - - - - - - - -      - - - - - - - - - dwh - - - - - - - - -     h    dwh   tot

  mon  qinc    qcout   qsin    qsl    qsout   qaux    qd      qsin    qsl   qsout   qaux    qd     - percent solar -
   1   4969.   1666.    891.    17.    889.   2191.   3597.   229.     6.    223.   291.   504.    39.1  42.2  39.5
   2   5611.   2016.   1235.    37.   1244.   1201.   2927.   250.     9.    248.   219.   455.    59.0  51.9  58.0
   3   7470.   2511.   1824.   115.   1674.    289.   2217.   348.    14.    329.   188.   504.    87.0  62.7  82.5
   4   7132.   1914.   1318.   236.   1039.     91.   1199.   416.    23.    386.   111.   488.    92.4  77.3  88.0
   5   7404.   1449.    826.   295.    374.      1.    390.   485.    32.    445.    65.   504.    99.7  87.2  92.6
   6   8201.   1076.    412.   414.      0.      0.      0.   529.    47.    481.     7.   488.   100.0  98.6  98.6
   7   7752.   1012.    397.   417.      0.      0.      0.   497.    43.    469.    38.   504.   100.0  92.5  92.5
   8   7963.   1088.    404.   415.      0.      0.      0.   554.    45.    492.    14.   504.   100.0  97.2  97.2
   9   7339.   1210.    590.   395.    307.      2.    324.   486.    41.    457.    34.   488.    99.5  93.0  95.6
  10   6107.   1392.    841.   315.    715.      6.    747.   437.    29.    417.    94.   504.    99.1  81.4  92.0
  11   4371.   1390.    942.    82.    805.    895.   1934.   255.     9.    246.   252.   488.    53.7  48.4  52.7
  12   4259.   1431.    791.    16.    829.   1918.   3148.   209.     6.    200.   305.   504.    39.1  39.5  39.2

 total 78858.  18155.  10471.  2753.   7955.   6504.  16484. , 4696.  302.   4400.  1618.  5936.    60.5  72.7  63.4


               qinc  - collector input
               qcout - collector output
               qsin  - storage input
               qsl   - storage loss
               qsout - storage output
               qaux  - auxiliary required
               qd    - demand load

  units: kwh
```

```
                               MONTHLY SOLAR PERFORMANCE SUMMARY            MON:    MONTH OF THE YEAR
                                                                            QCIN:   COLLECTOR INPUT
                               SYSTEM: IEA,AIR, SVS                         QCOUT:  COLLECTOR OUTPUT
                                                                            QSIN:   STORAGE INPUT
                               CITY:   MADISON                              QSL:    STORAGE LOSS
                                                                            QSOUT:  STORAGE OUTPUT
                                                                            QAUX:   AUXILIARY REQUIRED
         -COLLECTOR-    -------------HOUSE--------------   ---------------DHW--------------- QD:     DEMAND LOAD
  MON    QCIN  QCOUT    QSIN    QSL  QSOUT   QAUX     QD   QSIN   QSL  QSOUT   QAUX     QD   --PERCENT SOLAR--
    1    5104   1781    1045     20   1458   2141   3599    234     6    222    279    501      H    DWH    TOT
    2    5628   1944    1232     35   1674   1253   2927    234     8    233    220    453     41     44     41
    3    7341   2379    1699    101   1823    394   2217    350    14    330    171    501     57     51     56
    4    6997   1827    1261    183   1099     99   1198    397    21    374    111    485     82     66     79
    5    7325   1469     837    270    381      7    388    477    30    434     68    501     92     77     88
    6    8179   1176     424    404      0      0      0    526    48    478      7    485     98     86     92
    7    7641   1114     391    406      0      0      0    515    45    482     19    501      0     99     99
    8    7906   1189     415    403      0      0      0    551    46    491     11    501      0     96     96
    9    7266   1216     567    365    325      0    325    480    40    454     31    485      0     98     98
   10    6034   1383     827    261    741      7    748    427    27    405     96    501    100     94     96
   11    4346   1408     976     75   1045    890   1935    253     9    243    242    485     99     81     92
   12    4372   1533     945     20   1315   1831   3146    211     5    212    290    501     54     50     53
TOTAL   78141  18419   10619   2545   9861   6623  16484   4655   299   4357   1547   5905     42     42     42
                                                                                               60     74     64
```

MONTHLY SOLAR PERFORMANCE SYMMARY

UNITS: kWh

SYSTEM: IEA, AIR, D(PHILIPS)

CITY: Madison

mon: month of the year
qcin: collector input
qcout: collector output
qsin: storage input
qsl: storage loss
qsout: storage output
qaux: auxiliary required
qd: demand load

	-collector--		------------house------------					------------dwh------------					---percent solar---		
mon	qcin	qcout	qsin	qsl	qsout	qaux	qd	qsin	qsl	qsout	qaux	qd	h	dwh	tot
1	4939	1624	869	26	871	2159	3597	214	5	209	296	505			
2	5632	1873	1147	38	1153	1205	2927	229	8	221	235	456			
3	7477	2497	1831	112	1703	292	2217	343	14	329	176	505			
4	7100	1833	1264	196	1024	105	1199	392	22	370	118	488			
5	7383	1498	854	294	380	5	390	480	32	448	57	505			
6	8253	1148	440	434	0	0	0	529	48	481	7	488			
7	7729	1075	432	443	0	0	0	502	43	459	46	505			
8	7986	1176	394	412	0	0	0	545	44	501	4	505			
9	7440	1288	624	397	336	4	324	484	41	443	45	488			
10	6199	1438	869	289	751	8	747	427	29	398	107	505			
11	4652	1446	963	85	903	876	1934	246	8	238	250	488			
12	4562	1473	804	28	832	1867	3148	196	4	192	313	505			
total	79351	18368	10491	2754	7953	6521	16483	4587	298	4289	1654	5943	60.4	72.2	63.5

ANNEX III

ADDRESS LISTS

June 1979

IEA SOLAR HEATING AND COOLING PROGRAM

EXECUTIVE COMMITTEE MEMBERS

AUSTRIA	Prof. G. Faninger Austrian Solar and Space Agency Garnisongasse 7 A-1090 Vienna	Tel: (0222) 438177 Telex: 76560 assa a
(Alternate)		
BELGIUM	Mr. J. C. Delcroix Directeur Operationnel Programme National de R & D Energie Service de Programmation del la Politique Scientifique Rue de la Science 8 B-1040 Brussels	Tel: (02) 511-5985 Telex: 24501
(Alternate)	Mr. P. Wattiez (Same address as above)	
CANADA	Mr. Robert Aldwinckle National Research Council of Canada Bldg. M-24-Solar Energy Project Montreal Road Ottawa K1A 0R6	Tel: (613) 993-2730 Telex: 053-4134
(Alternate)	Dr. F. H. Krenz (Same address as above)	Tel: (613) 993-9224 Telex: 053-4134
DENMARK	Dr. N. O. Gram Ministry of Trade & Industry Slotsholmsgade 12 DK-1216 Copenhagen K	Tel: 121197 Telex: 22373
(Alternate)	Prof. Vagn Korsgaard Thermal Insulation Laboratory Building 118 Technical University of Denmark DK-2800 Lyngby	Tel: (02) 883511 Telex: 37529 DTH
EUROPEAN COMMISSION	Mr. A. Strub Directorate General for Research, Science and Education Commission of the European Communities 200 rue de la Loi 1040 Brussels, Belgium	Tel: (02) 735 8040 x4683 Telex: 21877 COMEU B

(Alternate)	Dr. E. Aranovitch European Commission Joint Research Center Euratom Ispra, Italy	Tel: 780131 Telex: EURATOM 38042
FEDERAL REPUBLIC OF GERMANY	Dipl. Ing. F. J. Friedrich Kernforschungsanlange Jülich GmbH Projektleitung Energieforschung Postfach 1913 D-5170 Jülich	Tel: (02461) 614743 Telex: 833556 kfa d
(Alternate)	Dr. H. Klein Ministerium fur Forschung und Technologie Stresemann Strasse 2 D-53 Bonn-Bad Godesberg	Tel: (02) 780190
GREECE	Prof. R. Rigopoulos Physics Laboratory II University of Patras Patras	Tel: (061) 991712 Telex:
(Alternate)		
ITALY	Prof. Mario Silvestri, Direttore Istituto di Fisica Tecnica Politecnico di Milano Piazza L. da Vinci 32 20133 Milano	Tel: (02) 780190 Telex:
(Alternate)	Dott. Ing. Giovanni Simoni Ministero Industria Commercio e Artigianato Via Veneto, 33 00100 Roma	Tel: 47052423 Telex:
JAPAN	Mr. T. Sunami Sunshine Project Headquarters Agency of Industrial Science and Technology - MITI 1-3-1, Kasumigaseki Chiyoda-Ku, Tokyo	Tel: (03) 434-5647 Telex: 22916 EIDMITI J
(Alternate)	Mr. K. Shimo Japanese Delegation to OECD 7 avenue Foche 75008 Paris	Tel: 766-0222 Telex:
NETHERLANDS	Mr. P. F. Sens Project Office for Energy Research Netherlands Energy Research Foundation Westerduinweg 3 Petten	Tel: (2246) 6262 Telex: 57211

(Alternate)	Mr. K. Joon (Same address as above)	
NEW ZEALAND	Mr. R. W. Foster Scientific Advisor New Zealand High Commission New Zealand House Haymarket London SW1Y 4TQ	Tel: (01) 930-8422 Telex: 24368
(Alternate)	Mr. R. Benzie New Zealand Delegation to OECO 7 rue Leonardo de Vinci 75116 Paris	Tel: 553-6650 Telex:
SPAIN	Dr. A. Muñoz Torralbo Centro de Estudios de la Energia Agustin de Foxa 29 Madrid 16	Tel: 7331608 Telex: 42885
(Alternate)	Mr. E. De Mora Fiol Spanish Delegation to OECD 42 rue de Lubeck 75016 Paris	Tel: 727-2750 Telex:
SWEDEN	Mr. A. Boysen (VICE-CHAIRMAN) Research Secretary Swedish Council for Building Research St. Göransgatan 66 S-11230 Stockholm	Tel: (08) 540640 Telex:
(Alternate)		
SWITZERLAND	Mr. G. Schriber Office de l'Economie Energetique Kapellenstrasse 14 CH-3001 Berne	Tel: (031) 615616 Telex: 33065
(Alternate)	Mr. Eichmann (Same address as above)	
UNITED KINDGOM	(1) Mr. David Curtis Faber Computer Operations Ltd. Marlborough House 18 Upper Marlborough Road St. Albans, Herts	Tel: (0) 727-61222 Telex: 889072
	(3) Prof. B. J. Brinkworth University College Newport Road Cardiff CF2 1TA Wales	Tel: (222) 44211 Telex: 49635

(Alternate)
Mr. W. B. Gillett
(Same address as above)

(4 & 5) Mr. A. C. Hardacre
Energy Technology Support Unit (ETSU)
Building 10
AERE
Harwell
Didcot, Oxfordshire OX11 ORA
Tel: 0235-24141 x2599
Telex: 83135

(Alternate)
Dr. G. Long
(Same address as above)

UNITED STATES
Dr. F. H. Morse (CHAIRMAN)
U.S. Department of Energy
Conservation and Solar
Applications
20 Massachusetts Ave., N.W.
Washington, D.C. 20585
Tel: (202) 376-9630
Telex: TWX 710 822 924

(Alternate)

OPERATING AGENTS

TASK I
Mr. O. Jorgensen
Thermal Insulation Laboratory
Building 118
Technical University of Denmark
DK-2800 Lyngby
Denmark
Tel: (02) 883511
Telex: 37529 DTH

TASK II
Mr. T. Sunami
Sunshine Project Headquarters
Agency of Industrial Science and
Technology - MITI
1-3-1, Kasumigaseki
Chiyoda-Ku, Tokyo
Japan
Tel: (03) 434-5647
Telex: 22916 EIDMITI J

TASK III
Dr. H. Talarek
Kernforschungsanlange Jülich GmbH
IKP - Solar Energy Branch
Postfach 1913
D-5170 Jülich
Federal Republic of Germany
Tel: (02461) 614540
Telex: 833556 KFA D

TASK IV	Mr. M. Riches U.S. Department of Energy Office of Energy Research - SPS 400 First Street, N.W. Washington, D.C. 20585	Tel: (202) 376-9364 Telex:
TASK V	Dr. L. Dahlgren Swedish Meteorological and Hydrological Institute Fack S-601 01 Norrkoping Sweden	Tel: 001/ 10 80 00 Telex: 6440 smhi s

IEA SECRETARIAT

Mr. L. Boxer International Energy Agency 2 rue Andre Pascal F-75755 Paris Cedex 16 France	Tel: 524-82-00 Telex: 630190F
Dr. G. Rubinstein (Same address as L. Boxer)	Tel: 524-9468 Telex: 630190F

June 1979

National Contact Persons for TASK 1

BELGIUM

Prof. André Pilatte
Faculté Polytechnique de Mons
Boulevard Dolez 31
B-7000 Mons
Tel: (065) 338191
Tlx:

DENMARK

M.sc.physics O. Jørgensen
Thermal Insulation Laboratory
Technical University of Denmark
Building 118
DK-2800 Lyngby
Tel: (02) 883511
Tlx: 37529DTHDIADK

GERMANY

Dr. F.A. Peuser
Projektleitung Energieforschung
Kernforschungsanlage Jülich GmbH
Postfach 1913
D-5170 Jülich
Tel: (02461) 61421
Tlx: 0833556 kfa d
FRIEDRICH PLE

ITALY

Professor Aldo Fanchiotti
C.N.R.
Progetto Finalizzato Energetica
V. Morgagni 30/E
Roma
Tel: (06) 844.0025
Tlx:

JAPAN

Mr. Taira Sunami
Senior Officer for Solar Energy Development Program
Agency of Industrial Science and Technology
MITI
3-1 Kasumigaseki, Chiyoda-Ku
Tokyo
Tel: 03-501-1511 ex. 4658
Tlx: EIDMITI J22916

NETHERLANDS

Prof. Ir. C.W.J. van Koppen
Eindhoven University of Technology
P.O. Box 513
Eindhoven
Tel:
Tlx:

NEW ZEALAND

Dr. R.F. Benseman
Physics and Engineering Laboratory
Dept. of Scientific and Industrial Research
Private Bag
Lower Hutt
Tel: 66 919 (Wellington)
Tlx: 3814 PHYSICS NZ

SPAIN

Mr. Eduardo G. Mezquida
Instituto Nacional de Técnica Aeroespacial
Torrejon de Ardoz
E-Madrid
Tel: 6750700, ex. 479
Tlx:

SWEDEN

Prof. Ingemar Höglund
The Royal Institute of Technology
Division of Building Technology
S-10044 Stockholm 70
Tel: 08/236320
Tlx:

SWITZERLAND

Dr. Phys. André Faist
Ecole Polytechnique Fédérale
de Lausanne
33 Av. de Cour
CH-1007 Lausanne
Tel: 021/264621
Tlx:

U.S.A.

Mr. J. Hedstrom
Los Alamos Scientific Laboratory
Mail Stop 571
Los Alamos
New Mexico 87545
Tel: (505) 667-6441
Tlx:

UNITED KINGDOM

Mr. David Curtis
Faber Computer Operations Ltd.
Marlborough House
18 Upper Marlborough Road
St. Albans
Herts AL1 3UT
Tel: (0) 727-61222
Tlx: 889072

EEC

Mr. E. Aranovitch
Joint Research Center
I - 21020 ISPRA (Varese)
Tel:
Tlx:

June 1979

Researchers Responsible for TASK 1

BELGIUM

Professor A. Pilatte
Faculté Polytechnique de Mons
Boulevard Dolez 31
B-7000 Mons
Tel: (065) 338191, ext. 339
Tlx:

DENMARK

M.sc.physics O. Jørgensen
Thermal Insulation Laboratory
Technical University of Denmark
Building 118
DK-2800 Lyngby
Tel: (02) 883511
Tlx: 37529DTHDIADK

GERMANY

Dr. Richard Bruno
Deutsche Philips GmbH
Forschungslaboratorium Aachen
Postfach 19 80
D-5100 Aachen
Tel: 0241/62071
Tlx: 832761

Dr. M. Meliss
Programmgruppe Systemforschung
und Technologische Entwicklung
der Kernforschungsanlage
Jülich GmbH
Postfach 1913
D-5170 Jülich 1
Tel:
Tlx:

ITALY

Mr. Federico Butera
Istituto di Fisica Tecnica
Universita de Palermo
Viale delle Scienze
Palermo
Tel:
Tlx:

JAPAN

Mr. Tatsuo Inooka (Mech.Engr.)
Nikken Sekkei Ltd.
38 Yokobori Nichome
Higashiku
Osaka 541
Tel: 06 (203) 2361
Tlx:
Cable: NKSEKKEI OSAKA

JAPAN (cont.)

Dr. Tetsuo Noguchi, Chief
Solar Research Laboratory, Girin
1, Hirate-machi, Kita-ku
Nagoya 462
Tel: 052-911-2111, ext. 255
Tlx:

NETHERLANDS

NEW ZEALAND

SPAIN

Mr. Eduardo G. Mezquida
Instituto Nacional de Técnica Aeroespacial
Torrejon de Ardoz
E-Madrid
Tel: 6750700, ex. 479
Tlx:

SWEDEN

Mr. Per Isakson
The Royal Institute of Technology
Division of Building Technology
S-10044 Stockholm 70
Tel: 08/236320
Tlx:

Mr. Egil Öfverholm
Swedish Council for Building Reasearch
Sankt Göransgatan 66
S-112 30 Stockholm
Tel: 08-540640

SWITZERLAND

Mr. G.-R. Perrin
Département de Physique
Ecole Polytechnique Féderale de Lausanne
P.O.Box 1024
CH-1001 Lausanne
Tel: (021) 473431
Tlx: 24478

UNITED KINGDOM

Mr. Peter Anderson
Faber Computer Operations Ltd.
Marlborough House
18 Upper Marlborough Road
St. Albans
Herts AL1 3UT
Tel: (0) 727-61222
Tlx: 889072

UNITED STATES

Mr. Tom Freeman
Altas Corporation
500 Chestnut St.
Santa Cruz
Ca. 95060
Tel: (408) 425-1211

Mr. E.R. Streed, Mech. Engr
Thermal Section
National Bureau of Standards
Bldg. 225, Room B 104
Washington, D.C. 20545
Tel: (301) 921-3505
Tlx:

EUROPEAN
COMMUNITIES

Within the IEA program to develop and test solar heating and cooling systems a comparison of simulation methods for predicting the performance of solar heating systems has been coordinated. The methods which were developed within IEA-countries participating in this work are presented and compared in this report. The methods have been used to predict the performance of both a liquid and an air based system. Hourly simulations have been carried out on weather data from three different locations in the world. In this report the predictions are compared on an hourly, a monthly and a yearly basis and show good agreement. Possible reasons for differences are sought, and a series of collector efficiency curves calculated by the different programs is therefore included in the report. The report opens with a chapter on the general aspects of solar systems modelling.

This report is part of the work of the
IEA Program to Develop and Test
Solar Heating and Cooling Systems
Task I: Investigation of the Performance
of Solar Heating and Cooling Systems
Subtask A: Modelling and Simulation

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Technical University of Denmark
Bldg. 118
DK-2800 Lyngby, Denmark

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