task I

investigation of the performance of solar heating and cooling systems

modelling and simulation

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MODELLING AND SIMULATION

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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 Republic 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 PERFORMANCE 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.
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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 parenthesis; 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(TRANYS), 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 similar 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 4(e) 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\textsuperscript{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.

1.3 **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 common 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 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.

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 Aerospatial, 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.
## Table 1.3.1

<table>
<thead>
<tr>
<th>Programs</th>
<th>USA (TRNSYS)</th>
<th>USA (LASYL)</th>
<th>DK (SVS)</th>
<th>D (PHILIPS) Finite Element</th>
<th>GB (FADER)</th>
<th>I (FTP)</th>
<th>E (INSOL)</th>
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<tbody>
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<td>Objective</td>
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<td>R &amp; D</td>
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<td>Research, Design, Studies and Evaluation</td>
<td>Research and Design</td>
<td>Design</td>
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<td>Any</td>
<td>-</td>
<td>Any</td>
<td>Residential</td>
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<td>Transfer Func. Degree Days External Calc.</td>
<td>Degree-Hour Method</td>
<td>Another Program</td>
<td>Another Program</td>
<td>Another Program</td>
<td>Degree-hour/external calc.</td>
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<td>Liquid Cooling Heating/Hot Water</td>
<td>Heating H.W.</td>
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<td>Liquid</td>
<td>Liquid heating H.W. Liquid Cooling Heating/H.W.</td>
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<td>Terminal</td>
<td>Cards</td>
<td>Tape Cards</td>
<td>Cards/Tape</td>
<td>Terminal interactive</td>
<td>Key board, magn., oass., p. tape</td>
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<td>MKH</td>
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<td>Large &gt;80 Bytes</td>
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<td>Fortran IV</td>
<td>ANS: Fortran IV</td>
<td>Basic</td>
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<td>Output Options</td>
<td>Plot Print Histograms</td>
<td>Print &amp; Plot</td>
<td>Print &amp; Cards/Plot</td>
<td>Printer, Cards</td>
<td>Printer, Disk File</td>
<td>Print, Plot</td>
<td></td>
</tr>
<tr>
<td>Availability</td>
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<td>Yes</td>
<td>No</td>
<td>No</td>
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<td></td>
<td></td>
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<td>Run Time</td>
<td>Long</td>
<td>Low 10 Sec. CDC 7600</td>
<td>6 min. (IBM 370/138)</td>
<td>1-2 min. (IBM 370/165)</td>
<td>7-15 min. CDC 7600</td>
<td>4-7 min. (Prime 300)</td>
<td>2.5-3.5 hours (H.P. 9330A) [H.P. 2100]</td>
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<tr>
<td>Active/Passive</td>
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<td>Active</td>
<td>Active</td>
<td>Active/Passive</td>
<td>Active</td>
<td>Active</td>
<td></td>
</tr>
</tbody>
</table>

- USA (TRNSYS): Insulated Continuum System
- USA (LASYL): Large System. Active
- DK (SVS): Danish System
- GB (FADER): British System
- I (FTP): Italian System
- E (INSOL): European System
CHAPTER II
MODELLING OF
SOLAR ENERGY SYSTEMS
(WHICH MODELS FOR WHAT)
WHICH MODELS FOR WHAT

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1 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 auxiliary 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 (i.e., 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, \( d \), given by:

\[
d = \left( \frac{\lambda \tau}{\pi p C} \right)^{1/2}
\]

where \( \lambda \) is the heat conductivity,
\( \tau \) is the time period of typical temperature changes (e.g. the cycling time of the solar collector circuit),
\( p \) 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 \( C_{Cj}^U \) and \( C_{Cj}^L \), 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%.

\(^1\) 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 straightforward
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 (i.e. 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 compo-
ponents, 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

\[ \dot{m}_c f \cdot (T_{\text{in}}^{(j)} - T_{\text{out}}^{(j)}) \]

gain and loss mechanisms,

and the capacitive effect \( C_C^{(j)} \) \( \frac{dT^{(j)}}{dt} \) for the \( j^{th} \) component. Since
a circuit, even with branching, is a one dimensional sequence of compo-
ents, the inlet and outlet temperatures of neighbouring compo-
nents are equal (e.g. \( T_{\text{in}}^{(j+1)} = T_{\text{out}}^{(j)} \)). 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 $T_{cin}^{(j)}$ and $T_{cout}^{(j)}$ 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.

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 (e.g. 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 (e.g. 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

\[
H_t(t) = S_T \frac{\cos \frac{\pi}{12} t - \cos w'}{1 - \cos w'}
\]

where

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

\( S_T \) = 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
\[ T_{\text{amb}}(t) = T_{\text{amb}} + \Delta T_{\text{amb}} \cos \left( \frac{\pi}{24}(t-\delta) \right) \]

where \[ T_{\text{amb}} = \frac{1}{24} \int_{0}^{24} T_{\text{amb \ data}}(t) \ dt, \Delta T_{\text{amb}} = \left( \frac{1}{24} \int_{0}^{24} (T_{\text{amb \ data}} - T_{\text{amb}})^2 \ dt \right)^{1/2} \]

and \( \delta \) is the time phase shift in hours. The wind velocity, \( V_{\text{amb}} \), used here for the collector is given by

\[ V_{\text{amb}}(t) = V_{\text{amb}} \]

\[ = \frac{1}{\tau_d/2} \int_{\tau_d/2}^{2} V_{\text{amb \ data}}(t) \ dt \]

where

\[ \tau_d' = FA C \left( \frac{\tau_d(0) + \tau_d(s)}{2} \right) \]

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 \( (S_T, T_d, V_{amb}, \Delta T_{amb}) \) 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 independent 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 \(= 5 \text{ m}^2 \text{C} \)
- Transmission-absorption factor \(= 0.86 \)
- Average front loss factor \(= 1.22 \text{ W/m}^2 \text{K} \)
- Back loss factor \(= 0.47 \text{ W/m}^2 \text{K} \)
- Total collector heat capacity \(= 4.0 \text{ Wh/m}^2 \text{K} \)
- Piping length \(= 40 \text{ m} \)
- Heat loss factor of piping \(= 0.2 \text{ W/Km} \)
- Total heat capacity of piping \(= 0.25 \text{ Wh/Km} \)
- Storage tank volume \(= 400 \text{ l} \) (water equivalent)
- Storage tank heat loss factor \(= 0.2 \text{ W/Km}^2 \)
- Fluid flow rate \(= 300 \text{ W/K} \)
- Heat exchanger rating \(= 300 \text{ W/K} \)
- Average hot water demand \(= 350 \text{ l/day} \)

\(^1\) 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 \(\Delta t_s\) used cannot be made smaller than \(\Delta t_c\), 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/m²K 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/m²K. 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 F i g s 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. F i g 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 ($\epsilon_{FWHM}$) 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 $\pm (\epsilon_{FWHM}/\sqrt{2})$ and a ~ 90% chance that they are no larger than $\pm \epsilon_{FWHM}$. This good agreement was to be expected. In going from basic system 1 to system 2 ( F i g 6), $\epsilon_{FWHM}$ 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 FAC, has the effect of distributing the errors, in a least square sense, normally about zero. F i g 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 $\epsilon_{FWHM}$ is twice that of system 1 whereas the average monthly and yearly errors remain at about $\pm 1%$. F i g 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 $\epsilon_{FWHM}$ ~ 2% for the lumped circuit model while $\epsilon_{FWHM}$ ~ 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 [16]. 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 independent 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 (\( \alpha_t \)), 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 oversooting 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 independent parts) requires some investigation.
References


[4] Engineering Experimental Station Report # 38, Solar Energy Laboratory, University of Wisconsin, Madison, Wisconsin, "TRNSYS, A Transient Simulation Program".


References


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+ Below this time interval information not physically valid ($\tau_f = \text{fluid cycle time}$)
++ Programs cannot be used with certain components or for accurate estimation of certain performance parameters ($\tau_c = \text{component's response time}$)
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<th>Load Calc.</th>
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+ for a more detailed list see [3]
++ not interactively coupled
### SIMPLIFIED SYSTEM ANALYSIS PROGRAMS

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<td>3200</td>
<td>3456</td>
<td>3478</td>
<td>3281</td>
<td>3453</td>
</tr>
<tr>
<td>For Tc &gt; 95 Energy still recoverable (kWh)</td>
<td>17</td>
<td>0</td>
<td>5</td>
<td>9</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Storage Tank Gain (kWh/year)</td>
<td>2876</td>
<td>2654</td>
<td>2791</td>
<td>2878</td>
<td>2726</td>
<td>2804</td>
</tr>
<tr>
<td>Solar Hot Water (kWh/year)</td>
<td>2799</td>
<td>2596</td>
<td>2725</td>
<td>2794</td>
<td>2655</td>
<td>2727</td>
</tr>
<tr>
<td>Auxiliary Energy (kWh/year)</td>
<td>2104</td>
<td>2307</td>
<td>2178</td>
<td>2109</td>
<td>2248</td>
<td>2176</td>
</tr>
<tr>
<td>Total Energy for Hot Water (kWh/year)</td>
<td>4903</td>
<td>4903</td>
<td>4903</td>
<td>4903</td>
<td>4903</td>
<td>4903</td>
</tr>
<tr>
<td>Percent Solar</td>
<td>57.1</td>
<td>52.9</td>
<td>55.6</td>
<td>57.0</td>
<td>54.2</td>
<td>55.6</td>
</tr>
<tr>
<td>Pumping Hours (hr/year)</td>
<td>2961</td>
<td>3178</td>
<td>3083</td>
<td>3069</td>
<td>3214</td>
<td>3181</td>
</tr>
</tbody>
</table>
### Table 5

**Dimensions and Static Physical Properties of the Reference House**

<table>
<thead>
<tr>
<th>Surface</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Total Heat Trans. Coefficient (W/m²K)</th>
<th>Surface Area (m²)</th>
<th>Wall Abs. (αₖ)</th>
<th>U-Value Glass (W/m²K)</th>
<th>Window Area (m²)</th>
<th>Trans. Glass (τ)</th>
<th>Door Heat Trans.Coeff. (W/m²K)</th>
<th>Door Area (m²)</th>
<th>Door Abs. (αₚ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>12.53</td>
<td>4.27</td>
<td>.374</td>
<td>51.8</td>
<td>.8</td>
<td>2.62</td>
<td>1.67</td>
<td>.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>West</td>
<td>5.87</td>
<td>4.27</td>
<td>.374</td>
<td>16.9</td>
<td>.8</td>
<td>2.62</td>
<td>8.18</td>
<td>.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>North</td>
<td>12.53</td>
<td>4.27</td>
<td>.374</td>
<td>51.1</td>
<td>.8</td>
<td>2.62</td>
<td>2.42</td>
<td>.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>East</td>
<td>5.87</td>
<td>4.27</td>
<td>.374</td>
<td>19</td>
<td>.8</td>
<td>2.62</td>
<td>4.95</td>
<td>.8</td>
<td>1.99</td>
<td>1.12</td>
<td>.8</td>
</tr>
<tr>
<td>Roof</td>
<td>12.53</td>
<td>5.87</td>
<td>.258</td>
<td>73.6</td>
<td>.87</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Floor</td>
<td>12.53</td>
<td>5.87</td>
<td>.185</td>
<td>73.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Temperature Setting Heating: 21.1 °C  
Temperature Setting Cooling: 23.9 °C  
Maximum Lighting Load: 6 W/m²  
Maximum Equipment Load: 18.9 W/m²  
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 CIRCUIT SEPARATION MODEL
SIMPLE SOLAR HOT WATER SYSTEM
Comparison of F-Chart and Exact Dynamic Calculation (Hamburg 1973)

Various House Types

- Normal House
- Swed. Std's House
- Exp.'l House

Deviation

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

Collector Parameters
CHAPTER III

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

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

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 Beckman1, for a flat plate collector.

\[
\dot{Q}_u = AF_R[H_f(t_a)-U_L(T_{in}-T_a)] \\
\dot{Q}_u = \dot{m}C_p(T_{out}-T_{in}) \\
FR/F' = (1-e^{-\phi})/\phi \\
\phi = AF'u_L/\dot{m}C_p \\
U_L = f_1 (\text{collector design, } T_a, T_{plate}, \text{wind, tilt}) \\
F' = f_2 (\text{collector design}) \\
(t_a) = f_3 (\text{collector design, angle of incidence of solar radiation})
\]

For preliminary design purposes, \( U_L, F' \) and \( t_a \) 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 \( H_f, \dot{m}, T_{in}, \) 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 Manual2 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
Each mode has a different set of INPUTS, PARAMETERS and OUTPUTS.

Communication between each component subroutine and TRANSYS 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 TRANSYS control information

For MODE 1 of the collector model, the array XIN corresponds to $T_{in}$, $m$, $T_b$ and $H_T$; the array OUT corresponds to $T_0$, and $Q_0$ as calculated from Eq. 1 and 2 and $m$, 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, $A$, $F$, $C_p$, $\alpha$, $U_L$ and $T$.

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:

$$
\left(\frac{d}{dt}\right)S (\dot{m}C_p)_T = (\dot{m}C_p)_L (T_L - T_s) + (\dot{m}C_p)_L (T_L - T_s) + (UA) (T_a - T_s)
$$

(8)

TRANSYS handles component differential equations with its own internal integrator. Through the T array, TRANSYS 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 TRANSYS 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 TRANSYS 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 $m$, to the collector. If the outlet temperature from the collector is less than $T_{set}$, the water is heated from $T_0$ 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, $q_b$, is described by the following equation:

$$q_b = \begin{cases} mc_p [T_{set} - T_0]; & T_r = T_{set}, T_0 \leq T_{set} \\ 0; & T_r = T_0 \\ \text{otherwise} \end{cases}$$

(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

$$Q_b = \int Q_b \, dt$$

(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, TRANYS 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, TRANYS 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 $T_0$ 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. TRANYS 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 TRANYS. 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

\[ \text{SIMULATION } t_0 \ t_f \ \Delta t \]

where \( t_0 \) is the time at the start of the simulation

\( t_f \) is the time at the end of the simulation

\( \Delta t \) 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.

\[
\begin{align*}
\text{UNIT } & n \text{ TYPE } m \text{ Comment} \\
\text{PARAMETERS } & j \\
P_1, P_2, \ldots P_j \\
\text{INPUTS } & k \\
u_1, u_2, O_2, \ldots u_k, O_k \\
v_1, v_2, \ldots v_k \\
\text{DERIVATIVES } & \ell \\
i_1, i_2, \ldots i_\ell
\end{align*}
\]

where

- \( n \) is a unique unit number
- \( m \) is a type number from the TRNSYS library
- \( j \) is the number of parameters for TYPE \( m \)
- \( P_1, P_2, \ldots P_j \) 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 \( m \)
- \( u_1, O_1, u_2, O_2, \ldots u_k, O_k \) are the UNIT numbers and corresponding OUTPUT numbers for the first, second ... and \( k \)th INPUT to this UNIT \( n \).
- \( v_1, v_2, \ldots v_k \) 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 \( O_i \) are set to zero, \( v_i \) is then the value of the \( i \)th input throughout the simulation.
- \( \ell \) 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.
- \( i_1, i_2, \ldots i_\ell \) are the \( \ell \) 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
10, 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 mnemonics which identify the printed output.
Klein, et al. 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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>Collector area</td>
</tr>
<tr>
<td>C_p</td>
<td>Heat capacity</td>
</tr>
<tr>
<td>F_R</td>
<td>Collector heat removal factor</td>
</tr>
<tr>
<td>F'_R</td>
<td>Collector plate efficiency factor</td>
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<tr>
<td>H_T</td>
<td>Total solar radiation on plane of collector per unit area</td>
</tr>
<tr>
<td>M</td>
<td>Mass of water in the storage tank</td>
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<tr>
<td>\dot{m}</td>
<td>Mass flow rate</td>
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<tr>
<td>Q_u</td>
<td>Useful energy output of collector</td>
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<tr>
<td>Q_B</td>
<td>Total auxiliary energy</td>
</tr>
<tr>
<td>Q_B</td>
<td>Auxiliary energy rate</td>
</tr>
<tr>
<td>T_a</td>
<td>Ambient temperature</td>
</tr>
<tr>
<td>T_{in}</td>
<td>Fluid temperature at collector inlet</td>
</tr>
<tr>
<td>T_o</td>
<td>Fluid temperature at collector outlet</td>
</tr>
</tbody>
</table>
\( T_{\text{set}} \) Set temperature for auxiliary heater

\( U_L \) Collector loss coefficient

\( UA \) Product of loss coefficient and area

\( \alpha \) Solar absorptance of collector plate

\( \tau \) Solar transmittance of collector cover system

**SUBSCRIPTS**

\( c \) Collector

\( L \) Load

\( s \) Storage

**REFERENCES**


2. TRNSYS - A Transient Simulation Program, Report #38, University of Wisconsin, Engineering Experiment Station (Nov. 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
DESCRIPTION OF LASTL 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 -- mixed tank
   thermal storage -- heat loss to ambient
   distribution -- heat exchange to a finned tube coil upstream of auxiliary
   -- auxiliary 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
   -- reversible flow direction
   -- heat loss to room
   distribution -- auxiliary 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) Schematic

![Simulation Schematic](image)

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 CDC 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$^2_c$ for temperature below 68°F

**Liquid System:**

- **SCPM** – Thermal Storage Mass, BTU/°F ft$^2_c$
- **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$^2_c$
- **EX** – glass extinction coefficient
- **TCONV** – design convection temperature, °F

\[
TCONV = T_{rm} + CEFF \times (T_{dw} - T_{rm})
\]

\[
CFM = \frac{(LOAD) \times (Design \Delta T)}{(24) \times (1.08) \times (T_{conv} - T_{rm})}
\]

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

- **WCP** – collector coolant flow rate, BTU/hr-°F-ft$^2_c$
- **H** – collector heat transfer coefficient, surface-to-coolant (average), BTU/hr-°F-ft$^2_c$
- **UHX** – heat exchanger heat transfer coefficient, collector coolant-to-water (averages), BTU/hr-°F-ft$^2_c$
- **UPIPE** – piping heat loss coefficient, BTU/hr-°F-ft$^2_c$
- **UBACK** – collector back and side loss coefficient, BTU/hr-°F-ft$^2_c$
- **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\textsuperscript{2}_c

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\textsuperscript{2}_c (based on \(\Sigma(68^\circ\text{F}-\text{ambient temperature}) \times \text{AL, when the quantity is greater than zero.})

ECOLL - energy collected by collector, BTU/ft\textsuperscript{2}_c

EAUX - auxiliary energy required, BTU/ft\textsuperscript{2}_c

EHORZ - solar radiation incident on horizontal surface, BTU/ft\textsuperscript{2}_c

EINC - solar radiation incident on collector, BTU/ft\textsuperscript{2}_c

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

% SOL - percent of solar heating, \(1 - \frac{\text{EAUX}}{\text{EBLDG}}\)

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:

\[ W C_p \frac{dT}{dx} = \frac{hA_s}{L} (T_s - T) \]

\[ M_s \cdot C_{ps} \frac{dT_s}{dt} = hA_s (T - T_s) \]

which after rearrangement become:

\[ \frac{dT}{d\left(\frac{T}{L}\right)} = \frac{L}{\lambda} (T_s - T) \]

\[ \frac{dT_s}{d\left(\frac{1}{r}\right)} = \frac{L}{\lambda} (T - T_s) \]

where

\[ \lambda = \frac{W C_p L}{hA} = \text{Rock bed relaxation length} \]

\[ r = \frac{M_s \cdot C_{ps}}{W C_p} \]

In the numerical form these equations become:

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

\[ T_{si} - T_{si}^l = \beta (T_i^l + \bar{T}_i^l - T_{si} - T_{si}^l) \]

\[ T_{i+1} = \frac{\alpha \beta (T_{i+1}^l + \bar{T}_i^l) + (1-\alpha+\beta)T_i^l + \alpha (1-\beta) (T_{si+1} + T_{si}^l)}{1 + \alpha + \beta} \]

\[ T_{si+1} = \frac{(1-\beta) T_{si+1}^l + \beta (T_{i+1} + T_{i+1}^l)}{1 + \beta} \]

where

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

\[ \beta = \frac{\Delta t}{2r} \cdot \frac{L}{\lambda} \]
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. Haki
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, Wis., 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) \((W/\text{m}^2)\)
b. Wind speed \((\text{M/SEC})\)
c. Dry bulb temperature \((^\circ\text{C})\)
d. Wet bulb temperature \((^\circ\text{C})\)
e. Dew point temperature \((^\circ\text{C})\)
f. Total cloud cover \((0 \text{ to } 10)\)
g. Sensible load \((\text{KW})\)
AC : Collector area
J : Solar radiation intensity
T : Temperature (°C)
L : Fluid flow rate (l/min)
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

Tilt (Latitude + 10°)

Orientation

* Front loss (See 3.3 (b) below)

Back and side loss

* Heat transfer coefficient from collector to circulating water

Collector surface

Δ

* Shade coefficient of glass
  (See 3.3 (a) below)

Heat transfer coefficient

Δ Heat capacity

Glazing spacing

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

Fluid flow rate

Heat loss

AC = 50 m² (Madison and Hamburg)
  = 20 m² (Santa Maria)

θ = 53° (Madison)
  = 45° (Santa Maria)
  = 65.6° (Hamburg)

KO = 3.23 W/m²·°C

KU = 0.42 W/m²·°C

rKW (Determined by KO, KU and F')

a = 0.95

ε = 0.9 (taken into account in KO above)

SCT = 0.915

F' = 0.95

Disregarded

0.04 M

LC = 1 /MIN·m²_C

UAC = 0.1 W/m²_C·°C
Ambient temperature \( TA = 20^\circ C \)

Heat capacity Disregarded

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

Fluid flow rate \( LS = 1 \text{ l/Min-M}^2\_C \)

Heat loss Disregarded

Heat capacity Disregarded

(d) Collector – Main Storage Heat Exchanger

Heat transfer coefficient \( U_{AE} = 60 \text{ W/M}^2\_C \cdot ^\circ C \)

Heat capacity Disregarded

(e) Main Storage Tank

Volume \( V = 80 \text{ l/M}^2\_C \) (Madison)

\( = 40 \text{ l/M}^2\_C \) (Hamburg Case 1)

\( = 20 \text{ l/M}^2\_C \) (Hamburg Case 2)

Shape (Cylinder) \( H/D = 1 \)

Heat loss \( U = 0.42 \text{ W/M}^2\_\text{ST} \cdot ^\circ C \)

Ambient temperature \( TA = 20^\circ C \)

No stratification

(f) Preheat Exchanger

Heat transfer coefficient \( U_{AP} = 1000 \text{ W/}^\circ C \)

Heat capacity Disregarded

Fluid flow rate (both sides) \( LP = 10 \text{ l/Min} \)

(g) Preheat Tank

Volume \( VP = 350 \text{ l} \)
Shape (Cylinder)

Heat loss

Hot water use

Ambient temperature

Cold water inlet temperature

Set point for hot water

\[ H/D = 1 \]

\[ U = 0.42 \text{ W/M}^2\text{K} \]

\[ LHW = 350 \text{ g/day} \]

\[ TA = 20^\circ\text{C} \]

\[ TCW = 10^\circ\text{C} \]

\[ THW = 50^\circ\text{C} \]

(h) House Heating Unit

Fluid flow rate

Piping length

Heat loss

Ambient temperature

Air flow rate

Air inlet temperature

Heat unit capacity

Coil effectiveness

\[ LH = 0.25 \text{ g/Min-M}^2\text{C} \]

20 m

\[ UAH = 0.15 \text{ W/M}^\circ\text{C} \]

\[ TA = 20^\circ\text{C} \]

\[ G = 1364 \text{ KG/H (Madison)} \]

\[ = 496 \text{ KG/H (Santa María)} \]

\[ = 745 \text{ KG/H (Hamburg)} \]

\[ TR = 20^\circ\text{C} \]

Disregarded

\[ \eta = 0.8 \]

(i) Controls

Collector

Off → On When TC1 > TST + 5°C

On → Off When TC1 > 95°C

On → Off When TC1 ≤ TC4

D.H.W. circuit Always on

Heating unit

On When QAC > 0

Off When QAC ≤ 0

Where, QAC: House heating requirement
(i) Initial Condition

Main storage tank \[ T_{SI} = 30^\circ C \]

Preheat tank \[ T_{SW} = 30^\circ C \]

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:

\[
KE = \frac{K_O + K_U}{K_O + K_U + K_W} \cdot K_W = F' \cdot (K_O + K_U) \tag{1}
\]

\[
TE = T_O + \frac{J_1 \cdot G_1 + J_d \cdot G_d}{K_O + K_U} \cdot S_C \cdot a - \frac{K_U}{K_O + K_U} \cdot (T_O - T_A) \tag{2}
\]

Where,

Solar radiation (Direct) \[ J_1 \quad W/m^2 \]

(Diffused) \[ J_d \quad W/m^2 \]

Radiation gain coefficient of glass (See 3.3 (a) below)

(Direct) \[ G_1 \]

(Diffused) \[ G_d = 0.808 \]

Outdoor temperature \[ T_O \]

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

\[
TC_1 = TE - (TE - TC_4) \cdot \exp(-KE \cdot AC/LC) \tag{3}
\]

Heat collected:

\[
Q_{SC} = LC \cdot (TC_1 - TC_4) \tag{4}
\]

(b) Heat Exchanger (Collector - Storage)

Heat exchanged:

\[
Q_{EX} = UAF \cdot ETD \tag{5}
\]

Where,

\[
ETD = \frac{\Delta_1 - \Delta_2}{\ln(\Delta_1/\Delta_2)} = \frac{(TC_2 - TS_2) - (TC_3 - TS_1)}{\ln(TC_2 - TS_2)/(TC_3 - TS_1)} \tag{6}
\]
(c) Piping

\[ TSI = TST \]

Heat loss:
\[ TC4 = TA - (TA - TC3) \exp (-UAC/LC) \quad (7) \]
\[ TC2 = TA - (TA - TC1) \exp (-UAC/LC) \quad (8) \]

Solar heat to storage:
\[ QST = LS \cdot (TS2 - TSI) \cdot 0.86 \quad (9) \]

(d) Preheat Exchanger

Heat exchanger:
\[ QF = UAP \cdot ETD \quad (10) \]

Where,
\[ ETD = \frac{\Delta l}{\ln(\Delta l/\Delta 2)} = \frac{(TP1 - TW2) - (TP2 - TW1)}{\ln(TP1 - TW2)/(TP2 - TW1)} \quad (11) \]

(e) Hot Water Supply

Hot water requirement:
\[ QHW = LHW \cdot (THW - TCW) \cdot 0.86 \quad (12) \]

\[ TSW \geq THW \]
Flow rate of cold water:
\[ LCW = LHW \cdot (THW - TCW)/(TSW - TCW) \quad (13) \]
Auxiliary heat:
\[ QA \cdot HW = 0 \quad (14) \]

\[ TSW < THW \]
Flow rate of cold water:
\[ LCW = LHW \quad (15) \]
Auxiliary heat:
\[ QA \cdot HW = LHW \cdot (THW - TSW) \quad (16) \]

(f) House Heating

\[ TH1 = TST \]
Coil inlet water temperature:
\[ TH2 = TA - (TA-TH1) \exp (-U/AH/LH) \]  
\[ \text{------- (17)} \]

Heating capacity of coil (Q):
\[ Q = G \cdot (TH2 - TR)n \]  
\[ \text{------- (18)} \]

\[ Q \geq Q_{AC} \quad (Q_{AC}: \text{House heating load}) \]
Aux. heat: \[ QA \cdot AC = 0 \]  
\[ \text{------- (19)} \]

\[ Q > Q_{AC} \]
Aux. heat: \[ QA \cdot AC = QAC - Q \]  
\[ \text{------- (20)} \]

Coil outlet water temperature:
\[ TH3 = TH2 - (QAC - QA \cdot AC)/LH \]  
\[ \text{------- (21)} \]

Temperature of return water:
\[ TH4 = TA - (TA - TH3) \exp (-U/AH/LH) \]  
\[ \text{------- (22)} \]

Storage load for house heating (QSOUT):
\[ QSOUT = LH \cdot (TH1 - TH4) \]  
\[ \text{------- (23)} \]

(g) Main Storage Tank

Heat loss:
\[ QLOSS = UAST \cdot (TA - TST) \]  
\[ \text{------- (24)} \]

Heat balance:
\[ EQ = LS \cdot (TS4 - TST) + LP \cdot (TP2 - TST) \]
\[ + LH \cdot (TH4 - TST) + QLOSS \]  
\[ \text{------- (25)} \]

Water temperature of thermal storage:
\[ TST(k) = TST(k-1) + EQ/V \cdot \Delta \]  
\[ \text{------- (26)} \]

Where,

K: Time
\[ \Delta: \text{Interval to be used for simulation} \]

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, K0 was obtained as 3.23 W/m²°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 ($G_i$) of glass (standard type, 3mm thick) is determined on the basis of obtained incident angles ($i$) on a collector.

Thus,

$$G_i = 2.3920 \cos i - 3.8636 (\cos i)^3 + 3.7568 (\cos i)^5 - 1.3952 (\cos i)^7$$

---------- (29)

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

$$G_d = 2 \int_0^{\pi/2} G_i \cdot \sin i \cdot \cos i \cdot di = 0.808$$

---------- (30)

For arbitrary types of glass, $G_i$ 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 paneled glass (as normal incidence)

$$G_i' = 0.8133$$

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

$$G_i = 0.889$$

Therefore,

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

(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 ($K_0 = 0.42 \, \text{W/M}^2\text{C}^\circ\text{C}$) only has been indicated. For the purpose of this simulation, however, heat loss through the glass surface, i.e., the front loss ($K_0$), must also be computed.
MONTHLY SOLAR PERFORMANCE SUMMARY

Unit = kwh

Collector
1. Collector input
   QCIN = (J1 + Jd) • A
2. Collector output
   QCOUT = LC • (TC1 - TC4)

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

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

DHW
8. Storage output
   QSOUT = LCW • (THW' - TCW)
9. Storage loss
   QSL = UASW • (TSW - TA)
10. Auxiliary required
    QAUX = LCW • (THW'' - THW')
11. Demand load
    QD = LH • (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 · (TCl - 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>
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<tr>
<th>Quantity Measured</th>
<th>FINITE ELEMENT</th>
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<tr>
<td>Solar Hot Water (kWh/year)</td>
<td>2799</td>
<td>2596</td>
<td>2725</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>Auxiliary Energy (kWh/year)</td>
<td>2104</td>
<td>2307</td>
<td>2176</td>
</tr>
<tr>
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<tr>
<td>Total Energy for Hot Water (kWh/year)</td>
<td>4903</td>
<td>4903</td>
<td>4903</td>
</tr>
<tr>
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<tr>
<td>Percent Solar</td>
<td>57.1</td>
<td>52.9</td>
<td>55.6</td>
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<td></td>
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<tr>
<td>Pumping Hours (hr/year)</td>
<td>2961</td>
<td>3178</td>
<td>3083</td>
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<td></td>
<td></td>
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</tbody>
</table>
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.
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.
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.
VVBI  Heat from storage to preheat tank.
VVBI  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.
QSO  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)

Start

First call? Yes

Constant parameters

Solar collector on

Yes

TT2 >
TCCH  5

Yes

Heat from air flow to preheat

No

Heat to hot water from preheat

Solar collector on

No

Heat to house

Yes

Heat to house

No

Call store

Yes

TEM >
TIH

Yes

Call store

No

Call store

TAF1 >
TIH

No

Heat to house from solar collector

Call store

Yes

Heat to house from solar collector

Call store

No

Auxiliary heat

Call store

Call store

Call store

Auxiliary heat

Collector inlet temperature

Collector inlet temperature

Collector inlet temperature

Return
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 $NTU_C \gg 10$, 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 $I$ $^\circ\text{C}$
- **Q(I,J):** Accumulated heat in the storage at the time $I$ for element $J$ $\text{J}$
- **QTS:** Accumulated heat in half an hour $\text{J}$
- **QA(I,J):** Heat loss from air to storage at the time $I$ for element $J$ $\text{J}$
- **QAS:** Heat loss from air in half an hour $\text{J}$
- **ST(I,J):** Heat loss to earth at the time $I$ for element $J$ $\text{J}$
- **QTAK:** Heat loss to earth in half an hour $\text{J}$
- **QC1(I,J) and QC2(I,J):** Heat conducted to and from the element $J$ at the time $I$ $\text{J}$
- **MCR:** Heat capacity for an element $\text{J/}^\circ\text{C}$
- **MCL:** Heat capacity of the air in a time element $\text{J/}^\circ\text{C}$
- **KA:** The effective axial thermal conductivity during non-flow conditions for an element in a time element $\text{J/}^\circ\text{C}$
- **UP:** Thermal loss coefficient for an element in a time element $\text{J/}^\circ\text{C}$
- **TJORD:** Temperature of the surroundings $^\circ\text{C}$
- **N:** Number of elements in the storage.
a) For heat entering the storage.

Element nr. J at a time I:

\[ QA(I,J) \]

\[ T(I,J-1) \]

\[ QC1 \]

\[ Q(I,J) \rightarrow ST(I,J) \]

\[ QC2 \]

\[ T(I,J) \]

(1) \[ Q(I,J) = QA(I,J) - ST(I,J) + QC1(I,J) - QC2(I,J) \]

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) \[ T(I,J) = \left[ MCL \cdot T(I,J-1) + MCR \cdot T(I-1,J) + KA \cdot (T(I,J-1) + T(I-1,J+1)) \cdot UP \cdot TJORD \right] / (MCL + 2KA + UP + MCR) \]
b) Heat out of the storage.

\[ Q_A(I,J) \]

\[ QC_2 \rightarrow T(I,J) \rightarrow Q(I,J) \rightarrow ST(I,J) \]

\[ QC_1 \rightarrow I(I,J) \]

Heat balance.

\[ Q(I,J) = Q_A(I,J) - ST(I,J) + QC_1(I,J) - QC_2(I,J) \]

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

\[ T_{US} = T_{IS} - Q_{AS}/TMCL \]
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)

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

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)

$$RE = \frac{1}{2} \left[ \frac{\sin^2(I-IB)}{\sin^2(I+IB)} + \frac{\tan^2(I-IB)}{\tan^2(I+IB)} \right]$$

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

That part of the beam radiation which is absorbed by the collector with the absorptance $\alpha$ 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:

\[ HW = (1 + 0.3W) \cdot 5.67 \quad W/m^2 \cdot ^\circ C \]

where W is the windspeed in miles/h and 5.67 the ratio between Btu/ft²·h·°F and W/m²·°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 \( \lambda \) is the isolation heat conductivity and e the thickness of the isolation.

The total heat loss coefficient therefore is:

\[ U1 = UP \cdot (1 + 0.05) + UR \]

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:

\[ q = F1 \cdot F2 \cdot F3 \cdot (QA2 - UL2(TT1 - TA)) \quad (1) \]

In this equation:

QA2 is the collection rate of solar radiation in W/m².

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

UL2 is the heat loss coefficient of the collector in W/°C.
TTL 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, \( \epsilon \), and the number of transfer 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:

\( \epsilon = \frac{TUD - TIC}{TUD - TTL} \)  \( \text{(2)} \)

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, \( \epsilon \), as a function of NTU and R, by the help of the heat exchanger equation:

\( \epsilon = \frac{1 - \exp(- NTU \cdot (1 - R))}{1 - R \cdot (\exp(- NTU \cdot (1-R)))} \)  \( \text{(3)} \)

\( R = \frac{FLOW}{FLOC} \)

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

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

For the solar collector we have the heat balance

\( q = FLOW (TUD - TIC) \)  \( \text{(4)} \)

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

\( q = \left[ \frac{F1 \cdot F2}{1 + \frac{UL2 \cdot F1 \cdot F2}{FLOW} \left( \frac{1}{\epsilon} - 1 \right)} \right] \cdot (QA2 - UL2(TTL - TA)) \)
Comparing this equation with equation (1) the heat exchanger factor is given by:

\[ F_3 = \frac{1}{1 + \frac{UL_2 \cdot F_1 \cdot F_2}{FLOW} \left[ \frac{1}{\epsilon} - 1 \right]} \]

The product \( F_2 \cdot F_3 \) is now given as a function of only \( H = \frac{F_1 \cdot UL_2}{FLOW} \), and \( \epsilon \):

\[ F_2 \cdot F_3 = \frac{1-e^{-H}}{H} \cdot \left[ \frac{1}{1 + H \cdot \left[ \frac{1-e^{-H}}{H} \right] \cdot \frac{1-\epsilon}{\epsilon}} \right] \]

\[ = \frac{1-e^{-H}}{H(1+(1-e^{-H}) \cdot \frac{1-\epsilon}{\epsilon})} \]

The program will now calculate \( F_3 \) as:

\[ F_3 = \frac{F_2 \cdot F_3}{F_2} \]
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:

\[
\begin{align*}
1 \leq DN < 21 & \quad TEQ = -2.6 - 0.44 \cdot DN \\
21 \leq DN < 136 & \quad TEQ = -5.2 - 9.0 \cdot \cos((DN-43) \cdot 0.0357) \\
136 \leq DN < 241 & \quad TEQ = -1.4 + 5.0 \cdot \cos((DN-135) \cdot 0.0449) \\
241 \leq DN < 336 & \quad TEQ = 6.3 + 10.0 \cdot \cos(DN-306) \cdot 0.0360 \\
336 \leq DN = 365 & \quad TEQ = -0.45 \cdot (DN-359)
\end{align*}
\]

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

\[
\begin{align*}
TET &= (TEQ + LOCALT)/60 \\
TEQ &= TET \cdot \pi/12
\end{align*}
\]
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:

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

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

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

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 $-0.3^\circ$)

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

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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Format</th>
<th>col</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMD</td>
<td>Month</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>NGD</td>
<td>Day</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>I HOUR</td>
<td>Hour</td>
<td>-</td>
<td>12</td>
</tr>
<tr>
<td>ISOLAR</td>
<td>Global radiation</td>
<td>W/m^2</td>
<td>14</td>
</tr>
<tr>
<td>IWS</td>
<td>Wind speed</td>
<td>m/s</td>
<td>12</td>
</tr>
<tr>
<td>DB</td>
<td>Temperature</td>
<td>°C</td>
<td>F5.1</td>
</tr>
<tr>
<td>ITC</td>
<td>Cloud cover</td>
<td>1/10</td>
<td>13</td>
</tr>
<tr>
<td>ISOLD</td>
<td>Diffuse radiation</td>
<td>W/m^2</td>
<td>14</td>
</tr>
<tr>
<td>QLOAD</td>
<td>House load</td>
<td>kW</td>
<td>F6.2</td>
</tr>
<tr>
<td>(converted to FF)</td>
<td>(converted to NN)</td>
<td>(converted to IDIFF)</td>
<td>(converted to QQ)</td>
</tr>
<tr>
<td>(converted to NN)</td>
<td>(converted to IDIFF)</td>
<td>(converted to QQ)</td>
<td></td>
</tr>
</tbody>
</table>

Subroutine TEST

With this a test is made upon the storage temperature. If the temperature deviates more than 1 °C 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.
References.

(1) Lawaetz, C.H.
Solar heating system with heat pump. Thermal Insulation Laboratory, D.T.H. June 1975 (report of degree work in Danish).

(2) Esbensen, T.

(3) Jordan, R.C.

(4) Lund, H.

(5) Petersen, E.
Solar radiation through and solar screening of windows. Thermal Insulation Laboratory, D.T.H.

(6) Lund, H. and Others.

(7) Lawaetz, C.H.

(8) Hughen, P.J., Klein S.A. & Close, C.J.

(9) Eckert, E.R.G. and Drake, R.M.

(10) Bugler, J.W.
The determination of hourly solar radiation incident upon an inclined plane from hourly measured global horizontal insulation. CSIRO. Solar Energy Studies July 1975.
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 (E_{TEMP}). By using the appropriate values of C_{TEMP} and E_{TEMP} comparison can be made directly with experiment. In the calculations made here C_{TEMP} was taken to be 0.1 Wh/°C and E_{TEMP} had two values depending on the measurement position and program run. The two values used were E_{TEMP} = ± 0.01°C and E_{TEMP} = ± E_{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.

3.1.6 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 computation 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°C. 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.
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 auxiliary 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 auxiliary energy required for heating in kWh.

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

AV TEMP1 = The average temperature of the main storage tank in °C.

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 auxiliary 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** = The average of the temperature difference between the top and bottom of the main storage tank in °C.
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
II Computer Model
III Individual Components & Subroutines
IV Programming Problems
V Discussion of Results

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
- mixed tank

Storage
- heat loss to ambient
House - heat exchange to finned tube coil
Distribution - 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

---Collector---

Main Storage

---Domestic Hot Water Supply---

---House Distribution---

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 Heating System Simulation

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<th>Ambient Temp. (Tank Only)</th>
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<td>1-305</td>
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<th>Recovery Distribution Over 54 Tanks</th>
<th>Any units = integers from 1 to 559</th>
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</table>

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 description 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. Pre-heating 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) **Input data.**
- 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:

\[
E = F_R F'' A \left[ H_T (\tau \alpha)_e - U_L (t_s - t_a) \right]
\]

where

\[
F_R = \left[ \left( \frac{C_G}{U_L} \right) \left[ 1 - \exp(-F'L/Gc_p) \right] \right]
\]

\( c_G \) = capacitance rate

\( F' = \) plate efficiency factor

\( U_L \) = overall heat loss coefficient

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

\( \varepsilon \) = heat exchanger efficiency

\( A \) = collector area

\( (\tau \alpha)_e \) = effective transmission-absorption product

\( H_T \) = total solar radiation incident on the tilted surface

\( t_s \) = storage tank temperature (no stratification)

\( t_a \) = ambient temperature

\( c_p, F', \varepsilon, A \) are given, for each system simulated, as input.

\( H_T \) 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).

\( F' \) is given as input

\( U_L \) can be either constant (as input) or variable as a
function of \( t_a, t_i, H_t \) 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 gi-
gen value of \( H_t \) (\( \tau \alpha \)) \( _e \) (200 W/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 \( t_i \) and for 10 values (1 to 
9 m/sec) of \( V \). The value of \( t_a \) is considered constant 
for all the matrices and equal to 0 °C.

Each hour, when the value of \( U_L \) is required as a func-
tion of the operating conditions of the collector, 
the appropriate \( U_L \) is calculated with linear interpola-
tion 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 transmit-
tance.

Collectors control is based on the conditions:

\[
E = 0 \quad \text{if} \quad H_t \ (\tau \alpha)_e < U_L \ (t_s-t_a) \\
E = 0 \quad \text{if} \quad t_s \geq 100 \ \degree C
\]

otherwise \( E \) has the value given by 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
\[ t_{s_{\text{new}}} = t_{s_{\text{old}}} + \frac{(E - Q_L - Q_A - Q_D)}{M_c} \]

where:

- \( E \) = collectors energy gain
- \( Q_L \) = solar heating load
- \( Q_A \) = solar DHW load
- \( Q_D \) = tank losses
- \( M_c \) = thermal capacity

**c) Solar heating load calculations**

Solar heating load is calculated as follows:

Mode 1) \[ Q_L = 0 \quad \text{if} \quad q(ts - ti) < Q_L' \]

\[ Q_L = Q_L' \quad \text{otherwise,} \quad \text{where} \]

\[ q = \frac{\text{design load}}{\text{(coil design temp. - air temp.)}} \]

\( Q_L' = \text{heating load (required)} \)

\( ti = \text{air temperature (ambient, internal)} \)

Mode 2) \[ Q_L = q(ts - ti) \quad \text{if} \quad Q_L < Q_L' \]

\[ Q_L = Q_L' \quad \text{otherwise} \]

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

\[ E > 0 \quad (T\text{coll.out}-T\text{coll.in.}) > 5 ^\circ C \]

\[ E = 0 \quad \text{otherwise} \]

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 enough 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 transfer 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.
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 Técnica 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 for 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 JEA. The input data are the ones recorded for different climates and loads by NBS at Madison (USA), Santa Maria (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 Hewlett Packard 2100 (64 KBYTES).

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 Maria (USA) and Hamburg (Germany) as has been mentioned above.

III DESCRIPTION OF THE INDIVIDUAL COMPONENTS AND SUBSYSTEMS

III.1 Solar Collector

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

\[ Q_{CC} = AC \cdot FR \cdot \{ JT \cdot e \cdot UC (TEC - TA) \} \]

\[ Q_{GC} = GMC \cdot CP (TSC - TEC) \]

\[ FR = \frac{GMC \cdot CP}{AC \cdot UC} (1 - e \cdot FP \cdot UC \cdot AC / GMC \cdot CP) \]
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 \( F_1, F_2 \text{ and } F_3 \).

\[
\frac{dT}{dt'} = F_1 \cdot G M C \cdot \frac{CP}{AUA} (T_{I1} - T) + F_2 \cdot G M 2 \cdot \frac{CP}{AUA} (T_{I2} - T) + F_3 \cdot G M 3 \cdot \frac{CP}{AUA} (T_{I1} - T) - (T - T_{EA})
\]

Where:

\( T = T_{A1} = \) main storage tank temp.
\( t' = t/ta \) ; \( ta = C/AUA \)

Controls

\( F_1 = 0 \text{ when } TSC \leq TEC \)
\( F_1 = 0 \text{ when } TSC > 95^\circ C \)
\( F_1 = 1 \text{ when } TSC > T + 5 \)
\( F_2 = 0 \text{ when } T \leq TA2 \)
\( F_2 = 1 \text{ when } T > TA2 \)
\( F_3 = 0 \text{ when } QLC \leq 0 \)
\( F_3 = 1 \text{ when } QLC > 0 \)

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.

\[
\frac{dT'}{dt'} = F_2 \cdot GM_2 \cdot \frac{CP}{AUL} (TLS - T') + F_4 \cdot GM_4 \cdot \frac{CP}{AUL} (TCO - T') - (T' - TEA)
\]

where:

\(T' = TA_2\) = preheat tank temperature
\(t'' = t/t_1\) \(te = CL/AUL\)

Controls:

\(F_2 = 0\) when \(TA_1 < T'\)
\(F_2 = 1\) when \(TA_1 > T'\)
\(F_4 = 40/(T' - 10)\) 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:

\[\text{NUT} = \frac{UACC}{CP \cdot GM}\]
\[\text{REC} = \frac{NUT}{(NUT + 1)}\]
\[\text{TSF} = \text{TIF} \cdot \text{REC} \cdot (\text{TIC} - \text{TIF})\]
\[\text{TSC} = \text{TIC} \cdot \text{REC} \cdot (\text{TIC} - \text{TIF})\]
\[\text{QT} = \text{GM} \cdot \text{CP} \cdot (\text{TIC} - \text{TSC})\]
\[\text{TSF} = \text{cold fluid outlet temp.}\]
\[\text{TSC} = \text{hot " " "}\]
\[\text{TIF} = \text{cold fluid inlet temp.}\]
\[\text{TIC} = \text{hot " " "}\]

III.5 Fan-Coil Heat Exchanger

The basic equations are:

\[\text{CC1} = \text{GM} \cdot \text{CP} \cdot F_3\]
\[\text{CC2} = \text{GM}^3 \cdot \text{CP} \cdot F_3\]
CM1 = CC1/CC2
TS0 = TA1-EPEC(CMI/CC2)/(TA1-TEA)
TS1 = TA1+EPEC(TA1-TEA)
QIE = EPEC·(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·sin(2·π·(284+DN)/365)·π/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 = π/12((HOUR-12)/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 r·a.

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 arisen 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  
τα = 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  
TFA = 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
## Monthly Solar Performance Summary

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<tr>
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<th>INSOL Nomenclature</th>
<th>I.E.A. Nomenclature</th>
<th>Units</th>
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<td>qin</td>
<td>KWH</td>
</tr>
<tr>
<td>Collectors output</td>
<td>QGC</td>
<td>qcout</td>
<td>KWH</td>
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<tr>
<td>Main storage input</td>
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<td>qsin</td>
<td>KWH</td>
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<td>Main storage loss</td>
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<tr>
<td>House heating storage output</td>
<td>QSCR</td>
<td>qout</td>
<td>KWH</td>
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<tr>
<td>House heating auxiliary required</td>
<td>QACR</td>
<td>qaux</td>
<td>KWH</td>
</tr>
<tr>
<td>House heating load</td>
<td>QLC</td>
<td>qd</td>
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<td>Preheat tank output</td>
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<td>KWH</td>
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<td>KWH</td>
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<td>Domestic hot water percent solar</td>
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<tr>
<td>Total percent solar</td>
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## Hourly Solar Performance Summary

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<th>I.E.A. Nomenclature</th>
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<td>Hot water tank temperature</td>
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<td>WATT/M</td>
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<td>WATT/M</td>
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<td>Energy delivered to house by solar</td>
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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.
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II.1 University of Wisconsin

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

(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

\[ R_B = \cos \theta_T / \cos \theta_H \]  

(2)

\( \theta_T \) is solar incidence angle on tilted surface
\( \theta_H \) is solar incidence angle on horizontal surface
\( s \) is collector slope (from horizontal, facing equator)
\( \rho \) is ground reflectance (assumed to be 0.3)

\( I_d \) 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 \( \frac{1}{2} \) hour from sunrise or sunset.

\[ 0 \leq R_B < R_B' \]

\[ R_B' = R_B \text{ at } \frac{1}{2} \text{ hour or less from sunrise or sunset} \]
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:

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

where

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

$PP$ is the & possible or $K_T$

$$PP = K_T = \frac{\text{horizontal radiation}}{\text{extraterrestrial radiation}} = \frac{I}{I_0}$$

Diffuse radiation is then given by

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

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

$$0 \leq R_B \leq 5 \quad (6)$$

Ground reflectance, $\rho$, is constant at 0.2.
II.3 Germany: Schreitmuller, Stuttgart

The German group also uses equation (1) with \( \rho \), 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.

\[
I_{DN} = \begin{cases} 
0 & \text{if } I \leq 0.2 I_o \\
I(I - 0.2 I_o)/0.7 I_o \sin h & 0.2 I_o < I < 0.85 I_o \\
0.4 I_o/\sin h & I > 0.85 I_o 
\end{cases} \tag{7}
\]

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\(^2\):

\[
0 < I_{DN} < 1100 \text{ W/m}^2 \text{ near sunset} \tag{8}
\]

II.4 Denmark

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

\[
I_d = \begin{cases} 
0.94 I & 0 \leq E < 0.4 \\
I(1.29 - 1.19 E)/(1 - 334 E) & 0.4 \leq E < 1.0 \\
0.15 I & E > 1 
\end{cases} \tag{9}
\]

where

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

\[
E = \frac{I}{I_{\text{clear day}}} \tag{10}
\]

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

\[
F = (F' - R) \cdot \left( \frac{8 - N}{8} \right) + \left( 1 + \cos s \right)/2
\]

\[
N = \text{cloud cover} \quad 1 \leq N \leq 8
\]

\[
F' = F' \left( 1 - \cos \phi_I \right) + \cos \phi_I
\]

\[
\phi_I = \text{incidence angle on tilted surfaces}
\]

\[
P' = \begin{cases} 0.55 + 0.437 \cos \phi_I + 0.313 \cos^2 \phi_I & \text{for } \cos \phi_I \geq 0.2 \\ 0.45 & \text{for } \cos \phi_I < -0.2 \end{cases}
\]

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 (11) 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.

\[
I_d = (I_o)(K_d)
\]

\[
K_d = \bar{K}_d + (1-f) \sigma
\]

\[
\bar{K}_d = 0.31 K_t + 0.139 \sin(4.62 K_t)
\]

\[
K_t = I/I_o
\]

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

\(0 \leq f \leq 1\) 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.

\[
I_{DN} = I_0 \cdot \frac{1}{\sec(h)} \quad \text{(Bouguer's Formula)} \quad (1)
\]

\[
I_d = \frac{1}{2} I_0 \cdot \sin(h) \cdot \frac{1 - \frac{p \cos(h)}{1 - l_{4} \cdot \ln P}}{1 - l_{2} \cdot \ln P} \quad \text{(Berlage's Formula)} \quad (2)
\]

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

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, particularly 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 uniformly 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 ($\mathbf{\alpha}$) is obtained as follows:

$$ I_T = I_D\sin(\theta_T) + I_d\frac{1 + \cos(\mathbf{\alpha})}{2} + \rho \cdot I \cdot \frac{1 - \cos(\mathbf{\alpha})}{2} \tag{4} $$

Where,

$\theta_T$ : Solar incidence angle on tilted surface

$\rho$ : 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 difficulty 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 $\sin(\text{Altitude}) < 0.017$.

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

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:
\[(T_F - T_A)/I = (T_{IN} - T_A)/I + \eta/(2 \pi h C_p)\]

For our given conditions this equation reduces to:

\[(T_F - T_A)/I = (T_{IN} - T_A)/I + 0.006 \cdot \eta\]

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 \(t_s = 0\) °C and fig. 4.2.8 - 4.2.12 using \(t_s = 20\) °C.

It is impossible to show how the differences between the calculated steady state efficiencies influence the yearly and monthly results of the programs because of the negative feedback mechanism of the solar systems and because these steady state efficiencies 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 $2.02 \text{ W/}^\circ\text{C m}^2_c$.

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

CASE 1
BASE

1. USA(LASL)
2. J(NIKKEN)
3. DK(SVS)
4. D(PHILIPS)
5. GB(FABER)
6. I(FTP)

\[
\frac{(T_{IN} - T_A)}{I}, \text{°Cm}^2/\text{W}
\]

Fig. 4.2.1

152
CASE 2
\[ \theta = 60^\circ \]

1. USA (LASL)
2. J (NIKKEN)
3. DK (SVS)
4. D (PHILIPS)
5. CB (FABER)
6. I (FTP)

Fig. 4.2.2
COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

CASE 3

V = 8 m/s

1. USA (LASL)
2. J (NITTO)
3. J (INKEN)
4. DK (SVS)
5. D (PHILIPS)
6. GB (FABER)
7. I (FTP)

![Graph showing efficiency vs. (T_{IN} - T_A)/I, in °Cm^2/W](image)

Fig. 4.2.3
Case 4

$V = 0 \text{ m/s}$

1. USA (LASL)
2. J (NIKKEN)
3. DK (SWS)
4. D (PHILIPS)
5. GB (FAVER)
6. I (FTP)

Fig. 4.2.4
CASE 5  
$t = 20^\circ C$  

1. USA (TRANYS)  
2. USA (LASL)  
3. J (NIKKEN)  
4. DK (SVS)  
5. D (PHILIPS)  
6. GB (FABER)  
7.  

Fig. 4.2.5
COMPARISON OF CALCULATED COLLECTOR EFFICIENCIES

CASE 6
DIFFUSE = 30%

1. USA (LASL)
2. J (NIKKEN)
3. D (SVS)
4. D (PHILIPS)
5. Q (FABER)
6. 7.

\[(T_{IN} - T_A)/I, \, \text{Cm}^2/\text{W}\]

Fig. 4.2.6

157
COMPARISON OF CALCULATED COLLECTOR EFFICIENCIES

CASE 7
$I = 100 \text{ W/m}^2$

1. USA (LASL)
2. J (NIKKEN)
3. D (SVS)
4. D (PHILLIPS)
5. G (FABER)
6. I (FTP)

Fig. 4.2.7

158
CASE 2
\[ t_s = 20 \, ^\circ C \]
\[ i = 60^\circ \]

1. USA (TRNSYS)
2. USA (LASL)
3. J (NIKEN)
4. DK (SVS)
5.
6. GB (FABER)

\[(T_{IN} - T_A) / 1, \, ^\circ \text{Cm}^2/\text{W}\]

Fig. 4.2.8

159
COMPARISON OF CALCULATED COLLECTOR EFFICIENCES

CASE 3
\( t_s = 20{}^\circ\text{C} \)
\( V = 8 \text{ m/s} \)

1. USA (TRNSYS)
2. USA (LASL)
3. J (NIKKEN)
4. DK (SVS)
5.
6. GB (FABER)

\[
\frac{(T_{\text{IN}} - T_A)}{I}, \text{ Cm}^2/\text{W}
\]

Fig. 4.2.9

160
CASE 4
\( t_s = 20{}^\circ C \)
\( V = 0 \text{ m/s} \)

1. USA (TRNSYS)
2. USA (LASL)
3. J (NIKKEN)
4. DK (SVS)
5. 
6. GB (FABER)

\( (T_{IN} - T_A)/I, \text{ } ^\circ \text{Cm}^2/\text{W} \)

Fig. 4.2.10

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CASE 5

$t_s = 20 \, ^\circ\mathrm{C}$

DIFFUS = 30 %

1. USA (TRNSYS)
2. USA (LASL)
3. J (NIKKEN)
4. DK (SVS)
5.
6. GB (FABER)

Fig. 4.2.11
CASE 7
$T_S = 20^\circ C$
$I = 100 \text{ W/m}$

1. USA (TRANSYS)
2. USA (LASL)
3. J (NIKKEN)
4. DK (SVS)
5.
6. GB (FABER)

Fig. 4.2.12

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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 efficiencies and piping losses. The absolute differences in the predicted percentages by these five programs range between ± 0.7 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 m² (Madison to Santa Maria) and forgetting that the length 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), DX(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>
<thead>
<tr>
<th>kWh</th>
<th>USA (TRNSYS)</th>
<th>USA (LASL)</th>
<th>J (NIKKEN)</th>
<th>DK (SVS)</th>
<th>D (PHILIPS)</th>
<th>GB (FABER)</th>
<th>I (FTP)</th>
<th>E (INSOL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHW Demand</td>
<td>5947</td>
<td>5936</td>
<td>5942</td>
<td>5893</td>
<td>5943</td>
<td>5933</td>
<td>6099</td>
<td>5942</td>
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<tr>
<td>House Demand</td>
<td>16480</td>
<td>16484</td>
<td>16482</td>
<td>16484</td>
<td>16484</td>
<td>16479</td>
<td>16475</td>
<td>16484</td>
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<tr>
<td>Total Demand</td>
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<td>22420</td>
<td>22424</td>
<td>22377</td>
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<td>22412</td>
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<td>1056</td>
<td>1080</td>
<td>966</td>
<td>998</td>
<td>1090</td>
<td>1094</td>
<td>883</td>
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<td>5481</td>
<td>734</td>
<td>5695</td>
<td>6260</td>
<td>5991</td>
<td>4835</td>
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<td>DHW Solar Supply</td>
<td>4689</td>
<td>4880</td>
<td>4862</td>
<td>4927</td>
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<td>4844</td>
<td>5007</td>
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<td>10993</td>
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<td>10789</td>
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### Energy Losses

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<td>DHW Storage Loss</td>
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<td>Main Storage Loss</td>
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<tr>
<td>Heat.Circ.pipe.Loss</td>
<td>598</td>
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<tr>
<td>Coll.Circ.Pipe.Loss</td>
<td>1270</td>
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<tr>
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<td>-26</td>
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### Collector Output

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<tr>
<td>Collector Input</td>
<td>78500</td>
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### Collector Efficiency

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<th>Collector Efficiency %</th>
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<td>DHW Solar Supply</td>
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<td>kWh</td>
<td>USA (TRNSYS)</td>
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<td>--------------</td>
</tr>
<tr>
<td>DHW Demand</td>
<td>5943</td>
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<td>House Demand</td>
<td>4826</td>
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<td>Total Demand</td>
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<td>DHW Auxiliary</td>
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<td>House Auxiliary</td>
<td>212</td>
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<tr>
<td>DHW Solar Supply</td>
<td>5669</td>
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<td>House Solar Supply</td>
<td>4614</td>
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<td>DHW Storage Loss</td>
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<td>Main Storage Loss</td>
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<td>Heat.Circ.pip.Loss</td>
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</tr>
<tr>
<td>Coll.Circ.Pip.Loss</td>
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<td>Collector Output</td>
<td>13900</td>
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<tr>
<td>House Solar Supply %</td>
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<tr>
<td>Total Solar Supply %</td>
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</tr>
<tr>
<td>kWh</td>
<td>USA (TRNSYS)</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------</td>
</tr>
<tr>
<td>DHW Demand</td>
<td>5948</td>
</tr>
<tr>
<td>House Demand</td>
<td>12590</td>
</tr>
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<td>Total Demand</td>
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<tr>
<td>DHW Auxiliary</td>
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<tr>
<td>House Auxiliary</td>
<td>7973</td>
</tr>
<tr>
<td>DHW Solar Supply</td>
<td>3641</td>
</tr>
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<td>House Solar Supply</td>
<td>4617</td>
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</tr>
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<td>Collector Eff. %</td>
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<tr>
<td>DHW Solar Supply %</td>
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<td>House Solar Supply %</td>
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<td>44.5</td>
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Table: 5.1.4

<table>
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<tr>
<th></th>
<th>Location: Hamburg</th>
<th>System: Liquid</th>
<th>Coll. area: 50 m²</th>
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<td></td>
<td>USA (TRNSYS)</td>
<td>USA (LASL)</td>
<td>J (NIKKEN)</td>
</tr>
<tr>
<td>kWh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DHW Demand</td>
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<td>5936</td>
<td>5942</td>
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<tr>
<td>House Demand</td>
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<td>12585</td>
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<td>18527</td>
</tr>
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<td>2268</td>
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<td>47399</td>
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<td>19.3</td>
<td>19.9</td>
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</tr>
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</tr>
<tr>
<td></td>
<td>USA (TRNSYS)</td>
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<td>J (NIKKEN)</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------</td>
<td>------------</td>
<td>------------</td>
</tr>
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<td><strong>DHW Demand</strong></td>
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<tr>
<td></td>
<td>Location: Madison</td>
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<tr>
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<td>-------------------</td>
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<tr>
<td></td>
<td>USA (TRNSYS)</td>
<td>USA (LASL)</td>
<td>DK (SVS)</td>
</tr>
<tr>
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</tr>
<tr>
<td>House Solar Supply %</td>
<td>61.0</td>
<td>60.0</td>
<td>59.8</td>
</tr>
<tr>
<td>Total Solar Supply %</td>
<td>63.9</td>
<td>63.4</td>
<td>63.5</td>
</tr>
</tbody>
</table>
EFFECT OF STORAGE SIZE
HAMBURG LIQUID SYSTEM

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.

yearly % solar

1 USA (TRANSPORT) 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

MADISON WATER SYSTEM

Fig. 5.2.1
MADISON WATER SYSTEM

Yearly % Solar

1. USA (TRNSYS) 64.8
2. USA (LASL) 62.0
3. JAPAN 67.8
4. DK (SVS) 65.2
5. D (PHILIPS) 65.5
6. GB (FABER) 62.0
7. I (FTP) 63.6
8. E (INSOL) 70.7

Fig. 5.2.2
HOT WATER DEMAND / SOLAR SUPPLY KWH.
yearly % solar

1 USA (TRNSYS) 78.8
2 USA (LASEL) 82.2
3 JAPAN 82.5
4 DK (SVS) 83.6
5 D (PHILIPS) 83.2
6 GB (FABER) 81.6
7 (FTP) 82.1
8 E (INSOL) 85.1

MADISON WATER SYSTEM

Fig. 5.2.3
TOTAL LOAD/SOLAR SUPPLY KWH.

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 (FABEL) 41.2
7
8 E (INSOL) 50.0

HAMBURG WATER SYSTEM 801/m²

Fig. 5.2.5
TOTAL LOAD / SOLAR SUPPLY KWH.

Yearly % solar
1 USA (TRNSYS) 40,3
2 USA (LASL) 37,4
3 JAPAN 40,9
4 DK (SVS) 42,1

HAMBURG WATER SYSTEM 201/m²

Fig. 5.2.7
TOTAL LOAD / SOLAR SUPPLY KWH

YEARLY % SOLAR

1. USA (TRNSYS) 63.9
2. USA (LASYL) 63.4
3. 
4. DK (SVS) 63.5
5. D (PHILIPS) 63.5

Fig. 5.2.8
<table>
<thead>
<tr>
<th>Weather data</th>
<th>Maximum Relative Difference, %</th>
<th>&quot;Old&quot; Programs Total Solar Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collector Input</td>
<td>Total Solar Supply</td>
</tr>
<tr>
<td>Madison</td>
<td>7 - 8</td>
<td>2.3</td>
</tr>
<tr>
<td>Santa Maria</td>
<td>3-4</td>
<td>-1.9</td>
</tr>
<tr>
<td>Hamburg</td>
<td>2</td>
<td>-6.2</td>
</tr>
</tbody>
</table>
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/m² collector). In all cases storage temperatures were initialized at 30°C and pipe and duct temperatures to 20°C. The requested output was punched cards 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]
- QCOL—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 composite 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 comparisons.

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 importance of this last factor is difficult to overstate. Nearly every participant had several opportunities 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 consistently peak higher than those of USA-TRANSYS and USA-ASL 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 intermittently 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 (figure 2) 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 different. 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" mechanisms 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 surprising, then, that the Santa Maria tank temperature plots of Figure 5 show poorer agreement than those for Madison. The English tank temperature predictions are consistently lower than the others, indicating a basic systematic difference in their model. Referring to the long term results in Table 4.2.2 it is clear that their collector predicts consistently 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/m² of collector to 40 and then to 20. Figure 7 shows the storage temperature for the Hamburg liquid system with 20 l/m² 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 contri-
buting 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 spatial 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 gratifying that the variety of approaches leads to very nearly the same results.
QDHW-DHW TANK ENERGY OUTPUT

ENERGY (KWH) vs TIME (HOURS)

- USA-TRNSYS
- USA-LASL
- DENMARK
- GERMANY
- JAPAN
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 56.1% 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 successful. 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>
<thead>
<tr>
<th>Program</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA(TRNSYS)</td>
<td>68.5</td>
</tr>
<tr>
<td>USA(LASL)</td>
<td>67.3</td>
</tr>
<tr>
<td>J(NIKKEN)</td>
<td>71.7</td>
</tr>
<tr>
<td>DK(SVS)</td>
<td>70.1</td>
</tr>
<tr>
<td>D(PHILIPS)</td>
<td>70.2</td>
</tr>
<tr>
<td>GB(FABER)</td>
<td>67.2</td>
</tr>
<tr>
<td>I(FTP)</td>
<td>68.6</td>
</tr>
<tr>
<td>E(INSOL)</td>
<td>74.5</td>
</tr>
</tbody>
</table>
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 successful, 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:

\[
\text{Area (m}^2\text{)} = \begin{cases} 50 \text{ m}^2 \\ 20 \text{ m}^2 \end{cases}
\]

- Madison
- Hamburg
- Copenhagen
- Tokyo
- Santa Maria

Tilt

- Orientation: South
- Latitude: +10° C

Number of glazings: 2

Glass absorptance (per sheet): 0.037

Refractive index: 1.526

Absorber surface α: 0.95

Absorber surface τ: 0.90

Overall effective heat transfer coefficient (P1): 0.95

Back and side losses: 0.42 W/°C m\text{c}^2

Back and side temperature: 20°C

Total heat capacity: 10 kJ/°C m\text{c}^2

Fluid flow rate: 1 L/min m\text{c}^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: \( = 0.1 \, \text{W/m}^2 \, ^\circ\text{C} \)
Total heat capacity: \( = 5 \, \text{kJ/}^\circ\text{C m}_c^2 \)
Ambient temperature: \( = 20 \, ^\circ\text{C} \)

Heating circuit pipe: (each side)

Length (\( m_H \)) = 20 m
Heat loss = 0.15 \( W/m_H \, ^\circ\text{C} \)
Total heat capacity = 2.16 \( \text{kJ/m}_H \, ^\circ\text{C} \)
Ambient temperature = 20 \( ^\circ\text{C} \)

Thermal Storage Tank.

Volume \( = 80.1 \, \text{L/m}_c^2 \)
Shape: cylinder
\( H/D = 1 \)
Thermal loss \( = 0.42 \, \text{W/m}^2 \, ^\circ\text{C} \)
\( m_{st}^2 \) = Storage surface
No stratification

Collector-storage heat exchanger.

\( U \cdot A = 60 \, \text{W/}^\circ\text{C m}_c^2 \)
Capacity \( = 0 \, \text{kJ/m}_c^2 \, ^\circ\text{C} \)
Fluid flowrate (heat exchanger - storage) \( 1 \, \text{L/min.m}_c^2 \)
Preheat tank

Volume

\[ V = 350 \text{ l} \]

Thermal loss

\[ Q = 0.42 \text{ W/m}^2 \text{ °C} \]

\[ m_p^2 = \text{Preheat surface} \]

Shape

\[ H/D = 1 \]

Cold water inlet temp.

\[ 10^\circ \text{C} \]

Hot water use (see figure 1.2)

\[ 350 \text{ L/day} \]

Ambient temperature

\[ 20^\circ \text{C} \]

Set point for hot water

\[ 50^\circ \text{C} \]

Preheat heat exchanger

\[ U-A = 1000 \text{ W/°C} \]

Heat Capacity

\[ 0 \text{ kJ/°C} \]

Fluid flow rate (both sides)

\[ 10 \text{ L/min} \]

House heating unit

Fluid flow rate

\[ 0.25 \text{ L/min.m}^2 \]

Maximum air flow rate

\begin{tabular}{l|c}
Madison & 1364 kg/h \\
Santa M. & 496 kg/h \\
Denmark & 867 kg/h \\
Hamburg & 745 kg/h \\
Tokyo & 621 kg/h \\
\end{tabular}

Air inlet temperature (to coil)

\[ 20^\circ \text{C} \]

Heating unit capacity

\[ 0 \text{ kJ/°C} \]
Controls

Collector
- On when $T_{\text{coll(out)}} > T_{\text{storage}} + 5^\circ \text{C}$
- Off when $T_{\text{coll(out)}} > 95^\circ \text{C}$
- Off when $T_{\text{coll(out)}} \leq T_{\text{coll(in)}}$

D.H.W. circuit:
- Always on
- Hot water from taps is mixed with cold water when preheat tank temperature is higher than 50$^\circ \text{C}$

Heating unit:
- **ON:** $Q_{\text{Load}} > 0.0$
- **OFF:** $Q_{\text{Load}} < 0.0$
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 ($m^2$)
  - 50 $m^2$ (Madison, Hamburg, Copenhagen)
  - 20 $m^2$ (Tokyo, Santa Maria)

Tilt

Orientation

- Number of glazing: 2
- Glass absorptance pr. sheet: 0.037
- Refractive index: 1.526
- Absorber surface $a$: 0.95
- Absorber surface $t$: 0.90
- Collector efficiency factor ($F^1$): 0.70
- Back and side losses: 0.42 W/°C $m^2$
- Back side temperature: 20 °C
- Total heat capacity: 1.8 kJ/°C $m^2$
- Fluid flow rate: 44 kg/h·$m^2$
- Glazing spacing: 0.04 m.
Storage: (pebble bed)

Volume
Shape

Effective density (including voids)
Specific heat of pebbles
Thermal loss coefficient

\( m_s^2 = \) storage surface

Axial conductivity (no flow)
Ambient temperature

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

D.H.W. heat exchanger.

Type =

\( U \cdot A = \)
Fluid flow rate (water)

cross flow (water mixed, air not mixed)

Preheat tank

Thermal loss
Volume
Shape
Cold water inlet
Hot water use (see figure 1.2)
Ambient temperature
Set point for hot water
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 m²
Heat capacity 5 kJ/°C m²
Ambient temperature 20 °C

**Heating circuit (each side)**

length (mₜ)

20 m

Heat loss 0.15 W/°C mₜ
Heat capacity 1.44 kJ/°C mₜ
Ambient temperature 20 °C

**House heating unit.**

Maximum air flow rate

<table>
<thead>
<tr>
<th>City</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madison</td>
<td>1364 kg/h</td>
</tr>
<tr>
<td>Santa M.</td>
<td>496 kg/h</td>
</tr>
<tr>
<td>Denmark</td>
<td>867 kg/h</td>
</tr>
<tr>
<td>Hamburg</td>
<td>745 kg/h</td>
</tr>
<tr>
<td>Tokyo</td>
<td>621 kg/h</td>
</tr>
</tbody>
</table>

House temperature

20°C
Controls

Collector

$\Delta t_{on} = 5^\circ C, \Delta t_{off} = 0^\circ C$ between collector outlet and cold end of pebles.

Preheat tank

$\Delta t_{on} = 5^\circ C, \Delta t_{off} = 0^\circ C$ between collector outlet and preheat tank.

Heating unit

on $Q_{load} > 0 \quad (T_{house} < 20^\circ C)$

off $Q_{load} \leq 0$.

1) P.J. Hughes, S.A. Klein, D.J. Close,
"Packed Bed Thermal Storage Models for Solar Air Heating and Cooling Systems"
ANNEX II

YEARLY SOLAR PERFORMANCE AND
MONTHLY SOLAR PERFORMANCE TABLES
## IEA RESULTS

### YEARLY SOLAR PERFORMANCE
**SUMMARY, TRNSYS**

<table>
<thead>
<tr>
<th>City (Location)</th>
<th>SANTA MARIA LIQUID</th>
<th>MADISON LIQUID</th>
<th>MADISON AIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector Area $m^2$</td>
<td>20</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Horizontal Insolation kWh/m²</td>
<td>2079</td>
<td>1431</td>
<td>1431</td>
</tr>
<tr>
<td>Collector Input</td>
<td>48,880</td>
<td>78,500</td>
<td>78,500</td>
</tr>
<tr>
<td>Collector Output</td>
<td>13,900</td>
<td>19,770</td>
<td>18,440</td>
</tr>
<tr>
<td>Main Storage Input</td>
<td>13,140</td>
<td>18,500</td>
<td>10,410</td>
</tr>
<tr>
<td>Main Storage Loss</td>
<td>1,478</td>
<td>2,171</td>
<td>2,670</td>
</tr>
<tr>
<td>Main Storage Output to House</td>
<td>11,630</td>
<td>16,350</td>
<td>7,767</td>
</tr>
<tr>
<td>House Auxiliary</td>
<td>212</td>
<td>5,797</td>
<td>6,417</td>
</tr>
<tr>
<td>House Demand</td>
<td>4,826</td>
<td>16,480</td>
<td>16,480</td>
</tr>
<tr>
<td>DHW Storage Input</td>
<td>6,171</td>
<td>5,069</td>
<td>4,548</td>
</tr>
<tr>
<td>DHW Storage Loss</td>
<td>498</td>
<td>385</td>
<td>295</td>
</tr>
<tr>
<td>DHW Storage Output</td>
<td>5,669</td>
<td>4,689</td>
<td>4,260</td>
</tr>
<tr>
<td>DHW Auxiliary</td>
<td>274</td>
<td>1,258</td>
<td>1,680</td>
</tr>
<tr>
<td>DHW Demand</td>
<td>5,943</td>
<td>5,947</td>
<td>5,940</td>
</tr>
</tbody>
</table>

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
### TRNSYS Results

**YEARLY SOLAR PERFORMANCE SUMMARY**

**SYSTEM: LIQUID (STORAGE SIZE TEST)**

<table>
<thead>
<tr>
<th>City (location)</th>
<th>HAMBURG (80 £/m²)</th>
<th>HAMBURG (40 £/m²)</th>
<th>HAMBURG (20 £/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector Area m²</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Horizontal Insolation kWh/m²</td>
<td>977.4</td>
<td>977.4</td>
<td>977.4</td>
</tr>
<tr>
<td>Collector Input</td>
<td>48260</td>
<td>48260</td>
<td>48260</td>
</tr>
<tr>
<td>Collector Output</td>
<td>11010</td>
<td>10190</td>
<td>9492</td>
</tr>
<tr>
<td>Main Storage Input</td>
<td>10190</td>
<td>9327</td>
<td>8526</td>
</tr>
<tr>
<td>Main Storage Loss</td>
<td>1418</td>
<td>9033</td>
<td>572</td>
</tr>
<tr>
<td>Main Storage Output</td>
<td>8749</td>
<td>8416</td>
<td>7940</td>
</tr>
<tr>
<td>House Auxiliary</td>
<td>7973</td>
<td>8285</td>
<td>8841</td>
</tr>
<tr>
<td>House Demand</td>
<td>12590</td>
<td>12590</td>
<td>12590</td>
</tr>
<tr>
<td>DHW Storage Input</td>
<td>3874</td>
<td>3916</td>
<td>3965</td>
</tr>
<tr>
<td>DHW Storage Loss</td>
<td>234</td>
<td>237</td>
<td>238</td>
</tr>
<tr>
<td>DHW Storage Output</td>
<td>3641</td>
<td>3680</td>
<td>3727</td>
</tr>
<tr>
<td>DHW Auxiliary</td>
<td>2307</td>
<td>2268</td>
<td>2219</td>
</tr>
<tr>
<td>DHW Demand</td>
<td>5948</td>
<td>5948</td>
<td>5948</td>
</tr>
<tr>
<td>House Percent Solar</td>
<td>36.7</td>
<td>34.2</td>
<td>29.8</td>
</tr>
<tr>
<td>DHW Percent Solar</td>
<td>61.2</td>
<td>61.9</td>
<td>62.7</td>
</tr>
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**Units: kWh**
### YEARLY SOLAR PERFORMANCE

#### SUMMARY, LAGL

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<th>Liquid</th>
<th>--Air--</th>
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*Units: kWh*
### TABLE I

**LASL YEARLY SOLAR PERFORMANCE SUMMARY**

**SYSTEM: LIQUID**

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<td>3060</td>
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**Units: kWh**
### Table IV

**Lasi**  
**Yearly Solar Performance Summary**  
**System:** Liquid

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<td>943</td>
<td>589</td>
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**Units:** kWh  
**No Collector Mass**
### Yearly Solar Performance Summary

**Nikken, Japan**

**System:** Liquid solar system

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<th>Santa Maria</th>
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<td>(kWh/m²)</td>
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<td>(kWh)</td>
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<td>(kWh)</td>
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<td>(kWh)</td>
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<td>(kWh)</td>
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<td>5726</td>
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<tr>
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<td>(%)</td>
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<td>Total percent solar</td>
<td>(%)</td>
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<td>96.7</td>
<td>43.3</td>
<td>41.5</td>
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### IBA Results

#### Yearly Solar Performance Summary

**System: S.V.S., liquid**

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<td>5893</td>
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<td>5893</td>
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</table>

| 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)

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**Units:** kWh
**IEA RESULTS**

**YEARLY SOLAR PERFORMANCE SUMMARY**

**SYSTEM:** Philips, liquid

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</table>

| 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:**

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**Units:** kWh
### IEA RESULTS

#### YEARLY SOLAR PERFORMANCE, I (FTP)

**SUMMARY**

**SYSTEM: LIQUID**

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*Units: kWh*
### YEARY SOLAR PERFORMANCE SUMMARY

**SYSTEM: INSOL, liquid**

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| House Percent Solar | 97.72 | 70.6 | 40.12 |
| DHW Percent Solar   | 98.00 | 85.1 | 70.9  |
| Total Percent Solar | 97.89 | 74.5 | 50.0  |

Units: kWh
## Monthly Solar Performance Summary, TRNSYS

**Units:** kWh

**System:** LIQUID

**City:** MADISON

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<th>Gaux</th>
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<th>DWH Qsin</th>
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**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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qinc - collector input  
qco - collector output  
qain - storage input  
qsl - storage loss  
qout - storage output  
qaux - auxiliary required  
qd - demand load  

units: kwh
### NIKKEN (JAPAN) ***

#### MONTHLY SOLAR PERFORMANCE SUMMARY

**UNITS:** (KWH)

**SYSTEM:** LIQUID SOLAR SYSTEM

**CITY:** MADISON

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**CITY:** MADISON

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** SUMARIO ACTUACIONES SOLARES MENSUALES **

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SYSTEM: INSOL, LIQUID

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CIUDAD ...... MADISON

--- collector ---

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**City:** Santa Maria

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liquid system, LASL
santa maria, Calif. 1/55 to 12/55

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qcol - collector output
qgain - storage input
qsl - storage loss
qout - storage output
qaux - auxiliary required
qd - demand load

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**City**: Santa Maria

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

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

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Qcout ....... Collector Output
Qsin ......... Storage Input
Qsout ........ Storage Output
Qsl .......... Storage Loss
Qaux ......... Auxiliary Required
Qd ........... Demand Load
%House ........ % Solar House
%DHW .......... % Solar DHW
%Total ........ % Solar Total
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** SYSTEM: INSOL, LIQUID **

** CIUDAD .... SANTA MARIA **

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liquid system  LASL
hamburg germany  1/73 to 12/73  80 l/m²

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qain - storage input
qsl - storage loss
qout - storage output
qaux - auxiliary required
qd - demand load

units: kWh
### NIKKEN (JAPAN) ###

**MONTHLY SOLAR PERFORMANCE SUMMARY**

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**SYSTEM:** LIQUID SOLAR SYSTEM

**CITY:** HAMBURG

**LST=80 L/SM**

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CITY: HAMBURG

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Qcin: Collector Input  
Qcout: Collector Output  
Qsin: Storage Input  
Qsout: Storage Output  
Qsl: Storage Loss  
Quax: Auxiliary Required  
Qd: Demand Load  
%House: %Solar House  
%DHW: %Solar DHW  
%Total: %Solar Total
**SUMARIO ACTUACIONES SOLARES MENSUALES**

**UNITS: kWh**

**SYSTEM: SOLAR, LIQUID**

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Table III
LASL RESULTS
Storage Size, 40 l/m²

Solar performance summary

Liquid system

Hamburg Germany 1/73 to 12/73

-qinc - collector input
-qcut - collector output
-qsin - storage input
-qsil - storage loss
-qaux - auxiliary required
-qd - demand load

Unit: kwh
### NIKKEN (JAPAN) ###

**MONTHLY SOLAR PERFORMANCE SUMMARY**

- **UNITS:** (kWh)
- **SYSTEM:** LIQUID SOLAR SYSTEM
- **CITY:** HAMBURG LST=40 L/SM

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MONTHLY SOLAR PERFORMANCE SUMMARY

SYSTEM: HYDRO

MONTH OF THE YEAR

COLLECT: COLLECTOR OUTPUT
STORAGE: STORAGE OUTPUT
AUXILIARY: AUXILIARY OUTPUT
TODAY: THERMAL OUTPUT
### MONTHLY SOLAR PERFORMANCE SUMMARY, US (TRANSYS)

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### TABLE II

**LAST RESULTS**

**Storage Size 20 k/m²**

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**Solar Performance Summary**

**Liquid System**

**Hamburg Germany 1/73 to 12/73**

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**Legend**

- **qinc** = collector input
- **qcout** = collector output
- **qgain** = storage input
- **qal** = storage loss
- **qaux** = storage output
- **qd** = auxiliary required
- **Q** = demand load

**Units kWh**
### NIKKEN (JAPAN) ###

**MONTHLY SOLAR PERFORMANCE SUMMARY**

**UNITS:** KWh

**SYSTEM:** LIQUID SOLAR SYSTEM

**CITY:** HAMBURG LST=20 L/SM

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Note: The output values are in squared meters (m²).
### Monthly Solar Performance Summary

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**System**: AIR  
**City**: MADISON

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### Solar Performance Summary

**System: LASL**

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- **QINC:** Collector Input
- **QOUT:** Collector Output
- **QAUX:** Storage Input
- **QSL:** Storage Loss
- **QST:** Storage Output
- **QAX:** Auxiliary Required
- **QD:** Demand Load

**Units:** Buh
## MONTHLY SOLAR PERFORMANCE SUMMARY

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**CITY:** MADISON

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ANNEX III

ADDRESS LISTS
IEA SOLAR HEATING AND COOLING PROGRAM

EXECUTIVE COMMITTEE MEMBERS

AUSTRIA
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Prof. R. Rigopoulos
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Patras

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Tel: 766-0222
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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
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