IEA
SOLAR R&D

INTERNATIONAL ENERGY AGENCY
solar heating and
cooling programme
task VII

central solar heating plants with seasonal storage

the MINSUN simulation and optimization program application and user's guide

SEPTEMBER 1985

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. Twenty-one countries are currently members of 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 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 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 Tasks were defined 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 Tasks 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 (Completed).

II. Coordination of R & D on Solar Heating and Cooling Components - Agency of Industrial Science and Technology, Japan (Completed).

III. Performance Testing of Solar Collectors - Kernforschungsanlage Julich, Federal Republic of Germany (Ongoing).

IV. Development of an Insolation Handbook and Instrumentation Package - United States Department of Energy (Completed).

V. Use of Existing Meteorological Information for Solor Energy Application - Swedish Meteorological and Hydrological Institute (Completed).

VI. Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors - U.S. Department of Energy. (Ongoing).

VII. Central Solar Heating Plants with Seasonal Storage - Swedish Council for Building Research (Ongoing).

VIII. Passive and Hybrid Solar Low Energy Buildings - U.S. Department of Energy (Ongoing)

IX. Solar Radiation and Pyronometry Studies - Atmospheric Environment Services of Canada (Ongoing).

X. Materials Research and Testing - Solar Research Laboratory, GIRIN, Japan (Ongoing).

TASK VII: CENTRAL SOLAR HEATING PLANTS WITH SEASONAL STORAGE

In colder climates, solar energy for heating of buildings is least abundant when it is needed most - during the winter. Seasonal storage is needed for making solar heat gained during warmer months available for later use. From investigations of various storage methods two observations can be made the choice of storage method will greatly influence the working conditions for and the optimal choice of the solar collectors and the heat distribution system; and based on the technology that is availabl today the most economic solutions will be found in large applications. The objective of Task VII is to determine the technical feasibility and cost-effectiveness of such solar/seasonal energy storage systems for large-scale district heating. The Participants will evaluate the merits of various components and system configurations for collecting, storing and distributing the energy, and prepare site-specific designs.

The work is divided into two phases, preliminary design and detailed design. The work during the first phase was undertaken in five sub-tasks:

Sub-task I(a) Systems Studies and Optimization
(Lead Country: Canada)

Sub-task I(b) Solar Collector Subsystems
(Lead Country: USA)

Sub-task I(c) Heat Storage
(Lead Country: Switzerland)

Sub-task I(d) Heat Distribution System
(Lead Country: Sweden)

Sub-task I(e) Preliminary Site Specific System Design
(Lead Country: Sweden)

The work in the second phase was divided into three sub-tasks:

Sub-task II(a) MINSUN Enhancements and Support
(Lead Country: Canada)

Sub-task II(b) Evaluation of Systems Concepts
(Lead Country: USA)

Sub-task II(c) Data Exchange
(Lead Country: The Netherlands)

The participants in this Task are Austria, Canada, Commission of European Communities, Denmark, German the Netherlands, Sweden, Switzerland, United Kingdo and the United States.

This report documents work carried out under Sub-ta I(a) and II(a) of this task.

central solar heating plants with seasonal storage

the MINSUN simulation and optimization program application and user's guide

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This report is part of the work within the IEA Solar Heating and Cooling Programme,
Task VII: Central Solar Heating Plants with Seasonal Storage
Sub-Task I(a): Systems Studies and Optimization

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* Performed under contract to the National Research Council, Ottawa, Canada

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This report has benefitted from significant contributions from many participants within Task VII and contributors within the participants' organizations in their respective countries. The originators of the MINSUN Program and the first MINSUN manual were Rune Håkansson and Sören Rolandsson of Studsvik Energiteknik AB in Sweden.

Contributors to the program development, and consequently to this report as well, include Charles A. Bankston, Consultant, and James Hedstrom of Los Alamos Laboratories, the U.S.A. for the collector sub-system models, Dwayne Breger of Argonne National Laboratory for the MINREP option and other program developments, Göran Hellström, Bengt Eftring and Johan Claesson of Lund University, Sweden and J. C. Hadorn of Sorane SA, Switzerland for the storage sub-system models, and Robin LaFontaine of Oscar Faber and Partners, the U.K., Roch Parayre, Ian Johnston, Mark Munday and Verne Chant of James F. Hickling Management Consultants Ltd. Canada and Rune Hakansson, Sören Rolandsson and Heimo Zinko of Studsvik Energiteknik, Sweden, for other program developments. All of the work undertaken by James F. Hickling Management Consultants Ltd. was performed under contract to the National Research Council, Ottawa, Canada under the direction of Ronald A. Biggs and Thomas LeFeuvre.

Other participants in Sub-Tasks I(a) and II(a) contributed to this report and program development by their comments and suggestions.

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1.0 INTRODUCTION

A solar heating system can be constructed in many different ways. Different constructions give different efficiencies and investment needs. In designing and sizing a solar heating system, engineers are continually faced with the difficult task of determining the most cost-effective system configuration satisfying the heating requirement.

To address this problem, a computer program, MINSUN, has been developed as part of Sub-Task I(a) of the International Energy Agency's Solar R&D Task VII - Central Solar Heating Plants with Seasonal Storage.

MINSUN is a system simulation and optimization program which models a solar energy system containing solar collectors, storage, heat pumps, auxiliary heaters and consumers. It can be a useful tool for solar applications research.

This report is divided into two parts. The main body of the report outlines the major characteristics and uses of the MINSUN set of programs. Along with Appendices A, B and F, this constitutes a manual for MINSUN users. Appendices C, D E and G present details concerning the MINSUN computer program structure and code. These Appendices are intended for programmers involved in implementing MINSUN on their computer system and for users wishing to make modifications to the program. Appendix G in this report provides information on how the complete program listing and data can be obtained in machine readable form.

For further information on the use of MINSUN in the analysis and evaluation of central solar heating plants with seasonal storage, the user should refer to the reports produced by participants in Sub-Tasks I(a) and II(b) of Task VII.[1]

This report applies to Version IV of MINSUN which was in use by task participants in May, 1985. Modifications may be made during the ongoing work of Task VII.

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1. refs 1, 2, 3, 4, 5

2.0 AN OVERVIEW OF MINSUN AND ITS APPLICATION

2.1 MODEL APPROACH AND CHARACTERISTICS

The MINSUN solar simulator is a set of FORTRAN programs that models a central solar energy heating system. The programs provide for system thermal simulation, costing and economic analysis and algorithmic optimization of selected system parameters. Sub-system capital costs are calculated by cost equations using user-specified parameters. Economic analysis combines capital costs and annual heat pump and auxiliary energy costs into an equivalent levelized annual cost using present value theory. Optimization is based on minimizing this levelized annual cost.

Each system is made up of several components as illustrated in Figure 2-1. The components are solar collectors, thermal storage, heat pumps, auxiliary heaters, a network of connecting pipes and residential heat load. There are several options for some of these components as shown in Figure 2-2.

Much of the underlying structure of MINSUN is the same as that in the TRNSYS program, developed at the University of Wisconsin by Klein et al. The TRNSYS program performs transient energy calculations for solar energy systems, and requires a minimum of programming effort.

The MINSUN routines developed or adapted from TRNSYS calculate the energy balance of the system. The routines operate in metric units.

2.2 TYPICAL APPLICATIONS

The MINSUN program can be used both to simulate the thermal behaviour of a central solar energy system and to determine the optimum size of some of the components in the system. These two MINSUN characteristics provide the user with three different modes for running the program - Single Simulation, Multiple Simulation and System Optimization. All

FIGURE 2-1: SOLAR SYSTEM CONFIGURATION

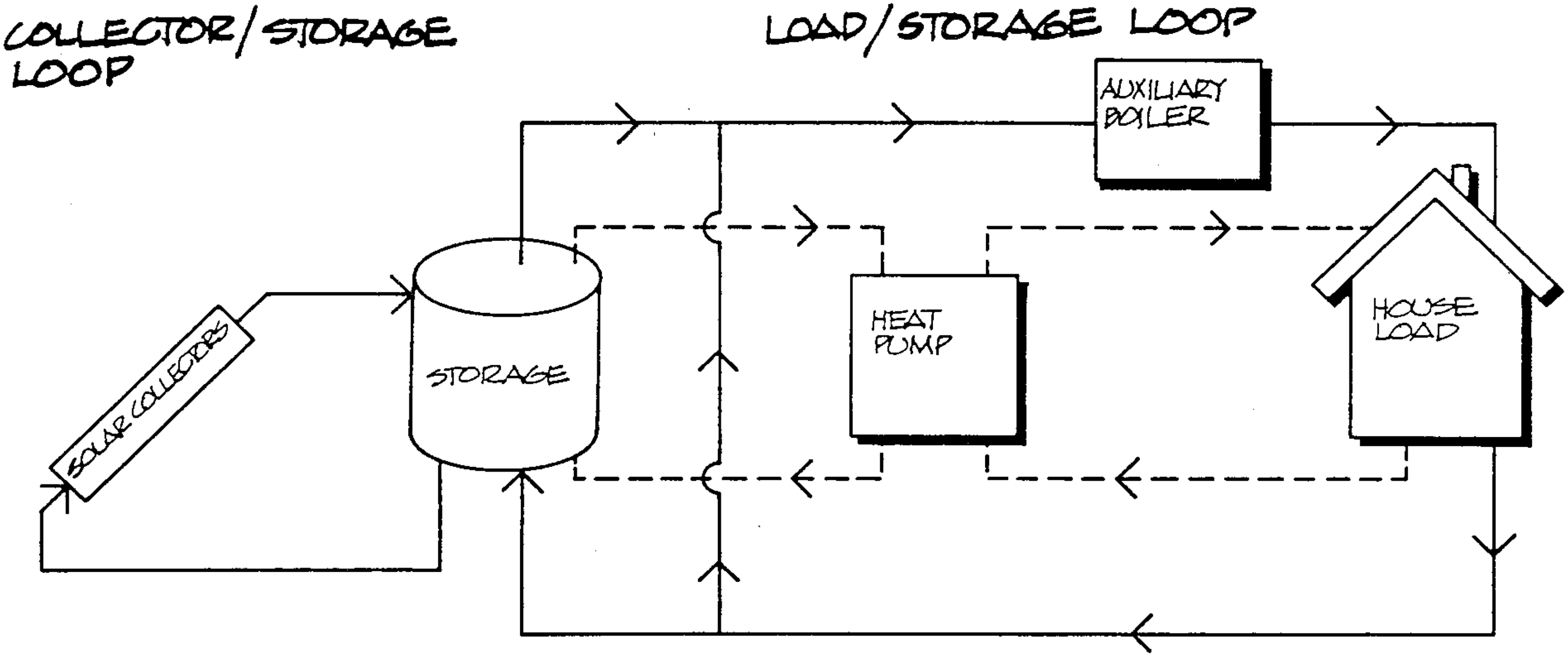
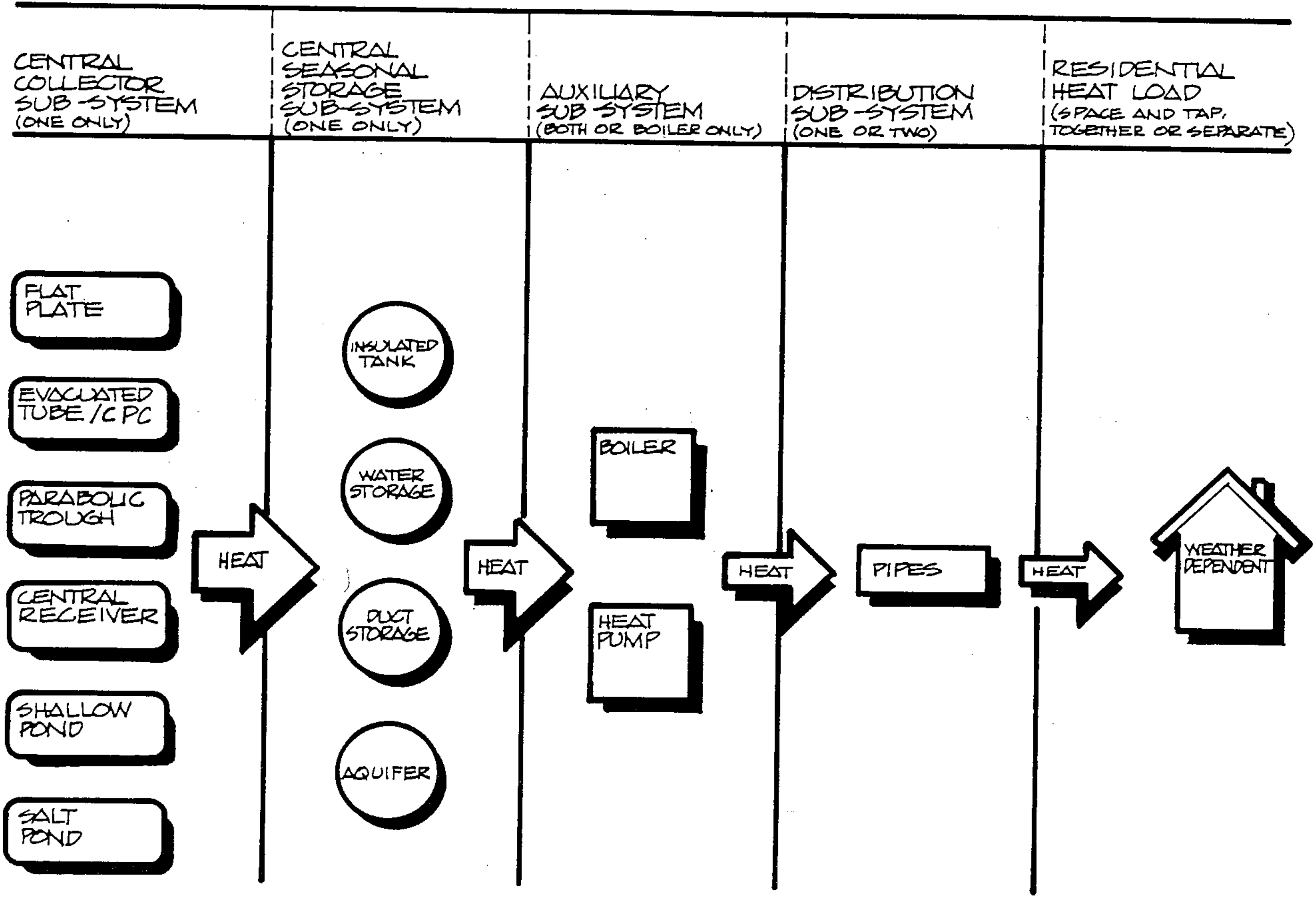


FIGURE 2-2: BASIC OPTIONS WITHIN **MINSUN** SET OF SIMULATORS



three modes require the user to supply the engineering parameters of the system being modeled and weather information to drive the simulator. The three different modes are described below.

It should be noted that MINSUN was developed as a simulator for central solar heating systems with seasonal storage. The applications which are modeled using MINSUN should therefore have a relatively large storage in order for the program to yield meaningful results.

2.2.1 Single Simulation of a System Configuration

The simplest application of MINSUN is to perform a thermal simulation for a given, fixed configuration. All parameters of the system are defined by the user. The program simulates the thermal behaviour, does the energy balance calculations, cost calculations and generates output on the thermal and economic characteristics of the system specified. The thermal characteristics can include monthly, weekly and daily specification of heat flows among the major sub-systems (from collectors, to and from storage, to load, losses, etc.).

2.2.2 Multiple Simulation of a System Configuration

MINSUN allows the user to perform several simulations in a single run while systematically varying the parameters defining the system. Only a limited number of result values are kept from each run. This mode is very useful for examining the effects of given input parameters on particular system results. It also uses less computation time than a large number of single simulation runs to get the same outputs.

These multiple runs can be made in two ways. Using the first and simplest of these, the MINSUN set of programs is capable of systematically varying any two (of nine) key design variables and performing single simulations at each point of the grid formed by the two variables. A typical application is to examine system cost as a function of two key variables, say collector area and storage volume. The program automatically spans a specified range for each variable with the requested number of points. Important results such as cost and solar fraction are selected from the simulation results for each grid point and are saved in a separate computer file. These results can then be examined by the user in numeric form or, as intended, plotted using three-dimensional graphics. Then the key results, such as cost or solar fraction, can be examined as a surface over the grid formed by the two variables selected.

The key system design variables that can be used for multiple simulation are:

- collector area
- storage volume
- storage height to diameter ratio
- storage insulation thickness
- specific heat transfer of heat pump evaporator in space distribution system
- specific heat transfer of heat pump condenser in space heating distribution system
- specific heat transfer of heat pump evaporator in tap water distribution system (if separate)
- specific heat transfer of heat pump condenser in tap water distribution system (if separate)
- duct storage number of ducts[1]

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[1] Not operational in current version.

The second Multiple Simulation option, the MINREP procedure, is slightly more complicated, but much more flexible. Single or iterative changes of any system parameters (not just the nine listed above) can be specified. In addition, any results which appear on the detailed Simulation Summary output (see Appendix F), to a maximum of thirty-six variables, can be specified for inclusion in the summary output.

Both Multiple Simulation mode options are discussed in detail in Chapter 7. Examples of the MINREP input parameters are included in Appendix A. Sample outputs from both Multiple Simulation mode options are included in Appendix F.

2.2.3 System Optimization

The MINSUN set of programs has the capability to automatically select optimum values for key design variables which minimize overall system levelized annual cost. The variables which can be optimized are the same as those listed above which can be varied in the multiple simulation. The program uses a search procedure to vary the values of the appropriate design variables. It then simulates the thermal behaviour and computes the cost of this system, and compares the cost of this system with that calculated in previous interations. In this way, the program closes in on the values of the design variables which minimize system cost. Any number of design variables listed above can be specified for the optimization process. The user should recognize, however, the significant increase in computation (computer) time as the number of variables optimized is increased.

The user must supply maximum and minimum acceptable values for some of the parameters being optimized in order to keep the optimizer from simulating unreasonable systems.

It should be noted that if the searching routine is started at a bad point, it might find a local minimum in the cost function instead of the overall minimum. It is recommended that a rough graph be generated using the multiple simulation mode before an optimization run is attempted. By doing this, the user can determine whether there are any local minima in the surface and can pick a good initial point at which to start the optimizer, or whether the cost surface is quite flat and thus not necessarily suitable for this optimization procedure.

Once the optimum system, as selected by the optimization algorithm, is determined, the program performs a single simulation and calculates the thermal and economic characteristics. Chapter 8 and Appendix E discuss system optimization in MINSUN in more detail.

2.3 THE MINSUN SET OF PROGRAMS

The MINSUN set of programs is illustrated in Figures 2-3 and 2-4. As indicated in Figure 2-3, there are two separate main programs: the collector model set and the system simulation and optimization model set. The collector model set, which includes the UMSORT and ADVANCE programs, requires collector system parameters and other parameters to be set by the user. It then takes hourly solar radiation and ambient temperature data and calculates the amount of energy that would be collected by a collector (per unit area) operating at a given temperature on a daily basis. Several operating temperatures are used and all results are stored for later use.

The system simulation model requires a large number (approximately 150) of system and other parameters to be specified by the user. It then simulates the thermal performance of a given system on an annual basis. As described above, this system can be applied in one of three modes: for single simulation, for multiple simulation or for optimization. Since the various storage model programs are large, there are separate programs for each storage type as depicted in Figure 2-3.

FIGURE 2-3 OVERVIEW OF **MINSUN** SET OF PROGRAMS

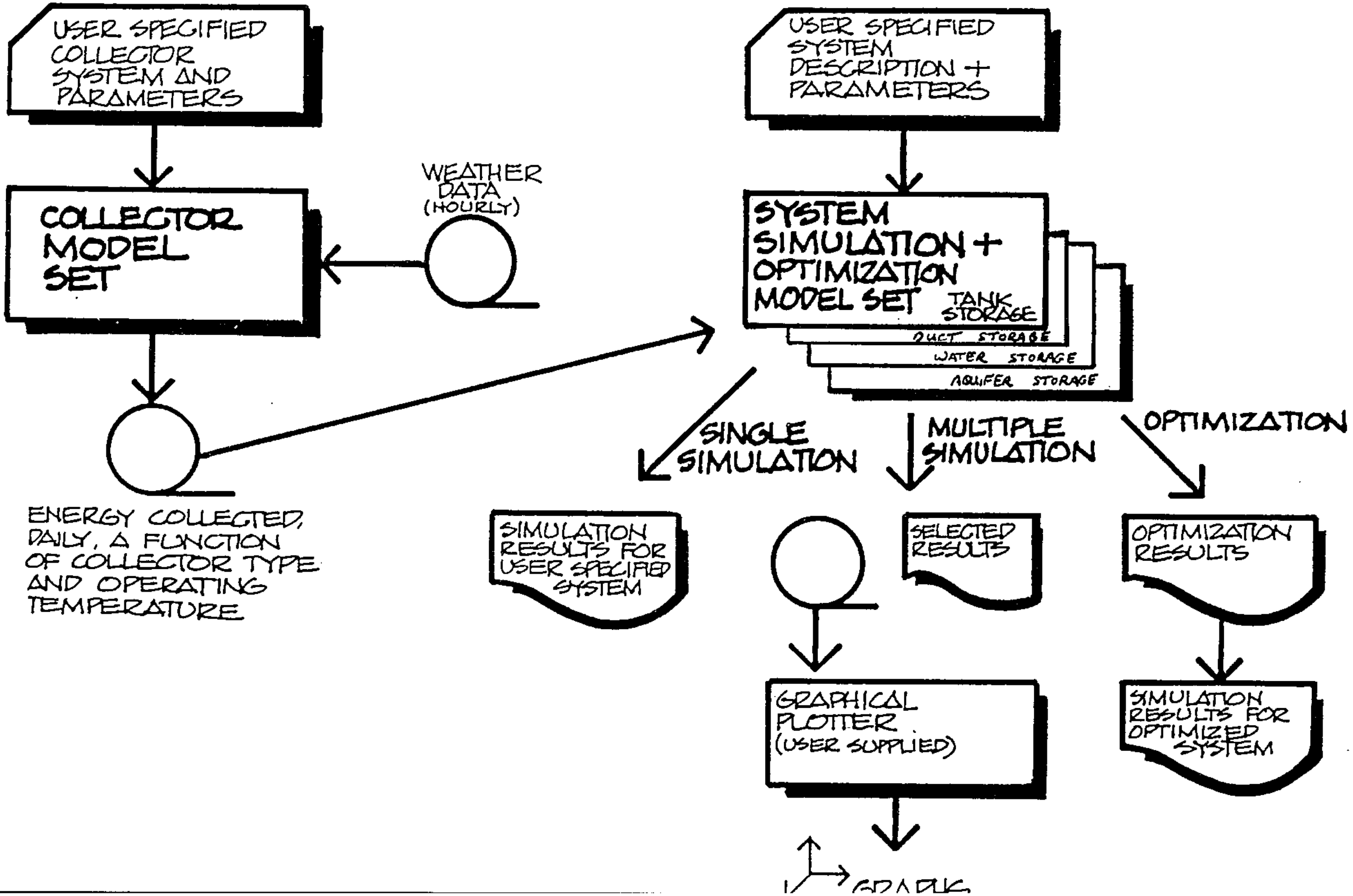
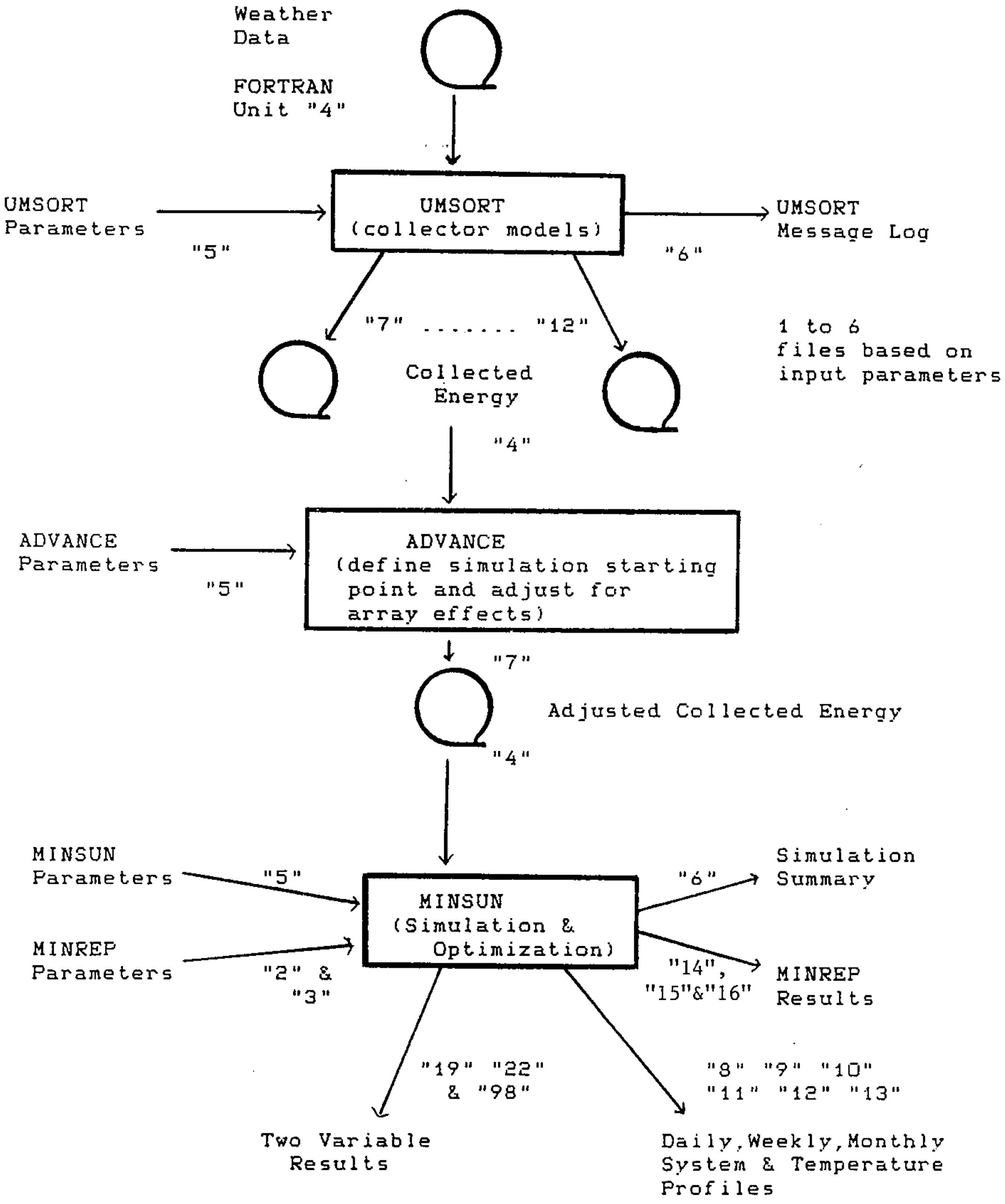


FIGURE 2-4

MINSUN SET OF PROGRAMS - OVERVIEW



3.0 DATA PREPROCESSING: THE COLLECTOR MODELS

While all the other physical components of the solar heating system are simulated in the MINSUN program, the solar collectors' effectiveness in collecting energy is determined in the UMSORT program introduced in the previous chapter. The exact simulation period is then set up in program ADVANCE.

3.1 COLLECTOR MODEL TYPES

The UMSORT program models the energy collection capability of six generic solar collector types. These are:

(1) flat plate solar collectors
(2) salt ponds
(3) evacuated tube solar collectors
(4) central receivers
(5) parabolic trough solar collectors
(6) shallow ponds.

The user selects the collector types which he wants modeled and defines the efficiency parameters for each of these. UMSORT then reads in the weather data file, processes it in conjunction with the input collector types and efficiency parameters and produces a file of amounts of energy which would be collected at a series of operating temperatures for each collector type requested.

3.2 UMSORT - COLLECTOR ENERGY CALCULATION

In order to run UMSORT, both weather data and collector parameters must be input.

There are five weather data variables read in by UMSORT. These variables, and the units in which they have to be expressed on input, are:

Variable	Units
Direct Normal Radiation	kJ/hr.m^2
Horizontal Radiation	kJ/hr.m^2
Ambient Dry Bulb Temperature	°C
Wind Speed	km/hr
Ambient Dew Point	°C

Hourly values have to be supplied to UMSORT for each of these five weather variables. UMSORT presently uses only the first three variables in its computation of collected energy.

Details of the weather file contents and part of a sample weather file are included in Appendix A.

Direct normal radiation is the radiant energy received directly from the sun on a surface which tracks the sun. Horizontal radiation is the total of direct and diffuse radiant energy received on a horizontal surface.

If both direct normal radiation and horizontal radiation readings are available, then the program uses them both and then deduces the diffuse radiation figure. The input parameter IBOZ is set to 0.

If, on the other hand, direct normal radiation readings are not available and horizontal radiation is the only available measurement, then the Boes model is used to approximate direct and diffuse radiation figures. IBOZ is then set to 1. Dummy direct normal radiation figures must be supplied to UMSORT, however, to keep the right format in the input file.

The parameters required by the UMSORT program are explained in Appendix A. A sample parameter file is also included in Appendix A.

3.3 ADVANCE – COLLECTOR ENERGY ADJUSTMENT

The ADVANCE program shifts a collector energy output file produced by UMSORT so that the user can start the simulation at a point in the year other than January 1. This program also multiplies the energy values calculated by UMSORT by a user specified constant to allow for the effects of shading in large arrays of collectors. Note that UMSORT generates up to six collector output files for a city – one for each collector model type; however, ADVANCE only processes one file at a time.

The output files generated by UMSORT consist of:

HEADER RECORD
TEMPERATURE VALUES RECORD
MONTH LENGTH VALUES RECORD
DAY 1 RECORD
DAY 2 RECORD   368 RECORDS
•
•
•
DAY 365 RECORD

ADVANCE simply takes the output file from UMSORT as input, along with a few input parameters, which are defined in Appendix A, and produces a modified collector power output file.

If ISTART is the day of the year on which the simulation is to begin, the resultant energy collected file generated by ADVANCE consists of:

```
HEADER RECORD
TEMPERATURE VALUES RECORD
MONTH LENGTH VALUES RECORD
DAY ISTART RECORD
DAY ISTART + 1 RECORD
     .
     .                            368 RECORDS
     .                            if IEND = 365
DAY IEND RECORD
DAY 1 RECORD
DAY 2 RECORD
     .
     .
DAY ISTART - 1 RECORD
```

This output (or if ADVANCE is not run, the output from the UMSORT program) is input to MINSUN and drives the simulator.

This file contains, for a specific collector type, the daily collector energy output (per unit area, expressed in KJ/day) for each of five different collector inlet temperatures, along with the number of hours of collector operation on that day at each of the collector inlet temperatures. Outdoor ambient temperature and load model temperature are also given for each day.

Part of a sample energy file produced by ADVANCE is included in Appendix F.

4.0 THE SIMULATION PROCESS - PROGRAM INITIATION

The main logic of the MINSUN program contains several steps, executed sequentially. This is illustrated in Figure 4-1.

4.1 DATA INPUT AND PRINTING

The first major task is to read in both the parameter and collector data files. The collector file, which drives MINSUN, is output from UMSORT/ADVANCE, as discussed in the preceding section.

The contents of the parameter file are detailed in Appendix A. This file is given in free format and ordered in blocks. The blocks each contain a number of parameters which describe a particular sub-system in the solar configuration being modelled or specify how the program is to be run. The different blocks are: collectors, collector network insulation, storage, houseload, heating period, heat pump(s), cost data, optimization parameters, plotting parameters, and report option.

The user can specify a few optional components in the system. Tapwater power can either be supplied by the house heating system or through a separate distribution system. A heat pump (or two, if a separate tapwater system is used) may also be included in the configuration.

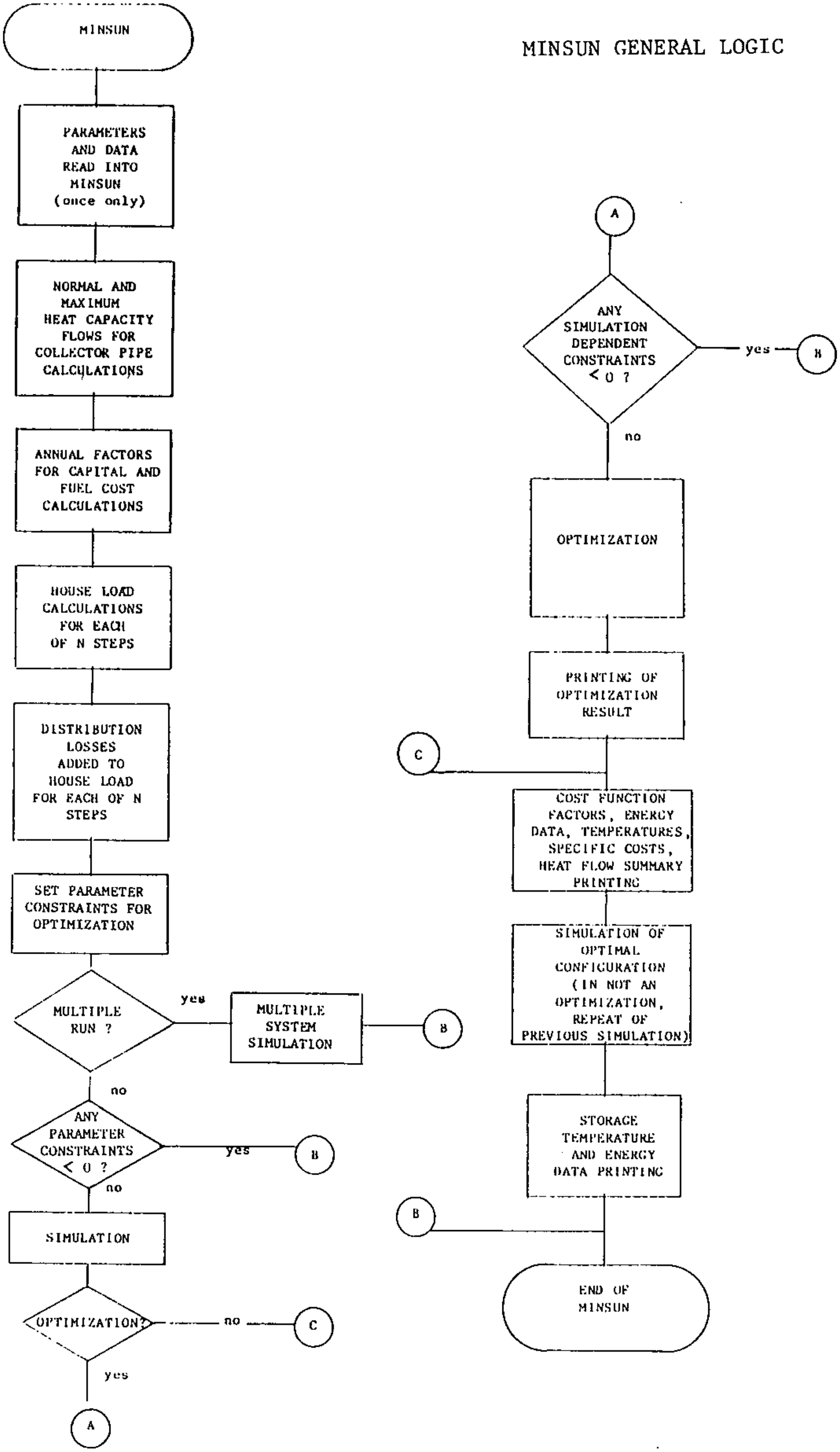
The input parameter values are printed out in a formatted form by the program.

4.2 COLLECTOR PIPES HEAT CAPACITY FLOWS

After the data have been read in and printed, total normal and maximum heat capacity flows for the collector pipes are calculated:

FIGURE 4-1

MINSUN GENERAL LOGIC



$$HCF_{tot} = A_{coll} \times C_p \times F_{norm} \quad ;$$

$$HCF_{max} = Acoll \times C_p \times F_{max} \quad ;$$

F is the normal or maximum flow rate, C_p is the specific heat capacity of water and A_{coll} is the area of the collector sub-system.

4.3 ECONOMIC ANALYSIS FACTORS

The annual capital and fuel cost factors are also determined before a simulation. The following equation shows how the annual capital cost annualization factor (A_{cap}) is related to the interest rate (R) and the depreciation time in years (T):

$$A_{cap} = \frac{R/(1+R)}{1 - \frac{1}{(1+R)^T}} \quad , \text{if } R \neq 0$$

or

$$= \frac{1}{T} \quad , \text{if } R = 0.$$

This annualization factor is used to transform the system capital cost into the economic equivalent stream of payments lasting for the system lifetime and starting at the time of initial investment.

The annual fuel cost annualization factor (A_{fuel}) is a function of both the annual capital cost annualization factor and the fuel inflation rate (Fla):

$$A_{fuel} = \frac{A_{cap}(1+R) - A_{cap}(1+R)\left(\frac{1+Fla}{1+R}\right)^T}{(R - Fla)} \quad , \text{if } R \neq Fla$$

or

$$= A_{cap} \times T \quad , \text{if } R = Fla.$$

These factors are used for calculating the cost function for the optimizer and for other annualized cost calculations.

4.4 LOAD AND DISTRIBUTION CALCULATIONS

The next task performed in the main logic is the computation of the distribution load for each time period. The load, which varies with ambient temperature, is the sum of the house space heating and tap hot water requirements. Both components employ the same equations.

First, the house space heating requirement is determined. The thermal conductivity (UA) (W/K) for the total system is the product of the number of houses, the area of each house and the heat transfer coefficient. The total human energy supply (Q_{human}) is determined by multiplying the number of houses by the human energy per house. The "human energy" is internal heat gain due to occupants, lighting, equipment etc. The space heating load (QH) for each house is:

$$QH = UA \times (T_{ind} - T_{mod}) - Q_{human} \quad \text{when } Q_{human} < UA \times (T_{ind} - T_{mod})$$

$$\text{or} \quad = 0 \quad \text{when } Q_{human} \geqslant UA \times (T_{ind} - T_{mod})$$

where ($T_{ind} - T_{mod}$) is the difference between the required indoor temperature and the degree-hour model temperature.

It is possible to specify that part of the year during which the house heating system is turned on and can be used. For all days outside of this heating season, the house load, QH, is set to zero independent of the ambient weather conditions.

The tap water requirement is a constant supplied by the user. It is added to QH if there is no separate tap water distribution system.

The distribution network is a series of connecting pipes of fixed length, diameter and insulation. There are two such networks if a separate tap water system is requested. The required temperature of the water put into the distribution network (TH) is empirically related to ambient temperature (T_{amb}):

$$TH = T_{con} + AK\,(T_r - T_{amb}) \quad ,$$

$$\text{or} \qquad = T_{con} \quad \text{iff } (T_r - T_{amb}) \leqslant 0.$$

T_r is the break point temperature, T_{con} is a constant temperature level, and AK is the gradient of the delivery temperature curve. The temperature of water returning from the load network can be defined in one of two ways. The user can specify a constant return temperature from the load network or a constant temperature difference across the network.

There will be some energy lost to the environment from the distribution piping network; MINSUN adjusts the heat capacity flow through the distribution system to allow for this energy loss.

$$HCF_{out} = HCF_{norm} \times (T_{in} - T_{earth})^{-A}$$

HCF_{norm} is the normal heat capacity flow for the distribution network. It is calculated from input parameters and may be different from the collector normal heat capacity flow. The variables T_{in} and T_{earth} are temperature measurements of the inlet (TH) and ground, and A is a function of pipe length, diameter, conductivity, insulation thickness and heat capacity flow.

The total distribution load is then summed for each time period. The load at the houses is the sum of space heating and tapwater energies minus the network losses. The supply-deficit balance is tested in the simulator by checking the temperature requirements against the supply temperature.

4.5 CONSTRAINT INITIATION AND EXAMINATION

As mentioned in section 2.2.3, the user must supply maximum and minimum acceptable values for some of the system parameters which can be optimized. Following the computation of the distribution losses, the first twelve constraint functions (plus the fifteenth if duct storage is used) are prepared for the optimizer.

The first pair of constraints represent the difference between the initial collector area and the specified minimum and maximum area values. The second pair represent the difference between the initial storage volume and the specified minimum and maximum storage volume values. The top of storage insulation thickness constraint functions are set using a minimum of .01 meters and a maximum of 5 meters. The storage height constraint functions are set based on a minimum acceptable height/diameter ratio of 0.01 and a maximum storage height supplied by the user. Evaporator and condenser heat transfer capacity constraint functions are set for both the space heating and tap water heating heat pumps. The minimum acceptable transfer rate is 100 kW/K in all cases.

Finally, if duct storage is used, the fifteenth constraint, which checks the number of ducts against a user-specified minimum, is checked.

If any of these constraints are violated at the starting point of an optimization run, the program will be terminated and meaningless results will be printed. The action taken if constaints are violated once the optimization process has been started are detailed in Chapter 8. The constraints are not checked in single simulation or multiple simulation runs.

In the absence of constraint violations, a simulation proceeds and, as is discussed in the next chapter, calculation of energy contributions to the system from the solar collectors, storage tank, heat pumps and the auxiliary heater are determined.

During optimization, the solar simulation is repeated many times, so that the optimal solution can be determined. Following the first simulation, estimates of the solar cover (the ratio of solar energy to total energy supplied by the system) and the storage fluid temperature decrease are produced. These values are used with user-specified constraint parameters to form the thirteenth and fourteenth constraint functions and are checked after each subsequent simulation. These are the simulation dependent constraints.

4.6 PRE-HEATING OF GROUND SURROUNDING STORAGE

With both the Duct Storage System and the Stratified Storage Temperature Model, a significant amount of energy passes through the boundaries of the storage volume to heat the initially cold surrounding ground.

The annual heat loss will decrease with the number of completed annual cycles. This heat loss approaches a steady-state value. The transient part of the heat loss which is responsible for the heating of the surrounding ground then becomes zero. During the first cycles this transient part is quite important. A thermal performance of the store which is more representative of a long-term operation is attained after a few cycles.

A complete MINSUN simulation for a few cycles may be too expensive - especially in an optimization or multiple simulation run. An alternative is to use a simple model to simulate the transient heating of the surrounding ground for the years preceeding a complete MINSUN cycle. Here, this is accomplished by specifying the temperature in the storage volume. It is not necessary to make any calculations of the local processes within the store. Only the global thermal process in the ground surrounding the store has to be calculated. The storage temperature is given as a sinusoidal variation with a period of one year. The store is assumed to be at its minimum temperature at the beginning of the cycle. The maximum temperature reached during the preheating cycle is given as an input value. Any number of cycles with preheating of the surrounding ground may be specified. However, it should be kept in mind that this increases the computing time for each node point in an optimization or multiple simulation run.

5.0 SIMULATION OF THERMAL PERFORMANCE

For each time period, the MINSUN simulator calculates the energy supplied from storage, the heat pumps and the auxiliary heater to satisfy the distribution load. The major steps in the simulation of each time period are outlined in Figure 5-1.

As shown in Figure 2-1, the simulated system is made up of two primary flow loops - a solar collector/storage loop and a heat load/storage loop - which interact via the storage. The part of MINSUN which models the storage volume is called once for each time-step DELT. (DELT is always 24 hours). During this time-step heated water is supplied from the solar collectors for a period DTIM. The remaining time, DELT-DTIM, is used for the house heating load. This chapter describes the storage sub-system models used by MINSUN, the control strategy for the solar collectors and the interaction between the collectors, the load and the storage.

5.1 STORAGE SUB-SYSTEM

There are four central seasonal storage models which can be used with MINSUN. These are:

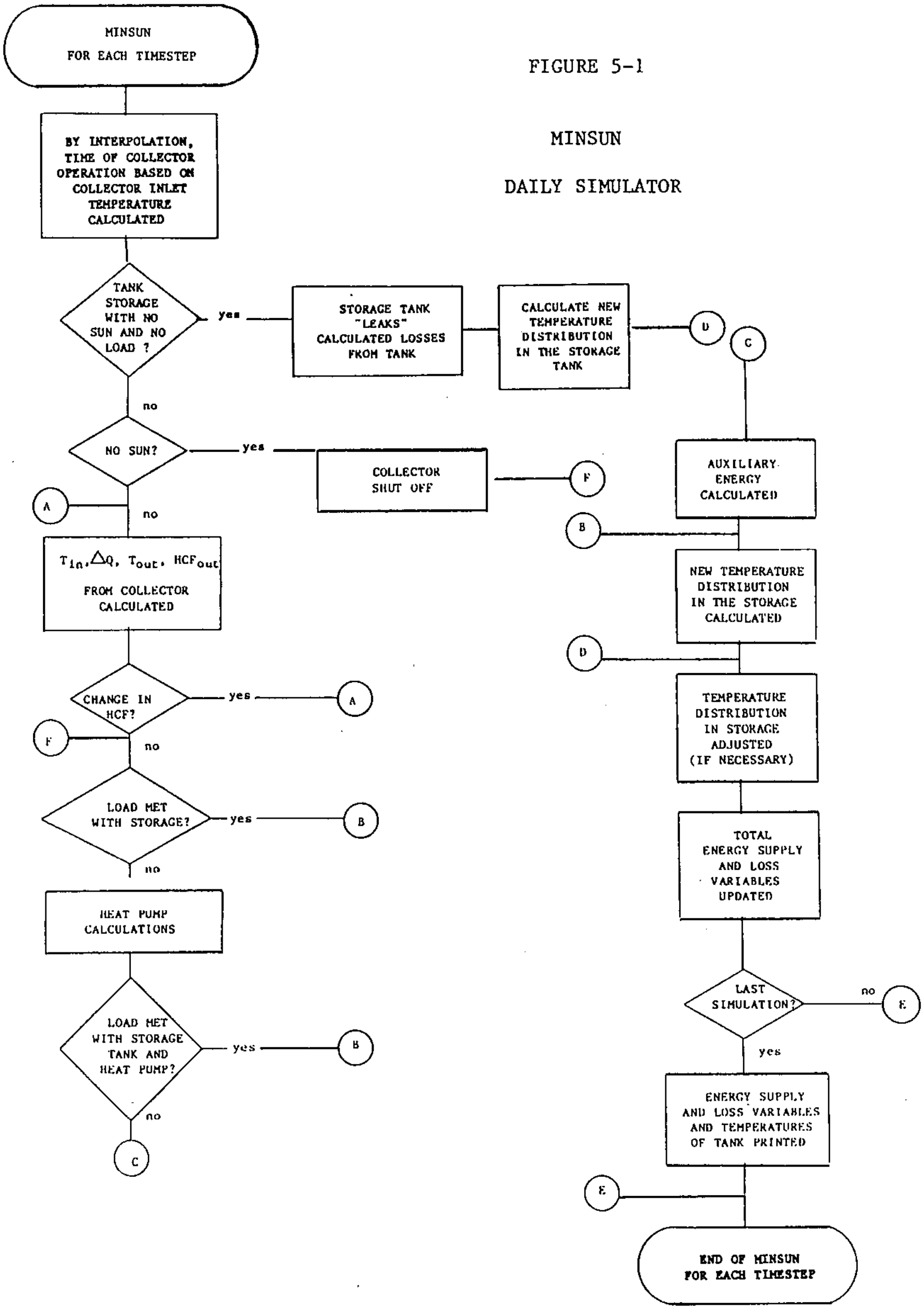
(1) Insulated Tank
(2) Duct Storage System (DST)
(3) Stratified Storage Temperature System (SST)
(4) Aquifer Storage System (AST)

The thermal processes simulated are different in each of these models. A brief description of each model follows.

FIGURE 5-1

MINSUN

DAILY SIMULATOR



5.1.1 Insulated Tank Storage

Energy is stored in a water-filled insulated tank, either above or below the ground. The tank has a user-specified number, NEQ, of "nodes" evenly spaced between the top and the bottom of storage. Water can be injected or extracted at any of the nodes. The water at the top node will always be the warmest and that at the bottom node the coldest.

The thermal model is very simple. The water is assumed to be in NEQ homogeneous layers. The mass flow and energy transfer between layers is considered as a one-dimensional process. The model also allows for some leakage of energy through the walls of the tank into the environment.

A typical tank is shown in figure 5-2.

5.1.2 Duct Storage System - DST[1]

A region of rock or soil is used for heat storage. Heat is injected and extracted via a duct system in which a heat carrier fluid is circulated. The thermal process in the storage region with its duct system is quite complex. There is a "global" temperature variation from the center of the store out to the boundaries and into the surrounding ground. There is also an important and often violent heat transfer process around each duct. Finally, there is a variation along the ducts, which is coupled to the heat exchange between fluid and ground. One also has to consider the flow pattern for the fluid through the storage. All of these processes must be fitted together. The local processes are important in order to obtain the right heat exchange between fluid and ground. But the local process depends on the global temperature level. The global temperature on the other hand is strongly influenced by the local injection/extraction of heat at the ducts.

The Duct Storage Model takes into account the variable temperature through the storage region and its interaction with the surrounding

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1. Users of the Duet Storage sub-system should refer to Reference 3 for further information on simulation procedures.

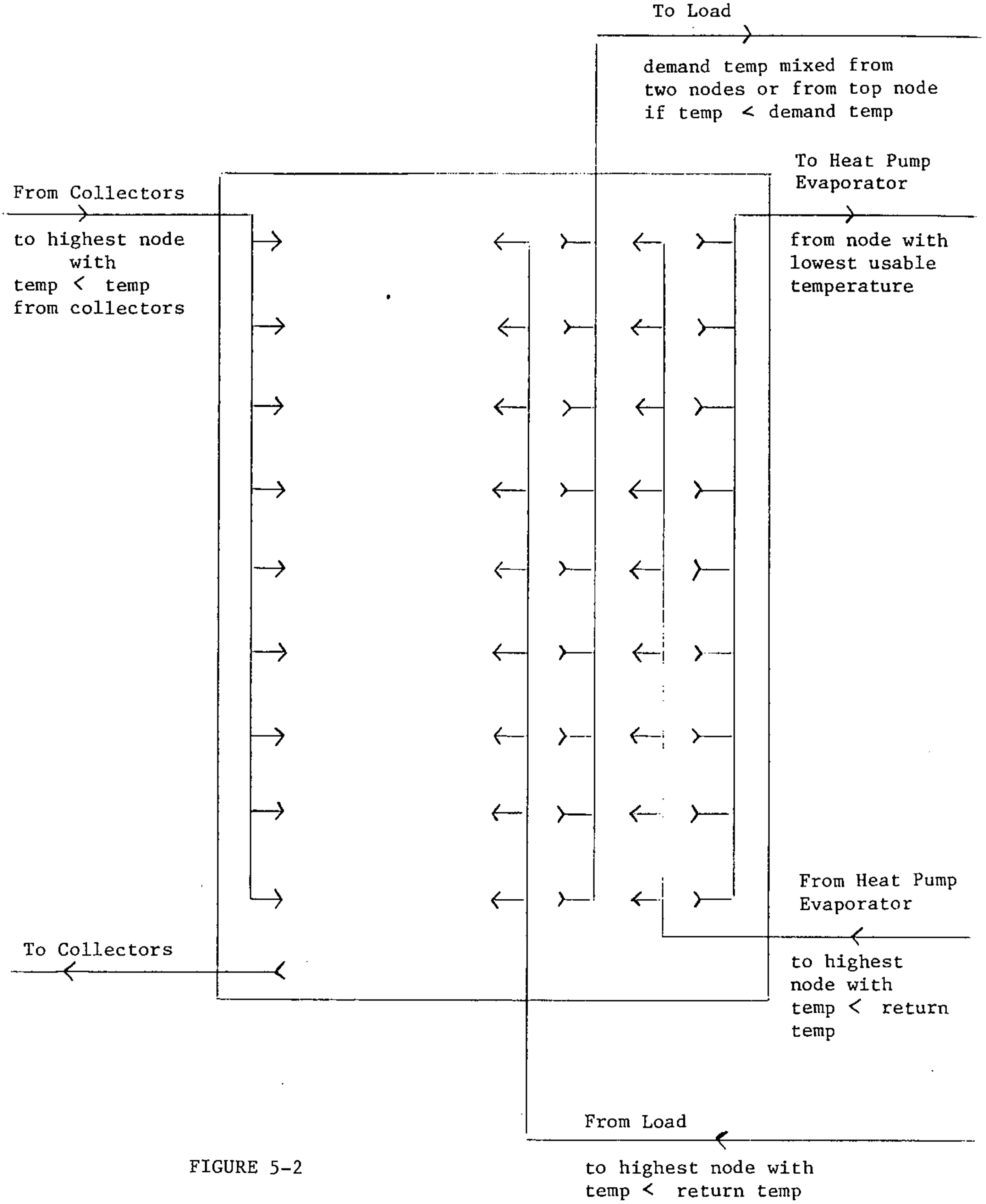

FIGURE 5-2

A Typical Tank with 9 Nodes

ground. The local process around the ducts at different points in the storage and the variation in the temperature of the fluid along the ducts are also considered.

The temperature in the storage region is represented by three parts: A global temperature, a local solution and a steady-flux part. The total temperature at a point is obtained by superposition of these three parts.

5.1.2.1 Global Problem

The global temperature is the solution of the heat conduction equation with a variable heat source/sink from the local solution and the steady-flux solution. It covers the large scale thermal process, which includes the interaction between the storage and the surrounding ground, between different parts within the storage, and the influence of the conditions at the ground surface. All details of the temperature field associated with individual ducts are left to the steady-flux and the local part.

Storage volume, thermal properties, arrangement of ducts, and global temperature field are assumed to exhibit cylindrical symmetry with respect to an axis through the center of the storage volume. The model assumes homogeneous thermal properties within the storage volume. The thermal properties in the surrounding ground are given for a number of horizontal strata.

Figure 5.3 shows a vertical cross-section of the ground with the center of storage on the left side. The cross-section is divided into cells, each of which is represented by a single point in the simulation. The mesh is generated automatically. The mesh size is determined by the thermal properties of the ground, daily changes in loading conditions and the duration of the simulation. A finer grid spacing is used where large temperature gradients are expected.

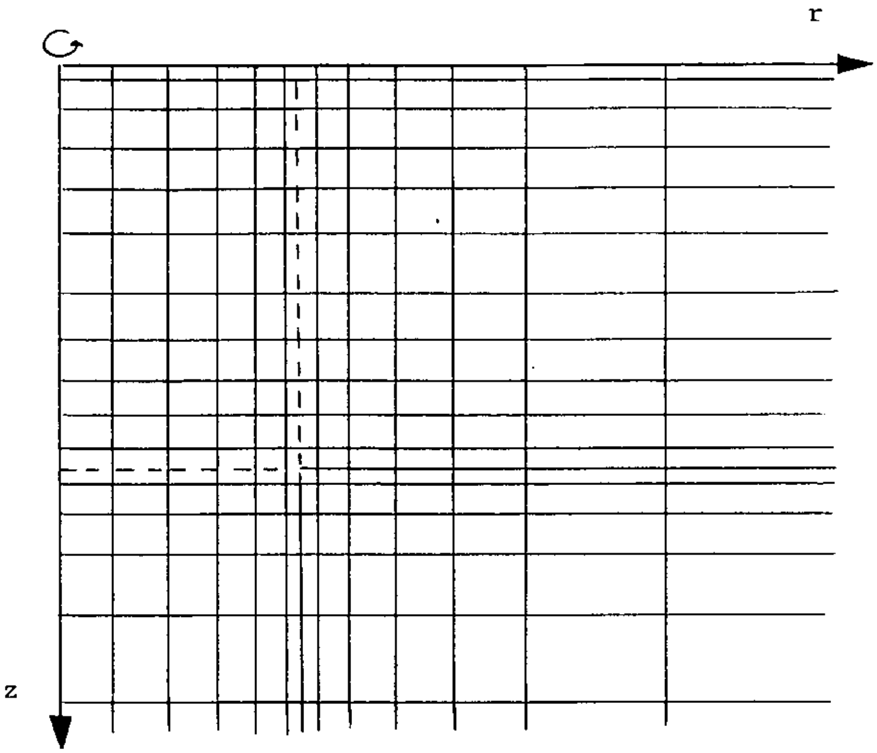

FIGURE 5-3

Example of Global Mesh for DST

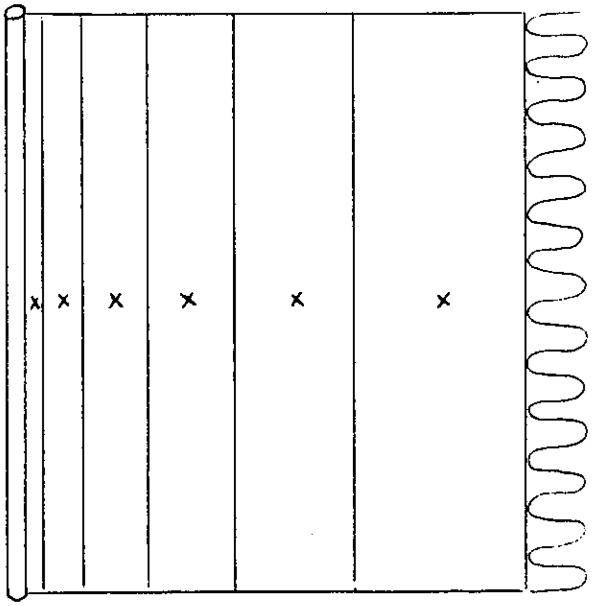

FIGURE 5-4

Example of Local Mesh for DST

5.1.2.2 Local Problem

The basic problem in the analysis of duct storage systems for ground heat storage is the interaction between the local thermal process around a pipe and the macroscale or global temperature process through the storage and the surrounding ground. A precise description of the local process is necessary in order to obtain the right amount of injected and extracted heat. The amounts of injected and extracted heat will govern the global thermal process. The local values of the global temperature field are on the other hand necessary for the local problem.

The distances between the ducts and hence the required number of pipes or boreholes are of decisive importance to the cost of the storage. The pipes are here assumed to lie in a regular pattern of equilateral triangles. It can be shown that a pattern of squares leads to almost the same results if the area per pipe in a cross-section is the same for the two patterns.

The thermal process around the individual ducts due to short time variations is modeled using a one-dimensional radial mesh. The local problem is assumed to be the same around each pipe.

Figure 5.4 shows an example of a mesh for the local problem with the duct on the left. The outer boundary is totally insulated, i.e. adiabatic conditions prevail.

5.1.2.3 Steady-Flux Problem

The fluid that passes through the storage region will feel a variable global temperature for the different mesh points. A redistribution of heat in accordance with this is made with use of the steady-flux solution. In this part a particular analytical solution is used. The idea is the following. Consider a situation of constant heat injection from a duct in the center of the store to the surrounding region. After a certain transient period there is a state of steady-flux. This means that the temperature at each point increases at a constant rate. The heat flux is constant in time at each point. There is a fixed temperature profile around the duct. This profile is just lifted at a constant rate. In this steady-flux regime there is a simple relation between the injection rate and the difference between fluid and ground mean temperature. The relation is obtained by solving analytically the local problem in the steady-flux regime. This result is used in the redistribution of heat in the storage volume.

The effect of the steady-flux solution (combined with the global solution) is to give the thermal conditions around the pipes with no net extraction or injection of heat from the store. The energy pulses associated with heat transfer to or from the store are then superposed on the combined steady-flux and global problem by means of the local solution.

5.1.2.4 Heat Balance For the Heat Carrier Fluid

When the temperature of the heat carrier fluid differs from the temperature of the surrounding ground there will be a transfer of heat between these two parts. The fluid will lose or gain energy, and its temperature will vary along its flow path through the storage volume. A simple heat balance equation, where transient terms are neglected, is used for the heat carrier fluid. It is used both in the local and the steady-flux problem.

It is assumed that all pipes in the store are coupled in parallel.

5.1.2.5 Applicability of the Model

The input data for this version of the code are given for a configuration with vertical pipes or boreholes. However, the model converts the total pipe length to a homogeneous density of pipes in the storage volume.

There is no need to know the exact location of each pipe. The important assumption is that the distribution of the pipes in the storage region should be rather homogeneous. Thus it is straightforward to convert a configuration with horizontal pipes to match the given input format.

Let L denote the total length of all horizontal pipes. The extension of the storage volume in the vertical direction is H. Then the equivalent number of vertical pipes, NBORE, is equal to L/H. No other input parameters have to be changed.

The steady-flux solution (Section 5.1.2.3) is used for one part of the thermal process around each pipe. It is assumed that the pipe is surrounded by other pipes. This is an approximation of the real conditions where some pipes are located at the boundary of the storage volume. At least half of the pipes should be located in the inner part of the store in order to ensure acceptable accuracy of the complete numerical simulation.

5.1.3 Stratified Storage Temperature System - SST[1]

The model simulates heat storage in a water-filled tank, cavern, or pond.

The storage volume may contain water or a mixture of water and stone. The temperatures in the storage volume are horizontally stratified. There is a vertical one-dimensional convective diffusive thermal process in the storage volume. In the surrounding ground there is three-dimensional diffusive heat flow. The two processes are coupled by the heat flow through the boundaries of the storage volume.

The storage volume is assumed to have the shape of a vertical cylinder. It is divided into ten horizontal layers with equal thickness.

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1. Users of the Stratified Storage Sub-system should refer to Reference 4 for further information on simulation procedures.

The thermal properties in the ground are given for a number of horizontal strata.

Figure 5.5 shows a vertical cross-section of the ground with the center of storage on the left side. The cross-section is divided into cells, each of which is represented by a single point in the simulation. The mesh is generated automatically. The mesh size is determined by the thermal properties of the ground, daily changes in loading conditions and the duration of the simulation. A finer grid spacing is used where large temperature gradients are expected.

5.1.4 Aquifer Storage System - AST[1]

The model simulates thermal energy storage in a confined aquifer. A single well is used for injection and extraction of heated water. A second remote well, which is not modelled by MINSUN, is used to supply cool water to the collectors and to dispose of water which has been used to meet the load. The thermal processes in the aquifer and the surrounding ground are dealt with by the model.

The aquifer is a porous layer in the ground, generally sand, which is surrounded above and below by impermeable material. MINSUN models a horizontal aquifer stratum with constant thickness. The thickness of the covering soil layers is also constant. The aquifer extends a long distance from the well in all directions.

The thermal properties of the aquifer are assumed to be uniform. The caprock (above the aquifer) and bedrock (below the aquifer) can each contain several layers with distinct thermal properties.

Inhomogeneities will complicate the thermal process in the aquifer. The phenomenon is called thermal macro-dispersion. It may be accounted for in an approximate way by an increase of the thermal conductivities; in particular in the flow direction.

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[1] Users of the Aquifer Storage Sub-system should refer to Reference 2 for further information on simulation procedures.

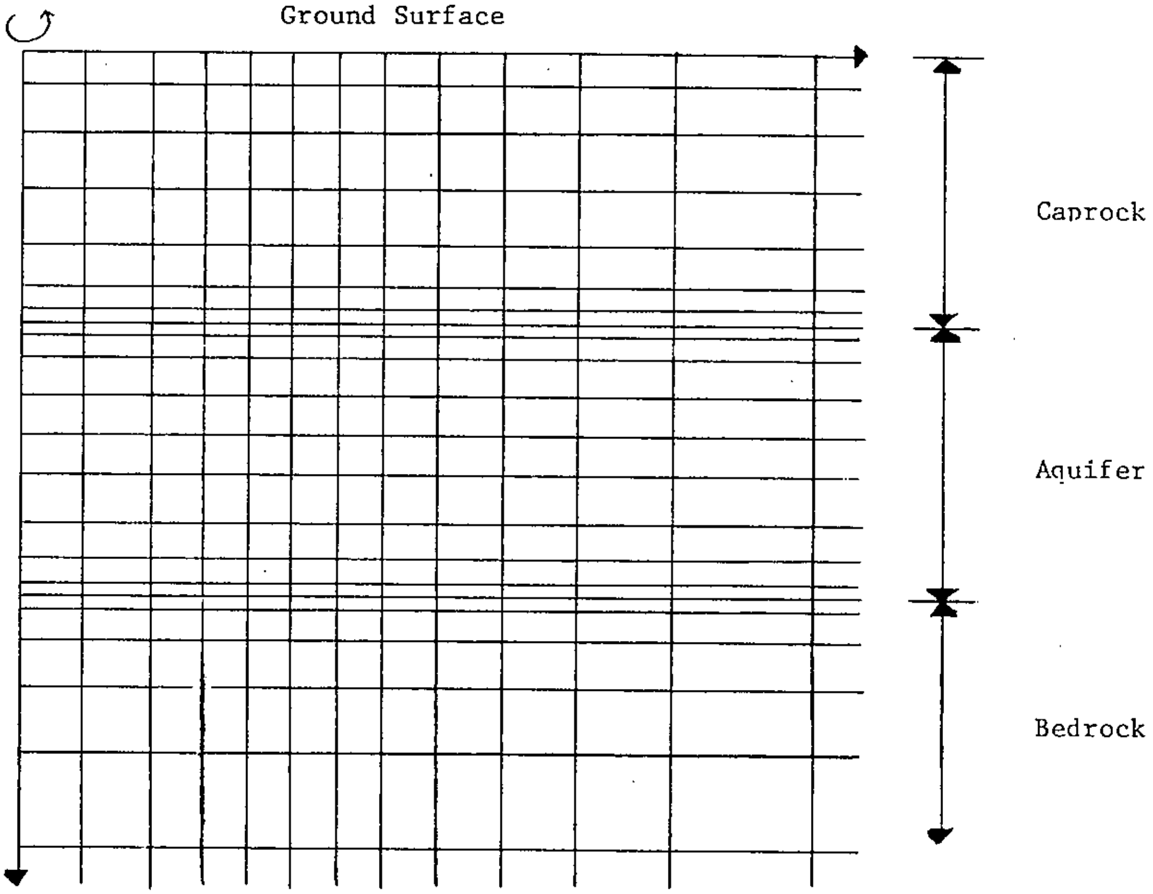


FIGURE 5-6

Example of AST Mesh in a
Vertical Cross-section of the Ground

The convective-diffusive heat transfer process in the aquifer and in the surrounding ground is simulated numerically, for each time-step, in two separate parts: 1. Ordinary diffusive heat transfer, 2. Convective radial displacement with use of an entropy conservation technique.

A particular problem in the numerical computation of combined diffusive and convective heat flow processes is the so-called numerical diffusion or dispersion. The effect is an enhanced, apparent heat conduction. A thermal front is smoothed out too rapidly.

An entropy conservation technique is used in the convective part of the heat transfer process. The temperature in a cell is represented by three parameters. The diffusive part is computed in a conventional way. Only the mean cell temperature is used.

Applicability of the Model

The basic assumption of the model is that the ground water flow is essentially radial in the thermally active region around the well. There are three conditions that must be fulfilled in order for an aquifer system to be well represented by this model:

- negligible natural ground water flow;
- negligible disturbance from the second well;
- negligible buoyancy flow.

The ground water flow is essentially radial near the well during injection and extraction. A natural ground water flow will influence the flow pattern. The model requires that the natural flow velocity is negligible compared to the radial velocity in the thermally active region around the well.

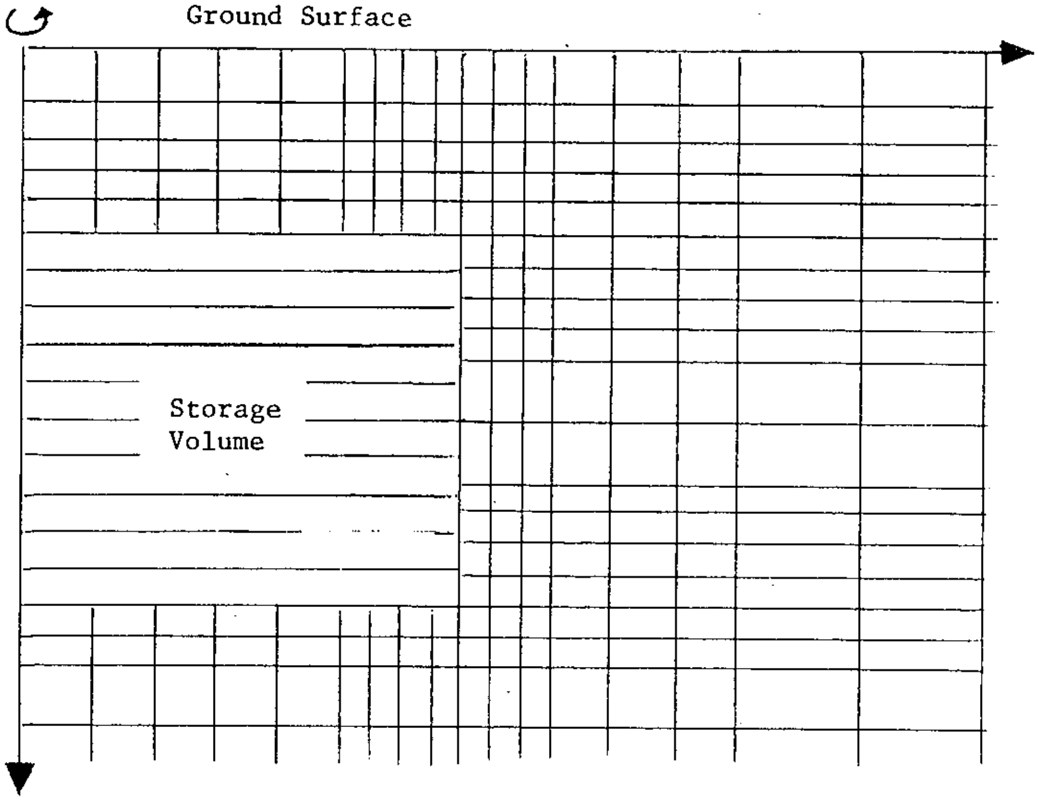


FIGURE 5-5

Example of SST Mesh in a
Vertical Cross-section of the Ground

The height and depth of the aquifer and the expected radius of the thermally active region are given as input values to the model. The region of computation is extended radially outwards and vertically downwards until more or less undisturbed conditions prevail. During extraction, ground water will flow into the aquifer through the outer boundary.

Figure 5-6 shows the grid used in a vertical cross-section of the ground to model the aquifer.

A finer grid spacing is used in the thermally active aquifer region near the well and at the boundaries between aquifer and caprock/bedrock. The spacing is increased strongly outwards and downwards.

The mesh is generated automatically. The size of the mesh is determined by the thermal properties in the ground, daily changes in loading conditions and duration of the simulated time period. A finer grid spacing is used where large temperature gradients are expected.

A special problem with a simulation of an aquifer storage system is that the storage volume is unconfined. The thermally active region in the aquifer will vary according to external conditions. It is somewhat difficult to choose a mesh for the numerical calculation which is suitable for all possible evolutions of the thermally active region. MINSUN handles this problem by re-running the simulation if necessary. For the first simulation, the mesh is generated using a thermal radius specified by the user. During the simulation, the true thermal radius - the maximum distance from the well reached by the injected water - is calculated. If this calculated radius is not between 60% and 150% of the radius specified by the user, the simulation is redone using the new calculated radius to generate the mesh. Because the simulation time-step is decreased as the mesh radius decreases, runs with small meshes take considerably more computation time than those with large meshes. To avoid long, meaningless runs, a run is aborted if, at any time during the simulation, the thermal radius calculated by the program is more than 1.6 times the radius used to generate the mesh.

The radial flow pattern around the well will also be deformed due to the effect of other active wells in the aquifer. Consider the case where the aquifer stratum is penetrated by two wells. Hot or cold water is stored around one well. The other well is used for supply of water to the system. The assumption of radial ground water flow is valid with satisfactory accuracy if

$$R_T < 0.8\ L$$

where L is the distance between the wells and R_T is the radius of the thermally active region around the storage well.

The varying water temperature in the aquifer will cause buoyancy flow. This will also disturb the radial flow pattern. The strength of the natural convection due to buoyancy must be small compared to the forced radial flow.

The case when the injection temperature varies rapidly must be treated with some caution. In the real storage aquifer these variations are smoothed out rapidly due to heat conduction. A true representation of this thermal process near the well requires a fine mesh. A coarse mesh cannot represent this process properly. The thermal process is however properly represented further away from the well. Only temperature variations on a time-scale above the time that it takes to convectively displace the temperature field through a cell width can be represented properly in the vicinity of the well.

5.2 ENERGY FROM THE COLLECTOR SUB-SYSTEM

The energy supplied to storage depends on the energy collected by the solar panels during the previous time period. The energy transmitted to the system is then determined in part by the solar collector control strategy.

5.2.1 Collector Operation

The solar collector operation time is estimated by linear interpolation, relating the five time and temperature steps from UMSORT. The independent variable is the average temperature of the water being circulated in the collector or an approximation to this value. This temperature is calculated differently by each of the storage models.

In all cases, two iterations are made to find the amount of energy collected. In the first step, the temperature of the water being input to the collectors is used as the independent variable to interpolate in the table of collected energy produced by UMSORT and ADVANCE. This first step gives a preliminary estimate of the outlet temperature from the collectors. The estimated inlet temperature and the preliminary outlet temperature are averaged to give an estimate of the average operating temperature of the collectors. This is then used as the independent variable in the second interpolation step to calculate the actual collected energy and outlet temperature.

If a day has poor weather conditions for solar collector operation or if the temperature of the water input to the collector is high, the linear interpolation can produce a zero or negative estimate for collector operation time. Conceptually, the collectors are "shut off" because there is insufficient insolation.

When positive estimates of collector operation time are produced, the collector supplies storage with energy. The collector output temperature, heat capacity flow and power are calculated.

5.2.2 The Solar Collector Control Strategy

The maximum output temperature from the collectors is controlled at each time period.

The program estimates two quantities - collected energy and outlet temperature. The collected energy per unit area of collector (Q_{out}) is estimated by linear interpolation between the collected energy values at standard input temperatures produced by UMSORT. The estimated collector input temperature (T_{in}) is the independent variable. The output temperature (T_{out}) is determined from the following equation:

$$T_{out} = T_{in} + [(Q_{out} \times A_{coll}) / (t_{est} \times HCF_{norm})];$$

t_{est} is the estimated time of collector operation, HCF_{norm} is the normal heat capacity flow calculated from input parameters and A_{coll} is the collector area.

These estimated values are checked against contraints on output temperature and heat capacity flow. The maximum acceptable output temperature (T_{max}) is determined from the control strategy curve (Figure 5-7). The independent variable is the highest storage temperature.

If the output temperature (T_{out}) does not exceed the maximum temperature allowed (T_{max}), then T_{out} and the normal heat capacity flow (HCF_{norm}) are accepted. However, if the maximum temperature constraint is exceeded, the output temperature is "set" to the maximum temperature (T_{max}) and a new heat capacity flow (HCF_{out}) is calculated:

$$HCF_{out} = (Q_{out} \times A_{coll}) / ((T_{max} - T_{in}) \times t_{est}) .$$

If the new heat capacity flow does not exceed the maximum heat capacity flow specified by the user, then the maximum temperature and the new flow are used. If the flow constraint is violated, the maximum temperature and maximum heat capacity flow are used to calculate the new (reduced) energy collected (Q_{out}). A new (average) solar output power (P_{new}) must then be calculated:

$$P_{new} = Q_{out} \times A_{coll} / t_{est}$$

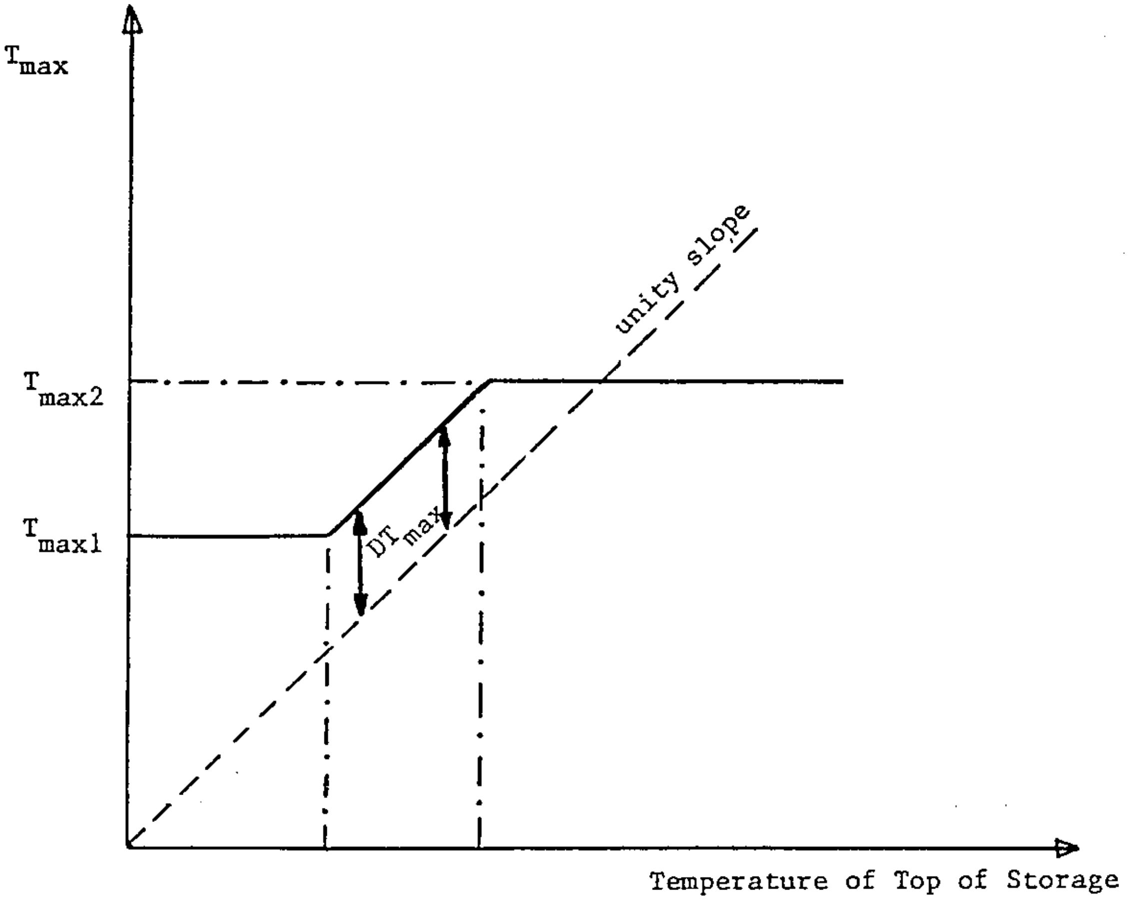


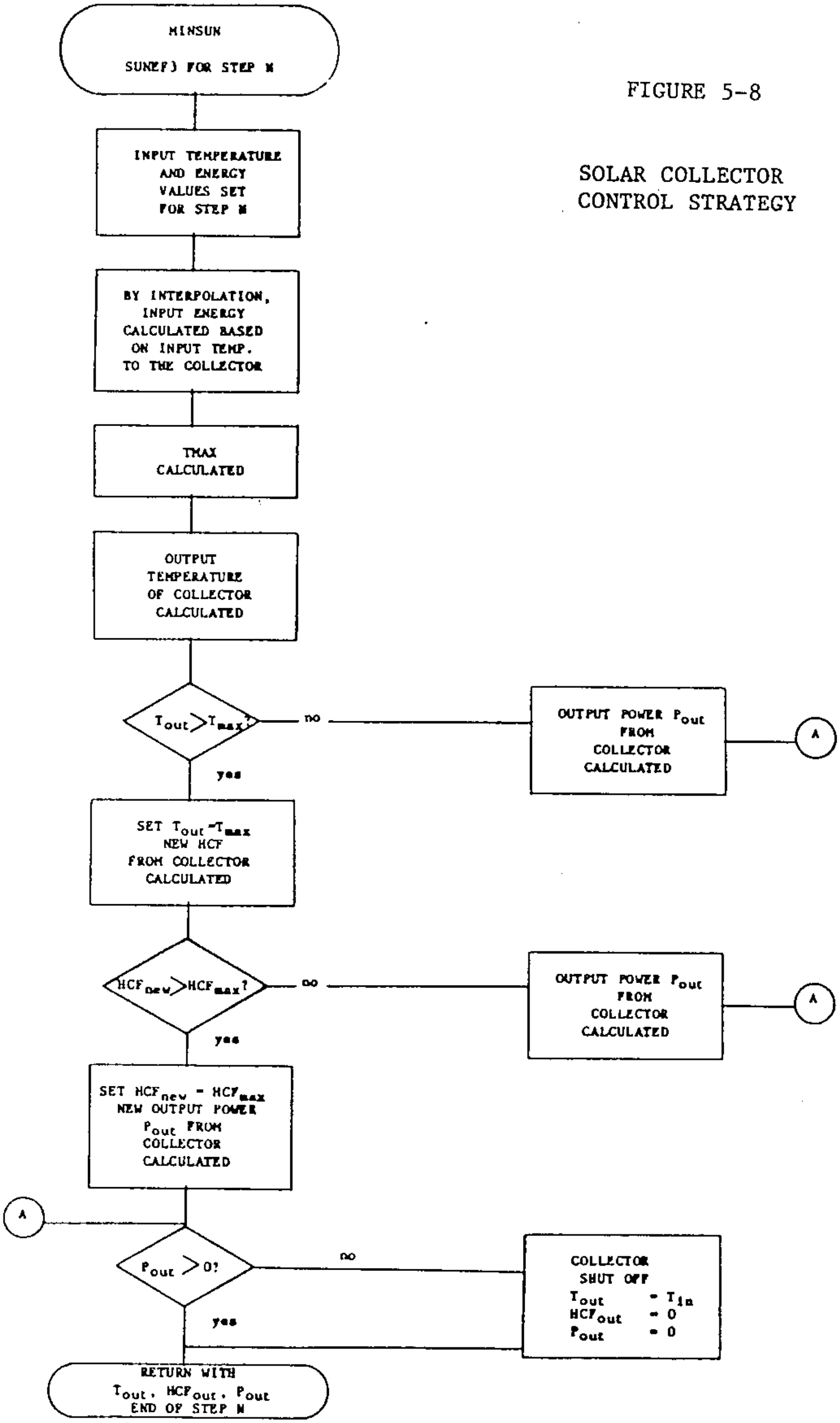
FIGURE 5-7

COLLECTOR CONTROL STRATEGY CURVE

T_{max1}, T_{max2} and DT_{max} are specified input parameters from which the inflection points (T_{max1}-DT_{max}) and (T_{max2}-DT_{max}) can be calculated.

FIGURE 5-8

SOLAR COLLECTOR CONTROL STRATEGY



Conceptually, the collector is operating at maximum conditions beyond which collected energy must be discarded.

The control strategy also tests for zero or negative solar power, the criterion for a non-operational collector. In that case, the inlet and outlet temperatures are equated. The heat capacity flow and collected energy are both zero. When aquifer storage is used, the collectors are shut off unless water can be output at the maximum temperature (T_{max}).

A flow diagram outlining the major steps of the solar collector control strategy is show in Figure 5-8.

The simulator was originally designed to permit the use of two collection systems. The first system consists of one large central array of collectors with pipe connections. The second system consists of a series of house mounted panels with a separate network of connecting pipes. The total energy supplied to storage is the sum of the output from these two systems. In this version of MINSUN, however, this option is not operational. Only the central collectors are used.

5.3 THE SOLAR COLLECTOR/STORAGE LOOP

As stated in section 5.2.1, the amount of energy absorbed by the solar collectors depends on the temperature of the water supplied to the collectors.

When Insulated Tank storage is used, this water is drawn from the bottom (i.e. the coolest) node in the tank. After passing through the collector, the heated water is returned to the highest node which has a temperature lower than that of the incoming water.

With the Stratified Storage Temperature model, water is again drawn from the bottom of storage. After passing through the collector, the heated water is returned to the highest node which has a temperature lower than that of the incoming water.

With the Aquifer model, water is supplied to the collectors from a remote well which is not affected by the operation of the storage. The water is supplied at a constant temperature throughout the year and is always returned to the storage well. The collectors are not operated for a given period unless the maximum acceptable outlet temperature can be provided. This maximum outlet temperature should be specified as a constant by setting T_{max1} and T_{max2} to the same value and setting the normal heat capacity flow to a small value. (See Figure 5-7). This strategy is used since this type of storage operates essentially on a displacement principle such that the last water injected is the first water to be extracted. There is no gradual heating over the course of the summer as in a confined volume storage system.

For Duct Storage, the calculation is somewhat more complex since the water from the collectors is circulated through the duct system where it loses some heat and is then fed back to the collectors. Thus the fluid temperature from the store depends on the temperature of the fluid delivered from the solar collectors and the flow rate. An iterative procedure to calculate the temperature of the water supplied from the storage has to be used each time the loading conditions are changed. During the first try it is set equal to the average temperature in the store. Then the fluid temperature from the solar collector is calculated and supplied to the storage subroutine for circulation through the duct storage system. This gives a new value of the storage output temperature which is used for another iteration of the calculation for the solar collector/storage loop. The accuracy of the calculation could be improved by increasing the number of iterations. With respect to computer time limitations the accuracy of just two iterations was judged to be acceptable.

5.4 THE HEAT LOAD/STORAGE LOOP

The way in which the heating load is met again depends on the storage model being used. The heat load consists of house heating and tap water heating. If separate distribution systems are used, the flow loops for these loads have the same structure and they are coupled in parallel.

With the Insulated Tank model, the water can be drawn from any node in the tank. It is taken from the node with the lowest temperature above the demand temperature and from the node with the highest temperature below the demand temperature and is mixed in order to supply the correct temperature to the load. If the temperature at any node is high enough to meet the load, then storage is used without any other heat source.

If the tank cannot meet the load and if heat pumps are included in the configuration, the heat pumps will be used to meet the load. They take water from the node with the lowest usable temperature. For a description of the heat pump model, refer to section 5.5.

If heat pumps cannot meet the entire load for a period, they are not used and auxiliary heaters are used to heat the best available water to the demand temperature.

Water returning from the heat load loop is always returned to the tank at the highest node with a temperature less than the return flow temperature.

With the Duct Storage, the Stratified Storage Temperature and the Aquifer Storage models, there is only one source of water and, therefore, only one available temperature from the storage. For SST, this is the top of the storage volume (i.e. the warmest water is used). For DST, the water comes out of the duct system. As in the solar collector/storage loop calculation, the temperature of this water is estimated using an iterative procedure. For AST, the water is taken from the storage well. As in the DST model, an estimate of the temperature of this water is used in determining the strategy to meet the load on each day.

If the estimated fluid temperature from the store is warmer than the demand temperature then some of the cool water returning from the heat load is mixed with the water from storage to yield water at the right temperature to meet the load.

It should be noted that the model will not give the 'right' temperature (in the sense discussed above) when the storage water and the return water are mixed. The proportions of the mixing are determined before the calculation for the timestep using the information about temperature levels in the store available at that moment. Due to the diffusive process in the storage and the surrounding ground there will be a cooling or heating of storage water during the time-step DELT-DTIM for the heat load/storage loop. The difference will be made up for by the auxiliary heater. In most applications of heat storage this means that the auxiliary heater will supply a small amount of heat to the water. Under some short time periods the auxiliary heater will cool the water, i.e. supply negative energy.

If the water available from DST, SST or AST storage is not warm enough to meet the load directly and if a heat pump is included in the system being modelled, an attempt is made to meet the load using the heat pump.

Finally, if the load cannot be met by the heat pump in a system using DST, SST or AST storage, an auxiliary heater is used to heat the best available water to the demand temperature. This best available water is either the return water from the heat load or the water from storage, whichever is warmer.

In the Aquifer Storage model, unlike the other models, storage water which is returned from the heat load is not put back into storage, but is "dumped" into a cool well from which the collectors are fed.

To minimize the problem of depleting the supply of good water in storage (and to avoid computational problems caused by inaccuracies in the estimation of the temperature of water available from AST storage), fresh storage water is not used as input to the auxiliary heater unless it is at least 5° (or one third of the temperature drop across the distribution system if that is less than 5°) warmer than the return water from the heat load.

The source of heat for the SST DST and AST systems is summarized in the following set of inequalities. Define the relevant parameters as:

TFH - Return temperature from house heating loop.
FLH - Fluid flow rate in house heating loop.
TFHP - Return temperature from heat pump evaporator.
FLHP - Flow rate through evaporator.

The flow in the load loop is given by:

FWSH = FLH + FLHP.

The return temperature from the load loop is:

TFSH = (FLH * TFH + FLHP * TFHP) / FWSH.

Let TTH be the demand temperature to the house heating load. TSTMX is the outlet temperature available from the storage volume at the beginning of the time-step. The demand temperature for the house heating is assumed to always be higher than the temperature of the return water in this loop.

There are three alternatives for the supply to the house heating load; the storage water, the return water, or a mixture of these two.

1. $TTH > TFSH > TSTMX$ The return water is used. (The store is not used.)

2. $TTH > TSTMX > TFSH$ The storage water is used.

3. TSTMX > TTH > TFSH A mixture of storage water and return water is used. A fraction of the return flow by-passes the store and is then mixed with the storage water so that the temperature of this mixture is TTH at the beginning of the heat load time-step. During the time-step the supply temperature may start to deviate from the demand temperature TTH. The deviation is corrected by the auxiliary heater.

The control logic for the tap water heating loop is similar.

5.5 THE HEAT PUMP MODEL

The MINSUN program models a water to water heat pump.

Heat pumps are used to transfer large quantities of lower temperature energy (storage water) to smaller quantities of higher temperature energy (house heating water). Work must be done to drive the system, but this energy is fully recovered as heat and usually represents less than a third of the total energy output of the heat pump.

A heat pump is composed of four main sections: 1) evaporator, 2) condenser, 3) compressor, 4) valve (see Figure 5-9). The condenser and evaporator are heat exchangers, the valve acts as an expansion nozzle. The working fluid within the heat pump is similar to the refrigerant found in common refrigerators.

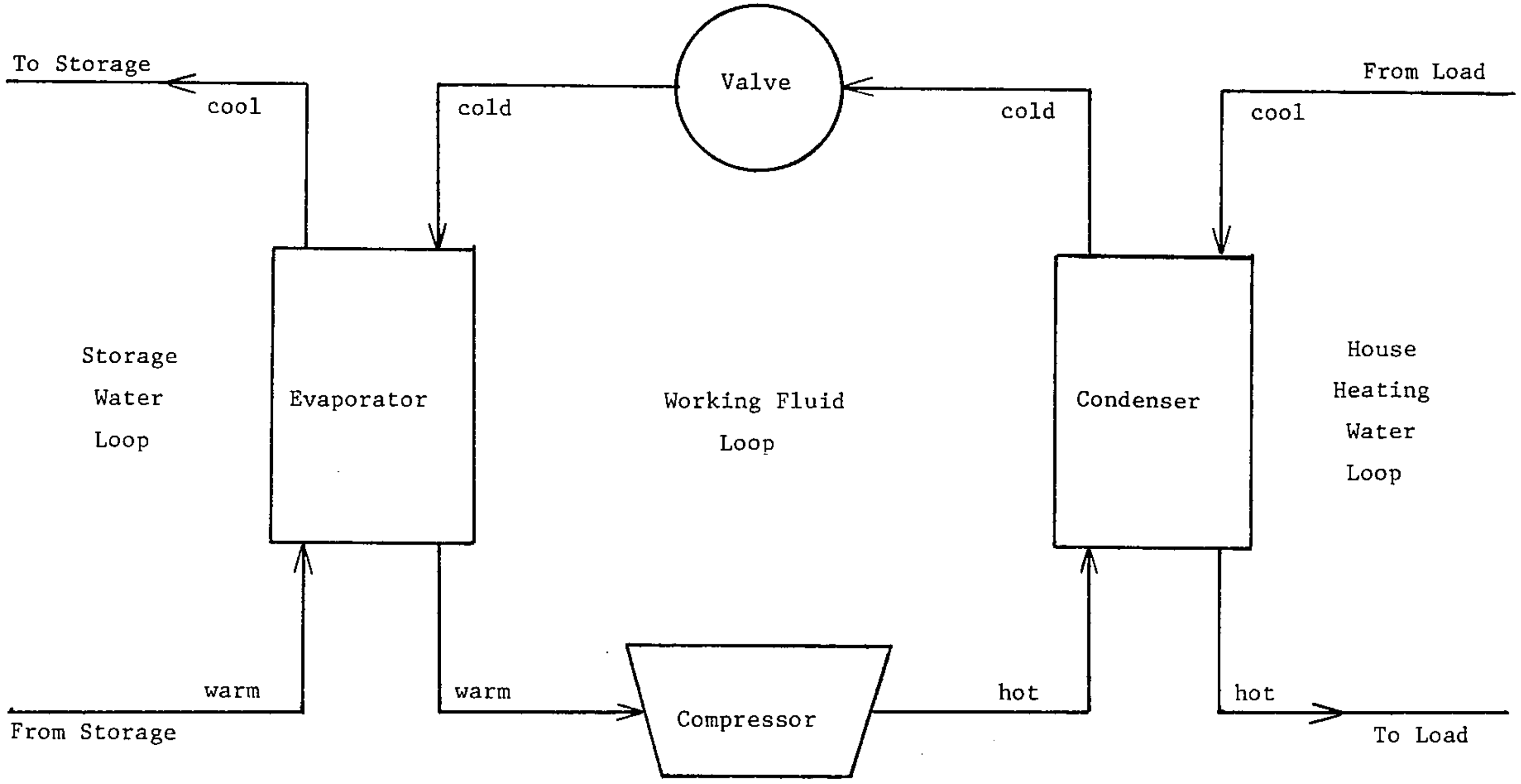


FIGURE 5-9

The Heat Pump

Mathematically the operation of the heat pump can be represented as follows:

Condenser

$$\mathrm{PPC} = \mathrm{AKC}\left(\mathrm{TTC} - \frac{\mathrm{TCIN} + \mathrm{TCUT}}{2}\right) \qquad (1)$$

$$\mathrm{PPC} = \mathrm{FLOWC}\,(\mathrm{TCUT} - \mathrm{TCIN}) \qquad (2)$$

Evaporator

$$\mathrm{PPF} = \mathrm{AKF}\left(\frac{\mathrm{TFIN} + \mathrm{TFUT}}{2} - \mathrm{TTF}\right) \qquad (3)$$

$$\mathrm{PPF} = \mathrm{FLOWE}\,(\mathrm{TFIN} - \mathrm{TFUT}) \qquad (4)$$

Coefficent of Performance

$$\mathrm{FITOT} = \frac{\mathrm{PPC}}{\mathrm{PPEL}} \qquad (5)$$

$$\mathrm{FITOT} = \mathrm{ETA} * \frac{\mathrm{TTC}}{\mathrm{TTC} - \mathrm{TTF}} \qquad (6)$$

$$\mathrm{ETA} = \begin{cases} \mathrm{ETATCF} & \text{if } \mathrm{TTC} - \mathrm{TTF} \leqslant \mathrm{TBROK} \\ \mathrm{ETATCF} - (\mathrm{TTC} - \mathrm{TTF} - \mathrm{TBROK}) * \mathrm{ETACON} & \text{if } \mathrm{TTC} - \mathrm{TTF} > \mathrm{TBROK} \end{cases}$$

Energy Conservation

$$\mathrm{PPEL} = \mathrm{PPC} - \mathrm{PPF} \qquad (7)$$

where: PPC - power transferred from the working fluid in the condenser to the house heating water

AKC - heat transfer ability of the condenser. Condenser heat transfer coefficient times heat transfer surface.

FLOWC - heat capacity flow of the water through the condenser
TTC - temperature of the working fluid in the condenser
TCIN - water temperature into the condenser
TCUT - water temperature out of the condenser
AKF - heat transfer ability of the evaporator. Evaporator heat transfer coefficient times heat transfer surface
FLOWE - heat capacity flow of the water through the evaporator
PPF - power transferred from the storage water to the working fluid in the evaporator
TFIN - water temperature into the evaporator
TFUT - water temperature out of the evaporator
PPEL - electrical power consumed by the compressor
FITOT - coefficient of performance
ETATCF - value of constant portion of the efficiency curve for the heat pump
TTF - temperature of the working fluid in the evaporator
TBROK - temperature difference between condenser and evaporator at which efficiency starts to decline
ETACON - slope of efficiency curve

If the heating load for a particular period cannot be met directly by the storage water, MINSUN will try to meet the load with a heat pump, if there is one in the system.

The MINSUN control strategy assumes that, if the heat pump is used, the entire heating load is supplied by the heat pump. Therefore the power transferred in the condenser (PPC) equals the heat load calculated elsewhere in the program.

The condenser working fluid temperature is then a function of known values:

$$TTC = f(PPC, AKC, FLOWC, TCUT)$$

At this point one of two assumptions must be made. Either the evaporator mass flow (FLOWE) or the evaporator outlet temperature (TFUT) is considered constant.

If the evaporator mass flow is considered constant (Option 1):

TFUT = f (PPF, TTC, FLOWE, AKE, TFIN, ETA).

When the Insulated Tank storage model is used, TFUT is calculated using the temperature of the bottom (coolest) node in the tank as the water temperature into the evaporator.

TFUT is then compared to a user defined minimum temperature (TFMIN). If TFUT does not exceed the minimum, TFIN is set to the next higher (warmer) storage node temperature and the calculation of TFUT is repeated. These iterations continue until either TFUT exceeds the minimum or there are no warmer storage nodes left. If TFUT does not exceed TFMIN even when the warmest storage water is used as input to the evaporator, the heat pump is not used.

With the Duct Storage, Stratified Storage Temperature and Aquifer Storage models, TFIN is an estimate of the temperature of water available from storage. In these cases, if TFUT does not exceed the minimum acceptable outlet temperature, the heat pump is not used.

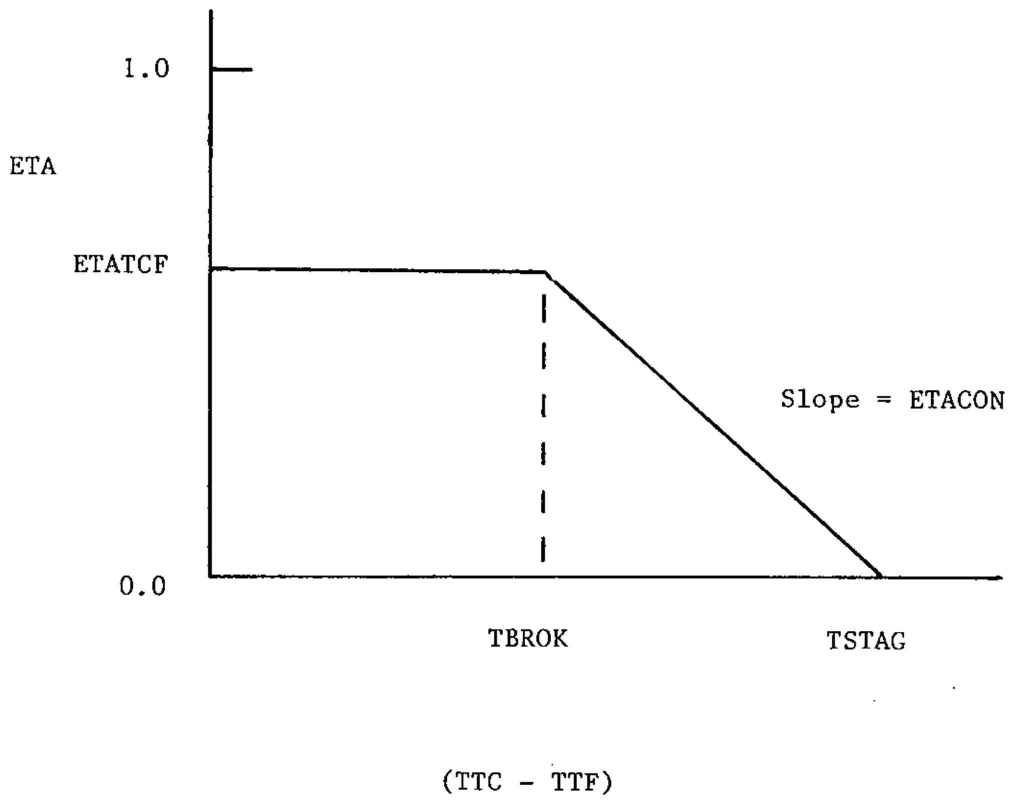
If the evaporator outlet temperature is considered constant (Option 2) the heat pump performance can be calculated explicitly without iterations. This option is only available when the Insulated Tank storage model is used.

First a storage node is chosen such that water supplied to the evaporator is more than 5 degrees above a user defined evaporator outlet temperature.

FLOWE = f(PPF, AKF, TFIN, TFUT, TTC, ETA).

FIGURE 5-10

Heat Pump Efficiency Curve



In both of the above options, the heat pump efficiency, ETA, is a function of (TTC - TTF) (see Figure 5-10). ETA has a constant user defined value until a user defined break point at which it slopes linearly to a user defined stagnation point.

If the heat pump is found to be operating past the break point the preceding calculations, of either option, are repeated to take into account the revised value of ETA.

If the entire load cannot be met with the heat pump, the heat pump is turned off and auxiliary power is used to boost the water supplied to the load to the correct temperature.

5.6 HEAT FLOW CALCULATIONS AND UPDATE

At the end of the simulation of each time period, total energy supply and losses are updated. This is done through some "bookkeeping" of the energy flows in each of the sub-systems just simulated. The energy supply, demand and losses for that time period, computed in the individual sub-system models as part of the simulation, are then added on to the total energy and heat flow values accumulated to date.

5.7 APPROXIMATION OF STEADY STATE CONDITIONS

In order to obtain results which reasonably reflect annual operations from a MINSUN simulation, the user must ensure that the storage temperature profile at the beginning of the simulation is approximately the same as that at the end. For DST and SST storage simulations, the pre-heating of the ground surrounding storage (see Section 4.6) should be performed using an annual storage temperature curve which approximates the true conditions.

These constaints are especially important for Multiple Simulation runs where two or more systems are being compared. If any of the systems are simulated at other than "steady state" conditions, the comparison of results will probably not be valid.

MINSUN includes logic to minimize this problem. The simulation is always run using the starting temperatures and pre-heating parameters specified by the user. At the end of this simulation, the average change in storage temperature from the beginning to the end of the year and the difference between the maximum storage temperature and the maximum temperature used in the pre-heating cycle (DST and SST only) are calculated. If either of these differences exceeds the maximum acceptable difference specified by the user, then the simulation is re-run. This applies to all storage models except AST for which the storage volume and, therefore the average storage temperature are not well defined. AST simulations always use the starting temperatures specified by the user.

The initial storage temperature for the new simulation is the final storage temperature from the first simulation. The maximum storage temperature used for the pre-heating cycle is the actual maximum storage temperature from the first simulation. This second simulation will be closer to the steady state conditions that the first. A maximum of two simulations is performed for each system configuration even if the two constraints are not met by the second simulation. If a second simulation is performed for a given configuration in a Multiple Simulation mode run, the new starting temperatures and pre-heating parameters and not the user specified values are used for all subsequent configurations.

It should be noted that users concerned about the increased computer time used for these resimulations can force MINSUN to perform only a single simulation of each configuration by specifying the maximum acceptable temperature differences as large numbers.

6.0 SYSTEM COST CALCULATIONS

Performing an economic analysis on a solar energy system involves calculating both the solar system costs and the auxiliary (conventional energy) system costs.

6.1 SOLAR SYSTEM COSTS

Solar system costs consist mainly of the capital costs of building the solar installation. Maintenance costs are not currently included in MINSUN. The solar system costs are therefore composed of the initial investments for:

- solar collectors
- storage
- piping and insulation
- heat pumps.

6.1.1 Solar Collector Costs

Solar collector costs are computed in a very straightforward manner. Regardless of the kind of solar collector specified in the design, the total costs of the solar collectors are simply the total area of collectors multiplied by the installed cost of collectors per unit area, input by the user.

6.1.2 Storage Costs

The program computes several storage-related costs, including the cost of digging the storage, and of purchasing the ground, concrete (for concrete tanks only) and insulation.

The largest component of the storage cost is the cost of contruction and installation, referred to in the program as the cost of "digging" the storage. This cost is calculated differently for each storage model. It depends on the size and shape of the storage and includes factors to allow for efficiencies in building large systems.

Ground costs, concrete costs and storage insulation costs are all computed by multiplying, for each of these variables, a user-input unit cost by the total amount of the variable (ground area, concrete and insulation) used.

For more information on the calculation of storage costs, the reader should refer to Appendix B and the Task VII report on storage costs[1].

6.1.3 Piping Costs

The piping networks also contribute to the capital cost of the solar system. The user supplies two parameters which determines the cost of the piping. CSNWL is a constant cost per metre of pipe. CSNWA is a diameter dependent cost i.e. cost/metre of diameter/metre of length. The total piping cost is, therefore,

$$((\text{diameter} * \text{CSNWA}) + \text{CSNWL}) * (\text{network length}).$$

The user also inputs a unit cost for pipe insulation. Multiplying the total volume of insulation in the network by this unit cost yields the total pipe insulation cost. Adding the total piping cost to the total pipe insulation cost gives the total cost of the pipe network.

For more information on the cost of the piping network, the reader should refer to the Task VII report on heat distribution systems[2].

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[1] ref 6.

[2] ref 7.

6.1.4 Heat Pump Costs

The final component of the solar system cost is the cost of the heat pump(s). The user inputs a specific cost, per watt per degree K, for both the evaporator and the condenser. MINSUN then multiplies these specific costs by the heat transfer capacity of the evaporator and condenser, respectively, and gives a total cost value for the evaporator and the condenser.

The cost of a heat pump motor, per watt, is also supplied by the user. This specific cost is multiplied by the peak heat pump power requirement, which determines the size of motor required, to yield the total motor (pump) cost.

Each of the capital costs for the heat pump, i.e., evaporator, condenser and motor, is multiplied by an exponential function to account for the difference in cost per unit power between a heat pump of the size used in the simulated system and a heat pump of the reference size for which the specific costs were input.

Therefore, for each of the evaporator and the condenser;

$$\text{Cost} = \underset{\substack{\text{(per watt,}\\ \text{per degree)}}}{\text{Specific Cost}} \times \underset{\substack{\text{(watts per}\\ \text{degree)}}}{\text{Actual Power}} \times \left[\frac{\text{Maximum Power}}{\text{Reference Power}}\right]^{\text{Exponent}}$$

The cost of the heat pump motor is:

$$\text{Cost} = \underset{\text{(per watt)}}{\text{Specific Cost}} \times \underset{\text{(watts)}}{\text{Actual Power}} \times \left[\frac{\text{Maximum Power}}{\text{Reference Power}}\right]^{\text{Exponent}}$$

The total heat pump cost is the sum of the costs of the evaporator, the condenser and the motor. In both of the above equations, Maximum Power refers to the peak power output from the condenser. Reference Power and Exponent are both input by the user.

The system can accommodate two heat pumps, one for house heating and one for tap water heating.

Finally, the electricity cost to operate the heat pump(s) is determined. It is the only solar system cost which is not a capital cost. The user supplies a cost of electricity (per kWh), which is then multiplied by the total electricity consumption of the heat pump(s) to give the total (annual) heat pump operation cost.

6.2 AUXILIARY SYSTEM COSTS

Auxiliary system costs are the costs of supplying, via auxiliary heating, the energy not supplied by the solar system.

The first auxiliary heating cost is the capital cost to install the auxiliary heater. This cost is computed as the product of a user-input installed auxiliary heater cost, per watt, and the peak auxiliary heater power requirement. This is done for both the house heating system auxiliary heater and the tap water heating system auxiliary heater, if these two systems were specified as separate.

The operation cost of the auxiliary heater(s) is simply obtained by multiplying the user-input cost of auxiliary fuel (e.g., oil, gas, ...), per kWh, by the total fuel required by the auxiliary heater(s) during the simulated period. The fuel cost supplied to the program must be the cost of providing heat. The program does not include a fuel efficiency factor

For the reader interested in more information concerning the costs as they are handled in MINSUN, all of the cost equations which have been discussed in this chapter are listed in Appendix B.

7.0 MULTIPLE SIMULATION

7.1 PROGRAM APPROACH

When run in Multiple Simulation mode, the MINSUN program simply runs a systematically defined series of Single Simulations. There is no attempt to optimize any of the parameters.

The program does not print a complete economic analysis and thermal profile for each configuration modelled. Instead, it only prints a small number of important results from the simulation and then moves to the next point.

There are two options in the Multiple Simulation mode. The Two Parameter Variation option systematically varies two key simulation parameters from a list of nine such parameters. The values printed are total annual costs and the solar cover fraction for each system.

The second option, the MINREP procedure, is much more flexible. Any simulation parameters can be varied and the user can select any output values produced by the simulation for inclusion in the printed report.

7.2 TWO PARAMETER VARIATION OPTION[1]

The simple Two Parameter Variation version of the Multiple Simulation mode is run if the option "GRAPH" is specified in the MINSUN parameter file (see Appendix A-4).

7.2.1 Definition of Simulated Systems

The user must select two system parameters, from the list in section 2.2.2, to be varied. For each of these, he supplies a maximum and a minimum value and the number of values through which the parameter should be varied.

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[1] This option is not operational with the Aquifer storage system.

If parameter 1 is to be varied from a minimum value of VMIN1 to a maximum value of VMAX1 through N1 points and parameter 2 is to be varied from VMIN2 to VMAX2 through N2 points, the program performs its first simulation at (VMIN1, VMIN2). It then increments parameter 2 by (VMAX2 - VMIN2) / (N2 - 1) and performs its second simulation. The first parameter is held constant at VMIN1, the second parameter is incremented and the simulations are repeated until parameter 2 reaches VMAX2. The first parameter is then incremented by (VMAX1 - VMIN1) / (N1 - 1), parameter 2 is reset to VMIN2 and the process is repeated. A total of N1 * N2 equally spaced points are simulated in total.

All parameters except the two being varied are kept constant for all of the runs at the values supplied in the parameter file. In particular, it should be noted that the storage height/diameter ratio is calculated based on the storage height and volume supplied in the STORAGE block (see Appendix A-4). If the storage volume is varied, but the height/diameter ratio is held constant, the height of the storage will be adjusted at each point to maintain the shape of storage specified in the STORAGE block.

If the user specifies more than two parameters to be varied, the program will only use the first two. If only one parameter is selected, storage volume will automatically be used as the second. Furthermore, if this version of Multiple Simulation mode is specified but no parameters are selected for variation, the program will use collector area and storage volume.

7.2.2 Simulation Results

As the program executes, it will print out the following line on logical output unit 98 (if running the program on-line, this should be specified as the user terminal):

```
"COLUMN n OF m HAS BEEN COMPLETED"
```

after each cycle through a complete set of values for variable 2. In the above, "n" represents the "current" column number, and "m" represents the total number of columns in the surface data matrix. This is essentially a diagnostic aid to inform the user that the program is actually running. The number of these messages printed is equal to the number of points specified along the direction of variable 1.

The results of all of the simulations are summarized in two output files. These files are described in Section 9.4 and Appendix F.

7.3 MINREP OPTION

This more flexible version of the Multiple Simulation mode is run if the option "REPT" is specified in the MINSUN parameter file (see Appendix A.4). This option requires two additional parameter files - one to specify the parameters to be changed and one to specify the values to be printed in the summary report. These extra files are documented in detail in Appendix A.5.

MINREP uses an array (the B-array) to store the current values of all system parameters and outputs. As the parameter file is read in by MINSUN, all of the inputs are stored in the appropriate elements of the B-array. The configuration defined by the parameter file is not run. MINREP immediately starts reading the file which specifies parameter changes. Single changes or iterative or nested changes can be specified for any parameters of the MINSUN program. Several changes can be made between simulations by specifying a change without a run for all but the last of these. It is also possible to change the collector type or weather information between runs by changing the FORTRAN logical unit from which the collector energy values are read.

Each change causes the appropriate element of the B-array to be updated and the old value of the parameter is lost.

After each simulation run, the simulation results are saved in the output section of the B-array. All variables selected by the user, up to a maximum of thirty-six, are written to the MINREP Multiple Simulation Results reports. Each simulation run produces one line in these summary reports.

A sample of the output produced by the MINREP option is included in Appendix F.

8.0 SYSTEM OPTIMIZATION[1]

8.1 OPTIMIZATION APPROACH

8.1.1 Design Variables

The MINSUN program was developed to allow a solar district heating system configuration to be specified and an optimizer to be invoked to yield the best selection of design variables to minimize the system capital and operating costs.

The package allows for optimization to proceed with respect to nine design variables. These variables are listed in Section 2.2.2. If the Duct Storage System is not used, only the first eight of these variables is available for optimizing.

8.1.2 Constraints

MINSUN's optimizer places fifteen (fourteen for non-DST storage) constraints on the system configuration. Eight of these constraints are set internally by the program. The remainder are supplied by the user. The constraints are included to prevent the optimizer from wasting computation time by simulating unreasonable systems. Table 8-1 identifies the constraints.

Categorically, there are two types of constraints. The first type is identified as being a condition on one of the nine independent variables of the system. The second type is a condition imposed on one of the quantities resulting from the simulation of the physical system over time.

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[1] This optimization algorithm is operational in this version of MINSUN with TANK, DST and SST (but not AST) storage. In practice, those who have used MINSUN for analysis have found that Multiple Simulation Mode with the MINREP option is a more flexible and reliable tool for system optimization. See references 1, 2, 3 and 4.

Table 8-1 **CONSTRAINT DEFINITION**

#	Constraint	Variable	Comment
1	Minimum collector area	COLMIN	input data
2	Maximum collector area	COLMAX	input data
3	Minimum storage volume	VOLMIN	input data
4	Maximum storage volume	VOLMAX	input data
5	Minimum storage height/diameter ratio		defined in FKT, value = .01
6	Minimum insulation thickness of storage		FKT, value = .01 m
7	Maximum insulation thickness of storage		FKT, value = 5.0 m
8	Minimum heat pump evap. heat transfer - tap water	ETMIN	FKT, value = 100 kW/K
9	Minimum heat pump condenser heat transfer - tap water	CTMIN	FKT, value = 100 kW/K
10	Minimum heat pump evap. heat transfer - house heating	EHMIN	FKT, value = 100 kW/K
11	Minimum heat pump condenser heat transfer - house heating	CHMIN	FKT, value = 100 kW/K
12	Maximum storage height	DEPMAX	input data
13	Minimum solar central heating cover	SUNCOV	input data
14	Maximum storage fluid temperature decrease		FKT, value = EPSIL (14)
15	Minimum number of Ducts in DST storage		not implemented in this version of MINSUN

8.1.3 Constraint Violation

Constraints 1 through 12 and 15 are those imposed on the nine independent variables. For a point lying on an optimization trajectory, tests for these thirteen constraints can be accomplished without another simulation run. Violation of any of these constraints results in an "out" condition and the point is rejected.

Constraints 13 and 14 are of the second type. Associated with each point lying on an optimization trajectory are two variables calculated in the simulation. These are the solar cover fraction and the temperature decrease over the year for the system storage.

Any valid minimum point must have a solar cover fraction and a temperature decrease number which satisfy the inequality conditions associated with constraints 13 and 14, respectively. If these constraints are not satisfied, a constraint violation (out condition) occurs and the optimizer retreats from that attempted simulation.

8.2 CONSTRAINT HANDLING - A PENALTY FUNCTION METHOD

8.2.1 Introduction and Definitions

MINSUN's optimization strategy uses a penalty function method as part of the implementaton of constraints. A penalty function is a positive function which is added to the cost function for points which lie sufficiently close to one or more of the constraint boundaries.

Penalty zone I is defined to be the interior region, around constraint I, in which the penalty function is added to the cost function. Since there can be a maximum of 15 constraints, there can be a maximum of 15 penalty zones. Table 8-2 contains definitions related to the penalty function approach. The distance from constraint I at which a penalty is applied and the magnitude of the penalty weighting coefficient are supplied as input data. All penalties are imposed as a quadratic function of distance into penalty zone I.

8.2.2 Penalty Application

The penalty function logic is contained in subroutine MINIM. If a point lying on an optimization trajectory is in a penalty zone, a penalty is added to the cost function value as described above. Intersecting penalty zones will cause multiple penalties to be applied to the cost value. Penalty implementation is illustrated by the algorithm below. The variables are defined in Table 8-2.

The Penalty Application Algorithm

```
FKTVST = FKTV
for (I = 1, 2, ..., 15)
If      EPSIL(I) - RAND(I)  0
        FKTVST = FKTVST + ALPHA(I) * $[EPSIL(I) - RAND(I)]^2$
        IDRAND(I) = 1
Else    IDRAND(I) = 0
```

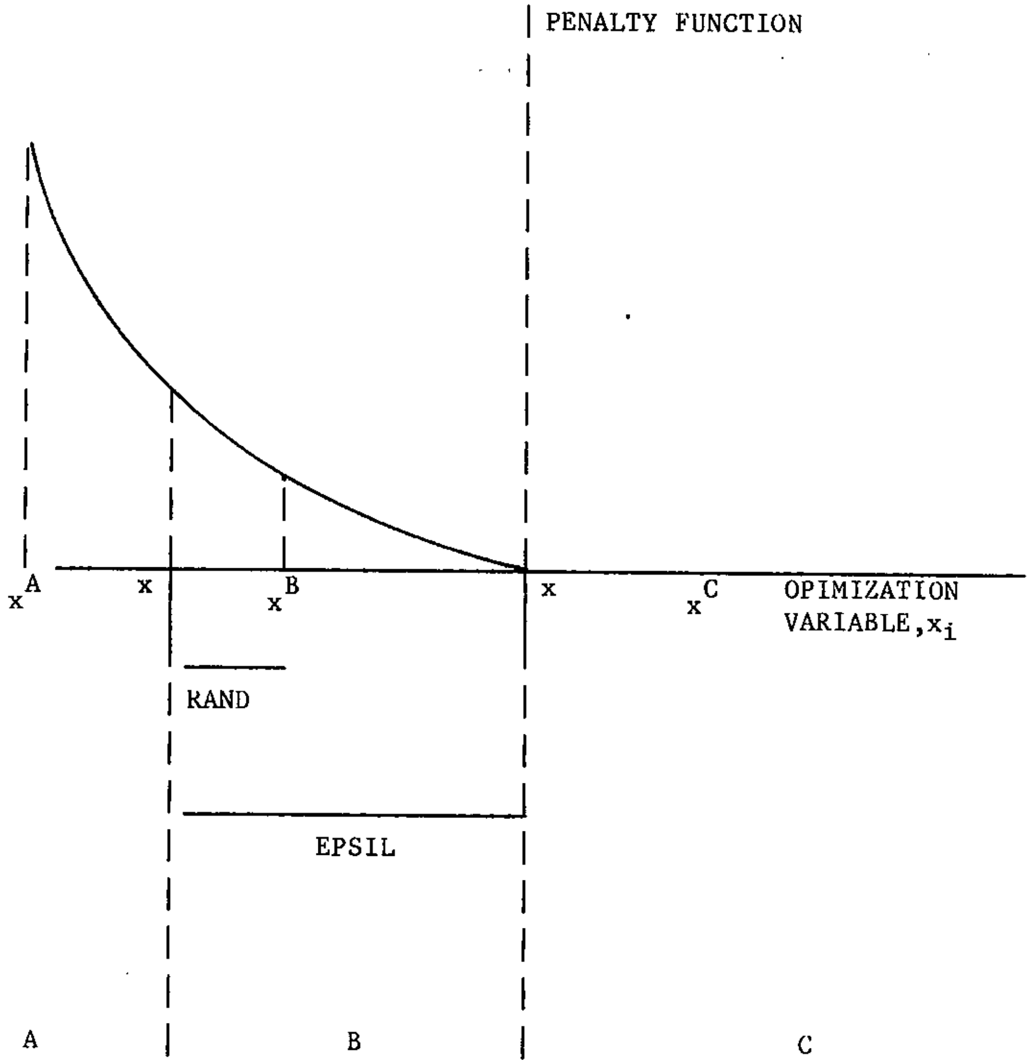
The severity of the penalty applied is a function of the number of penalty zones penetrated and the degree of penetration of each zone. Figure 8-1 is a graphic description of penalty application due to penetration of a constraint's penalty zone.

TABLE 8-2 DEFINITIONS RELATED TO THE PENALTY FUNCTION METHOD

FKTV	cost function value at point under consideration	calculated in FKT
FKTVST	cost function value + penalty value at point under consideration	calculated in MINIM
EPSIL (I)	distance from boundary I at which penalty starts	input data
RAND (I)	distance from point under consideration to boundary I	calculated in FKT
IDRAND (I)	= 0 if point is not in penalty zone I = 1 if point is in penalty zone I (*)	calculated in MINIM
ALPHA (I)	weighting coefficient for penalty applied when point under consideration is within penalty zone I (*)	input data

(*) penalty zone I is considered to be a defined portion of the interior region (except for constraint #14, where the penalty zone is outside boundary I), adjacent to boundary I, in which a penalty is applied to the cost function.

FIGURE 8-1 ILLUSTRATION OF PENALTY IMPLEMENTATION FOR A CONSTRAINT IMPOSED ON OPTIMIZATION VARIABLE x_i



A. Forbidden Region (Optimizer retreats from this region)

B. Portion of Defined Penalty Zone Overlapping with the Allowed Region (Cost function suffers the penalty shown in the graph)

C. Allowed Region (No penalty inflicted)

8.3 THE OPTIMIZATION PROCESS AND ITS STOPPING CRITERIA

The optimization program moves in a given direction until it finds a minimum cost value on that line. It then determines a new direction in which to search and finds the minimum value on this line. At each change of direction, the calculated cost is compared to the costs at the previous two changes of direction. The process is terminated if any of the following conditions is true:

1. The changes in the cost function between the last three direction changes is less than a user specified value.

2. The calculated costs at the last two direction changes are identical.

3. The maximum number of simulations supplied by the user has been exceeded.

In addition, if the first of these criteria is used, the program compares the values of the system parameters being optimized at the last two simulation points. If the number of significant figures in each design variable is not at least a user specified minimum, the optimization process continues until this condition is met.

The optimization control strategy and the stopping criteria are explained in much more detail in Appendix E.

8.4 STANDARD DEVIATION OF THE COST FUNCTION

As part of any optimization run, MINSUN calculates the standard deviation of the 50 cost function values generated immediately prior to a minimum being found. Several related values are printed. These are:

1. the number of cost function values used (which may be less than 50 if fewer than that number of evaluations have been performed).
2. the accumulated sum of the cost function values,
3. the average value of the cost function,
4. the standard deviation,
5. the minimum value of the cost function, and
6. the maximum value of the cost function.

The calculation of the standard deviation of the last 50 cost function values encountered prior to the declaration of a minimum being found provides insight into the nature (the smoothness) of the cost function surface in the vicinity of the minimum. It also provides an indication of the meaningfulness of the precision specified for the design variables.

It is expected that this information will be useful to the designer in interpreting the results of an optimization run.

9.0 PROGRAM OUTPUTS

9.1 INTRODUCTION

The MINSUN program produces up to twelve files of output. These are:

- Simulation Summary;
- Monthly System Profile;
- Monthly Temperature Profile;
- Weekly System Profile;
- Weekly Temperature Profile;
- Daily System Profile;
- Daily Temperature Profile;
- Two Parameter Variation Cost Figures;
- Two Parameter Variation Details;
- MINREP Multiple Simulation Results (up to 3 files).

Not all of these files are produced by every MINSUN run. Single Simulation and System Optimization runs produce the Simulation Summary and some subset of the Time Profile Reports determined by the user. Multiple Simulation mode runs using the Two Parameter Variation option produce the Simulation Summary and the two "Two Parameter Variation" files. Multiple Simulation mode runs using the MINREP option produce the Simulation Summary and MINREP Multiple Simulation Results.

9.2 SIMULATION SUMMARY

This output file is produced by all MINSUN runs. It is made up of three main sections:

- A formatted summary of all input parameters;
- A Summary of the optimization process;
- The results of the simulation.

The first of these is included for all runs. The optimization summary is only produced by System Optimization runs. The simulation results section is printed for both Single Simulation and System Optimization runs.

9.2.1 Optimization Process Output

When used in optimization mode, MINSUN can print out results from the iterations of the optimization process. The user must specify, in the input parameter file, the frequency with which these results are to be printed.

On the printout, immediately following the input parameters, the line

START OF OPTIMIZATION

is printed, indicating that the optimizer has been invoked and that the optimization iterations will be printed next.

The values associated with each new point generated by the optimization process are printed in two lines.

The first of these lines gives:

VAR(I), I = 1,...,9

The value (size) of each of the nine system components which can be optimized: collector area, storage volume, storage height/diameter ratio, storage insulation thickness, specific heat transfer of the evaporator for tap water, of the condenser for tap water, of the evaporator for house heating, of the condenser for house heating, and number of ducts for DST storage. All nine values are given at each iteration, even when fewer than nine variables are being optimized on. If DST storage is not used only the first eight values are printed.

The second line gives:

FKTV
The value of the cost function at the point under consideration.

FKTVST
The value of the cost function + penalty at the point under consideration.

If the point is in the penalty zone of any constraint, then the second line also contains:

i
The constraint number (1-15) whose penalty region has been entered.

RAND(i)
The distance between the point and the boundary of constraint #i.

If more than one constraint's penalty region is entered, this second line contains the penalty information for the other "penalized" constraints as well.

In the case where constraint #i is completely violated (i.e., when the point falls outside of the boundary of constraint #i), the second line only shows the message

```
OUT i
```

and does not give any other information.

These two lines are printed for every point calculated by the optimizer (unless the user specifies otherwise).

The program also prints out

CHANGE OF DIRECTION

when the optimizer has finished searching in a given direction and starts a search in the next direction.

In addition, when a coordinate transformation occurs, the program prints the total number of points calculated so far. LAMBDA (the vector of step lengths in each of the search directions) is also given. Finally, the direction matrix, which defines the coordinate transformation, is printed.

When a minimum point has been found (i.e., when LAMBDA is equal to the null vector), the program prints the word

MINIMUM POINT

followed on the next line by the values of the nine "optimal" design variables, and finally, on the line following that, by the minimum value of the cost + penalty function.

Following this, the standard deviation of the cost function and other related values (ref. section 8.4) are printed. This is then followed by a formatted printing of the optimization results.

9.2.2 Simulation Results

This part of the output is itself made up of two sections which present details of the cost of the system and its thermal performance. For a Single Simulation, this information is given for the system specified by the user. For an optimization run, this output is for the optimal system found by the program.

9.2.2.1 Economic Analysis

The economic analysis output is divided into three parts.

Cost function factors are first printed. The total capital cost and capital cost annualization factor, along with the total first-year operation cost and operation cost annualization factor, are given. The total annual cost, which is the annualized capital cost plus the annualized operating cost, is then given.

The capital cost of each of the system components is then printed.

Finally, the specific capital and operation costs for each of the sub-systems, per MWH, are printed. Central (solar) system costs are added to auxiliary system costs to yield the cost, per unit of supplied energy, of the total system.

Details of the calculation of many of the variables contained in the economic output from MINSUN, which have just been outlined, are included in Appendix B. The investment costs in the specific costs section which are not documented in Appendix B are calculated by multiplying the capital costs (which are included in Appendix B) by the capital cost annualization factor.

9.2.2.2 Thermal Performance

A summary of the annual thermal characteristics of the system constitutes most of the output from MINSUN. These characteristics, along with the units in which they are expressed, are clearly indicated and formatted on the output.

The heat flow summary for the system is first presented. The energy collected in the solar collector sub-system, minus collector network losses, is the energy which goes into storage. From this quantity are subtracted the storage losses and the storage heat gain/loss during the year, to give net collector/storage energy supplied.

The energy supplied by the heat pump(s) and by the auxiliary heater are then added to the solar (collector/storage) supply to give the total amount of energy supplied to meet the load. This supplied energy is equal to total load requirements plus distribution network losses.

Three energy ratios are also given. These ratios, which are three different expressions of "solar fraction", give a quick indication of the solar contribution to the system.

After these ratios have been given, a summary of the temperature changes of storage is presented.

The last results printed for most simulations are the heat pump(s) energy input and output and the diameter and insulation thickness of the collector network pipes.

For runs which use the Aquifer (AST) Storage model, a summary of the aquifer performance is included in the simulation summary file. This section gives the maximum and final size of the thermally active region of storage and the total volumes and average temperatures of water injected into the active well and dumped into the cool feed well (which is not modelled).

9.3 TIME PROFILE REPORTS

For Single Simulation and System Optimization runs, a number of files can be produced which give details of the thermal processes throughout the system. For a Single Simulation, this information is given for the system defined by the user. For a System Optimization run, this output is for the optimal system found by the program.

For each period, the information printed in the System Profile reports includes:

- collected energy;
- piping losses;

- storage temperatures (only top and bottom nodes for TANK storage);
- storage losses;
- auxiliary energy added;
- heat pump electrical energy added and condenser output;
- system load;
- collector temperature into storage;
- collector flow into storage.

The Temperature Profile reports give storage temperatures at the end of each period. They are produced only by simulations using the TANK and SST storage model.

The number of these reports produced is determined by the user through the parameter IPRINT in the Report Option block of the MINSUN parameter file as follows:

IPRINT	TIME PROFILES PRODUCED
<1	none (default)
1	Monthly
2	Monthly and Weekly
>2	Monthly, Weekly and Daily

Further details on these reports and sample reports are included in Appendix F.

9.4 MULTIPLE SIMULATION OUTPUTS

The output produced by a Multiple Simulation run depends on the option chosen. For Two Parameter Variation runs, a number of important results are printed for each configuration modelled. These are:

- the values of the two varied design parameters;
- the total annual cost of the system;
- the solar cover fraction;
- the total capital cost and annual operating cost;
- the change in average storage temperature from the beginning to the end of the simulation.

These figures appear in two output files. The first, which can be used as input to a three-dimensional plotting routine contains only the parameter values and the total annual costs. The second contains all of the above information.

If the MINREP option is used, up to three reports are produced which consist of one record for each simulation performed. The values printed in these reports are specified by the user through a pararmeter file which is explained in Appendix A.5.

More details on these reports and sample reports are included in Appendix F.

REFERENCES

REFERENCES

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5. Tools for Design and Analysis, Verne G. Chant and Ronald C. Biggs, December, 1983, National Research Council, Canada, available as CENSOL1 from Technical Information Office, Solar Energy Program, National Research Council, Ottawa, Canada, K1A 0R6.

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7. Basic Design Data for the Heat Distribution System, Tomas Bruce, Lennart Lindeberg an Stefan Roslund, October, 1982, Swedish Council for Building Research, Sweden, available as D22:1982 from Svensk Byggtjänst, Box 7853, S-10399, Stockholm, Sweden.

APPENDIX A

USER SUPPLIED INPUTS TO THE MINSUN SET OF PROGRAMS

The user must supply inputs to the MINSUN set of programs in six files:

1. Weather Data File
2. UMSORT Parameter File
3. ADVANCE Parameter File
4. MINSUN Parameter File
5. MINREP Output Specification File
6. MINREP Parameter Change Specification File

Appendix A describes the contents of these files and also includes a sample of each.

A.1 Weather Data File

The following five values must be supplied to the UMSORT program on FORTRAN Logical Unit 4 for each hour of the year:

Variable	Units
Direct Normal Radiation	$kJ/hr.m^2$
Horizontal Radiation	$kJ/hr.m^2$
Ambient Dry Bulb Temperature	°C
Wind Speed	km/hr
Ambient Dew Point	°C

Direct normal radiation is the radiant energy received directly from the sun on a surface which tracks the sun. Horizontal radiation is the total of direct and diffuse radiant energy received on a horizontal surface. See section 3.2.1 for more details.

The first line of the file identifies the city for which the data is supplied. This is read in the format A4 and reprinted by UMSORT. Following this, the required data is supplied a day at a time with five lines for each day - one line for each variable listed above. The format of each line is (3I2, 24F7.2).

Each line starts with the date corresponding to the data in the form MMDDYY. The remainder of the line gives the 24 hourly values for a data element.

The next page is an example of the first few days of the 1978 weather file for Madison, Wisconsin.

```
MADI
 10176   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 10178   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36  90.85 124.92 158.99 113.57  90.85  34.07  11.36   0.00   0.00
 10178   1.11   1.11   1.11   1.11   1.11   1.11   1.11   0.56   0.56   0.56   1.11   1.11   1.11   1.11   1.11   1.11   0.56   0.56
 10178  14.48  14.48  14.48  17.70  19.31  22.53  20.92  19.31  17.70  17.70  16.09  14.48  11.27   8.05   4.83   6.44   9.66  11.27
 10178  -3.33  -3.33  -3.33  -2.78  -2.22  -1.67  -1.67  -1.11  -1.11  -0.56  -0.56   0.00   0.00   0.00   0.00   0.00   0.00   0.00
 10278   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.361726.201817.052555.232521.162135.041067.52   0.00   0.00
 10278   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36  56.78 147.641022.091090.231237.871112.94 806.32 363.41  45.43   0.00
 10278   0.00   0.00   0.00   0.00   0.56   0.56   0.56   0.56   0.56   1.11   1.67   2.22   2.22   1.67   1.67   0.56  -0.56  -2.22
 10278  17.70  20.92  22.53  22.53  22.53  22.53  24.14  25.75  27.36  25.75  24.14  22.53  24.14  24.14  25.75  25.75  24.14  24.14
 10278   0.00   0.00   0.00   0.00   0.00   0.00  -0.56  -1.11  -1.67  -2.22  -3.33  -3.89  -4.44  -4.44  -5.00  -5.56  -6.11  -6.67
 10378   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00 783.602123.682543.872736.932736.932350.811919.261203.80   0.00   0.00
 10378   0.00   0.00   0.00   0.00   0.00   0.00   0.00  34.07 283.91 794.961090.231260.581260.581044.80 749.53 329.34  34.07   0.00
 10378  -5.00  -5.56  -6.11  -6.67  -7.22  -7.78  -7.22  -7.22  -6.67  -4.44  -1.67   0.56   1.11   1.67   2.22   0.56  -1.67  -3.33
 10378  11.27   8.05   4.83   3.22   1.61   0.00   0.00   0.00   0.00   3.22   6.44   9.66   8.05   8.05   8.05   8.05   8.05   9.66
 10378  -7.78  -7.78  -8.33  -8.33  -8.89  -9.44  -8.89  -8.33  -7.78  -6.67  -5.56  -4.44  -3.89  -3.33  -3.33  -3.89  -4.44  -5.56
 10478   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  22.71 227.13  34.07   0.00  34.07  45.43   0.00  11.36   0.00   0.00
 10478   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36 249.84 635.97 624.61 601.90 704.11 635.97 386.12 158.99  22.71   0.00
 10478  -3.33  -3.33  -2.78  -2.78  -2.78  -3.33  -2.22  -1.67  -1.11  -0.56   0.00   0.56   1.11   1.11   1.67   1.11   0.00  -0.56
 10478  14.48  16.09  16.09  16.09  14.48  12.87  14.48  16.09  16.09  20.92  24.14  27.36  24.14  20.92  17.70  16.09  14.48  12.87
 10478  -5.00  -4.44  -3.89  -4.44  -4.44  -5.00  -4.44  -3.89  -3.33  -2.78  -2.78  -2.78  -2.22  -2.22  -2.22  -2.22  -2.22  -2.78
 10578   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  90.85 340.70 976.671612.631010.74 454.26 488.33 601.90   0.00   0.00
 10578   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36 181.71 488.33 817.671181.081022.09 704.11 556.47 283.91  22.71   0.00
 10578   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.56   0.56   1.11   2.22   2.78   2.78   3.33   3.33   1.67   0.00  -1.67
 10578  14.48  12.67  11.27   9.66   9.66   9.66  11.27  14.48  16.09  16.09  16.09  14.48  11.27   8.05   4.83   3.22   1.61   0.00
 10578  -1.67  -1.67  -1.67  -1.67  -1.11  -1.11  -1.67  -1.67  -2.22  -2.22  -2.22  -2.22  -2.78  -3.33  -3.89  -3.89  -3.89  -3.89
 10678   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36  11.36  11.36   0.00   0.00
 10678   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  56.78 113.57 215.77 522.40 454.26 238.49 204.42 113.57   0.00   0.00
 10678  -1.11  -1.11  -0.56  -0.56   0.00   0.00   0.00   0.56   0.56   1.11   2.22   2.78   2.78   3.33   3.33   2.78   2.78   2.22
 10678   6.44   9.66  11.27  11.27  11.27  11.27  11.27  11.27  11.27  14.48  16.09  17.70  12.87   6.44   0.00   3.22   8.05  11.27
 10678  -2.22  -2.22  -2.22  -1.67  -1.11  -0.56  -0.56   0.00   0.00   0.56   0.56   1.11   1.11   1.67   1.67   1.67   1.11   1.11
 10778   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  22.71  11.36  11.36  11.36   0.00   0.00   0.00   0.00   0.00   0.00
 10778   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36  68.14 193.06 261.20 227.13 124.92  90.85  22.71  22.71  11.36   0.00
 10778   4.44   5.00   5.00   4.44   4.44   3.89   4.44   4.44   5.00   5.56   6.67   7.22   6.67   6.67   6.11   6.11   6.11   6.11
 10778  17.70  16.09  14.48  12.87  11.27   9.66  11.27  14.48  16.09  14.48  11.27   9.66   9.66   9.66  11.27   9.66   9.66   9.66
 10778   2.78   3.33   3.33   3.33   2.78   2.78   3.33   3.33   3.89   4.44   5.00   5.56   5.56   5.00   5.00   5.00   5.56   5.56
 10878   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36  11.36  68.14   0.00
 10878   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36  34.07  34.07 102.21  79.50  56.78  68.14 113.57 136.28  22.71   0.00
 10878   4.44   3.89   2.78   3.33   4.44   5.00   5.00   5.00   5.00   5.00   5.00   5.00   3.33   1.11  -0.56  -2.78  -5.56  -7.78
 10878   3.22   6.44   9.66   8.05   8.05   8.05   4.83   3.22   0.00   1.61   3.22   4.83  12.87  19.31  25.75  30.58  33.80  38.62
 10878   4.44   3.33   2.78   3.33   4.44   5.00   5.00   5.00   5.00   5.00   4.44   4.44   2.22  -0.56  -2.78  -5.56  -8.33 -11.67
 10978   0.00   0.00   0.00   0.00   0.00   0.00   0.00  68.14 533.761873.832475.732668.802668.802362.17 340.70  11.36  34.07   0.00
 10978   0.00   0.00   0.00   0.00   0.00   0.00   0.00  34.07 374.77 806.321147.011317.361317.361124.30 692.75 170.35  22.71   0.00
 10978 -14.44 -15.00 -15.56 -16.11 -16.67 -17.22 -16.67 -16.67 -16.67 -15.56 -14.44 -13.33 -12.78 -12.22 -12.22 -12.78 -13.33 -14.44
 10978  25.75  25.75  25.75  24.14  24.14  22.53  24.14  24.14  25.75  24.14  22.53  20.92  19.31  17.70  16.09  16.09  16.09  16.09
 10978 -20.56 -20.56 -21.11 -21.67 -22.22 -22.78 -23.33 -23.89 -24.44 -23.89 -22.78 -22.22 -21.67 -21.11 -20.56 -20.56 -21.11 -21.11
 11078   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36 329.342305.382577.942396.241612.631760.27 874.46 306.63   0.00
 11078   0.00   0.00   0.00   0.00   0.00   0.00   0.00  11.36 193.06 556.471124.301294.651249.22 988.02 783.60 397.48  45.43   0.00
 11078 -17.78 -17.78 -17.78 -17.22 -17.22 -16.67 -16.11 -15.56 -15.00 -13.33 -12.22 -10.56  -9.44  -8.33  -7.22  -7.22  -7.22  -7.78
 11078   8.05   8.05   8.05   8.05   9.66  11.27   9.66   9.66   9.66  11.27  14.48  16.09  16.09  16.09  16.09  14.48  12.87  11.27
 11078 -22.22 -22.22 -22.22 -22.78 -22.78 -23.33 -22.22 -21.11 -20.56 -19.44 -18.33 -17.78 -16.67 -15.56 -13.89 -13.33 -12.78 -12.22
 11178   0.00   0.00   0.00   0.00   0.00   0.00   0.00 193.06  22.71  22.71  45.43 340.70  45.43 295.27  11.36  11.36  90.85   0.00
 11178   0.00   0.00   0.00   0.00   0.00   0.00   0.00  34.07 147.64 329.34 420.19 908.53 454.26 556.47 295.27 181.71  45.43   0.00
 11178 -10.56 -11.67 -13.33 -13.33 -13.33 -13.89 -13.33 -12.22 -11.67  -8.33  -5.56  -2.78  -2.22  -1.67  -1.11  -1.67  -1.67  -2.22
```

A.2 UMSORT Parameter File

The UMSORT parameter file is read in free format. The exact position of the parameters on a line is not important.

The parameters required by UMSORT are:

• DYMON(1) to DYMON(12)	specifies the number of days in each of the 12 months of the year consistent with the weather file.
• ION(I), I = 1,...,6	= 0 or 1 specifies if collector output files are to be produced (1 for yes, 0 for no), for each of: I = 1: flat plate; I = 2: salt pond; I = 3: evacuated tube; I = 4: central receiver; I = 5: parabolic trough; I = 6: shallow pond.
• IBOZ	= 0 or 1 specifies if Boes model is to be used (1 for yes, 0 for no). See section 3.2.1 for more details.
For I = 1 to 6 (I defined as above):	
• TALPHA(I)	collector transmittance-absorptance product $(\tau\alpha)$.
• UL1(I)	collector linear heat loss coefficient $[W/m^2K]$.
• UL2(I)	collector quadratic heat loss coefficient $[W^2/m^4K^2]$.
• BO(I)	incident angle modifier coefficient.
• TILT(I)	angle of incline of collector from horizontal [degrees].
• DIR(I)	direction in which collectors are pointing [degrees: south = 0].

• RHO (I)	ground reflectance coefficient It should be noted that the Flat Plate and Evacuated Tube collector models include a calculation of energy reflected from the ground. For large collector arrays, however, this energy will be minimal. In these cases, RHO should be given a value of 0.
• ALAT	latitude of city (North is assumed) [degrees].
• DLONG	shift in solar time hour angle (city longitude - standard meridian) [degrees].
• TEMP(1) to TEMP(5)	specifies 5 collector operating temperatures [°C] for which daily collected energy is calculated using the collector model.
• TMAMB	outdoor temperature limit above which house heating is not needed [°C].
• TROOM	desired indoor temperature [°C].

The next page is an example of an UMSORT parameter file.

NOTE: Each record of collector efficiency parameters is processed by UMSORT using a collector specific model. Therefore, a flat plate collector must be specified in line 1, a pond in line 2, an evacuated-tube collector in line 3, etc.

```
*       SAMPLE PARAMETER INPUT TO UMSCRT
* J  F  M  A  M  J  J  A  S  O  N  D
 31 28 31 30 31 30 31 31 30 31 30 31
*
* FLPL POND EVAC CENT PART SHPO  BOES
   0     0   1    0    0    0     0
*
* TALPHA     UL1      UL2       BO       TILT      DIR       RHO
 000.8080 004.4000 00000000 000.1000 043.0000 00000000 000.2000
 000.3370 000.2900 00000000 000.0500 00000000 00000000 00000000
 000.5100 001.3100 00000000 000.1700 043.0000 00000000 000.2000
 000.9800 00000000 00000000 00000000 00000000 00000000 00000000
 000.8070 000.0890 000.8690 00000000 00000000 00000000 000.2000
 000.6400 004.4000 00000000 00000000 00000000 00000000 00000000
*
* LAT   LONG  T1  T2  T3  T4  T5 AMB ROOM
 43.00 00000 030 050 070 090 110 010 018
```

A.3 ADVANCE Parameter File

The ADVANCE parameter file is read in free format. The parameters contained in the file are:

ADVANCE INPUT PARAMETERS

• ISTART	number of day in the the year (January 1st = 1) on which simulation is to begin.
• IEND	must = 365, or else the present version of MINSUN will not run.
• ADJUST	multiplicative (efficiency) factor normally less than or equal to 1.0, to compensate for "array effects" in collectors.

A sample ADVANCE parameter file is shown on the next page.

```
* SAMPLE ADVANCE PARAMETER FILE
*      START    END     ADJUST
        91       365     0.70
* NOTE:  END WILL NORMALLY BE 365, AND ADJUST < 1.0
* ADJUST VARIES WITH COLLECTOR TYPE AS FOLLOWS:
*      FLAT PLATE              0.66
*      EVACUATED TUBE          0.70
*      PARABOLIC TROUGH        0.77
*      CENTRAL RECEIVER        0.85
```

A.4 MINSUN Parameter File

The MINSUN parameter file is given in free format and ordered in blocks. Each data block has a block name which is identified by the first three letters of this name. Although the ordering of blocks within the file is generally quite flexible, there are some restrictions. It is recommended that the blocks be supplied in the order in which they are outlined below. Note, in particular, that the first card of the file must be a title card and the last one an END card. A card beginning with a * is treated as a comment card and ignored. Such a card can be placed anywhere in the input deck after the title card.

Card 1: Title card

The first card in the file is a title card which is used for identification purposes only. It is read in A80 format. An optional second card may contain words to change the default options. If none of these words are included in the file, the program will run in system optimization mode, with a heatpump, but with no seperate tap water distribution system.

WORD	**Changes to**
SING	Single Simulation.
GRAPH	Multiple Simulation - Two Parameter Variation.
REPT	Multiple Simulation - MINREP procedure.
NOHEATP	No heat pump in the system.
TAPW	Separate distribution system for tapwater.
*	Another card with options follows (may be repeated as necessary).

The words SING, GRAPH and REPT are mutually exclusive and at most one can be used for any run.

Block: Collector network insulation

This block must always be included.

INS	Block identification.
CONDIS	Insulation thermal conductivity coefficient (W/mK).
TEARTH	Earth temperature (°C).
DIMIS	Diameter dependent insulation thickness (m of insulation/m diameter).
FIXIS	Insulation thickness (m). Total insulation thickness is DIMIS * diam + FIXIS.

Block: Collector

This block must always be included.

COL	Block identification.
OPT	Option parameter must = 3 for MINSUN to use UMSORT power data (IEA collector models).
COLARZ	Collector area. If the collector area is one of the system parameters being optimized, this is the initial value. (Should fit the collector network diameter initial value) (m^2).
DTEMP	Not used by this version of the program. Supply an arbitrary value.
DTMAX	Maximum difference between collector outlet temperature and highest storage temperature if inlet temperature is greater than (TMAX1 - DTMAX). (See Figure 5-7).

TMAX1	Maximum collector outlet temperature if inlet temperature is less than (TMAX1 - DTMAX).
DUMMY	Not used by this version of the program. Supply an arbitrary value.
TMAX2	Maximum collector outlet temperature (°C) This is also the maximum temperature attainable by the storage volume.
COLFLZ	Normal collector mass flow (kg/m^2s). For aquifer storage systems, TMAX1 and TMAX2 should be equal and COLFLZ should be small in order to force a constant collector outlet temperature (see Section 5-3).
FLOWMZ	Maximum collector mass flow (kg/m^2s).
CNWLZ	Collector network length (m).
SISCOZ	Not used by this version of MINSUN. Supply an arbitrary value.
DRC1	Network pipe diameter (m) (should fit collector area initial value). This value changes as collector area changes if collector area is optimized.

Block: Storage

This block must always be included.

The parameters in the storage block vary considerably depending on the storage model used. For TANK storage, the parameters are:

STO	Block identification.
VOL	Storage volume (m^3). If volume is one of the system parameters being optimized, this is the initial value.

HEIGHT	Storage height (m). If storage height/diameter ratio is not being optimized, HEIGHT and VOL will be used to calculate a constant ratio. If height/diameter ratio is optimized, this will be used as the initial value.
NEQ	Number of nodes in the tank.
DENS	Fluid density (kg/m^3).
TGR	Ground temperature outside storage (°C).
TSTA	Start temperature vector for NEQ nodes, beginning from top (°C) (NEQ values).
DTSMAX	Maximum acceptable difference between average storage temperature at beginning of simulation and average storage temperature at end of simulation. If the actual difference calculated in the simulation is more than DTSMAX, the starting temperature is reset to the calculated end temperature and the simulation is repeated (See Sectoin 5.7).
TLID	Thickness of top insulation (m).
TWAL	Thickness of wall insulation (m).
TBOT	Thickness of bottom insulation (m). If insulation thickness is optimized, TLID, TWAL and TBOT will be the initial values. The ratios between TLID, TWAL and TBOT will be preserved throughout the calculation. For System Optimization runs, the Store Insulation Thickness printed in the Optimization Results section of the Simulation Summary is the insulation thickness on the walls of the tank.
UT	Thermal conductivity of top insulation (W/m K).
UW	Thermal conductivity of wall insulation (W/m K).

UB	Thermal conductivity of bottom insulation (W/m K).
IPAR	Option IPAR = 1 means ground temperature (TGR) just below the bottom, ambient temperature elsewhere. IPAR = 2 means ground temperature also outside the wall. IPAR = 3 means ground temperature everywhere.
THICR	Thickness of concrete (m).

If DUCT storage is used, the storage block contains the following parameters:

STO	Block identification.
VOLUME	Volume of storage region (m^3).
DEEP	Depth of the vertical bore-holes (m). Defines distance between ground surface and bottom of storage. Note that this value should by considerably larger than DEPTH (see below).
NBORE	Number of boreholes.
RO	Outer radius of each borehole (m).
THISO	Thickness of covering thermal insulation (m).
RISLAM	Thermal conductivity of insulation (W/mK).
ISO	= 0, no thermal insulation. = 1, insulation on upper surface and side of storage volume. An upper fraction FRISO of the side is covered. = 2, insulation on upper surface of the storage. This horizontal insulation extends a certain distance beyond the side of the storage. This distance is a fraction FRISO of the height of the storage volume.

FRISO	Fraction of the height of the storage volume. See definition of ISO, above, for details.
DEPTH	Distance between ground surface and upper surface of storage volume (m).
RLAMR	Thermal conductivity in the storage volume (W/mK).
RMPIPE	Thermal resistance (mK/W) between fluid and soil/rock at the pipe radius. The thermal resistance of the pipe wall is calculated as ln(RO/Ri)/(2*3.14159*Zp) where RO is the outer radius and Ri is the inner radius of the pipe. The thermal conductivity of the pipe material is denoted Zp. An effective thermal resistance between the fluid and the inner side of the pipe, and a surface resistance at the outer side of the pipe should be included in this value.
TIMO3	Maximum duration of the simulation (years). This parameter is only used for the generation of the numerical mesh.
TSTMAX	Maximum mean temperature allowed in the storage volume (°C). The solar heat collected during a day is discarded and not stored if this maximum temperature would be exceeded.
IPRE	Number of annual cycles with preheating of the ground surrounding the storage. The temperature of the store used in the preheating calculation is then a sinusoidal variation with a period of one year. The minimum temperature is given by the start value and the maximum temperature is given by TCMAX (see below). IPRE must be given an integer value which is greater than or equal to zero.
TCMAX	Maximum storage temperature during the preheating period (°C). See definition of IPRE, above.

DTPMAX	Maximum acceptable difference between maximum storage temperature used in preheating period (TCMAX above) and actual maximum storage temperature. If the actual difference calculated in the simulation is more than DTPMAX, the simulation is re-done using the actual maximum temperature to define the preheating curve. The storage starting temperature is reset to the end temperature from the initial run (See Section 5.7).
TSTART	Initial ground surface temperature (°C).
TGRAD	Temperature gradient used together with TSTART to define initial temperature in the ground (°C/m).
ILAY	Number of layers in the ground with different thermal properties. ILAY must be greater than zero.
RLAM(I)	Thermal conductivity in a layer (W/mK).
CL(I)	Volumetric heat capacity in a layer (J/m^{3}K).
THL(I)	Thickness of a layer (m).
	The above three parameters must be repeated, as a group, for each of the ILAY layers in the ground. That is, RLAM, CL and THL for the top layer; RLAM, CL and THL for the second layer, etc. Note that the deepest layer must extend beyond the bottom of the mesh generated by the program. This can be accomplished by making the thickness of the last layer very large.
TSTA	Starting temperatures at the two nodes (two values) (°C).
DTSMAX	Maximum acceptable difference between average storage temperature at beginning of simulation and average storage temperature at end of simulation. If the actual difference calculated in the simulation is more than DTSMAX, the starting temperature is reset to the calculated end temperature and the simulation is repeated (See Section 5.7).

If the STRATIFIED ground storage model is used, the storage block contains the following parameters:

STO	Block Identification.
VOLST	Volume of storage region (m^3).
HEIGHT	Height of storage region (m).
THISO	Thickness of covering thermal insulation (m).
FRIST	Relative weight for insulation thickness on upper surface of the storage region. The insulation thickness then becomes FRIST*THISO (m).
FRISS	Relative weight for insulation thickness on the sides of the storage region.
FRISB	Relative weight for insulation thickness on bottom of storage region.
RISLAM	Thermal conductivity of insulation (W/mK).
DEPTH	Distance between ground surface and upper surface of storage volume (m).
TSTIN	Initial temperature in the storage volume (°C).
DTSMAX	Maximum acceptable difference between average storage temperature at beginning of simulation and average storage temperature at end of simulation. If the actual difference calculated in the simulation is more than DTSMAX, the starting temperature is reset to the calculated end temperature and the simulation is repeated (See Section 5.7).

WFLOWX	Maximum specific fluid flow rate i.e. maximum volumetric fluid flow ($m^3 H_2O$/day) divided by volume of storage region. This parameter is only used when the dispersion length differs from zero. An increased value of WFLOWX results in longer computing times for the thermal process in the storage volume.
RLSTO	Characteristic length (m) for the dispersion term (=0 if pure fluid).
DISPER	Power of darcy-flow dependency for the dispersion term.
RLAMST	Thermal conductivity (W/mK) in the storage volume.
CSTO	Volumetric heat capacity (J/m^3K) in the storage volume.
TIMO3	Maximum duration of the simulation (years). This parameter is only used for the generation of the numerical mesh.
IPRE	Number of annual cycles with preheating of the ground surrounding the storage. The temperature of the store used in the preheating calculation is then a sinusoidal variation with a period of one year. The minimum temperature is given by the start value and the maximum temperature is given by TCMAX (See below). IPRE must be an integer value which is greater than or equal to zero.
TCMAX	Maximum storage temperature during the preheating period (°C). See definition of IPRE, above.
DTPMAX	Maximum acceptable difference between maximum storage temperature used in preheating period (TCMAX above) and actual maximum storage temperature. If the actual difference calculated in the simulation is more than DTPMAX, the simulation is re-done using the actual maximum temperature to define the preheating curve. The storage starting temperature is reset to the end temperature from the initial run (See Section 5.7).

TSTART	Initial ground surface temperature (°C).
TGRAD	Temperature gradient used together with TSTART to define initial temperature in the ground (°C/m).
ILAY	Number of layers in the ground with different thermal properties. ILAY must be greater than zero.
RLAM(I)	Thermal conductivity in a layer (W/mK).
CL(I)	Volumetric heat capacity in a layer (J/m^3K).
THL(I)	Thickness of a layer (m).

The final three parameters must be repeated, as a group, for each of the ILAY layers in the ground. That is, RLAM, CL and THL for the top layer; RLAM, CL and THL for the second layer, etc. Note that the deepest layer must extend below the bottom of the mesh generated by the program. This can be accomplished by making the thickness of the last layer very large.

For AQUIFER storage runs, the storage block parameters are:

STO	Block Identification.
HEIGHT	Thickness (m) of aquifer stratum.
RADIUS	Estimated maximum thermal radius (m) of heated region in the aquifer. This estimate is used to generate the numerical mesh for the simulation. If the estimate is not close to the actual thermal radius calculated by the program, the mesh is regenerated and the simulation is repeated. (See section 5.1.4).
RLHOR	Horizontal thermal conductivity (W/mK) in the aquifer.
RLVER	Vertical thermal conductivity (W/mK) in the aquifer.

C0	Volumetric Heat Capacity (J/m^3K) in the aquifer.
TFEED	Constant temperature of remote well from which water is supplied to the collectors (°C).
TIM03	Maximum duration of simulation (years). This parameter is only used for the mesh generation.
TSTART	Initial ground surface temperature (°C).
TGRAD	Temperature gradient used together with TSTART to define intial temperature in the ground (°C/m).
ILAYT	Number of layers in the ground above the aquifer with different thermal properties. ILAYT must be greater than zero.
RLAM (I)	Thermal conductivity in a layer (W/mK).
CL (I)	Volumetric heat capacity in a layer (J/m^3K).
THL (I)	Thickness of a layer (m).

The above three parameters must be repeated, as a group, for each of the ILAYT layers above the aquifer, starting with the top layer. That is, RLAM, CL and THL for the top layer; RLAM, CL and THL for the second layer, etc.

ILAYB	Number of layers in the ground below the aquifer with different thermal properties.
RLAM (I)	Thermal conductivity in a layer (W/mK).
CL (I)	Volumetric heat capacity in a layer (J/m^3K).
THL (I)	Thickness of a layer (m).

The above three parameters must be repeated, as a group for each of the ILAYB layers below the aquifer, starting from the top. That is, RLAM, CL and THL for the top layer; RLAM, CL and THL for the second layer, etc. Note that the deepest layer must extend beyond the bottom of the mesh generated by the program. This can be accomplished by making the thickness of the last layer very large.

Block: Heating Season

This block is not required. If it is not included, the heating system will be available to meet the load throughout the year.

PER	Block Identification.
IPERB	First day of heating season.
IPERE	Last day of heating season.

The above two parameters are expressed in days from the beginning of the year (i.e. January 1 = 1, December 31 = 365).

Block: Houseload

This block must always be included.

HOU	Block identification.
NH	Number of houses. All houses are assumed to be identical by the load model.
ARE	Heat loss area per house (m^2).
VALK	Heat loss coefficient (W/m^2 K).
TIN	Indoor temperature (°C).

ISYS	Option for district network. ISYS = 3 means three way system. ISYS = 4 means four way system.
IOPT	IOPT = 1: return temperature will be given. IOPT = 2: network temperature decrease will be given.
TCON	Constant temperature part of delivery temperature curve for the district heating system (°C).
AK	Slope coefficient of delivery temperature curve for the district heating system.
TBR	Break point temperature for delivery temperature curve for the district heating system (°C).
TRE	Return temperature or network temperature decrease for the district heating system, depending on IOPT (°C).
QGEN	Power generation per house from humans, equipment etc. (W).

If the option "separate tap water circuit" is used, four additional values corresponding to TCON, AK, TBR and TRE must be supplied for the tap water network at this point.

QWAT	Tap water power per house (W).
HNWL	District heating distribution system length (m).
SISHL	Insulation thickness for district heating distribution system (m).
DRHH	Diameter of district heating distribution system pipe (m).

If the seperate tap water option is used, three additional values corresponding to HNWL, SISHL and DRHN must be supplied for the tap-water system network at this point.

Block: Heat Pump

This block is not necessary if option NOHEATPUMP is specified.

HEA	Block identification.
IPAR	Option. IPAR = 1: constant heat capacity flow through evaporator. IPAR = 2: constant outlet temperature from evaporator. Note that option 2 is only available when the TANK storage system is used.
ETATCF	Value of constant part of heat pump motor efficiency curve for district heating system (see Figure 5-10).
TBROK	Break point in heat pump motor efficiency curve for district heating system (°C).
TSTAG	Stagnation temperature in heat pump motor efficiency curve for district heating system (°C).
TFMIN	Lower limit of evaporator outlet temperature for district heating system (°C) (= Constant evaporator outlet temperature if IPAR = 2).
FIMIN	Minimum coefficient of performance for use of heat pump in district heating system.
EVAK	Evaporator heat transfer capacity for district heating system (kW/K).
CONDKH	Condenser heat transfer capacity for district heating system (kW/K).

If a separate tap water distribution network is used, eight additional values corresponding to these eight parameters must be supplied for the tap water heat pump.

Block: Cost data

This block must always be included.

(Monetary unit is arbitrary. American \$ are used for documentation purposes.)

Although many of the parameters in this block are the same for all runs, the cost parameters related to storage are different for each of the four storage models. The first parameters are used by all models:

COS	Block identification.
CCOLL	Cost of collectors (\$/m^2).

For the Tank Storage model, the storage cost parameters are:

CTINF	Asymptotic (large volume) specific cost of storage (\$/m^3).
CTZERO	Specific cost for a small storage of volume SMLVOL (\$/m^3).
SMLVOL	Small storage volume for which CTZERO is known (m^3).
BETA	Scale factor ($0 \leqslant \beta \leqslant 1$) in the storage volume ("digging") cost equation (see Appendix B).
CDEEP	Exponent for cost increase because of storage depth (m^{-1}) (see Appendix B).
CCONCR	Cost of concrete (\$/m^3).
CGRONS	Ground cost (\$/m^2).
CINS	Cost of insulation material (\$/m^3).

For the DST Storage model, the storage cost parameters are:

CTINF	Asymptotic (large volume) specific cost of storage ($\$/\mathrm{m}^3$).
CTZERO	Specific cost for a small storage of volume SMLVOL ($\$/\mathrm{m}^3$).
SMLVOL	Small storage volume for which CTZERO is known (m^3).
BETA	Scale factor ($0 \leqslant \beta \leqslant 1$) in the storage volume ("digging") cost equation (see Appendix B).
CDEEP	Exponent for cost increase because of storage depth (m^{-1}) (see Appendix B).
GAMMA	Exponent for calculating cost of several boreholes. Cost of n holes = (Cost of one hole * (n ** GAMMA)).
CBH	Cost of boreholes ($/m/borehole).
CGRONS	Ground cost ($\$/\mathrm{m}^2$).
CINS	Cost of insulation material ($\$/\mathrm{m}^3$).

For the SST Storage model, the storage cost parameters are:

CTINF	Asymptotic (large volume) specific cost of storage ($\$/\mathrm{m}^3$).
CTZERO	Specific cost for a small storage of volume SMLVOL ($\$/\mathrm{m}^3$).
SMLVOL	Small storage volume for which CTZERO is known (m^3).
BETA	Scale factor ($0 \leqslant \beta \leqslant 1$) in the storage volume ("digging") cost equation (see Appendix B).
CDEEP	Exponent for cost increase because of storage depth (m^{-1}) (see Appendix B).

GAMMA	Exponential scale factor related to the distance between ground level and the top of storage.
CGRONS	Ground cost ($\$/m^2$).
CINS	Cost of insulation material ($\$/m^3$).

For the AST Storage model, the storage cost parameters are:

CWELL	Cost of drilling wells ($/m/well).
ALPHA	Exponential coefficient expressing non-linearity of cost with depth.
NWELLS	Number of wells. This parameter is for costing purposes only. The model always simulates a single well system.
GAMMA	Exponential coefficient expressing non-linearity of cost with number of wells. Cost of n wells = (cost of one well * (n ** GAMMA)).
Q0	Reference flow rate for which the costs CWELL and CEQUIP are valid. This determines the diameter required for the well once the hydraulic head is known (m^3/s).
WFEXP	Exponential coefficient expressing non-linearity of specific well cost with flow rate.
CEQUIP	Cost of equipment (pumps etc.) for flow rate Q0 ($).
EFEXP	Exponential coefficient expressing non-linearity of equipment cost with flow rate.
AGRONS	Ground surface area used by the storage system (m^2).
CGRONS	Ground cost ($\$/m^2$).

The remainder of the cost parameters are the same for all storage models:

CCOND	Specific cost of condenser ($*K/W - this unit comes from using W/K to dimension the heat transfer surface).
CEVAP	Specific cost of evaporator ($*K/W).
CELM	Cost of heat pump motor ($/W).
REFP	Reference Power. CCOND, CEVAP and CELM are given for a heat pump of this condenser power (MW).
HPEXP	Scale Factor for heat pump costs (see Section 6.1.4). This exponent reflects the change in cost per unit power as the heat pump power changes from the reference power.
CSNWA	Dimension dependent cost of collector system pipes ($/m^2).
CSNWL	Specific cost of collector system pipes of zero diameter ($/m). Total pipe cost per metre is CSNWL + CSNWA * diam.
CSNWIS	Cost of insulation of collector system network ($/m^3).
CCAUXH	Installation cost of auxiliary heater for district heating ($/W).
CAUXH	Fuel cost of auxilliary heater for district heating ($/kWh). Note that this is the cost of providing heat. The program does not include a fuel efficiency factor.

If the option "separate tap water circuit" is used, two additional parameters corresponding to CCAUXH and CAUXH must be supplied for the tap water circuit.

CEL	Cost of fuel to heat pump ($/kWh).

T	Depreciation time (years).
R	Interest (per cent) (real).
FLA	Fuel inflation over the normal inflation (per cent).

Block: Optimization process

This block is not necessary if a System Optimization run is not being made. Refer to Appendix E for a fuller explanation of some of these parameters.

OPT	Block identification.
NANTUT	Frequency of printed optimization parameters (Less than or equal to one means the parameters are printed at every calculated point).
MAXANT	If the minimum point is not yet reached after MAXANT points have been calculated, the calculations will be stopped at the next coordinate transformation.
EPS	Relative convergence criteria for each dimension. Even if this criterion is not fulfilled after calculation of 16 points, the next dimension will be varied instead.
EPZ	Overall convergence criterion. If the function values at any two consecutive coordinate transformations differ by less than EPZ, the optimization will be considered finished. (EPZ can be set to zero).
NSIG	Minimum acceptable number of significant figures in design variables. If the optimization process satisfies the EPZ constraint but the number of significant figures is not at least NSIG the optimization will continue.

IDVAR	Eight numbers, individually set to 1 if that parameter gets optimized or to 0 otherwise. The numbers correspond to collector area, storage volume, storage height/diameter ratio, storage insulation thickness (lid), specific heat transfer of heatpump evaporator for tap water, of condenser for tap water, of evaporator for house heating and of condenser for house heating. If the DUCT storage model is being used, a ninth number must be supplied to determine whether the number of ducts gets optimized.
DELVAR	Steplength for the eight parameters (nine if DUCT storage is used). The steplengths should be chosen so that the derivative of the cost function over each step is of the same order.
GAMM	Three numbers giving the parts of the steps chosen for the first three points for each parameter (e.g., 0.02, 6.0, 10.0).
EPSIL	Fifteen[1] numbers (fourteen if duct storage is not used) defining the distance from the constraint boundaries (see section 8.1 and 8.2 and Table 8.2) where the penalty functions are added.
ALFA	Fifteen[1] numbers (fourteen if duct storage is not used) defining the level of the penalty functions.
COLMAX	Maximum collector area (m^2).
COLMIN	Minimum collector area (m^2).
VOLMAX	Maximum storage volume (m^3).

---

[1] At this point, the optimization of the number of ducts is not operational. EPSIL and ALFA should only be fourteen numbers even if Duct Storage is used.

VOLMIN	Minimum storage volume (m^3).
DEPMAX	Maximum height of storage (m).
SUNCOV	Lowest acceptable solar energy cover fraction (%).

Block: Plot data generation

This block is not necessary if the GRAPH option is not specified. If GRAPH option is specified, then the OPTIMIZATION Block parameters must be included in the input data.

PLO	Block identification.
NPLOT	Number of the plot. This is for identification only.
ITITLE	Title of the plot. This must be at most 59 characters long and must be on the same input card as NPLOT. No other parameters may appear on this card.
IPLVAR	Eight numbers determine which two parameters are the independent variables on the graph. Set to 0 if the parameter is not varied or 1 otherwise. The numbers represent: collector area, storage volume, storage height/diameter ratio, storage insulation thickness (lid), specific heat transfer of heatpump evaporator for tap water, of condenser for tap water, of evaporator for house heating and of condenser for house heating. If the DUCT storage model is used, a ninth number must be supplied, representing the number of ducts. If more than two 1's appear, the first two will be used.
VMIN1	The minimum value of the first parameter (the parameter corresponding to the first 1 in IPLVAR) to be varied.
VMAX1	The maximum value of the first parameter.

NOPTSG1	The number of points between VMIN1 and VMAX1 to be plotted (including the two end points).
VMIN2	The minimum value of the second parameter.
VMAX2	The maximum value of the second parameter.
NOPTSG2	The number of points between VMIN2 and VMAX2 to be plotted (including the two end points).

Block: Report option code.

This block is not necessary unless one or more time profiles of the system are desired. If included in the parameter file for a Multiple Simulation run, this block is ignored.

REP	Block Identification.
IPRINT	Report option code.

IPRINT	TIME PROFILES PRINTED
< 1	None
1	Monthly
2	Monthly, Weekly
> 2	Monthly, Weekly, Daily

A sample MINSUN parameter file, using the Insulated Tank storage model, appears on the following pages. For examples of parameter sets for the other storage models, refer to the reports produced by participants in Sub-Tasks I(a) and II(b) of Task VII[1].

---

[1] refs 1, 2, 3, 4, 5

```
TANK STORAGE SAMPLE RUN - NOVEMBER 1984

*
INSULATION
* COLL NETW    EARTH     DIAM        FIX
* INSULATION   TEMP      DEPENDENT    INSULATION
* COND                   INSUL
*   W/M/K        C         M           M
*
    .03         10.       0.1        .02
*
COLLECTORS
* OPTION       AREA  TEMP  DTMAX   TMAX1  DUMMY  TMAX2  NORMAL  MAX
* 3 FOR IEA          STEP                         TEMP   FLOW   FLOW
* OPTION
*               M2    C                             C   KG/S/M2 KG/S/M2
*
   3         25000.   0.0  20.     50.     0.0     97.  .005   .1
*
* NETWORK   INSUL   PIPE
* LENGH     THICK   DIAM
*           NESS
*  M         M       M
*
  100.     -0.0      .25
*
STORAGE
*
* VOLUME    HEIGHT  NUMBER   DENSITY  GROUND  START TEMP IN EACH SEGMENT
*                   OF                TEMP     FROM TOP TO BOTTOM
*                   SEGMENT
*   M3        M                KG/M3  C              C
*
  50000.      10.      3.      1000.    10.      52.  48.  45.
*
* MAXIMUM   INSULATION THICKNESS   THERMAL  COND   OPTION       THICKNESS
* AVG TEMP  LID  WALL   BOTTOM     LID   BOTTOM   1OR2OR3      OF
*  CHANGE                             WALL        TEMP DISTR   CONCRETE
*    C            M                 W/M/K        ENVIRONMENT    M
*
     2.0    0.2   0.2     0.2      .05 .05 .05        3            2.
*
*
PERIOD
*          FIRST DAY              LAST DAY          OF HEATING SEASON
*                                               (FROM BEGINNING OF YEAR)
             274                    132
*
*
HOUSELOAD AND DISTRIBUTION
* NUMBER OF  WITH K-     INDOOR  OPTION  OPTION  FEED TEMP HOUSE
* HOUSES     AREA VALUE   TEMP   WAY     RETURN  EKV. PARAMETERS
*             M2  W/M2/K   C                      C       C   C
*
   500.      350.  .5     18.     3       1      55.  1.0  0.  45.
```

```
*
* HUMAN    TAPWATER  HOUSELOAD  INSULATION  PIPE
* POWER    POWER     NETWORK    THICKNESS   DIAM
*                    LENGH
* W/HOUSE  W/HOUSE     M          M          M
   400.     635.     7000.       0.05       0.1
*
HEATPUMP
*
*  IPAR     ETA      TBROK     TSTAG    TFMIN   MIN    EVAKT    CONDKT
*                      C         C        C     COP    KW/K     KW/K
*
    1       .65       50.       100.      5.     1.     1000.    300.
*
COST
*
* COLLEC ASYMPT. SPECIFIC  SIZE   BETA DEPTH CONCRETE GROUND INSULATION
*  TOR   STORAGE FOR SMALL OF SML      COST
*                STORAGE   STORAGE     EXP
*  $/M2   $/M3    $/M3      M3          /M    $/M3    $/M2     $/M3
*
   370.    25.0     88.  10000.    0.4  5.E-3    0.    0.    100.
*
*CONDEN EVAPO HEAT PUMP  INST DIM  AREA   LENGTH PIPE   AUX HOUSE FUEL
* SER   RATOR EL MOTOR   REF  EXPO DISTRI DISTRI INSULA  HEATING
*             INSTALLED  POWER NENT BUTION BUTION  TION   INSTALLED
* $*K/W $*K/W  $/W        MW         $/M2   $/M     $/M3    $/W    $/KWH
*
    0.2   0.2   0.2      0.6   -0.3   2000.   124.    0.    0.1   0.05
*
* ELCOST  DEPRECIATION  INTEREST  REAL INCREACE
*         TIME                    ENERGY PRICE
*  $/KWH  YEAR          PER CENT  PER CENT
   0.05     20.           5.        2.
*
*
OPTIMIZATION
* OPTION    MAX         CONVERGENCE         SIGNIFICANT
* PRINT     NR OF          PARAM            FIGURES IN
* EVERY     POINT   FOR            MIN      INDEPENDENT
* XXXPOINT  CALC    DIRECTIONS     POINT    VARIABLES
*
    1      200        2.E+4         2.E+4        4
*
* OPTION VARIABLE VARIED
* COLL STORAGE   INSUL  HEAT PUMP TAP   HEAT PUMP HEAT
* AREA VOL  H/D  THICKN EVAPOR  COND    EVAPOR   CONDENSER
   1    1    0      0     0      0        0         0
*
* BASIC STEP LENGTHS FOR EACH VARIABLE
*
*  M2    M3           M   ---------KW/K-----------
*
 100.  1000.     0.01    .2    10.     10.    10.    10.
```

```
 *
 * PARTS OF STEPLENGTHS FOR THE FIRST TRIALS
 *
   .01    6.    10.
 *
 * DISTANCE FROM BOUNDARY WHERE PENALTY APPLIES
 *
 * COL    COL    VOL    VOL    H/D    INSUL    INSUL
 * MIN    MAX    MIN    MAX    MIN     MIN      MAX
 *
   10.    50.    100.   100.   .01    .0001    .01
 *
 * DISTANCE FROM BOUNDARY WHERE PENALTY APPLIES
 *
 * EVAP   COND   EVAP    COND    STOR    SOLAR    STOR
 * TAP    TAP    HOUSE   HOUSE   DEPTH   FRACT    TEMP
 * MIN    MIN    MIN     MIN     MAX     MIN    DECREASE
 *
   .05    .1     .1       .1      .5     .01      9999.
 *
 *
 * PENALTY AT BOUNDARY
 *
    1.     .04    .01    .01    1.E6   1.E10   1.E6
    1.E4  1.E4   1.E4   1.E4   1.E6   1.E6    0.
 *
 *     COLLECTOR      STORAGE      STORAGE     SOLAR
 *     AREA           VOLUME       DEPTH       COVER
 *  MAX       MIN    MAX      MIN    MAX         FACTOR
 *  M2        M2     M3       M3      M
 *
 40000.  10000.  100000.  10000. 100.      0.0
 *
PLOT
*  PLOT NUMBER  TITLE OF PLOT
*
     1           SAMPLE RUN
*
* OPTION VARIABLE VARIED
* COLL STORAGE   INSUL   HEAT PUMP TAP    HEATPUMP HEAT
* AREA VOL  H/D  THICKN  EVAPOR  COND     EVAPOR  CONDENSER
   1    1    0     0       0      0         0        0
*
* MINIMUM     MAXIMUM     NO. OF
*  VALUE       VALUE      POINTS
*VARIABLE 1
*
  1000.        60000.      16.
*
*VARIABLE 2
*
   30000.      150000.     16.
REPORT OPTION
*
   3
END
```

A.5 MINREP PARAMETER FILES

In addition to the standard MINSUN parameter file (see Appendix A.4), runs using the MINREP option of the Multiple Simulation mode require two extra files of inputs.

The first, which is assigned to logical unit 2, specifies the variables to be included in the output file. The first record in this file is the run title (A80 format) to be printed at the top of the MINREP output listings. The title must be included although it may be specified as a blank line. All subsequent records contain the index in the B-array corresponding to the desired MINSUN variable and headings to appear in the two lines above the column of output. Each of these lines is read using the format.

(I3, 2 (1X, A7))

A maximum of 36 variables may be specified for inclusion in the output files. These may be chosen from the MINSUN input parameters and all values which are printed in the Simulation Summary.

A list of all MINSUN variables which can be printed and their associated indices in the B-array is included in this section. Also included is a sample Simulation Results section from the Simulation Summary with the B-array indices associated with each output.

If the output variables are to be changed in the middle of a MINREP run (NVAR = 998 - see below), the successive output specification lists must be seperated by a blank line. The last record of this file must contain a zero, blank, or 999 in the I3 position.

The second extra file required by MINREP, which is assigned to logical unit 3, specifies the desired changes to the system parameters.

Each record contains the values

NVAR, VALUE1, VALUE2, VALUE3, VALUE4

which are read using the format

(I3, 4 (1X, F7.0))

NVAR is the index in the B-array associated with the input parameter to be changed. A list of all MINSUN variables which can be printed and their associated indices is included in this section. Those variables with indices under 200 can be changed. In addition, NVAR = 998 is specified when a new output variable list is desired, and NVAR = 999 must be specified in the last record of the file to terminate program execution. When successive records of this file refer to the same NVAR, NVAR may be left blank.

VALUE1 through VALUE4 are used to determine new parameter value and program control. They should include an explicit decimal point to avoid uncertainty. A number of options are possible to conveniently control the parameter changes and MINREP logical flow.

a) Single change of parameter:

For a single change of a parameter, the new value is specified in VALUE1. If no simulation run is desired the value of VALUE2 must be non-zero and non-blank. VALUE3 and VALUE4 must be blank in either case.

b) Incremental change of parameter:

A parameter is incremented by specifying the beginning value in VALUE1, the ending value in VALUE2, and the increment step size in VALUE3. VALUE4 must be blank unless the nested option is desired. The beginning value must be less than the ending value and the increment step size must be positive.

c) Nested incremental changes in parameters:

To nest incremental parameter changes, the parameter to increment less frequently is specified first as in option (b) above. VALUE 4, however must be non-zero and non-blank. MINREP then reads the following line to determine the increment strategy for the more frequently changing parameter specified as in option (b). At most, two parameters can be nested unless the first is collector type as described next.

To specify a collector/weather file change, NVAR=1 if only collector type is changing and NVAR=2 if the TMY conditions and system load are to change. VALUE1 through VALUE4 are used to specify the logical units to which the new collector/weather files are assigned. In order to simulate the same system with more than one collector/weather file, the logical units associated with each file must be specified in the VALUE fields. Up to four files can be chosen. If fewer than four are needed, the unused VALUE fields must be left blank. If the collector/weather file is to be changed but no simulation made, then the new collector/weather logical unit is specified in VALUE1 and VALUE2 must be equal to 999. To nest incremental changes of one or two system parameters below collector/weather type, only two or three collector/weather files can be specified and a value of 999 must be placed in the first unused VALUE field, either VALUE3 or VALUE4.

The following two pages include examples of a MINREP output specification file and a parameter change specification file. These are followed by a list of MINSUN variables with their associated B-array indices and a sample Simulation Summary showing the B-array indices associated with the outputs.

```
  SAMPLE MINREP TANK RUN
 21   AREA    M2
 50   VOL     M3
150  CCOLL   $/M2
 55   TSTA     C
275   TEND     C
286   TMIN     C
287   TMAX     C
250  QCOLL    MWH
258 HP ELEC   MWH
260   AUX     MWH
272  SOL F     %
327  TCALL   $/MWH
999
```

```
 50  60000.  90000.  10000.  999.
 21  20000.  40000.   5000.
150    200.    999.
 50  60000.  90000.  10000.    999.
 21  20000.  40000.   5000.
999
```

MINSUN VARIABLES AND ASSOCIATED B-ARRAY INDICES

INPUT PARAMETER SECTION

For an explanation of variable names in the Input Parameter section, see Appendix A.4.

NVAR B(***)	VARIABLE NAME
COLLECTOR/TMY	
1	COLLECTOR/WEATHER FILE LOGICAL UNIT - collector type change only
2	COLLECTOR/WEATHER FILE LOGICAL UNIT - TMY/load condition change
INSULATION	
10	CONDIS
11	TEARTH
12	DIMIS
13	FIXIS
COLLECTOR	
20	OPT
21	COLARZ
22	DTEMP
23	DTMAX
24	TMAX1
25	U1
26	TMAX2
27	COLFLZ
28	FLOWMZ
29	CNWLZ
30	SISCOZ
31	DRC1

STORAGE	Tank Model	Duct Model	SST Model	AST Model
50	VOL	VOL	VOLST	HEIGHT
51	HEIGHT	DEEP	HEIGHT	RADIUS
52	NEQ	NBORE	THISO	RLHOR
53	DENS	RO	FRIST	RLVER
54	TGR	THISO	FRISS	C0
55	TSTA(1)	RISLAM	FRISB	TFEED
56	TSTA(2)	ISO	RISLAM	TIM03
57	TSTA(3)	FRISO	DEPTH	TSTART
58	TSTA(4)	DEPTH	TSTIN	TGRAD
59	TSTA(5)	RLAMR	DTSMAX	ILAYT
60	TSTA(6)	RMPIPE	WFLOWX	RLAM(1)
61	TSTA(7)	TIMO3	RLSTO	CL(1)
62	TSTA(8)	TSTMAX	DISPER	THL(1)
63	TSTA(9)	IPRE	RLAMST	RLAM(2)
64	TSTA(10)	TCMAX	CSTO	CL(2)
65	DTSMAX	DTPMAX	TIMO3	THL(2)

66	TLID	TSTART	IPRE	RLAM(3)
67	TWAL	TGRAD	TCMAX	CL(3)
68	TBOT	ILAY	DTPMAX	THL(3)
69	UT	RLAM(1)	TSTART	RLAM(4)
70	UW	CL(1)	TGRAD	CL(4)
71	UB	THL(1)	ILAY	THL(4)
72	IPAR	RLAM(2)	RLAM(1)	RLAM(5)
73	THICR	CL(2)	CL(1)	CL(5)
74		THL(2)	THL(1)	THL(5)
75		RLAM(3)	RLAM(2)	ILAYB
76		CL(3)	CL(2)	RLAM(ILAYT+1)
77		THL(3)	THL(2)	CL(ILAYT+1)
78		RLAM(4)	RLAM(3)	THL(ILAYT+1)
79		CL(4)	CL(3)	RLAM(ILAYT+2)
80		THL(4)	THL(3)	CL(ILAYT+2)
81		RLAM(5)	RLAM(4)	THL(ILAYT+2)
82		CL(5)	CL(4)	RLAM(ILAYT+3)
83		THL(5)	THL(4)	CL(ILAYT+3)
84		RLAM(6)	RLAM(5)	THL(ILAYT+3)
85		CL(6)	CL(5)	RLAM(ILAYT+4)
86		THL(6)	THL(5)	CL(ILAYT+4)
87		RLAM(7)	RLAM(6)	THL(ILAYT+4)
88		CL(7)	CL(6)	RLAM(ILAYT+5)
89		THL(7)	THL(6)	CL(ILAYT+5)
90		TSTA(1)	RLAM(7)	THL(ILAYT+5)
91		TSTA(2)	CL(7)	
92		DTSMAX	THL(7)	

HOUSELOAD

100	NH	
101	ARE	
102	VALK	
103	TIN	
104	ISYS	
105	IOPT	
106	TCON	
107	AK	
108	TBR	
109	TRE	
110	QGEN	Separate Tapwater
111	QWAT	TCONT
112		AKT
113		TBRT
114		TRET
115		QWAT
116	HNWL	
117	SISHL	
118	DRHH	
119		TNWL
120		SISTW
121		DRTW

PERIOD

125	IPERB
126	IPERE

HEATPUMP		
130	IPAR	
131	ETA	
132	TBROK	
133	TSTAG	
134	TFMIN	
135	FIMIN	
136	EVAKH	
137	CONDKH	Separate Tapwater
138		IPAR
139		ETA
140		TBROK
141		TSTAG
142		TFMIN
143		FIMIN
144		EVAKT
145		CONDKT

COST	Tank Model	Duct Model	SST Model	AST Model
150	CCOLL	CCOLL	CCOLL	CCOLL
151	CTINF	CTINF	CTINF	CWELL
152	CTZERO	CTZERO	CTZERO	ALPHA
153	SMLVOL	SMLVOL	SMLVOL	NWELLS
154	BETA	BETA	BETA	GAMMA
155	CDEEP	CDEEP	CDEEP	Q0
156	CCONCR	GAMMA	GAMMA	WFEXP
157	CGRONS	CBH	CGRONS	CEQUIP
158	CINS	CGRONS	CINS	EFEXP
159	CCOND	CINS	CCOND	AGRONS
160	CEVAP	CCOND	CEVAP	CGRONS
161	CELM	CEVAP	CELM	CCOND
162	REFP	CELM	REFP	CEVAP
163	HPEXP	REFP	HPEXP	CELM
164	CSNWA	HPEXP	CSNWA	REFP
165	CSNWL	CSNWA	CSNWL	HPEXP
166	CSNWIS	CSNWL	CSNWIS	CSNWA
167	CCAUXH	CSNWIS	CCAUXH	CSNWL
168	CAUXH	CCAUXH	CAUXH	CSNWIS
169	CCAUXT	CAUXH	CCAUXT	CCAUXH
170	CAUXT	CCAUXT	CAUXT	CAUXH
171	CEL	CAUXT	CEL	CCAUXT
172	T	CEL	T	CAUXT
173	R	T	R	CEL
174	FLA	R	FLA	T
175		FLA		R
176				FLA

OUTPUT PARAMETER SECTION

For more information on the output variables, see the sample output immediately following this table.

205	SOLCOS
206	CSTCNV
207	CSTMWH

216	QMAXAH
217	QMAXAT
218	PMCONH
219	PMCONT
220	COSCAP
221	AKAP
223	COSOPE
224	AFUEL
225	COSTOT
230	COLCOS
231	TONCOS
232	BETCOS
233	CISCOS
234	COHCOS
235	COTCOS
236	CEHCOS
237	CETCOS
238	CMHCOS
239	CMTCOS
240	GROCOS
241	AUHCOS
242	AUTCOS
243	COSNC1
244	COSNC2
245	COSNHH
246	COSNTW
250	QCOLL
251	QLNC1F
252	QLNC1R
253	TCOLLS
254	QENV
255	TCOLST
256	SGAIN
257	TSTRG
258	QPELH
259	QPELT
260	QAUXH
261	QAUXT
262	TAUXSP
263	QLNWHF
264	QLNWTF
265	QLNWHR
266	QLNWTR
267	THLOAD
268	TAUXSP
270	RATO1
271	RATO2
272	RATO3

275	TEND(1)
276	TEND(2)
277	TEND(3)
278	TEND(4)
279	TEND(5)
280	TEND(6)
281	TEND(7)
282	TEND(8)
283	TEND(9)
284	TEND(10)
285	TCH
286	TMIN
287	TMAX
288	DEMI
289	DEMA
290	PAR(NPAR(IDIC1))
291	PAR(NPAR(IDIC1+1))
292	QPELT
293	QCONDT
294	COPT
295	QPELH
296	QCONDH
297	COPH
300	CINVCO
301	CAPCOL
302	COPCOL
303	TOCOL
304	CINVNE
305	CAPNET
306	COPNET
307	TONET
308	CINVST
309	CAPSTO
310	COPSTO
311	TOSTO
312	CINVHE
313	CAPHEP
314	COPHEP
315	TOHEP
316	CINVCE
317	CAPCEN
318	COPCEN
319	TOCEN
320	CINVAU
321	CAPAUX
322	COPAUX
323	TOAUX
324	CINVAL
325	CAPALL
326	COPALL
327	TOALL

329	THRMAX
330	VAQMAX
331	THRAD
332	VAQFIN
333	TINJAQ
334	FINJAQ
335	TFEDEH
336	TDMPEH
337	DTEH
338	FDMPEH
339	TFEDRH
340	TDMPRH
341	DTRH
342	FDMPRH
343	TFEDET
344	TDMPET
345	DTET
346	FDMPET
347	TFEDRT
348	TDMPRT
349	DTRT
350	FDMPRT
998	read new output variable list
999	terminate program execution

MINREP - "B-ARRAY"
INDICES FOR OUTPUT VARIABLES

CAPACITY REQUIREMENTS

Maximum Auxiliary Heater Power (House) (MW)	-216-
Maximum Auxiliary Heater Power (Tap Water) (MW)	-217-
Maximum Condenser Power (House Heating) (MW)	-218-
Maximum Condenser Power (Tap Water) (MW)	-219-

COST FUNCTION FACTORS

Total Capital Cost of Heating System	-220-
Capital Cost Annualisation Factor	-221-
First Year Operating Costs for System	-223-
Operating Cost Annualisation Factor	-224-
Average Yearly Costs (Capital + Operation)	-225-

CAPITAL COST SUMMARY

All Costs in Thousands of US$

Cost of Solar Collectors	-230-
Cost of Store Excavations	-231-
Cost of Concrete	-232-
Cost of Store Insulation	-233-
Cost of House Heating Heat Pump Condenser	-234-
Cost of Tap Water Heat Pump Condenser	-235-
Cost of House Heating Heat Pump Evaporator	-236-
Cost of Tap Water Heat Pump Evaporator	-237-
Cost of House Heating Heat Pump Motor	-238-
Cost of Tap Water Heat Pump Motor	-239-
Cost of Ground for Store	-240-
Installed Cost for Auxiliary Heater (House)	-241-
Installed Cost of Auxiliary Heater (Tap Water)	-242-
Cost of Collector Array Pipework (Central)	-243-
Cost of Collector Array Pipework (House Mounted)	-244-
Cost of House Heating Distribution Network	-245-
Cost of Tap Water Distribution Network	-246-

HEAT FLOW SUMMARY

Collector Sub-System		
Collector Output	-250-	
Central Collectors		
Pipe Loss Forward	-251-	
Pipe Loss Return	-252-	
Collector Supply		-253-
Storage Sub-System		
Storage Losses	-254-	
Collector Supply Minus Storage Losses		-255-
Stored Heat Year End Minus Year Beginning	-256-	
Collector and Storage Supply		-257-
Auxiliary		
Heat Pump Electric Energy		
House Heat	-258-	
Tap Water	-259-	
Auxiliary Heater		
House Heat	-260-	
Tap Water	-261-	
Total Supply		-262-
Load		
Distribution Loss Forward		
House Heat	-263-	
Tap Water	-264-	
Distribution Loss Return		
House Heat	-265-	
Tap Water	-266-	
House Load	-267-	
Total Load		-268-
Ratios		
Collector Supply/Total Load		-270-
Collector Supply Minus Storage Losses/Total Load		-271-
Collector and Storage Supply/Total Load		-272-

TEMPERATURE OF STORAGE

START

END -275- -276- -277- -278- -279- -280- -281- -282- -283- -284-

CHANGE OF AVERAGE TEMPERATURE -285-

MIN. TEMPERATURE -286- MAX. TEMPERATURE -287-

MIN. CHANGE OF STORAGE -288- MAX. -289-

DIAMETER OF CENTRAL COLLECTOR ARRAY PIPES -290-
INSULATION THICKNESS ROUND PIPES -291-

HEAT PUMP PERFORMANCE

	EL-MOTOR	COND. POWER	C.O.P.
TAP WATER	-292-	-293-	-294-
HOUSE HEAT	-295-	-296-	-297-

SPECIFIC COSTS

	INVESTMENT (US$/MWH/Y)	CAPITAL (US$/MWH)	OPERATION (US$/MWH(	TOTAL (US$/MWH)
SOLAR COLLECTORS	-300-	-301-	-302-	-303-
COLL. PIPEWORK	-304-	-305-	-306-	-307-
STORAGE	-308-	-309-	-310-	-311-
HEAT PUMP	-312-	-313-	-314-	-315-
TOTAL SOLAR SYSTEM	-316-	-317-	-318-	-319-
AUXILIARY	-320-	-321-	-322-	-323-
TOTAL SYSTEM	-324-	-325-	-326-	-327-

TOTAL SOLAR COST (/MWH DELIVERED FROM SOLAR SYSTEM) -205-

AQUIFER PERFORMANCE

MAXIMUM RADIUS OF STORAGE (M)	-329-
MAXIMUM VOLUME OF STORAGE (000 M**3)	-330-
FINAL RADIUS OF STORAGE (M)	-331-
FINAL VOLUME OF STORAGE (000**3)	-332-
AVERAGE TEMPERATURE OF INJECTED WATER (C)	-333-
TOTAL INJECTED VOLUME (000**3)	-334-
AVERAGE EVAPORATOR FEED TEMPERATURE - HOUSE (C)	-335-
AVERAGE EVAPORATOR DUMP TEMPERATURE - HOUSE (C)	-336-
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	-337-
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	-338-
AVERAGE DISTRIBUTION FEED TEMPERATURE - HOUSE (C)	-339-
AVERAGE DISTRIBUTION DUMP TEMPERATURE - HOUSE (C)	-340-
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	-341-
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	-342-
AVERAGE EVAPORATOR FEED TEMPERATURE - TAPWATER (C)	-343-
AVERAGE EVAPORATOR DUMP TEMPERATURE - TAPWATER (C)	-344-
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	-345-
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	-346-
AVERAGE DISTN FEED TEMPERATURE - TAPWATER (C)	-347-
AVERAGE DISTN DUMP TEMPERATURE - TAPWATER (C)	-348-
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	-349-
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	-350-

APPENDIX B

OUTPUT VARIABLE CALCULATIONS

Output for the MINSUN program is divided into several sections, within which various values appear. In this Appendix, the equations producing the energy and cost values, their corresponding MINSUN FORTRAN variable names and a simple definition of the variables involved are shown in a quick reference format.

Many of the equations contain references to a set of house-mounted solar collectors. These collectors are not simulated by this version of the program. The reader should, therefore, ignore these references.

TOTAL COSTS (thousands of dollars)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
$TC_{coll} = (A_{colllest} \times C_{coll}) + (A_{coll2} \times C_{coll})$	COLCOS	TC_{coll} = total cost of solar collectors $A_{colllest}$ = area of central collector array (estimated by optimizer) A_{coll2} = area of house mounted collectors (total) C_{coll} = unit cost (/m^2) of collectors
$TC_{dig} = V_{est} \times (C_{inf} + (C_{small} - C_{inf}) / (V_{est} / V_{small})^{BETA}) \times e^{H_{est} \times C_{deep}}$ (for TANK) $= V_{est} \times (C_{inf} + (C_{small} - C_{inf}) / (V_{est} / V_{small})^{BETA}) + C_{borehole} \times H_{est}^{C_{deep}} \times Nbore^{GAMMA_{DST}}$ (for DST) $= V_{est} \times (C_{inf} + (C_{small} - C_{inf}) / (V_{est} / V_{small})^{BETA}) \times e^{(H_{est} \times C_{deep} + H_{top} \times GAMMA_{SST})}$ (for SST) $= C_{well} \times H_{est}^{C_{deep}} \times N_{well}^{GAMMA\ AST} \times \left(\frac{Q}{Q_o}\right)^{WFEXP} + C_{equip} \times \left(\frac{Q}{Q_o}\right)^{EFEXP}$. (for AST)	TONCOS	TC_{dig} = total cost of storage "digging" V_{est} = storage volume (estimated by optimizer) C_{inf} = asymptotic cost of storage C_{small} = specific cost for a small volume V_{small} V_{small} = small volume for which C_{small} is known BETA = scale factor H_{est} = storage height or well depth (estimated by optimizer) C_{deep} = coefficient expressing the increase of specific cost with depth $C_{borehole}$ = cost of drilling a borehole per metre Nbore = number of boreholes in system $GAMMA_{DST}$ = scale factor for number of boreholes H_{top} = distance between ground surface and top of storage $GAMMA_{SST}$ = scale factor for costs related to H_{top} C_{well} = Cost of drilling a well per meter N_{well} = Number of wells in system $GAMMA_{AST}$ = Scale factor for number of wells Q = Actual maximum flow rate Q_o = Reference flow rate for which C_{well} and C_{equip} are valid WFEXP = Scale factor for drilling costs with flow rate C_{equip} = Cost of pumps etc. for flow rate Q_o EFEXP = scale factor for equipment costs with flow rate
$TC_{concr} = \left(\frac{V_{est}}{H_{est}} + 2H_{est}\left(\frac{V_{est}}{H_{est}}\pi\right)^{\frac{1}{2}}\right) \times Th_{concr} \times C_{concr}$	BETCOS	TC_{concr} = total cost of concrete = total volume of concrete used x unit cost C_{concr} = unit cost (/m^3) of concrete
		TC_{ins} = total cost of tank insulation I_{lid} = thickness of insulation on tank lid C_{ins} = unit cost (/m^3) of insulation

TOTAL COSTS (thousands of dollars)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
$TC_{ins} = \left(\frac{V_{est}}{H_{est}}\left(\frac{I_{lid}}{I_{wall}} + \frac{I_{bot}}{I_{wall}}\right) + 2H_{est}\left(\frac{V_{est}}{H_{est}}\pi\right)^{\frac{1}{2}}\right) \times I_{wall} \times C_{ins}$ (for TANK and SST storage)	CISCOS	TC_{ins} = total cost of tank insulation I_{lid} = thickness of insulation on tank lid C_{ins} = unit cost (/m^3) of insulation FR_{height} = fraction of storage height covered by insulation
$= 0$ for DST with ISO = 0		
$= \left(\frac{V_{est}}{H_{est}} + FR_{height} \times 2H_{est}\left(\frac{V_{est}}{H_{est}}\pi\right)^{\frac{1}{2}}\right) \times I_{lid} \times C_{ins}$ (for DST with ISO = 1)		
$= \pi\left(FR_{height} \times H_{est} + \left(\frac{V_{est}}{H_{est}}\pi\right)^{\frac{1}{2}}\right) \times I_{lid} \times C_{ins}$ (for DST with ISO = 2)		

TOTAL COSTS (thousands of dollars)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN
$TC_{condH} = HT_{condHest} \times C_{cond} \times \left(\frac{MAXP}{REFP}\right)^{HPEXP}$	COHCOS
$TC_{condT} = HT_{condTest} \times C_{cond} \times \left(\frac{MAXP}{REFP}\right)^{HPEXP}$	COTCOS
$TC_{evapH} = HT_{evapHest} \times C_{evap} \times \left(\frac{MAXP}{REFP}\right)^{HPEXP}$	CEHCOS
$TC_{evapT} = HT_{evapTest} \times C_{evap} \times \left(\frac{MAXP}{REFP}\right)^{HPEXP}$	CETCOS
$TC_{pumpH} = Q_{maxpumpH} \times C_{elmotor} \times \left(\frac{MAXP}{REFP}\right)^{HPEXP}$	CMHCOS

DEFINITION OF VARIABLES

TC_{condH} = total cost of condensor for house heating
$HT_{condHest}$ = specific condensor heat transfer for house heating system heat pump (estimated by optimizer)
C_{cond} = specific cost of condensor ($·K/W)

MAXP = maximum condenser power (calculated by program)
REFP = reference condenser power for which input specific costs are valid
HPEXP = exponent to reflect change in cost per unit power as maximum power changes

TC_{condT} = total cost of condensor for tap water heating

TC_{evapH} = total cost of evaporator for house heating

TC_{evapT} = total cost of evaporator for tap water heating

TC_{pumpH} = total cost of pump for house heating
$Q_{maxpumpH}$ = maximum power required by pump motor
$C_{elmotor}$ = cost of heat pump motor ($/W)

TOTAL COSTS (thousands of dollars)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
$TC_{pumpT} = Q_{maxpumpT} \times C_{elmotor} \times \left(\frac{MAXP}{REFP}\right)^{HPEXP}$	CMTCOS	TC_{pumpT} = total cost of pump for tap water heating
$TC_{ground} = A_{botSTR} \times C_{ground}$	GROCOS	TC_{ground} = total cost of ground space for the storage tank
$TC_{auxH} = Q_{maxauxH} \times CC_{auxH}$	AUHCOS	TC_{auxH} = total cost of auxiliary house heater CC_{auxH} = unit installed cost of auxiliary house heater
$TC_{auxT} = Q_{maxauxT} \times CC_{auxT}$	AUTCOS	TC_{auxT} = total cost of auxiliary tap water heater CC_{auxT} = unit installed cost of auxiliary tap water heater
$TC_{net1} = 2 \times L_1 \times (D_1 \times C_{dis} + C_{diso} + (D_1 + I_{thick1}) \times I_{thick1} \times \pi \times C_{insNET})$	COSNC1	TC_{net1} = total cost of 1st collector array network = piping cost + insulation cost = network length x (unit cost of piping + (insulation volume x unit cost of network insulation))
$TC_{net2} = 2 \times L_2 \times (D_2 \times C_{dis} + C_{diso} + (D_2 + I_{thick2}) \times I_{thick2} \times \pi \times C_{insNET})$	COSNC2	TC_{net2} = total cost of 2nd (roof-mounted) collector array
$TC_{disH} = 2 \times l_1 \times (d_1 \times C_{dis} + C_{diso} + (d_1 + i_{thick1}) \times i_{thick1} \times \pi \times C_{insNET})$	COSNHH	TC_{disH} = total cost of house heating distribution network

TOTAL COSTS (thousands of dollars)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
$TC_{disT} = 2 \times l_2 \times (d_2 \times C_{dis} + C_{diso} + (d_2 + i_{thick2})$ $\times\, i_{thick2} \times \pi \times C_{insNET})$	COSNTW	TC_{disT} = total cost of tap water heating
$TC_{coll1} = A_{coll1est} \times C_{coll}$		TC_{coll1} = total cost of central array of collectors
$TC_{cap} = TC_{coll1} + TC_{dig} + TC_{concr} + TC_{ins} +$ $TC_{condH} + TC_{condT} + TC_{evapH} + TC_{evapT} + TC_{pumpH}$ $TC_{pumpT} + TC_{ground} + TC_{auxH} +$ $TC_{auxT} + TC_{net1} + TC_{net2} + TC_{disH} + TC_{disT}$	COSCAP	TC_{cap} = total capital cost required to supply heat
$TC_{op} = (Q_{hpumpTH} \times C_{el}) + (Q_{auxH} \times C_{auxH}) +$ $(Q_{auxT} \times C_{auxT})$	COSOPE	TC_{op} = total operating cost of the system C_{el} = cost of electricity C_{auxH} = cost of auxiliary fuel for house heating
$TC_{tot} = (TC_{cap} \times A_{cap}) + (TC_{op} \times A_{fuel})$	COSTOT	TC_{tot} = total yearly costs A_{cap} = annualization factor for capital cost

ENERGY CALCULATION (MWH)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
COLLECTOR		
$Q_{coll} = (P_{coll1} \times t_{op}) + (P_{coll2} \times t_{op})$	QCOLL	Q_{coll} = total collector energy P_{coll1} = total power of collector array 1 t_{op} = estimated collector operation time
$Q_{lossF} = (P_{net1F} \times t_{op}) + (P_{net2F} \times t_{op})$	QLNC1F + QLNC2F	Q_{lossF} = total energy loss, forward pipe P_{net1F} = total power loss, forward pipe
$Q_{lossR} = (P_{net1R} \times t_{op}) + (P_{net2R} \times t_{op})$	QLNC1R + QLNC2R	Q_{lossR} = total energy loss, return pipe
STORAGE		
$Q_{lossSTR} = (P_{STR} \times t_{step})$	QENV	$Q_{lossSTR}$ = total energy loss of storage P_{STR} = total power loss of storage t_{step} = length of time step (hours)
$Q_{supSTR} = T_{STR} \times V_{STRest} \times C_p$	TCH x SVOL x 4.18	Q_{supSTR} = total energy supplied by storage T_{STR} = maximum temperature change in storage V_{STRest} = estimated storage volume C_p = specific heat capacity flow
AUXILIARY		
$Q_{auxTH} = (HCF_H \times (T_{HF} - MAX[T_{HR}, T_{topSTR}]) \times t_{step}) + (HCF_T \times (T_{TF} - MAX[T_{TR}, T_{topSTR}]) \times t_{step})$	QAUXH + QAUXT	Q_{auxTH} = total energy delivered by the auxiliary heater (tap & house heat) HCF_H = heat capacity flow (house heating network) HCF_T = heat capacity flow (tap water network) T_{HF} = house forward water temperature ... T_{topSTR} = top of storage water temperature
$Q_{hpumpTH} = (P_{hpumpH} \times t_{step}) + (P_{hpumpT} \times t_{step})$	QPELH + QPELT	$Q_{hpumpTH}$ = total energy delivered to heat pump (tap & house heat) P_{hpumpH} = total power delivered to heat pump for house heating P_{hpumpT} = total power delivered to heat pump for tap water heating
$Q_{condTH} = (P_{condH} \times t_{step}) + (P_{condT} \times t_{step})$	QCONDH + QCONDT	Q_{condTH} = total energy delivered through the condensor (tap & house heat)
$COP_T = Q_{condT}/Q_{hpumpT}$	COPT	COP_T = coefficient of performance of the heat pump for tap water heating
$COP_H = Q_{condH}/Q_{hpumpH}$	COPH	COP_H = coefficient of performance of the heat pump for house heating
DISTRIBUTION		
$Q_{lossFTH} = (P_{lossFH} \times t_{step}) + (P_{lossFT} \times t_{step})$	QLNWHF + QLNWTF	$Q_{lossFTH}$ = total energy losses, forward pipes (tap & house heat) P_{lossFH} = total power loss from the house heating network, forward pipe
$Q_{lossRTH} = (P_{lossRH} \times t_{step}) + (P_{lossRT} \times t_{step})$	QLNWHR + QLNWTR	$Q_{lossRTH}$ = total energy losses, return pipes (tap & house heat) P_{lossRT} = total power loss from the tap water delivery system, return pipe

SPECIFIC COSTS (\$/MWH)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
$SC_{coll} = [A_{cap} \times TC_{coll} / Q_{cen}] + [0]$ $Q_{cen} = Q_{hpumpTH} + Q_{coll} - Q_{lossSTR} - Q_{lossF} - Q_{lossR}$	COPCOL + CAPCOL (TOCOL)	SC_{coll} = specific costs of collectors (capital cost exclusively) Q_{cen} = total energy supplied by solar system [0] = operating costs assumed to be zero
$SC_{net} = [A_{cap} \times (TC_{net1} + TC_{net2}) / Q_{cen}] + [0]$	COPNET + CAPNET (TONET)	SC_{net} = specific costs of collector network
$SC_{str} = [A_{cap} \times (TC_{dig} + TC_{concr} + TC_{ins} + TC_{ground}) / Q_{cen}] + [0]$	COPSTO + CAPSTO (TOSTO)	SC_{str} = specific costs of storage
$SC_{hpump} = [Q_{hpumpTH} \times C_{el} \times A_{fuel} / Q_{cen}] + [A_{cap} \times (TC_{condH} + TC_{condT} + TC_{evapH} + TC_{evapT} + TC_{pumpH} + TC_{pumpT}) / Q_{cen}]$	COPHEP + CAPHEP (TOHEP)	SC_{hpump} = specific costs of heat pump
$SC_{cen} = [Q_{hpumpTH} \times C_{el} \times A_{fuel} / Q_{cen}] + [A_{cap} \times (TC_{net1} + TC_{net2} + TC_{dig} + TC_{concr} + TC_{ins} + TC_{ground} + TC_{condH} + TC_{condT} + TC_{evapH} + TC_{evapT} + TC_{pumpH} + TC_{pumpT} + TC_{coll}) / Q_{cen}]$	COPCEN + CAPCEN (TOCEN)	SC_{cen} = specific costs of solar system supplied energy
$SC_{aux} = [((Q_{auxH} \times C_{auxH}) + (Q_{auxT} \times C_{auxT})) \times A_{fuel} / (Q_{auxH} + Q_{auxT})] + [A_{cap} \times (TC_{auxH} + TC_{auxT}) / (Q_{auxH} + Q_{auxT})]$	COPAUX + CAPAUX (TOAUX)	SC_{aux} = specific costs of auxiliary system supplied energy
$SC_{all} = [(Q_{hpumpTH} \times C_{el} \times A_{fuel}) + (((Q_{auxH} \times C_{auxH}) + (Q_{auxT} \times C_{auxT})) \times A_{fuel}) + ((TC_{net1} + TC_{net2} + TC_{dig} + TC_{concr} + TC_{ins} + TC_{ground} + TC_{condH} + TC_{condT} + TC_{evapH} + TC_{evapT} + TC_{pumpH} + TC_{pumpT} + TC_{coll}) + TC_{auxH} + TC_{auxT}) \times A_{cap})] / (Q_{cen} + Q_{auxH} + Q_{auxT})$	COPALL + CAPALL (TOALL)	SC_{all} = specific costs of total energy supplied

SPECIFIC COSTS ($/MWH)	EQUIVALENCE WITH FORTRAN VARIABLES IN MINSUN	DEFINITION OF VARIABLES
$AC_{sol} = [(TC_{net1} + TC_{net2} + TC_{dig} + TC_{concr} + TC_{ins} +$ $TC_{ground} + TC_{condH} + TC_{condT} + TC_{evapH} + TC_{evapT} +$ $TC_{pumpH} + TC_{pumpT} + TC_{coll})$ $\times A_{cap}] / (Q_{coll} - Q_{lossSTR} - Q_{lossF} - Q_{lossR})$	SOLCOS	Annualized cost of solar energy per MWh
$AC_{cnv} = C_{auxH} \times A_{fuel}$	CSTCNV*	Annualized cost of auxiliary fuel per MWh
$AC_{sys} = [(Q_{hpumpTH} \times C_{el} \times A_{fuel}) +$ $(((Q_{auxH} \times C_{auxH}) + (Q_{auxT} \times C_{auxT})) \times A_{fuel}) +$ $((TC_{net1} + TC_{net2} + TC_{disH} + TC_{dig} + TC_{concr} + TC_{ins} +$ $TC_{ground} + TC_{condH} + TC_{condT} + TC_{evapH} + TC_{evapT} +$ $TC_{pumpH} + TC_{pumpT} + TC_{coll}) + TC_{auxH} + TC_{auxT})$ $\times A_{cap})] / (Q_{cen} + Q_{auxH} + Q_{auxT})$	CSTMWH*	Annualized cost of all energy from system per MWh

* These values are only available from MINREP runs.

APPENDIX C

COMPUTER PROGRAM STRUCTURE AND SUBROUTINES

Figure C1 shows the general organization of the MINSUN program when the Insulated Tank storage system is used.

Most of the work of the program is done by FKT and its associated subroutines. FKT is responsible for reading all parameters, formulating the boundary conditions, calling routines to calculate the cost function and writing out the results.

The simulation of one time period (e.g. one year) is performed by XSIM and its subroutines. If a single simulation or a system optimization is performed and the report option is not zero, the simulation is repeated by XSIM2 to produce monthly, weekly and/or daily profile reports. The individual time step calculations are administered by XDEL.

The routines associated with MINIM perform the optimization process. They determine the points to be evaluated in the search for the lowest cost system and also determine when an acceptable minimum cost system has been found.

TALLY is use to calculate the standard deviation of the cost function values generated in an optimization run.

When DST storage is used, the STORES routine used for TANK storage must be removed and replaced by those routines shown in figure C2.

For SST storage, the routines in figure C3 are used.

For AST storage, the organization is as shown in figure C4.

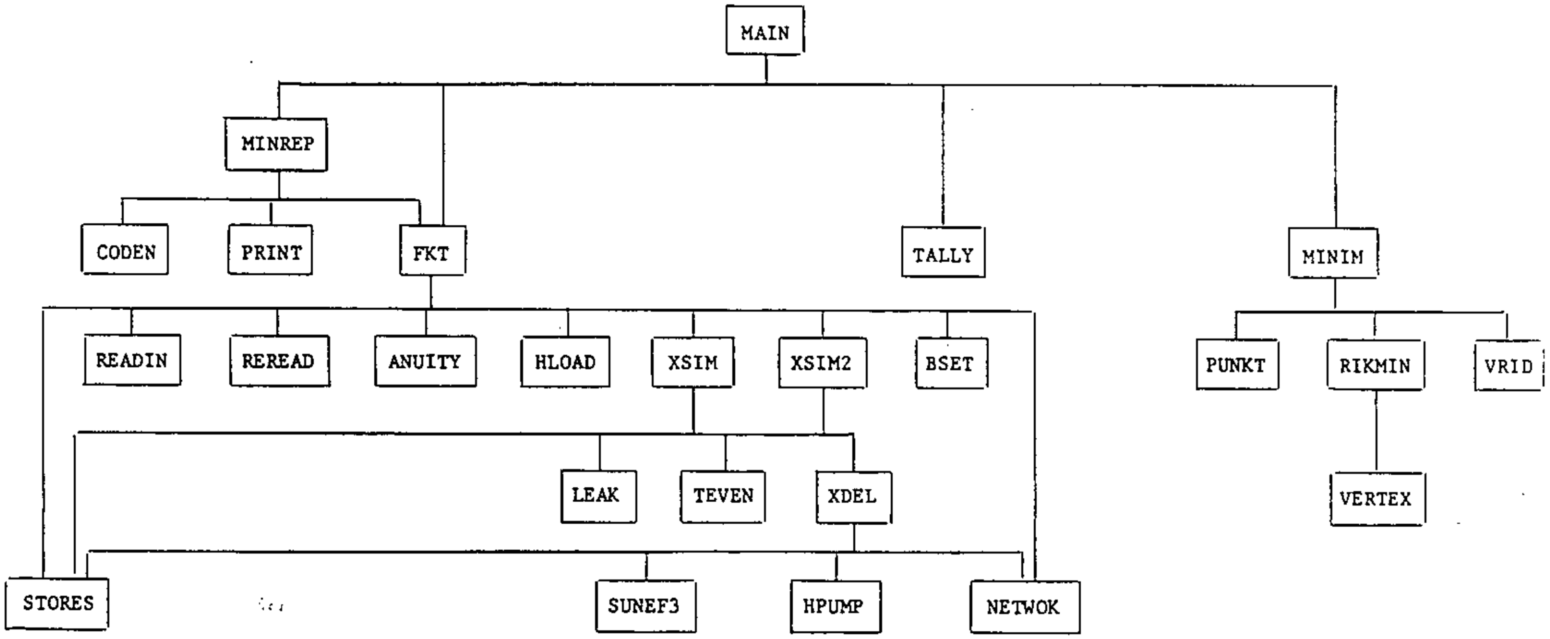


FIGURE C1

Organisation of the MINSUN Program

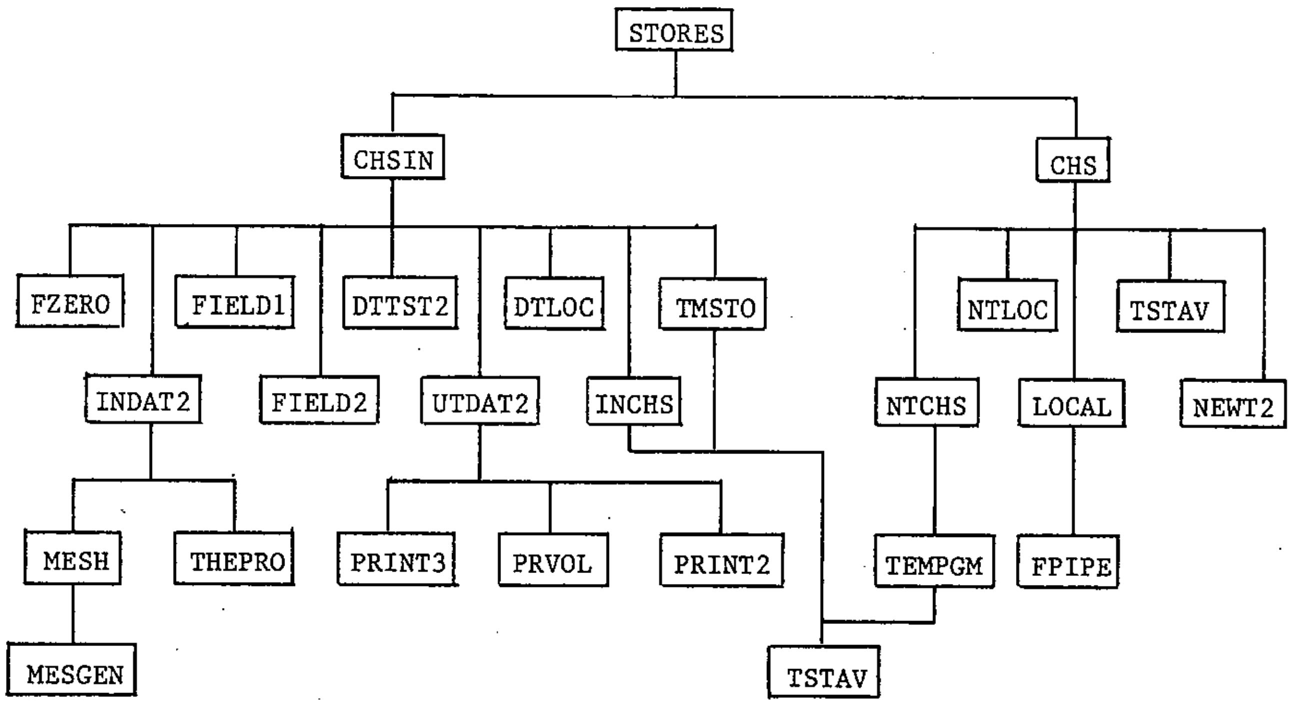


FIGURE C2

Program Organization - Duct Storage Model

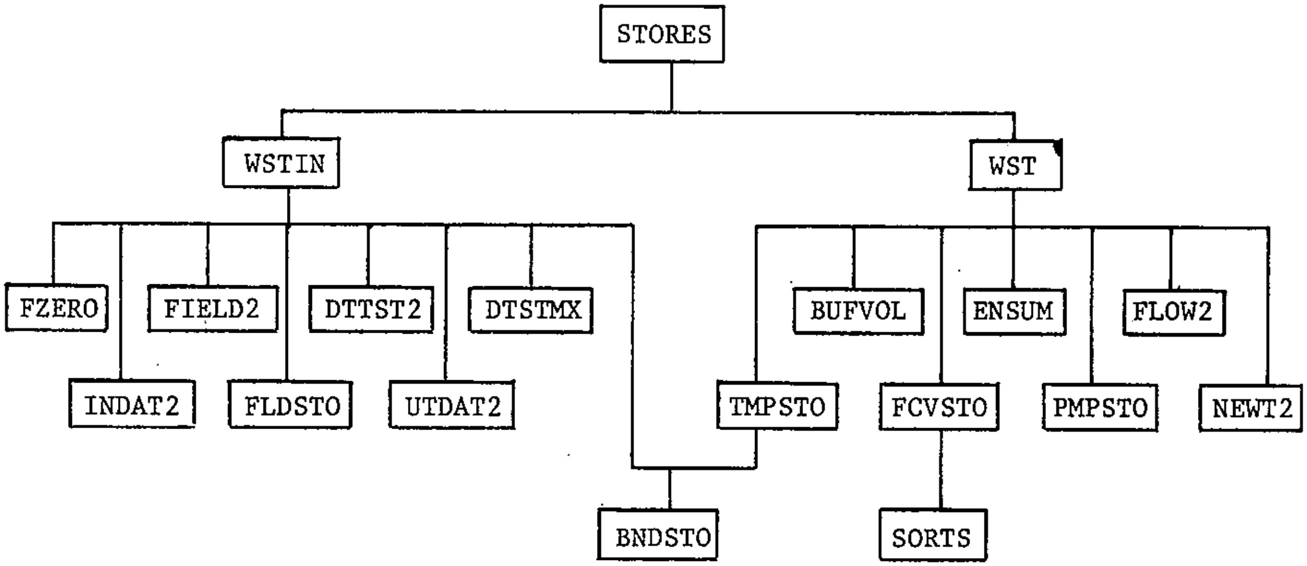


FIGURE C3

Program Organization - Stratified Storage Temperature Model

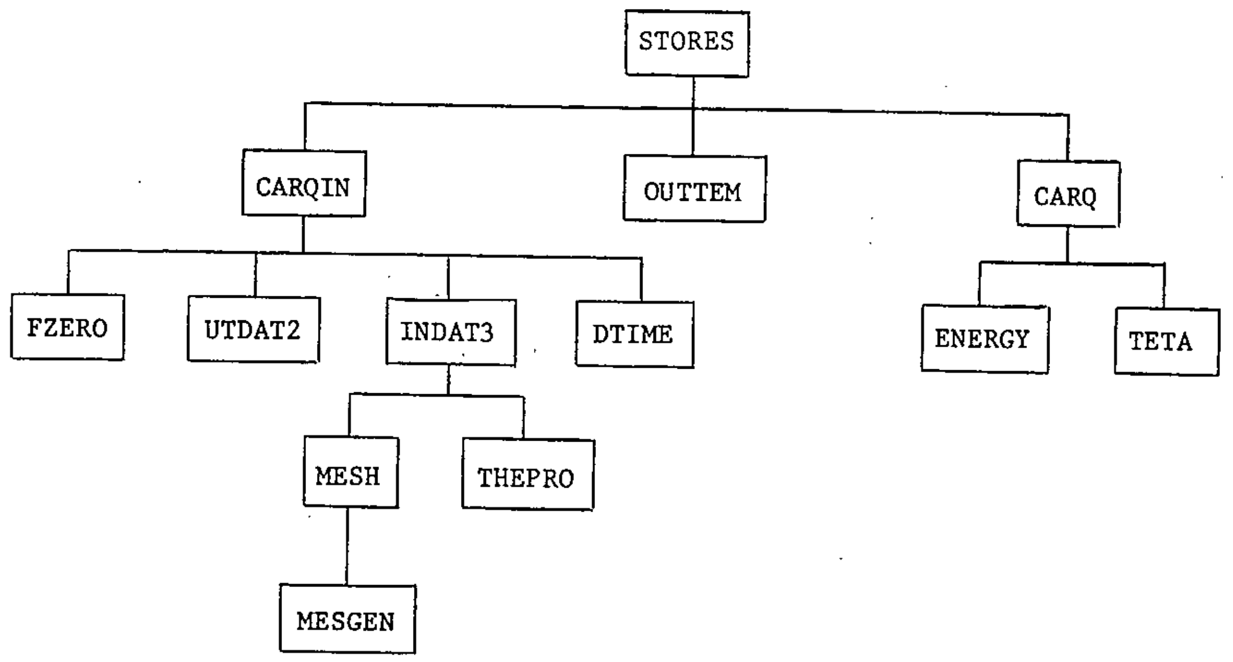


FIGURE C4

Program Organization - Aquifer Storage Model

APPENDIX D

GUIDE TO SELECTED PROGRAM VARIABLES AND ARRAYS

D.1 INTRODUCTION

The purpose of this Appendix is to identify and describe a few FORTRAN variables used in MINSUN. This document benefits system users who wish to affect modifications to the program.

This Appendix has two sections. The first section describes variables used to represent input power data for each time period. The second section briefly reports on the optimizer, load, subroutine utility and SUNEF3 arrays.

D.2 INPUT VARIABLES

a) Solar Power Data

Input data for MINSUN is produced by UMSORT and ADVANCE. The input data file is discussed in the UMSORT description presented in sections 3.2 and 3.3 of this manual. The following variables are used in this file:

IDEE

The IDEE variable contains the version identifier (either IEA or SWEDEN) and is used to set a logical switch (IEA) to control the execution of FORTRAN code in MINSUN. Only the IEA version of the collector models is supported by the current MINSUN package.

NSTP

This variable is a constant value which is used to control the number of lines (days) read from the input file, the number of simulation iterations, and the number of lines written onto the output energy data file.

TIND, TMAM

The average indoor temperature variable (TIND) is used to print the indoor temperature variable from UMSORT. As well TMAM, the ambient temperature constraint used in UMSORT, is printed with an output message.

PAR(10) to PAR(14)

The temperature values used as collector inlet temperatures for the power calculations in UMSORT are passed directly into the collector section of the parameter file (see Section b). These temperatures are in degrees Celsius.

After these data are read, the program reads time period data. The following variables are used:

ISLA

This variable contains the date for the time period. It is used to print the last record read from the input data file.

DSTPA

DSTPA contains the number of hours for the time period. It is used to load the DSTP array.

HT(1) to HT(5)

These variables contain the input solar power (KJ/M^2day) for each of the five temperature values. They are loaded into the HINS array.

TAMA

TAMA represents the average ambient outdoor temperature (°C) for the period. It is calculated from data on the weather data file used by UMSORT. The appropriate member of the TAM array is set to its value.

TLOADA

The temperature (°C) for the degree-hour model is read into TLOADA. This variable is used to set the TLOAD array.

HI(1) to HI(5)

These variables are used for the hours of collector operation for each of the five temperature values. The HTIM array is set to these values.

b) Parameter File

In addition to these data, several parameters are read by subroutine FKT(3). The input parameter file is described in Appendix A-4.

The input parameters are loaded into the unidimensional array PAR. The array contains constants for the MINSUN subroutines. The placement of values into the array members depends on the definition of a position variable called NPAR, which is set in the first executable section of code in FKT(3). As illustrated in Table D1, multiples of ten or fifteen PAR members are allocated for each block of parameters. Parameters are read by the TRNSYS subroutine READIN. The PAR array is also used by other subroutines through a labelled common block.

c) Centralized Constants

Within subroutine FKT(3), a few constants are defined and used throughout MINSUN. For example, the FORTRAN logical input and output file assignments are set for the LUNITS common block. LUR and LUW are the FORTRAN variables for the input parameter and output message files respectively, and LUA and LUB are the input and output data files respectively.

VARIABLE	VALUE	NUMBER OF MEMBERS	USAGE
NPAR (ICOLL1)	1	15	Central solar panels
NPAR (ILOAD)	16	15	House load
NPAR (ITANK)	31	15	Storage tank
NPAR (IVPT)	46	15	Heat pump tap water
NPAR (IVPH)	61	15	Heat pump house heating
NPAR (ICOLL2)	76	15	House mounted solar panels
NPAR (IDIC1)	116	15	Central collector network
NPAR (IDIC2)	166	10	House mounted collector network
NPAR (IDIHH)	126	10	House load distribution network
NPAR (IDITW)	136	10	Tap water load distribution network
INP (ICOLL1)	1	10	Central solar panels
INP (ILOAD)	11	10	House load
INP (ITANK)	21	20	Storage tank
INP (IVPT)	41	10	Heat pump tap water
INP (IVPH)	51	10	Heat pump house heating
INP (ICOLL2)	61	10	House mounted solar panels
INP (IDIC1)	71	10	Central collector network
INP (IDIC2)	81	10	House mounted collector network
INP (IDIHH)	91	10	House load distribution network
INP (IDITW)	101	10	Tap water load distribution network

TABLE D1

Array positioned parameters for

PAR and XIN arrays

A constant (MONEY) is used to set the currency label in the output message file. Although the program is set to print US$, this variable can be reset.

In addition, several logical switches are set from the input parameter file. These logical switches are passed through a labelled common block. They are SING for a single point calculation, NOHP for no heatpump in the system, TAPW for a separate tap water distribution network, GRAPH for a Multiple Simulation Mode Two Parameter Variation run and REPT for a Multiple Simulation Mode MINREP run.

Other variables, including the specific heat capacity of water (CP), the value (PI) and the network system option (ISYS) are initialized in the FKT(3) subroutine.

D.3 SUBROUTINE ARRAYS

a) Optimizer Arrays

The initial values for the variables to be optimized are read from the parameter file. In subroutine FKT(3), these values are passed to the X array. During optimization, the X array is updated with each simulation and is used to print the optimal results.

The constraints for the optimizer are represented by the G array. The G values are the differences between the input or derived values in the X array and the constraint boundaries. The G array is initialized in FKT(1) and is reset before each simulation.

b) Load Parameters

As described in the main text, the distribution load is calculated before the simulations. Six arrays are set in the FKT(3) subroutine that contain the distribution load data. They are:

HTR

HTR represents the feed temperature required for each time period. It is calculated from the delivery temperature curve as defined in Section 4.4. Temperature values are expressed in degrees Celsius.

HCF

HCF represents the heat capacity flow (KJ/HR°C) required for the house heating distribution system.

HTRE

The variable HTRE (°C) gives the return water temperature difference (if specified in the option) for the house heating distribution load.

HTRT

HTRT represents the feed temperature (°C) for the tap water distribution system, according to the delivery temperature curve defined earlier.

HCFT

The variable HCFT contains the heat capacity flow (KJ/HR°C) required for the tap water distribution system.

HTRET

HTRET specifies the return water temperature difference, in degrees Celsius, for the tap water distribution system if a separate tap water system is specified in the parameter file.

c) XIN, OUT and INFO Arrays

Throughout MINSUN, the utility arrays XIN, OUT and INFO are used to pass values for subroutine calculations. XIN is a unidimensional array, whose members are identified by a positional scalar INP (initialized in subroutine FKT(3)). As shown in Table D1, ten or twenty positions are allocated for each system component. There is one essential difference between XIN and PAR. The XIN array values may change with each simulation, but the PAR array values do not change.

The OUT array is two-dimensional. It contains output values from the subroutines. The columns are unique for each system component. The rows relate to secondary features such as forward or return pipes.

The INFO array is rarely used but contains numbers used as switches between subroutines. This array differs from other logical switches because it is used only between certain subroutines.

d) SUNEF3 Variables

The SUNEF3 subroutine, which uses UMSORT energy data, contains the variables listed below:

TMAX1

Variable TMAX1 is the lower bound of the control strategy curve. It is read from the parameter file, in degrees Celsius.

TMAX2

Variable TMAX2 is the upper bound of the control strategy curve. It is also read from the parameter file, in degrees Celsius.

DTMAX

Variable DTMAX represents the displacement of the control strategy curve between the upper and lower bounds from the input and output temperature equivalence line. It, too, is read from the parameter file, in degrees Celsius.

TSTR

The top of storage temperature (TSTR) is read from XIN set in the XDEL subroutine.

TCRIT1, TCRIT2

TCRIT1 (°C) and TCRIT2 (°C) are the intersection points of the inflections in the control strategy curve with the input temperature axis.

TOUT

TOUT (°C) in the calculated output temperature of the solar collector. It is used to determine if the maximum output temperature for the collector exceeded.

PHCF

The variable PHCF represents the new heat capacity flow (KJ/HR°C) from the solar collector. It is calculated if the maximum temperature is exceeded.

PQOA

If the maximum heat capacity flow is exceeded, the new solar output power (KJ/HR$\cdot$M^2) from the solar collector is derived.

TMAX

The variable TMAX (°C) is the calculated maximum temperature constraint for the solar collector, derived from the control strategy curve.

FMAX

FMAX (KJ/HR°C) is the maximum heat capacity flow of the solar collector pipes. It is calculated in subroutine FKT(3) and is an element of the PAR array.

HCF

The normal heat capacity flow (KJ/HR°C) of the solar collector network is also calculated in FKT(3). It is an element of the PAR array.

OUT(3)

In the OUT array, the total solar output power (KJ/HR) is used instead of the output power per square meter.

DELT

DELT is calculated in XDEL and DTIM. In this version of MINSUN, it represents the estimated time (in hours) of solar collector operation. The distribution load period is also expressed as DELT (hours), but this is not the DELT variable used in SUNEFF, SUNEF2, and SUNEF3.

APPENDIX E

GUIDE TO THE MINSUN OPTIMIZER

E.1 OPTIMIZATION ALGORITHM

E.1.1 Introduction

The MINSUN optimizing strategy consists of searching in an initially specified direction for a minimum in the cost function. The initial search direction established by the program corresponds to that of optimization variable number one. Subsequent search directions are taken orthogonally with the initial sequence that of the ordering of these variables. After sequencing through all the variables, a new best direction is determined. This direction is searched for a minimum, followed by a search in an orthogonal direction, and so on, in a "Gram-Schmidt" type of process.

The objective (cost) function simulation/evaluation routine FKT is invoked by the main line program and all the necessary cost function (and other variable) values are transferred through COMMON blocks. MINIM calls three subroutines, RIKMIN, PUNKT, and VRID, as the organization chart for the subroutines (in Appendix C) shows.

RIKMIN implements the derivative approximation and determines the appropriate sense and size of the step to be taken. PUNKT evaluates the variable values associated with each step.

E.1.2 Initialization

Initialization of variables related to the optimization strategy occurs primarily in subroutine MINIM. Tables E1 and E2 serve as a guide to the initialization process.

Another scalar, initialized by subroutine RIKMIN, is FUNKMIN. This variable contains the cost function value for the last saved minimum point and is initialized to the function value plus penalty for the starting point.

TABLE E1 INITIALIZATION OF SCALAR VALUES RELATED TO OPTIMIZATION

Scalar Value	Initial Value	Comment
FUNKV1	.1 E28	cost function value at 2nd last saved minimum point
FUNKV2	.1 E36	cost function value at 3rd last saved minimum point
NRIKT	1	counter, max. value is the number of variables being optimized
NANT	0	counter, max. value is the max. number of calculations allowed for a direction (currently 16, or 100 for single variable optimization)

TABLE E2 INITIALIZATION OF VECTOR VALUES RELATED TO OPTIMIZATION

Vector Name	Initial Value	Comment
RIKTN	I - the identify matrix	the direction generation matrix (ref. E.1.3, E.1.7)
VEKT	$(1\ 0\ 0\ \ldots)^T$	the direction vector for initial search
MINP	starting point = VAR(I), (I = 1,2,...,9)	contains the design variable values for the most recently saved function minimum
RANMIN	RAND(I) (I = 1,2,...,15)	contains distance from boundary I to MINP
IDRMIN	IDRAND(I) (I = 1,2,...,15)	= 0 if MINP is in penalty zone I = 1 if MINP is in the allowed region

E.1.3 Search Direction Definition - Matrix RIKTN

For an N variable optimization, the N directions of search are defined as rows in the square matrix RIKTN. A coordinate transformation amounts to recalculation of RIKTN's elements.

When beginning optimization, a coordinate transformation is not calculated and RIKTN is initialized as

$$\text{RIKTN} = \text{I} = \begin{bmatrix} 1 & & & & & & 0 \\ & \bullet & & & & & \\ & & \bullet & & & & \\ & & & \bullet & & & \\ & & & & \bullet & & \\ & & & & & \bullet & \\ 0 & & & & & & 1 \end{bmatrix} \quad \text{N x N}$$

Search along the n^{th} direction amounts to a variation of the n^{th} variable to be optimized. (Note that after the first change of direction has occured, combinations of variables are simultaneously optimized, consistent with the new "best" direction.)

E.1.4 Point Calculation

MINSUN's optimizer sequentially examines each orthogonal search axis associated with a given "best" direction. A maximum of 16 points (or of 100 points in a single variable optimization) in the variable space can be evaluated per axis.

The algorithm which follows shows how subroutine PUNKT calculates the set of optimization variables associated with each point.

<u>The Point Calculation Algorithm (PUNKT)</u>

```
(a)    K = 1
(b)    for I = (1, 2, ..., 9)
       If  IDVAR(I) = 1
           VAR(I) = H * RIKTN(NRIKT,K) * DELVAR(I) + MINP(I)
       K = K + 1
```

TABLE E3 VARIABLES RELATED TO THE POINT CALCULATION ALGORITHM

Variable Name	Comment
H	A calculated step length factor (ref. E.3.1)
RIKTN	The direction matrix (ref. E.1.3 and E.1.7)
NRIKT	A counter indicating the direction being searched. Possible values are (1,2,...,N)
DELVAR(I)	The basic step length for variable I. These values are input data.
MINP(I)	The I^{th} design variable value for the minimum point of the last direction searched.

E.1.5 Mimimum Point Updating

By the nature of the optimization scheme, the minimum point of the current search direction will have a cost function value which is less than or equal to the function value of each of the minimum points for all previously searched directions.

When a search direction has been completed (ref. E.1.4) the observed minimum point is saved by subroutine PUNKT in the MINP vector. The updating algorithm is identical to the point calculation algorithm just given, with the exception that MINP(I) is updated, as opposed to VAR (I).

E.1.6 LAMBDA

A major item which must be updated before an optimization direction change or coordinate transformation is a vector named LAMBDA.

For optimization in direction I, LAMBDA is updated as

$$\text{LAMBDA}(I) = h'$$

where h' is the H value (ref. E.1.4) used to step from the minimum point of the (I-1)st search direction to the minimum point of the Ith direction.

LAMBDA plays an important role in the calculation of RIKTN (a coordinate transformation matrix).

E.1.7 Coordinate Transformations - Calculation of RIKTN

For an N variable optimization, once all N search directions have been exhausted, a coordinate transformation is performed. The coordinate transformation, calculated by subroutine VRID, consists of recalculation of the matrix RIKTN.

Before reassignment of values to RIKTN can proceed, some intermediate calculations must be performed. As the algorithm below explains, an (N+1)xN matrix named A is calculated.

The A Matrix Algorithm

```
(a)     for   (I = 1, 2,...., N)
        if    LAMBDA(I) .NE. 0.0
              A(I,J) = RIKTN(I,J)    J = 1,2,....,N
(b)           A(N+1,J) = 0.0         J = 1,2,....,N
(c)           K = N + 1
(d)     for   (I = N, N-1, N-2,...., 1)
        if    LAMBDA(I) .NE. 0.0
              A(I,J) = A(K,J) + LAMBDA(I) * RIKTN(I,J)
                                     J = 1,2,....,N
              K = K-1
```

When LAMBDA(I) is equal to 0.0, A(I,J) (J = 1,2,...,N) is not calculated and the values from the previous calculation of A are used.

After A has been calculated, the direction matrix is computed. The algorithm below explains the calculation of RIKTN.

The RIKTN Calculation Algorithm

```
      for (I = 1,2,...,N), do
(a)           VEKT(K) = A(I,K)        (K = 1,2,...,N)
(b)           IF I = 1, go to (e)
(c)           SKALAR = 0.0
(d)           SKALAR = SKALAR + A(I,K) * RIKTN(J,K)
                                      (K = 1,2,...,N)
              VEKT(K) = VEKT(K) - SKALAR * RIKTN(J,K)
                                      (K = 1,2,...,N)
(e)           VNORM = 0.0
(f)           VNORM = VNORM + VEKT(K)^2  (K = 1,2,...,N)
(g)           VNORM = VNORM^½
(h)           RIKTN(I,K) = VEKT(K) / VNORM    (K = 1,2,...,N)
```

In the above calculation for RIKTN, it will be noted that VEKT(K), which is effectively the coordinate transformation unit vector, does not explicitly depend on partial derivatives of the cost function. Rather, VEKT(K) depends, independent of RIKTN, upon A and, thereby, LAMBDA. That is, the direction search is selected on the basis of success over a search direction independent of the amount of success (partial derivative evaluation). Thereby, the method used appears not to be a variant of the gradient search type but rather of the generalized hill-climbing type.

E.1.8 Optimization Halt Conditions

Four conditions can stop the optimization process in a multi-variable optimization case. These conditions, contained in subroutine MINIM, are evaluated immediately after a coordinate transformation occurs. When any one condition is satisfied, the true function minimum is considered to be approximated with sufficiently small error and optimization is halted. These optimization halt conditions, or stopping criteria, are discussed in detail in Section E.2.

E.2 STOPPING CRITERIA

There are, as mentioned in the last paragraph, four stopping criteria in force in the program. They are applied after all the axes of the design variables have been searched for a minimum in the cost function.

E.2.1 The First Criterion

The first criterion is the overall convergence criterion, EPZ.

After a coordinate transformation has been implemented, the searches take place along the newly-defined coordinate axes. A test determines whether or not the last three minima so found satisfy the overall stopping criterion - i.e., that the last two successive changes in the cost function are smaller than the specified criterion value. These successive changes are the improvements in the cost function value which result from successful previous searches.

This test appears in the program as follows:

```
If          FUNKV2 - FUNKV1 < EPZ
                     and
            FUNKV1 - FKTMIN < EPZ
STOP
```

FUNKV2, FUNKV1 and FKTMIN have been discussed in section E.1.2. EPZ is the overall convergence criterion and is an input value.

E.2.2 The Second Criterion

Another overall convergence criterion, expressed differently from the one just presented, also serves as an optimization halt condition. The criterion states that if the last coordinate transformation produced absolutely no change in the cost function value, then the optimization is stopped.

```
If          FUNKV1 = FKTMIN
STOP
```

E.2.3 The Third Criterion

The optimization will also terminate when the maximum number of point calculations (iterations) in a run is exceeded.

```
If          NANT ≥ MAXANT
STOP
```

MAXANT is an upper bound, input by the user, on the number of points calculated during an optimization. NANT is the number of points calculated.

E.2.4 The Fourth Criterion

A fourth stopping criterion, based on the precision specified on the design variables, is also applied.

The criterion consists of the number of significant figures of accuracy required on the design variables at the cost function minimum. It is expressed as the limit on the relative change between the last and prior values of each of the design variables.

The criterion is specified as a one digit parameter, NSIG, which is the number of significant figures of accuracy desired.

$$\text{If } \left| \frac{\text{MINP(I) - VLAST1(I)}}{\text{VAVG}} \right| < 10^{-\text{NSIG}}$$

and

$$\left| \frac{\text{VLAST1(I) - VLAST2(I)}}{\text{VAVG}} \right| < 10^{-\text{NSIG}}$$

for all I, I = 1,...,N1

STOP

The limit imposed must not be exceeded for any design variable for the last two successful minima. Thus, after the original criteria have been met and a minimum point is about to be declared, the most recent two changes in design variable values (which correspond to improvements to the objective function) are examined. If their normalized value exceeds "10**(-NSIG)" in absolute value the optimization procedure continues. If their normalized value is less than "10**(-NSIG)" in absolute value for every design variable, the run is allowed to terminate, and a message

"CONVERGENCE ACHIEVED TO WITHIN
nsig SIGNIFICANT FIGURES FOR EACH DESIGN VARIABLE"

is printed in the output file (logical output unit 6). The normalizing factor is the average of the last three values of the design variable (whose difference is being examined). An average was taken in order to eliminate the possibility of division by zero in the normalization. Furthermore, if NSIG is "0" or "1", the changes in the design variable may be large enough that only one of them is not representative of them all (in terms of magnitude).

Tightening this accuracy criterion (i.e., increasing NSIG) forces the optimizer to explore more cost function values in the vicinity of the declared minimum.

E.2.5 USE OF STOPPING CRITERIA

In the implementation of the design variable accuracy stopping criterion, experimentation has lead to the following observations:

(a) During testing, the value of EPZ has generally been set to 10**-6. This must be relaxed in order for the variable accuracy criterion (NSIG) to have an effect. The original criterion is quite stringent and seems to force the design values to be within any reasonable limits of precision specified by NSIG (i.e., for NSIG anywhere between 1 and 8).

(b) If the original criteria (EPS and EPZ which are defined as absolute values rather than relative amounts) are both set to 10**(+4), the variable accuracy criterion determines when the optimization process terminates.

As stated above, tightening the new accuracy criterion (i.e., increasing NSIG) forces the optimizer to explore more cost function values in the vicinity of the declared minimum.

However, after a limited amount of testing of this criterion, it was found that the "improvements" in the calculated measures of the cost function set of values are not uniformly sensitive to changes in NSIG - i.e., the cost function does not (apparently) change by consistent amounts for given changes in NSIG for design variable accuracy in the range of 1 to 8 significant figures. It is here that the cost function standard deviation calculation can be useful in interpreting this sensitivity.

E.2.6 Optimization on a Single Design Variable

It should be emphasized that for single variable optimization, there can be no direction change. Therefore, the maximum number of evaluations for a single design variable is 100, as is currently built into MINSUN.

When optimizing on a single design variable, the MINSUN optimization package bypasses the overall accuracy criterion test, and stops the program if

1. the single axis accuracy criterion, EPS, is met (see sections E.3.5 and E.3.7); or

2. the number of cost function evaluations allowed for a one axis search (100) is reached.

The design variable accuracy criterion was specified to be applied <u>after</u> the overall criteria had been met. Therefore it is not possible to make this additional accuracy criterion apply in the single variable case.

When a single design variable optimization run is invoked, the following message is issued on logical output unit 6:

```
SINGLE VARIABLE OPTIMIZATION.  NUMBER OF FUNCTION EVALUATIONS
IS LIMITED TO 100
```

at the beginning of the optimization.

E.3 STEP SIZE AND CHANGES OF DIRECTION

E.3.1 Introduction

The scalar H plays an important role in the determination of optimization step length and the determination of the halt conditions for direction searches. The calculation of H can be found in subroutines RIKMIN and VERTEX.

During the course of a direction search, two conditions can arise. Either the function minimum for the search direction will exist on one or more constraints or, conversely, the function minimum does not lie on any constraint.

In the first case, H will be adjusted so that a direction change will be performed when the optimizer has obtained an approximation to the true minimum value (for that direction) which is sufficiently close to the constraint.

In the second case, H will be adjusted so that a direction change will be performed after the true minimum value (for that direction) has been windowed with several iterations and an approximation with sufficiently small error in cost has been obtained.

E.3.2 Initial H Calculations (Step Length)

For the first move from either the starting point or the most recently saved minimum point (after a change of direction), H is given by

H = GAMM(1)

GAMM(1) is an input parameter. After a step with this value, H will be reset and a second step made.

If the first step was not successful (either a constraint was violated or the cost function value was not decreased), H will be reset as

$$H = -\ \text{GAMM}(1)$$

When a successful step with $|H| = \text{GAMM}(1)$ is made, H will then be calculated by the equation given in the next section (E.3.3).

It is possible that after a first failure, a second may occur. Under this condition, if optimization is from the initial point, more often than not, a program abort will occur. Table E4 outlines the repeated failure conditions which cause the program to abort.

However, if optimization is proceeding from a minimum point saved after a coordinate transformation, the optimizer will be able to consider the true minimum to be either windowed or lying on a constraint. Here, optimization proceeds with the next point being calculated by subroutine VERTEX.

TABLE E4 CONDITIONS WHICH CAUSE A PROGRAM ABORT WHEN OPTIMIZATION PROCEEDS FROM A FEASIBLE STARTING POINT

Condition	Previous Failure	Current Failure	H Calculation
1	constraint violation	constraint violation	results in program abort
2	constraint violation	not able to decrease cost function value	results in program abort
3	not able to decrease cost function value	constraint violation	results in program abort
4	not able to decrease cost function value	not able to decrease cost function value	refer to windowing section

E.3.3 Increasing Step Length

Step length is increased after a successful step has been made with $|H| = \text{GAMM}(1)$. The increase is due to recalculation of the stepping parameter H as

$$H = \text{GAMM}(2) * H$$

GAMM(2) is an input parameter. This equation will be applied repeatedly if the cost function decreases monotonically along the optimization trajectory.

E.3.4 Windowing a Search Direction's Minimum Point

If a search direction's minimum point does not lie on any constraint, MINSUN's optimizer is able to detect and window this minimum with 3 points. Consider X_1, X_2 and X_3.

$$\text{If} \quad f(X_1) \geq f(X_2) \quad \text{and} \quad f(X_3) \geq f(X_2)$$

the optimizer is able to determine that X_2 lies close to the local minimum of the direction being searched. Under these conditions,

$$\text{If} \quad f(X_1) - f(X_2) = 0 \quad \text{or} \quad f(X_3) - f(X_2) = 0 \qquad (1)$$

H will be calculated by subroutine VERTEX (ref. E.3.6) and subsequent calculations of H will proceed by way of VERTEX until the window has been made sufficiently small or the maximum number of calculations per direction has been reached.

Failure of conditions (1) results in the evaluation of another condition,

$$(2)\quad \text{If } [f(X_1) - f(X_2)] * GAMM(3) < f(X_3) - f(X_2) \quad \text{or} \quad f(X_1) - f(X_2) > [f(X_3) - f(X_2)] * GAMM(3)$$

subroutine RIKMIN will determine

$$\min\, [f(X_1),\ f(X_3)]$$

and set

$$H = 0.5 * h_2 * h'$$

where h' is the H value used to step to the point associated with min $[f(X_1),\ f(X_3)]$. h_1, h_2 and h_3 are defined in section E.3.6.

Failure of condition (2) will result in calculation of H by VERTEX.

In essence, the optimizer is attempting to window the perceived minimum point by iteration. When (1) is satisfied or (2) is not satisfied, subroutine VERTEX is used to compute H. At this stage,

$$\begin{array}{ll} \text{If} & |h_1| < GAMM(1) \\ \text{and} & |h_3| < GAMM(1) \end{array}$$

and either the window has been made sufficiently small (ref. E.3.7 (iii)) or the maximum number of calculations per direction has been reached, a flag will be set (II = 3) and a change of direction or coordinate transformation will be performed.

E.3.5 Approximating a Constraint Value Minimum Point

If a search direction's minimum point exists on a constraint, it is possible to approximate this point with 3 calculations. Consider X_1, X_2 and X_3.

If $f(X_1) \geqslant f(X_2)$
and X_3 causes an "OUT"* condition,

then MINSUN's optimizer is able to determine that the search direction's minimum point lies between X_1 and a constraint.

Under this condition, if

$$(1) \qquad \left| \frac{f(X_1) - f(X_2) * (h_3 - h_2)}{(h_2 - h_1) * f(X_2)} \right| - EPS \geqslant 0$$

H will be set as

$$(2) \qquad H = 0.5 * (h_1 + h_2),$$

and optimization will proceed. Here, h_1 is the H value used to step to X_1, h_2 the value for X_2 and EPS is the direction convergence criterion (input data).

Repeated application of (2) will result in either failure of (1) or in the maximum number of calculations for that direction being exceeded. In either case, a flag is set (IIR = 3) and a change of direction or a coordinate transformation is performed.

E.3.6 Calculation of H by Subroutine VERTEX

If condition (1) of section E.3.4 is true or condition (2) of the same section fails, subroutine VERTEX is used to calculate H. Consider X_1, X_2 and X_3 such that

---

* An "OUT" condition means that the attempted combination of design variables violates a constraint.

$f(X_1) \geqslant f(X_2)$

and

$f(X_3) \geqslant f(X_2)$

Let h_1 be the H factor used to step to X_1, h_2 the H factor for X_2 and h_3 the H factor for X_3. The following algorithm shows how VERTEX calculates H.

VERTEX - The H Calculation Algorithm

```
(a)  $SL1 = h_1 2 - h_2 2$
     $SL2 = h_1 2 - h_3 2$

(b)  $D = SL1 * (h_1 - h_3) - SL2 * (h_1 - h_2)$

(c)  If $D = 0$, go to (j)

(d)  $A = [f(X_2) - f(X_1)] * (h_1 - h_3) - [f(X_3) - f(X_1)] * (h_1 - h_2)$ /D

(e)  If $A = 0$, go to (j)

(f)  $B = SL1 * [f(X_3) - f(X_1)] - SL2 * [f(X_2) - f(X_1)]$ /D

(g)  $C = f(X_1) - A * h_1^2 - B * h_1$

(h)  $H = \frac{-B}{2.0 * A}$

(i)  $Yo = A * H^2 + B * H + C$
     RETURN

(j)  $H = 0.5 * (h_1 + h_3)$

(k)  $Yo = f(X_2)$
```

E.3.7 Changing Search Direction

A coordinate transformation defines N search directions, one for each design variable, and each direction is searched in turn. Three conditions will result in a flag being set (IIR = 3) and a change of search direction being made.

(i) Condition One

When optimizing on two or more design variables, the maximum number of calculations allowed in one direction is set to 16. When this maximum is reached, a change of direction is made.

For N = 1, i.e., when optimizing on a single design variable, this change of direction is not possible, so the optimization halts. In this case the maximum number of calculations allowed in one direction is set to 100 (ref. E.2.5). This has the effect of allowing a single variable optimization run to be terminated by the accuracy related stopping criterion applicable to an axis (condition three, below) rather than the limit on the number of function evaluations.

(ii) Condition Two

When a search direction's minimum point is detected as existing on a constraint, failure of condition (1) of section E.3.5 will result in a change of search direction.

(iii) Condition Three

When a search direction's minimum point has been windowed and calculation of H is being performed by subroutine VERTEX, the program performs the test calculation

$$\text{Is} \quad \left| \frac{f(x_2) - Yo}{f(x_2)} \right| - \text{EPS} \geqslant 0 \ ?$$

If the inequality holds, a flag is set and a change of direction is made. Yo is calculated by VERTEX. If the equality is satisfied, the minimum point has been windowed with sufficiently small error.

After all directions have been searched, a coordinate transformation occurs so that a new set of directions is searched with respect to these transformed axes. Refer to sections E.1.3 and E.1.7 for this procedure.

APPENDIX F

SAMPLE OUTPUT FILES

OUTPUTS FROM THE MINSUN SYSTEM

The MINSUN set of programs produces the following output files, examples of which are included in this Appendix.

- UMSORT Message Log;
- Energy Data Files;
- Simulation Summary;
- Time Profiles - System Profile
  - Temperature Profile;
- Two Parameter Variation - Cost Figures
  - Details;
- MINREP Multiple Simulation Results.

An example of each of these outputs appears in this appendix. All outputs were produced using the parameter files in Appendix A.

F.1 UMSORT Message Log

This file is produced on FORTRAN Logical Unit #6 every time the UMSORT program is run. The first section presents a formatted version of the contents of the UMSORT parameter file.

The second part summarizes the energy information produced in the Energy Data Files (ref. Appendix F.2). For each collector type requested in the UMSORT parameter file, a table is produced giving monthly and annual totals for radiation and for energy collected per square metre of collector area at the requested operating temperatures.

An example of an UMSORT Message Log appears on the following pages.

```
  IEA DATA PROGRAM VERSION 1
   MONTH END DAYS  31  28  31  30  31  30  31  31  30  31  30  31
   COLLECTOR SWITCHES 1=ON.0=OFF

    FLAT PLATE=0 SALT POND=0 EVAC TUBE=1
    CENTRAL RECV=0 PARB TROUGH=0 SHAL POND=0
   BOES MODEL=0

       ALPHA            UL1            UL2        BO           TILT          DIR          RHO
 0.8080E 00   0.4400E 01        0.0000   0.1000E 00   0.4300E 02        0.0000   0.2000E 00
 0.3370E 00   0.2900E 00        0.0000   0.5000E-01       0.0000        0.0000       0.0000
 0.5100E 00   0.1310E 01        0.0000   0.1700E 00   0.4300E 02        0.0000   0.2000E 00
 0.9800E 00       0.0000        0.0000       0.0000       0.0000        0.0000       0.0000
 0.8070E 00   0.8900E-01    0.8690E 00       0.0000       0.0000        0.0000   0.2000E 00
 0.6400E 00   0.4400E 01        0.0000       0.0000       0.0000        0.0000       0.0000

ALAT=43.00 DLONG= 0.00 TEMPS= 30. 50. 70. 90.110.
 TMAMB=10.  TROOM=18.
```

```
        * IEA * UMSORT OUTPUT SUMMARY *

                 FOR COLLECTOR NUMBER  :  3
                 FOR LOCATION          :MADI

 - TEMPERATURES        IN      DEGREES CELCIUS
 - ALL ENERGIES        IN      MEGAJCULES/MONTH OR YEAR

******************************************************************************************************************************
*         MONTH            *   J   *   F   *   M   *   A   *   M   *   J   *   J   *   A   *   S   *   O   *   N   *   D   **   YEAR   *
******************************************************************************************************************************
* AMB. TEMPERATURE         * -8.3  * -6.0  * -1.9  *  8.7  * 14.6  * 19.6  * 22.1  * 20.0  * 16.8  * 10.5  *  2.3  * -3.7  **    7.9   *
* TEMP. FOR LOAD MOD       * -8.3  * -6.0  * -1.8  * 10.0  * 15.2  * 17.7  * 18.0  * 17.7  * 16.7  * 12.1  *  3.2  * -3.7  **    7.6   *
******************************************************************************************************************************
* DIRECT NORMAL RAD.       *  273. *  292. *  470. *  387. *  499. *  500. *  559. *  556. *  448. *  335. *  243. *  183. **   4744.  *
* TOTAL HORIZONTAL         *  183. *  256. *  427. *  471. *  599. *  639. *  675. *  616. *  455. *  305. *  174. *  133. **   4933.  *
******************************************************************************************************************************
* TOTAL INCIDENT           *  298. *  353. *  528. *  489. *  555. *  572. *  618. *  617. *  520. *  398. *  267. *  216. **   5429.  *
******************************************************************************************************************************
* COLLECTED AT    30.      *  110. *  130. *  215. *  197. *  231. *  243. *  274. *  279. *  233. *  170. *  104. *   79. **   2265.  *
* COLLECTED AT    50.      *   95. *  112. *  193. *  171. *  200. *  210. *  239. *  246. *  206. *  148. *   90. *   68. **   1978.  *
* COLLECTED AT    70.      *   82. *   98. *  173. *  150. *  175. *  182. *  208. *  217. *  181. *  130. *   76. *   59. **   1733.  *
* COLLECTED AT    90.      *   71. *   85. *  156. *  131. *  152. *  157. *  182. *  191. *  160. *  115. *   68. *   51. **   1519.  *
* COLLECTED AT   110.      *   61. *   73. *  140. *  115. *  132. *  135. *  158. *  167. *  141. *  101. *   59. *   43. **   1326.  *
******************************************************************************************************************************
* OP. HOURS AT    30.      *  168. *  207. *  254. *  305. *  356. *  390. *  407. *  376. *  320. *  260. *  167. *  128. **   3338.  *
* OP. HOURS AT    50.      *  146. *  170. *  216. *  247. *  296. *  323. *  346. *  332. *  268. *  204. *  128. *  104. **   2780.  *
* OP. HOURS AT    70.      *  125. *  147. *  197. *  211. *  253. *  275. *  301. *  288. *  246. *  175. *  111. *   92. **   2421.  *
* OP. HOURS AT    90.      *  113. *  127. *  172. *  182. *  229. *  251. *  262. *  270. *  214. *  155. *  101. *   86. **   2162.  *
* OP. HOURS AT   110.      *  107. *  115. *  160. *  157. *  206. *  217. *  236. *  234. *  189. *  138. *   94. *   75. **   1928.  *
******************************************************************************************************************************
END OF IEADATA PROCESSING
```

F.2 Energy Data Files

These files are produced by UMSORT/ADVANCE and are required as input to the MINSUN program. One file is produced for each collector type requested in the UMSORT parameter file. The correspondence between collector type and FORTRAN Logical Unit is given in the following Table.

Collector Type	L.U.
FLAT PLATE	7
SALT POND	8
EVACUATED TUBE	9
CENTRAL RECEIVER	10
PARABOLIC TROUGH	11
SHALLOW POND	12

If ADVANCE is run (ref. section 3.3), one of the above files output by UMSORT must be supplied as input to ADVANCE on Logical Unit 4. The adjusted file is written to Logical Unit 7.

To run MINSUN, one of these Energy Data Files must be assigned to Logical Unit 4.

The first page of a sample Energy Data File appears on the following page. This file was produced by the ADVANCE program. It contains energy data for Evacuated Tube Collectors generated using Madison weather.

```
IEA          MADI                      EVAC TUBE
   365   18.   10.     30.     50.    70.    90.   110.
  31   28    31    30    31     30    31    31    30    31     30     31
   91      24 8722.50 8062.26 7402.02 6762.74 6211.05       0.93      0.93 10.  10.  10.   9.   8.
   92      24  257.70   21.32    0.00    0.00    0.00       3.73      3.73  5.   1.   0.   0.   0.
   93      24 8298.92 7697.45 7103.23 6539.62 6011.43      -0.53     -0.53 10.   9.   9.   8.   8.
   94      24 7610.65 6950.41 6354.60 5765.32 5237.13      -0.72     -0.72 10.  10.   9.   8.   8.
   95      24   15.90    0.00    0.00    0.00    0.00       1.74      1.74  1.   0.   0.   0.   0.
   96      24 4592.25 4003.75 3492.62 3136.44 2872.34       9.77     12.26 10.   8.   6.   4.   4.
   97      24 1087.16  626.21  379.23  245.63  115.36       4.28      4.28  7.   5.   3.   2.   1.
   98      24 4597.58 3916.69 3362.88 2897.93 2481.39       1.27      1.27 11.   9.   8.   7.   6.
   99      24 8925.63 8208.66 7555.49 6961.29 6367.07       6.46      8.16 12.  10.   9.   9.   9.
  100      24 8857.00 8122.99 7462.75 6802.51 6186.32       8.66     10.16 12.  10.  10.  10.   9.
  101      24 4163.02 3456.58 2820.79 2291.50 1869.14      14.40     14.41 12.  10.   9.   7.   6.
  102      24 2251.30 1607.30 1109.65  780.65  516.55      14.19     17.17 11.   8.   7.   4.   4.
  103      24 1230.33  645.99  361.30  197.85   83.00      11.27     13.73 10.   7.   3.   2.   1.
  104      24 5855.10 5172.11 4575.04 4006.72 3535.14       9.42     11.88 12.  10.   9.   8.   7.
  105      24 4902.02 4185.61 3525.39 2894.78 2356.28       7.99     10.48 12.  10.  10.   9.   8.
  106      24 8216.55 7445.76 6739.80 6079.56 5419.33      18.01     15.21 13.  11.  10.  10.  10.
  107      24 3357.85 2720.27 2250.74 1837.80 1447.54      17.85     18.00 11.   8.   7.   6.   5.
  108      24 2245.14 1648.35 1120.17  714.87  411.83       5.99      6.33 10.   8.   8.   5.   4.
  109      24 2980.26 2310.12 1839.29 1443.15 1083.81       6.06      7.04 11.   9.   6.   6.   5.
  110      24 2539.54 1946.85 1434.72 1011.35  760.56       8.75     10.56  9.   8.   7.   6.   2.
  111      24 7305.12 6582.14 5922.48 5346.25 4839.77      15.37     15.77 11.  10.   9.   8.   7.
  112      24 6676.10 6022.52 5459.48 4931.29 4428.63       9.98     11.55 10.   9.   8.   8.   7.
  113      24 3093.91 2440.13 1900.95 1407.99 1016.64       8.05      9.46 10.   9.   8.   7.   5.
  114      24 8631.69 7849.48 7176.04 6515.80 5890.75       6.99      8.72 12.  11.  10.  10.   9.
  115      24 8478.76 7695.16 7021.58 6361.34 5730.38       9.33     10.45 12.  11.  10.  10.   9.
  116      24 6237.62 5522.28 4863.02 4268.81 3712.01      12.48     13.55 11.  10.   9.   9.   7.
  117      24 1398.20  790.86  442.67  251.40  119.35      15.32     18.00 11.   9.   4.   2.   2.
  118      24 4071.02 3366.03 2783.05 2350.27 1954.13      13.33     17.64 11.  10.   8.   6.   6.
  119      24  495.19  143.99   77.50   11.47    0.00      10.09     15.50  8.   2.   1.   1.   0.
  120      24  989.93  512.17  224.25   27.82    0.00       9.74     12.44 10.   5.   4.   1.   0.
  121      24  942.35  608.17  409.26  226.85   94.80       9.38     11.45  8.   4.   3.   2.   2.
  122      24   80.29    0.00    0.00    0.00    0.00       6.25      6.25  4.   0.   0.   0.   0.
  123      24  963.45  605.31  331.51  148.20   63.99       7.69     10.14  6.   5.   4.   2.   1.
  124      24 5569.88 4843.62 4140.61 3516.83 2961.96       9.81     11.38 11.  11.  10.   9.   8.
  125      24 8804.46 8016.05 7340.59 6740.04 6145.82      12.22     14.35 12.  11.  10.   9.   9.
  126      24 3738.32 3088.19 2582.21 2142.41 1746.26      13.75     15.96 10.   8.   7.   6.   6.
  127      24 3029.60 2348.55 1831.49 1435.35 1039.21      15.42     17.64 11.   9.   6.   6.   6.
  128      24 6639.71 5813.05 5089.79 4429.56 3788.99      19.91     18.00 13.  12.  10.  10.   9.
  129      24 8011.78 7192.35 6408.94 5738.11 5137.25      20.88     18.00 13.  12.  11.  10.   9.
  130      24 6204.73 5428.85 4738.54 4110.29 3555.38      21.07     18.00 13.  11.  10.   9.   8.
  131      24 8956.98 8152.39 7394.78 6734.55 6105.41      16.97     18.00 13.  12.  10.  10.   9.
  132      24 6170.37 5378.08 4697.06 4036.82 3466.80      13.70     15.62 12.  12.  10.  10.   8.
  133      24 6059.00 5266.71 4594.06 3999.85 3405.64       4.51      5.13 12.  12.   9.   9.   9.
  134      24 2572.16 1935.45 1407.27 1009.83  740.65       7.68     10.41 11.   8.   8.   5.   3.
  135      24 8135.08 7393.01 6707.06 6046.82 5471.68      12.94     13.85 12.  11.  10.  10.   8.
  136      24 4070.54 3354.89 2772.14 2243.95 1766.92      15.60     16.06 12.  10.   8.   8.   7.
  137      24  471.95   74.63    0.00    0.00    0.00      12.29     18.00 11.   2.   0.   0.   0.
  138      24 4818.23 3993.36 3294.95 2634.71 1991.95      14.37     16.12 13.  12.  10.  10.   9.
  139      24 8758.54 7957.35 7236.89 6576.65 5933.04      14.84     14.82 13.  12.  10.  10.   9.
  140      24 7754.52 7012.51 6286.25 5679.43 5085.21      20.42     18.00 12.  11.  11.   9.   9.
  141      24 3781.68 3018.43 2358.19 1700.68 1117.85      13.40     18.00 12.  10.  10.   9.   8.
```

F.3 Simulation Summary

This file is produced by MINSUN on Logical Unit 6. The contents of the file are described in section 9.2.

A sample Simulation Summary File appears on the following pages.

```
IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4(A) - NOV 19

                   RUN TITLE :   TANK STORAGE SAMPLE RUN - NOVEMBER 1984



         S U M M A R Y   O F   I N P U T   D A T A .
         ---------------------------------------------

STORAGE OPTION SELECTED :

                             INSULATED TANK MODEL

                                      W E A T H E R   D A T A   D E T A I L S
                                      -------------------------------------------

IEA MODEL - DATA PRE-PROCESSED BY PROGRAM UMSORT

TITLE CARD (CITY AND COLLECTOR TYPE) :           MADI                EVAC TUBE

WEATHER DATA FILE HAS BEEN READ.

LAST DATE READ WAS                                 90           INDOOR TEMPERATURE (C)                                 18.0
HEATING IF AMBIENT TEMP. LESS THAN (C)           10.0



RUN OPTIONS SELECTED FOR THIS RUN :

                                            I N S U L A T I O N   D A T A
                                            ------------------------------

COLLECTOR PIPE INSULATION CONDUCTIVITY (W/MK)    0.030          EARTH TEMPERATURE (C)                                 10.00
DIAMETER DEPENDENT INSULATION THICKNESS (M/M)    0.100          FIXED INSULATION THICKNESS (M)                        0.020

                                  C O L L E C T O R   D A T A   (CENTRAL MOUNTED)
                                  -------------------------------------------------

OPTION (MUST BE 3.)                                3.          COLLECTOR AREA (SQ.M)                               25000.0
MAX. (COLL. OUTLET - TOP STORAGE TEMP.) (C)      20.0          OUTLET TEMP. AT WHICH FLOW IS INCREASED (C)            50.0
MAXIMUM COLLECTOR OUTLET TEMPERATURE (C)         97.0
NORMAL FLOW RATE (KG / S SQ.M)                 0.0050          MAXIMUM FLOW RATE (KG / S SQ.M)                      0.1000
COLLECTOR PIPING NETWORK LENGTH (M)             100.0          INSULATION THICKNESS (M)                              0.000
PIPE DIAMETER (M)                               0.250
```

```
IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4(A) - NOV 19

                   RUN TITLE :   TANK STORAGE SAMPLE RUN - NOVEMBER 1984


                                      S T O R A G E    D A T A  (INSULATED TANK)
                                      ------------------------------------------

VOLUME (CU.M)                                 50000.0          HEIGHT (M)                                        10.0
NUMBER OF VERTICAL SEGMENTS                         3          DENSITY (KG / CU.M)                             1000.0
SPECIFIC HEAT CAPACITY (KJ / KG K)               4.18          GROUND TEMPERATURE (C)                           10.00
INITIAL TEMPERATURE (C) FROM TOP OF TANK        52.00     48.00     45.00
MAXIMUM AVERAGE TEMPERATURE CHANGE (C) WITHOUT STARTING TEMP. ADJUSTMENT                                         2.00
INSULATION THICKNESS ON LID (M)                 0.200          INSULATION THICKNESS AROUND SIDES (M)            0.200
INSULATION THICKNESS UNDER BOTTOM (M)           0.200
THERMAL CONDUCTIVITY OF TOP INSULATION (W/MK)    0.05          CONDUCTIVITY OF SIDE INSULATION (W/MK)            0.05
CONDUCTIVITY OF BOTTOM INSULATION (W/MK)         0.05

OPTIONS :  1. SURFACE TANK (GROUND TEMPERATURE UNDER TANK ONLY)
           2. PARTIALLY BURIED TANK (GROUND TEMPERATURE ROUND SIDES ALSO)
           3. COMPLETELY BURIED TANK

OPTION SELECTED                                     3

THICKNESS OF CONCRETE (M)                        2.00

FIRST DAY OF THE HEATING PERIOD :  DAY 274
 LAST DAY OF THE HEATING PERIOD :  DAY 132
```

```
IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4(A) - NOV 19

                   RUN TITLE :   TANK STORAGE SAMPLE RUN - NOVEMBER 1984


                                          H O U S E   L O A D   D A T A
                                          -----------------------------

NUMBER OF HOUSES                                 500          HEAT LOSS AREA PER HOUSE (SQ.M)                  350.0
HEAT LOSS COEFFICIENT ( W / SQ.M K)            0.500          DESIGN INDOOR TEMPERATURE (C)                    18.00
DISTRIBUTION NETWORK OPTION (3 OR 4 WAY)           3
RETURN TEMPERATURE OPTIONS : 1. RETURN TEMPERATURE GIVEN
                             2. NETWORK TEMPERATURE DECREASE GIVEN

OPTION SELECTED                                    1

FEED TEMPERATURE IS GIVEN BY :  55.0 + 1.00 * MAX(  0.0-TAMB, 0.0)    WHERE TAMB = AMBIENT TEMPERATURE
RETURN TEMPERATURE OR TEMPERATURE DIFFERENCE   45.00          CASUAL GAINS (FROM PEOPLE ETC) (W/HOUSE)         400.0
TAP WATER POWER REQUIREMENT (W/HOUSE)           635.

HOUSE DISTRICT HEATING NETWORK LENGTH (M)     7000.0          INSULATION THICKNESS (M)                         0.050
PIPE DIAMETER (M)                              0.100


RESULTS FROM CALCULATION OF DISTRICT HEATING NETWORK LOAD AND LOSSES
--------------------------------------------------------------------

TOTAL ENERGY DEMAND FROM HOUSES (MWH/YEAR)   9512.47
TOTAL LOSS FROM SUPPLY PIPEWORK (MWH/YEAR)    767.77          TOTAL LOSS FROM RETURN PIPEWORK (MWH/YEAR)       573.18
```

```
IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4(A) - NOV 19

                    RUN TITLE :   TANK STORAGE SAMPLE RUN - NOVEMBER 1984


                                             H E A T   P U M P   D A T A
                                             ---------------------------

HEATING SYSTEM HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)          0.650

TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)                         50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)      100.0

MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)         5.0       MINIMUM COP FOR OPERATION OF HEAT PUMP             1.00
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)      1000.00       CONDENSER HEAT TRANSFER CAPACITY (KW/K)          300.00

                                                  C O S T   D A T A
                                                  -----------------

COST OF COLLECTORS ( / SQ.M)                370.00 US$      COST OF LARGE STORAGE ( / CU.M)              25.00 US$
COST OF SMALL STORAGE ( / CU.M)              88.00 US$      SMALL STORAGE VOLUME (CU.M)                 10000.
EXCAVATION COST EQUATION FACTOR (BETA)        0.4000        EXPONENT FOR COST INCREASE DUE TO DEPTH      0.0050
COST OF CONCRETE (/ CU.M)                     0.00 US$      COST OF GROUND ( / SQ.M)                     0.00 US$
COST OF INSULATION ( / CU.M)                100.00 US$

HEAT PUMP COSTS

COST OF CONDENSER HEAT EXCHANGER (K/W)        0.20 US$      COST OF EVAPORATOR HEAT EXCHANGER (K/W)      0.20 US$
COST OF MOTOR ( / W INSTALLED)                0.20 US$      REFERENCE POWER (MW)                         0.600
HEAT PUMP SCALE FACTOR FOR COSTS            -0.3000

COST OF PIPING BETWEEN COLLECTORS AND STORAGE

DIAMETER DEPENDENT (/M(LENGTH)/M(DIAM))  2000.00 US$        FIXED COST ( / M)                          124.00 US$
COST OF INSULATION OF PIPEWORK ( / CU.M)    0.00 US$

AUXILIARY HEATER COSTS

INSTALLATION OF HEATER ( / W INSTALLED)     0.10 US$        FUEL COST ( / KWH)                           0.05 US$
COST OF FUEL FOR HEAT PUMP ( / KWH)         0.05 US$

OTHER ECONOMIC PARAMETERS

DEPRECIATION TIME (YEARS)                       20.         REAL INTEREST RATE (PERCENT)                      5.00
FUEL INFLATION RATE ABOVE NORMAL INFLATION      2.00
```

```
IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4(A) - NOV 19

                   RUN TITLE :   TANK STORAGE SAMPLE RUN - NOVEMBER 1984


                                             O P T I M I S A T I O N   D A T A
                                             ---------------------------------

NO. OF CALCULATION POINTS BETWEEN PRINTING          1        MAXIMUM NO. OF POINTS TO BE CALCULATED                200
CONVERGENCE CRITERION FOR EACH DIMENSION     2.00E 04        OVERALL CONVERGENCE CRITERION                    2.00E 04
MIN. NO. OF SIGNIFICANT FIGS. FOR CONVERGENCE       4

DESCRIPTION OF VARIABLE             WHETHER VARIED      STEP LENGTH

COLLECTOR AREA                           YES             100.00
STORAGE VOLUME                           YES            1000.00
STORAGE HEIGHT/DIAMETER RATIO            NO                0.01
STORAGE INSULATION THICKNESS             NO                0.20
TAP WATER HEAT PUMP EVAPORATOR SIZE      NO              10.0000
TAP WATER HEAT PUMP CONDENSER SIZE       NO              10.0000
HOUSE HEATING HEAT PUMP EVAPORATOR SIZE  NO              10.0000
HOUSE HEATING HEAT PUMP CONDENSER SIZE   NO              10.0000
PARTS OF STEPLENGTHS FOR THE FIRST TRIALS IN EACH DIRECTION
     0.01      6.00      10.00

DETAILS OF PENALTY FUNCTIONS -  DISTANCE = DISTANCE FROM BOUNDARY WHERE PENALTY APPLIES
                                PENALTY  = PENALTY VALUE (MULTIPLIED BY SQUARE OF DISTANCE FROM BOUNDARY)

     DESCRIPTION                             DISTANCE       PENALTY

COLLECTOR AREA MAXIMUM                       1.00E 01       1.00E 00
COLLECTOR AREA MINIMUM                       5.00E 01       4.00E-02
STORAGE VOLUME MAXIMUM                       1.00E 02       1.00E-02
STORAGE VOLUME MINIMUM                       1.00E 02       1.00E-02
STORAGE HEIGHT/DIAM. MINIMUM                 1.00E-02       1.00E 06
STORAGE INSULATION THICKNESS MAX.            1.00E-04       1.00E 10
STORAGE INSULATION THICKNESS MIN.            1.00E-02       1.00E 06
TAP WATER HEAT PUMP EVAP. MIN.               5.00E-02       1.00E 04
TAP WATER HEAT PUMP COND. MIN.               1.00E-01       1.00E 04
HOUSE HEATING HEAT PUMP EVAP. MIN.           1.00E-01       1.00E 04
HOUSE HEATING HEAT PUMP COND. MIN.           1.00E-01       1.00E 04
STORAGE DEPTH MAXIMUM                        5.00E-01       1.00E 06
SOLAR FRACTION MINIMUM                       1.00E-02       1.00E 06
STORAGE TEMP. DECREASE MAX.                  1.00E 04           0.00

MAXIMUM COLLECTOR AREA (SQ.M)                  40000.        MINIMUM COLLECTOR AREA (SQ.M)                    10000.
MAXIMUM STORAGE VOLUME (CU.M)                 100000.        MINIMUM STORAGE VOLUME (CU.M)                    10000.
MAXIMUM HEIGHT OF STORE (M)                    100.00
MINIMUM SOLAR COVER FRACTION                     0.00
```

```
IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4(A) - NOV 19

                   RUN TITLE :   TANK STORAGE SAMPLE RUN - NOVEMBER 1984


                                                     P L O T   D A T A
                                                     -----------------

NOTE: GRAPH OPTION NOT SPECIFIED - THESE PARAMETERS ARE IGNORED
PLOT NUMBER:  1
TITLE: #####          SAMPLE RUN                                 #####

DESCRIPTION OF VARIABLE              WHETHER VARIED

COLLECTOR AREA                            YES
STORAGE VOLUME                            YES
STORAGE HEIGHT/DIAMETER RATIO              NO
STORAGE INSULATION THICKNESS               NO
TAP WATER HEAT PUMP EVAPORATOR SIZE        NO
TAP WATER HEAT PUMP CONDENSER SIZE         NO
HOUSE HEATING HEAT PUMP EVAPORATOR SIZE    NO
HOUSE HEATING HEAT PUMP CONDENSER SIZE     NO
VARIABLE  1 VARIED FROM  1.0000E 03 TO  6.0000E 04    THROUGH 16 POINTS
VARIABLE  2 VARIED FROM  3.0000E 04 TO  1.5000E 05    THROUGH 16 POINTS

REPORT OPTION :
       0 - SIMULATION SUMMARY ONLY
       1 - SIMULATION SUMMARY & MONTHLY PROFILE
       2 - SIMULATION SUMMARY, MONTHLY & WEEKLY PROFILES
       3 - SIMULATION SUMMARY, MONTHLY, WEEKLY & DAILY PROFILES

         OPTION SELECTED :     3
```

```
S T A R T   O F   O P T I M I S A T I O N

  0.250000E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14365290E 07  0.14365290E 07 14  0.999499E 04
  0.250010E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399340E 07  0.14399340E 07 14  0.999845E 04
  0.249990E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399060E 07  0.14399060E 07 14  0.999845E 04
  0.250000E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399110E 07  0.14399110E 07 14  0.999845E 04

  CHANGE OF DIRECTION
  0.250000E 05  0.500100E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399360E 07  0.14399360E 07 14  0.999845E 04
  0.250000E 05  0.499900E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14398650E 07  0.14398650E 07 14  0.999845E 04
  0.250000E 05  0.499999E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399120E 07  0.14399120E 07 14  0.999845E 04
NUMBER OF POINTS =    7    LAMBDA(I)
   0.0000    0.0000

DIRECTION MATRIX
 1.000000  0.000000
 0.000000  1.000000
  0.250010E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399340E 07  0.14399340E 07 14  0.999845E 04
  0.249990E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399060E 07  0.14399060E 07 14  0.999845E 04
  0.250000E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399110E 07  0.14399110E 07 14  0.999845E 04

CHANGE OF DIRECTION
  0.250000E 05  0.500100E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399360E 07  0.14399360E 07 14  0.999845E 04
  0.250000E 05  0.499900E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14398650E 07  0.14398650E 07 14  0.999845E 04
  0.250000E 05  0.499999E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
   0.14399120E 07  0.14399120E 07 14  0.999845E 04
NUMBER OF POINTS =   13    LAMBDA(I)
   0.0000    0.0000
```

```
DIRECTION MATRIX
 1.000000  0.000000
 0.000000  1.000000
 0.250010E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399340E 07  0.14399340E 07 14  0.999845E 04
 0.249990E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399060E 07  0.14399060E 07 14  0.999845E 04
 0.250000E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399110E 07  0.14399110E 07 14  0.999845E 04

CHANGE OF DIRECTION
 0.250000E 05  0.500100E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399360E 07  0.14399360E 07 14  0.999845E 04
 0.250000E 05  0.499900E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14398650E 07  0.14398650E 07 14  0.999845E 04
 0.250000E 05  0.499999E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399120E 07  0.14399120E 07 14  0.999845E 04
NUMBER OF POINTS =    19    LAMBDA(I)
   0.0000    0.0000

DIRECTION MATRIX
 1.000000  0.000000
 0.000000  1.000000
 0.250010E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399340E 07  0.14399340E 07 14  0.999845E 04
 0.249990E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399060E 07  0.14399060E 07 14  0.999845E 04
 0.250000E 05  0.500000E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399110E 07  0.14399110E 07 14  0.999845E 04

CHANGE OF DIRECTION
 0.250000E 05  0.500100E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399360E 07  0.14399360E 07 14  0.999845E 04
 0.250000E 05  0.499900E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14398650E 07  0.14398650E 07 14  0.999845E 04


CONVERGENCE ACHIEVED TO WITHIN
  4 SIGNIFICANT FIGURES FOR EACH DESIGN VARIABLE


 0.250000E 05  0.499999E 05  0.125331E 00  0.200000E 00  0.110000E 03  0.110000E 03  0.360000E 07  0.108000E 07
  0.14399120E 07  0.14399120E 07 14  0.999845E 04
NUMBER OF POINTS =    25    LAMBDA(I)
   0.0000    0.0000

DIRECTION MATRIX
 1.000000  0.000000
 0.000000  1.000000

MINIMUM POINT
  0.250000E 05    0.500000E 05    0.125331E 00    0.200000E 00    0.110000E 03    0.110000E 03    0.360000E 07    0.108000E 07

  0.14365290E 07
```

```
FOR   25 COST FUNCTION EVALUATIONS,
THE ACCUMULATED SUM IS : $ 0.3599429E 08
THE AVERAGE COST FUNCTION IS $  1439771.
THE STANDARD DEVIATION IS : $  2773.005
THE MINIMUM COST IS : $  1436529.
THE  MAXIMUM COST IS : $  1439936.
```

```
                 O P T I M I S A T I O N   R E S U L T S
                 ---------------------------------------

COLLECTOR AREA (SQ.M)                                         25000.
STORE VOLUME (CU.M)                                           50000.
STORE HEIGHT/DIAMETER RATIO                                    0.13
STORE HEIGHT (M)                                              10.00
STORE INSULATION THICKNESS (M)                                0.200
TAP WATER HEAT PUMP EVAPORATOR SIZE (KW/K)                       0.
TAP WATER HEAT PUMP CONDENSER SIZE (KW/K)                        0.
HOUSE HEATING HEAT PUMP EVAPORATOR SIZE (KW/K)                1000.
HOUSE HEATING HEAT PUMP CONDENSER SIZE (KW/K)                  300.


MAXIMUM AUXILIARY HEATER POWER (HOUSE) (MW)                   0.000
MAXIMUM AUXILIARY HEATER POWER (TAP WATER) (MW)               0.000
MAXIMUM CONDENSER POWER (HOUSE HEATING) (MW)                  4.092
MAXIMUM CONDENSER POWER (TAP WATER) (MW)                      0.000

                C O S T   F U N C T I O N   F A C T O R S
                -----------------------------------------

TOTAL CAPITAL COST OF HEATING SYSTEM                       1.760E 07 US$
CAPITAL COST ANNUALISATION FACTOR                          7.642E-02

FIRST YEAR OPERATING COSTS FOR SYSTEM                      8.086E 04 US$
OPERATING COST ANNUALISATION FACTOR                         1.18

AVERAGE YEARLY COSTS (CAPITAL + OPERATION)                 1.440E 06 US$

                C A P I T A L   C O S T   S U M M A R Y
                ---------------------------------------

         ALL COSTS IN THOUSANDS OF US$

COST OF SOLAR COLLECTORS                                        9250.0
COST OF STORE EXCAVATIONS                                       3053.6
COST OF CONCRETE                                                   0.0
COST OF STORE INSULATION                                         250.1
COST OF HOUSE HEATING HEAT PUMP CONDENSER                         33.7
COST OF TAP WATER HEAT PUMP CONDENSER                              0.0
COST OF HOUSE HEATING HEAT PUMP EVAPORATOR                       112.4
COST OF TAP WATER HEAT PUMP EVAPORATOR                             0.0
COST OF HOUSE HEATING HEAT PUMP MOTOR                            235.8
COST OF TAP WATER HEAT PUMP MOTOR                                  0.0
COST OF GROUND FOR STORE                                           0.0
INSTALLED COST FOR AUXILIARY HEATER (HOUSE)                        0.0
INSTALLED COST OF AUXILIARY HEATER (TAP WATER)                     0.0
COST OF COLLECTOR ARRAY PIPEWORK (CENTRAL)                       124.8
COST OF COLLECTOR ARRAY PIPEWORK (HOUSE MOUNTED)                   0.0
COST OF HOUSE HEATING DISTRIBUTION NETWORK                      4536.0
COST OF TAP WATER DISTRIBUTION NETWORK                             0.0
```

```
                     H E A T   F L O W   S U M M A R Y
                     ---------------------------------

OLLECTOR SUB-SYSTEM

    COLLECTOR OUTPUT                          10143.67 MWH
    CENTRAL COLLECTORS
         PIPE LOSS FORWARD                        4.95 MWH
         PIPE LOSS RETURN                         6.14 MWH

                   COLLECTOR SUPPLY                          10132.58 MWH

TORAGE SUB-SYSTEM

    STORAGE LOSSES                              927.95 MWH

              COLLECTOR SUPPLY MINUS STORAGE LOSSES           9204.64 MWH

    STORED HEAT YEAR END
    MINUS YEAR BEGINNING                        -31.86 MWH

              COLLECTOR AND STORAGE SUPPLY                    9236.49 MWH


UXILIARY

    HEAT PUMP ELECTRIC ENERGY
         HOUSE HEAT                            1617.15 MWH
         TAP WATER                                0.00 MWH
    AUXILIARY HEATER
         HOUSE HEAT                               0.00 MWH
         TAP WATER                                0.00 MWH
                   TOTAL SUPPLY                              10853.64 MWH

OAD

    DISTRIBUTION LOSS FORWARD
         HOUSE HEAT                             767.77 MWH
         TAP WATER                                0.00 MWH
    DISTRIBUTION LOSS RETURN
         HOUSE HEAT                             573.18 MWH
         TAP WATER                                0.00 MWH
    HOUSE LOAD                                 9512.69 MWH

                   TOTAL LOAD                                10853.64 MWH


ATIOS

        COLLECTOR SUPPLY/TOTAL LOAD                            93.36 PERCENT
        COLLECTOR SUPPLY MINUS STORAGE LOSSES/TOTAL LOAD       84.81 PERCENT
        COLLECTOR AND STORAGE SUPPLY/TOTAL LOAD                85.10 PERCENT
```

```
               T E M P E R A T U R E S   O F   S T O R A G E
              ---------------------------------------------

START    20.2  10.5    8.9

END      19.6  10.0    8.3

CHANGE OF AVERAGE TEMPERATURE     -0.549  C

MIN. TEMPERATURE         5.1 C   MAX.TEMPERATURE       78.9 C

MIN CHANGE OF STORAGE    -2152.38 MWH    MAX    1620.58 MWH

DIAMETER OF CENTRAL COLLECTOR ARRAY PIPES       0.250 M
INSULATION THICKNESS ROUND PIPES                0.045 M
                 H E A T    P U M P    P E R F O R M A N C E
                 -----------------------------------------

                EL-MOTOR    COND POWER  C.O.P.
TAP WATER         0.00        0.00       0.00
HOUSE HEAT     1617.15     7268.94       4.49


                       S P E C I F I C    C O S T S
                       ----------------------------


                    INVESTMENT   CAPITAL      OPERATION   TOTAL
                    (US$ /MWH/Y)  (US$ /MWH)  (US$ /MWH)  (US$ /MWH)

SOLAR COLLECTORS        854.76       65.32        0.00       65.32

COLL. PIPEWORK           11.53        0.88        0.00        0.88

STORAGE                 305.29       23.33        0.00       23.33

HEAT PUMP                35.30        2.70        8.79       11.49
                    -----------------------------------------------

TOTAL SOLAR SYSTEM     1206.87       92.23        8.79      101.02

AUXILIARY                 0.00        0.00        0.00        0.00
                    -----------------------------------------------

TOTAL SYSTEM           1206.87       92.23        8.79      101.02


TOTAL SOLAR COST (/MWH DELIVERED FROM SOLAR SYSTEM)         108.06
```

F.4 Time Profiles

Up to six time profile reports can be produced by MINSUN Single Simulation and System Optimization runs. The reports produced are determined by the user as detailed in section 9.3.

The six reports and their associated FORTRAN Logical Units are:

LU	REPORT
8	Daily System Profile
9	Weekly System Profile
10	Monthly System Profile
11	Daily Temperature Profile
12	Weekly Temperature Profile
13	Monthly Temperature Profile

The System Profile reports give daily, weekly and monthly totals for:

- energy from collectors (MWH);
- piping losses (MWH);
- top of storage temperature (end of period);
- bottom of storage temperature (end of period);
- storage losses (MWH);
- auxiliary energy (MWH);
- heat pump electricity input (MWH);
- heat pump condenser output (MWH);
- system load (MWH);
- collector temperature into storage;
- collector flow into storage.

The daily profile indentifies each line by the day number from the beginning of the year (January 1 = 1, December 31 = 365). These summary lines use the format (I4, 3X, 1P11E10.2). The first 22 lines of the file contain a description of the output.

The weekly profile identifies each line by the number of weeks from the beginning of the simulation. The number of days in the "week" is also printed. A standard 365 day year is summarized as 53 "weeks", with the last "week" being only one day long. The energy totals in this last line will be for one day. The summary data is printed in the weekly profile using the format (I4, I3, 1P11E10.2). The first 24 lines of this file contain a description of the output.

The monthly summary identifies each line by the name of the month. The number of days included in the energy totals is also printed. This will be equal to the length of the month except when a simulation starts of ends in the middle of a month. In this case, the first and last summary lines will contain totals for partial months. The summary information is printed using the format (A4, I3, 1P11E10.2). The first 20 lines of this file contain a description of the output.

The temperature profile reports give the temperatures at all storage nodes at the end of each period. They are only produced by simulations which use the TANK and SST storage system.

The daily profile identifies each line by the day number from the beginning of the year. Each line is written using the format (4X, I4, 5X, 11F10.3). The first 9 lines of the file describe the output.

The weekly profile identifies each line by the number of weeks from the beginning of the simulation. The format (4X, I4, 5X, 11F10.3) is used to print the summary. The first 11 lines of this file describe the output.

The monthly profile identifies each line by the name of the month. Each line is written using the format (4X, A4, 5X, 11F10.3). The first 10 lines of this file describe the output.

Samples of the first page of each type of Time Profile report are included in the following pages. These examples are from the November 1984 version of MINSUN and do not include columns for collector temperatures into storage and collector flow into storage which have since been added.

```
TITLE OF RUN:
  TANK STORAGE SAMPLE RUN - NOVEMBER 1984
NUMBER OF DAYS IN SIMULATION:  365
NUMBER OF NODES IN STORAGE  :    3

DAILY SUMMARY OF SYSTEM PARAMETERS

  VALUES PRINTED FOR EACH DAY ARE:
    - DAY OF YEAR
    - ENERGY FROM COLLECTORS (MWH)
    - PIPING LOSSES (MWH)
    - TOP OF STORAGE TEMPERATURE (C)
    - BOTTOM OF STORAGE TEMPERATURE (C)
    - STORAGE LOSSES (MWH)
    - AUXILIARY ENERGY (MWH)
    - HEAT PUMP ELECTRICITY (MWH)
    - CONDENSER OUTPUT (MWH)
    - SYSTEM LOAD (MWH)

  91      5.59E 01  4.95E-02  5.28E 01  4.51E 01  2.90E 00  1.36E 01      0.00      0.00  4.23E 01
  92      5.29E-01  8.36E-03  5.20E 01  4.50E 01  2.91E 00  9.15E 00      0.00      0.00  3.64E 01
  93      5.33E 01  4.48E-02  5.29E 01  4.50E 01  2.90E 00  1.61E 01      0.00      0.00  4.54E 01
  94      4.84E 01  4.85E-02  5.31E 01  4.50E 01  2.92E 00  1.33E 01      0.00      0.00  4.58E 01
  95      2.68E-02  1.05E-03  5.21E 01  4.49E 01  2.91E 00  8.96E 00      0.00      0.00  4.06E 01
  96      2.82E 01  3.83E-02  5.18E 01  4.52E 01  2.88E 00  6.29E 00      0.00      0.00  1.85E 01
  97      4.98E 00  2.38E-02  5.11E 01  4.52E 01  2.88E 00  1.23E 01      0.00      0.00  3.53E 01
  98      2.76E 01  4.29E-02  5.05E 01  4.52E 01  2.85E 00  1.67E 01      0.00      0.00  4.16E 01
  99      5.69E 01  4.97E-02  5.18E 01  4.55E 01  2.87E 00  1.25E 01      0.00      0.00  2.71E 01
 100      5.62E 01  5.02E-02  5.28E 01  4.60E 01  2.93E 00  8.17E 00      0.00      0.00  2.29E 01
 101      2.44E 01  4.77E-02  5.26E 01  4.65E 01  2.96E 00  4.25E 00      0.00      0.00  1.39E 01
 102      1.16E 01  3.86E-02  5.24E 01  4.69E 01  2.97E 00  3.81E 00      0.00      0.00  1.12E 01
 103      4.99E 00  3.39E-02  5.22E 01  4.69E 01  2.97E 00  5.03E 00      0.00      0.00  1.54E 01
 104      3.59E 01  4.93E-02  5.25E 01  4.71E 01  2.97E 00  6.43E 00      0.00      0.00  1.93E 01
 105      2.91E 01  4.89E-02  5.25E 01  4.73E 01  2.99E 00  6.68E 00      0.00      0.00  2.22E 01
 106      5.13E 01  5.59E-02  5.34E 01  4.78E 01  3.02E 00  4.19E 00      0.00      0.00  1.22E 01
 107      1.89E 01  3.93E-02  5.32E 01  4.81E 01  3.05E 00  3.21E 00      0.00      0.00  1.12E 01
 108      1.16E 01  3.90E-02  5.29E 01  4.81E 01  3.05E 00  6.83E 00      0.00      0.00  3.10E 01
 109      1.61E 01  4.40E-02  5.25E 01  4.79E 01  3.03E 00  7.54E 00      0.00      0.00  2.95E 01
 110      1.36E 01  3.89E-02  5.23E 01  4.78E 01  3.02E 00  6.59E 00      0.00      0.00  2.21E 01
 111      4.52E 01  5.12E-02  5.33E 01  4.83E 01  3.03E 00  4.05E 00      0.00      0.00  1.12E 01
 112      4.13E 01  4.64E-02  5.40E 01  4.84E 01  3.08E 00  4.87E 00      0.00      0.00  2.00E 01
 113      1.69E 01  4.43E-02  5.37E 01  4.83E 01  3.09E 00  4.03E 00      0.00      0.00  2.44E 01
 114      5.38E 01  5.72E-02  5.47E 01  4.84E 01  3.10E 00  4.90E 00      0.00      0.00  2.59E 01
 115      5.27E 01  5.73E-02  5.54E 01  4.87E 01  3.14E 00  2.59E 00      0.00      0.00  2.23E 01
 116      3.78E 01  5.13E-02  5.55E 01  4.92E 01  3.17E 00  1.50E 00      0.00      0.00  1.58E 01
 117      5.55E 00  4.40E-02  5.53E 01  4.91E 01  3.18E 00  1.61E 00      0.00      0.00  1.12E 01
 118      2.31E 01  5.00E-02  5.52E 01  4.97E 01  3.18E 00  1.74E 00      0.00      0.00  1.12E 01
 119      9.97E-01  9.81E-03  5.50E 01  4.94E 01  3.18E 00  1.85E 00      0.00      0.00  1.16E 01
 120      3.55E 00  2.45E-02  5.48E 01  4.91E 01  3.16E 00  2.00E 00      0.00      0.00  1.81E 01
 121      4.22E 00  1.96E-02  5.45E 01  4.88E 01  3.14E 00  2.41E 00      0.00      0.00  2.02E 01
 122      2.85E-02  9.78E-04  5.41E 01  4.82E 01  3.11E 00  3.41E 00      0.00      0.00  3.11E 01
 123      4.33E 00  2.41E-02  5.38E 01  4.80E 01  3.08E 00  3.78E 00      0.00      0.00  2.29E 01
 124      3.34E 01  5.49E-02  5.37E 01  4.83E 01  3.07E 00  4.07E 00      0.00      0.00  2.03E 01
 125      5.49E 01  5.74E-02  5.48E 01  4.89E 01  3.11E 00  3.35E 00      0.00      0.00  1.41E 01
 126      2.12E 01  4.03E-02  5.46E 01  4.92E 01  3.14E 00  2.17E 00      0.00      0.00  1.12E 01
 127      1.61E 01  4.45E-02  5.45E 01  4.97E 01  3.15E 00  2.29E 00      0.00      0.00  1.12E 01
 128      3.96E 01  6.16E-02  5.49E 01  5.02E 01  3.17E 00  2.39E 00      0.00      0.00  1.12E 01
 129      4.88E 01  6.38E-02  5.57E 01  5.07E 01  3.21E 00  2.08E 00      0.00      0.00  1.12E 01
 130      3.68E 01  5.82E-02  5.60E 01  5.11E 01  3.25E 00  1.45E 00      0.00      0.00  1.12E 01
 131      5.51E 01  6.40E-02  5.71E 01  5.16E 01  3.29E 00  1.21E 00      0.00      0.00  1.12E 01
 132      3.63E 01  6.31E-02  5.72E 01  5.20E 01  3.34E 00  3.41E-01      0.00      0.00  1.14E 01
 133      3.54E 01  6.21E-02  5.74E 01  5.25E 01  3.36E 00  3.30E-01      0.00      0.00  1.12E 01
 134      1.27E 01  4.32E-02  5.72E 01  5.27E 01  3.38E 00  1.96E-01      0.00      0.00  1.12E 01
 135      4.96E 01  6.15E-02  5.83E 01  5.30E 01  3.40E 00  3.05E-01      0.00      0.00  1.12E 01
 136      2.22E 01  5.26E-02  5.81E 01  5.32E 01  3.43E 00      0.00      0.00      0.00  1.12E 01
 137      4.28E-01  8.81E-03  5.80E 01  5.28E 01  3.42E 00      0.00      0.00      0.00  1.12E 01
```

```
TITLE OF RUN:
   TANK STORAGE SAMPLE RUN - NOVEMBER 1984
 NUMBER OF DAYS IN SIMULATION:  365
 NUMBER OF NODES IN STORAGE  :    3

 WEEKLY SUMMARY OF SYSTEM PARAMETERS

   VALUES PRINTED FOR EACH WEEK ARE:
     - NUMBER OF WEEKS FROM BEGINNING OF SIMULATION
     - NUMBER OF DAYS IN "WEEK"
          LESS THAN 7 IF  SIMULATION ENDS IN MID-WEEK
     - ENERGY FROM COLLECTORS (MWH)
     - PIPING LOSSES (MWH)
     - TOP OF STORAGE TEMPERATURE (C)
     - BOTTOM OF STORAGE TEMPERATURE (C)
     - STORAGE LOSSES (MWH)
     - AUXILIARY ENERGY (MWH)
     - HEAT PUMP ELECTRICITY (MWH)
     - CONDENSER OUTPUT (MWH)
     - SYSTEM LOAD (MWH)

   1  7  1.91E 02  2.14E-01  5.11E 01  4.52E 01  2.03E 01  7.97E 01       0.00       0.00  2.64E 02
   2  7  2.18E 02  3.12E-01  5.25E 01  4.71E 01  2.05E 01  5.69E 01       0.00       0.00  1.51E 02
   3  7  1.86E 02  3.17E-01  5.33E 01  4.83E 01  2.12E 01  3.91E 01       0.00       0.00  1.39E 02
   4  7  2.31E 02  3.51E-01  5.52E 01  4.97E 01  2.19E 01  2.12E 01       0.00       0.00  1.31E 02
   5  7  1.01E 02  1.91E-01  5.48E 01  4.89E 01  2.19E 01  2.09E 01       0.00       0.00  1.38E 02
   6  7  2.54E 02  3.95E-01  5.72E 01  5.20E 01  2.26E 01  1.19E 01       0.00       0.00  7.84E 01
   7  7  2.00E 02  3.57E-01  5.90E 01  5.37E 01  2.38E 01  8.30E-01       0.00       0.00  7.82E 01
   8  7  1.72E 02  3.52E-01  6.03E 01  5.47E 01  2.46E 01      0.00       0.00       0.00  7.82E 01
   9  7  3.06E 02  4.67E-01  6.37E 01  5.80E 01  2.58E 01      0.00       0.00       0.00  7.82E 01
  10  7  1.85E 02  4.14E-01  6.42E 01  5.99E 01  2.72E 01      0.00       0.00       0.00  7.82E 01
  11  7  1.89E 02  4.35E-01  6.60E 01  6.12E 01  2.77E 01      0.00       0.00       0.00  7.82E 01
  12  7  2.58E 02  5.17E-01  6.88E 01  6.35E 01  2.90E 01      0.00       0.00       0.00  7.82E 01
  13  7  2.00E 02  4.16E-01  7.08E 01  6.48E 01  2.97E 01      0.00       0.00       0.00  7.82E 01
  14  7  3.04E 02  5.32E-01  7.41E 01  6.82E 01  3.12E 01      0.00       0.00       0.00  7.82E 01
  15  7  2.44E 02  5.58E-01  7.57E 01  7.11E 01  3.27E 01      0.00       0.00       0.00  7.82E 01
  16  7  2.08E 02  4.69E-01  7.82E 01  7.15E 01  3.40E 01      0.00       0.00       0.00  7.82E 01
  17  7  1.51E 02  5.15E-01  7.83E 01  7.29E 01  3.42E 01      0.00       0.00       0.00  7.82E 01
  18  7  2.39E 02  5.27E-01  8.05E 01  7.50E 01  3.50E 01      0.00       0.00       0.00  7.82E 01
  19  7  2.36E 02  5.73E-01  8.25E 01  7.73E 01  3.61E 01      0.00       0.00       0.00  7.82E 01
  20  7  2.32E 02  5.69E-01  8.48E 01  7.91E 01  3.71E 01      0.00       0.00       0.00  7.82E 01
  21  7  2.13E 02  5.71E-01  8.62E 01  8.07E 01  3.84E 01      0.00       0.00       0.00  7.82E 01
  22  7  1.74E 02  4.96E-01  8.67E 01  8.20E 01  3.88E 01      0.00       0.00       0.00  7.82E 01
  23  7  1.95E 02  4.77E-01  8.87E 01  8.30E 01  3.94E 01      0.00       0.00       0.00  7.82E 01
  24  7  2.18E 02  5.25E-01  9.09E 01  8.40E 01  4.04E 01      0.00       0.00       0.00  7.82E 01
  25  7  1.79E 02  4.66E-01  9.13E 01  8.56E 01  4.08E 01      0.00       0.00       0.00  7.82E 01
  26  7  1.67E 02  4.72E-01  9.22E 01  8.64E 01  4.12E 01      0.00       0.00       0.00  7.82E 01
  27  7  1.71E 02  4.51E-01  9.22E 01  8.49E 01  4.15E 01      0.00       0.00       0.00  1.42E 02
  28  7  1.01E 02  2.59E-01  9.18E 01  8.20E 01  4.12E 01      0.00       0.00       0.00  1.22E 02
  29  7  1.37E 02  3.41E-01  9.11E 01  7.89E 01  4.04E 01      0.00       0.00       0.00  1.81E 02
  30  7  1.47E 02  3.82E-01  9.06E 01  7.89E 01  3.94E 01      0.00       0.00       0.00  1.30E 02
  31  7  1.24E 02  3.14E-01  9.00E 01  7.91E 01  3.92E 01      0.00       0.00       0.00  1.04E 02
  32  7  8.61E 01  2.04E-01  8.92E 01  7.18E 01  3.86E 01      0.00       0.00       0.00  2.16E 02
  33  7  7.96E 01  1.71E-01  8.83E 01  6.13E 01  3.60E 01      0.00       0.00       0.00  2.83E 02
  34  7  7.36E 01  1.45E-01  8.71E 01  5.17E 01  3.30E 01      0.00       0.00       0.00  2.89E 02
  35  7  6.54E 01  1.32E-01  8.59E 01  4.87E 01  3.10E 01      0.00       0.00       0.00  3.43E 02
  36  7  1.33E 02  1.90E-01  8.46E 01  4.93E 01  3.01E 01      0.00       0.00       0.00  3.89E 02
  37  7  5.50E 01  9.14E-02  7.85E 01  4.68E 01  2.87E 01      0.00       0.00       0.00  3.67E 02
  38  7  2.74E 01  6.95E-02  6.59E 01  4.51E 01  2.56E 01      0.00       0.00       0.00  3.56E 02
  39  7  7.19E 01  1.00E-01  5.44E 01  4.43E 01  2.21E 01  3.63E 01       0.00       0.00  3.33E 02
  40  7  8.53E 01  1.44E-01  4.90E 01  4.43E 01  1.98E 01  1.73E 02       0.00       0.00  3.51E 02
  41  7  5.53E 01  9.57E-02  4.75E 01  4.42E 01  1.90E 01  3.12E 02       0.00       0.00  3.96E 02
  42  7  1.24E 02  1.91E-01  4.85E 01  4.43E 01  1.91E 01  4.11E 02       0.00       0.00  4.94E 02
  43  7  8.06E 01  1.27E-01  4.73E 01  4.42E 01  1.91E 01  2.81E 02       0.00       0.00  3.75E 02
  44  7  1.71E 02  2.21E-01  4.89E 01  4.43E 01  1.93E 01  4.41E 02       0.00       0.00  5.38E 02
  45  7  7.98E 01  1.41E-01  4.80E 01  4.43E 01  1.90E 01  2.42E 02       0.00       0.00  3.39E 02
```

```
TITLE OF RUN:
  TANK STORAGE SAMPLE RUN - NOVEMBER 1984
NUMBER OF DAYS IN SIMULATION:  365
NUMBER OF NODES IN STORAGE  :    3

MONTHLY SUMMARY OF SYSTEM PARAMETERS

  PARAMETERS PRINTED FOR EACH MONTH ARE:
    - NUMBER OF DAYS IN MONTH
         LESS THAN MONTH LENGTH IF SIMULATION STARTS OR ENDS IN MID-MONTH
    - ENERGY FROM COLLECTORS (MWH)
    - PIPING LOSSES (MWH)
    - TOP OF STORAGE TEMPERATURE (C)
    - BOTTOM OF STORAGE TEMPERATURE (C)
    - STORAGE LOSSES (MWH)
    - AUXILIARY ENERGY (MWH)
    - HEAT PUMP ELECTRICITY (MWH)
    - CONDENSER OUTPUT (MWH)
    - SYSTEM LOAD (MWH)

APR  30  8.30E 02  1.23E 00  5.48E 01  4.91E 01  9.03E 01  2.01E 02       0.00       0.00  7.15E 02
MAY  31  9.38E 02  1.59E 00  6.26E 01  5.71E 01  1.05E 02  2.98E 01       0.00       0.00  3.99E 02
JUN  30  9.23E 02  1.92E 00  7.08E 01  6.48E 01  1.21E 02      0.00       0.00       0.00  3.35E 02
JUL  31  9.91E 02  2.29E 00  7.91E 01  7.33E 01  1.47E 02      0.00       0.00       0.00  3.46E 02
AUG  31  9.85E 02  2.44E 00  8.68E 01  8.17E 01  1.65E 02      0.00       0.00       0.00  3.46E 02
SEP  30  7.91E 02  2.08E 00  9.20E 01  8.61E 01  1.73E 02      0.00       0.00       0.00  3.35E 02
OCT  31  5.74E 02  1.48E 00  9.02E 01  7.75E 01  1.79E 02      0.00       0.00       0.00  6.08E 02
NOV  30  3.84E 02  8.34E-01  8.61E 01  4.85E 01  1.51E 02      0.00       0.00       0.00  1.14E 03
DEC  31  3.32E 02  5.18E-01  5.21E 01  4.42E 01  1.17E 02  9.73E 01       0.00       0.00  1.62E 03
JAN  31  4.72E 02  6.87E-01  5.02E 01  4.44E 01  8.49E 01  1.49E 03       0.00       0.00  1.93E 03
FEB  28  5.57E 02  8.12E-01  5.07E 01  4.48E 01  7.74E 01  1.16E 03       0.00       0.00  1.60E 03
MAR  31  9.40E 02  1.06E 00  5.18E 01  4.51E 01  8.97E 01  6.83E 02       0.00       0.00  1.49E 03
```

```
TITLE OF RUN:
  TANK STORAGE SAMPLE RUN - NOVEMBER 1984
NUMBER OF DAYS IN SIMULATION:  365
NUMBER OF NODES IN STORAGE  :    3

DAILY SUMMARY OF STORAGE TEMPERATURES

DAY OF YEAR    STORAGE TEMPERATURES FROM TOP

     91          52.833    48.322    45.100
     92          51.989    47.778    44.957
     93          52.873    47.974    44.966
     94          53.129    48.304    45.045
     95          52.131    47.686    44.878
     96          51.760    48.432    45.178
     97          51.132    47.923    45.235
     98          50.531    48.566    45.187
     99          51.818    48.956    45.544
    100          52.841    49.510    45.956
    101          52.619    49.773    46.522
    102          52.441    49.656    46.882
    103          52.191    49.480    46.876
    104          52.502    49.977    47.102
    105          52.475    50.375    47.273
    106          53.405    50.967    47.827
    107          53.246    51.232    48.125
    108          52.869    50.804    48.121
    109          52.529    50.932    47.872
    110          52.305    50.951    47.824
    111          53.260    51.341    48.288
    112          54.039    51.676    48.366
    113          53.716    51.718    48.308
    114          54.703    52.139    48.431
    115          55.422    52.675    48.717
    116          55.510    53.197    49.158
    117          55.332    53.026    49.133
    118          55.186    53.173    49.672
    119          55.015    53.008    49.390
    120          54.770    52.715    49.114
    121          54.500    52.388    48.848
    122          54.097    51.854    48.193
    123          53.778    51.473    47.966
    124          53.728    51.907    48.308
    125          54.775    52.431    48.858
    126          54.619    52.725    49.185
    127          54.480    52.604    49.655
    128          54.884    53.123    50.160
    129          55.713    53.675    50.663
    130          56.029    54.175    51.074
    131          57.118    54.764    51.556
    132          57.186    55.343    52.038
    133          57.362    55.801    52.496
    134          57.219    55.670    52.683
    135          58.258    56.137    53.001
    136          58.126    56.439    53.224
    137          57.986    56.288    52.782
    138          57.875    56.540    53.255
    139          58.991    57.008    53.667
    140          59.655    57.594    54.071
    141          59.575    57.646    54.350
    142          59.485    57.510    54.431
    143          59.404    57.978    54.675
    144          59.309    57.837    54.173
    145          59.221    57.693    54.249
    146          60.330    58.248    54.663
    147          60.892    58.876    55.127
```

```
TITLE OF RUN:
  TANK STORAGE SAMPLE RUN - NOVEMBER 1984
NUMBER OF DAYS IN SIMULATION:  365
NUMBER OF NODES IN STORAGE  :    3

WEEKLY SUMMARY OF STORAGE TEMPERATURES
    SIMULATION STARTS ON DAY   91 OF YEAR

WEEKS FROM START     STORAGE TEMPERATURES FROM TOP
OF SIMULATION

      1          51.132     47.923     45.235
      2          52.502     49.977     47.102
      3          53.260     51.341     48.288
      4          55.186     53.173     49.672
      5          54.775     52.431     48.858
      6          57.186     55.343     52.038
      7          58.991     57.008     53.667
      8          60.330     58.248     54.663
      9          63.712     61.885     58.037
     10          64.198     63.565     59.939
     11          66.046     64.696     61.211
     12          68.757     67.491     63.492
     13          70.779     68.895     64.820
     14          74.124     72.244     68.179
     15          75.651     74.677     71.059
     16          78.207     76.578     71.516
     17          78.269     77.066     72.940
     18          80.468     79.238     75.024
     19          82.476     81.177     77.320
     20          84.752     83.124     79.121
     21          86.167     85.106     80.694
     22          86.700     86.130     82.039
     23          88.682     87.227     82.956
     24          90.900     89.029     84.042
     25          91.324     90.110     85.597
     26          92.151     90.883     86.442
     27          92.228     91.686     84.926
     28          91.837     91.695     82.044
     29          91.147     91.147     78.894
     30          90.557     90.557     78.911
     31          89.986     89.986     79.077
     32          89.243     89.243     71.843
     33          88.302     88.302     61.334
     34          87.131     86.282     51.694
     35          85.939     74.533     48.699
     36          84.634     60.462     49.315
     37          78.526     51.460     46.825
     38          65.853     47.505     45.149
     39          54.421     46.993     44.305
     40          48.967     46.687     44.282
     41          47.481     45.761     44.239
     42          48.454     45.843     44.330
     43          47.253     45.412     44.247
     44          48.899     46.538     44.329
     45          48.001     45.588     44.293
     46          49.275     45.850     44.759
     47          49.578     46.793     44.609
     48          51.187     47.271     44.775
     49          53.801     49.084     45.549
     50          51.496     47.906     44.970
     51          51.981     48.220     45.270
     52          51.494     48.110     45.125
     53          51.755     48.281     45.123
```

```
TITLE OF RUN:
  TANK STORAGE SAMPLE RUN - NOVEMBER 1984
NUMBER OF DAYS IN SIMULATION:  365
NUMBER OF NODES IN STORAGE  :    3

MONTH END STORAGE TEMPERATURES
    SIMULATION STARTS ON DAY   91 OF YEAR

  MONTH        STORAGE TEMPERATURES FROM TOP

   APR          54.770    52.715    49.114
   MAY          62.560    60.840    57.093
   JUN          70.779    68.895    64.820
   JUL          79.067    77.767    73.274
   AUG          86.779    85.974    81.716
   SEP          91.991    90.849    86.107
   OCT          90.187    90.187    77.482
   NOV          86.102    76.571    48.473
   DEC          52.114    47.285    44.201
   JAN          50.227    46.256    44.437
   FEB          50.691    47.449    44.805
   MAR          51.755    48.281    45.123
```

F.5 Two Paramter Variation - Cost Figures

For Multiple Simulation runs using the Two Parameter Variation option, this file is output on Logical Unit 19.

Its contents are convenient for use with plotting packages which plot a graph of the surface from a user-specified view point (such as the one presented in Appendix F-7). The first line contains the following:

1. the number of points in the direction of variable 1,
2. the number of points in the direction of variable 2,
3. the number assigned to the plot, and
4. the title supplied for the graph,

in the FORMAT (3I2,59A1).

The second line contains:

1. the upper limit for variable 1,
2. the lower limit for variable 1,
3. the increment for variable 1 between computed points,
4. the upper limit for variable 2,
5. the lower limit for variable 2, and
6. the increment for variable 2 between computed points,

in the FORMAT (6(2X,F14.7)).

The third line contains the labels for the axes for variable 1 and variable 2 (in order) in the FORMAT(2X,2(36A1)).

Succeeding lines in this output stream are all identical and contain:

1. the cost function (with no penalty included),
2. the cost function with the penalty included,
3. the value of variable 1 for this point,
4. the value of variable 2 for this point, and
5. the value of a counter associated with each point generated.

These lines are printed in FORMAT(4(1X,F19.9),2X,I5).

It should be noted that variable 2 is cycled most frequently - i.e., variable 1 is held constant at its first value (its minimum), while variable 2 is incremented through its range from its minimum value to its maximum, after which variable 1 is incremented to its next value, etc.

The first page of a sample file appears on the next page.

```
1616 1        SAMPLE RUN
   60000.00        1000.000        3933.333        150000.0        30000.00        8000.000
 (C)OLLECTOR (A)REA M**2 $           (S)TORAGE (V)OLUME M**3 $
     1201623.00          1452613.00          1000.00000          30000.0000          1
     1249110.00          1500100.00          1000.00000          38000.0000          2
     1267562.00          1518552.00          1000.00000          46000.0000          3
     1298191.00          1549181.00          1000.00000          54000.0000          4
     1328482.00          1579472.00          1000.00000          62000.0000          5
     1371028.00          1622018.00          1000.00000          70000.0000          6
     1400175.00          1651165.00          1000.00000          78000.0000          7
     1430774.00          1681764.00          1000.00000          86000.0000          8
     1459535.00          1710525.00          1000.00000          94000.0000          9
     1486131.00          1737121.00          1000.00000          102000.000         10
     1513910.00          1764900.00          1000.00000          110000.000         11
     1541463.00          1792453.00          1000.00000          118000.000         12
     1568640.00          1819630.00          1000.00000          126000.000         13
     1595881.00          1846871.00          1000.00000          134000.000         14
     1622772.00          1873762.00          1000.00000          142000.000         15
     1649414.00          1900404.00          1000.00000          150000.000         16
     1215337.00          1466327.00          4933.33203          30000.0000         17
     1248581.00          1499571.00          4933.33203          38000.0000         18
     1273207.00          1524197.00          4933.33203          46000.0000         19
     1311121.00          1562111.00          4933.33203          54000.0000         20
     1341505.00          1592495.00          4933.33203          62000.0000         21
     1368463.00          1619453.00          4933.33203          70000.0000         22
     1398967.00          1649957.00          4933.33203          78000.0000         23
     1427751.00          1678741.00          4933.33203          86000.0000         24
     1458645.00          1709635.00          4933.33203          94000.0000         25
     1486711.00          1737701.00          4933.33203          102000.000         26
     1514654.00          1765644.00          4933.33203          110000.000         27
     1541890.00          1792880.00          4933.33203          118000.000         28
     1568852.00          1819842.00          4933.33203          126000.000         29
     1593928.00          1844918.00          4933.33203          134000.000         30
     1622598.00          1873588.00          4933.33203          142000.000         31
     1649526.00          1900516.00          4933.33203          150000.000         32
     1232708.00          1483698.00          8866.66406          30000.0000         33
     1263493.00          1514483.00          8866.66406          38000.0000         34
     1293953.00          1544943.00          8866.66406          46000.0000         35
     1323262.00          1574252.00          8866.66406          54000.0000         36
     1353863.00          1604853.00          8866.66406          62000.0000         37
     1382924.00          1633914.00          8866.66406          70000.0000         38
     1411133.00          1662123.00          8866.66406          78000.0000         39
     1437647.00          1688637.00          8866.66406          86000.0000         40
     1467131.00          1718121.00          8866.66406          94000.0000         41
     1492145.00          1743135.00          8866.66406          102000.000         42
     1521610.00          1772600.00          8866.66406          110000.000         43
     1549406.00          1800396.00          8866.66406          118000.000         44
     1575613.00          1826603.00          8866.66406          126000.000         45
     1602840.00          1853830.00          8866.66406          134000.000         46
     1629163.00          1880153.00          8866.66406          142000.000         47
     1655702.00          1906692.00          8866.66406          150000.000         48
     1261437.00          1512427.00          12799.9961          30000.0000         49
     1291620.00          1542610.00          12799.9961          38000.0000         50
     1317806.00          1568796.00          12799.9961          46000.0000         51
     1348624.00          1599614.00          12799.9961          54000.0000         52
     1376324.00          1627314.00          12799.9961          62000.0000         53
     1403763.00          1654753.00          12799.9961          70000.0000         54
     1430822.00          1681812.00          12799.9961          78000.0000         55
     1458062.00          1709052.00          12799.9961          86000.0000         56
     1485681.00          1736671.00          12799.9961          94000.0000         57
     1512514.00          1763504.00          12799.9961          102000.000         58
     1539116.00          1790106.00          12799.9961          110000.000         59
     1565716.00          1816706.00          12799.9961          118000.000         60
     1590737.00          1841727.00          12799.9961          126000.000         61
     1616894.00          1867884.00          12799.9961          134000.000         62
     1644799.00          1895789.00          12799.9961          142000.000         63
```

F.6 Two Parameter Variation - Details

For Multiple Simulation runs using the Two Parameter Variation option, this file is output on Logical Unit 22.

Its contents provide the user with the values of a selected set of key system characteristics which are associated with the simulation of each configuration.

The file contains:

1. the title of the graph centered between two groups of the symbols #####,

2. the number assigned to the plot by the user,

3. the label for the design variable 1 axis on a line beginning with 'NUMBER OF POINTS ALONG'
   and ending with the number of design variable 1 values used in the generation of surface data,

4. the range and increment for the values of design variable 1,

5. the label, number of values used, range and increment for the design variable 2 (in a format identical to that outlined for variable 1),

6. the value of the "CAPITAL COST ANNUALIZATION FACTOR", and

7. the value of the "FUEL COST ANNUALIZATION FACTOR".

The above parameters are followed by lists of the main quantities of interest which vary from point to point on the surface. For each of these points, the following items are printed in suitably headed columns:

1. the value of design variable 1,
2. the value of design variable 2,
3. the total annual cost of the system,
4. the solar cover fraction,
5. the total capital cost,
6. the total annual operating cost, and
7. the change of average temperature in the storage.

The FORMAT for each line is (' ',7F16.7). The ordering of the output (i.e., the sequence of values of variable 1 and variable 2) is as described in Appendix F.5.

The first page of a sample file appears on the next page.

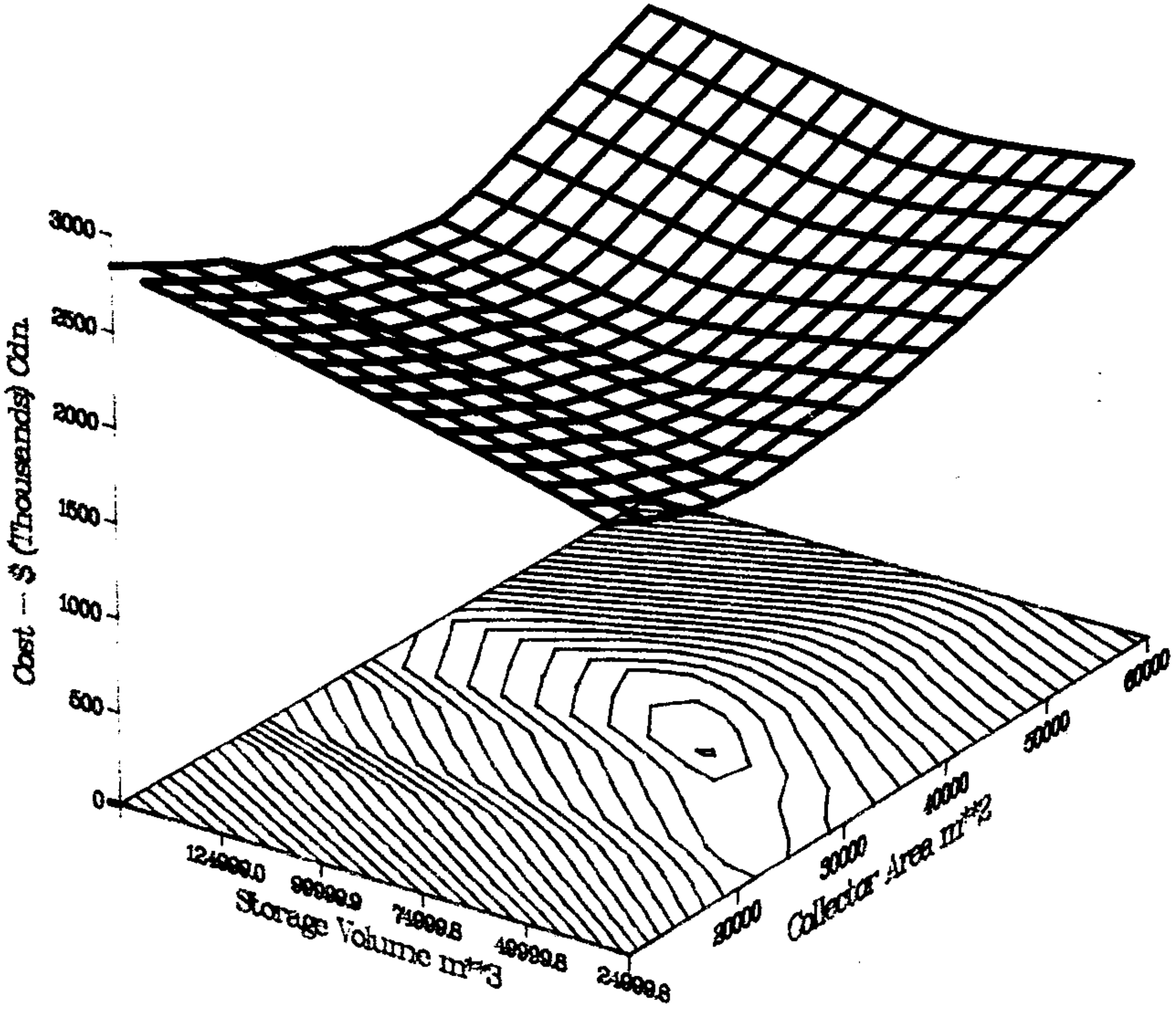
```
TITLE OF GRAPH:-

                  #####            SAMPLE RUN                                         #####

PLOT NUMBER:-  1

          NUMBER OF POINTS ALONG  (C)OLLECTOR (A)REA M**2 $            AXIS (VARIABLE 1) IS:- 16
               FROM   1000.000     TO   60000.00     IN INCREMENTS OF  3933.333

          NUMBER OF POINTS ALONG  (S)TORAGE (V)OLUME M**3 $            AXIS (VARIABLE 2) IS:- 16
               FROM   30000.00     TO   150000.0     IN INCREMENTS OF  8000.000


         CAPITAL COST ANNUALIZATION FACTOR=   0.7642215E-01

           FUEL  COST ANNUALIZATION FACTOR=    1.176792

     DESIGN          DESIGN          TOTAL ANNUAL    SOLAR COVER    TOTAL CAPITAL   TOTAL ANNUAL    CHANGE OF AVERAGE
   VARIABLE 1      VARIABLE 2            COST           FRACTION          COST      OPERATING COST    TEMPERATURE IN
                                        (US$)                            (US$)         (US$)        STORAGE (C)

    1000.000        30000.00        1201623.       0.5809730E-01    7852625.        511142.9     -0.9552844
    1000.000        38000.00        1249110.       0.5832511E-01    8475909.        511019.3     -0.4916779
    1000.000        46000.00        1267562.       0.5836016E-01    8717644.        511000.3     -0.1576827
    1000.000        54000.00        1298191.       0.5898863E-01    9123689.        510659.3     -0.3938548E-01
    1000.000        62000.00        1328482.       0.5976760E-01    9526552.        510236.6      0.2416325E-01
    1000.000        70000.00        1371028.       0.5971217E-01   0.1008282E 08    510266.6      0.1698373
    1000.000        78000.00        1400175.       0.6054449E-01   0.1047117E 08    509814.9      0.1776136
    1000.000        86000.00        1430774.       0.6146115E-01   0.1087922E 08    509317.5      0.1707881
    1000.000        94000.00        1459535.       0.6168246E-01   0.1125742E 08    509197.4      0.2320337
    1000.000        102000.0        1486131.       0.6465536E-01   0.1163027E 08    507584.1      0.3305276E-01
    1000.000        110000.0        1513910.       0.6530440E-01   0.1199919E 08    507231.9      0.5702591E-01
    1000.000        118000.0        1541463.       0.6593287E-01   0.1236498E 08    506890.8      0.8026981E-01
    1000.000        126000.0        1568640.       0.6671834E-01   0.1272716E 08    506464.6      0.8651507E-01
    1000.000        134000.0        1595881.       0.6708002E-01   0.1308664E 08    506268.3      0.1166849
    1000.000        142000.0        1622772.       0.6764954E-01   0.1344328E 08    505959.3      0.1313546
    1000.000        150000.0        1649414.       0.6836212E-01   0.1379785E 08    505572.6      0.1358843
    4933.332        30000.00        1215337.       0.2355023        9514535.        414870.5     -0.5949087
    4933.332        38000.00        1248581.       0.2357857        9951904.        414716.7     -0.2445074
    4933.332        46000.00        1273207.       0.2368324       0.1028289E 08    414148.6     -0.1561956
    4933.332        54000.00        1311121.       0.2385821       0.1079363E 08    413199.1     -0.1933969
    4933.332        62000.00        1341505.       0.2394581       0.1119853E 08    412723.8     -0.1307325
    4933.332        70000.00        1368463.       0.2405044       0.1156002E 08    412155.9     -0.1144295
    4933.332        78000.00        1398967.       0.2391218       0.1194762E 08    412906.3      0.1979659
    4933.332        86000.00        1427751.       0.2397661       0.1232965E 08    412556.6      0.2090746
    4933.332        94000.00        1458645.       0.2403512       0.1273879E 08    412239.1      0.2238000
    4933.332        102000.0        1486711.       0.2405943       0.1310807E 08    412107.2      0.2693233
    4933.332        110000.0        1514654.       0.2411152       0.1347807E 08    411824.5      0.2897297
    4933.332        118000.0        1541890.       0.2419374       0.1384133E 08    411378.3      0.2766972
    4933.332        126000.0        1568852.       0.2433718       0.1420612E 08    410599.9      0.2174088
    4933.332        134000.0        1593928.       0.2435853       0.1453603E 08    410484.1      0.2487405
    4933.332        142000.0        1622598.       0.2444121       0.1491809E 08    410035.4      0.2352934
    4933.332        150000.0        1649526.       0.2447505       0.1527327E 08    409851.7      0.2494608
    8866.664        30000.00        1232708.       0.3807821       0.1095585E 08    336031.4      0.3311113
    8866.664        38000.00        1263493.       0.3856286       0.1139917E 08    333401.3      0.2659111
    8866.664        46000.00        1293953.       0.3888942       0.1182503E 08    331629.1      0.3236208
    8866.664        54000.00        1323262.       0.3923277       0.1223724E 08    329765.8      0.3165658
    8866.664        62000.00        1353863.       0.3951044       0.1266087E 08    328259.1      0.2479502
    8866.664        70000.00        1382924.       0.3968477       0.1305571E 08    327313.0      0.2994471
    8866.664        78000.00        1411133.       0.3996468       0.1344821E 08    325794.1      0.1893650
    8866.664        86000.00        1437647.       0.4004797       0.1380214E 08    325342.1      0.2824414
    8866.664        94000.00        1467131.       0.4022831       0.1420300E 08    324363.4      0.2569526
    8866.664        102000.0        1492145.       0.4048302       0.1455160E 08    322981.1      0.1497484
    8866.664        110000.0        1521610.       0.4057149       0.1494455E 08    322501.1      0.1885951
    8866.664        118000.0        1549406.       0.4061557       0.1531194E 08    322261.8      0.2577270
```

F.7 Sample Cost Surface Plot

The following page shows a graph of annual cost for various combinations of collector area and storage volume. The graph was generated using the sample file from Appendix F.5.

It should be noted that the MINSUN package only produced the data to be used by a plotter (i.e. the file in Appendix F.5). The actual plotting of the data must be done by the individual user.

tank storage — fuel at 15 cents



PLOT 1 12.28.33 TUES 30 DEC, 1985 JOB-D42, NRC CANADA DISSPLA 9.0

F.8 MINREP Multiple Simulation Results

For Multiple Simulation runs using the MINREP option, up to three files are produced. These files are associated with FORTRAN Logical units 14, 15 and 16.

The first five lines of each file are headings. In particular, line 2 is the title for the report as specified by the user (80A1 format). Lines 4 and 5 contain the column heading specified by the user. Each of these lines uses the format (12(4X,7A1)).

Each subsequent line contains the values requested by the user for a single system simulation. The format of these lines is (12(1X,F10.3)).

If twelve or fewer variables are requested in the output (ref. Appendix A.5), only one output file is produced. If thirteen to twenty-four variables are selected, two files are produced. If twenty-five to thirty-six variables are specified, all three files are produced.

A sample MINREP Multiple Simulation Results report appears on the next page.

```
SAMPLE MINREP TANK RUN

    AREA        VOL        CCOLL       TSTA       TEND       TMIN       TMAX      QCOLL     HP ELEC       AUX       SOL F
     M2          M3        $/M2         C          C          C          C         MWH        MWH         MWH         %
20000.000  60000.000    370.000     11.433      7.627      5.100     57.299   8795.719   2081.355     507.590     76.14
25000.000  60000.000    370.000     20.854     21.580      5.616     71.454  10323.898   1599.800       0.427     85.25
30000.000  60000.000    370.000     35.571     36.200     17.138     87.380  11409.793    986.166       0.000     90.91
35000.000  60000.000    370.000     41.453     41.851     29.029     97.000  12146.727    564.288       0.000     94.80
40000.000  60000.000    370.000     44.827     44.827     33.659     97.000  12419.824    413.191       0.256     96.19
20000.000  70000.000    370.000     18.111      7.582      5.184     53.791   8859.301   2175.438     211.870     78.00
25000.000  70000.000    370.000     32.371     32.692      7.022     66.776  10435.098   1626.003       0.000     85.01
30000.000  70000.000    370.000     36.252     36.912     19.330     81.163  11567.434    970.130       0.000     91.06
35000.000  70000.000    370.000     42.086     43.507     32.140     94.659  12482.594    505.693       0.000     95.34
40000.000  70000.000    370.000     48.018     48.018     39.072     97.000  12907.008    239.889       0.290     97.78
20000.000  80000.000    370.000     20.617     10.997      5.199     51.210   8875.500   2279.873       0.000     78.99
25000.000  80000.000    370.000     32.851     33.354      8.534     62.450  10529.129   1623.050       0.294     85.04
30000.000  80000.000    370.000     36.435     37.423     20.607     76.065  11710.211    973.542       0.000     91.03
35000.000  80000.000    370.000     42.341     43.980     32.456     89.041  12671.309    505.157       0.167     95.34
40000.000  80000.000    370.000     49.995     50.976     43.258     97.000  13410.738    125.695       0.082     98.84
20000.000  90000.000    370.000     33.044     14.265      5.347     49.734   8896.773   2249.205       0.000     79.27
25000.000  90000.000    370.000     33.520     33.844      9.725     59.183  10593.359   1629.444       0.127     84.98
30000.000  90000.000    370.000     36.814     37.649     21.091     71.880  11829.141    986.207       0.319     90.91
35000.000  90000.000    370.000     42.389     44.163     32.563     84.335  12836.176    516.483       0.077     95.24
40000.000  90000.000    370.000     49.811     51.770     43.124     95.464  13735.797    109.272       0.051     98.99
20000.000  60000.000    200.000     11.127      7.599      5.064     57.190   8803.648   2088.398     507.174     76.08
25000.000  60000.000    200.000     20.817     21.574      5.608     71.428  10324.848   1600.783       0.000     85.25
30000.000  60000.000    200.000     35.566     36.199     17.137     87.379  11409.891    986.127       0.000     90.91
35000.000  60000.000    200.000     41.452     41.851     29.029     97.000  12146.727    564.283       0.019     94.80
40000.000  60000.000    200.000     44.827     44.827     33.659     97.000  12419.824    413.191       0.256     96.19
20000.000  70000.000    200.000     18.111      7.582      5.184     53.791   8859.301   2175.438     211.870     78.00
25000.000  70000.000    200.000     32.371     32.692      7.022     66.776  10435.098   1626.003       0.000     85.01
30000.000  70000.000    200.000     36.252     36.912     19.330     81.163  11567.434    970.130       0.000     91.06
35000.000  70000.000    200.000     42.086     43.507     32.140     94.659  12482.594    505.693       0.000     95.34
40000.000  70000.000    200.000     48.018     48.018     39.072     97.000  12907.008    239.889       0.290     97.78
20000.000  80000.000    200.000     20.617     10.997      5.199     51.210   8875.500   2279.873       0.000     78.99
25000.000  80000.000    200.000     32.851     33.354      8.534     62.450  10529.129   1623.050       0.294     85.04
30000.000  80000.000    200.000     36.435     37.423     20.607     76.065  11710.211    973.542       0.000     91.03
35000.000  80000.000    200.000     42.341     43.980     32.456     89.041  12671.309    505.157       0.167     95.34
40000.000  80000.000    200.000     49.995     50.976     43.258     97.000  13410.738    125.695       0.082     98.84
20000.000  90000.000    200.000     33.044     14.265      5.347     49.734   8896.773   2249.205       0.000     79.27
25000.000  90000.000    200.000     33.520     33.844      9.725     59.183  10593.359   1629.444       0.127     84.98
30000.000  90000.000    200.000     36.814     37.649     21.091     71.880  11829.141    986.207       0.319     90.91
35000.000  90000.000    200.000     42.389     44.163     32.563     84.335  12836.176    516.483       0.077     95.24
40000.000  90000.000    200.000     49.811     51.770     43.124     95.464  13735.797    109.272       0.051     98.99
```

APPENDIX G

MINSUN PROGRAM LISTING

MINSUN PROGRAM LISTING

Copies of the MINSUN source code and associated input and output files are available on tape. They can be ordered from:

Heimo Zinko
Studsvik Energiteknik AB
611 82 Nyköping
Sweden

The code is written in FORTRAN IV but does not adhere to all FORTRAN IV standards. It will require some modification to run on most computers.

The lengths of the programs (approximate number of lines) are as follows:

Program	Length
UMSORT	1200
ADVANCE	350
MINSUN-TANK	4800
MINSUN-DST	2100*
MINSUN-SST	2100*
MINSUN-AST	2100*

* Used with the MINSUN-TANK code - total for these models is stated length plus 4800 lines.

The longest of these programs requires approximately 860K when compiled with the FORTRAN G compiler under the IBM TSS operating system.

LIST OF TASK VII REPORTS

Tools for Design and Analysis, Verne G. Chant and Ronald C. Biggs, December, 1983, National Research Council, Canada, available as CENSOL1 from Technical Information Office, Solar Energy Program, National Research Council, Ottawa, Canada, K1A 0R6.

The MINSUN Simulation and Optimization Program: Application and User's Guide, Edited by Verne G. Chant and Rune Håkansson, December, 1983, National Research Council, Canada, available as CENSOL2 from Technical Information Office, Solar Energy Program, National Research Council, Ottawa, Canada, K1A 0R6.

Basic Performance, Cost, and Operation of Solar Collectors for Heating Plants with Seasonal Storage, Charles A. Bankston, 1984, Argonne National Laboratories, U.S.A., available from National Technical Information Services, 5285 Port Royal Road, Springfield, VA, 22161, U.S.A.

Heat Storage Models: Evaluation and Selection, Jean-Christophe Hadorn and Pierre Chuard, EDMZ, Switzerland, available from Eidgenossiche Drucksachen and Material Zentrale, Bern, Switzerland.

Cost Data and Cost Equations for Heat Storage Concepts, Jean-Christophe Hadorn and Pierre Chuard, EDMZ, Switzerland, available from Eidgenossiche Drucksachen and Material Zentrale, Bern, Switzerland.

Heat Storage Systems: Concepts, Engineering Data and Compilation of Projects, Jean-Christophe Hadorn and Pierre Chuard, EDMZ, Switzerland, available from Eidgenossiche Drucksachen and Material Zentrale, Bern, Switzerland.

Basic Design Data for the Heat Distribution System, Tomas Bruce, Lennart Lindeberg and Stefan Roslund, October, 1982, Swedish Council for Building Research, Sweden, available as D22:1982 from Svensk Byggtjänst, Box 7853, S-10399, Stockholm, Sweden.

Preliminary Designs for Ten Countries, Arne Boysen, Hidemark and Damielson Ark.HB, available from Swedish Council for Building Research as D12:1985 from Svensk Byggtjänst, Box 7853, S-10399, Stockholm, Sweden.

ABSTRACT

This report summarizes the work carried out in Sub-Task I(a), Systems Studies and Optimization and Sub-Task II(a), MINSUN Enhancements, of Task VII, Central Solar Heating Plants with Seasonal Storage (CSHPSS), of the IEA Solar Heating and Cooling Program.

The objectives of these Sub-Tasks were:

- to develop procedures and analytic tools for studying system feasibility and for evaluation, and
- to recommend specific systems analysis procedures and tools for use in Sub-Task I(e), Site-Specific Preliminary Design, and Sub-Task II(b), Evaluation of Systems Concepts, of Task VII.

The approach adopted was to select, modify and further develop two analytic tools as design aids for CSHPSS and to examine the appropriateness of these tools by undertaking application case studies. The principal analytic tool is the MINSUN Program for simulation and optimization of CSHPSS.

This report presents an overview of the MINSUN set of programs and its application in the analysis of CSHPSS. It also provides detailed descriptions of what input parameters must be defined by the user and how to interpret the program output and results. Information is provided on the thermal simulation and economic analysis aspects of the program such that the user may make minor modifications in order to represent a CSHPSS configuration or control strategy that is not readily modelled by the existing options within MINSUN.

Sample program input and output formats and data sets are presented in the appendices.

Additional copies available from:
Document # CENSOL2
Technical Information Office

Solar Energy Program
National Research Council

Montreal Road, Bldg R-92
Ottawa, Ontario K1A 0R6