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FINAL REPORT

On The

Validation of Solar House Design Programs Phases I & II

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DISCLAIMER

TABLE OF CONTENTS

I. INTRODUCTION

A model is a qualitative or quantitative representation of a physical process. There are two aspects to checking a model. The first is model verification, that is, the process of determining that there are no internal inconsistencies (i.e., programming errors, etc.) in the model The second is model validation. This is the process of determining if the model actually represents the system that it was intended to model. This means that performance data from the "real" system must be used to validate the model. Thus, to validate a model, one should consider all aspects related to the modeling process; i.e., one should discuss all of the following areas:

(1) the "goodness" of the input data used for model validation,

(2) the validation of model assumptions,

(3) the validation of model logic, and

(4) the validation of model behavior.

The first area is related to data analysis and data selection techniques for model calibration and model validation.

The second and third areas are related to the techniques to be used in the modeling process, the goal to be achieved by the model, and the types and amount of input data available. The fourth area is needed to assure that the behavior of a model is in accordance with the real system. The following steps should be taken in carrying out step 4:

(1) Calibrate the model (or adjust the model parameters) with a given input data set;

(2) Compare the simulation results with past data;.and

(3) Compare the simulation results with future performance.

Thus, for validation purposes, the following questions areis:

(1) Does the given data set contain only "good" data and have sufficient length for the calibration and validation of the models, and

(2) What procedures and techniques are to be used to analyze systematically and effectively the model behavior?

The first question is related to the problem of data filtering, record extension (if needed), and data selection. The second question is related to the effectiveness of the procedures and techiques to be used in analyzing the simulation results.

Finally, given a set of competing models to be used in the simulation of a particular process, the next question to be considered is: Which of these models is the "best" to be used in fulfilling a specified purpose? This is a problem related to the selection criteria to be developed to measure the "goodness" of candidate models.

This report presents the results obtained by applying the above-mentioned procedures to validate four simulation models of solar heated buildings. These models are SOLSIM (2) and SOLCOST (1), TRNSYS (4), and SIMSHAC (5). The scope of the work is briefly described in Section II, a summary of important results is presented in Section III, and conclusions and recommendations are presented in Section IV. Detailed discussions of the methodology are given in Appendix A and detailed validation results are presented in Appendix B.

II. SCOPE OF WORK

Realizing the need to have a systematic and efficient way to validate solar house design models, and to select a "best" model for further study, ERDA has granted to SEEC a contract (No. E(11-1)-2929) to develop a methodology for systematic data filtering, data selection, model validation, and model discrimination; also to apply the proposed approach to the validation of the SOLCOST, SOLSIM, SIMSHAC, and TRNSYS solar house design models, using data from SOLAR I, an experimental solar house at Colorado State University, Fort Collins, Colorado. Efforts were made to obtain additional performance data for other building types in locations other than Colorado but data have not been made available in time for inclusion in this report.

III. SUMMARY OF IMPORTANT RESULTS

III.1 Solar House Data Analysis Procedure

The need to have adequate and sufficient weather and solar house component operating data is one of the most important requirements in any attempt to evaluate solar house design characteristics or the goodness of any solar house design model.

A comprehensive description of the design and construction of SOLAR I, an experimental solar house at Colorado State University, along with data acquisition and handling techniques has already been reported to the National Science Foundation/Research Applied to National Needs by the Solar Energy Applications Laboratory, Colorado State University (8) . The Data Acquisition Equipment Specifications are listed in Figure 1 for informative purposes. Following is a methodology developed by SEEC for further screening and analyzing SOLAR I data (Figure 2).

(1) First, a preliminary screening by simple thresholding is carried out to eliminate unreasonable values in the data set. This first step will eliminate shot noise imbedded in the collected data.

(2) The data of each hour of each month are then input to an outliers identification program, using a selected distance function (i.e., Bhattacharyya distance), for discriminant analysis. All outliers are identified; their values are considered as missing and new values are to be filled in in step (3). Sample results for May/13:00 hour data are presented in Figure B1.1 of Appendix B1.

EQUIPMENT USED FOR DATA ACQUISITION AT SOLAR I

Data Logger	
Manufacturer	Doric Scientific
Model Number	210
Temperature Range	-190 to +400 C
Temperature Calibration Accuracy	±3 C
Millivoltage Range	±200 MV
Millivoltage Calibration Accuracy	±.004 MV
Number of Channels	100
Scan Rate	2 Channels/second
Magnetic Tape Recorder	
Manufacturer	Kennedy
Model	1600
Tape	7 Track ½ inch
Data Density	556 bits/inch
Pyranometers	
Manufacturer	Eppley Laboratory, Inc.
Model	8-48
Accuracy	±1% 0-2.0 cal/cm^2 - min
Thermocouples	
Manufacturer	Thermo-Electric
Model	41403
Type	Copper-Constantan
Flowmeters	
Sensor Manufacturer	Honeywell
(Orifice plates and sensor cases made by C.S.U. Machine Shop)	
Calibration Accuracy	± 3%
Integrators	
(Solar, electricity, and natural gas integrators made by C.S.U. electronic shop)	
Calibration Accuracy	± 2%

Figure 1: Data Acquisition Equipment Specifications

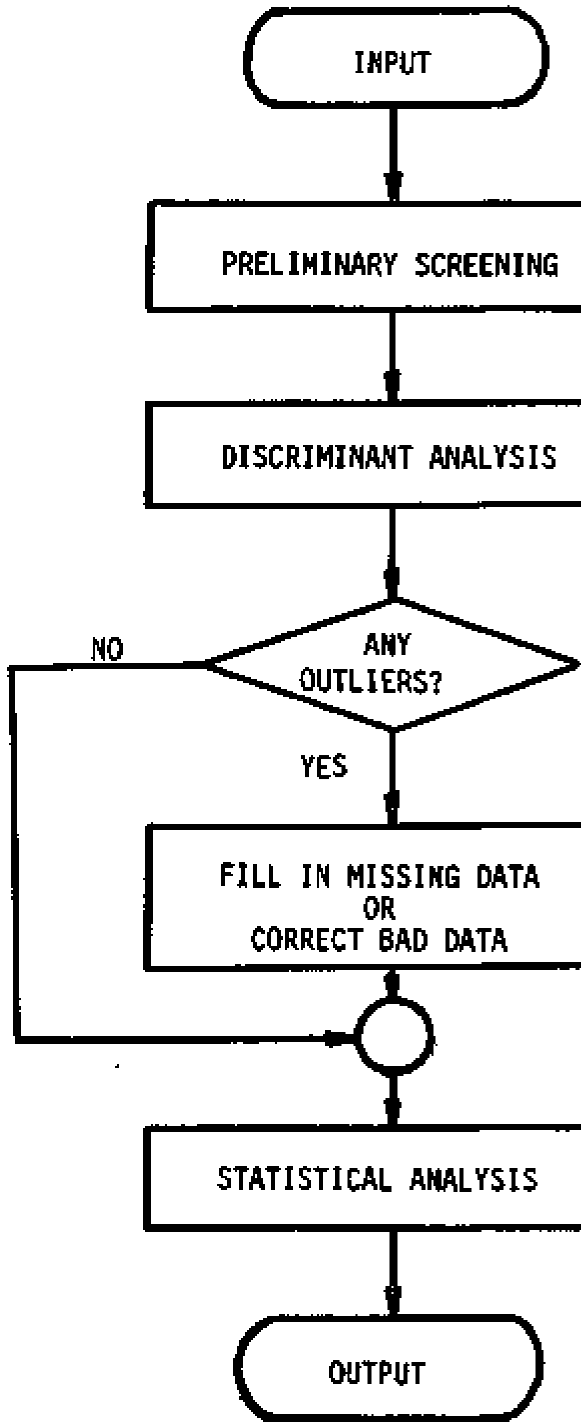


Figure 2: Solar House Data Analysis Procedure

(3) In this step, a multivariate statistical approach is used to fill in missing data points or to correct some unreasonable data values. This approach and other more sophisticated filtering techniques based on spectral analysis, estimation theory, or the Group Method of Data Handling (GMDH) which are more suitable for generating large missing records have already been described in Progress Reports Nos. 2 and 3 of this project; however, they are again given in Appendix A1 for reference.

(4) Finally, the whole data set (usually one year) is input to a statistical computer program package to compute the relative and cumulative frequency distribution functions for data of each month and for monthly averages of the data-year under study. Sample results of this statistical analysis package are given in Figures B1.2 - B1.16 of Appendix B1.

III.2 Solar House Design Model Validation Procedure

The model validation process is a scientific approach using up-to-date techniques to evaluate the "goodness" of a model. The necessary steps in the model validation process are presented in Figure 3. Detailed discussions of the model validation approach proposed by SEEC, along with the flowchart of the Model Validation Package are given in Appendix A3. Following are some principal points that SEEC has used to validate the SOLCOST, SOLSIM, SIMSHAC and TRNSYS solar house design models.

(1) Data Selection for Model Validation

Given a large data set for use in the validation of some particular models, the first question one should ask is: how do we select the training sequences for model calibration and the checking sequences

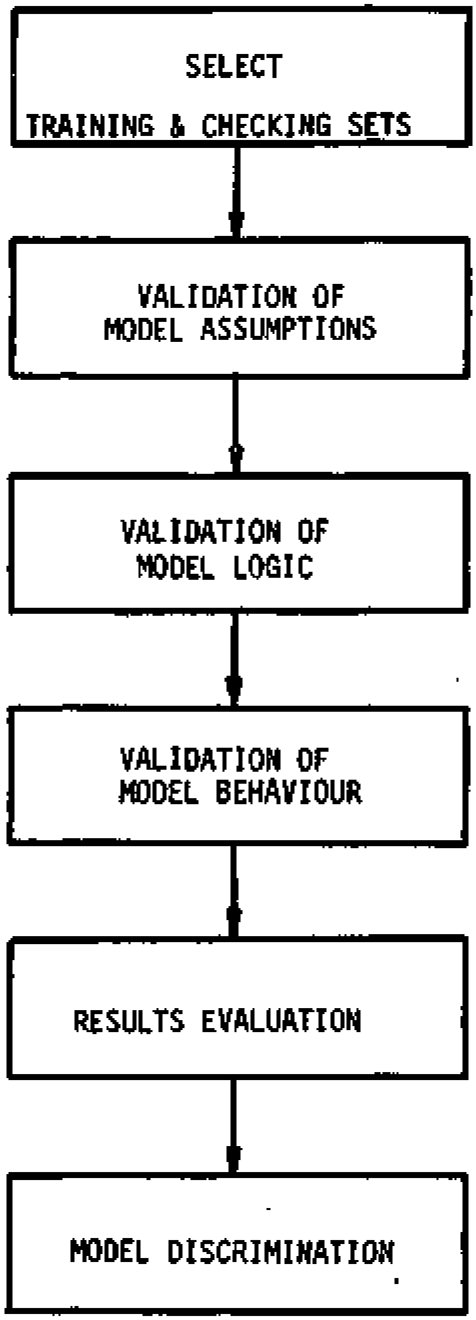


Figure 3. Flowchart of Necessary Steps in the Model Validation Process

for testing model performance? The length of these data sequences is then determined based on model characteristics (i.e. required time-period for the model to stabilize or cyclic conditions to be achieved).

Data selection techniques based on the variance or some clustering criteria are presented in Appendix A2. For the case of SOLCOST, SOLSIM, SIMSHAC and TRNSYS validation purposes, the chosen time-period was three days, and one training and one checking sequence were selected for each month. Samples of training and checking sequences selected for January data, 1975, are given in Appendix B1. Following is the list of all training and checking periods used in the validation process of SOLCOST, SOLSIM, SIMSHAC and TRNSYS (Figure 4).

MONTH	TRAINING	CHECKING
September	9-28	9-11
October	10-3	10-26
November	11-27	11-23
December	12-6	12-22
January	1-12	1-7
February	2-5	2-10
March	3-3	3-7
April	4-5	4-7
May	5-13	5-5
June	6-20	6-12
July	7-8	7-17
August	8-3	8-19

Figure 4: List of Training and Checking Sequences

(2) Validation of Model Assumptions

Assumptions are necessary to define the modeling problem in order to arrive at some useable model. However, each assumption made will reduce the domain of applicability of the model. Thus, the following questions need to be answered in the validation of model assumptions:

- What are the assumptions made in the model?
- Are they valid assumptions for the design purposes of the model?
- How much do they limit the applicability of the model?
- What are the advantages of using them?

(3) Validation of Model Logic

The logic in a model is related to the model structure, the computational procedure used in each model component, the input-output relationship and the control of information flow. To validate model logic, the following questions should be answered:

- How does the model structure set-up?
- What are the computational procedures used in the model and in each of its components?
- Are the computational procedures effective and easy to manipulate?
- What are the input-output relationships of the model?
- Are the inputs accessible and easy to change for various application conditions?
- What are the control options used in the model?
- Do the control options satisfy the intended purposes of the model?

(4) Validation of Model Behavior

This is the most important step in the Model Validation process, since the purpose of the model building process is to develop a model which can reproduce as closely as possible the real system. In addition to investigating model performance analysis the model computer program should also be analyzed to determine the applicability of the package to potential users. Hence, the following questions need to be carefully examined:

- The accuracy and frequency distributions of the simulation results.
- How are the simulation errors distributed ?
- Are there any systematic errors in the model?
- What are the computer execution statistics related to the model?
- How much does the model program depend on the computer machine language, or the system's library routines?
- Is the model stable for changes in the input data?

From the analysis of tasks (2), (3), and (4) above, one can identify what needs to be done to improve the model behavior, extend its domain of applicability, and put it in a more flexible form to attract potential users.

(5) Model Selection Criteria

Criteria for choosing among competing digital simulation models are set-up based on various model features which are presented in tasks (2), (3), and (4). Thus, the "goodness" of a systems model may be found from:

- Capability to perform the desired tasks;

- Input data requirements;
- Calibration and production costs;
- Feasibility of improvement;
- Cost of improving the model;
- Pay-off of the improved model.

Among those criteria for model comparison, the first one is the most important, and, for design models, it should include the capability of automatic selection of subsystem components to optimize systems relative to selected design criteria, and be able to conduct a life cycle cost analysis for a given system.

Some approaches for systematic choosing among competing digital simulation models based on simulation performance are also presented in Appendix A4.

III.3 Discussions of Solar House Design Model Validation Results

Based on the above analysis procedures, each model will be discussed from the starting of the modeling objective through the end of the simulation performance. Among the four models under study, SOLCOST has some distinct characteristics and different design objectives, and therefore will be discussed first. The other three models, i.e., SOLSIM, SIMSHAC, and TRNSYS, will be treated under the same conditions for easy comparison. Since the version of SOLSIM that SEEC received from the Martin-Marietta Co. did not have the cooling mode built into the model, only four winter months - November, December, January, and February - were used to validate these three models.

A. SOLCOST

1. Objective:

To build a simplified solar system design model for the non-engineer user.

2. Model Assumptions

(1) It was assumed that the non-engineer user is more interested in the effect of investment cost on solar system design, and that the collector and the storage tank are the two principal system components which over-shadow the operations and the costs of other smaller components in the system.

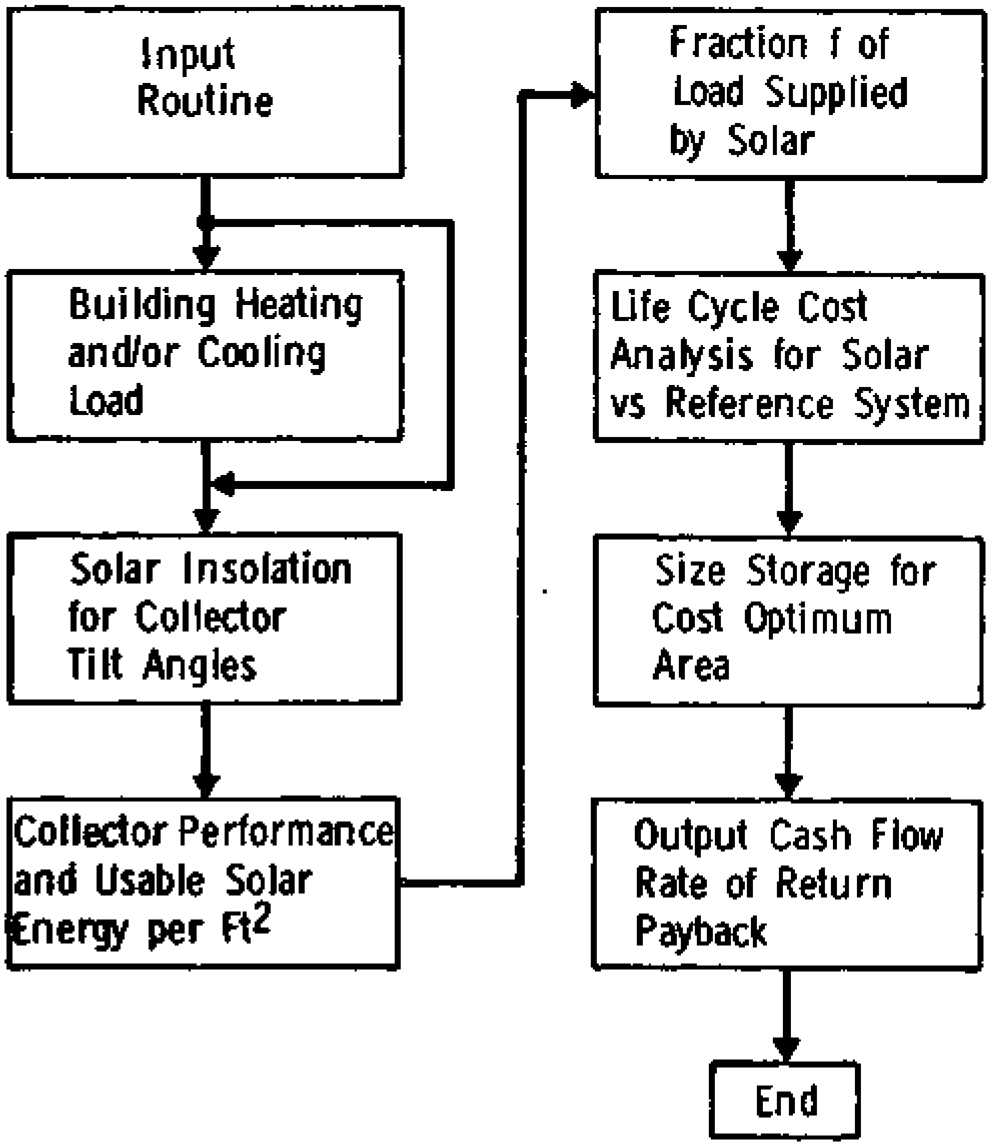
(2) It was further assumed that the users will not have good backgrounds in computer programming and life cycle cost analysis techniques.

The above assumptions are reasonable for the non-engineer users. The model developed, based on these assumptions, will give the users an overview of how large the collector and the storage tank should be to assure heating/cooling of their houses even in the worst months of the year; how much the investment cost would be if such a system were to be installed; and, what is the net lifetime cost savings for a selected collector area and tilt angle. In summary, this type of model will give an excellent picture of the investment cost for a solar heating/cooling system. However, it does not fit properly with the model objective, since its "design method" is not complete (i.e., cannot answer questions such as: what are the components of the solar heating/cooling sytem that one should buy? How do they affect the operation and the life cycle cost of the solar system?).

3. Model Logic

The structure and logic of SOLCOST are given in Figure 5 and the various types of input data required to run SOLCOST are given in Figure 6. The user's data is entered through an input routine. The internal logic flags and default data values are set and data bank information

OVERVIEW - SOLCOST FLOW CHART



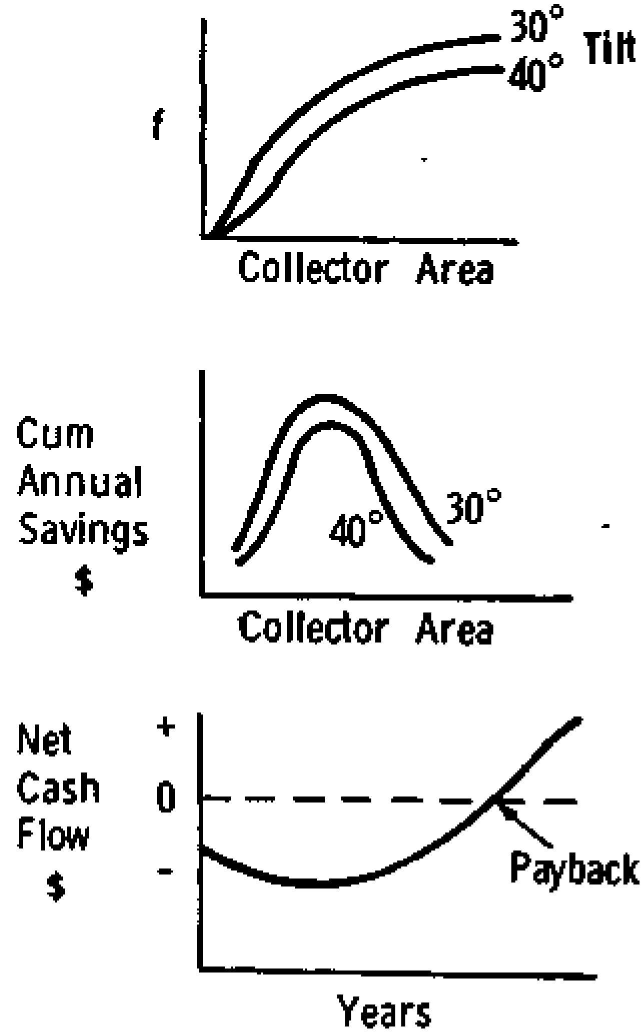


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Figure 5.

SOLCOST INPUT

Mandatory Input

- Job Site
- Collector Type
- Finance Scenario Flag
- Fuel Type Flags (Reference & Auxiliary)
- Construction Loan Term and Interest Rate
- Heating / Cooling Flags (by Month)
- Building Energy Load, or Building Definition
- Heating / Cooling System Type Flag

Defaulted Input	Value
Collector Area Limit	10^6
Collector Azimuth Angle	0.
Fuel Sales Tax Rate	0.
System Life (Years)	20.
Building Useage (Days per Wk)	7.
Auxiliary Furnace Eff	0.7
Salvage Value Fraction	0.1
Fire Insurance Rate Fraction	TBD
Maintenance Cost Fraction	TBD
Investment Credit Fraction	0.1
First Year Depreciation Fraction	0.2
Down Payment Fraction	0.1
Depreciation Method	S. L
Depreciation Period (Years)	10.
Property Tax Fraction	0.
Clearness Factor	1.0
Liquid Storage Size Gal/Ft^2	1.5

Input from Data Banks

- Percent of Possible Sun Fractions
- Site Latitude
- Collector Efficiency Data
- Solar HVAC System Fixed Initial Cost
- Solar HVAC System Installed Cost Per Unit Area
- Reference HVAC System Initial Cost
- Collector Inlet Temperatures (by Month)
- Solar System Efficiency (by Month)
- Reference System Efficiency (by Month)
- Collector Slope Angles
- Min. Daily Ambient Temperatures
- Max. Daily Ambient Temperatures
- Energy Cost Schedules and Escalation Rates

Note:
All Default & Data Bank Inputs May be Overridden by Direct User Input

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Figure 6.

is supplied depending on the user's problem description.

The user has an option of choosing his own heating/cooling loads or using the loads routine available in SOLCOST. The latter option requires the user to define his building in "sufficient detail" so the program can make an "accurate" loads calculation, based on a generalized thermal network contained in the program. The loads network solution routine uses a forward-backward differencing technique which allows an accelerated time step to speed the program through the transient execution of the problem.

The program computes an optimum collector area and tilt angle from an analysis of life cycle cost differences for a solar system versus a reference (conventional) HVAC system.

Having determined the optimum collector area, SOLCOST next generates a storage system size for the optimum collector area.

Finally, the output from this program contains collector area, tilt angle, storage size, and cost data.

The following remarks can be made:

(1) Since SOLCOST is a subprogram expanded from the Martin Interactive Thermal Analysis System (MITAS), which is a highly machine dependent package, it is very difficult to use for average users.

(2) The specific solar house model (e.g., system structure) must be coded into the SOLCOST program. To change the system structure requires recompilation of the whole MITAS package.

(3) The idea of using pre-computed values for default input and information from a Solar Data Bank to keep the user input requirement to a

minimum is excellent and fits with the model design purposes. However, it also requires that any organization using SOLCOST must have a compatible computer system and an equivalent Solar Data Bank as the one being used at the Martin Marietta Co.

(4) The use of the life cycle cost analysis results for sizing the collector and the storage tank is excellent. However, disregarding the other components of the solar house system could lead to too optimistic conclusions in the analysis of investment costs.

(5) The insolation model in SOLCOST is based on Chapter 59 of the ASHRAE Application Handbook with some modification to adjust the clearness number for each month. This model requires rather extensive input data and computation times to generate solar flux incident on a tilted collector.

4. Model Behavior

Summary statistics of SOLCOST Model performance are given in Table 1. Detailed analysis of SOLCOST cost analysis for SOLAR I and ECO-ERA (another experimental solar house) are given in Appendix B2, for comparison of SOLCOST performance with the actual design based on an approach developed by the SOLARON Corp. of Denver.

B. SOLSIM

1. Objective:

To build a transient solar system simulation model for engineering users familiar with thermal network methods.

ECO-ERA No. 2

PARAMETER	SOLCOST	SOLARON
COLLECTOR SIZE (Ft^2)	481	412
STORAGE SIZE (Tons)	NOT CALCULATED	12
TILT ANGLE (Deg.)	50	45
AVG. ANNUAL COST SAVINGS ($)	804	750
ANNUAL FRACTION	0.83	0.75

Table 1: Summary Statistics of SOLCOST Performance vs. SOLARON Approach

2. Model Assumptions

(1) It was assumed that the user of SOLSIM is already familiar with the MITAS computer program package and can access this program on the CYBERNET and Utility Network of America time-sharing networks.

(2) A solar energy system can be approximated by a resistance-capacitance network so that MITAS can be used to solve for the system transient solution.

As already mentioned in the case of SOLCOST, the MITAS package is a generalized thermal network analyzer; it is efficient for solving heat transfer problems; however, it is a highly machine dependent package. Therefore, the above assumptions will limit the use of SOLSIM to a class of selected engineering users.

3. Model Logic

SOLSIM thermal models (there are five models presently available(*)) contain user routines describing a solar energy system as a thermal network, and are solved transiently for temperatures and heat flows by MITAS.

(*) 1. Space and domestic water heating system with liquid collectors,

2. Domestic hot water heating system only with liquid collectors,

3. Space and domestic hot water heating system with air collectors,

4. Combined space cooling (using an absorption cycle cooler) and space heating with liquid type collectors,

5. Solar assisted heat pump system with liquid type collectors.

Each SOLSIM model is coded for one particular solar energy system; therefore the user should know how to modify the SOLSIM networks to model his own unique solar system.

Thermal modeling of some principal types of equipment used in solar energy systems is summarized as follows:

(1) Solar collectors for which the performance can be specified by a curve of efficiency versus the parameter $(T_{in} - T_{amb})/Q_1$ have been modeled in SOLSIM with one node whose temperature corresponds to the collector outlet temperature.

(2) Liquid storage tanks have been modeled in SOLSIM with one node with thermal capacitance corresponding to the mass of fluid in the tank. This node will be coupled to the collector and a system thermal load with one-way conductors. Losses through the storage tank's insulation are modeled with a regular conductor whose $KA/\Delta x$ value is computed from the insulation conductivity and thickness. This insulation conductor will be tied to a boundary node for the tank surroundings.

Stratification in liquid storage tanks results in a multiple node vertical model of the tank fluid.

(3) Heat exchanger performance has been modeled by an effectiveness technique in the SOLSIM program. This technique involves an iterative process on the outlet temperature until the prediction with the overall heat transfer coefficient U and $\overline{\Delta T}$ (log mean temperature difference) matches the heat transfer predicted by the temperature rise and drop in the cold and hot side fluids.

Figures 7 and 8 present the case of using SOLSIM to simulate a simple solar house heating system and are presented here for illustrative

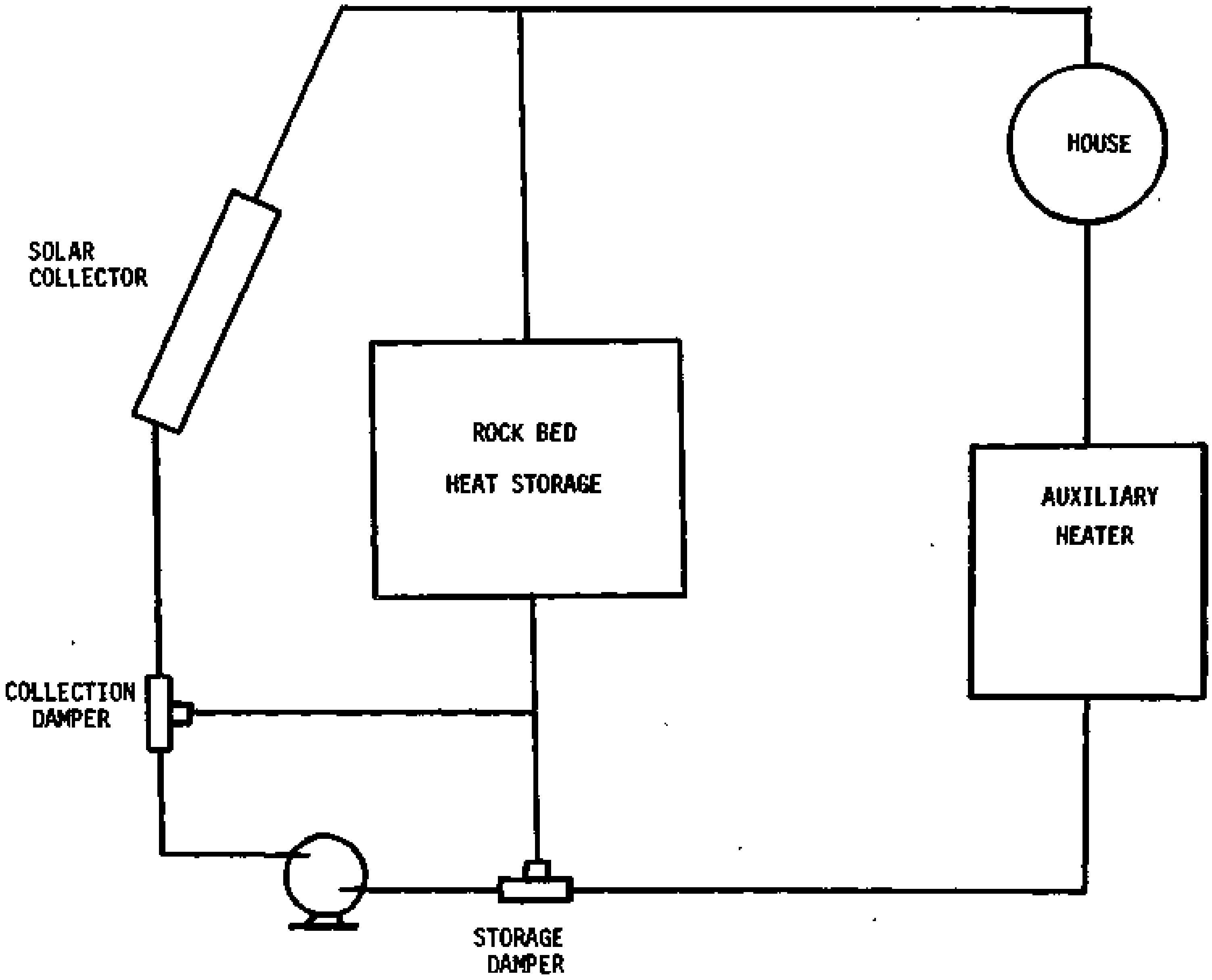

Figure 7: Air System Schematic

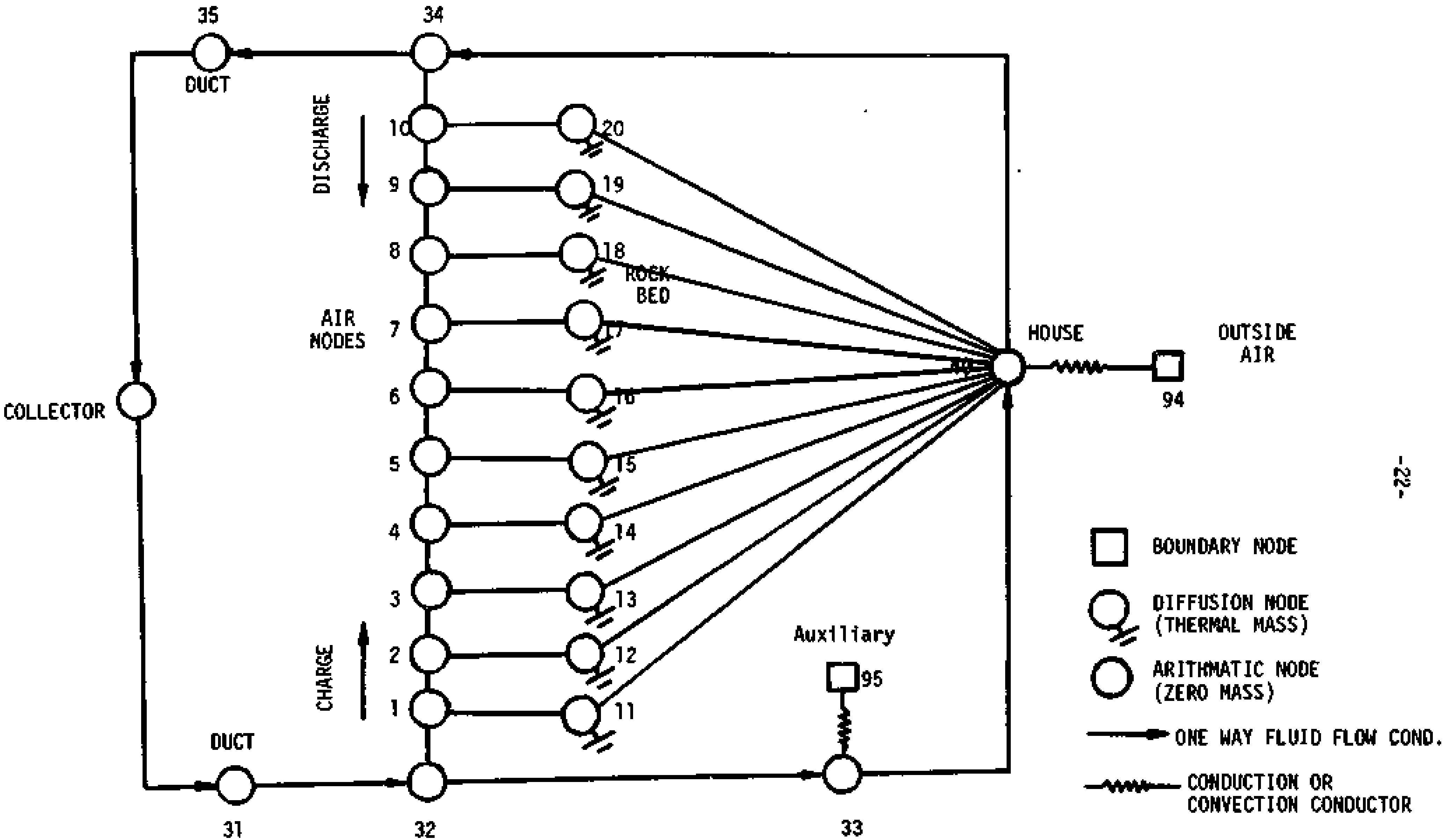

Figure 8: Air System Thermal Network

purposes. The model logic discussed above shows that SOLSIM has a rigid structure for a given thermal system, and therefore the adaptation of the model to a more complex system will require a large amount of time to reset the system thermal network and recode the SOLSIM program.

4. Model Behavior

Summary statistics of SOLSIM simulation errors in modeling SOLAR I for the four winter months are presented in Tables 2a and 2b. Detailed analyses with plots of observed values versus simulated values are given in Appendix B3. Following are some remarks on the model behavior for the checking periods:

(1) SOLSIM under-estimates the storage tank temperatures in 90 per cent of the time, in the average of the four winter months. The mean-error in the simulation for that period is -11.2^{O}F.

(2) Since the control used in the program is a simple on-off controller, the simulated enclosure temperatures fluctuate between 64.5^{O}F to 68^{O}F, with an average error for the winter period equal to -2.3^{O}F.

(3) The simulation of the collector operation (i.e. timing) is very good. However, the model under-estimates the collector inlet and outlet temperatures in most of the cases, especially during the months of December and January. The mean-errors in the simulation of the collector inlet and outlet temperatures respectively for the winter period are -0.6^{O}F and -1.8^{O}F.

(4) The simulation of the collector mass flow rate is also good, the mean simulation-error for the winter period being -0.6 lbm/min.

(5) SOLSIM always under-estimates the ammount of solar energy collected by the collector. The mean simulation-error for the winter period is -51924 Btu/Day.

(6) The calculation of the heating load gives an average error of 39222 Btu/Day for the winter period.

(7) The model over-estimates the amount of auxilary energy required for heating the building in 70 percent of the time, on the average, during the winter period. The mean simulation-error for this period is 59904 Btu/Day.

(8) Since SOLSIM uses solar data as direct input to the model and then interpolates to obtain values at some desired time interval, it is evident that the simulated values of solar radiation on the tilted surface are very close to the measured values.

(9) SOLSIM requires a relatively long time-period for compiling (i.e. 75 sec.); however, it uses only a rather short time-period (i.e. 5.8 sec.) to run the 3-day simulation of SOLAR I on the CSU/CDC6400 computer system.

C. SIMSHAC

1. Objectives

The objectives in the development of SIMSHAC were to:

(1) Develop a general model, that is, one that can be used for any specified system configuration for solar heating and/or cooling of buildings.

(2) Modularize the program so that subsystems can be introduced or replaced as more sophisticated subsystems become available.

(3) Develop a model that is simple in terms of the knowledge required by the system designer, and hence easy to use.

COMPONENT	MONTH								WINTER AVERAGE	
	November		December		January		February			
	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
STORAGE TANK (oF)	-13.7	10.2	-7.6	6.4	-7.0	5.3	-6.0	12.4	-8.6	8.6
ENCLOSURE (°F)	0.1	2.1	-0.2	1.5	-1.5	2.8	-2.2	2.5	-1.0	2.2
COLLECTOR INLET (°F)	- 2.2	4.4	-1.4	3.9	-2.4	2.5	-1.8	5.0	-2.0	4.0
COLLECTOR OUTLET (°F)	0.7	5.0	-1.7	4.9	-0.9	3.9	-2.7	5.3	-1.2	4.8
COLL. FLOW RATE (lbm/min)	2.2	1.6	-1.1	3.0	-0.6	1.9	0.1	1.7	0.2	2.1
ENERGY COLLECTED (BTU/day)	-1680	22801	-54335	19489	-49469	24732	-13161	6890	-29661	18478
HEATING LOAD (BTU/day)	-23209	8233	16928	63974	-5750	19147	78171	76342	16535	41924
AUX. ENERGY SUPPL (BTU/day)	11844	16536	46240	89221	34885	21983	49043	65392	35503	48283
SOLAR INSOL (45°) (BTU/SQ FT /HR)	-0.2	6.0	-0.1	6.9	-0.4	8.3	-0.4	6.3	-0.3	6.9

Table 2a: Summary Statistics of Simulation Errors of SOLSIM for the Four Winter Training Periods.

COMPONENT	MONTH								WINTER AVERAGE	
	November		December		January		February			
	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
STORAGE TANK (°F)	-17.6	7.8	-13.5	7.3	-9.5	6.3	-4.3	4.6	-11.2	6.5
ENCLOSURE (°F)	- 4.0	2.2	- 0.1	2.4	-0.9	1.7	-4.3	3.1	- 2.3	2.4
COLLECTOR INLET (°F)	- 0.4	6.4	- 1.6	4.2	-1.1	2.7	0.9	2.2	-0.6	3.9
COLLECTOR OUTLET (°F)	- 3.9	5.9	- 2.0	5.3	-1.5	3.5	0.4	3.2	-1.8	4.5
COLL. FLOW RATE (lbm/min)	1.6	5.6	- 1.3	3.5	0.5	0.9	-3.1	2.9	-0.6	3.2
ENERGY COLLECTED (BTU/day)	-45872	41732	-62980	41987	-57590	30708	-41254	14259	-51924	32172
HEATING LOAD (BTU/day)	1860	31333	79136	36117	109666	25890	-33774	30342	39222	30921
AUX. ENERGY SUPPL. (BTU/day)	-1032	1459	66618	64647	114127	76352	(*)	(*)	59904	47486
SOLAR INSOL (45°) (BTU/SQ FT/HR	- 0.1	8.0	- 1.3	5.4	-0.3	8.1	-0.5	6.5	-0.6	7.0

(*): No Auxiliary Energy Used

Table 2b: Summary Statistics of Simulation Errors of SOLSIM for the Four Winter Checking Periods.

(4) Develop a dynamic model because the primary problem being modeled is a dynamic problem, and, therefore, the dependence on time is certainly required.

(5) Develop a dynamic point design performance analysis model with a specifiable level of simulation complexity such that a very simple module might be used for sensitivity analyses, and more complex simulation subsystems could be used for detailed time-step by time-step analysis of the overall system.

(6) Develop a control driven model so that the total system responds to the decisions and actions of the control system.

2. Model Assumptions:

(1) It was assumed that the structure and storage tank had a linear heat loss characteristic and a uniform storage capacity (no stratification).

(2) The user was assumed to have some background in computer programming, in order to be able to develop a control routine to simulate the type of control that he desired to have in his solar system.

This latter assumption somehow limits the applicability of the model to some class of users, i.e. someone that can write a control routine in the FORTRAN language. One approach which is under consideration by SEEC to overcome this weakness is to build into the SIMSHAC program a set of control routines simulating all of the commonly used controllers existing in the market. Then, according to the user's selection, the chosen control routine will coordinate the execution of all other components in the system.

The first assumption was used to satisfy one of the model objectives (i.e., simplicity); however, it limits the simulation performance of the model.

3. Model Logic

The structure and logic of SIMSHAC are shown in Figure 9, and the various types of input data required to run SIMSHAC are given in Figure 10.

The program is executor and library file oriented. The library file contains all of the subsystem models. At present, the following subsystems are in the library: collectors (both flat plate and focusing), plumbing, valves, pumps, heat storage devices, auxiliary heating and cooling devices, heat exchangers, the enclosure model, and the control unit. To use the program, the user has merely to specify the components included in the system and the manner in which they are connected. The executer program in SIMSHAC will then write the computer program for the specific system to be analyzed.

The overall schematic for the program structure shows that there are three overlay levels in SIMSHAC. The first level is the input overlay and reads the weather data from magnetic tape, the second is the executor overlay, and the third is the output overlay.

The program has been developed so that any type of incident solar radiation data or model can be used. The integrator model is a variable order Runge-Kutta routine of second, fourth, fifth, or eighth order.

The program is written in EXTENDED FORTRAN for a CDC 6400 computer. The structure and logic of SIMSHAC, as briefly described above,

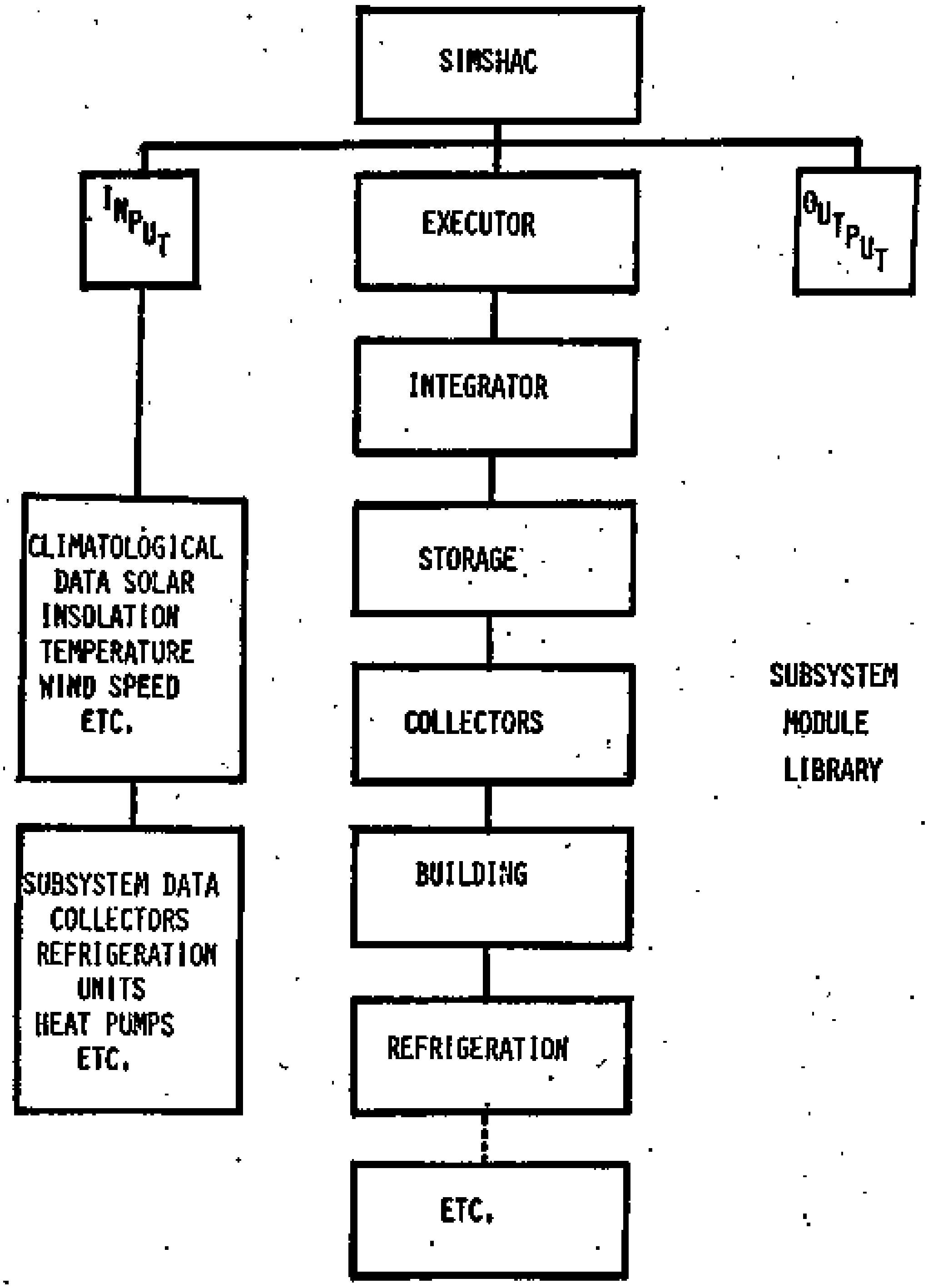
SIMSHAC
INPUT
EXECUTOR
OUTPUT
INTEGRATOR
CLIMATOLOGICAL DATA SOLAR INSOLATION TEMPERATURE WIND SPEED ETC.
STORAGE
COLLECTORS
SUBSYSTEM MODULE LIBRARY
SUBSYSTEM DATA COLLECTORS REFRIGERATION UNITS HEAT PUMPS ETC.
BUILDING
REFRIGERATION
ETC.

Figure 9

NO DEFAULT VALUES

Enclosure

1. Wall Area
2. Glass Area
3. Door Area
4. Floor Area
5. R-Valve for each of the Above
6. Number of People
7. Heat Gain due to Lights
8. Heat Gain due to Machines

HAS DEFAULT VALUES

Collector

1. Collector Area
2. Plate and Cover Glass Absorbance
3. Specific Heat of Fluid
4. Tilt Angle of Collector
5. Outside and Inside Diameter of Tubes
6. Fin Thickness
7. Thermal Conductivity of Insulation
8. Thermal Conductivity of Plate
9. Longitude and Latitude
10. Emissivity of the Cover Glasses
11. Emissivity of the Cover Plates
12. Thickness of Cover Glass
13. Extinction of Cover Glass

Storage Tank

1. Tank Volume
2. Area
3. Fluid Specific heat
4. Fluid Density
5. Loss Coefficient

Enclosure

1. Heat Capacity
2. Effectiveness of House Heat Exchanger
3. Solar Heat Gain

Figure 10: SIMSHAC Input Requirement

give the model a great flexibility to adapt to any kind of solar house heating/cooling system structure. The model building concept should make SIMSHAC a good solar system design tool if one were to incorporate a life cycle cost analysis capability into it.

4. Model Behavior

Summary statistics of SIMSHAC simulation errors in modeling SOLAR I for the four winter months are presented in Tables 3a and 3b. Sample plots of observed values versus simulated values are given in Appendix B4. Following are some remarks on the model behavior for the checking periods :

(1) SIMSHAC over-estimates the storage tank temperatures in 70 per cent of the time, in the average of the four winter months. The mean simulation-error for that period is 4.7°F.

(2) The control routine in the SIMSHAC program is written to reflect the actual control system in used at SOLAR I, therefore, the model gives a relatively good simulation of the enclosure temperature. The mean simulation-error for that period is 0.3°F.

(3) The simulation of the timing of the collector operation needs improvement, since there are some delays which can be recognized in the plots of observed values versus simulated values of the collector inlet and outlet temperatures (see Appendix B4). However, most of the time during the winter period, the average simulation errors are -0.3°F and 0°F, for the collector inlet and outlet temperatures, respectively.

(4) The simulation of the collector mass flow rate has the same weakness mentioned in (3). The average simulation-error for the winter period is 1.6 lbm/min.

(5) SIMSHAC over-estimates the amount of solar energy collected in 65 percent of the time, with an average error of 9336 Btu/Day, for the winter period.

(6) Similarly, the model also over-estimates the amount of energy delivered to the enclosure during the study period. The average simulation error for the winter period is 9021 Btu/Day.

(7) The model under-estimates the amount of auxilary energy required for heating the building in 65 percent of the time, on the average, during the winter period. The mean simulation-error for this period is 7012 Btu/Day.

(8) The solar insolation model in the SIMSHAC program over-estimates, in 85 percent of the time, the solar radiation flux on a tilted surface. The mean simulation-error for the winter period is 36 $Btu/Hr\text{-}Ft^2$.

(9) SIMSHAC requires, on the average, 54 sec for compiling and 11.4 sec to run the 3-day simulation of SOLAR I on the CSU/CDC 6400 computer system.

D. TRNSYS

1. Objectives

(1) To develop a simulation model for the analysis of the transient operation of solar energy systems.

(2) To use modular concepts in the simulation of solar energy systems to facilitate the interconnection and information transfer between subsystem components.

(3) To give users a flexible design tool for the analysis and design of solar energy systems.

COMPONENT	MONTH								WINTER AVERAGE	
	November		December		January		February			
	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
STORAGE TANK (°F)	8.7	6.0	0.5	4.3	-5.0	4.9	-1.7	8.9	0.6	6.0
ENCLOSURE (°F)	1.7	1.1	-0.3	1.6	-0.6	2.0	0.3	2.7	0.3	1.9
COLLECTOR INLET (°F)	0.4	1.9	-0.2	2.7	-0.4	3.8	-1.6	4.1	-0.5	3.1
COLLECTOR OUTLET (°F)	-0.8	3.1	-1.5	2.9	1.5	4.6	-0.6	5.7	-0.4	4.1
COLL. FLOW RATE (lbm/min)	-0.6	3.6	0.1	0.7	0.8	1.4	0.4	2.8	0.2	2.1
ENERGY COLLECTED (BTU/day)	74259	82678	7080	38446	44842	46516	53490	39214	44918	51714
HEATING LOAD (BTU/day)	-1716	10754	-47432	94217	-64375	45335	117432	82112	977	58105
AUX. ENERGY SUPPL (BTU/day)	- 372	526	-59247	60585	-69003	69038	45333	39111	-20822	42315
SOLAR INSOL (45°) (BTU/SQ FT/HR	32.6	56.0	45.0	102.0	25.0	82.4	28.3	72.5	32.7	78.2

Table 3a: Summary Statistics of Simulation Errors of SIMSHAC for the Four Winter Training Periods.

COMPONENT	MONTH								WINTER AVERAGE	
	November		December		January		February			
	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
STORAGE TANK (°F)	12.6	6.7	3.5	4.3	1.8	4.2	0.9	5.3	4.7	5.1
ENCLOSURE (°F)	-1.2	1.7	1.1	1.2	0.8	1.0	0.6	3.9	0.3	2.0
COLLECTOR INLET (°F)	-0.7	4.7	-0.7	1.7	2.0	3.2	-1.7	2.2	-0.3	3.0
COLLECTOR OUTLET (°F)	1.9	4.1	-1.6	1.3	-0.6	1.6	0.2	1.7	0	2.2
COLL. FLOW RATE (lbm/min)	3.5	8.3	-0.6	2.8	1.8	1.0	1.5	3.2	1.6	3.8
ENERGY COLLECTED (BTU/day)	21666	15858	3549	11855	25991	13272	-13863	40965	9336	20488
HEATING LOAD (BTU/day)	-3725	21266	16028	16927	16660	10794	7121	25399	9021	18597
AUX. ENERGY SUPPL. (BTU/day)	-1032	1459	(*)	(*)	-266	376	22333	10444	7012	4093
SOLAR INSOL (45°) (BTU/SQ FT/HR)	34.7	94.0	52.9	99.8	24.0	95.0	32.4	97.3	36.0	96.5

(*): No Auxiliar Energy Used

Table 3b: Summary Statistics of Simulation Errors of SIMSHAC for the Four Winter Checking Periods.

2. Model Assumptions

(1) It was assumed that the structure and sotrage tank had a linear heat loss characteristic and a uniform storage capacity.

(2) The user was assumed to have some background in FORTRAN programming in order to understand the model structure, and be able to modify the input set-up according to the system design requirements.

The first assumption was used to simplify the modeling task; however, the model can be easily modified to handle the case of a stratified storage tank.

3. Model Logic

The structure and logic of TRNSYS are similar to SIMSHAC's as shown on Figure 9, and the various types of input data required to run TRNSYS are given in Figure 12.

The program is of modular type and executor control oriented. Most of the solar system components in use at solar houses in the United States, such as collectors, valves, pumps, heat storage devices, auxiliary heating and cooling devices, heat exchangers, and the control unit are represented by subroutines that the user can assemble into any desired configuration according to the solar system under study. Data manipulation programs such as interpolation and integration are also incorporated into the TRNSYS package. A cost analysis component has also been considered to make TRNSYS a flexible and complete design tool for solar house heating and cooling systems.

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Solar Collector

1. Collector Area
2. Collector Efficiency factor
3. Fluid Thermal Capacitance
4. Collector Plate Absorbance
5. Number of Glass Covers
6. Collector Plate Emittance
7. Loss Coefficient for bottom and Edges
8. Collector Tilt Angle
9. Extinction Coefficient and glass cover Thickness Product

Storage Tank

1. Tank Volume
2. Tank Height
3. Fluid Specific Heat
4. Fluid Density
5. Loss Coefficient Between the Tank and its Environment

Enclosure

1. Building heat loss Coefficient
2. The Building Heat Capacity
3. Maximum flow rate through Load Heat Exchanger
4. Specific of Heat Delivery Fluid
5. Effectiveness of Load Heat Exchanger
6. Minimum Capacitance rate of Load Heat Exchanger
7. Constant Heat Gain Rate

TRNSYS has no default values. All values must be specified on input for each model to be considered.

Figure 12: TRNSYS Input Requirement

4. Model Behavior

Summary statistics of TRNSYS simulation errors in model SOLAR I for the four winter months are presented in Tables 4a and 4b. Sample plots of observed values versus simulated values are given in Appendix B5. Following are some remarks on the model behavior for the checking periods:

(1) TRNSYS over-estimates the storage tank temperatures in 80 percent of the time, in the average of the four winter months. The mean simulation error is relatively small and has the value of 7.3°F for that period.

(2) The simulation of the enclosure temperatures is very good as one can see from the plot of the observed values versus the measured values (see Appendix B5). The mean simulation-error is relatively small and has the value of -0.3°F for the winter period.

(3) On the average, the simulation of the collector inlet and outlet temperatures is good. However, like SIMSHAC, TRNSYS shows some delays in the simulation of the collector operation (i.e. timing) as one can recognize from the plots of the observed values versus the measured values of the collector inlet and outlet temperatures (see Appendix B5). The average simulation-errors for the winter period are 1.2°F and 0.7°F, for the collector inlet and outlet temperatures, respectively.

(4) The simulation of the collector mass flow rate has the same weakness mentioned in (3). On the average, the simulation-error has the value of 0.6 lbm/min for the winter period.

(5) TRNSYS over-estimates the amount of solar energy collected in most cases, 85 percent of the time, except data from February, which shows that TRNSYS under-estimates the amount of solar energy collected. The mean simulation-error for the winter period is 27988 Btu/Day.

(6) TRNSYS over-estimates the building heating load in 65 percent of

COMPONENT	MONTH								WINTER AVERAGE	
	November		December		January		February			
	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
STORAGE TANK (°F)	2.1	5.8	1.1	1.9	-0.6	3.1	0.5	7.0	0.8	4.5
ENCLOSURE (°F)	0.1	0.9	0.1	0.7	0.1	1.7	0.1	1.6	0.1	1.2
COLLECTOR INLET (°F)	0.9	1.2	2.2	1.0	-1.1	2.5	1.1	1.9	0.8	1.7
COLLECTOR OUTLET (°F)	0.4	1.5	1.8	1.4	0.4	2.1	-2.1	2.7	0.1	1.9
COLL. FLOW RATE (lbm/min)	-0.3	1.1	-1.8	1.4	-0.6	3.5	1.1	0.7	-0.4	1.7
ENERGY COLLECTED (BTU/day)	81165	72010	7498	36398	16896	43690	30928	47219	34122	49829
HEATING LOAD (BTU/day)	5487	6685	4364	66409	37281	42916	18016	63044	16287	44764
AUX. ENERGY SUPPL. (BTU/day)	-372	526	8165	40185	457	32375	(*)	(*)	2750	24362
SOLAR INSOL (45°) (BTU/SQ FT/HR)	39.5	66.0	15.9	50.6	17.2	31.2	6.0	27.4	19.7	43.8

(*): No Auxiliary Energy Used

Table 4a: Summary Statistics of Simulation Errors of TRNSYS for the Four Winter Training Periods.

COMPONENT	MONTH								WINTER AVERAGE	
	November		December		January		February			
	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV	Mean	STDV
STORAGE TANK (°F)	24.3	11.0	1.0	2.5	0.8	3.5	2.9	5.6	7.3	5.7
ENCLOSURE (°F)	-2.5	1.2	0.6	1.6	1.0	1.0	-0.4	1.3	-0.3	1.3
COLLECTOR INLET (°F)	1.3	7.2	2.0	1.3	2.0	2.2	-0.4	4.7	1.2	3.9
COLLECTOR OUTLET (°F)	0.2	8.1	0.3	2.2	1.0	1.3	1.3	3.0	0.7	3.7
COLL. FLOW RATE (lbm/min)	2.1	2.3	0.6	1.8	1.0	1.3	-1.2	3.3	0.6	2.2
ENERGY COLLECTED (BTU/day)	80091	74178	28813	25836	29327	12678	-26278	7771	27988	30116
HEATING LOAD (BTU/day)	-3777	30543	77022	22593	142982	11743	-65542	44318	37671	27299
AUX. ENERGY SUPPL. (BTU/day)	-1032	1459	11848	15797	23430	31240	(*)	(*)	11415	16165
SOLAR INSOL (45°) (BTU/SQ FT/HR)	77.4	176.	34.8	75.2	21.5	38.6	3.12	16.6	34.2	76.4

(*) : No Auxiliary Energy Used

Table 4b: Summary Statistics of Simulation Errors of TRNSYS for the Four Winter Checking Periods.

the time. The mean simulation-error for the winter period is 11415 BTU/Day.

(8) The solar insolation model in TRNSYS can be improved, since the mean-error in the simulation of solar radiation flux on a tilted surface is 34.2 BTU/Hr-Ft^2 for the winter period.

(9) TRNSYS requires only 15 sec. for compiling and 5.4 sec. for a 3-day run of the simulation of SOLAR I on the CSU/CDC 6400 computer system.

D. Model Features Comparison

A summary of model performance features is given in Tables 5 - 13. The characteristics of the computer program packages of SOLCOST, SOLSIM, SIMSHAC, and TRNSYS are also shown in Table 14 for easy comparison.

Following are some remarks relating to each model characteristic feature in each validation area.

1. Model Assumptions

(1) In order to build a useful model for a large class of users, the model design concepts should be simple, and the computational techniques should be at the same level of understanding of that class of users, so they could understand the model and modify its set-up to fit with the design configuration of a system under study. Thus, the assumption about user's knowledge of FORTRAN programming to run the SIMSHAC and/or the TRNSYS package is accpetable, since FORTRAN is a widely known computer programming language. However, the assumption that the user must have a background on thermal networks to modify and run the SOLOCST and/or the SOLSIM packages is too optimistic. Section E shows some of the changes one should make in order to run the SOLCOST or the SOLSIM packages on the CDC 6400 computer system without changing any system configurations. Otherwise, SOLCOST and SOLSIM should be run on the same computer system actually in use by the Martin Marietta Co. and by personnel familiar enough with the programs and solar

systems to use the programs properly.

2. Model Logic

(1) SOLCOST has an excellent life cycle cost analysis of solar energy systems. The logic used to size the collector and the storage tank based on a life cycle cost analysis appears to be very good. These characteristic features of SOLCOST do not exist in the other three models examined.

(2) SOLCOST and SOLSIM have some drawbacks related to their design concepts: they are highly machine dependent packages because they are based on the thermal network concept of MITAS and use this latter package for solving transient heat transfer problems; also, the normal inputs are kept down to a minimum, but the actual inputs required to run the models are very large if one does not have a similar data bank as the one in use by the Martin Marietta Co.

(3) Each SOLSIM version corresponds to one particular solar energy system structure and therfore the model structure is very rigid. Application of SOLSIM to other solar energy systems requires a re-setting of the thermal network and a recoding of the SOLSIM program. The SOLCOST model is more general than SOLSIM. Although its structure is rigid, the application of SOLCOST to other solar energy systems requires less modification work. On the contrary, SIMSHAC and TRNSYS structures are based on modular concepts and one executor controlled therefore, very flexible. The user can adapt SIMSHAC and TRNSYS to any kind of solar energy system structure with very little modification made to the input data.

(4) The sizing of the collector and the storage tank is done automatically in SOLCOST, as already mentioned in (1). This is not the case for the other three models. However, the bypass of other component subsystems in the computation of life cycle cost for a solar energy system can lead to too optimistic conclusions about the system to be contructed. SIMSHAC and TRNSYS can also be considered as design tools for solar energy systems, by simple adjustment of subsystem components. However, their best uses are for solar energy systems analysis and control studies.

3. Model Behavior

(1) SOLSIM under-estimates the storage tank temperatures in most of the time, while SIMSHAC and TRNSYS over-estimate these values. The performances of SIMSHAC and TRNSYS are about the same, with an average simulation-error equal to 6°F for the winter period. The performance of SOLSIM is inferior compared to the other two models, with an average simulation-error equal to +11.2°F for the same period.

(2) SOLSIM, SIMSHAC, and TRNSYS have about the same performance in the simulation of enclosure temperatures during the winter period. In some cases (i.e., in January and February) SIMSHAC and TRNSYS seem to give slightly better results. The average simulation-error of the three models is less than 2.5°F for the winter period.

(3) SOLSIM has a tendency to under-estimate the collector inlet and outlet temperatures, while SIMSHAC and TRNSYS slightly over-estimate these values. However, the absolute average simulation-error of the three models is about the same and is equal to 0.7°F and 0.8°F for the inlet and outlet temperatures, respectively.

(4) As far as the timing of the collector coperation, SOLSIM offers a very good simulation, while SIMSHAC and TRNSYS show some delays in the process.

(5) SOLSIM, SIMSHAC, and TRNSYS have about the same performance in the simulation of collector mass flow rates, the magnitude of the average simulation-error for the winter period is 0.9 lbm/min.

(6) SOLSIM usually under-estimates the amount of solar energy collected, while SIMSHAC and TRNSYS have tendencies to over-estimate it. SIMSHAC and TRNSYS give a slightly better performance on the magnitude of the average simulation error.

(7) SOLSIM, SIMSHAC, and TRNSYS over-estimate the building heating load in some cases. Their average simulation-error for the winter period is less than 40,000 BTU/Day.

(8) SOLSIM over-estimates the amount of auxiliary energy supplied to the heating system more frequently than SIMSHAC and TRNSYS. Among these three models, SIMSHAC offers a slightly better result.

(9) SOLCOST has a good approach to simulate mean monthly solar radiation flux on a tilted surface. SIMSHAC and TRNSYS solar insolation models are simpler and give reasonable hourly estimates of this component. SOLSIM does not have a solar insolation model incorporated in its package, because its approach to obtain desired values of the solar radiation flux on a tilted surface is through interpolation of the direct input data.

(10) SIMSHAC is a relatively big computer program package, compared with SOLCOST, SOLSIM, and TRNSYS; however it takes less time for compiling compared with SOLCOST and SOLSIM. The average run time of all four programs is about the same order.

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Table 5

Errors in the Simulation of
Storage Tank Temperature
(°F)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	-13.7	10.2	-32.1	3.1	-17.4	7.8	-28.4	1.8	SOLSIM
	8.7	6.0	-1.5	22.8	12.6	6.7	0.0	22.6	SIMSHAC
	2.1	5.8	-12.9	11.5	24.3	11.0	0.0	37.9	TRNSYS
DECEMBER	- 7.6	6.4	-19.7	3.3	-13.5	7.3	-23.9	1.2	SOLSIM
	0.5	4.3	- 8.0	8.7	3.5	4.3	- 5.4	9.2	SIMSHAC
	1.1	1.9	- 2.9	5.3	1.0	2.5	-4.9	5.7	TRNSYS
JANUARY	- 7.0	5.3	-17.1	0.0	-9.5	6.3	-22.1	3.1	SOLSIM
	- 5.0	4.9	-19.4	0.0	1.8	4.2	- 5.2	11.3	SIMSHAC
	- 0.6	3.1	- 8.3	3.6	0.8	3.5	- 7.0	7.3	TRNSYS
FEBRUARY	- 6.0	12.4	-26.2	12.9	- 4.3	4.6	-12.7	3.1	SOLSIM
	- 1.7	8.9	-19.5	13.4	0.9	5.3	-10.0	12.0	SIMSHAC
	0.5	7.0	-11.1	13.9	2.9	5.6	-6.5	16.7	TRNSYS
WINTER average	- 8.6	8.6	-23.8	4.8	-11.2	6.5	-21.7	2.3	SOLSIM
	0.6	6.0	-12.1	11.2	4.7	5.1	- 5.1	13.7	SIMSHAC
	0.8	4.5	- 8.8	8.5	7.3	5.7	- 4.6	16.9	TRNSYS

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Table 6

Errors in the Simulation of
Enclosure Temperature
(°F)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	0.1	2.1	-4.3	4.4	-4.0	2.2	-8.9	1.0	SOLSIM
	1.7	1.1	-0.6	4.6	-1.2	1.7	-4.2	3.9	SIMSHAC
	0.1	0.9	-1.8	1.9	-2.5	1.2	-5.9	0.5	TRNSYS
DECEMBER	-0.2	1.5	-4.6	3.1	-0.1	2.4	-7.5	5.5	SOLSIM
	-0.3	1.6	-3.9	2.5	1.1	1.2	-1.7	4.0	SIMSHAC
	0.1	0.7	-1.3	2.1	0.6	1.6	-3.6	3.9	TRNSYS
JANUARY	-1.5	2.8	-7.6	5.2	-0.9	1.7	-4.5	3.4	SOLSIM
	-0.6	2.0	-5.5	4.6	0.8	1.0	-2.1	2.9	SIMSHAC
	0.1	1.7	-3.3	4.4	1.0	1.0	-1.1	3.4	TRNSYS
FEBRUARY	-2.2	2.5	-6.9	3.7	-4.3	3.1	-9.0	2.1	SOLSIM
	0.3	2.7	-4.4	6.9	0.6	3.9	-6.4	9.5	SIMSHAC
	0.1	1.6	-3.6	3.1	-0.4	1.3	-2.9	2.8	TRNSYS
WINTER average	-1.0	2.2	-5.8	4.1	-2.3	2.4	-7.4	3.0	SOLSIM
	0.3	1.9	-3.6	4.6	0.3	2.0	-3.6	5.1	SIMSHAC
	0.1	1.2	-2.5	2.8	-0.3	1.3	-3.4	2.6	TRNSYS

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Table 7

Errors in the Simulation of
Collector Inlet Temperature
(°F)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	-2.2	4.4	-25.9	-	-0.4	6.4	-20.9	2.0	SOLSIM
	0.4	1.9	- 0.1	11.9	-0.7	4.7	- 2.5	17.5	SIMSHAC
	0.9	1.2	- 2.2	10.1	1.3	7.2	- 1.7	26.2	TRNSYS
DECEMBER	-1.4	3.9	-17.9	0.0	-1.6	4.2	-17.5	0.0	SOLSIM
	-0.2	2.7	- 9.8	0.8	-0.7	1.7	- 6.6	6.2	SIMSHAC
	2.2	1.0	- 2.5	6.8	2.0	1.3	- 3.2	7.3	TRNSYS
JANUARY	-2.4	2.5	-10.5	-	-1.1	2.7	-19.3	-	SOLSIM
	-0.4	3.8	-17.3	4.6	2.0	3.2	- 7.4	21.7	SIMSHAC
	-1.1	2.5	-2.1	12.6	2.0	2.2	+	17.5	TRNSYS
FEBRUARY	-1.8	5.0	-25.4	4.1	0.9	2.2	-7.1	1.7	SOLSIM
	-1.6	4.1	-18.4	-	-1.7	2.2	-11.6	3.9	SIMSHAC
	1.1	1.9	- 4.2	11.4	-0.4	4.7	- 2.0	20.4	TRNSYS
WINTER average	-2.0	4.0	-19.9	2.0	-0.6	3.9	-16.2	1.2	SOLSIM
	-0.5	3.1	-11.4	5.7	-0.3	3.0	- 7.0	12.3	SIMSHAC
	0.8	1.7	- 2.7	10.2	1.2	3.9	- 2.3	17.8	TRNSYS

5% red.

Table 8

Errors in the Simulation of
Collector Outlet Temperature
(°F)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	0.7	5.0	-24.3	1.7	-3.9	5.9	-25.5	-	SOLSIM
	-0.8	3.1	- 1.6	11.1	1.9	4.1	+	22.0	SIMSHAC
	0.4	1.5	0.0	9.8	0.2	8.1	- 3.1	34.9	TRNSYS
DECEMBER	-1.7	4.9	-24.2	0.0	-2.0	5.3	-27.5	0.0	SOLSIM
	-1.5	2.9	- 8.9	-	- 1.6	1.3	- 8.1	2.0	SIMSHAC
	1.8	1.4	- 3.0	7.2	0.3	2.2	- 6.1	11.2	TRNSYS
JANUARY	-0.9	3.9	-19.0	0.3	- 1.5	3.5	-25.8	-	SOLSIM
	1.5	4.6	-21.9	11.6	- 0.6	1.6	- 5.7	9.5	SIMSHAC
	0.4	2.1	- 5.3	10.6	1.0	1.3	+	6.2	TRNSYS
FEBRUARY	-2.7	5.3	-27.3	-	0.4	3.2	-12.8	1.6	SOLSIM
	-0.6	5.7	-25.3	1.4	0.2	1.7	-15.5	1.6	SIMSHAC
	-2.1	2.7	-18.4	8.9	1.3	3.0	- 4.6	15.3	TRNSYS
WINTER average	-1.2	4.8	-23.7	0.7	-1.8	4.5	-22.9	0.8	SOLSIM
	-0.4	4.1	-14.4	8.0	-0.0	2.2	- 9.8	8.7	SIMSHAC
	0.1	1.9	- 6.7	9.1	0.7	3.7	- 4.6	16.9	TRNSYS

5% red.

Table 9

Errors in the Simulation of
Collector Mass Flow Rate
(lbm/min)

MONTH	TRAINING PERIODS Mean	TRAINING PERIODS STDV	TRAINING PERIODS max under-est	TRAINING PERIODS max over-est	CHECKING PERIODS Mean	CHECKING PERIODS STDV	CHECKING PERIODS max under-est	CHECKING PERIODS max over-est	MODEL
NOVEMBER	2.2	1.6	+	14.2	1.6	5.6	-0.6	21.8	SOLSIM
	-0.6	3.6	-1.5	15.6	3.5	8.3	-0.1	27.5	SIMSHAC
	-0.3	1.1	-8.4	3.8	2.1	2.3	-6.1	12.1	TRNSYS
DECEMBER	-1.1	3.0	-12.2	0.0	-1.3	3.5	-11.2	0.0	SOLSIM
	0.1	0.7	- 2.6	2.5	-0.6	2.8	-14.7	0.5	SIMSHAC
	-1.8	1.4	-6.3	6.8	0.6	1.8	- 3.7	9.8	TRNSYS
JANUARY	-0.6	1.9	-1.1	11.0	0.5	0.9	- 3.5	4.8	SOLSIM
	0.8	1.4	-3.6	8.8	1.8	1.0	- 2.3	6.1	SIMSHAC
	-0.6	3.5	-5.2	22.7	1.0	1.3	- 6.9	5.3	TRNSYS
FEBRUARY	0.1	1.7	-0.5	7.6	-3.1	2.9	- 8.2	1.4	SOLSIM
	0.4	2.8	-0.2	6.4	1.5	3.2	-10.9	10.4	SIMSHAC
	1.1	0.7	-2.7	1.2	-1.2	3.3	-14.9	3.5	TRNSYS
WINTER average	0.2	2.1	-4.6	8.2	-0.6	3.2	- 5.8	7.0	SOLSIM
	0.2	2.1	-2.0	8.3	1.6	3.8	- 7.0	11.1	SIMSHAC
	-0.4	1.7	-5.6	8.6	0.6	2.2	- 7.9	7.6	TRNSYS

Table 10

Errors in the Simulation of
Useful Energy Collected
(BTU/day)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	-1680	22801	-35882	30841	-45872	41732	-108472	-	SOLSIM
	74259	82678	+	198277	21666	15858	+	45455	SIMSHAC
	81165	72010	+	189181	80091	74178	+	191359	TRNSYS
DECEMBER	-54335	19489	-110736	-	-62980	41987	-105829	-	SOLSIM
	7080	39446	- 43509	64749	3549	11855	-10684	21333	SIMSHAC
	7498	36398	-39600	62096	28813	25836	+	81975	TRNSYS
JANUARY	-49469	24732	-71958	-	-57590	30708	-94858	-	SOLSIM
	44842	46516	-24932	81833	25991	13272	+	41762	SIMSHAC
	16896	43690	-43446	82432	29327	12678	+	42243	TRNSYS
FEBRUARY	-13161	6890	-22073	-	-41254	14259	-62644	-	SOLSIM
	53490	39214	-5332	106721	-13863	40965	-50783	47585	SIMSHAC
	30928	47219	-39901	75710	-26278	7771	-48855	-	TRNSYS
WINTER average	-29661	18478	-60162	30841	-51924	32172	-92950	-	SOLSIM
	44918	51714	-24591	112895	9336	20488	-30733	39033	SIMSHAC
	34122	49829	-40982	102354	27988	30116	-48855	105192	TRNSYS

5% red,

Table 11

Errors in the Simulation of Heating Load (BTU/day)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	-23209	8233	-33327	-	1860	31333	-26112	48860	SOLSIM
	-1716	10754	-16947	14415	-3725	21266	-35625	21036	SIMSHAC
	5487	6685	-4540	14369	-3777	30543	-49592	19144	TRNSYS
DECEMBER	16928	63974	-64133	112881	79136	36117	+	107027	SOLSIM
	-47432	94217	-188759	93714	16028	16927	-9362	35709	SIMSHAC
	4364	66409	-95250	95723	77022	22593	+	110913	TRNSYS
JANUARY	-5750	19147	-34471	21278	109666	25890	+	148502	SOLSIM
	-64375	45335	-132379	-	16660	10794	+	26672	SIMSHAC
	37281	42916	-27093	101304	142982	11743	+	160598	TRNSYS
FEBRUARY	78171	76342	+	192685	-33774	30342	-57887	11738	SOLSIM
	117432	82112	+	240601	7121	25399	-30977	43351	SIMSHAC
	18016	63044	-38205	112583	-65542	44318	-10366	935	TRNSYS
WINTER average	16535	41924	-43977	108948	39222	30921	-41999	79031	SOLSIM
	977	58105	-112695	116243	9021	18597	-25321	31692	SIMSHAC
	16287	44764	-41272	80994	37671	27299	-76429	72897	TRNSYS

5% rel.

Table 12

Errors in the Simulation of
Auxiliary Energy Supplied
(BTU/day)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	11844	16536	-1116	36649	-1032	1459	-3096	-	SOLSIM
	-372	526	-1116	-	-1032	1459	-3096	-	SIMSHAC
	-372	526	-1116	-	-1032	1459	-3096	-	TRNSYS
DECEMBER	46240	89221	-87592	122882	66618	64647	+	163589	SOLSIM
	-59247	60585	-106020	31631	(*)	(*)	(*)	(*)	SIMSHAC
	8165	40185	-49518	43948	11848	15797	+	35545	TRNSYS
JANUARY	34885	21983	+	67860	114127	76352	+	181026	SOLSIM
	-69003	69038	-172560	14260	-266	376	-800	-	SIMSHAC
	457	32375	-48869	23430	31240	-800	71090	71090	TRNSYS
FEBRUARY	49043	65392	+	147131	(*)	(*)	(*)	(*)	SOLSIM
	45333	39111	+	104250	22333	10444	+	37500	SIMSHAC
	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	TRNSYS
WINTER average	35503	48283	-44354	93630	59904	47486	-3096	172307	SOLSIM
	-20822	42315	-93232	50047	7012	4093	-1948	37500	SIMSHAC
	2750	24362	-32913	44408	11415	16165	-1948	53317	TRNSYS

57 ned.

Table 13

Errors in the Simulation of

Solar Insolation on the Tilted Surface
(BTU/SQ FT/HR)

MONTH	TRAINING PERIODS				CHECKING PERIODS				MODEL
	Mean	STDV	max under-est	max over-est	Mean	STDV	max under-est	max over-est	
NOVEMBER	-0.2	6.0	-14.2	13.1	-0.1	8.0	-18.7	13.7	SOLSIM
	32.6	56.0	-117.0	285.0	34.7	94.0	-125.0	217.0	SIMSHAC
	39.5	66.0	- 32.0	214.0	77.4	176.0	-149.0	459.2	TRNSYS
DECEMBER	- 0.1	6.9	- 16.7	13.6	- 1.3	5.4	- 15.2	13.4	SOLSIM
	45.0	102.0	- 14.3	300.0	52.9	99.8	-120.0	254.2	SIMSHAC
	15.9	50.6	- 48.0	172.8	34.8	75.2	-53.1	244.0	TRNSYS
JANUARY	- 0.4	8.3	- 15.6	14.3	- 0.3	8.1	-24.0	15.7	SOLSIM
	30.7	89.4	- 152.0	215.0	24.0	95.0	-221.5	243.7	SIMSHAC
	17.2	31.2	- 49.0	103.1	21.5	38.6	- 30.4	145.1	TRNSYS
FEBRUARY	- 0.4	6.3	- 11.0	12.5	- 0.5	6.5	- 13.3	12.2	SOLSIM
	22.5	65.4	- 26.2	186.0	32.4	97.2	- 132.0	231.6	SIMSHAC
	6.0	27.4	- 48.0	95.2	3.1	15.6	-58.2	35.4	TRNSYS
WINTER average	- 0.3	6.9	- 14.4	13.4	- 0.6	7.0	-17.8	13.7	SOLSIM
	32.7	78.2	- 77.4	246.5	-36.0	96.5	-149.6	236.6	SIMSHAC
	19.7	43.8	- 69.2	146.3	34.2	76.4	- 72.7	220.9	TRNSYS

Table 14

Summary of Computational Features
of Solar House Design Models

FEATURES	SOLCOST	SOLSIM	SIMSHAC	TRNSYS
Average Compile Time	16 sec	64 sec	78 sec	56 sec
Average run time/day	NA	5.74 sec	3.8 sec	5.42 sec
Max. Central memory Required	67K	48 K	80 K	56 K
Programming language	FORTRAN & COMPASS	FORTRAN & COMPASS	FORTRAN	FORTRAN
Model Structure	Rigid	Rigid	Overlay + Modular	Modular
Weather Input Form	Tape	Tape	Tape	Cards

E. <u>Suggested Changes in MITAS, SOLCOST, and SOLSIM</u>

The following suggestions are based on SEEC's experience in attempting to make MITAS, SOLSIM, and SOLCOST operational on the CDC-6400 computing system at Colorado State University.

A. Modifications to the Preprocessor

1. Correct the octal constants (suffix of B instead of prefix of O)
2. Correct the end-of-file function. It is nonstandard in the present version.
3. Correct transfer of control to statements within the range of a DO loop from outside the loop, as these are also nonstandard in the present configuration.
4. Correct the use of STOP and RETURN statements in the overlays.
5. Correct OVERLAY and BLANK COMMON statements so that the overlays will be loaded into the first word of blank common. This is also nonstandard in the current version.
6. The use of the timing function, SECOND, is also nonstandard and should be corrected.
7. Use of rountines such as ALTFILE is dependent upon specific characteristics of the compiler, run-time I/O routines, and operating system interfaces. This should be corrected.

B. Modifcations to the Library

1. Correct the use of the GO TO statement in conjunction with the use of the ASSIGN statement; this is nonstandard FORTRAN
2. Correct the transfer of Control to statements within the range of a DO LOOP from outside the loop.

3. Correct the Octal Constants (suffix of B instead of prefix of 0).
4. Correct UNIT and EOF functions to be compatible with other systems.
5. Correct functions using Double Precision variables to use Double Precision functions as well.
6. Correct or rewrite all assembly language routines to accept FTN subroutine linkage as well as to adapt to other systems. This was a major effort, and was very nonstandard.
7. Correct all routines to use variable unit numbers for I/O operations so that unsatisfied externals were not produced. This was because of use of routine ALTFILE.
8. Correct the UNIT function in the SOLCOST library..

C. Non-Standard Items In MITAS

1. Use of Assembly language routines in library.
2. Use of Octal Constants for masking - especially characters.
3. Use of Octal Constants for representing characters. (Depending on CDC Character set as well as six bits per character).
4. Use of Non-Standard fortran (Assign statements, function, etc.)
5. LOADING of overlays.
6. Plotting routines in library, except CDC plotting routines.
7. Must have some library utility to satisfy all the externals.
8. Declaration of files is local to CDC fortran.

IV. CONCLUSIONS AND RECOMMENDATIONS

The techniques that have been developed by SEEC during the conduct of this research program may be quickly and easily applied to determine quantitative results concerning the performance of any solar system simulation program. These techniques were applied to determine the relative performance of SOLSIM, TRNSYS, and SIMSHAC when used to model CSU SOLAR I. This system was selected for validation purposes because of the availability of the performance measurements for the system in operation at CSU SOLAR I. Specific quantitative results were presented in Tables 5 - 14. From the results presented in these tables it is apparent that TRNSYS and SIMSHAC are fairly comparable in their performance measures; these are followed closely by SOLSIM. However, the differences are relatively insignificant for this particular case. It is apparent that in some cases one program is superior to the others but the situation changes with respect to which state variable is being examined. It should be pointed out, however, that the radiation values on the tilted surface used in program SOLSIM were interpolated from the measured data. This is not a fair comparison with the other two programs since the other two programs calculated the radiation on the tilted surface from observed values on the horizontal surface. This is the more common situation since most designers will not have available to them radiation values at the desired tilt angles.

It is recommended that the comparison between the programs be extended to additional building types and more locations. SEEC has recently received some data on a commercial office building and is in the process of validating the simulation programs for that specific building and its location. SEEC has also requested data from several other sources and plans to continue the validation studies as the new data sets become available. It is further recommended that consideration be given to the suggested modifications to SOLSIM and SOLCOST that were presented in Section III.3. These are of particular importance if these programs are to be transported to other computing centers.

Finally, it is recommended that SOLCOST be applied to some sample case studies. SEEC has made arrangements with personnel from Port Hueneme, California, to apply SOLCOST to a building of their design for which they will provide the completed input data forms as suggested by Martin Marietta. SEEC will transcribe these forms to the input required to run SOLCOST and will then execute SOLCOST and send the results to the customer. This experiment should be repeated a number of times in order to assist in eliminating the possible bugs in program SOLCOST. We believe that if SOLCOST were to be released at the present time and were to receive widespread dissemination then there would be many users who would attempt to apply it to system types for which it has not been adequately validated.

The above conclusions and recommendations have been of a general nature. More specific remarks are presented below.

Because of the constraint on SOLSIM operation (i.e. for solar house heating only), and the limited amount of solar house data available (i.e. only one set of SOLAR I Data), only tentative conclusions could be made relative to the behavior of the models under consideration.

(1) The SOLCOST approach to compute the life cycle cost of a solar energy system is excellent. It gives the user all the necessary information pertaining to the economic analysis of the structure which is to be built (see sample output of SOLCOST); hence, the design purpose of SOLCOST is very suitable for a large class of users.

(2) As already mentioned in the previous chapter, SOLCOST uses only the collector and the storage tank in the computation of the life cycle cost of a solar house system. The bypass of other subsystem components in this evaluation process can lead to too optimistic conclusions about the system under study.

(3) SOLCOST and SOLSIM are hard to use by average users because of their rigid structures and machine dependent program language, and also because of the required knowledge of thermal network systems of MITAS.

(4) The SOLCOST approach to compute the mean monthly solar radiation flux on a tilted surface, and also to the sizing of the collector and the storage tank based on life cycle cost analysis is very good, which makes the model more attractive in system design analysis. However, it does not have the capability of sizing the other subsystem components, which are also important in the determination of the system efficiency and system life.

(5) For engineering-type users, it seems that SOLSIM has a good performance in the simulation of the collector operation, especially in the timing of the collector mass flow rate, compared with SIMSHAC and TRNSYS, which show some delays in the simulation of the collector response.

(6) Between the three engineering-type models: SOLSIM, SIMSHAC, and TRNSYS, the last two offer more advantages compared with the first one,

namely, a flexible model structure, a less machine dependent program package, less input data requirements, and less compiling time.

(7) After calibration in the training periods, all three models: SOLSIM, SIMSHAC, and TRNSYS give reasonable simulation results for each component of the solar house SOLAR I heating system.

In summary,

SOLCOST should be a very good design model for solar energy systems if one could:

- include other subsystem components into the model for the analysis of the life cycle cost of a given system, and also for the purpose of automatic sizing of all these components;

- rewrite the program using modular concepts to make the model flexible and adaptable to other solar energy system structures;

- correct all non-standard FORTRAN statements in the computer program package to make the model less machine dependent;

- simplify or modify the input data requirement to make the model a practical design tool for a large class of users.

SOLSIM could become a very good transient energy system analysis model if one could:

- rewrite the program using modular concepts to make the model flexible and adaptable to other solar energy system structures;

- correct all non-standard FORTRAN statements in the computer program package to make the model usable by average engineering-type users;

- include a solar insolation model into the package to make it less dependent on the direct solar input data.

SIMSHAC could become a very good design and analysis tool for solar energy systems if one could:

- build into the package all control routines which reflect the existing types of controllers in use at various solar energy systems in the United States, and let the user just select the one he likes the best and incorporate it into the system configuration;

- incorporate the life-cycle cost analysis component into the package for design cost evaluation;

- modify the package to include the automatic selection of subsystem components feature for optimal solar energy systems design.

TRNSYS could also become an excellent design and analysis tool for solar energy sytems if one could:

-modify the control model to include more efficient control techniques for energy systems control;

- modify the economic analysis component to give it the capability of conducting a complete life-cycle cost analysis for a given solar energy system.

- modify the package to include the automatic selection of subsystem components feature for optimal solar energy systems design.

Thus, actually no one of the four models under validation is an ideal design and analysis tool for solar energy systems users yet. The best model could be approached in two different ways: either by modifying one of the models discussed above, after a careful selection based on all aspects of the model validation process and using more solar data obtained at various locations in the United States, or by developing a new model which has all the interesting features of the existing models and eliminates all the existing drawbacks.

The following recommendations are proposed:

Recommendation 1: Reconduct the validation of the above models and, also, other solar insolation models with data collected from various locations in the United States. By this means, one can assess the "goodness" and the universality of a solar energy model and be able to select the best model for further improvement and adaptation.

Recommendation 2: A modification of SOLCOST and SOLSIM programs as discussed above is desirable for an accurate cost analysis and design evaluation of solar energy systems.

Recommendation 3: A modification of SIMSHAC or TRNSYS programs (since the two models have many features in common) as discussed above is also desirable for a quick analysis and design evaluation of solar energy systems by average users.

REFERENCES

I. Reports, Technical Manuals, Theses, Books

(1) SOLCOST USER's MANUAL - Martin Marietta Co., Engineering Department, Denver Division, Sept. 1, 1976.

(2) INTRODUCTION TO SOLSIM THERMAL MODELS - Martin Marietta Co., Engineering Department, Denver Division, (Draft Copy) September, 1976.

(3) MITAS - Technical Manual, M-76-2 - Martin Marietta Co., Engineering Department, Denver Division, May 1976.

(4) TRNSYS, A Transient Simulation Program - Report 38, Solar Energy Laboratory - University of Wisconsin - Madison, Madison, Wisconsin 53706, November 1975.

(5) Documentation and Validation of SIMSHAC - Dwight E. Hull, III, unpublished M.S. Thesis - Department of Mechanical Engineering, Colorado State University, Fort Collins, Colorado 80521, Spring 1976.

(6) The Statistical Analysis of Time Series - Anderson, T.W. - John Wiley & Sons, Inc., 1958.

(7) Spectral Analysis and Its Applications - Jenkins, G.M. and Watts, D.G. - Holden Day, 1969.

(8) Design and Construction of a Residential Solar Heating and Cooling System.- Report NSF/RANN/SE/GI-40457/PR/74/2 - Colorado State University, Fort Collins, Colorado and The University of Wisconsin, Madison, Wisconsin, August 1974.

II. Technical Papers

(9) Butz, L.W., Beckman, W.A., and J.A. Duffie, 1974 - Simulation of a Solar Heating and Cooling System - Solar Energy, Vol 16, 129-136, Pergamon Press.

(10) Klein, S.A. et. al., 1975 - A Method of Simulation of Solar Processes and Its Application - Solar Energy, Vol 17, 29-37, Pergamon Press.

(11) Winn, C.B. and G.R. Johnson, 1974 - Dynamic Simulation for Performance Analysis of Solar Heated and Cooled Buildings - ASME, Winter Annual Meeting, New York, N.Y., Nov. 17-22.

(12) Winn, C.B., Johnson G.R., and J.B. Moore, 1975 - Optimal Utilization of Solar Energy in Heating and Cooling of Buildings - International Solar Energy Society, Fort Collins, Colorado.

(13)Ikeda, S., Ochiai, M. and Sawaragi, Y., 1976 - Sequential GMDH Algorithm and Its Application to River Flow Prediction - IEEE Trans. on Systems, Man, and Cybernetics, Vol SMC-6, No. 7, pp 473-479.

APPENDIX A

METHODOLOGY

A1. DATA FILTERING AND RECORD EXTENSION

In order to carry out a filtering process on solar radiation data, one should be able to, first, identify the various components which constitute this time-series, and, then, construct an optimal filter to separate these components or eliminate those corresponding to system noise.

One technique to be used in the identification of various components of a time-series is "Spectral Analysis".

Data treatment by this technique can be illustrated as in Figure A-1. One can find the basic theory and computation procedure in Anderson (1958) and Jenkins and Watts (1969).

All the various algorithms proposed in the past to calculate the spectrum of a time-series might be grouped into two large families:

(1) One which uses the Fast Fourier Transform (FFT), and

(2) One which computes the spectrum from the autocovariance function. The latter approach allows one to have a better resolution.

In this case, the estimator of the spectrum PS(f) equals the Fourier transform of the m first terms of the autocovariance function $C_{xx}(k)$

$$PS(f) = 2\left[C_{xx}(0) + 2\sum_{k=1}^{m-1} C_{xx}(k)w(k)\cos 2\pi fk\right], \quad 0 \leq f \leq \tfrac{1}{2} \quad (1)$$

where

$$C_{xx}(k) = \frac{1}{N} \sum_{t=1}^{N-k} (x(t)-\bar{x})\,(x(t-k)-\bar{x}), \quad 0 \leq k \leq m-1 \quad (2)$$

w(k) is a spectral window used to minimize the fluctuations of the estimator. For this study, the Tukey-Hanning window will be used, which has the following form:

$$w(k) = \begin{cases} \tfrac{1}{2}\left[1+\cos(\pi k/m)\right] & , |k| \leq m \\ 0 & , |k| > m \end{cases} \quad (3)$$

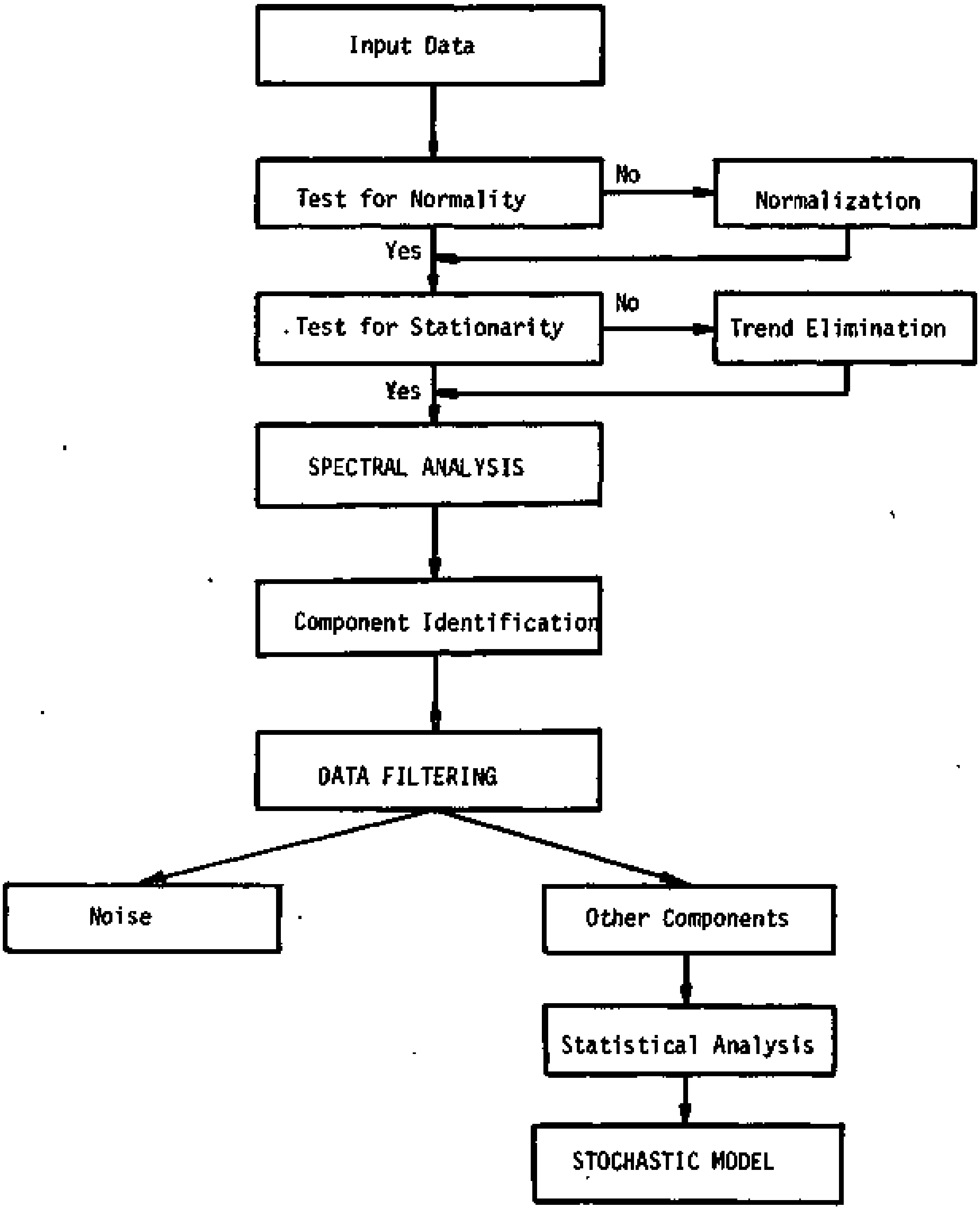


Figure A.1 : Flow-chart of Data Treatment by Spectral Analysis.

The selection of m is a very delicate task. We know that (Jenkins and Watts, 1969)

variance x bandwidth = constant.

For the Tukey-Hanning window, the bandwidth has the following value

$$B = \frac{1.333}{m} , \qquad (4)$$

and the variance

$$var = \frac{0.75m}{N} , \qquad (5)$$

where N is the length of the series.

Knowing the existence of cyclic components in the solar radiation data, one might use various moving average filters to decompose the observed data into:

(1) a short term cyclic component

(2) a long term cyclic component, and

(3) a noise, or residual, component.

From this analysis, one might, then, build up a stochastic model for solar radiation, which will be used in filling in missing radiation records or for record extensions.

For this objective, one might use an autoregressive model of the form

$$X(t) - \mu = \alpha_1(X(t-1)-\mu) + \alpha_2(X(t-2)-\mu) + \cdots + \alpha_m(X(t-m)-\mu) + Z'(t) \qquad (6)$$

where m is the order of the process; $\alpha_1, \alpha_2, \ldots \alpha_m$ are process parameters, and $Z(t)$ is a white noise process.

Using the maximum likelihood approach, one can estimate the parameters $\alpha_1, \alpha_2, \ldots, \alpha_m$ by

$$C_{xx}(j) = \alpha_1 C_{xx}(j-1) + \alpha_2 C_{xx}(j-2) + \cdots + \alpha_m C_{xx}(j-m) \qquad (7)$$

where $C_{xx}(j)$ is the autocovariance function.

If one uses the auto-correlation function, eqn.(7) becomes

$$r_{xx}(j) = \alpha_1 r_{xx}(j-1) + \alpha_2 r_{xx}(j-2) + \cdots + \alpha_m r_{xx}(j-m) \qquad (8)$$

with

$$r_{xx}(j) = C_{xx}(j)/C_{xx}(0) \quad . \qquad (9)$$

For solar radiation data, m might have the value of 1 or 2. If m equals 1, eqn.(8) is reduced to

$$\alpha_1 = r_{xx}(1) \qquad (10)$$

and if m equals 2,

$$\alpha_1 = \frac{r_{xx}(1)\,(1-r_{xx}(2))}{1-r_{xx}^2(1)} \qquad (11)$$

$$\alpha_2 = \frac{r_{xx}(2)-r_{xx}^2(1)}{1-r_{xx}^2(1)} \quad . \qquad (12)$$

The use of statistical filters for filling-in missing data or for record extension can be formulated as follows:

(1) It was assumed that several hours correlation existed between various weather variables(i.e., solar radiation, air temperature, humidity, wind velocity, and dew point temperature). Plots of the auto-correlation and cross-correlation functions can be used to ascertain the actual number of hours to be included in the following model.

(2) A set of stochastic linear difference equations of multiple order may be used to express the dynamics of the weather variables, i.e.,

Solar radiation:

$$\begin{aligned} s_{k+1} = {} & a_{11}\, s_k + a_{12}\, s_{k-1} + \cdots + a_{1n}\, s_{k-n+1} \\ & + b_{11} t_k + b_{12}\, t_{k-1} + \cdots + b_{1n} t_{k-n+1} \\ & + c_{11}\, h_k + c_{12} h_{k-1} + \cdots + c_{1n} h_{k-n+1} \\ & + d_{11}\, v_k + d_{12} v_{k-1} + \cdots + d_{1n}\, v_{k-n+1} \\ & + e_{11}\, w_k + e_{12} w_{k-1} + \cdots + e_{1n} w_{k-n+1} + u_{1k} \end{aligned} \quad (13)$$

where

s_k, t_k, h_k, v_k, and w_k are, respectively, the k^{th} hour solar radiation, air temperature, humidity, wind velocity, and dew point temperature;

u_{1k} is a "noise" sequence which takes account of the modeling error and the actual noise in the data;

$a_{1j}, b_{1j}, c_{1j}, d_{1j}, e_{1j}$, $j = 1, \cdots, n$ are the unknown parameters of the solar radiation model (1) ; and n is the number of hours for which correlation exists.

Air temperature

$$\begin{aligned} t_{k+1} = {} & a_{21} s_k + a_{22} s_{k-1} + \cdots + a_{2n}\, s_{k-n+1} \\ & + b_{21} t_k + b_{22} t_{k-1} + \cdots + b_{2n} t_{k-n+1} \\ & + c_{21} h_k + c_{22} h_{k-1} + \cdots + c_{2n} h_{k-n+1} \\ & + d_{21} v_k + d_{22} v_{k-1} + \cdots + d_{2n} v_{k-n+1} \\ & + e_{21} w_k + e_{22} w_{k-1} + \cdots + e_{2n} w_{k-n+1} \end{aligned} \quad (14)$$

where

$a_{2j}, b_{2j}, c_{2j}, d_{2j}, e_{2j}$, $j = 1, \ldots, n$ are the unkown parameters of the air temperature model (14).

Humidity:

$$\begin{aligned} h_{k+1} = {} & a_{31}s_k + a_{32}s_{k-1} + \cdots + a_{3n}s_{k-n+1} \\ & + b_{31}t_k + b_{32}t_{k-1} + \cdots + b_{3n}t_{k-n+1} \\ & + c_{31}h_k + c_{32}h_{k-1} + \cdots + c_{3n}h_{k-n+1} \\ & + d_{31}v_k + d_{32}v_{k-1} + \cdots + d_{3n}v_{k-n+1} \\ & + e_{31}w_k + e_{32}w_{k-1} + \cdots + e_{3n}w_{k-n+1} + u_{3k} \end{aligned} \tag{15}$$

where

a_{3j}, b_{3j}, c_{3j}, d_{3j}, e_{3j}, $j=1,\ldots,n$, n are the unknown parameters of the humidity model (15).

Wind Velocity

$$\begin{aligned} v_{k+1} = {} & a_{41}s_k + a_{42}s_{k-1} + \cdots + a_{4n}s_{k-n+1} \\ & + b_{41}t_k + b_{42}t_{k-1} + \cdots + b_{4n}t_{k-n+1} \\ & + c_{41}h_k + c_{42}h_{k-1} + \cdots + c_{4n}h_{k-n+1} \\ & + d_{41}v_k + d_{42}v_{k-1} + \cdots + d_{4n}v_{k-n+1} \\ & + e_{41}w_k + e_{42}w_{k-1} + \cdots + e_{4n}w_{k-n+1} + u_{4k} \end{aligned} \tag{16}$$

where

a_{4j}, b_{4j}, c_{4j}, d_{4j}, e_{4j}, $j = 1, \ldots, n$ are the unknown parameters of the wind velocity model (16).

Dew Point Temperature

$$\begin{aligned} w_{k+1} = {} & a_{51}s_k + a_{52}s_{k-1} + \cdots + a_{5n}s_{k-n+1} \\ & + b_{51}t_k + b_{52}t_{k-1} + \cdots + b_{5n}t_{k-n+1} \\ & + c_{51}h_k + c_{52}h_{k-1} + \cdots + c_{5n}h_{k-n+1} \\ & + d_{51}v_k + d_{52}v_{k-1} + \cdots + d_{5n}v_{k-n+1} \\ & + e_{51}w_k + e_{52}w_{k-1} + \cdots + e_{5n}w_{k-n+1} + u_{5k} \end{aligned} \tag{17}$$

where

a_{5j}, b_{5j}, c_{5j}, d_{5j}, e_{5j}, $j = 1, \ldots, n$ are the unknown parameters of the dew point temperature model (17).

(3) let:

$$\underline{y}(k) \triangleq [s_{k+1}, t_{k+1}, h_{k+1}, v_{k+1}, w_{k+1}]^T$$

$$H(k) \triangleq \begin{Bmatrix} \underline{s}_k\underline{t}_k\underline{h}_k\underline{v}_k\underline{w}_k & & & & 0 \\ & \underline{s}_k\underline{t}_k\underline{h}_k\underline{v}_k\underline{w}_k & & & \\ & & \underline{s}_k\underline{t}_k\underline{h}_k\underline{v}_k\underline{w}_k & & \\ & & & \underline{s}_k\underline{t}_k\underline{h}_k\underline{v}_k\underline{w}_k & \\ 0 & & & & \underline{s}_k\underline{t}_k\underline{h}_k\underline{v}_k\underline{w}_k \end{Bmatrix}$$

where:

$$\underline{s}_k \triangleq [s_k, s_{k-1}, \ldots, s_{k-n+1}]$$

$$\underline{t}_k \triangleq [t_k, t_{k-1}, \ldots, t_{k-n+1}]$$

$$\underline{h}_k \triangleq [h_k, h_{k-1}, \ldots, h_{k-n+1}]$$

$$\underline{v}_k \triangleq [v_k, v_{k-n}, \ldots, v_{k-n+1}]$$

$$\underline{w}_k \triangleq [w_k, w_{k-n}, \ldots, w_{k-n+1}]$$

The state-vector is defined as a 25n - dimensional vector of the unkown parameters:

$$\underline{x}(k) \triangleq [A_1, B_1, C_1, D_1, E_1, A_2, B_2, C_2, D_2, E_2, \ldots, A_5, B_5, C_5, D_5, E_5]^T$$

where:

$$A_i \triangleq [a_{i1}, a_{i2}, \ldots, a_{in}]$$

$$B_i \triangleq [b_{i1}, b_{i2}, \ldots, b_{in}]$$

$$C_i \triangleq [c_{i1}, c_{i2}, \ldots, c_{in}]$$

$$D_i \triangleq [d_{i1}, d_{i2}, \ldots, d_{in}]$$

$$E_i \triangleq [e_{i1}, e_{i2}, \ldots, e_{in}] \quad ; i = 1,2,3,4,5,$$

and, lastly, the "noise" vector $\underline{u}$ (k) is defined as

$$\underline{u}(k) \triangleq [u_{1k}, u_{2k}, u_{3k}, u_{4k}, u_{5k}]^T \quad ;$$

the covariance matrix R(k) of this "noise" is assumed to be a 5 X 5 diagonal matrix having R_{1k}, R_{2k}, R_{3k}, R_{4k}, R_{5k} as the diagonal elements. The R_{ik} (i = 1,2,3,4,5) are the variances of the "noise" sequences u_{ik} which are assumed to be zero mean white gaussian.

Thus, equations (13) - (17) can now be written together as:

$$\underline{y}(k) = H(k)\, \underline{x}\,(k) + u(k). \qquad (18)$$

(4) Assume that the unkown parameters are slowly varying then we may represent the state by a random-walk model, i.e.,

$$\underline{x}\,(k+1) = \underline{x}\,(k) + \underline{\eta}\,(k) \qquad . \quad (19)$$

where $\underline{\eta}(k)$ is another "noise" sequence vector which is zero mean white gaussian and having covariance matrix Q(k).

(5) If we assume that the initial state $\underline{x}(0)$ is given, which is an independent white gaussian sequence with a covariance matrix P(0), then the following adaptive filter can be used to estimate the state (i.e., the unknown parameters) of the model (18) - (19):

$$\hat{\underline{x}}\,(k|k) = \hat{\underline{x}}\,(k-1|k-1) = K(k)[[\underline{y}(k) - H(k)\,\hat{\underline{x}}\,(k-1|k-1)]$$

$$K(k) = \underline{P}\,(k\,|k-1)\, H^T(k)\, [\hat{H}(k)\, \underline{P}(k|k-1)\, H^T(k) + \hat{R}(k-1|k-1)]^{-1}$$

$$\underline{P}(k|k-1) = P(k-1|k-1) + \hat{Q}\,(k-1|k-1)$$

$$P(k|k) = [I-K(k)\, H(k)]\, P(k|k-1)$$

$$\hat{R}(k|k) = \frac{1}{k}\,[(k-1)\,\hat{R}(k-1|k-1) + \hat{\underline{y}}(k)\hat{\underline{y}}^T(k) - H(k)P(k|k-1)H^T(k)]$$

$$\hat{Q}(k\ k) = \frac{1}{k}\,[(k-1)\hat{Q}(k-1\,|k-1) + K(k)\hat{\underline{y}}(k)\hat{\underline{y}}^T(k)K^T(k) + P(k|k) - P(k-1|k-1)]$$

where

$$\hat{\underline{y}}(k) = \underline{y}(k) - H(k)\hat{\underline{x}}(k-1|k-1).$$

After obtaining the best estimates for the unknown coefficients based on available records, the equations (13) - (17) can now be used for prediction, i.e., get the best estimates of s_{k+1}, t_{k+1}, h_{k+1}, v_{k+1}, and w_{k+1} based on

the observations $s_k, s_{k-1} \ldots s_{k-n+1}, t_k, t_{k-1} \ldots, t_{k-n+1}, h_k, h_{k-1}, \ldots,$
$v_k, v_{k-1}, \ldots v_{k-n+1}, w_k, w_{k-1}, \ldots, w_{k-n+1}.$

Besides the above-mentioned approaches, the following are two other interesting methods for solving the data analysis and missing information problem, namely Pattern Recognition and Group Method of Data Handling (GMDH).

(1) Pattern Recognition Approach

This approach is very convenient for comparative data analysis. Based on a selected distance function (i.e., Bhattacharya distance), the following two types of analysis can be performed:

Discriminant analysis: for outliers identification; and

Clustering analysis: for group association investigation.

One approach to clustering of data points that one might use is centroid clustering, where the distance from the data point to the cluster center is chosen as a criterion for grouping. The data point will be assigned to the cluster having minimum distance which is also less than a certain threshold. Using different thresholds, a two-dimensional representation of the n-dimensional space (through nonlinear mapping) of data points will be as shown in Figure A-2. The dashed lines enclose points that clustered together first, while the solid lines enclose later results which produced larger clusters. When examining Figure A-2 the attention of the analyst will be immediately drawn to the isolated points having off-nominal behavior. These points will later be deleted from the data set.

(2) Group Method of Data Handling (GMDH)

The GMDH is based on the self-organization principle which originated from Rosenblatt's perception concept. This technique was first proposed by A.G. Ivakhnenko for dealing with complex nonlinear systems with limited

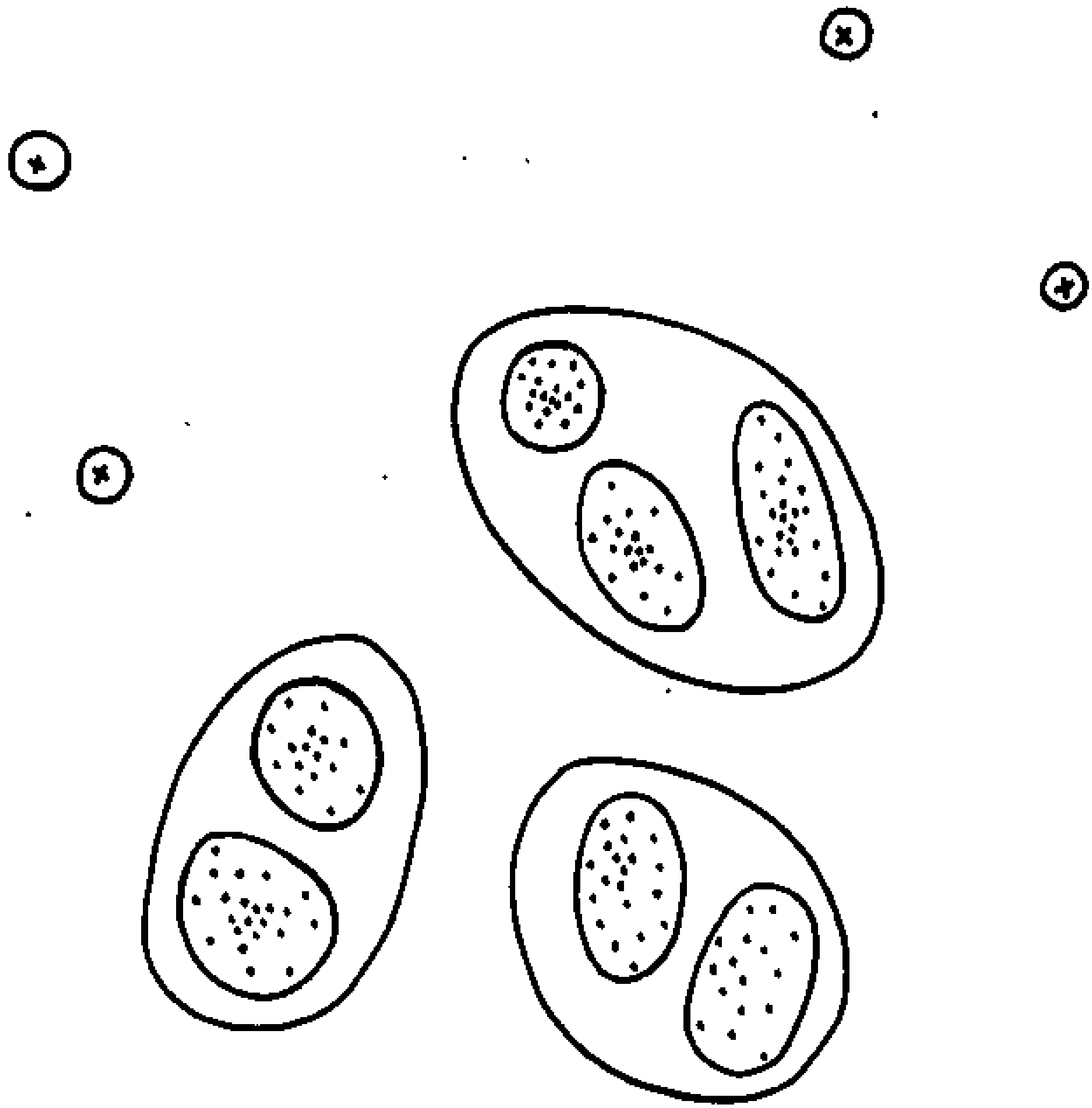


Figure A-2

record length of input-output data.

By the use of this method, the following nonlinear input-output relation is self-learned:

$$y = f(x_1, x_2, \ldots x_n) \qquad (2)$$

where y is an output of interest, x_i ($i = 1, 2, \ldots, n$) are inputs to the nonlinear system, and f(x) is assumed to be represented by a Kolmogorov-Gabor polynomial or a Volterra series for the stationary stochastic process under study:

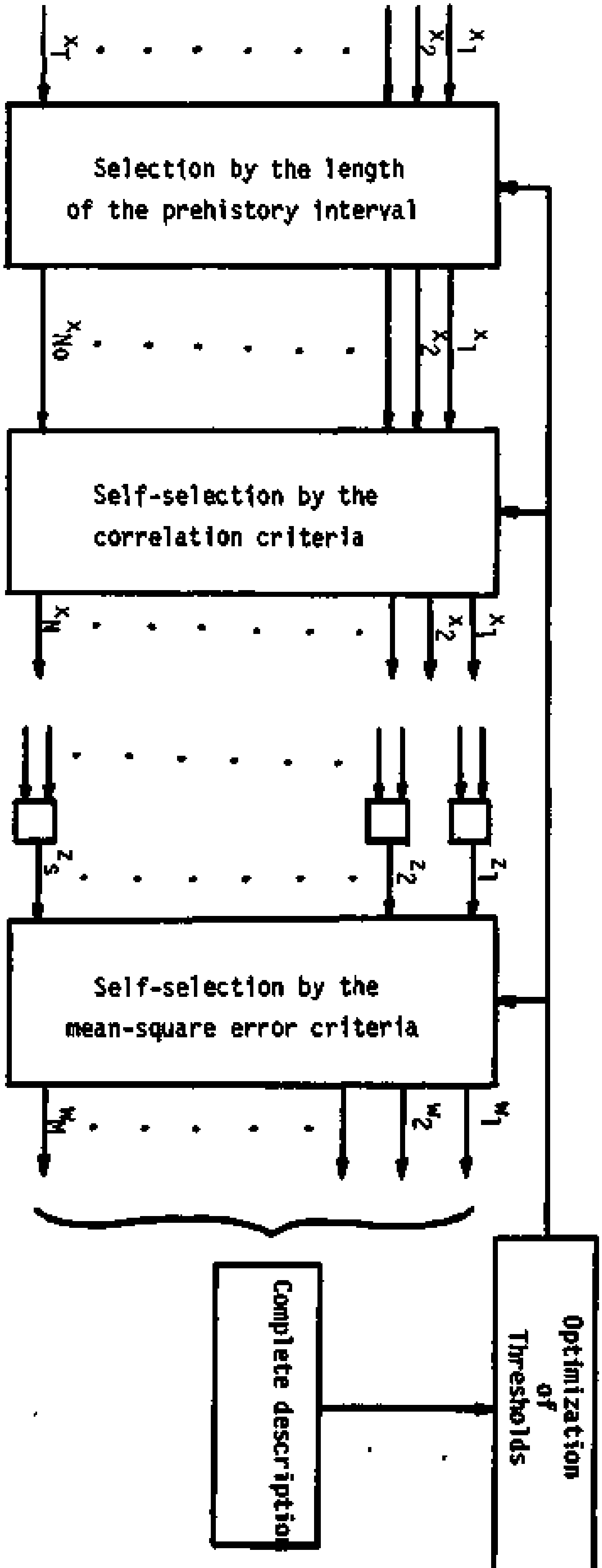
$$y = a_0 + \sum_i a_i x_i + \sum_i \sum_j a_{ij} x_i x_j + \sum_i \sum_j \sum_k a_{ijk} x_i x_j x_k + \ldots$$

The structure of the basic GMDH proposed by Ivakhnenko is shown in Figure A-3, which illustrate a multilayered perceptron type: the inputs from the previous layer are used for constructing all possible combinations of two inputs. Partial descriptions are chosen by the same thresholds, and then the process proceeds to the next layer.

A sequential GMDH algorithm to stabilize the structure of the prediction model, using a sequential least-squares technique to update the partial descriptions in each layer, was recently proposed by Saburo Ikeda et al. (July 1976), and applied to the construction of a nonlinear prediction model of river flow.

Thus, using the GMDH approach one can learn the structure of a complex nonlinear system (i.e., solar house) from input-output data, and then use the obtained relation for filling-in missing data or record extension.

Another simpler technique for solving the missing information problem is the use of a multivariate statistical approach.



$(N_0 > N > M)$

FIGURE A-3

Suppose that we have a vector $\underline{x}$ of p components following a multivariate normal distribution

$$\underline{x} \simeq N(\S_i, \Sigma);$$

the subscript i implies that the vector $\underline{x}$ comes from the i^{th} of a set of normal populations with different means but common covariance matrix . Let the vector $\underline{x}$ be partitioned into two subvectors: $\underline{x}^{(1)}$ of order q is observed; $\underline{x}^{(2)}$ of order p-q is missing. The best predictor of $\underline{x}^{(2)}$ is

$$\hat{\underline{x}}^{(2)} = \S_i^{(2)} + \Sigma_{21} \Sigma_{11}^{-1} (\underline{x}^{(1)} - \S_i^{(1)})$$

where

$$\S_i \triangleq \begin{Bmatrix} \S_i^{(1)} \\ \\ \S_i^{(2)} \end{Bmatrix} \quad \text{and } \Sigma \triangleq \begin{Bmatrix} \Sigma_{11} & \Sigma_{12} \\ \\ \Sigma_{21} & \Sigma_{22} \end{Bmatrix}$$

The vector of errors of prediction by $\hat{\underline{x}}^{(2)}$ has zero mean and covariance matrix $\Sigma_{22} - \Sigma_{21} \Sigma_{11}^{-1} \Sigma_{12}$.

A2. DATA SELECTION FOR MODEL CALIBRATION AND MODEL VALIDATION

The most important point in the selection of data for model calibration and, later, for model validation is that data used in designing the model should not be used in validating it. Thus, given a data set, after the processing stage mentioned in Appendix A1, one needs to divide the data set into two separate sequences: a training set for model calibration purposes and a checking set for model validation purposes. Now, the following question arises: "How to select the training and checking sequences from a given data set?"

To solve this problem, the following argument would be useful. In the training sequence one must include points that are furthest apart and most remote from the other points to take into account all process characteristics in the calibration phase. On the contrary, the checking sequence must include points that represent the average process characteristics; i.e., points that cluster closely to each other. Thus, in order to divide the data set into training and checking sequences, one needs to have a measure of separation which can be any distance measure from the mean. The simplest normalized statistical distance from the mean is the variance, defined by

$$D^2 = \left\{\frac{X_1 - \overline{X}_1}{\overline{X}_1}\right\}^2 + \left\{\frac{X_2 - \overline{X}_2}{\overline{X}_2}\right\}^2 + \cdots + \left\{\frac{X_n - \overline{X}_n}{\overline{X}_n}\right\}^2$$

Points with a large variance must then be included in the training sequence, and points with a small variance must be included in the checking sequence.

A3. MODEL VALIDATION PACKAGE

This computer program package was developed to assist users in the analysis of simulated values and simulation residuals of subsystem components for system model validation. It constitutes one step in the validation process of solar house design models, namely the analysis of model performance. The outputs of each simulation model, i.e., the simulated values of the states and simulation residuals, are read into the validation program and the following steps are successively carried out:

(1) Plot (optional) the simulated values versus the observed values for each subsystem component;

(2) Compute the basic statistics, i.e., mean, standard deviation, third and fourth moments about the mean, minimum and maximum values, and correlation coefficients between simulated values and observed values for each subsystem component;

(3) Compute the same basic statistics for subsystem simulation residuals;

(4) Compute and plot the relative and cummulative frequency distributions for values of each subsystem component;

(5) Reform clustering analysis of simulated values and simulation residuals to examine for possible systematic errors in the model;

(6) Output presentation for further analysis.

The flowchart in Figure A-4 gives the basic ideas of how this model validation package was set-up. Sample results are listed in Appendix B for each model under study.

A-16

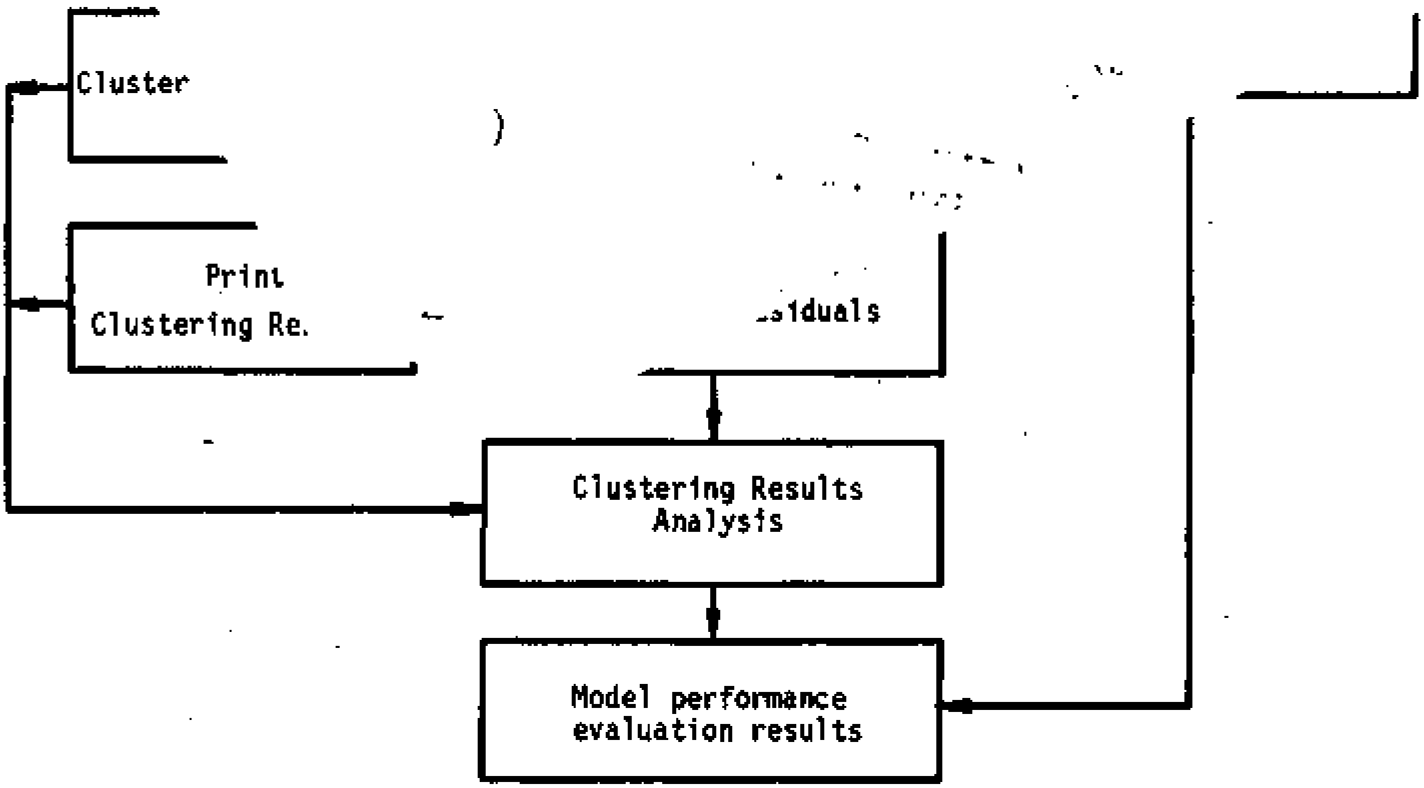


FIGURE A-4: Flowchart of the Model Validation Package.

A4. PROBLEM OF CHOOSING AMONG COMPETING DIGITAL SIMULATION MODELS

Given a number of digital simulation models of a complex solar energy system. What kind of information should one use to pick out the best model for use in simulating that system. The criteria for "best" simulation model for system design have been discussed in Chapter 3 of this report; following are two approaches for systematic selection among competing digital simulation models based on their simulation performances.

1. Bayesian discrimination

A digital simulation model may be thought of as a device for producing an ordered set of vectors, $X_1, X_2, \ldots, X_N$. The vector X_i ($i = 1, 2, \ldots, N$) may be taken to represent a complete description of the "state" of the simulation model after the i^{th} "event" has occurred to change the previous state. The X_i are considered to be random variables. Associated with model $\bar{M}^j$ is a sequence of random vectors $X_1^j, X_2^j, \ldots, X_N^j$, such that the distribution of $X_1^j, X_2^j, \ldots, X_{i-1}^j$ depends only on the previously realized values of $X_1^j, X_2^j, \ldots, X_{i-1}^j$.

Suppose simulation models $\bar{M}^1, \bar{M}^2, \ldots, \bar{M}^j, \ldots, \bar{M}^k$ are proposed to explain the fact that the underlying time-series random variables $Y_1, Y_2, \ldots, Y_N$ took on the observed values $y_1, y_2, \ldots, y_N$. The discrimination problem may then be started by assuming that exactly one model $\bar{M}^j$ is correct, and based on the probability $P(\bar{M}^j)$, $j = 1,2,\ldots,k$, for making decisions. For the purposes of Bayesian analysis, this probability may be considered either prior to or posterior to information contained in the empirical time-series data. If we let

$$S_h = \left\{Y_1 = y_1 \text{ and } Y_2 = y_2 \text{ and } \ldots \text{ and } Y_h = y_n\right\} ; \; h = 1,2,\ldots, N$$

be the proposition that the underlying (correct) time-series phenomenon $Y_1, Y_2, \ldots, Y_h$ has produced the first h empirically observed values $y_1, y_2, \ldots, y_h$, we may write the desired posterior probability via Bayes' theorem

$$P(A^j \mid S_h) = \frac{P(S_h \mid A^j)\, P(A^j)}{\sum_{j=1}^{k} P(S_h \mid A^j)\, P(A^j)} \qquad h = 1, 2, \ldots, N. \qquad (1)$$

The evaluation procedure will be as follows: first, decide on the a priori probabilities for all candidate models; second, estimate the $P(S_n \mid A^j)$ by simulation using these candidate models; and third, calculate the a posteriori probability of each candidate model using expression (3). The discrimination then will be based on the probability $P(A^j \mid S_h)$, $j = 1, 2, \ldots, k$; $h = 1, 2, \ldots, N$.

2. Decision making based on an information index

Judgement of the goodness of model performance based on the sum of squares of the simulation errors may lead to a wrong conclusion; since a large sum of squares may result for a bigger size system, and a small sum of squares may come from a smaller size of a similar type system. Thus, the use of an objective index for decision making on the quality of a simulation model is necessary. One such index will be discussed below:

The output of a model can be considered as a random variable X with variate value $x(t_i) = x_i$. The entropy of X is defined as

$$H(X) \triangleq -\sum_{i=1}^{n} p(x_i) \log p(x_i) \qquad (2)$$

where $p(x_i)$ is the probability of occurrence of x_i. It can be shown that the value of $H(X)$ is maximum (i.e., $H_{max}(X) = \log n$) when all the x_i are equally likely, that is, when the output has maximum uncertainty. On the contrary, when all outputs except one have zero probability, $H(X)$ vanishes; this corresponds to absolute certainty.

Consider now a second system with outputs y_j, $j = 1,2, . . . ,n$, having the probability of occurrence $p(y_j)$. If these outputs are related to those x_i of the first system, then the uncertainty of X, given knowledge of Y, is

$$H(X|Y) \triangleq - \sum_{i=1}^{n} \sum_{j=1}^{n} p(x_i,y_j) \log p(x_i|y_j) \qquad (3)$$

where $p(x_i|y_j)$ is the conditional probability of $X = x_i$ given $Y = y_j$, and $p(x_i,y_j)$ is the joint probability of $X = x_i$ and $Y = y_j$. Thus, $H(X|Y)$ is the conditional entropy of X given Y. It is clear that, if all the $p(x_i|y_j)$ equal 1, that is if there were an exact correspondence between X and Y, it would follow that $H(X,Y) = 0$. In this case, knowledge of Y would eliminate all uncertainty from X.

Based on the above considerations, an information index can then be defined as the relative conditional entropy of X given Y:

$$\begin{aligned} I_X &\triangleq H(X|Y) / H_{max}(X) \\ &= H(X|Y) / \log n \end{aligned} \qquad (4)$$

If Y is the observed output of a given system, X is the simulated value obtained from one of the models of the system under study; then the information index (4) may be used as criteria for selecting the best model among competing digital simulation models. For example, if, for two models (a) and (b), $I_a < I_b$, the choice should be model (a).

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APPENDIX B

VALIDATION RESULTS

APPENDIX B1

SOLAR I DATA ANALYSIS

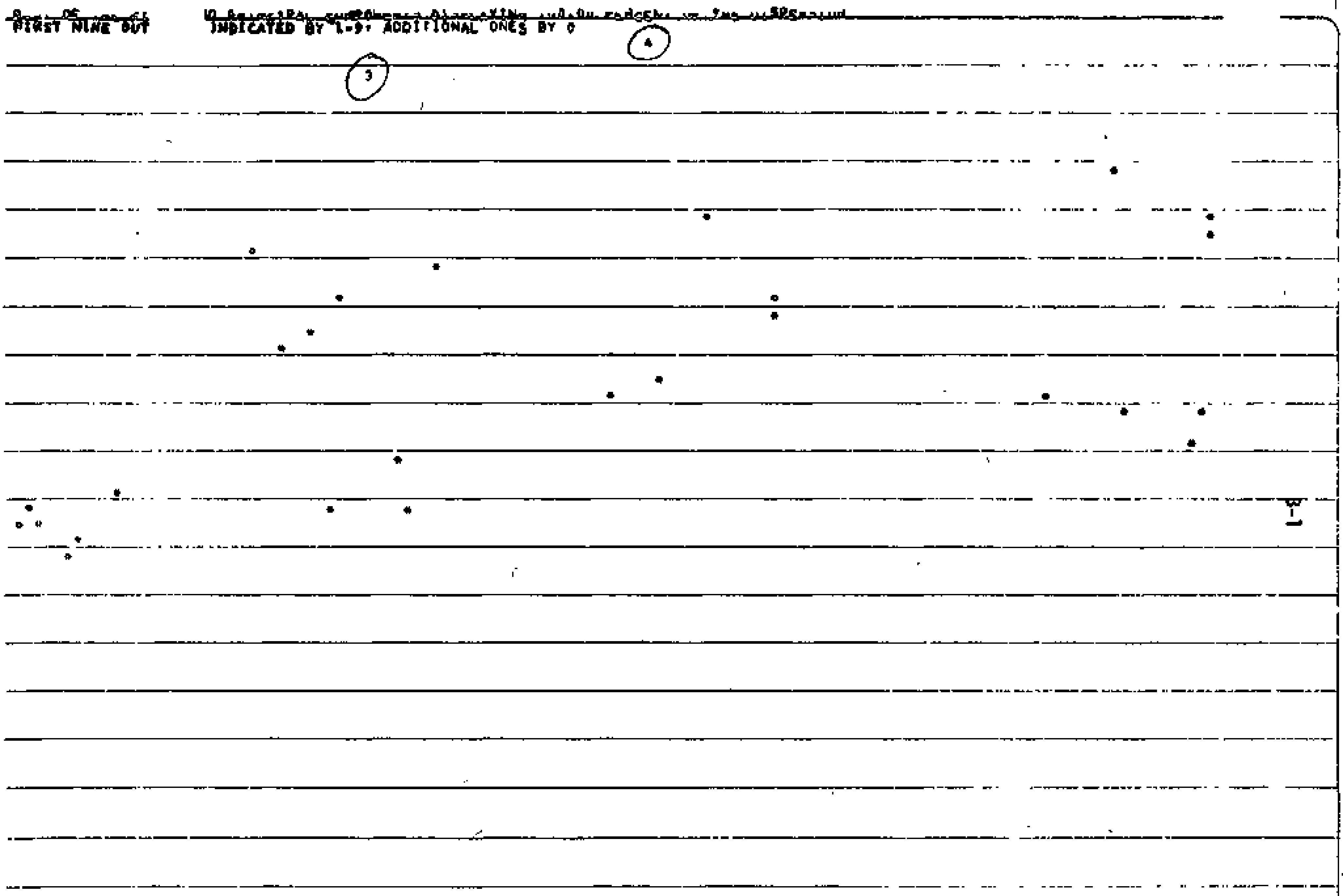

Figure B1.1: Outliers Identification by Clustering.

TABLE OF THE COMPUTED RELATIVE FREQUENCIES (PDF), AND THE CUMULATIVE FREQUENCIES (CDF)
AVERAGE INCIDENT SOLAR RADIATION ON HORIZONTAL SURFACE --- DECEMBER 1974

NO.	RANGE		MID-RANGE	OBS. FREQ.	CDF	PDF
1	(-2.6122	2.6122)	-.0000	51.00000	.16452	.16452
2	(2.6122	7.8367)	5.2245	10.00000	.19677	.03226
3	(7.8367	13.0612)	10.4490	5.00000	.21290	.01613
4	(13.0612	18.2857)	15.6735	8.00000	.23871	.02581
5	(18.2857	23.5102)	20.8980	5.00000	.25484	.01613
6	(23.5102	28.7347)	26.1224	8.00000	.28065	.02581
7	(28.7347	33.9592)	31.3469	4.00000	.29355	.01290
8	(33.9592	39.1837)	36.5714	7.00000	.31613	.02258
9	(39.1837	44.4082)	41.7959	3.00000	.32581	.00968
10	(44.4082	49.6327)	47.0204	4.00000	.33871	.01290
11	(49.6327	54.8571)	52.2449	9.00000	.36774	.02903
12	(54.8571	60.0816)	57.4694	4.00000	.38065	.01290
13	(60.0816	65.3061)	62.6939	7.00000	.40323	.02258
14	(65.3061	70.5306)	67.9184	7.00000	.42581	.02258
15	(70.5306	75.7551)	73.1429	12.00000	.46452	.03871
16	(75.7551	80.9796)	78.3673	11.00000	.50000	.03548
17	(80.9796	86.2041)	83.5918	4.00000	.51290	.01290
18	(86.2041	91.4286)	88.8163	6.00000	.53226	.01935
19	(91.4286	96.6531)	94.0408	2.00000	.53871	.00645
20	(96.6531	101.8776)	99.2653	2.00000	.54516	.00645
21	(101.8776	107.1020)	104.4898	7.00000	.56774	.02258
22	(107.1020	112.3265)	109.7143	9.00000	.59677	.02903
23	(112.3265	117.5510)	114.9388	6.00000	.61613	.01935
24	(117.5510	122.7755)	120.1633	2.00000	.62258	.00645
25	(122.7755	128.0000)	125.3878	4.00000	.63548	.01290
26	(128.0000	133.2245)	130.6122	4.00000	.64839	.01290
27	(133.2245	138.4490)	135.8367	6.00000	.66774	.01935
28	(138.4490	143.6735)	141.0612	5.00000	.68387	.01613
29	(143.6735	148.8980)	146.2857	2.00000	.69032	.00645
30	(148.8980	154.1224)	151.5102	9.00000	.71935	.02903
31	(154.1224	159.3469)	156.7347	6.00000	.73871	.01935
32	(159.3469	164.5714)	161.9592	6.00000	.75806	.01935
33	(164.5714	169.7959)	167.1837	3.00000	.76774	.00968
34	(169.7959	175.0204)	172.4082	12.00000	.80645	.03871
35	(175.0204	180.2449)	177.6327	1.00000	.80968	.00323
36	(180.2449	185.4694)	182.8571	5.00000	.82581	.01613
37	(185.4694	190.6939)	188.0816	14.00000	.87097	.04516
38	(190.6939	195.9184)	193.3061	12.00000	.90968	.03871
39	(195.9184	201.1429)	198.5306	5.00000	.92581	.01613
40	(201.1429	206.3673)	203.7551	4.00000	.93871	.01290
41	(206.3673	211.5918)	208.9796	8.00000	.96452	.02581
42	(211.5918	216.8163)	214.2041	2.00000	.97097	.00645
43	(216.8163	222.0408)	219.4286	3.00000	.98065	.00968
44	(222.0408	227.2653)	224.6531	0.00000	.98065	0.00000
45	(227.2653	232.4898)	229.8776	3.00000	.99032	.00968
46	(232.4898	237.7143)	235.1020	0.00000	.99032	0.00000
47	(237.7143	242.9388)	240.3265	1.00000	.99355	.00323
48	(242.9388	248.1633)	245.5510	1.00000	.99677	.00323
49	(248.1633	253.3878)	250.7755	0.00000	.99677	0.00000
50	(253.3878	258.6122)	256.0000	1.00000	1.00000	.00323

Figure B1.2

CUMULATIVE RELATIVE FREQUENCY CURVE
AVERAGE INCIDENT SOLAR RADIATION ON HORIZONTAL SURFACE --- DECEMBER 1974

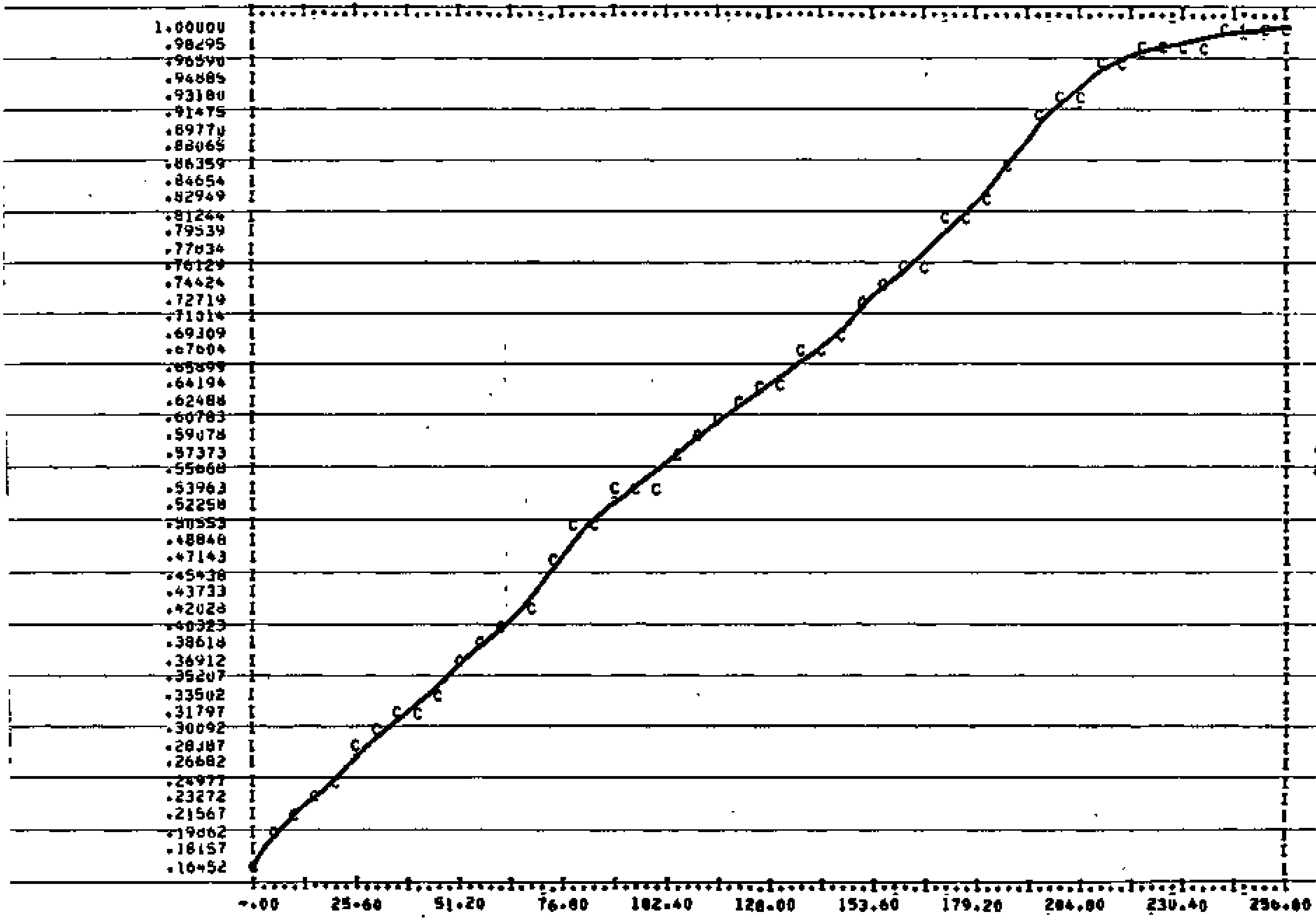

Figure B1.3

5% red.

87

TABLE OF THE COMPUTED RELATIVE FREQUENCIES(PDF)AND THE CUMULATIVE FREQUENCIES (CDF)
AVERAGE INCIDENT SOLAR RADIATION ON 40DEG. TILTED SURFACE --- DECEMBER 1974

NO.	RANGE		MID-RANGE	OBS. FREQ.	CDF	PDF
1	(-2.9898	2.9898)	-.0000	43.00000	.13871	.13871
2	(2.9898	8.9694)	5.9796	16.00000	.19032	.05161
3	(8.9694	14.9490)	11.9592	4.00000	.20323	.01290
4	(14.949.	20.9286)	17.9388	5.00000	.21935	.01613
5	(20.9286	26.9082)	23.9184	6.00000	.23871	.01935
6	(26.9082	32.8878)	29.8980	4.00000	.25161	.01290
7	(32.8878	38.8673)	35.8776	4.00000	.26452	.01290
8	(38.8673	44.8469)	41.8571	5.00000	.28065	.01613
9	(44.8469	50.8265)	47.8367	4.00000	.29355	.01290
10	(50.8265	56.8061)	53.8163	5.00000	.30968	.01613
11	(56.8061	62.7857)	59.7959	3.00000	.31935	.00968
12	(62.7857	68.7653)	65.7755	2.00000	.32581	.00645
13	(68.7653	74.7449)	71.7551	6.00000	.34516	.01935
14	(74.7449	80.7245)	77.7347	7.00000	.36774	.02258
15	(80.7245	86.7041)	83.7143	3.00000	.37742	.00968
16	(86.7041	92.6837)	89.6939	2.00000	.38387	.00645
17	(92.6837	98.6633)	95.6735	2.00000	.39032	.00645
18	(98.6633	104.6429)	101.6531	6.00000	.40968	.01935
19	(104.6429	110.6224)	107.6327	11.00000	.44516	.03548
20	(110.6224	116.6020)	113.6122	8.00000	.47097	.02581
21	(116.6020	122.5816)	119.5918	5.00000	.48710	.01613
22	(122.5816	128.5612)	125.5714	11.00000	.52258	.03548
23	(128.5612	134.5408)	131.5510	5.00000	.53871	.01613
24	(134.5408	140.5204)	137.5306	2.00000	.54516	.00645
25	(140.5204	146.5000)	143.5102	7.00000	.56774	.02258
26	(146.5000	152.4796)	149.4898	5.00000	.58387	.01613
27	(152.4796	158.4592)	155.4694	5.00000	.60000	.01613
28	(158.4592	164.4388)	161.4490	6.00000	.61935	.01935
29	(164.4388	170.4184)	167.4286	2.00000	.62581	.00645
30	(170.4184	176.3980)	173.4082	4.00000	.63871	.01290
31	(176.398.	182.3776)	179.3878	2.00000	.64516	.00645
32	(182.3776	188.3571)	185.3673	2.00000	.65161	.00645
33	(188.3571	194.3367)	191.3469	9.00000	.68065	.02903
34	(194.3367	200.3163)	197.3265	6.00000	.70000	.01935
35	(200.3163	206.2959)	203.3061	7.00000	.72258	.02258
36	(206.2959	212.2755)	209.2857	9.00000	.75161	.02903
37	(212.2755	218.2551)	215.2653	5.00000	.76774	.01613
38	(218.2551	224.2347)	221.2449	3.00000	.77742	.00968
39	(224.2347	230.2143)	227.2245	7.00000	.80000	.02258
40	(230.2143	236.1939)	233.2041	3.00000	.80968	.00968
41	(236.1939	242.1735)	239.1837	1.00000	.81290	.00323
42	(242.1735	248.1531)	245.1633	11.00000	.84839	.03548
43	(248.1531	254.1327)	251.1429	8.00000	.87419	.02581
44	(254.1327	260.1122)	257.1224	9.00000	.90323	.02903
45	(260.1122	266.0918)	263.1020	6.00000	.92258	.01935
46	(266.0918	272.0714)	269.0816	8.00000	.94839	.02581
47	(272.0714	278.0510)	275.0612	6.00000	.96774	.01935
48	(278.0510	284.0306)	281.0408	4.00000	.98065	.01290
49	(284.0306	290.0102)	287.0204	3.00000	.99032	.00968
50	(290.0102	295.9898)	293.0000	3.00000	1.00000	.00968

Figure B1.4

CUMULATIVE RELATIVE FREQUENCY CURVE
AVERAGE INCIDENT SOLAR RADIATION ON 45 DEG. TILTED SURFACE --- DECEMBER 1976

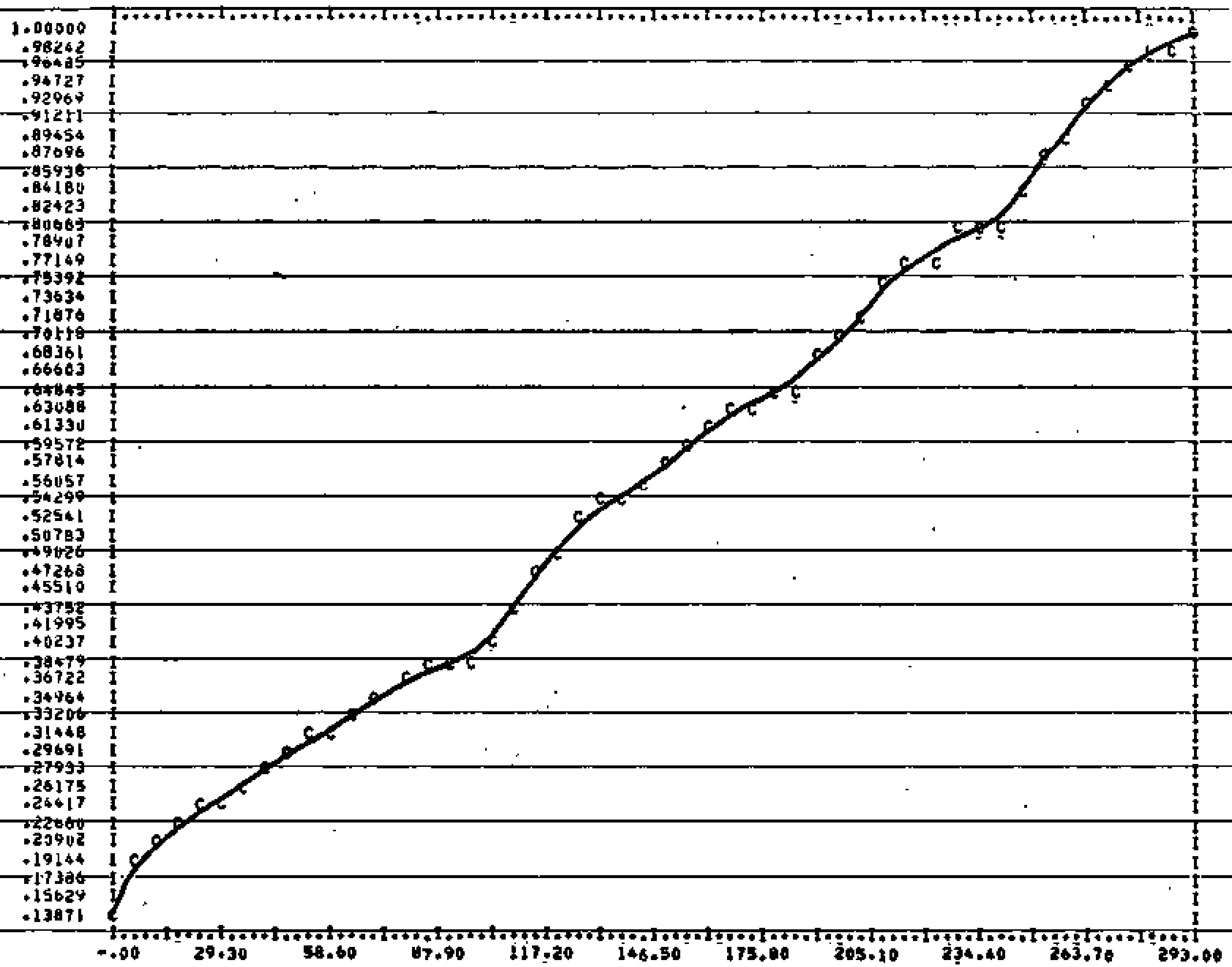

Figure B1.5

TABLE OF THE COMPUTED RELATIVE FREQUENCIES (PDF), AND THE CUMULATIVE FREQUENCIES (CDF)
AVERAGE DAILY AIR TEMPERATURE -- DECEMBER 1974

NO.	RANGE		MID-RANGE	OBS. FREQ.	CDF	PDF
1	(.3418	1.4582)	.9000	1.00000	.00134	.00134
2	(1.4582	2.5745)	2.0163	1.00000	.00269	.00134
3	(2.5745	3.6908)	3.1327	3.00000	.00672	.00403
4	(3.6908	4.8071)	4.2490	5.00000	.01344	.00672
5	(4.8071	5.9235)	5.3653	9.00000	.02554	.01210
6	(5.9235	7.0398)	6.4816	3.00000	.02957	.00403
7	(7.0398	8.1561)	7.5980	3.00000	.03360	.00403
8	(8.1561	9.2724)	8.7143	1.00000	.03495	.00134
9	(9.2724	10.3888)	9.8306	3.00000	.03898	.00403
10	(10.3888	11.5051)	10.9469	2.00000	.04167	.00269
11	(11.5051	12.6214)	12.0633	2.00000	.04435	.00269
12	(12.6214	13.7378)	13.1796	6.00000	.05242	.00806
13	(13.7378	14.8541)	14.2959	5.00000	.05914	.00672
14	(14.8541	15.9704)	15.4122	6.00000	.06720	.00806
15	(15.9704	17.0867)	16.5286	14.00000	.08602	.01882
16	(17.0867	18.2031)	17.6449	20.00000	.11290	.02688
17	(18.2031	19.3194)	18.7612	18.00000	.13710	.02419
18	(19.3194	20.4357)	19.8776	16.00000	.15860	.02151
19	(20.4357	21.5520)	20.9939	20.00000	.18548	.02688
20	(21.5520	22.6684)	22.1102	29.00000	.22446	.03898
21	(22.6684	23.7847)	23.2265	24.00000	.25672	.03226
22	(23.7847	24.9010)	24.3429	23.00000	.28763	.03091
23	(24.9010	26.0173)	25.4592	30.00000	.32796	.04032
24	(26.0173	27.1337)	26.5755	50.00000	.39516	.06720
25	(27.1337	28.2500)	27.6918	35.00000	.44220	.04704
26	(28.2500	29.3663)	28.8082	33.00000	.48656	.04435
27	(29.3663	30.4827)	29.9245	51.00000	.55511	.06855
28	(30.4827	31.5990)	31.0408	29.00000	.59409	.03898
29	(31.5990	32.7153)	32.1571	43.00000	.65188	.05780
30	(32.7153	33.8316)	33.2735	26.00000	.68683	.03495
31	(33.8316	34.9480)	34.3898	28.00000	.72446	.03763
32	(34.9480	36.0643)	35.5061	34.00000	.77016	.04570
33	(36.0643	37.1806)	36.6224	25.00000	.80376	.03360
34	(37.1806	38.2969)	37.7388	22.00000	.83333	.02957
35	(38.2969	39.4133)	38.8551	17.00000	.85618	.02285
36	(39.4133	40.5296)	39.9714	17.00000	.87903	.02285
37	(40.5296	41.6459)	41.0878	11.00000	.89382	.01478
38	(41.6459	42.7622)	42.2041	10.00000	.90726	.01344
39	(42.7622	43.8786)	43.3204	12.00000	.92339	.01613
40	(43.8786	44.9949)	44.4367	14.00000	.94220	.01882
41	(44.9949	46.1112)	45.5531	5.00000	.94892	.00672
42	(46.1112	47.2276)	46.6694	4.00000	.95430	.00538
43	(47.2276	48.3439)	47.7857	8.00000	.96505	.01075
44	(48.3439	49.4602)	48.9020	6.00000	.97312	.00806
45	(49.4602	50.5765)	50.0184	4.00000	.97849	.00538
46	(50.5765	51.6929)	51.1347	5.00000	.98522	.00672
47	(51.6929	52.8092)	52.2510	4.00000	.99059	.00538
48	(52.8092	53.9255)	53.3673	2.00000	.99328	.00269
49	(53.9255	55.0418)	54.4837	3.00000	.99731	.00403
50	(55.0418	56.1582)	55.6000	2.00000	1.00000	.00269

Figure B1.6

CUMULATIVE RELATIVE FREQUENCY CURVE
AVERAGE DAILY AIR TEMPERATURE --- DECEMBER 1974

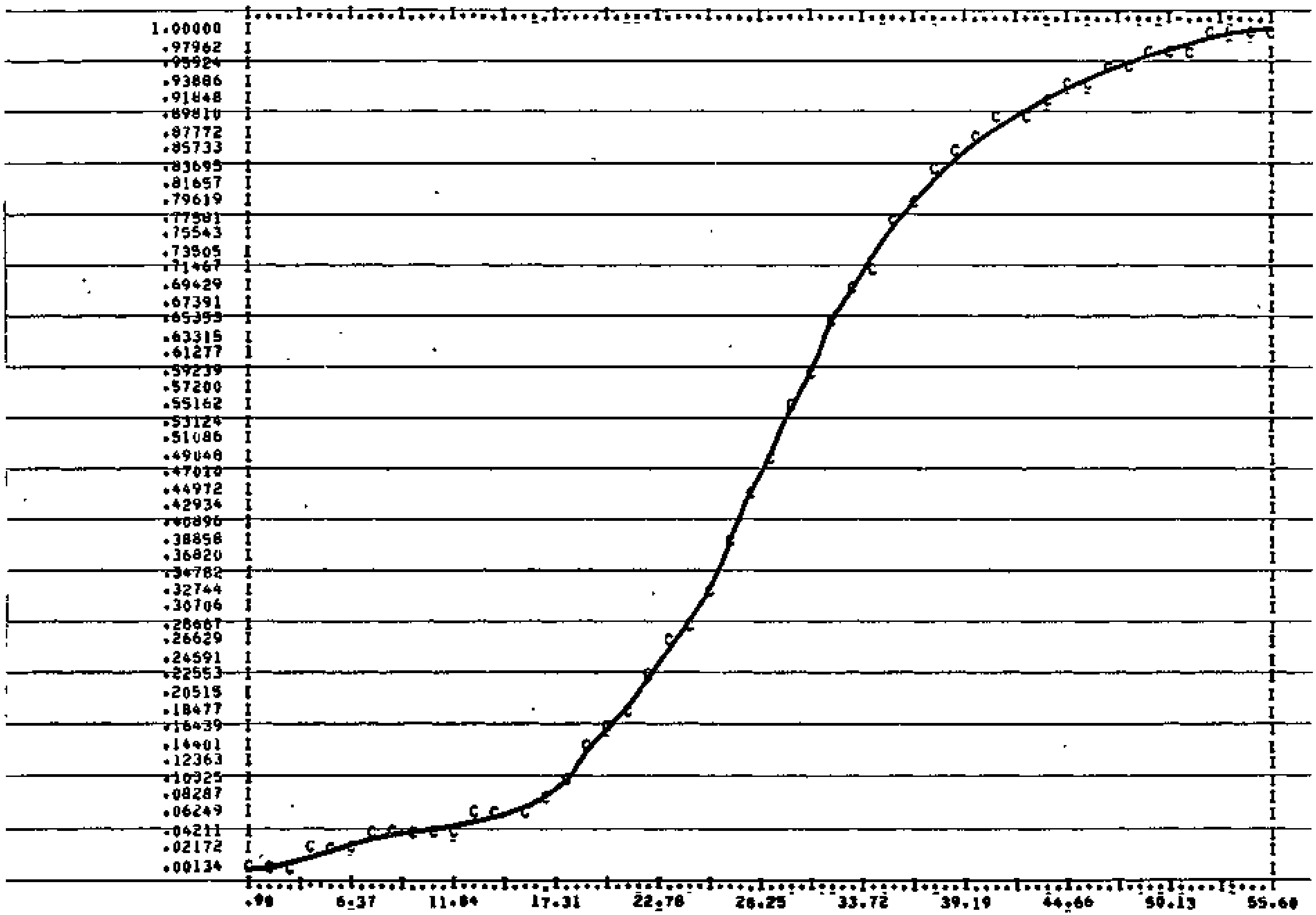

Figure B1.7

B-7

SOLAR1 --- AVERAGE INCIDENT SOLAR RADIATION ON HORIZONTAL SURFACE FROM 9AM TO 6PM

DAY	SEP 1974	OCT 1974	NOV 1974	DEC 1974	JAN 1975	FEB 1975	MAR 1975	APR 1975	MAY 1975	JUN 1975	JUL 1975	AUG 1975
1	46.	155.	66.	127.	123.	109.	110.	101.	157.	230.	234.	185.
2	60.	169.	18.	125.	24.	110.	137.	211.	173.	212.	225.	207.
3	176.	119.	47.	100.	119.	128.	108.	196.	205.	165.	196.	225.
4	192.	122.	119.	123.	101.	15.	143.	199.	202.	210.	217.	216.
5	110.	101.	117.	53.	111.	65.	159.	194.	137.	233.	138.	180.
6	184.	138.	90.	129.	120.	123.	43.	194.	174.	186.	206.	114.
7	192.	136.	98.	21.	62.	106.	59.	124.	91.	147.	140.	136.
8	102.	151.	98.	130.	59.	50.	122.	122.	135.	97.	211.	215.
9	130.	159.	36.	125.	74.	75.	54.	150.	170.	102.	128.	195.
10	144.	109.	85.	123.	53.	73.	52.	37.	132.	92.	266.	154.
11	39.	31.	115.	133.	30.	131.	28.	66.	190.	218.	214.	127.
12	52.	17.	121.	121.	80.	109.	164.	199.	100.	164.	231.	102.
13	158.	175.	114.	117.	63.	79.	152.	194.	221.	198.	222.	33.
14	116.	125.	94.	105.	79.	32.	160.	166.	225.	147.	116.	106.
15	102.	126.	89.	99.	51.	63.	94.	166.	157.	225.	161.	148.
16	172.	118.	114.	92.	55.	121.	170.	202.	164.	89.	155.	143.
17	161.	166.	108.	82.	80.	105.	136.	70.	144.	137.	156.	150.
18	126.	128.	90.	65.	79.	137.	157.	200.	139.	104.	157.	176.
19	127.	122.	99.	49.	93.	133.	181.	210.	175.	198.	179.	136.
20	84.	118.	105.	30.	93.	112.	172.	183.	42.	201.	127.	112.
21	174.	85.	72.	37.	76.	136.	119.	178.	31.	136.	145.	143.
22	170.	112.	57.	122.	97.	139.	151.	218.	60.	175.	189.	143.
23	178.	95.	115.	14.	64.	104.	131.	146.	137.	223.	157.	147.
24	175.	89.	106.	109.	123.	145.	188.	202.	232.	188.	216.	164.
25	178.	81.	78.	127.	67.	152.	115.	217.	84.	190.	225.	176.
26	158.	138.	126.	50.	120.	160.	63.	205.	233.	239.	224.	182.
27	11.	142.	64.	110.	72.	145.	165.	63.	141.	287.	227.	140.
28	174.	147.	32.	102.	60.	127.	107.	221.	25.	234.	160.	156.
29	170.	140.	106.	84.	105.	0.	156.	115.	66.	241.	184.	177.
30	144.	93.	129.	116.	92.	0.	132.	114.	190.	242.	151.	182.
31	0.	37.	0.	100.	104.	0.	53.	0.	135.	0.	141.	181.
MO.AVG.	134.	118.	90.	94.	82.	107.	124.	162.	144.	184.	184.	157.

NOTE --- UNIT OF MEASURE FOR INCIDENT SOLAR RADIATION IS BTU/HOUR/SQUARE-FOOT.

Figure B1.8

B-8

TABLE OF THE COMPUTED RELATIVE FREQUENCIES (PDF), AND THE CUMULATIVE FREQUENCIES (CDF)
AVERAGE INCIDENT SOLAR RADIATION ON HORIZONTAL SURFACE - FROM SEP 74 TO AUG 75

NO.	RANGE		MID-RANGE	OBS. FREQ.	CDF	PDF
1	(8.3867	14.0133)	11.2000	1.00000	.00274	.00274
2	(14.0133	19.6398)	16.8265	4.00000	.01370	.01096
3	(19.6398	25.2663)	22.4531	2.00000	.01918	.00548
4	(25.2663	30.8929)	28.0796	5.00000	.03288	.01370
5	(30.8929	36.5194)	33.7061	5.00000	.04658	.01370
6	(36.5194	42.1459)	39.3327	4.00000	.05753	.01096
7	(42.1459	47.7724)	44.9592	4.00000	.06849	.01096
8	(47.7724	53.3990)	50.5857	7.00000	.08767	.01918
9	(53.3990	59.0255)	56.2122	6.00000	.10411	.01644
10	(59.0255	64.6520)	61.8388	10.00000	.13151	.02740
11	(64.6520	70.2786)	67.4653	8.00000	.15342	.02192
12	(70.2786	75.9051)	73.0918	5.00000	.16712	.01370
13	(75.9051	81.5316)	78.7184	8.00000	.18904	.02192
14	(81.5316	87.1582)	84.3449	6.00000	.20548	.01644
15	(87.1582	92.7847)	89.9714	10.00000	.23288	.02740
16	(92.7847	98.4112)	95.5980	8.00000	.25479	.02192
17	(98.4112	104.0378)	101.2245	15.00000	.29589	.04110
18	(104.0378	109.6643)	106.8510	16.00000	.33973	.04384
19	(109.6643	115.2908)	112.4776	16.00000	.38356	.04384
20	(115.2908	120.9173)	118.1041	14.00000	.42192	.03836
21	(120.9173	126.5439)	123.7306	19.00000	.47397	.05205
22	(126.5439	132.1704)	129.3571	16.00000	.51781	.04384
23	(132.1704	137.7969)	134.9837	17.00000	.56438	.04658
24	(137.7969	143.4235)	140.6102	14.00000	.60274	.03836
25	(143.4235	149.0500)	146.2367	12.00000	.63562	.03288
26	(149.0500	154.6765)	151.8633	8.00000	.65753	.02192
27	(154.6765	160.3031)	157.4898	17.00000	.70411	.04658
28	(160.3031	165.9296)	163.1163	10.00000	.73151	.02740
29	(165.9296	171.5561)	168.7429	7.00000	.75068	.01918
30	(171.5561	177.1827)	174.3694	15.00000	.79178	.04110
31	(177.1827	182.8092)	179.9959	7.00000	.81096	.01918
32	(182.8092	188.4357)	185.6224	8.00000	.83288	.02192
33	(188.4357	194.0622)	191.2490	7.00000	.85205	.01918
34	(194.0622	199.6888)	196.8755	9.00000	.87671	.02466
35	(199.6888	205.3153)	202.5020	7.00000	.89589	.01918
36	(205.3153	210.9418)	208.1286	4.00000	.90685	.01096
37	(210.9418	216.5684)	213.7551	7.00000	.92603	.01918
38	(216.5684	222.1949)	219.3816	7.00000	.94521	.01918
39	(222.1949	227.8214)	225.0082	8.00000	.96712	.02192
40	(227.8214	233.4480)	230.6347	5.00000	.98082	.01370
41	(233.4480	239.0745)	236.2612	2.00000	.98630	.00548
42	(239.0745	244.7010)	241.8878	3.00000	.99452	.00822
43	(244.7010	250.3276)	247.5143	0.00000	.99452	0.00000
44	(250.3276	255.9541)	253.1408	0.00000	.99452	0.00000
45	(255.9541	261.5806)	258.7673	0.00000	.99452	0.00000
46	(261.5806	267.2071)	264.3939	1.00000	.99726	.00274
47	(267.2071	272.8337)	270.0204	0.00000	.99726	0.00000
48	(272.8337	278.4602)	275.6469	0.00000	.99726	0.00000
49	(278.4602	284.0867)	281.2735	0.00000	.99726	0.00000
50	(284.0867	289.7133)	286.9000	1.00000	1.00000	.00274

Figure B1.9

93

CUMULATIVE RELATIVE FREQUENCY CURVE
AVERAGE INCIDENT SOLAR RADIATION ON HORIZONTAL SURFACE - FROM SEP 74 TO AUG 75

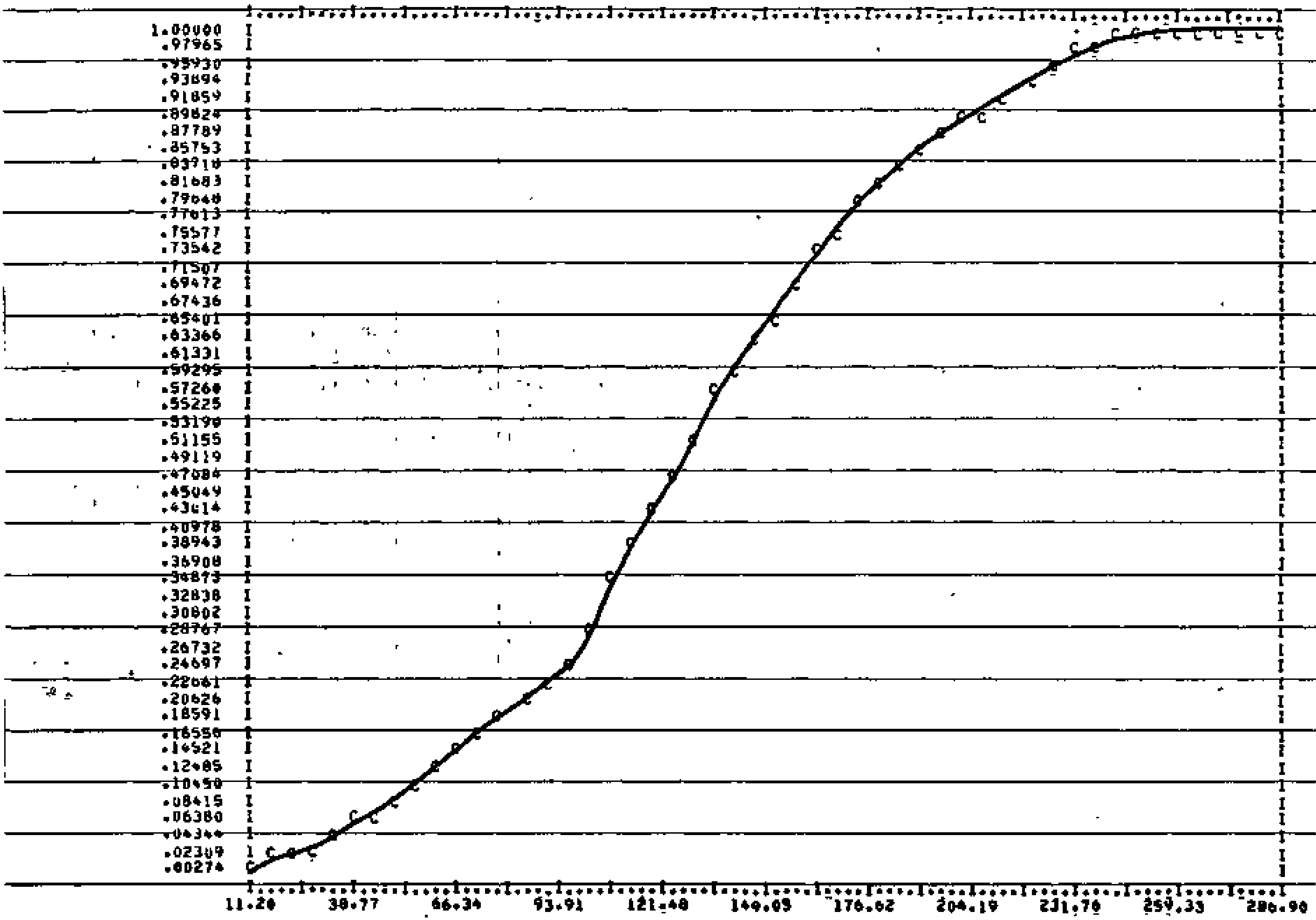

Figure B1.10

B-10

Stored.

94

[redacted]

SOLAR1 --- AVERAGE INCIDENT SOLAR RADIATION ON 45 DEG. TILTED SURFACE FROM 9AM TO 6PM

DAY	SEP 1974	OCT 1974	NOV 1974	DEC 1974	JAN 1975	FEB 1975	MAR 1975	APR 1975	MAY 1975	JUN 1975	JUL 1975	AUG 1975
1	40.	200.	84.	172.	175.	194.	143.	186.	159.	207.	211.	179.
2	55.	203.	13.	168.	34.	195.	191.	255.	167.	194.	209.	201.
3	197.	149.	43.	141.	167.	201.	135.	243.	204.	147.	184.	216.
4	215.	154.	185.	165.	152.	14.	194.	240.	200.	189.	199.	209.
5	115.	130.	187.	75.	162.	69.	222.	221.	134.	208.	127.	173.
6	211.	170.	130.	167.	170.	198.	40.	221.	165.	166.	181.	187.
7	222.	182.	107.	29.	98.	178.	53.	127.	81.	129.	128.	127.
8	108.	185.	164.	173.	78.	46.	154.	125.	125.	82.	195.	211.
9	140.	199.	34.	170.	116.	88.	55.	160.	163.	86.	115.	198.
10	181.	139.	133.	153.	90.	93.	48.	31.	123.	74.	188.	194.
11	35.	31.	193.	164.	26.	206.	25.	59.	183.	196.	192.	123.
12	47.	15.	165.	154.	126.	164.	210.	224.	93.	149.	205.	95.
13	189.	205.	157.	153.	86.	92.	198.	212.	209.	180.	199.	31.
14	126.	150.	138.	141.	146.	29.	202.	172.	211.	131.	106.	186.
15	108.	157.	129.	138.	89.	127.	104.	172.	141.	200.	144.	151.
16	213.	145.	197.	130.	80.	198.	213.	216.	147.	78.	143.	153.
17	203.	201.	155.	118.	125.	148.	168.	70.	134.	124.	136.	158.
18	163.	158.	128.	97.	150.	225.	200.	209.	129.	93.	144.	187.
19	184.	156.	145.	78.	177.	207.	196.	222.	163.	173.	159.	140.
20	108.	151.	146.	47.	173.	163.	211.	185.	36.	179.	113.	113.
21	204.	111.	98.	56.	122.	191.	137.	182.	26.	122.	133.	155.
22	210.	142.	83.	176.	177.	213.	173.	222.	52.	154.	174.	180.
23	209.	118.	167.	20.	102.	133.	135.	144.	117.	204.	137.	162.
24	201.	118.	155.	150.	200.	209.	229.	222.	210.	177.	194.	186.
25	209.	106.	114.	180.	100.	213.	123.	227.	76.	165.	205.	209.
26	192.	171.	172.	66.	151.	213.	60.	212.	211.	206.	206.	213.
27	14.	176.	87.	150.	83.	208.	174.	61.	126.	262.	209.	154.
28	207.	169.	40.	141.	101.	176.	226.	226.	23.	214.	143.	179.
29	212.	164.	135.	117.	183.	0.	185.	110.	57.	219.	174.	213.
30	175.	113.	171.	158.	151.	0.	154.	105.	173.	217.	138.	218.
31	0.	35.	0.	136.	186.	0.	47.	0.	125.	0.	132.	219.
MO.AVG.	155.	145.	127.	129.	128.	157.	149.	173.	134.	164.	165.	166.

NOTE --- UNIT OF MEASURE FOR INCIDENT SOLAR RADIATION IS BTU/HOUR/SQUARE-FOOT.

Figure B1.11

95

TABLE OF THE COMPUTED RELATIVE FREQUENCIES (PDF), AND THE CUMULATIVE FREQUENCIES (CDF)
AVERAGE INCIDENT SOLAR RADIATION ON 45 DEG. TILTED SURFACE - SEP 74 TO AUG 75

NO.	RANGE		MID-RANGE	OBS. FREQ.	CDF	PDF
1	(10.6602	15.7398)	13.2000	4.00000	.01096	.01096
2	(15.7398	20.8194)	18.2796	1.00000	.01370	.00274
3	(20.8194	25.8990)	23.3592	3.00000	.02192	.00822
4	(25.8990	30.9786)	28.4388	3.00000	.03014	.00822
5	(30.9786	36.0582)	33.5184	8.00000	.05205	.02192
6	(36.0582	41.1378)	38.5980	2.00000	.05753	.00548
7	(41.1378	46.2173)	43.6776	3.00000	.06575	.00822
8	(46.2173	51.2969)	48.7571	4.00000	.07671	.01096
9	(51.2969	56.3765)	53.8367	5.00000	.09041	.01370
10	(56.3765	61.4561)	58.9163	4.00000	.10137	.01096
11	(61.4561	66.5357)	63.9959	1.00000	.10411	.00274
12	(66.5357	71.6153)	69.0755	2.00000	.10959	.00548
13	(71.6153	76.6949)	74.1551	3.00000	.11781	.00822
14	(76.6949	81.7745)	79.2347	6.00000	.13425	.01644
15	(81.7745	86.8541)	84.3143	6.00000	.15068	.01644
16	(86.8541	91.9337)	89.3939	3.00000	.15890	.00822
17	(91.9337	97.0133)	94.4735	5.00000	.17260	.01370
18	(97.0133	102.0929)	99.5531	5.00000	.18630	.01370
19	(102.0929	107.1724)	104.6327	9.00000	.21096	.02466
20	(107.1724	112.2520)	109.7122	5.00000	.22466	.01370
21	(112.2520	117.3316)	114.7918	8.00000	.24658	.02192
22	(117.3316	122.4112)	119.8714	6.00000	.26301	.01644
23	(122.4112	127.4908)	124.9510	14.00000	.30137	.03836
24	(127.4908	132.5704)	130.0306	11.00000	.33151	.03014
25	(132.5704	137.6500)	135.1102	12.00000	.36438	.03288
26	(137.6500	142.7296)	140.1898	12.00000	.39726	.03288
27	(142.7296	147.8092)	145.2694	11.00000	.42740	.03014
28	(147.8092	152.8888)	150.3490	13.00000	.46301	.03562
29	(152.8888	157.9684)	155.4286	15.00000	.50411	.04110
30	(157.9684	163.0480)	160.5082	11.00000	.53425	.03014
31	(163.0480	168.1276)	165.5878	19.00000	.58630	.05205
32	(168.1276	173.2071)	170.6673	14.00000	.62466	.03836
33	(173.2071	178.2867)	175.7469	15.00000	.66575	.04110
34	(178.2867	183.3663)	180.8265	10.00000	.69315	.02740
35	(183.3663	188.4459)	185.9061	9.00000	.71781	.02466
36	(188.4459	193.5255)	190.9857	7.00000	.73699	.01918
37	(193.5255	198.6051)	196.0653	14.00000	.77534	.03836
38	(198.6051	203.6847)	201.1449	15.00000	.81644	.04110
39	(203.6847	208.7643)	206.2245	15.00000	.85753	.04110
40	(208.7643	213.8439)	211.3041	27.00000	.93151	.07397
41	(213.8439	218.9235)	216.3837	6.00000	.94795	.01644
42	(218.9235	224.0031)	221.4633	10.00000	.97534	.02740
43	(224.0031	229.0827)	226.5429	4.00000	.98630	.01096
44	(229.0827	234.1622)	231.6224	1.00000	.98904	.00274
45	(234.1622	239.2418)	236.7020	0.00000	.98904	0.00000
46	(239.2418	244.3214)	241.7816	2.00000	.99452	.00548
47	(244.3214	249.4010)	246.8612	0.00000	.99452	0.00000
48	(249.4010	254.4806)	251.9408	0.00000	.99452	0.00000
49	(254.4806	259.5602)	257.0204	1.00000	.99726	.00274
50	(259.5602	264.6398)	262.1000	1.00000	1.00000	.00274

Figure B1.12

CUMULATIVE RELATIVE FREQUENCY CURVE
AVERAGE INCIDENT SOLAR RADIATION ON 45 DEG. TILTED SURFACE - SEP 74 TO AUG 75

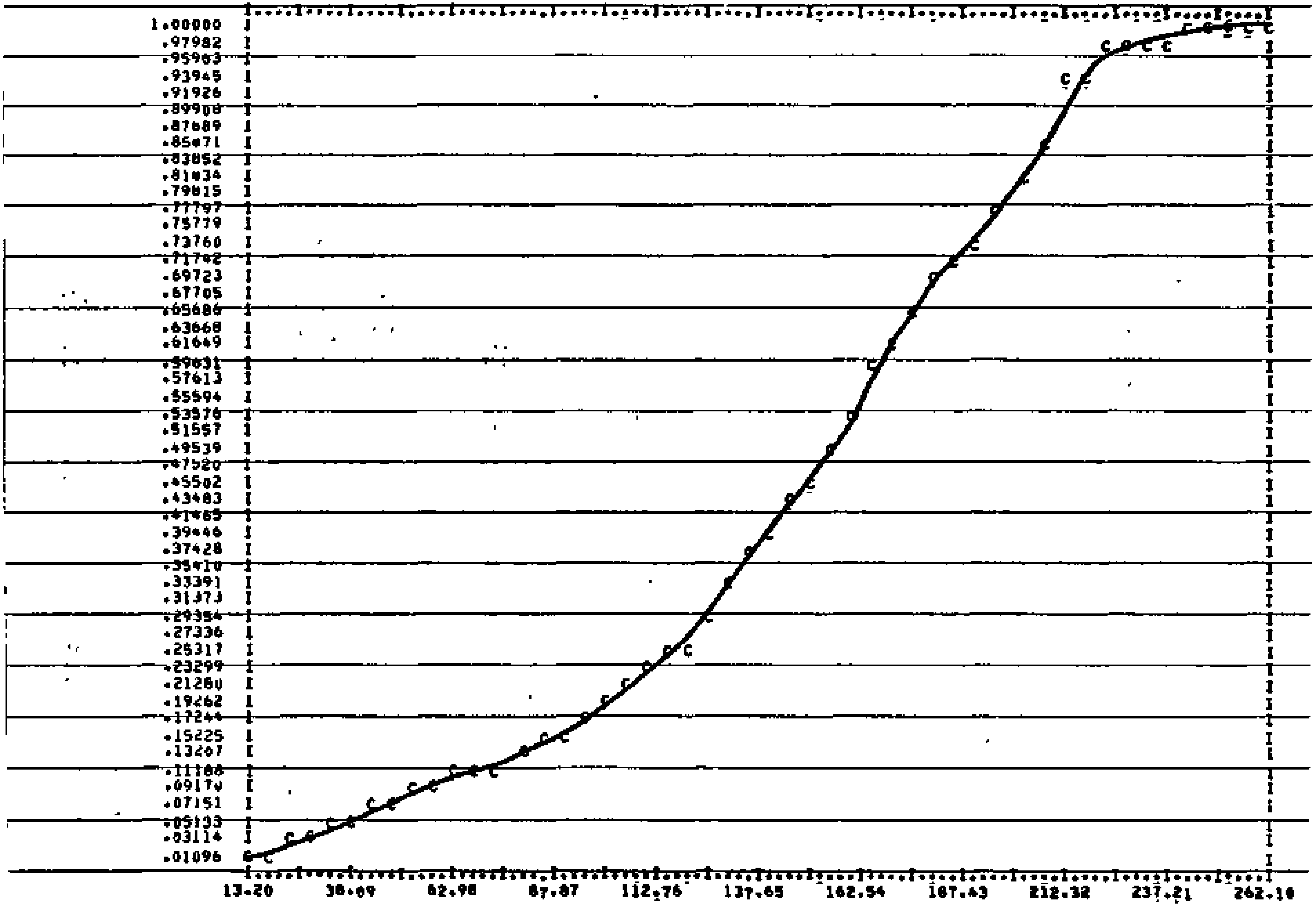

Figure B1.13

SOLAR I --- AVERAGE DAILY AIR TEMPERATURE

DAY	SEP 1974	OCT 1974	NOV 1974	DEC 1974	JAN 1975	FEB 1975	MAR 1975	APR 1975	MAY 1975	JUN 1975	JUL 1975	AUG 1975
1	52.	53.	40.	26.	23.	30.	50.	17.	49.	54.	78.	70.
2	45.	59.	36.	30.	24.	33.	39.	17.	53.	63.	76.	71.
3	52.	67.	31.	34.	28.	26.	36.	30.	56.	68.	75.	76.
4	62.	63.	33.	40.	30.	17.	43.	42.	62.	64.	77.	78.
5	67.	50.	38.	43.	30.	9.	50.	48.	52.	68.	72.	75.
6	64.	41.	38.	34.	40.	12.	34.	48.	46.	73.	73.	78.
7	72.	60.	38.	28.	32.	34.	28.	43.	48.	67.	73.	80.
8	70.	60.	44.	27.	27.	39.	31.	38.	50.	59.	73.	73.
9	75.	61.	39.	35.	30.	45.	32.	37.	54.	50.	69.	77.
10	78.	58.	39.	31.	17.	41.	29.	34.	57.	47.	70.	76.
11	57.	51.	40.	30.	8.	39.	26.	32.	58.	59.	71.	77.
12	60.	44.	50.	34.	13.	40.	27.	36.	49.	66.	69.	72.
13	64.	50.	56.	28.	40.	48.	34.	38.	54.	73.	73.	57.
14	72.	42.	43.	29.	48.	36.	39.	44.	63.	67.	74.	60.
15	76.	47.	40.	30.	41.	18.	39.	52.	65.	72.	75.	64.
16	77.	57.	39.	31.	29.	16.	30.	56.	68.	60.	73.	65.
17	79.	61.	42.	36.	38.	25.	42.	42.	65.	56.	73.	69.
18	70.	58.	44.	33.	41.	22.	45.	37.	63.	57.	77.	72.
19	59.	58.	38.	33.	32.	25.	55.	46.	67.	62.	78.	74.
20	49.	55.	39.	32.	44.	29.	55.	51.	46.	64.	71.	74.
21	51.	57.	48.	42.	23.	22.	41.	47.	49.	62.	75.	72.
22	54.	48.	48.	29.	25.	19.	43.	55.	48.	64.	74.	70.
23	66.	49.	40.	17.	40.	35.	34.	57.	51.	67.	70.	73.
24	64.	47.	36.	8.	41.	46.	36.	54.	60.	70.	71.	74.
25	63.	47.	43.	17.	31.	34.	35.	61.	54.	70.	76.	63.
26	69.	47.	36.	25.	35.	30.	27.	64.	54.	65.	77.	70.
27	46.	51.	30.	28.	20.	44.	13.	44.	59.	70.	77.	73.
28	52.	51.	25.	33.	24.	45.	19.	43.	41.	70.	75.	73.
29	59.	47.	16.	23.	27.	0.	20.	40.	43.	72.	79.	73.
30	55.	40.	15.	24.	21.	0.	33.	41.	55.	77.	76.	72.
31	0.	38.	0.	24.	19.	0.	31.	0.	52.	0.	72.	76.
MO.AVG.	63.	52.	38.	30.	30.	31.	36.	43.	54.	65.	74.	72.

Figure B1.14

TABLE OF THE COMPUTED RELATIVE FREQUENCIES (PDF), AND THE CUMULATIVE FREQUENCIES (CDF)
AVERAGE DAILY AIR TEMPERATURE --- FROM SEP 1 1974 TO AUG 31 1975

NO.	RANGE		MID-RANGE	OBS. FREQ.	CDF	PDF
1	(7.4059	8.8691)	8.1375	2.00000	.00548	.00548
2	(8.8691	10.3324)	9.6008	1.00000	.00822	.00274
3	(10.3324	11.7957)	11.0640	1.00000	.01096	.00274
4	(11.7957	13.2589)	12.5273	2.00000	.01644	.00548
5	(13.2589	14.7222)	13.9905	1.00000	.01918	.00274
6	(14.7222	16.1855)	15.4538	2.00000	.02466	.00548
7	(16.1855	17.6487)	16.9171	7.00000	.04384	.01918
8	(17.6487	19.1120)	18.3804	1.00000	.04658	.00274
9	(19.112-	20.5753)	19.8436	4.00000	.05753	.01096
10	(20.5753	22.0385)	21.3069	2.00000	.06301	.00548
11	(22.0385	23.5018)	22.7702	4.00000	.07397	.01096
12	(23.5018	24.9651)	24.2334	7.00000	.09315	.01918
13	(24.9651	26.4283)	25.6967	4.00000	.10411	.01096
14	(26.4283	27.8916)	27.1599	7.00000	.12329	.01918
15	(27.8916	29.3548)	28.6232	8.00000	.14521	.02192
16	(29.3548	30.8181)	30.0865	12.00000	.17808	.03288
17	(30.8181	32.2814)	31.5497	9.00000	.20274	.02466
18	(32.2814	33.7446)	33.0130	10.00000	.23014	.02740
19	(33.7446	35.2079)	34.4763	8.00000	.25205	.02192
20	(35.2079	36.6712)	35.9395	11.00000	.28219	.03014
21	(36.6712	38.1344)	37.4028	5.00000	.29589	.01370
22	(38.1344	39.5977)	38.8661	15.00000	.33699	.04110
23	(39.5977	41.0610)	40.3293	14.00000	.37534	.03836
24	(41.0610	42.5242)	41.7926	10.00000	.40274	.02740
25	(42.5242	43.9875)	43.2559	12.00000	.43562	.03288
26	(43.9875	45.4508)	44.7191	7.00000	.45479	.01918
27	(45.4508	46.9140)	46.1824	10.00000	.48219	.02740
28	(46.914-	48.3773)	47.6457	12.00000	.51507	.03288
29	(48.3773	49.8406)	49.1089	5.00000	.52877	.01370
30	(49.8406	51.3038)	50.5722	11.00000	.55890	.03014
31	(51.3038	52.7671)	52.0355	7.00000	.57808	.01918
32	(52.7671	54.2304)	53.4987	6.00000	.59452	.01644
33	(54.2304	55.6936)	54.9620	9.00000	.61918	.02466
34	(55.6936	57.1569)	56.4253	7.00000	.63836	.01918
35	(57.1569	58.6202)	57.8885	9.00000	.66301	.02466
36	(58.6202	60.0834)	59.3518	7.00000	.68219	.01918
37	(60.0834	61.5467)	60.8151	8.00000	.70411	.02192
38	(61.5467	63.0099)	62.2783	6.00000	.72055	.01644
39	(63.0099	64.4732)	63.7416	11.00000	.75068	.03014
40	(64.4732	65.9365)	65.2048	6.00000	.76712	.01644
41	(65.9365	67.3997)	66.6681	6.00000	.78356	.01644
42	(67.3997	68.8630)	68.1314	4.00000	.79452	.01096
43	(68.863-	70.3263)	69.5946	10.00000	.82192	.02740
44	(70.3263	71.7895)	71.0579	10.00000	.84932	.02740
45	(71.7895	73.2528)	72.5212	19.00000	.90137	.05205
46	(73.2528	74.7161)	73.9844	8.00000	.92329	.02192
47	(74.7161	76.1793)	75.4477	10.00000	.95068	.02740
48	(76.1793	77.6426)	76.9110	10.00000	.97808	.02740
49	(77.6426	79.1059)	78.3742	6.00000	.99452	.01644
50	(79.1059	80.5691)	79.8375	2.00000	1.00000	.00548

Figure B1.15

CUMULATIVE RELATIVE FREQUENCY CURVE
AVERAGE DAILY AIR TEMPERATURE --- FROM SEP 1 1974 TO AUG 31 1975

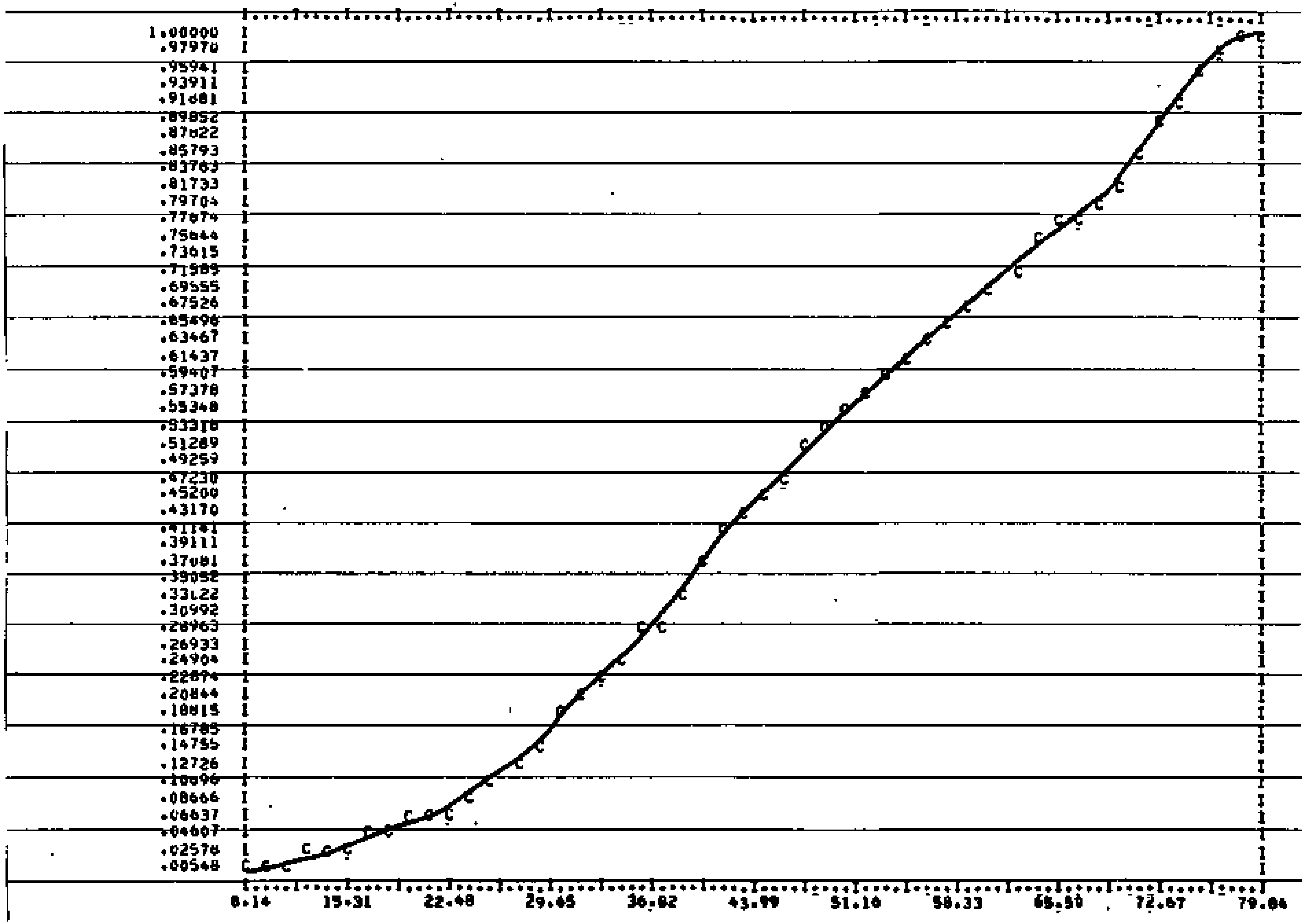

Figure B1.16

Table B1.1: TRAINING AND CHECKING SEQUENCES FOR JANUARY DATA (1975)

TRAINING SEQUENCE			CHECKING SEQUENCE		
HOURS	SOLAR	TANK	HOURS	SOLAR	TANK
144	0.	-0.	264	0.	-16.
145	0.	-2.	265	2.	-15.
146	0.	-6.	266	3.	-15.
147	0.	2.	267	1.	-15.
148	0.	2.	268	0.	-15.
149	0.	-8.	269	1.	-15.
150	0.	2.	270	1.	-18.
151	0.	-1.	271	1.	-19.
152	217.	-2.	272	227.	-19.
153	672.	-1.	273	645.	-17.
154	769.	4.	274	1398.	-14.
155	748.	5.	275	1526.	-10.
156	314.	5.	276	1453.	-8.
157	412.	3.	277	1702.	-6.
158	2145.	4.	278	1761.	-5.
159	1576.	4.	279	672.	-5.
160	867.	3.	280	323.	-5.
161	101.	1.	281	91.	-6.
162	7.	-0.	282	1.	-7.
163	5.	-1.	283	0.	-7.
164	4.	-4.	284	2.	-8.
165	7.	-4.	285	2.	-8.
166	3.	-5.	286	3.	-6.
167	3.	-5.	287	0.	-4.
168	1.	-5.	288	1.	-4.
169	2.	-7.	289	2.	-3.
170	1.	-7.	290	3.	6.
171	2.	-8.	291	2.	0.
172	1.	-8.	292	0.	7.
173	0.	-10.	293	1.	7.
174	1.	-9.	294	2.	6.
175	5.	-8.	295	2.	4.
176	69.	-7.	296	65.	5.
177	182.	-6.	297	288.	1.
178	314.	-5.	298	720.	2.
179	762.	-7.	299	1127.	4.
180	1760.	-0.	300	1243.	6.
181	1338.	2.	301	1224.	6.
182	1225.	4.	302	547.	6.
183	732.	4.	303	978.	6.
184	313.	3.	304	768.	7.
185	79.	2.	305	158.	7.
186	6.	1.	306	0.	8.
187	8.	-1.	307	0.	5.
188	6.	-1.	308	0.	3.
189	4.	0.	309	1.	2.
190	3.	-1.	310	1.	2.
191	2.	0.	311	1.	4.
192	2.	-1.	312	3.	5.
193	1.	-2.	313	0.	3.
194	2.	-1.	314	1.	3.
195	2.	1.	315	1.	3.
196	1.	1.	316	1.	6.
197	1.	1.	317	2.	4.
198	1.	1.	318	1.	5.
199	6.	-0.	319	4.	9.
200	20.	-1.	320	54.	9.
201	322.	-1.	321	461.	9.
202	743.	-0.	322	1802.	12.
203	1820.	4.	323	1469.	13.
204	1743.	1.	324	1065.	14.
205	1495.	1.	325	1029.	14.
206	1559.	1.	326	1937.	15.
207	1087.	0.	327	894.	14.
208	816.	-1.	328	705.	13.
209	84.	-2.	329	158.	12.
210	0.	-3.	330	5.	11.
211	0.	-4.	331	4.	11.
212	0.	-5.	332	1.	8.
213	0.	-6.	333	2.	8.
214	0.	-5.	334	3.	5.
215	0.	-4.	335	5.	5.

APPENDIX B2

SOLCOST PERFORMANCE ANALYSIS

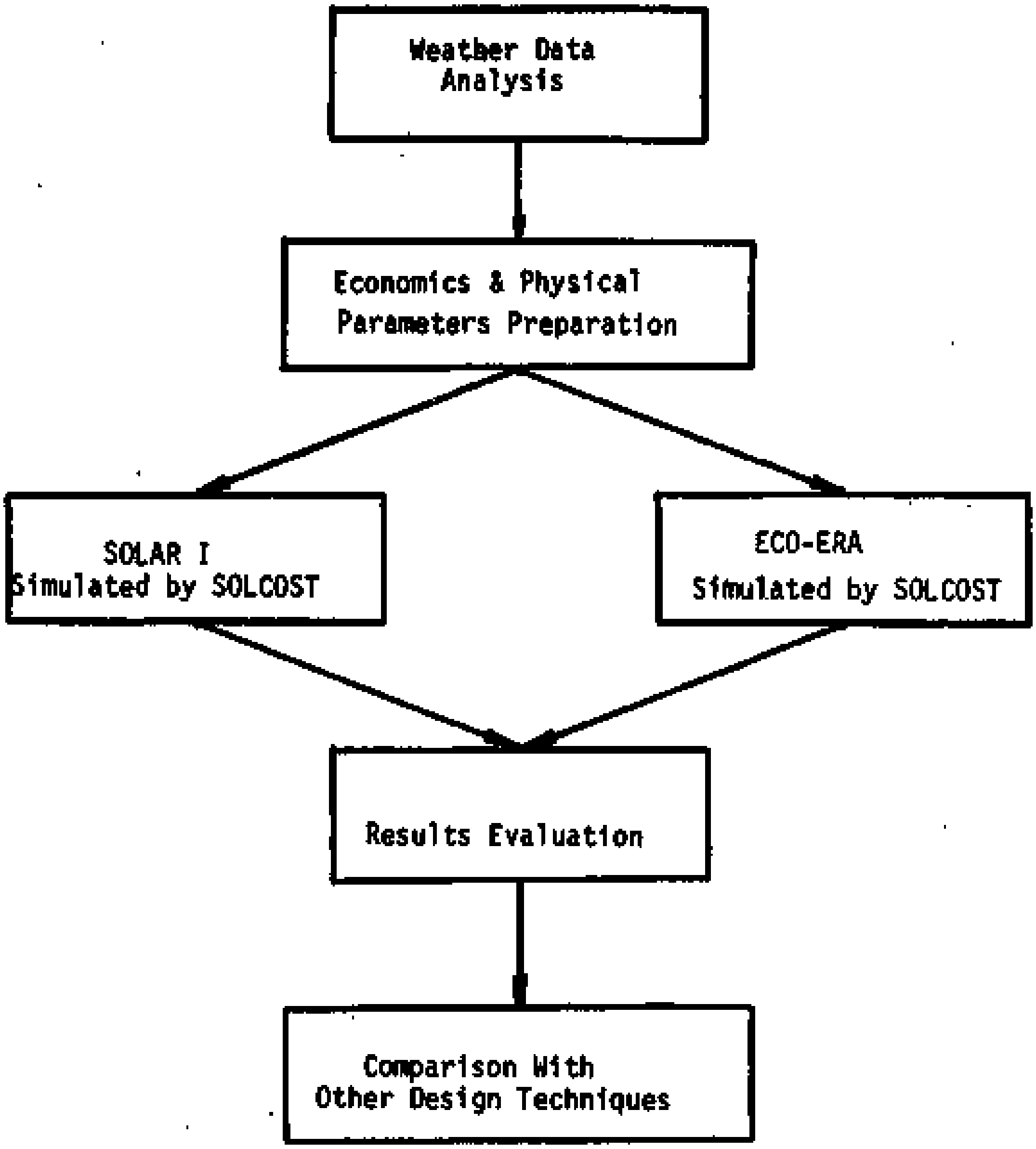

Figure B2.1: Flowchart of the Validation Process of SOLCOST

SAMPLE PROBLEM :DENVER RESIDENCE SPACE HEATING

COLLECTOR SIZE OPTIMIZATION BY MITAS/SOLCOST

COLLECTOR TYPE = USER DEFINED
BEST SOLAR COLLECTOR SIZE FOR TILT ANGLE OF 55. DEGREES (SQUARE FEET) 1019.2

ECONOMIC COMPARISON ANALYSIS - OPTIMUM COLLECTOR SIZE FOR 55. DEGREE TILT ANGLE. FINANCIAL SITUATION--RESIDENCE

TAX CASH FLOW

YR	(A) BEFORE TAXES CASH FLOW	(B) ANNUAL PROP. TAX	(C) ANNUAL INTEREST	(D) TAX SAVING	(E) ANNUAL TAX	(F) AFTER TAXES CASH FLOW	(G) MORTGAGE PAYMENTS	(H) NET CASH FLOW
0	-21893.49					-21893.49	-19704.15	-2189.35
0					-0.00	0.00		0.00
1	917.27	547.34	1773.37	765.83	N/A	1683.10	2158.52	-475.42
2	1027.07	547.34	1738.71	754.40	N/A	1781.46	2158.52	-377.06
3	1144.56	547.34	1700.93	741.93	N/A	1886.48	2158.52	-272.04
4	1270.27	547.34	1659.74	728.34	N/A	1998.60	2158.52	-159.92
5	1404.78	547.34	1614.85	713.52	N/A	2118.30	2158.52	-40.22
6	1548.71	547.34	1565.92	697.38	N/A	2246.08	2158.52	87.56
7	1702.71	547.34	1512.59	679.78	N/A	2382.49	2158.52	223.97
8	1867.49	547.34	1454.46	660.59	N/A	2528.09	2158.52	369.57
9	2043.81	547.34	1391.09	639.68	N/A	2683.49	2158.52	524.97
10	2232.47	547.34	1322.02	616.89	N/A	2849.36	2158.52	690.84
11	2434.34	547.34	1246.74	592.04	N/A	3026.38	2158.52	867.86
12	2650.33	547.34	1164.68	564.96	N/A	3215.30	2158.52	1056.78
13	2881.45	547.34	1075.23	535.45	N/A	3416.90	2158.52	1258.38
14	3128.75	547.34	977.74	503.27	N/A	3632.02	2158.52	1473.50
15	3393.35	547.34	871.46	468.20	N/A	3861.56	2158.52	1703.04
16	3676.48	547.34	755.63	429.98	N/A	4106.46	2158.52	1947.94
17	3979.43	547.34	629.37	388.31	N/A	4367.74	2158.52	2209.22
18	4303.58	547.34	491.75	342.90	N/A	4646.48	2158.52	2487.96
19	4650.42	547.34	341.74	293.39	N/A	4943.82	2158.52	2785.30
20	5021.54	547.34	178.23	239.44	N/A	5260.98	2158.52	3102.46
TOTALS	29385.36	10399.41	21692.88	10590.45	N/A	39975.76	23466.29	17275.34

RATE OF RETURN ON INVESTMENT BEFORE TAXES (PERCENT) 7.2 SIMPLE PAYBACK ON INVESTMENT BEFORE TAXES (YEARS) 12.43

RATE OF RETURN ON INVESTMENT AFTER TAXES (PERCENT) 10.1 SIMPLE PAYBACK ON INVESTMENT AFTER TAXES (YEARS) 10.83

RATE OF RETURN ON INVESTED EQUITY (PERCENT) 13.2

LIFETIME COST SAVING, BEST COLLECTOR SIZE $ 13662.92

ANNUAL ENERGY SAVING, BEST COLLECTOR SIZE (MILLIONS OF BTU) = 144.45
FRACTION OF ENERGY DEMAND SAVED (PERCENT) = 90.5

A = ANNUAL OPERATING COST DIFFERENCE (SOLAR MINUS REFERENCE)
B = ANNUAL PROPERTY TAX COST DIFFERENCE
C = ANNUAL INTEREST COST DIFFERENCE
D = INCOME TAX RATE TIMES (B + C)
E = INCOME TAX RATE TIMES (D)
F = A + D
G = ANNUAL MORTGAGE PAYMENT DIFFERENCE
H = F - G

Figure B2.2

SAMPLE PROBLEM ,DENVER RESIDENCE SPACE HEATING

SOLAR ENERGY SYSTEM ECONOMIC COMPARISON ANALYSIS BY MITAS/SOLCOST

SITE LOCATION CODE--DEN SITE LATITUDE = 39.8 CANDIDATE COLLECTOR TILT ANGLES = 55.0
BUILDING FLOOR AREA = 2000.0 BUILDING HEAT LOSS FACTOR = 10.0
SOLAR SYSTEM = LIQUID WITH 1.5 GAL. STORAGE PER SQ. FT. OF COLLECTOR
AUXILIARY ENERGY-- ELECTRIC
LENGTH OF ANALYSIS (YEARS) 20.0

	SOLAR ENERGY SYSTEM	REFERENCE SYSTEM
INITIAL COST (FIXED)	1000.00	0.00
INITIAL COST (PER SQ. FT. OF COLLECTOR)	19.00	--
DOWN PAYMENT (PERCENT)	10.0	10.0
LOAN TERM (YEARS)	20.0	20.0
INTEREST RATE (PERCENT)	9.0	9.0
INCOME TAX RATE (PERCENT)	33.0	33.0
PROPERTY TAX RATE (PERCENT OF INITIAL COST)	2.5	2.5
FIRE INSURANCE RATE (PERCENT)	.500	.500
MAINTENANCE COST PER YEAR (PERCENT OF INITIAL COST)	1.000	.240

MONTH	1	2	3	4	5	6	7	8	9	10	11	12
SOLAR SYSTEM TYPE FLAGS	1	1	1	1	1	1	1	1	1	1	1	1
COLLECTOR INLET TEMPERATURES	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0
SOLAR SYSTEM EFFICIENCY	.950	.950	.950	.950	.950	.950	.950	.950	.950	.950	.950	.950
REFERENCE SYSTEM EFFICIENCY	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
REFERENCE SYSTEM FUEL TYPE FLAGS (SEE BELOW)	2	2	2	2	2	2	2	2	2	2	2	2
BUILDING ENERGY DEMAND (MIL. BTU PER DAY)	.84	.71	.60	.46	.28	.13	.09	.10	.17	.37	.63	.78
MEAN DAILY MINIMUM TEMPERATURE (DEG. F)	15.0	18.0	23.0	32.0	42.0	51.0	57.0	56.0	47.0	36.0	24.0	18.0
MEAN DAILY MAXIMUM TEMPERATURE (DEG. F)	42.0	45.0	50.0	61.0	71.0	82.0	88.0	87.0	79.0	67.0	52.0	45.0
SOLAR FRACTION (PERCENT OF POSSIBLE SUN)	.670	.670	.650	.630	.610	.690	.680	.680	.710	.710	.670	.650
HEATING DEGREE DAYS (DEG. F PER MO.)	1132.0	938.0	887.0	558.0	288.0	66.0	6.0	9.0	117.0	428.0	819.0	1035.0
BUILDING USE SCHEDULE (DAYS PER WEEK)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0

ENERGY COST SCHEDULES---

ELECTRICITY (FUEL TYPE 2)-- $ .038 PER KWH FOR FIRST 6000. KWH PER MONTH, $ .029 PER KWH FOR NEXT 14000. KWH,
$ .016 PER KWH FOR NEXT 100000. KWH
$ .015 PER KWH FOR NEXT 0000000. KWH
DEMAND CHARGE = $0.00 PER KW FOR FIRST 25.0 KW $0.00 PER KW ABOVE 25.0 KW. COST ESCALATION RATE = .070

	NAT. GAS	FUEL OIL	LP GAS	COAL
FUEL TYPE FLAG	1	3	4	5
$ PER MIL. BTU.	0.00	0.00	0.00	0.00
COST ESCALATION RATES	.000	.000	.000	.000

Figure B2.3

DESIGN OF ECO-ERA NUMBER II

ECO-ERA Number II was a house recently constructed in Fort Collins, Colorado as part of the HUD demonstration projects. This house utilizes the air system supplied by the SOLARON Corp. and the system was designed using methods developed at SOLARON and also the F-Chart program developed at the University of Wisconsin. A design goal was that the solar system provide 75 percent of the annual space heating and service hot water requirements. The resulting design led to a collector array consisting of 412 sq. ft. and a storage system containing approximately 11 tons of rocks.

Program SOLCOST was utilized as part of this study to determine the most economic solar system for that particular house. The results shown on Figures B2.4 and B2.5. The input data required to describe the system are shown on Figure B2.4. The results obtained for a collector tilt angle of 45 degrees are shown on Figure B2.5. From Figure B2.5 we see that the optimal collector size is 489.2 sq. ft. and that this sytem would provide 83 percent of the total heating load. This result correlates quite satisfactorily with the result obtained from the other design methods for a system to provide 75 percent of the annual heating load. The lifetime cost savings, obtained from program SOLCOST, are seen to be $15,741.00. This result is also comparable with that obtained by the previously used methods.

DATE 09/29/76 MITAS (MARTIN MARIETTA CDC6000 SERIES VERSION) - NUMERICAL DIFFERENCING ANALYZER - FD23B PAGE 1

ECO-AIR HOUSE WITH DENVER WEATHER

SOLAR ENERGY SYSTEM ECONOMIC COMPARISON ANALYSIS BY MITAS/SOLCOST

SITE LOCATION CODE--DEN SITE LATITUDE = 39.8 CANDIDATE COLLECTOR TILT ANGLES = 30.0 35.0 40.0 45.0 50.0

9.0 65.0
BUILDING FLOOR AREA = 1950.0 BUILDING HEAT LOSS FACTOR = 7.4
SOLAR SYSTEM = AIR
AUXILIARY ENERGY-- ELECTRIC
LENGTH OF ANALYSIS (YEARS) 20.0

	SOLAR ENERGY SYSTEM	REFERENCE SYSTEM
INITIAL COST (FIXED)	0.00	0.00
INITIAL COST (PER SQ. FT. OF COLLECTOR)	25.00	--
DOWN PAYMENT (PERCENT)	10.0	10.0
LOAN TERM (YEARS)	20.0	20.0
INTEREST RATE (PERCENT)	9.0	9.0
INCOME TAX RATE (PERCENT)	33.0	33.0
PROPERTY TAX RATE (PERCENT OF INITIAL COST)	2.5	2.5
FIRE INSURANCE RATE (PERCENT)	.500	.500
MAINTENANCE COST PER YEAR (PERCENT OF INITIAL COST)	.800	.240

MONTH	1	2	3	4	5	6	7	8	9	10	11	12
SOLAR SYSTEM TYPE FLAGS	7	7	7	7	7	7	7	7	7	7	7	7
SOLAR SYSTEM EFFICIENCY	.950	.950	.950	.950	.950	.950	.950	.950	.950	.950	.950	.950
REFERENCE SYSTEM EFFICIENCY	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
REFERENCE SYSTEM FUEL TYPE FLAGS (SEE BELOW)	2	2	2	2	2	2	2	2	2	2	2	2
BUILDING ENERGY DEMAND (MIL. BTU PER DAY)	.63	.54	.51	.36	.23	.12	.09	.09	.15	.29	.48	.58
MEAN DAILY MINIMUM TEMPERATURE (DEG. F)	15.0	18.0	23.0	32.0	42.0	51.0	57.0	56.0	47.0	36.0	24.0	16.0
MEAN DAILY MAXIMUM TEMPERATURE (DEG. F)	42.0	45.0	50.0	61.0	71.0	82.0	88.0	87.0	79.0	67.0	42.0	45.0
SOLAR FRACTION (PERCENT OF POSSIBLE SUN)	.670	.670	.650	.630	.610	.690	.680	.680	.710	.710	.670	.650
HEATING DEGREE DAYS (DEG. F PER MO.)	1132.0	938.0	487.0	558.0	288.0	66.0	6.0	9.0	117.0	428.0	819.0	1035.0
BUILDING USE SCHEDULE (DAYS PER WEEK)	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0

ENERGY COST SCHEDULES---

ELECTRICITY (FUEL TYPE 2)-- $ .030 PER KWH FOR FIRST 6000. KWH PER MONTH. $ .029 PER KWH FOR NEXT 148000. KWH.
$ .016 PER KWH FOR NEXT 130000. KWH
$ .015 PER KWH FOR NEXT 99031000. KWH
DEMAND CHARGE = $0.00 PER KW FOR FIRST 25.0 KW $0.00 PER KW ABOVE 25.0 KW. COST ESCALATION RATE = .070

	NAT. GAS	FUEL OIL	LP GAS	COAL
FUEL TYPE FLAG	1	3	4	5
$ PER MIL. BTU.	0.00	0.00	0.00	0.00
COST ESCALATION RATES	.000	.000	.000	.000

Figure B2.4

DATE 09/29/76 MITAS (MARTIN MARIETTA CDC6400 SERIES VERSION) - NUMERICAL DIFFERENCING ANALYZER - FOR38 PAGE 5

ECO-AIR HOUSE WITH DENVER WEATHER

COLLECTOR SIZE OPTIMIZATION BY MITAS/SOLCOST

COLLECTOR TYPE = AIR
BEST SOLAR COLLECTOR SIZE FOR TILT ANGLE OF 45. DEGREES (SQUARE FEET) 489.2

ECONOMIC COMPARISON ANALYSIS - OPTIMUM COLLECTOR SIZE FOR 45. DEGREE TILT ANGLE. FINANCIAL SITUATION--RESIDENCE

TAX CASH FLOW

YR	(A) BEFORE TAXES CASH FLOW	(B) ANNUAL PROP. TAX	(C) ANNUAL INTEREST	(D) TAX SAVING	(E) ANNUAL TAX	(F) AFTER TAXES CASH FLOW	(G) MORTGAGE PAYMENTS	(H) NET CASH FLOW
0	-13329.87					-13329.87	-11996.88	-1332.99
0					-0.00	0.00		0.00
1	739.55	333.25	1079.72	466.28	N/A	1205.82	1314.22	-108.40
2	819.07	333.25	1058.61	459.31	N/A	1278.39	1314.22	-35.83
3	904.17	333.25	1035.61	451.72	N/A	1355.89	1314.22	41.67
4	995.22	333.25	1010.54	444.45	N/A	1439.67	1314.22	124.45
5	1092.64	333.25	983.20	434.43	N/A	1527.07	1314.22	212.85
6	1196.89	333.25	953.41	474.60	N/A	1671.49	1314.22	357.27
7	1360.43	333.25	920.94	411.88	N/A	1772.31	1314.22	458.10
8	1427.74	333.25	885.55	402.20	N/A	1829.98	1314.22	515.77
9	1555.48	333.25	846.97	389.47	N/A	1944.95	1314.22	630.74
10	1692.13	333.25	804.91	375.59	N/A	2067.72	1314.22	753.50
11	1834.34	333.25	759.08	360.47	N/A	2198.80	1314.22	884.58
12	1995.79	333.25	709.11	343.95	N/A	2339.76	1314.22	1024.54
13	2162.17	333.25	654.66	326.01	N/A	2488.18	1314.22	1173.96
14	2341.28	333.25	595.29	306.42	N/A	2647.70	1314.22	1333.48
15	2528.93	333.25	530.59	285.07	N/A	2818.00	1314.22	1503.78
16	2738.00	333.25	460.07	261.79	N/A	2999.79	1314.22	1685.57
17	2957.42	333.25	383.19	236.42	N/A	3193.84	1314.22	1879.63
18	3194.20	333.25	299.40	206.77	N/A	3400.97	1314.22	2086.75
19	3448.41	333.25	208.07	178.63	N/A	3622.04	1314.22	2307.83
20	3712.21	333.25	108.51	145.78	N/A	3857.99	1314.22	2543.77
TOTALS	25314.22	6331.69	13207.72	6446.00	N/A	31762.22	14287.44	17941.06

RATE OF RETURN ON INVESTMENT BEFORE TAXES (PERCENT) 9.5 SIMPLE PAYBACK ON INVESTMENT BEFORE TAXES (YEARS) 10.1?

RATE OF RETURN ON INVESTMENT AFTER TAXES (PERCENT) 12.3 SIMPLE PAYBACK ON INVESTMENT AFTER TAXES (YEARS) 8.0?

RATE OF RETURN ON INVESTED EQUITY (PERCENT) 21.6

LIFETIME COST SAVING, BEST COLLECTOR SIZE $ 15741.63

ANNUAL ENERGY SAVING, BEST COLLECTOR SIZE (MILLIONS OF BTU) = 103.06
FRACTION OF ENERGY DEMAND SAVED (PERCENT) = 83.0

A = ANNUAL OPERATING COST DIFFERENCE (SOLAR MINUS REFERENCE) E = INCOME TAX RATE TIMES (D)
B = ANNUAL PROPERTY TAX COST DIFFERENCE F = A + D
C = ANNUAL INTEREST COST DIFFERENCE G = ANNUAL MORTGAGE PAYMENT DIFFERENCE
D = INCOME TAX RATE TIMES (B + C) H = F - G

Figure B2.5

APPENDIX B3

SAMPLE RESULTS OF SOLSIM PERFORMANCE ANALYSIS FOR DECEMBER TRAINING PERIOD

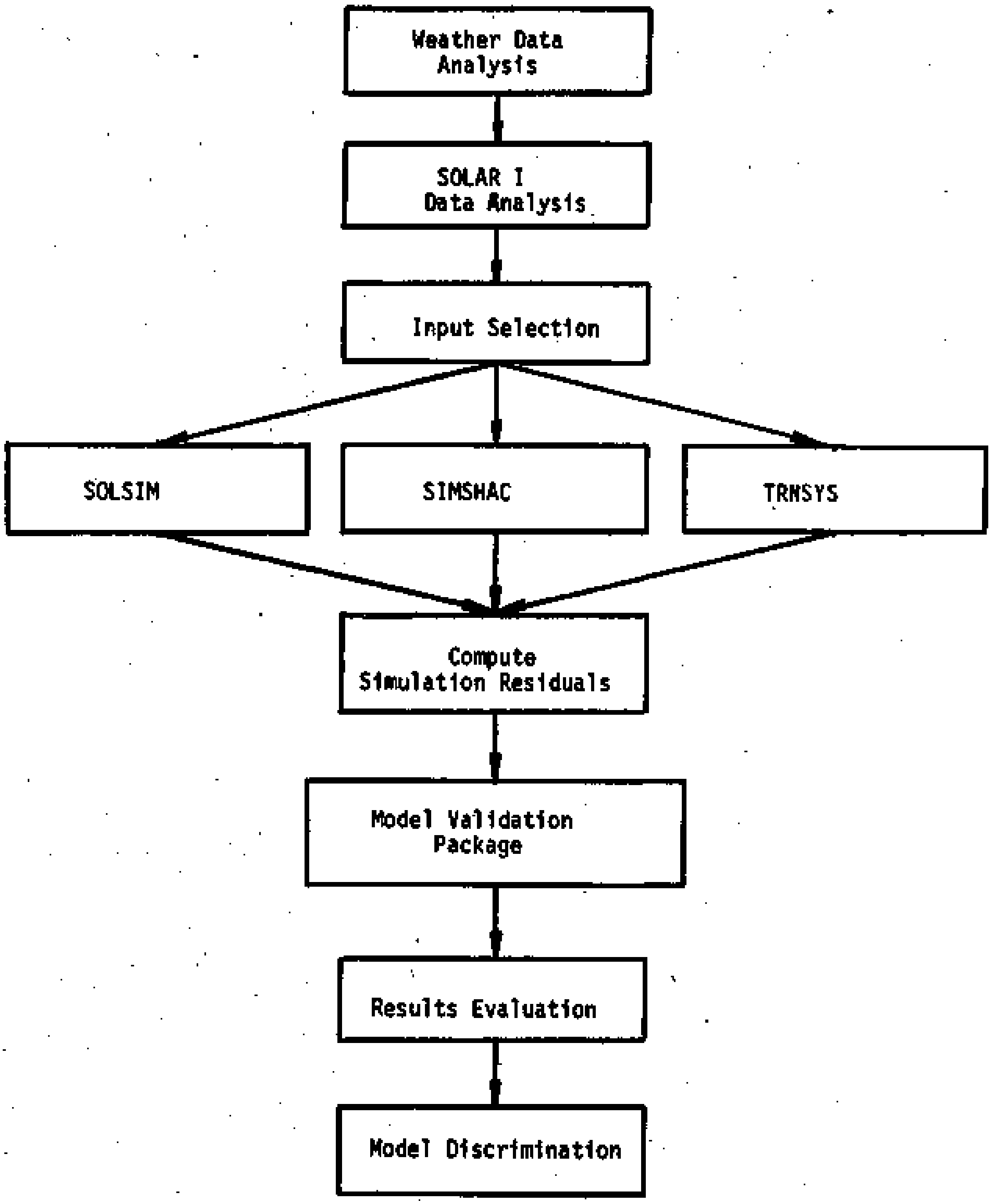

Figure B3.1: Flowchart of the Validation Process of SOLSIM

108

SOLSIM COMPONENTS
(Set-Up for SOLAR I)

- Flat Plate Collector
- Auxiliary Heater
- Hot Water Storage
- Solar Service Hot Water
- UA Heatloss Analysis

Figure B3.2

SOLAR INSOLATION ON THE HORIZONTAL

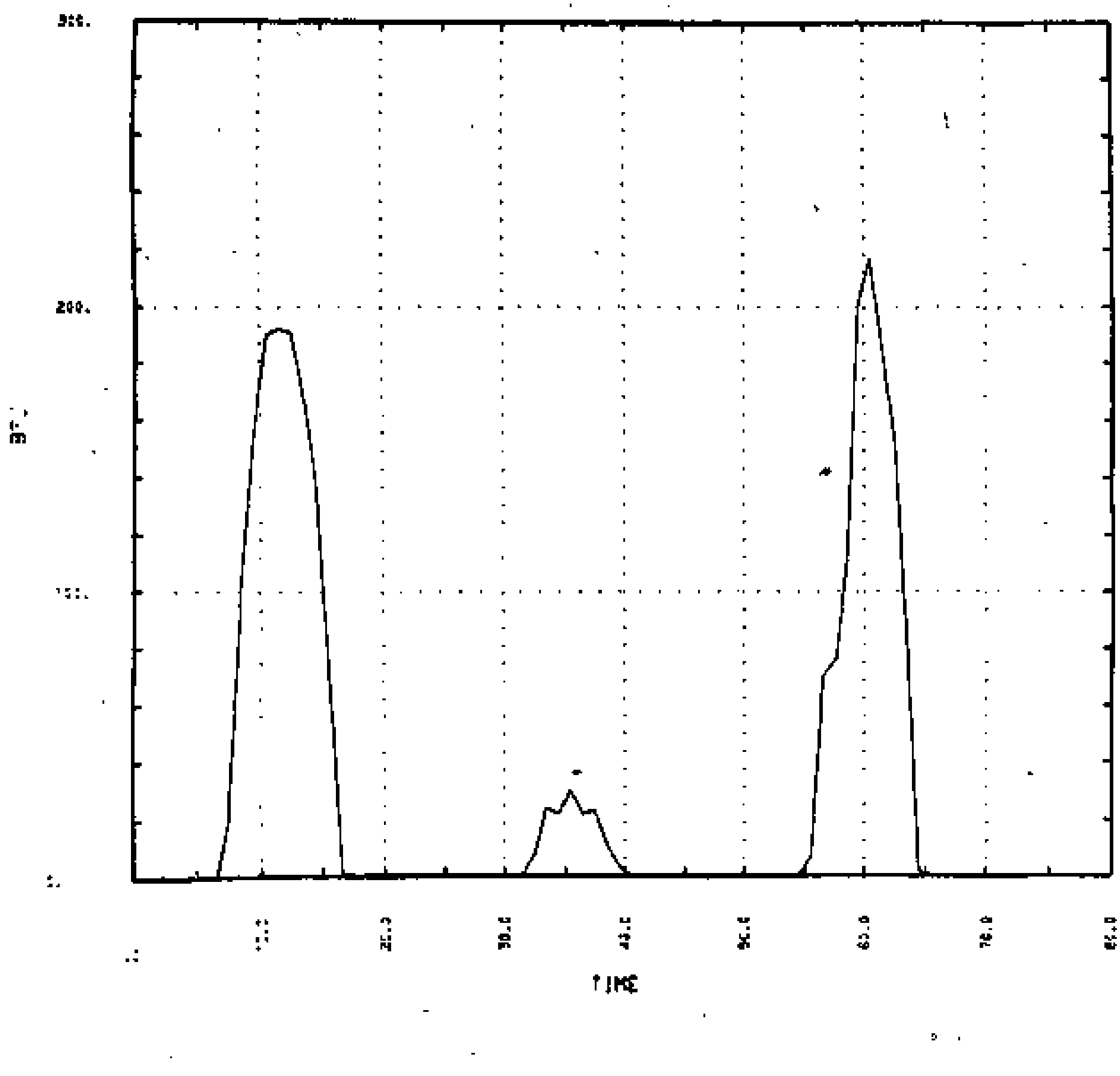

Figure B3.3

OUTDOOR TEMPERATURE

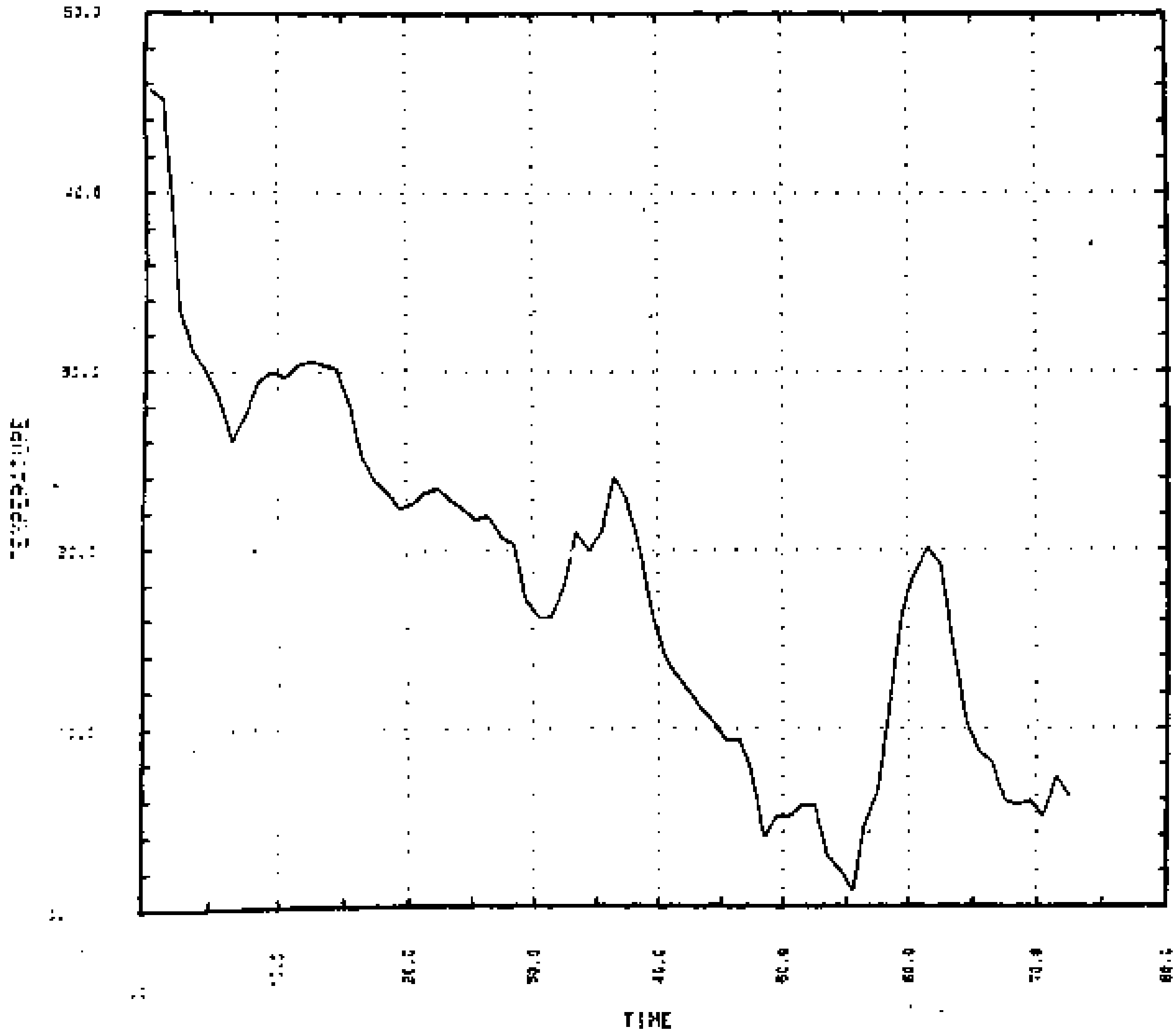

Figure B3.4

STORAGE TANK TEMPERATURE

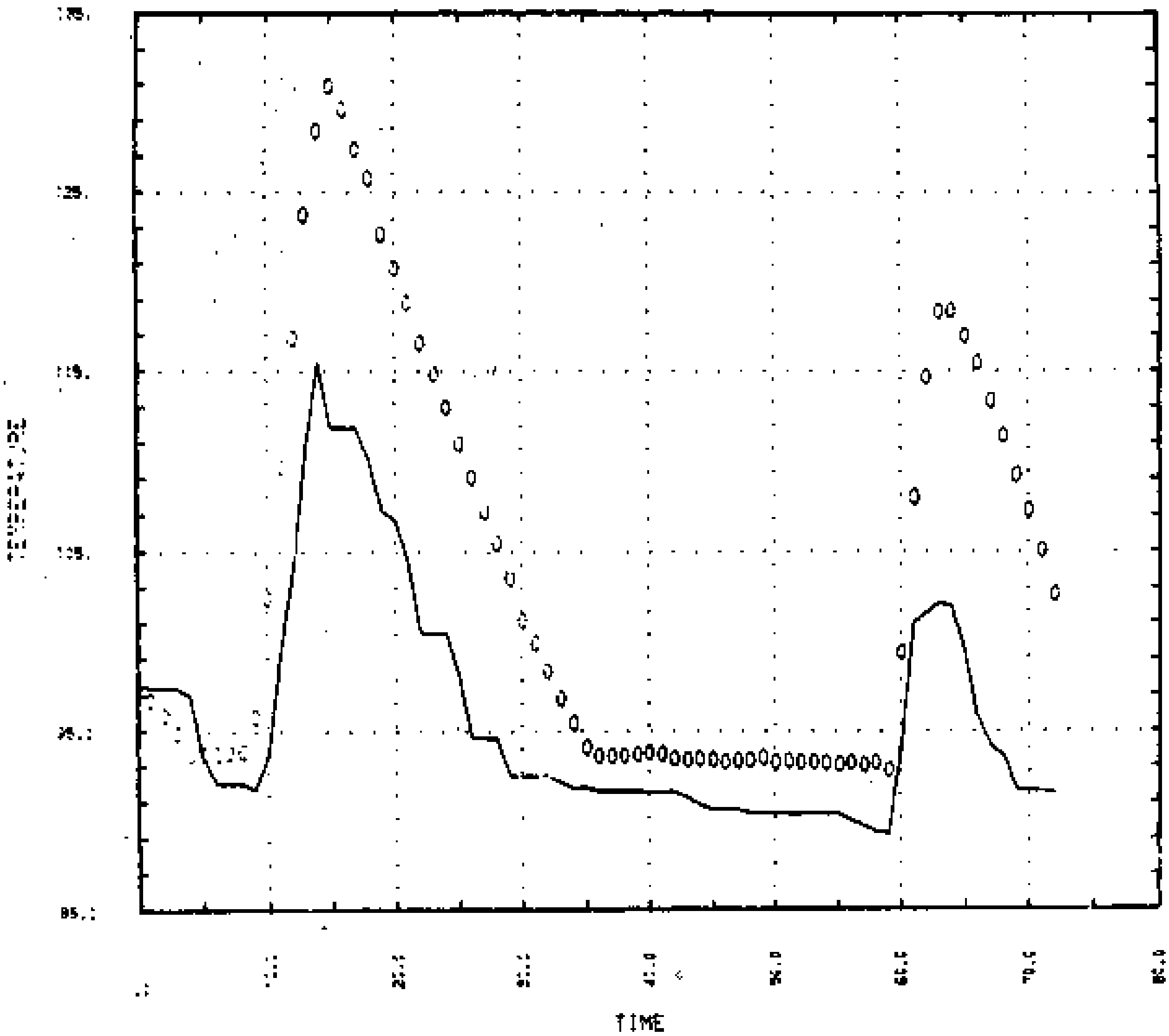

Figure B3.5 : SOLSIM PERFORMANCE ANALYSIS

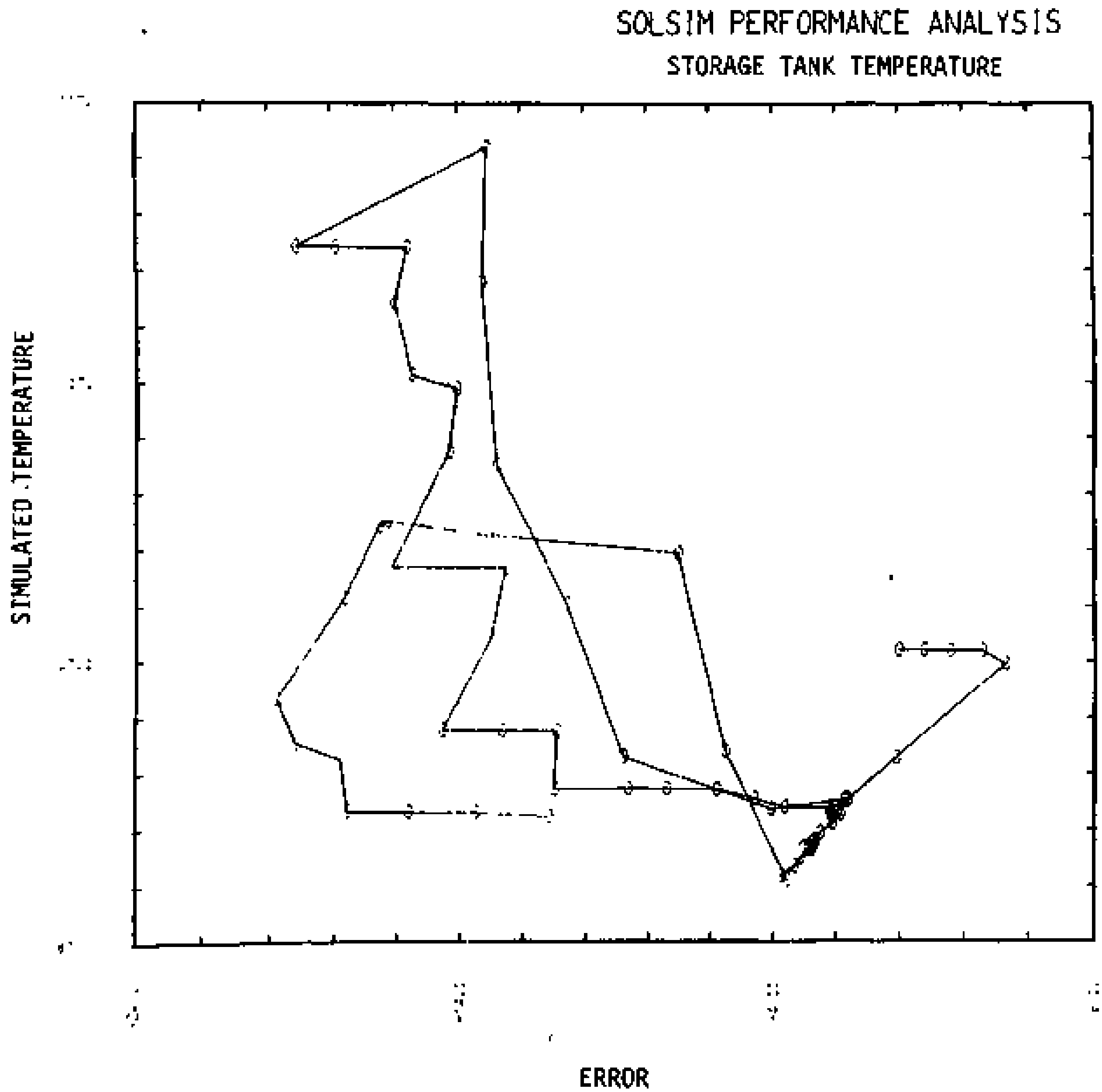

Figure B3.6 : SIMULATED DATA VS. SIMULATION ERROR

113

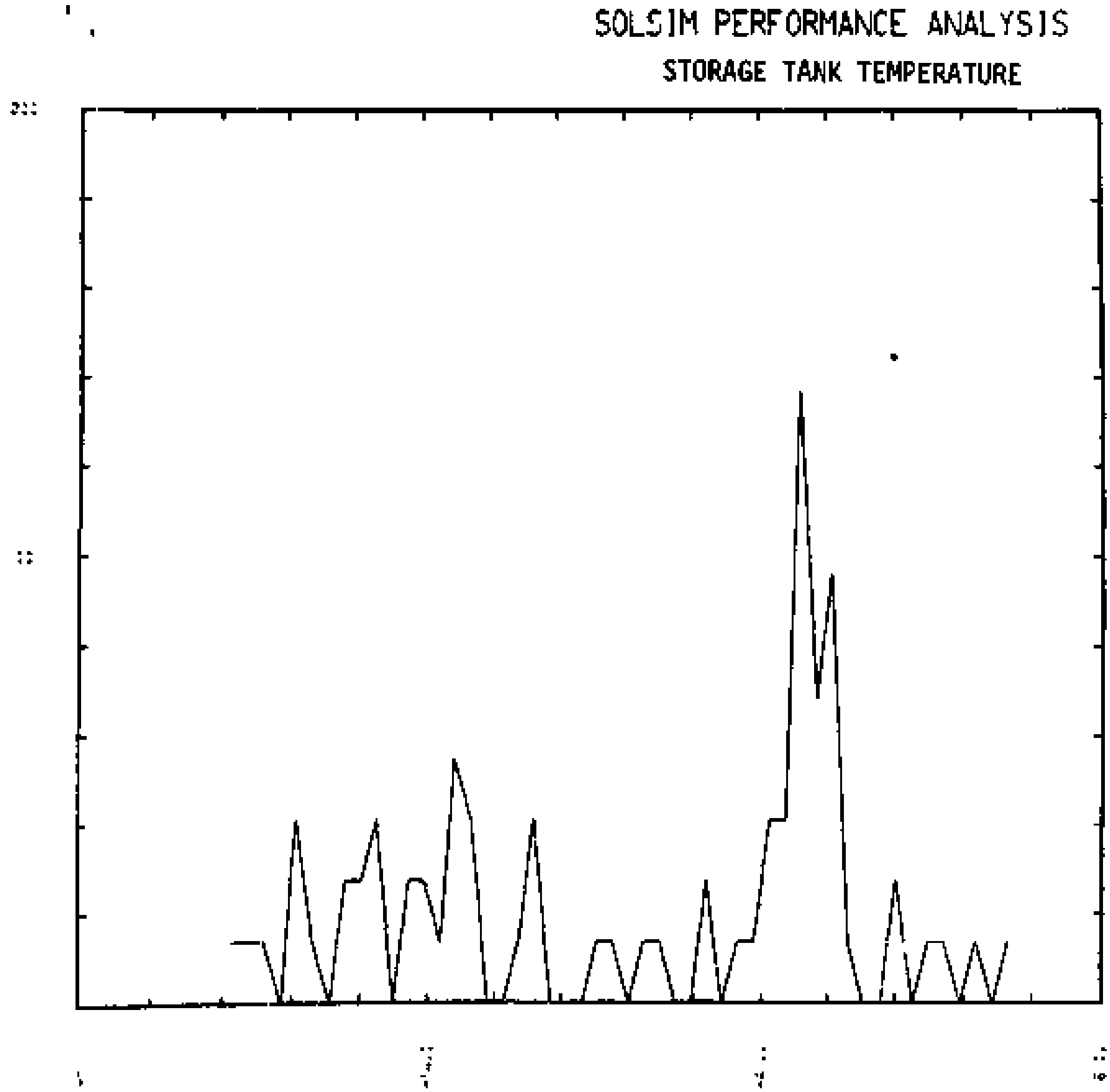

Figure B3.7 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

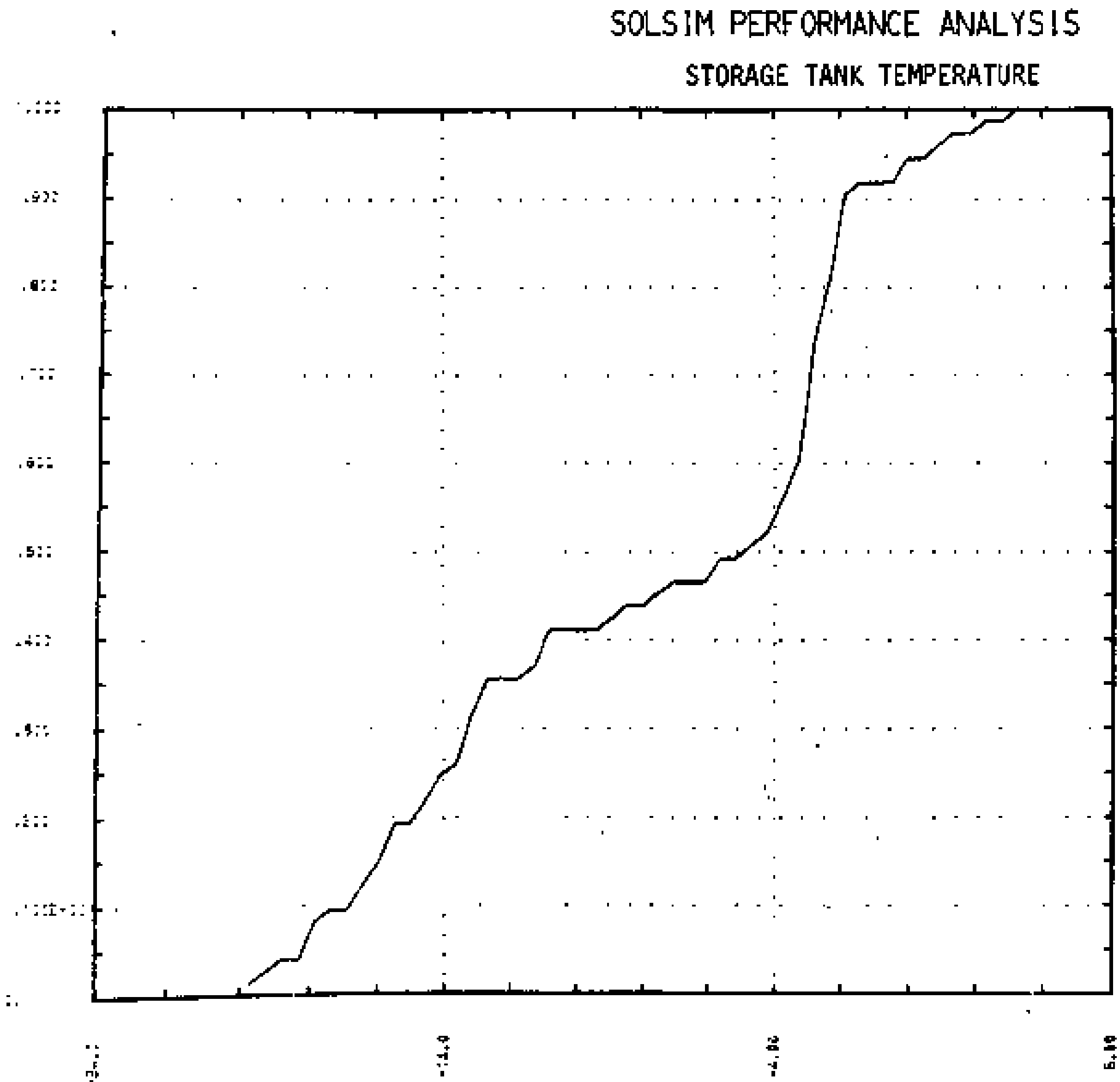

Figure B3.8: CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

ENCLOSURE TEMPERATURE

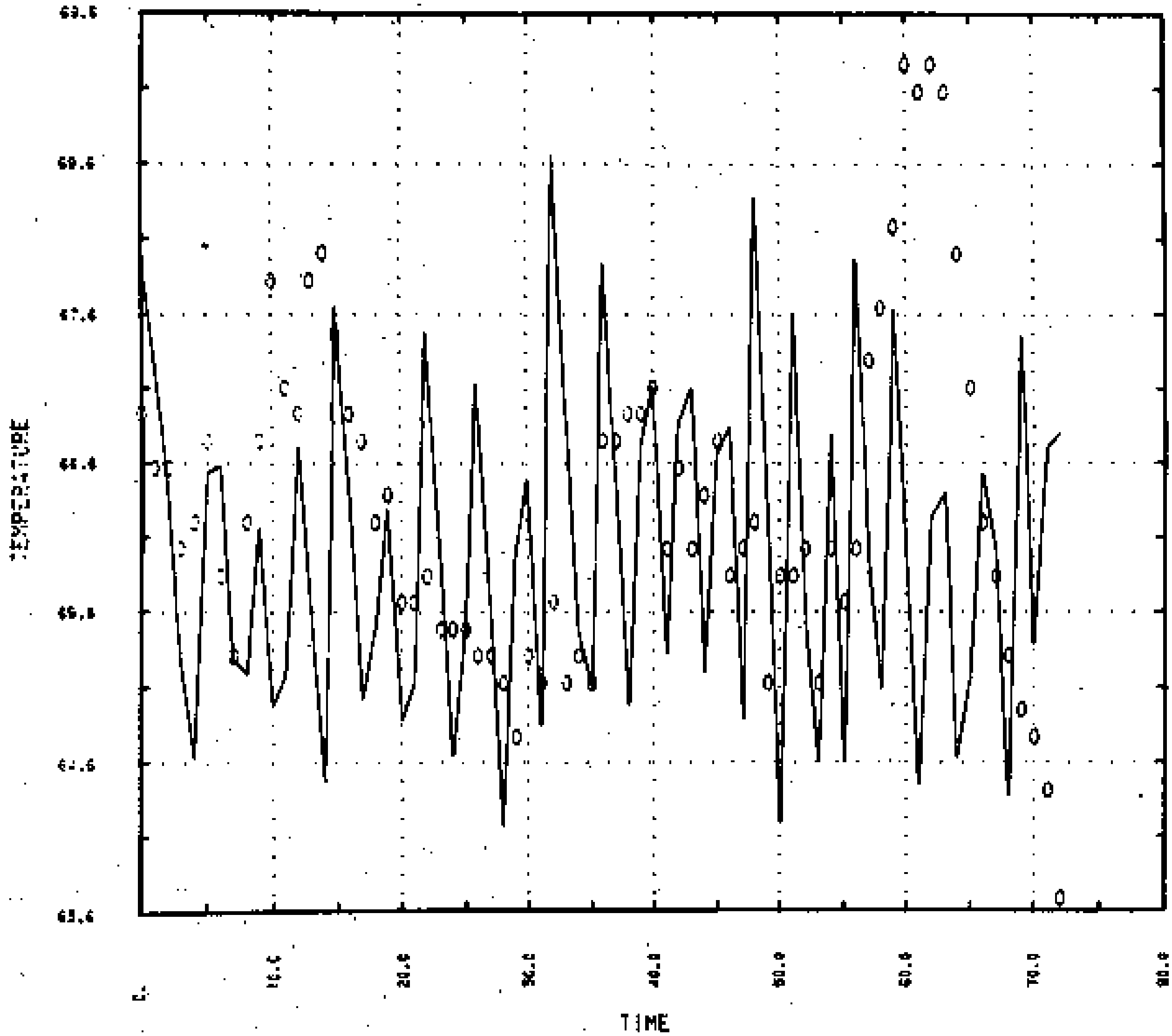

Figure B3.9 : SOLSIM PERFORMANCE ANALYSIS

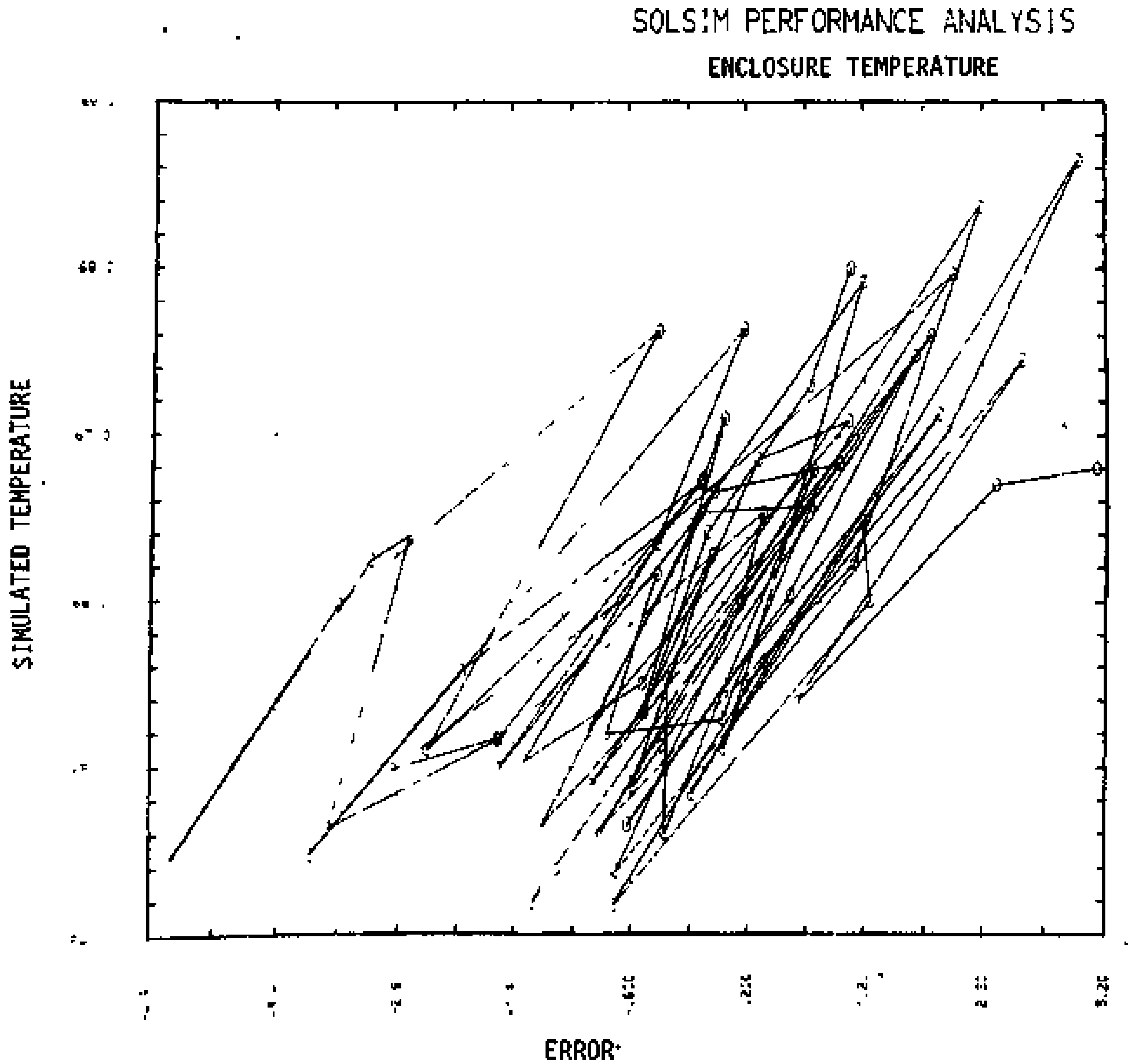

Figure B3.10 : SIMULATED DATA VS. SIMULATION ERROR

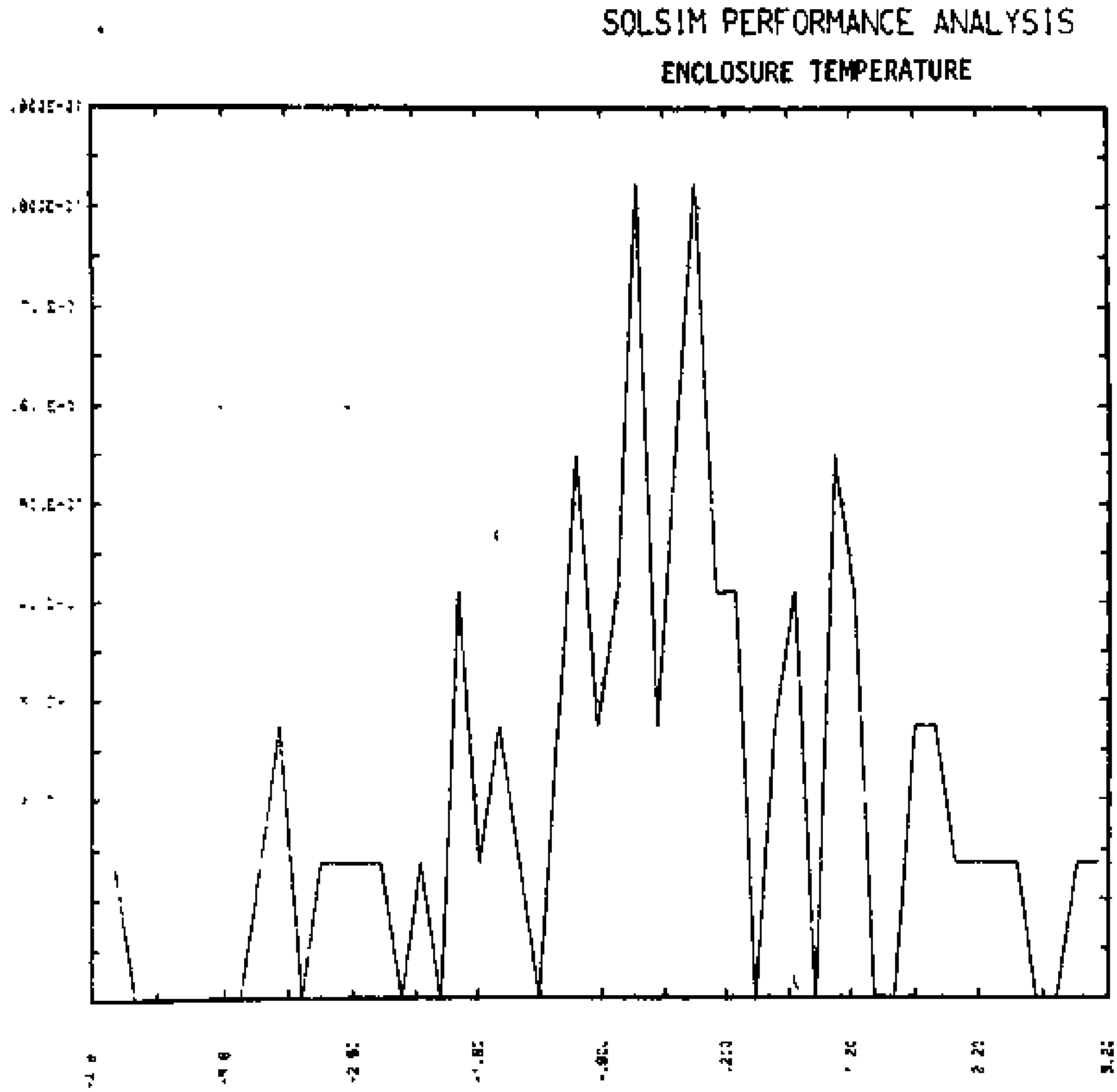

Figure B3.11: RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

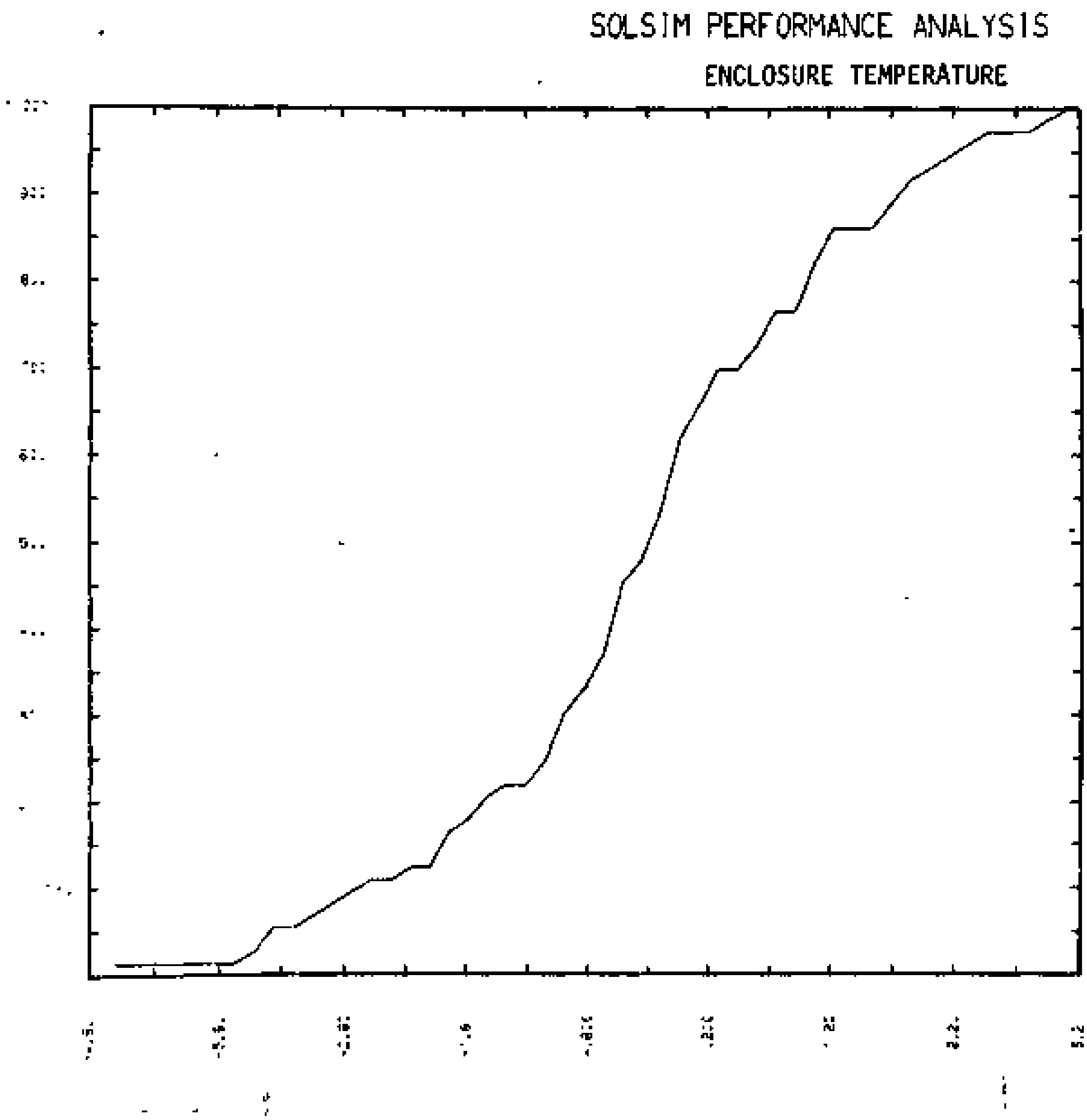

Figure B3.12: CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

COLLECTOR INLET TEMPERATURE

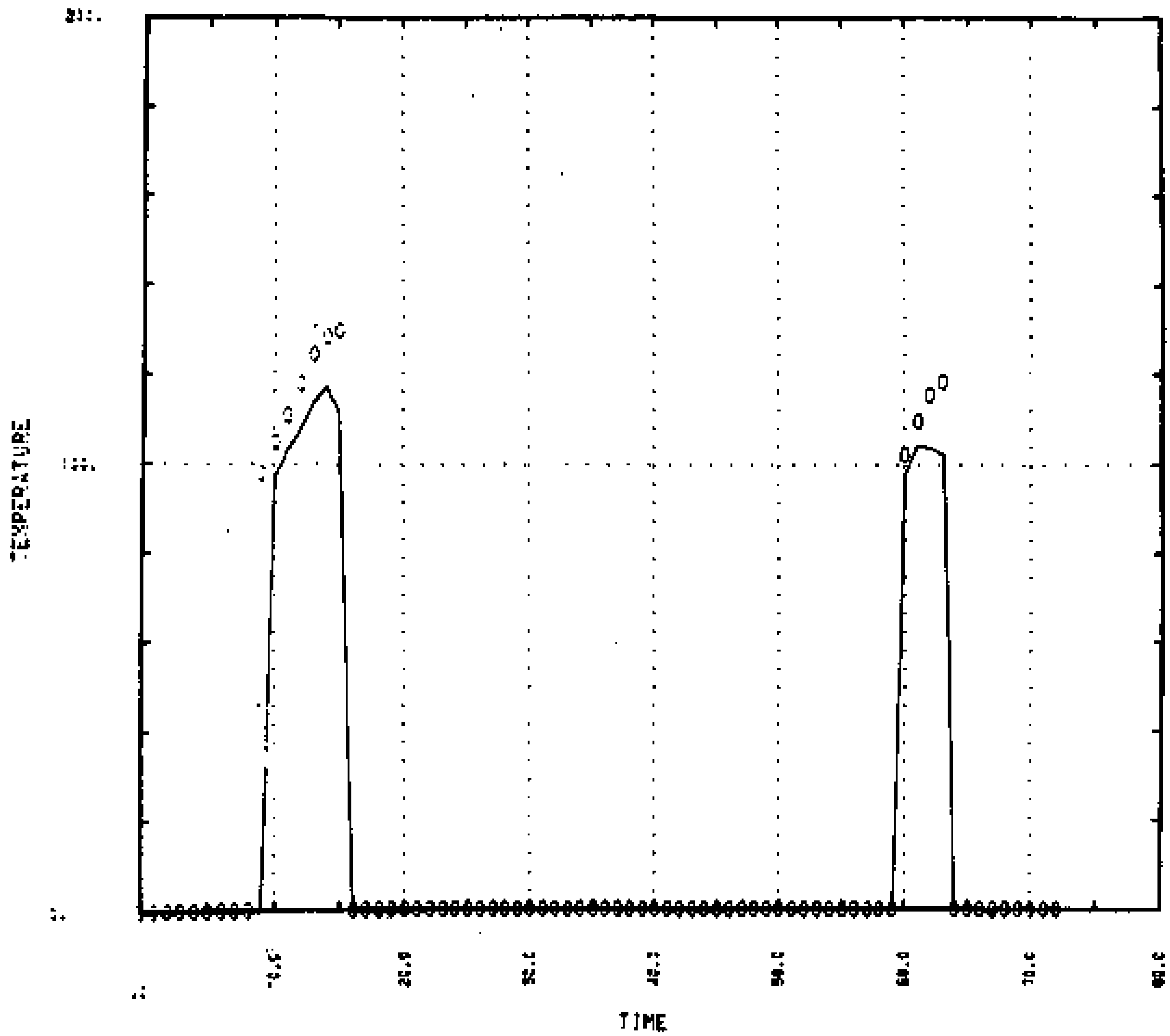

Figure B3.13 : SOLSIM PERFORMANCE ANALYSIS

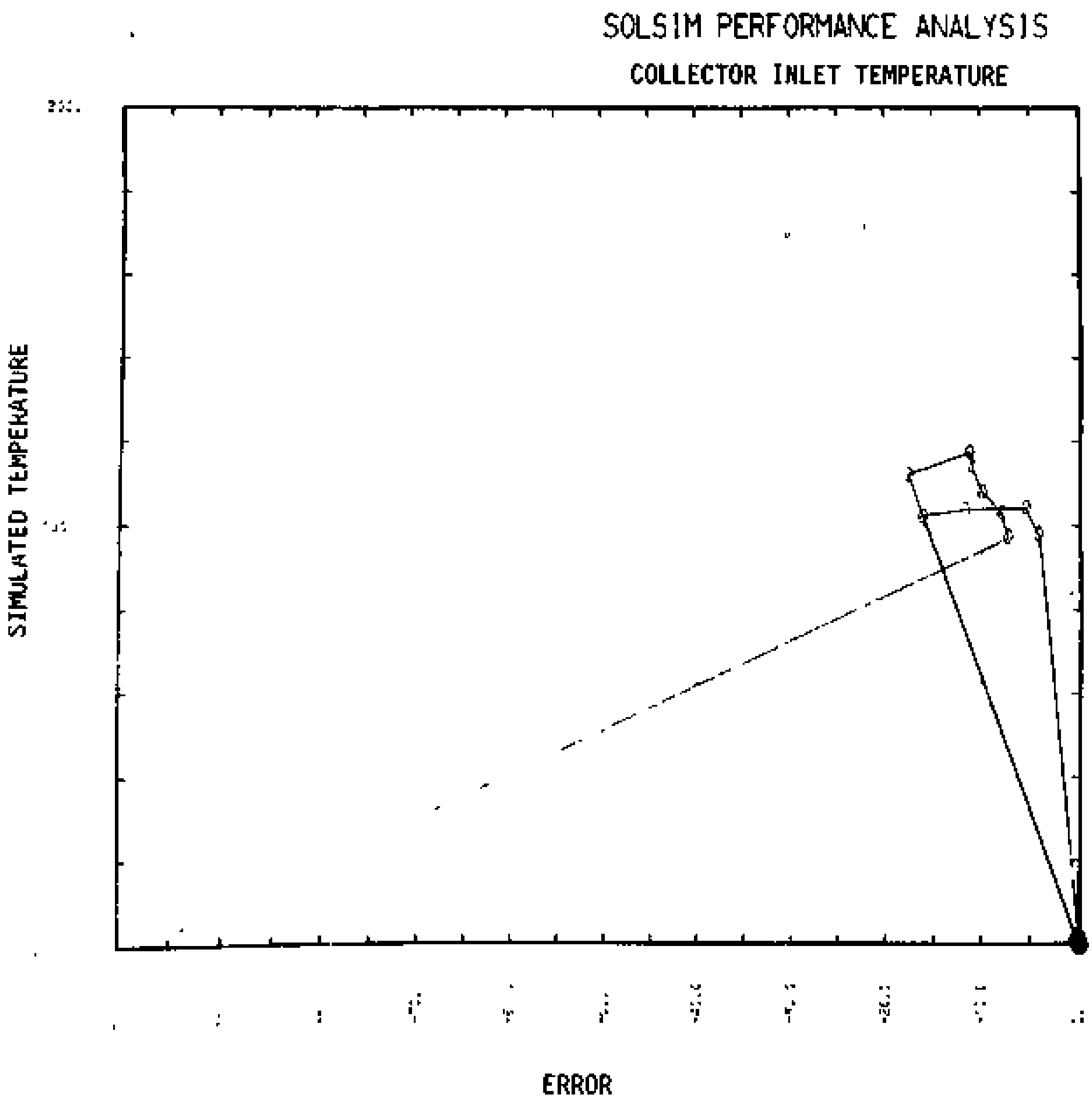

Figure B3.14: SIMULATED DATA VS. SIMULATION ERROR

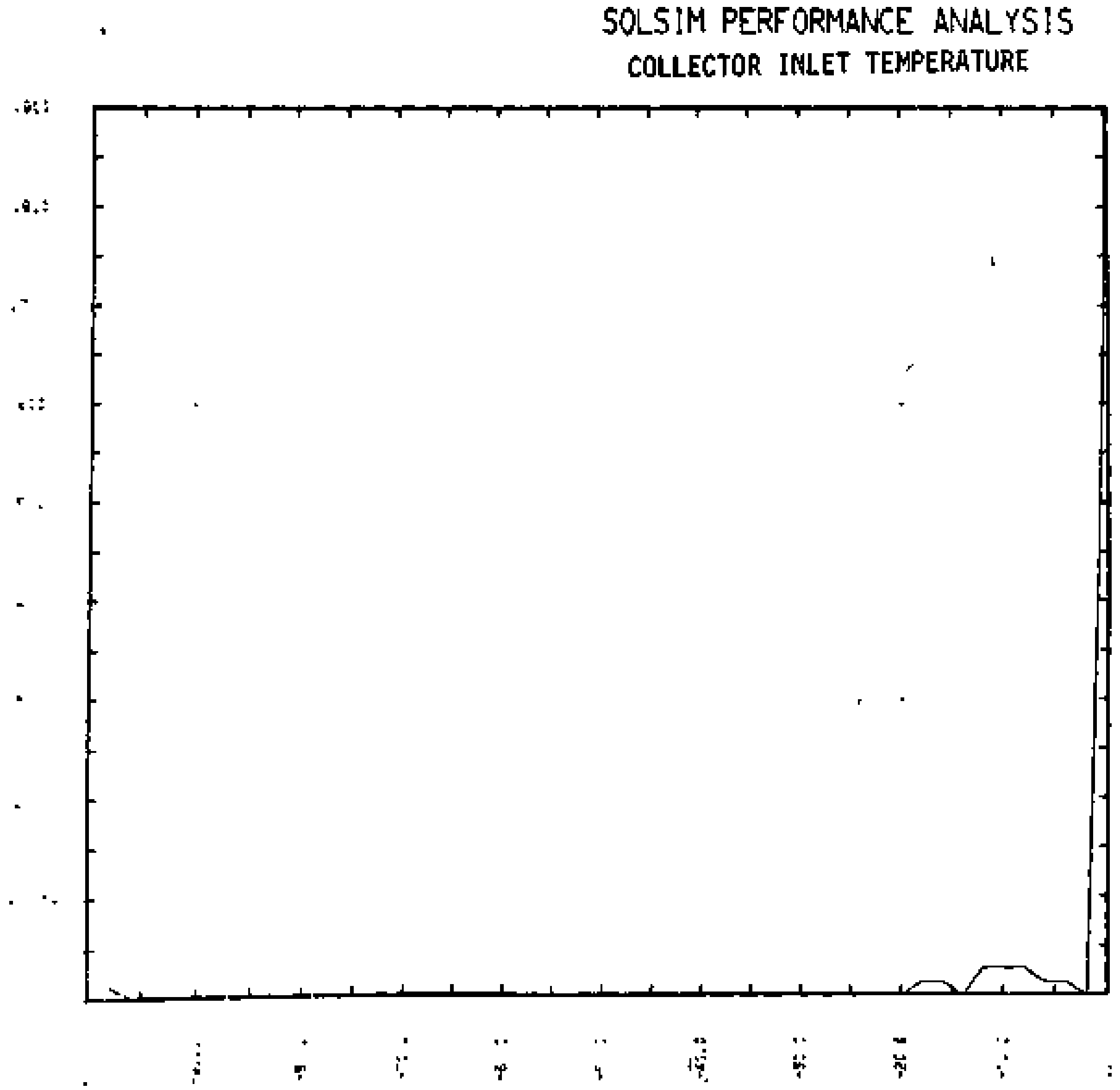

Figure B3.15 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

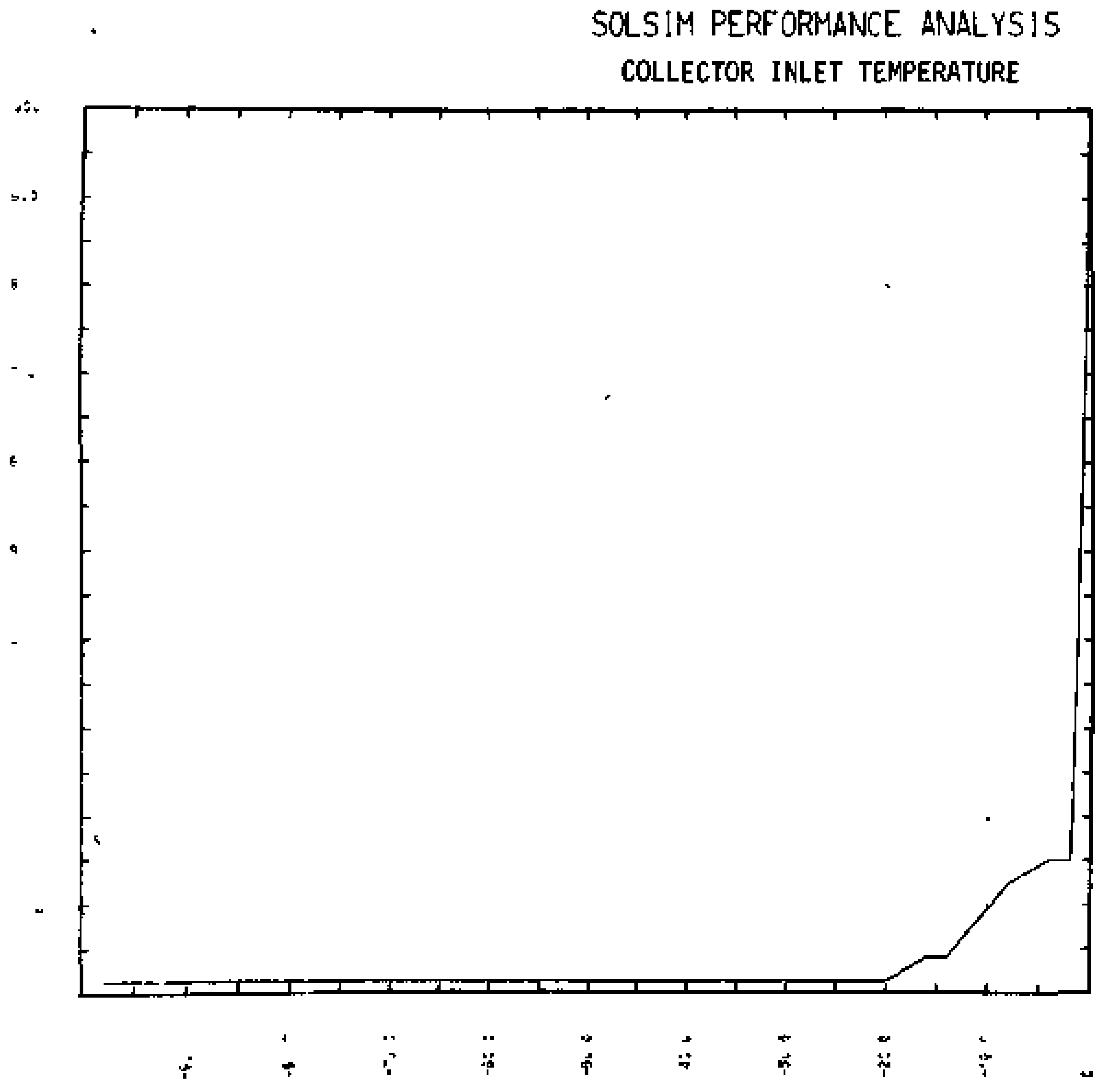

Figure B3.16; CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

COLLECTOR OUTLET TEMPERATURE

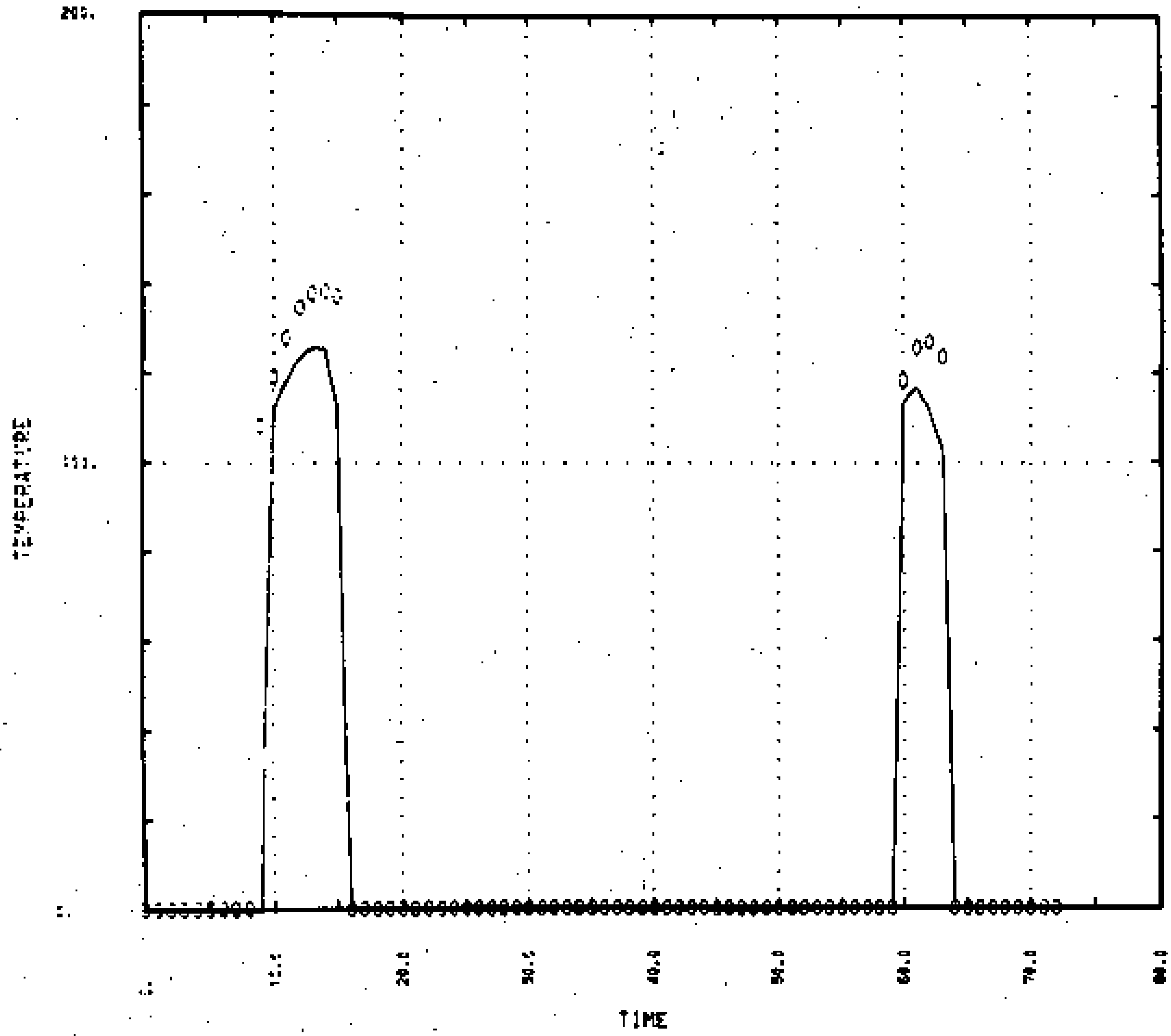

Figure B3.17: SOLSIM PERFORMANCE ANALYSIS

124

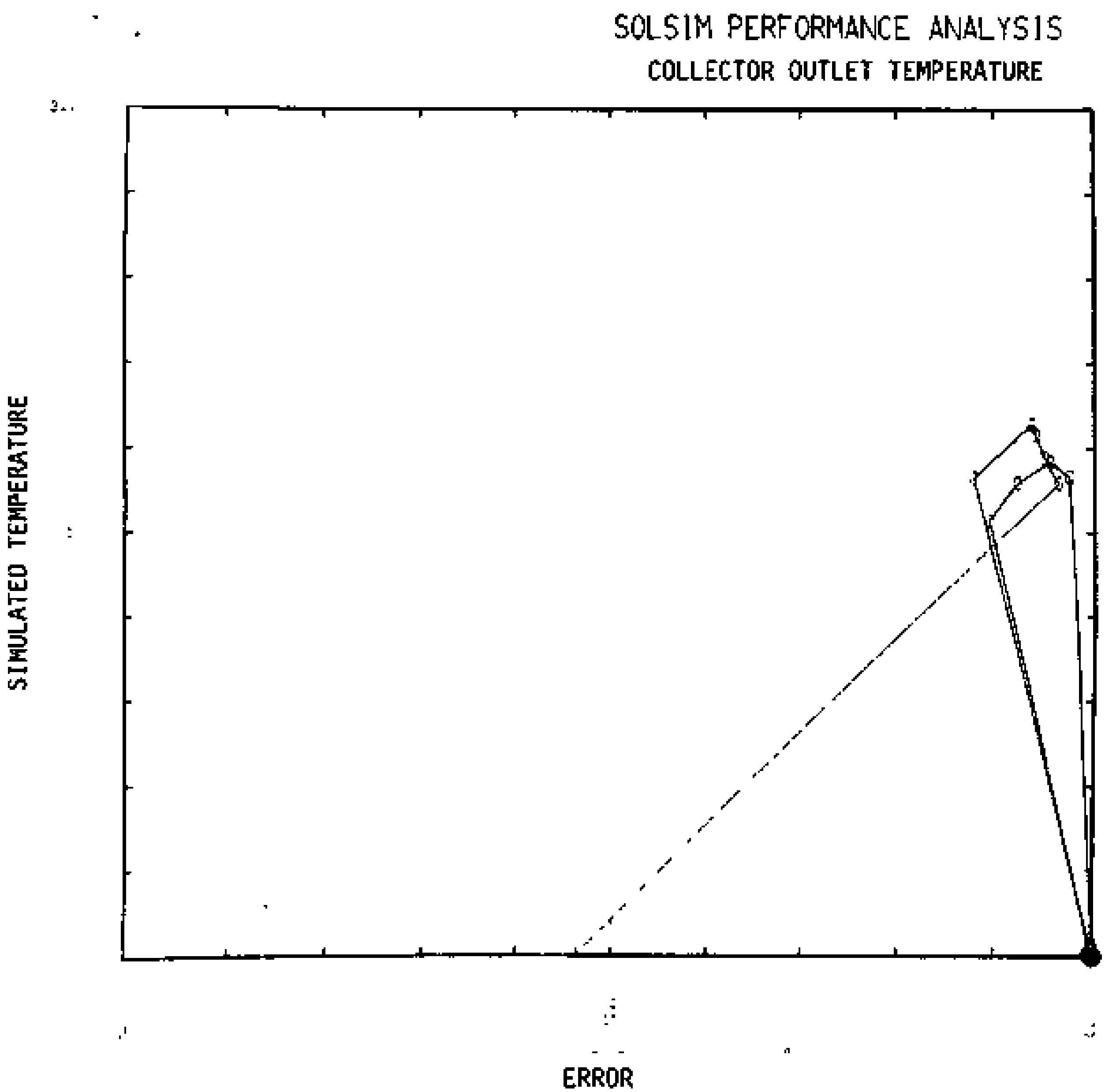

Figure B3.18: SIMULATED DATA VS. SIMULATION ERROR

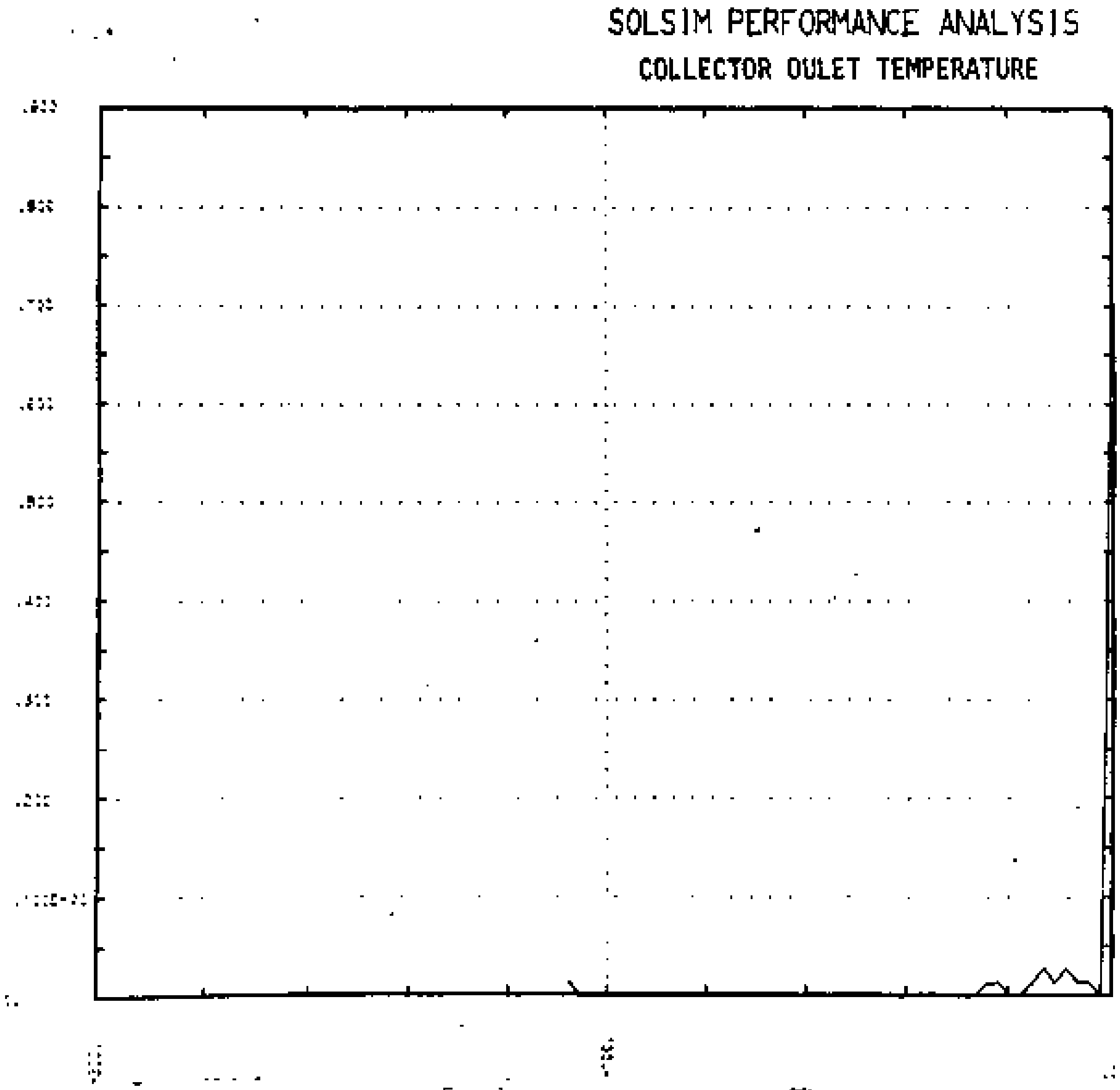

Figure B3.19: RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

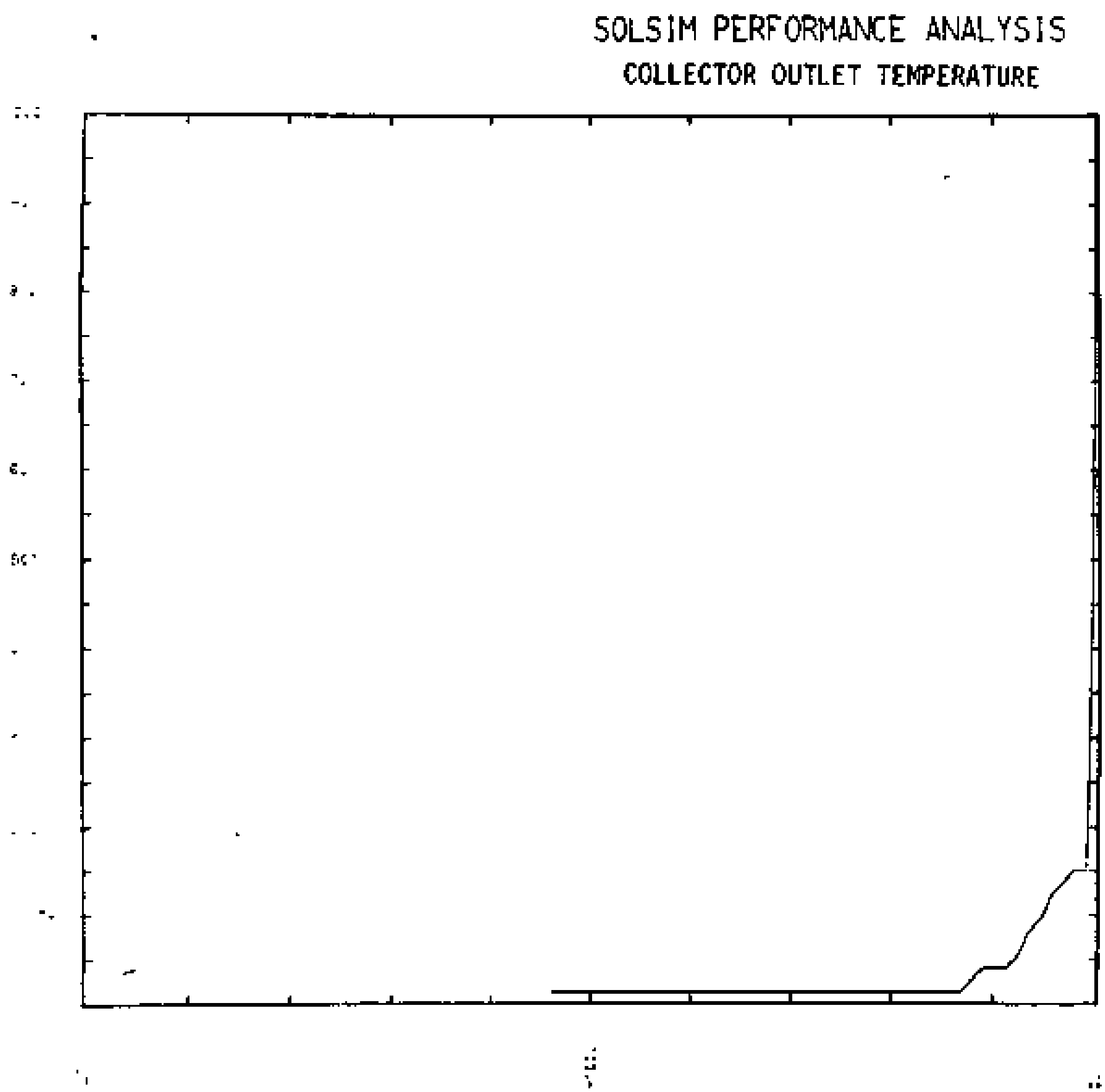

Figure B3.20 : CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

127

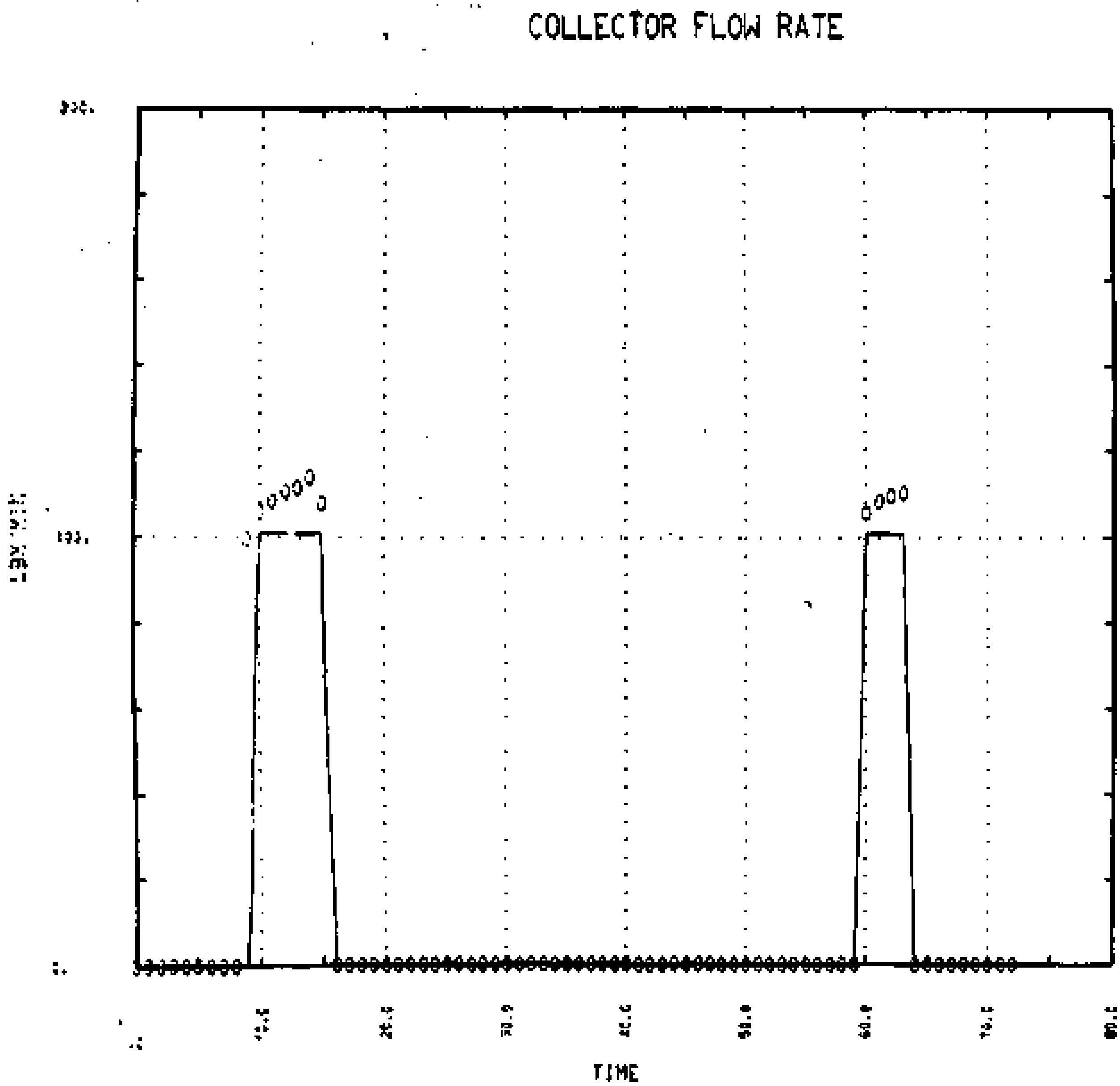

Figure B3.21 : SOLSIM PERFORMANCE ANALYSIS

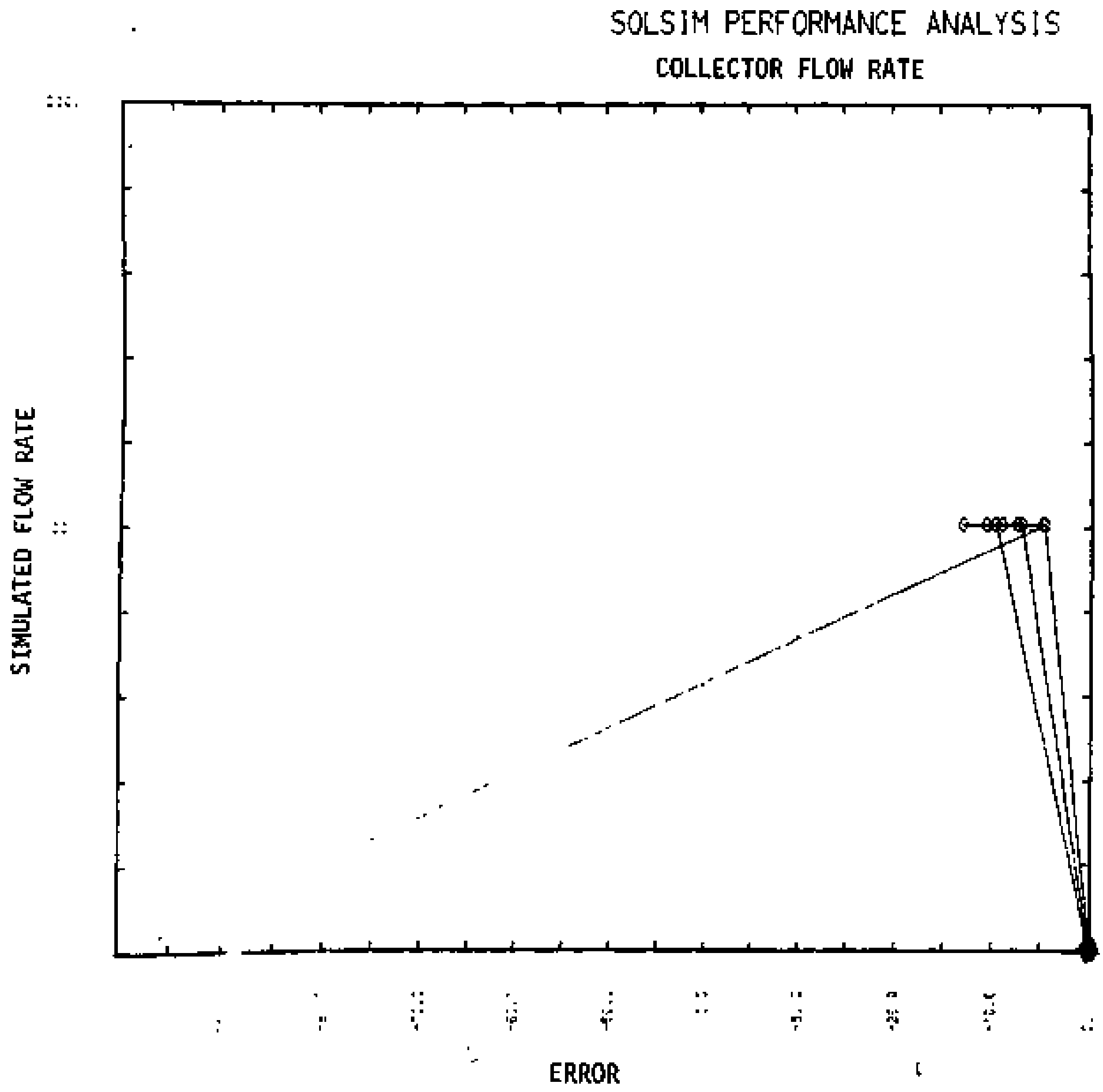

Figure B3.22 : SIMULATED DATA VS. SIMULATION ERROR

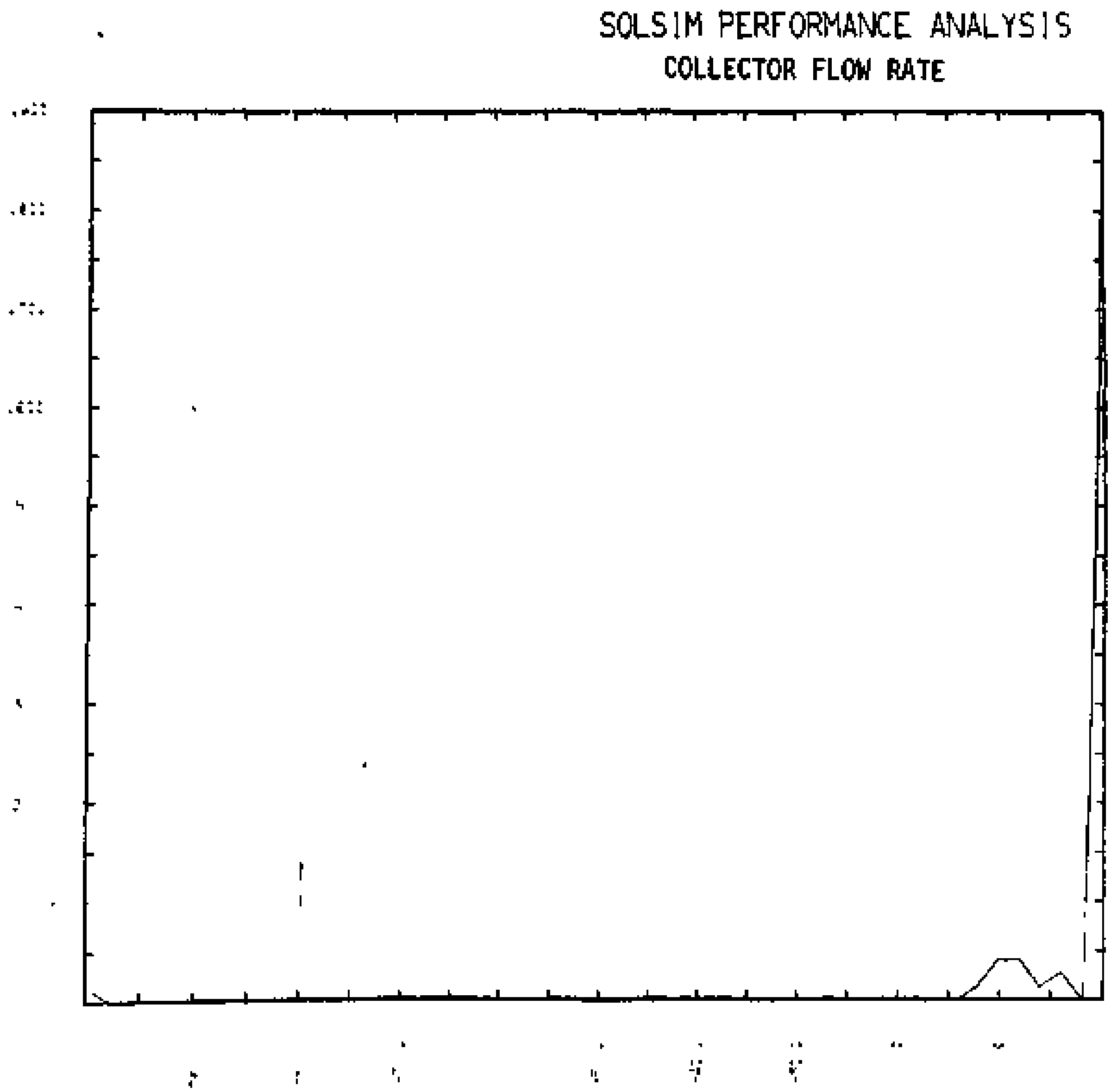

Figure B3.23 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

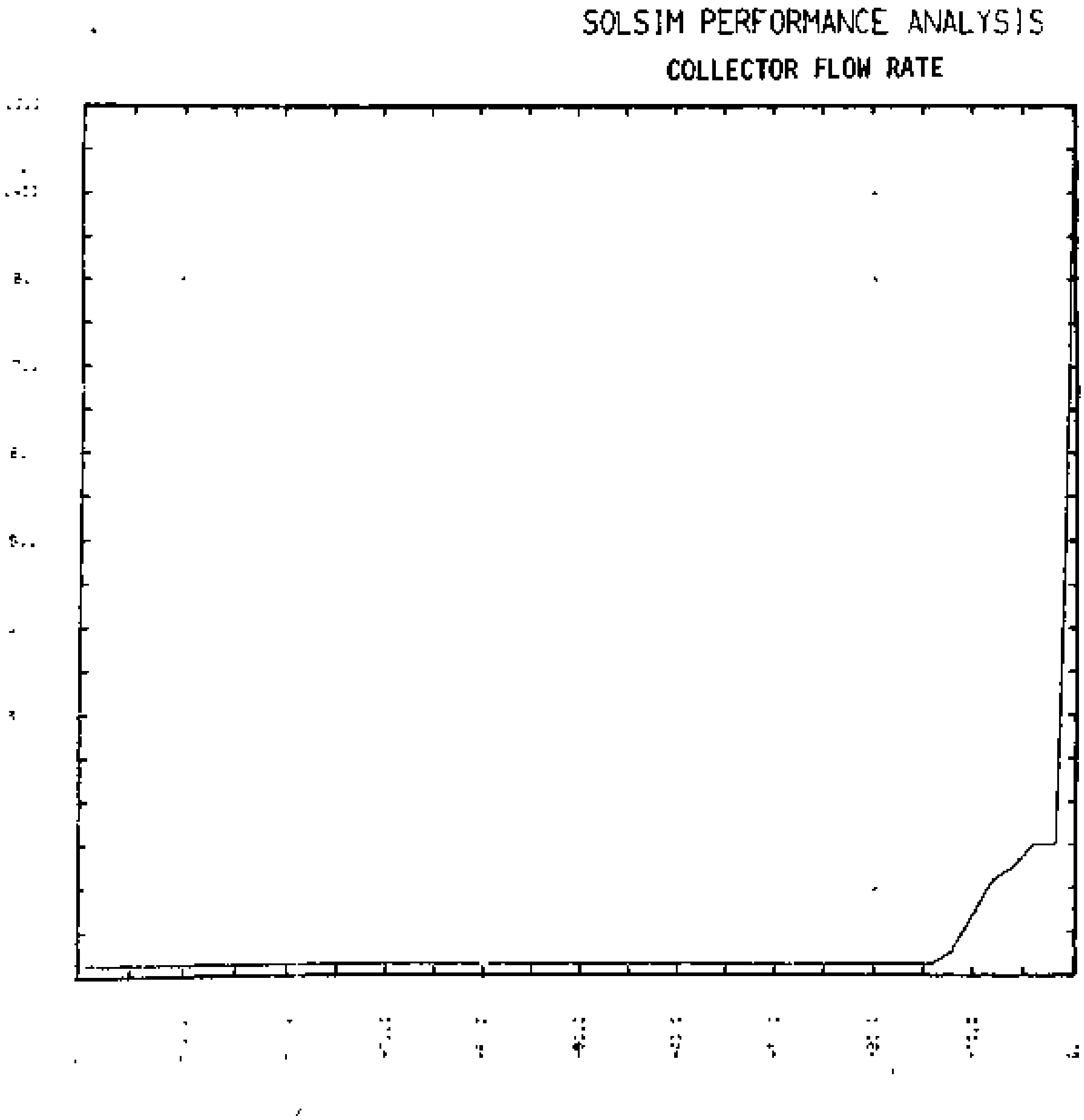

Figure B3.24: CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

USEFUL ENERGY COLLECTED

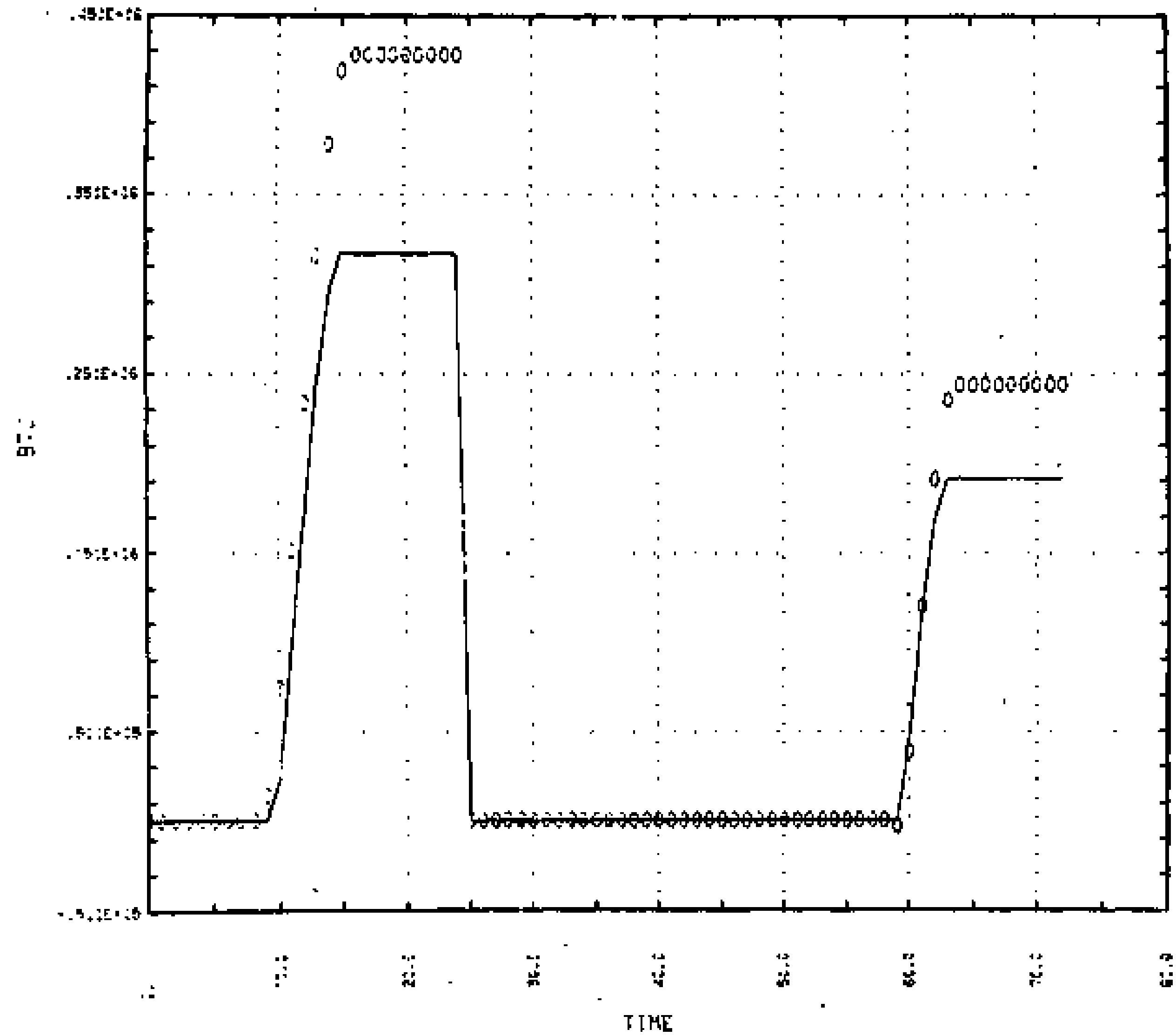

Figure B3.25 : SOLSIM PERFORMANCE ANALYSIS

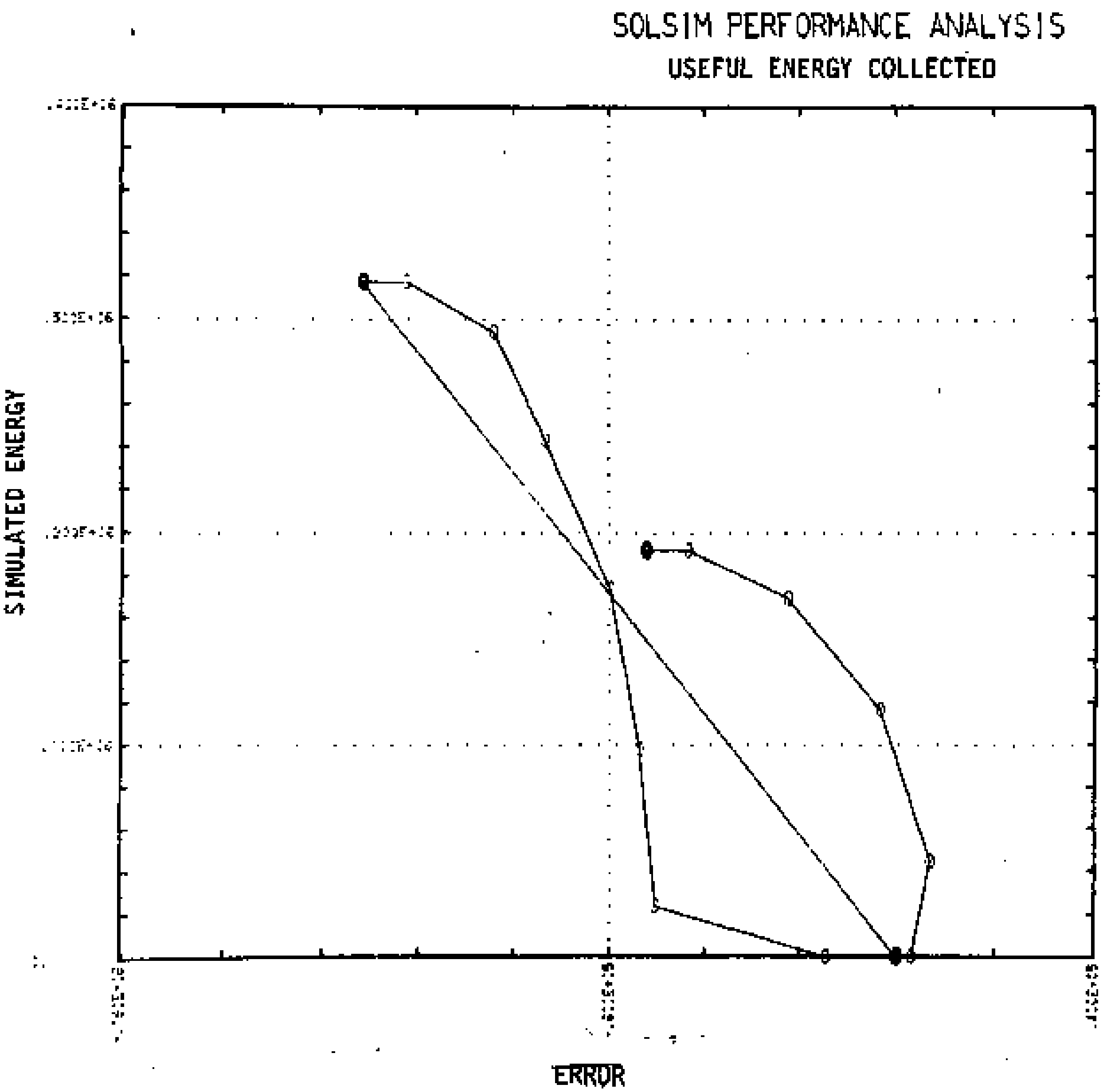

Figure B3.26: SIMULATED DATA VS. SIMULATION ERROR

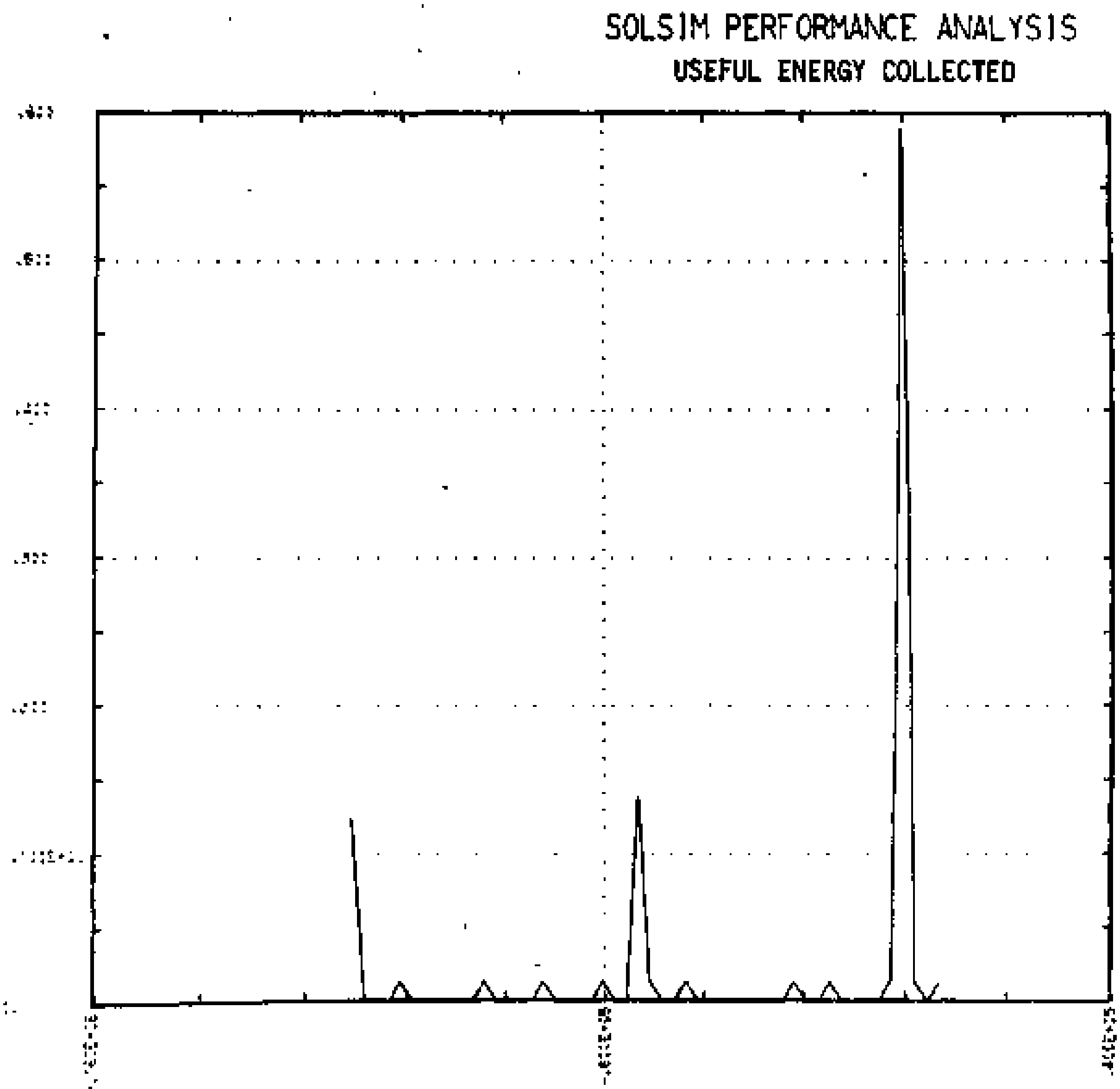

Figure B3.27 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

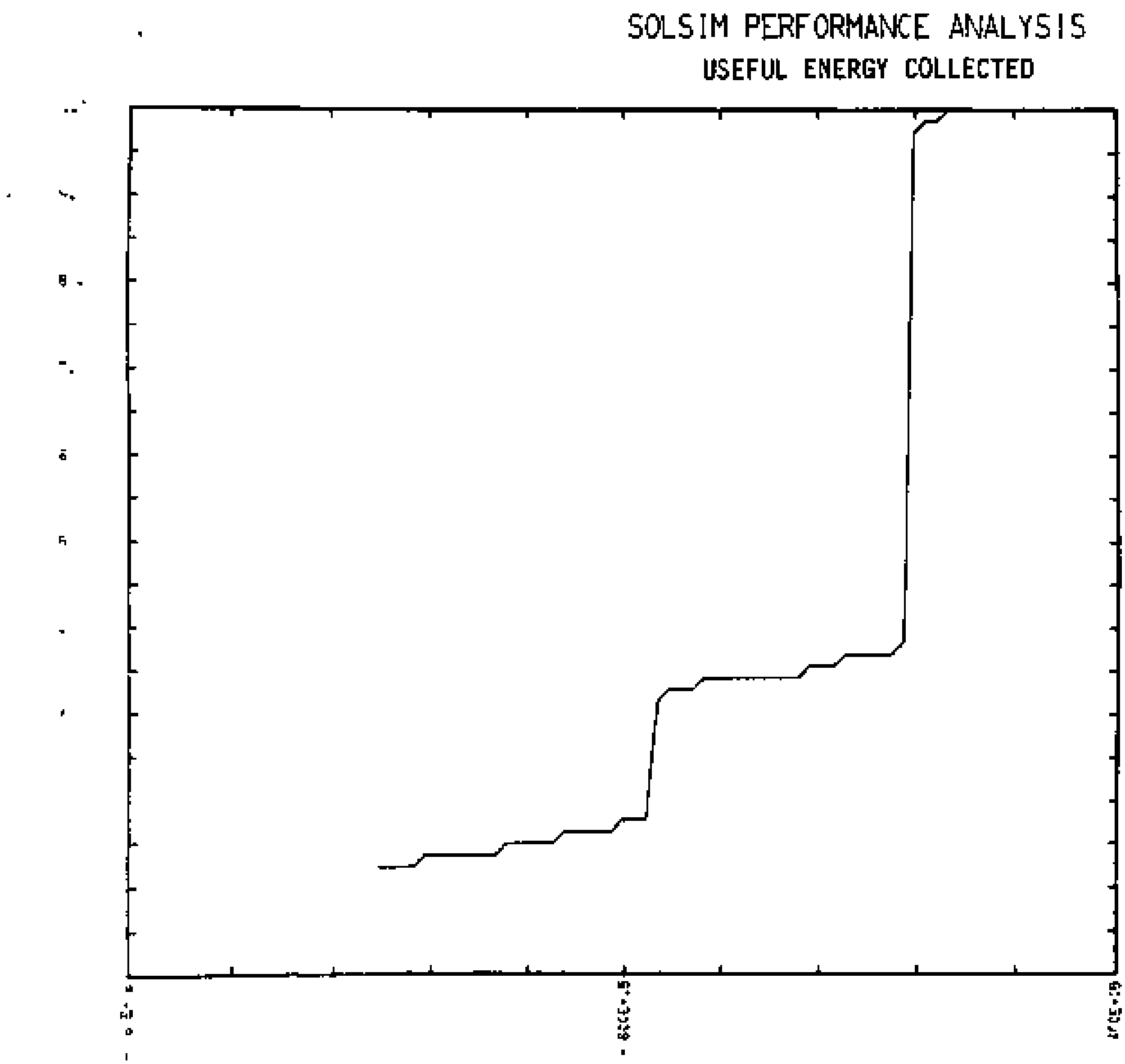

Figure B3.28 : CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

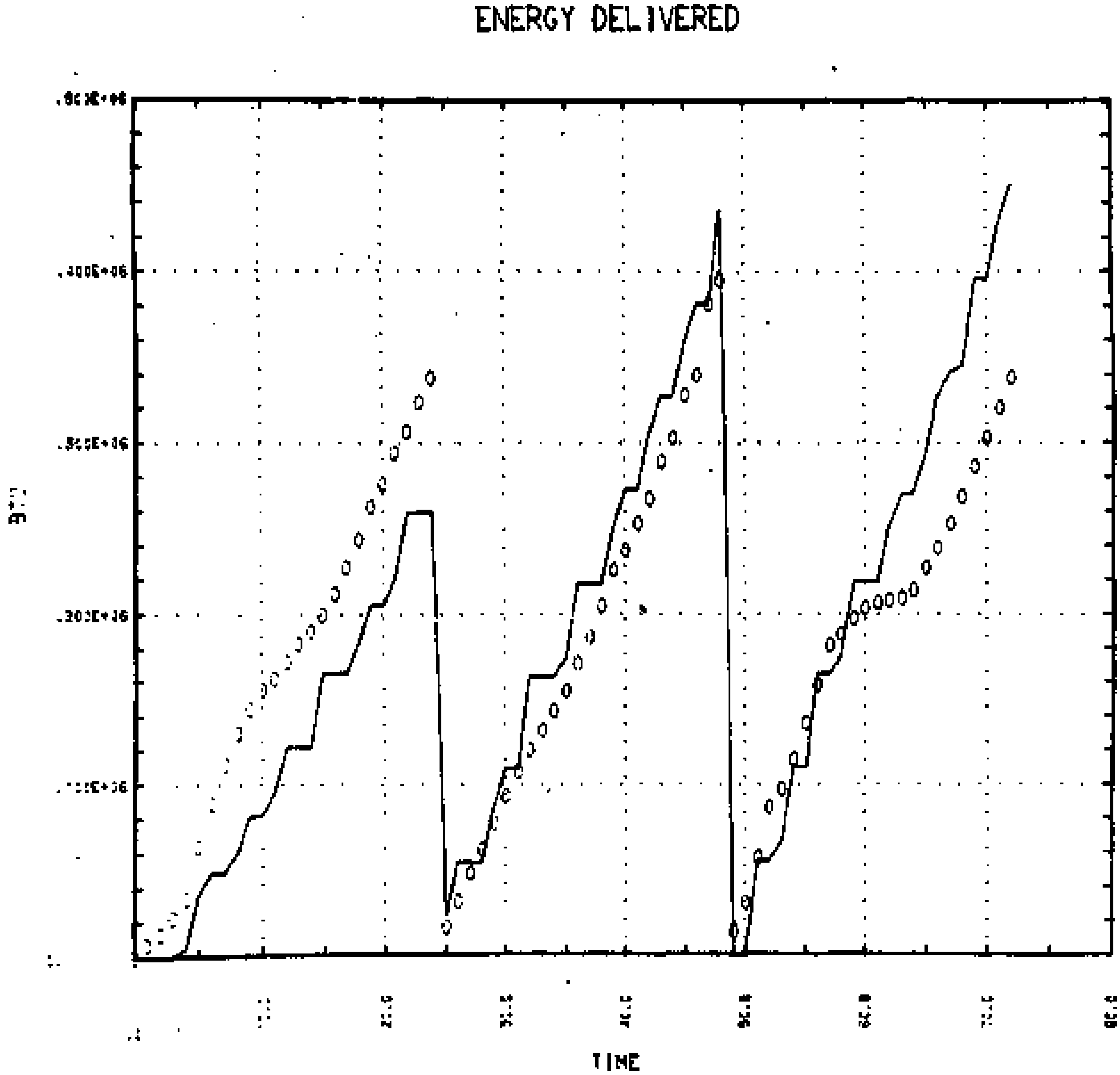

Figure B3.29 : SOLSIM PERFORMANCE ANALYSIS

SOLSIM PERFORMANCE ANALYSIS

ENERGY DELIVERED

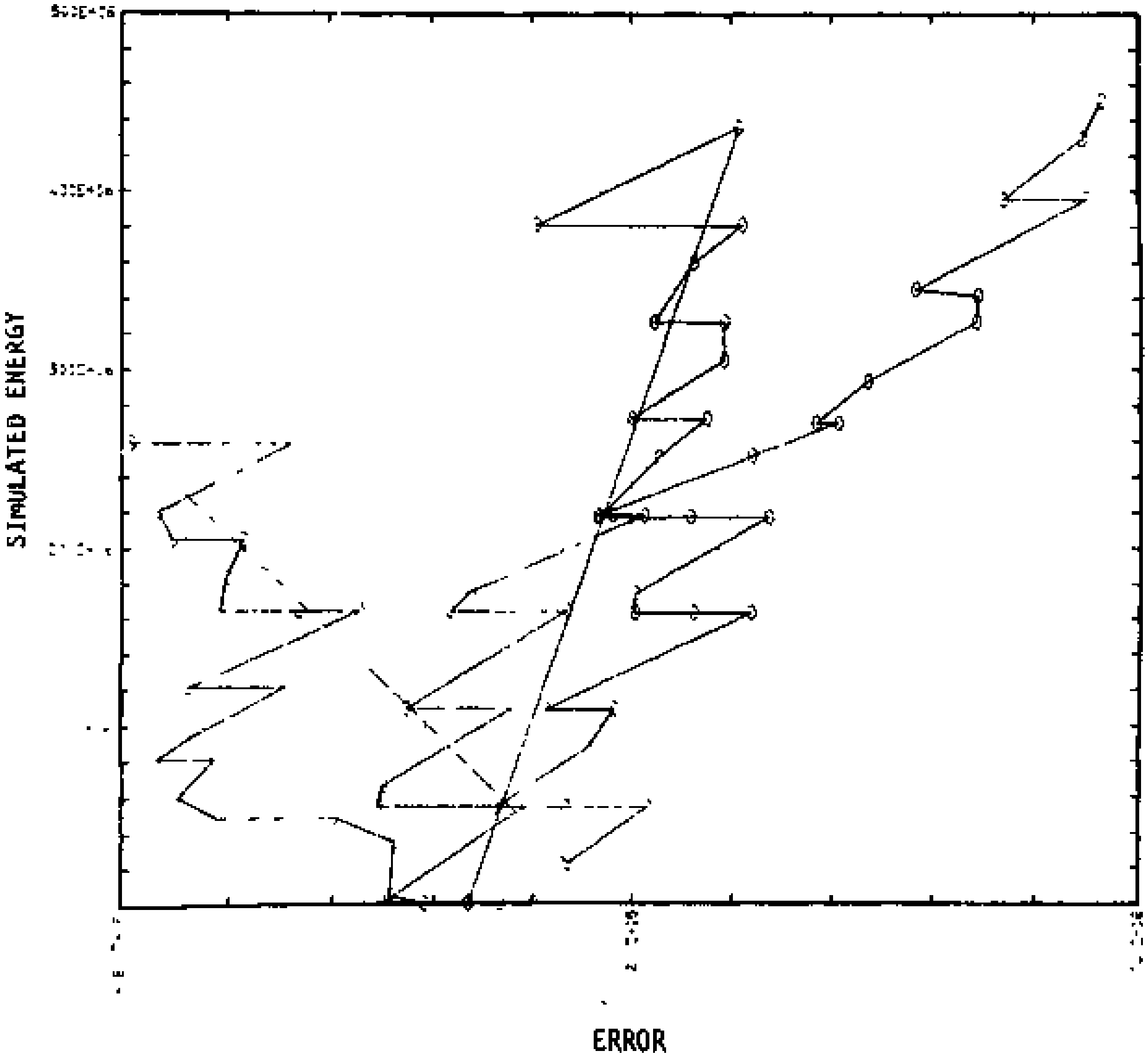

Figure B3.30 ; SIMULATED DATA VS. SIMULATION ERROR

SOLSIM PERFORMANCE ANALYSIS
ENERGY DELIVERED

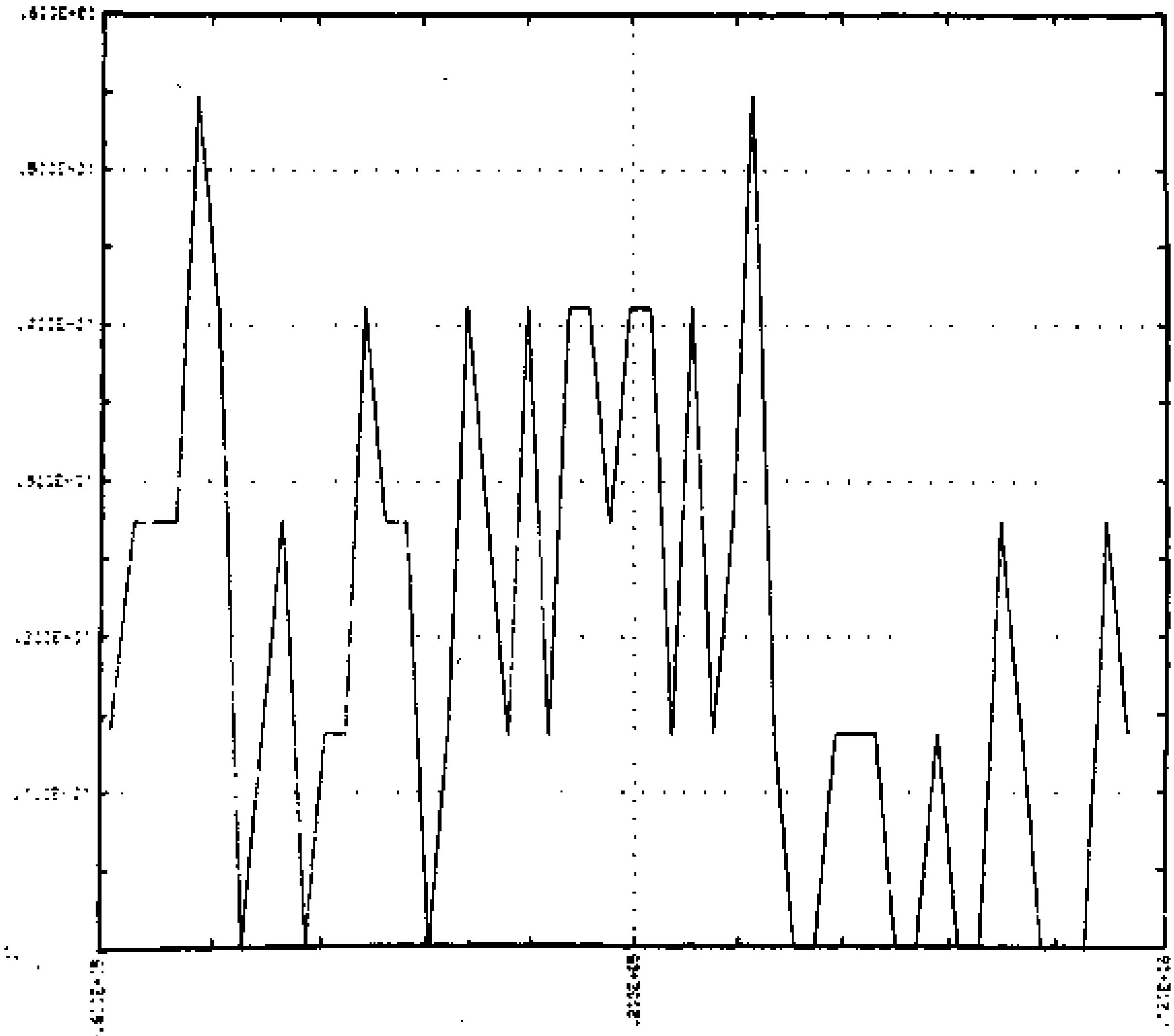

Figure B3.31 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

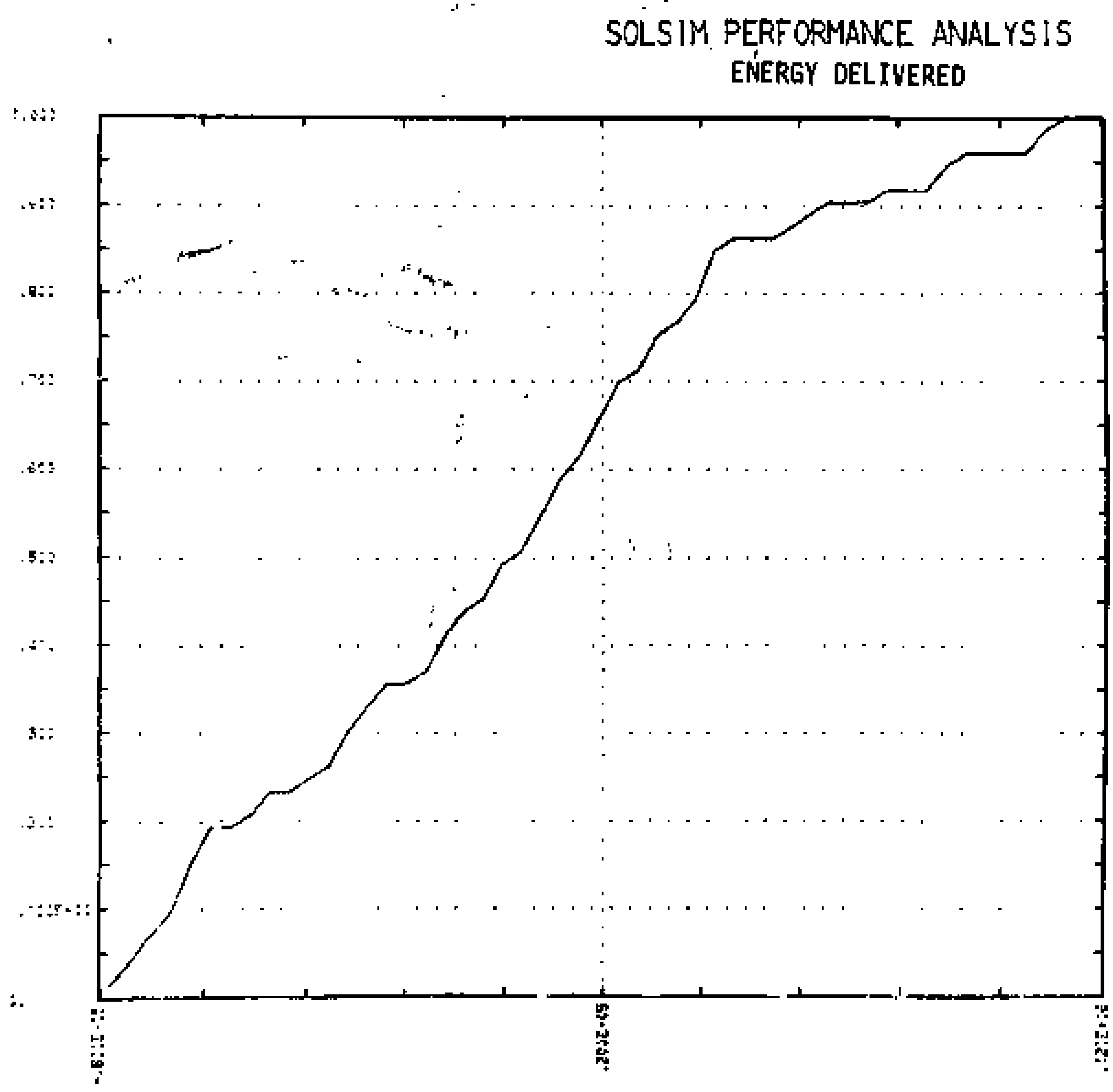

Figure B3.32: CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

AUXILIARY ENERGY SUPPLIED

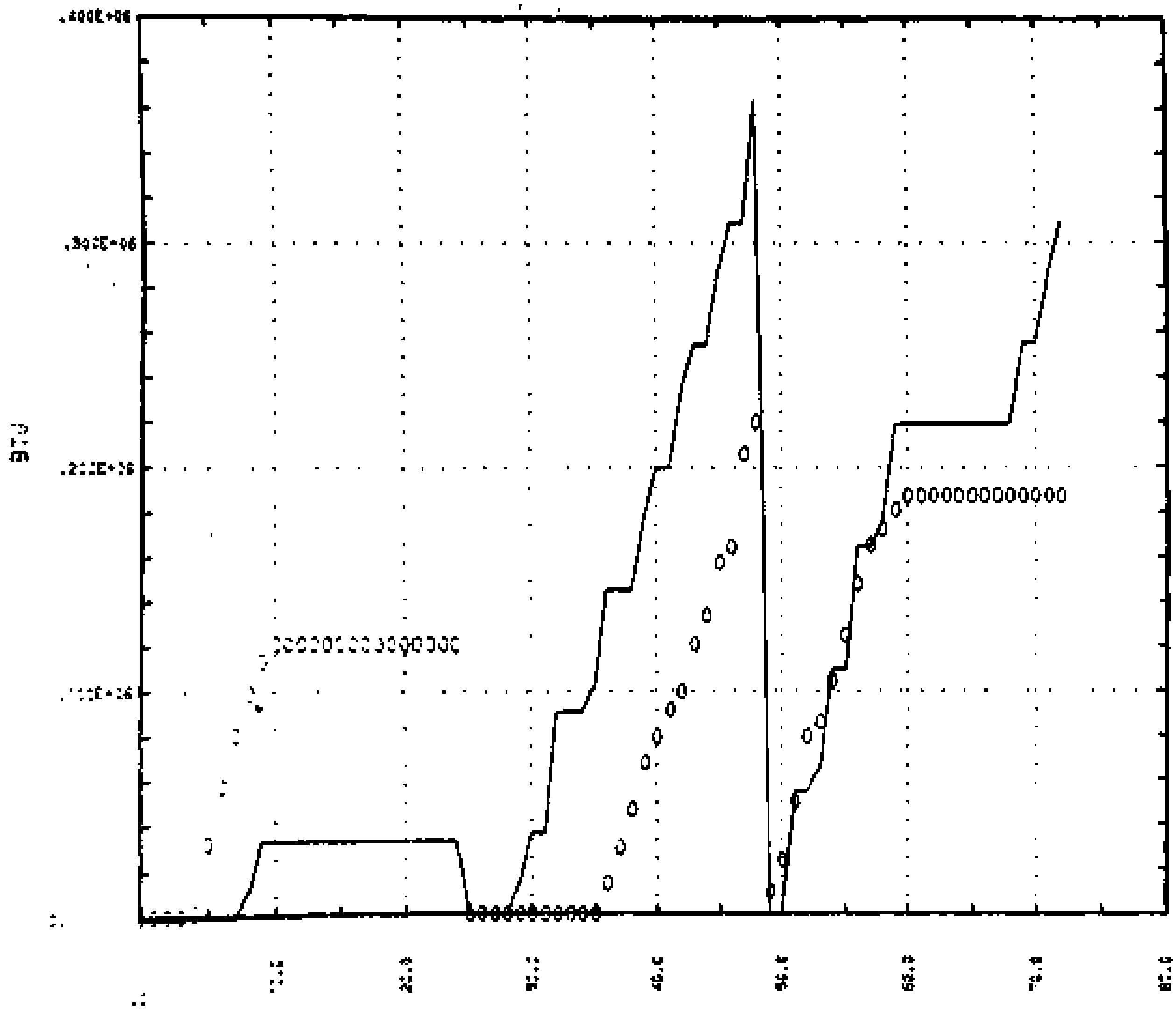

Figure B3.33 : SOLSIM PERFORMANCE ANALYSIS

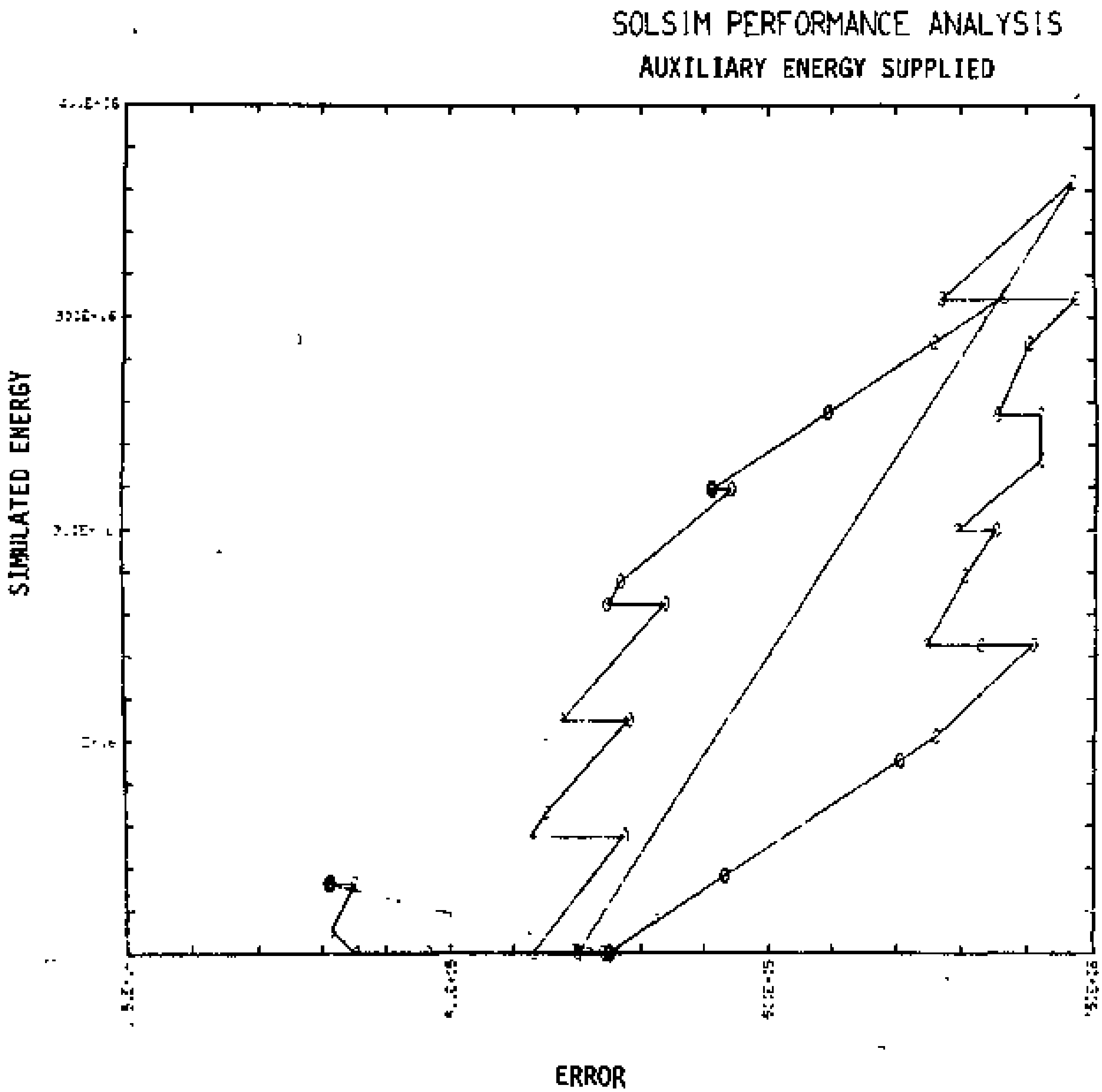

Figure B3.34 : SIMULATED DATA VS. SIMULATION ERROR

141

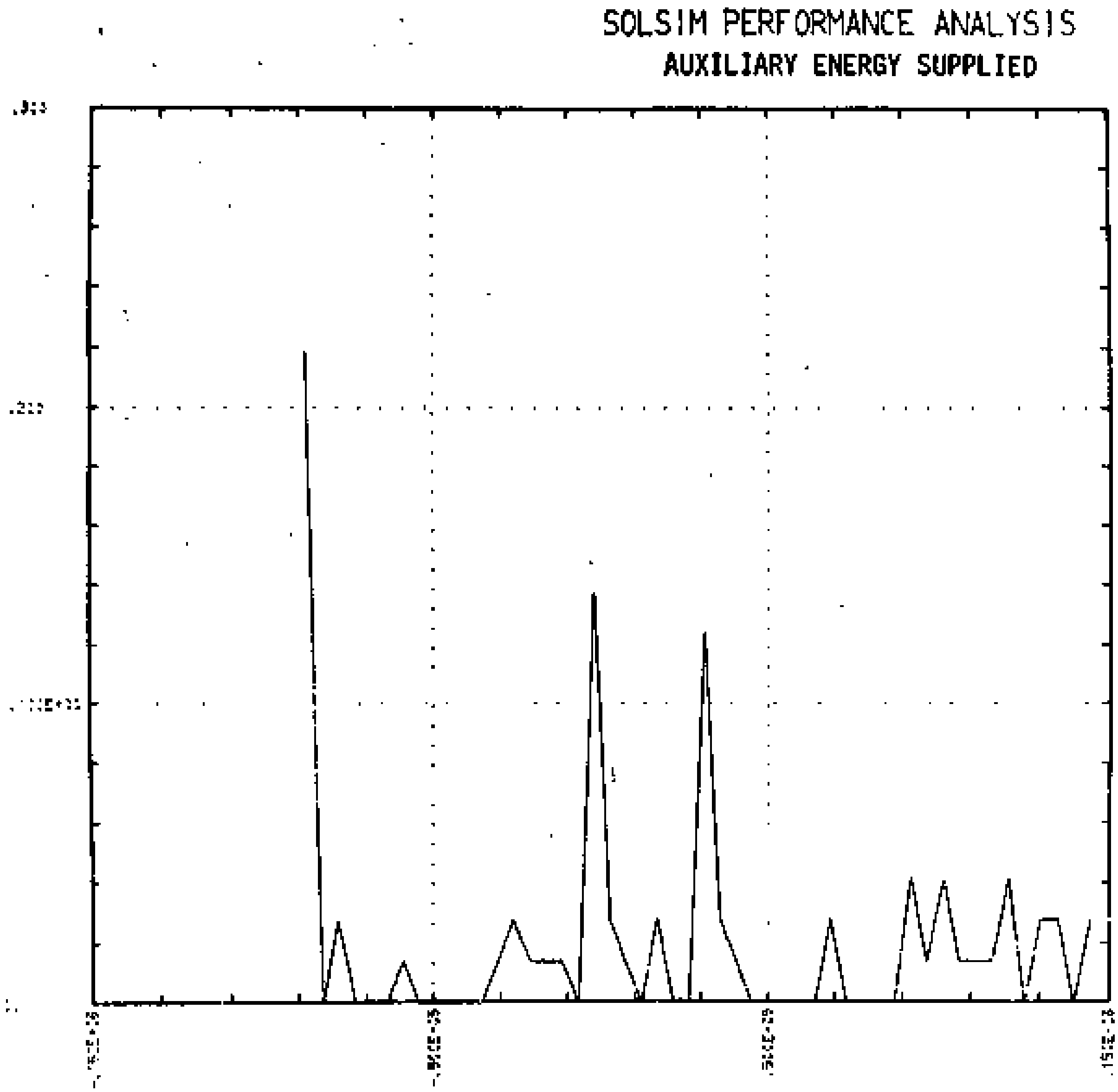

Figure B3.35 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

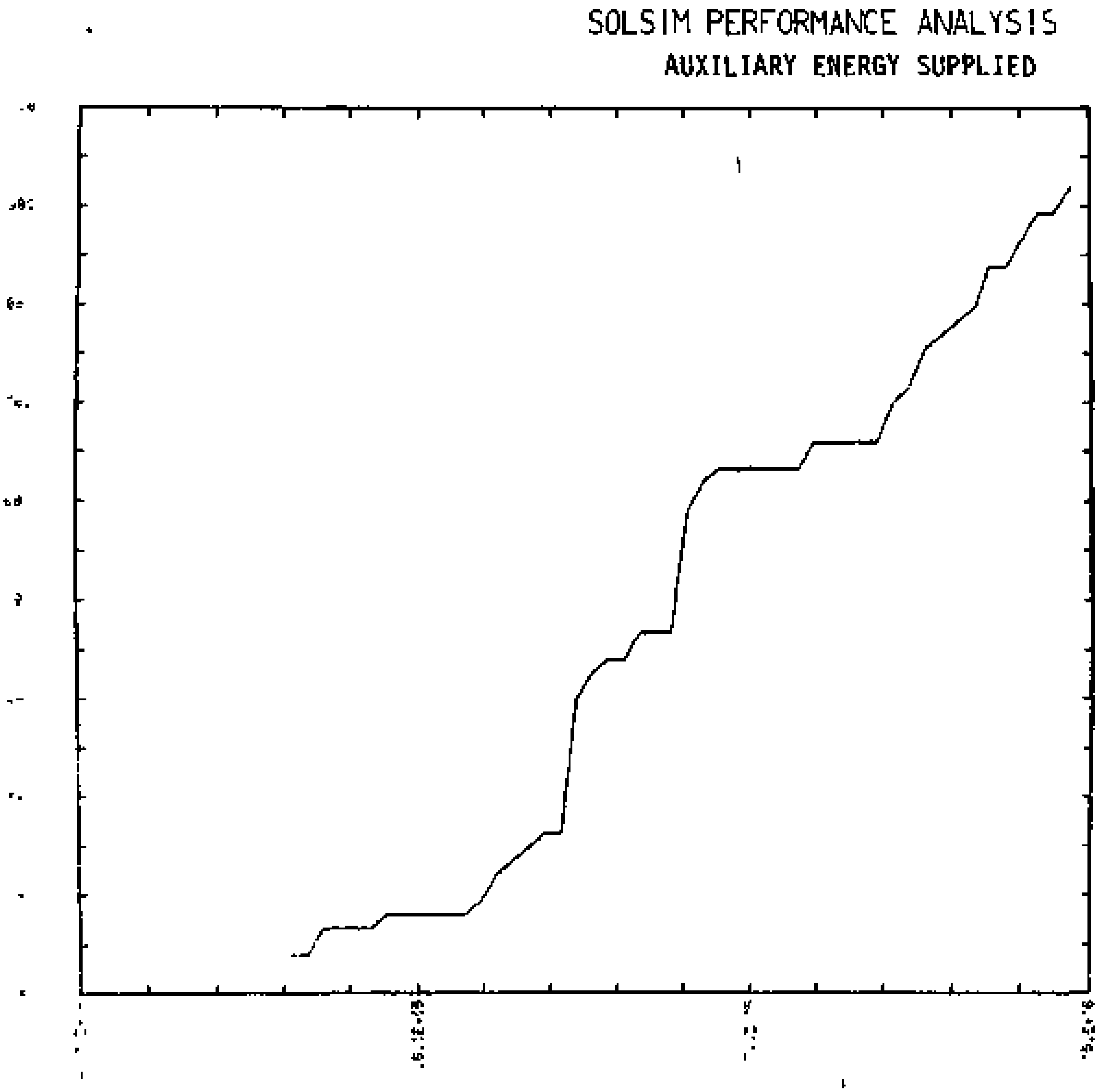

Figure B3.36 : CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

SOLAR INSOLATION ON THE TILT

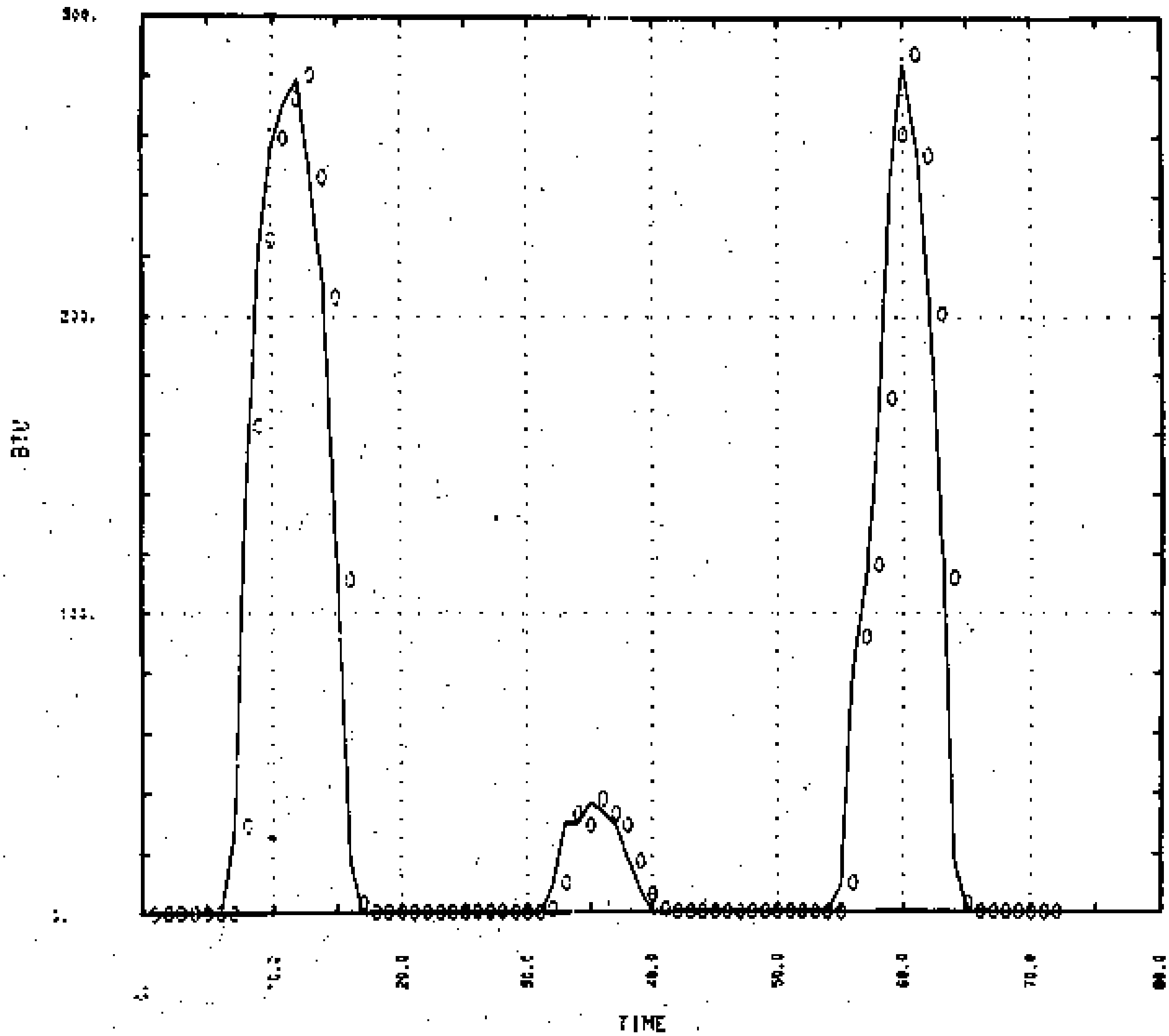

Figure B3.37 : SOLSIM PERFORMANCE ANALYSIS

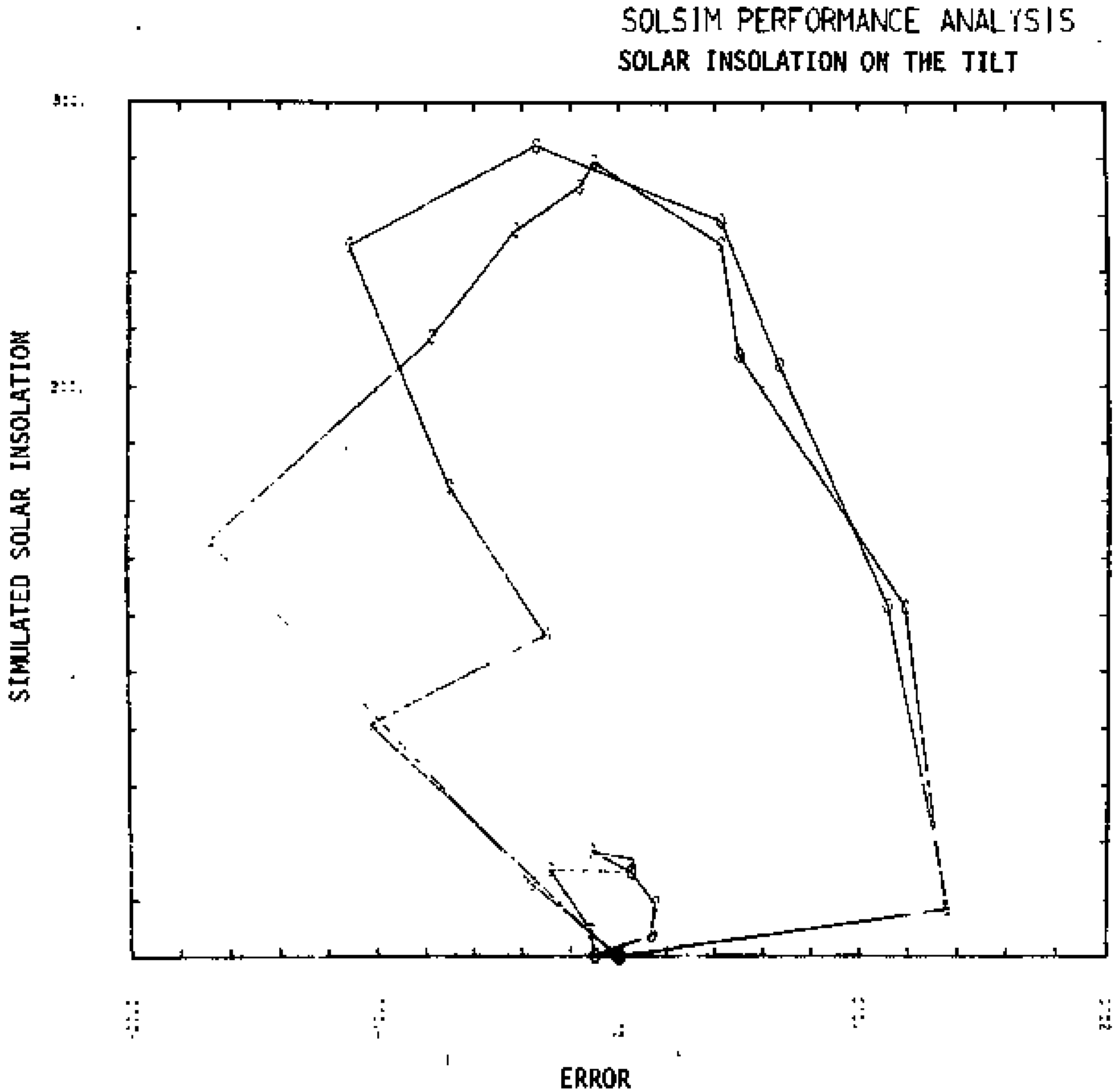

Figure B3.38: SIMULATED DATA VS. SIMULATION ERROR

145

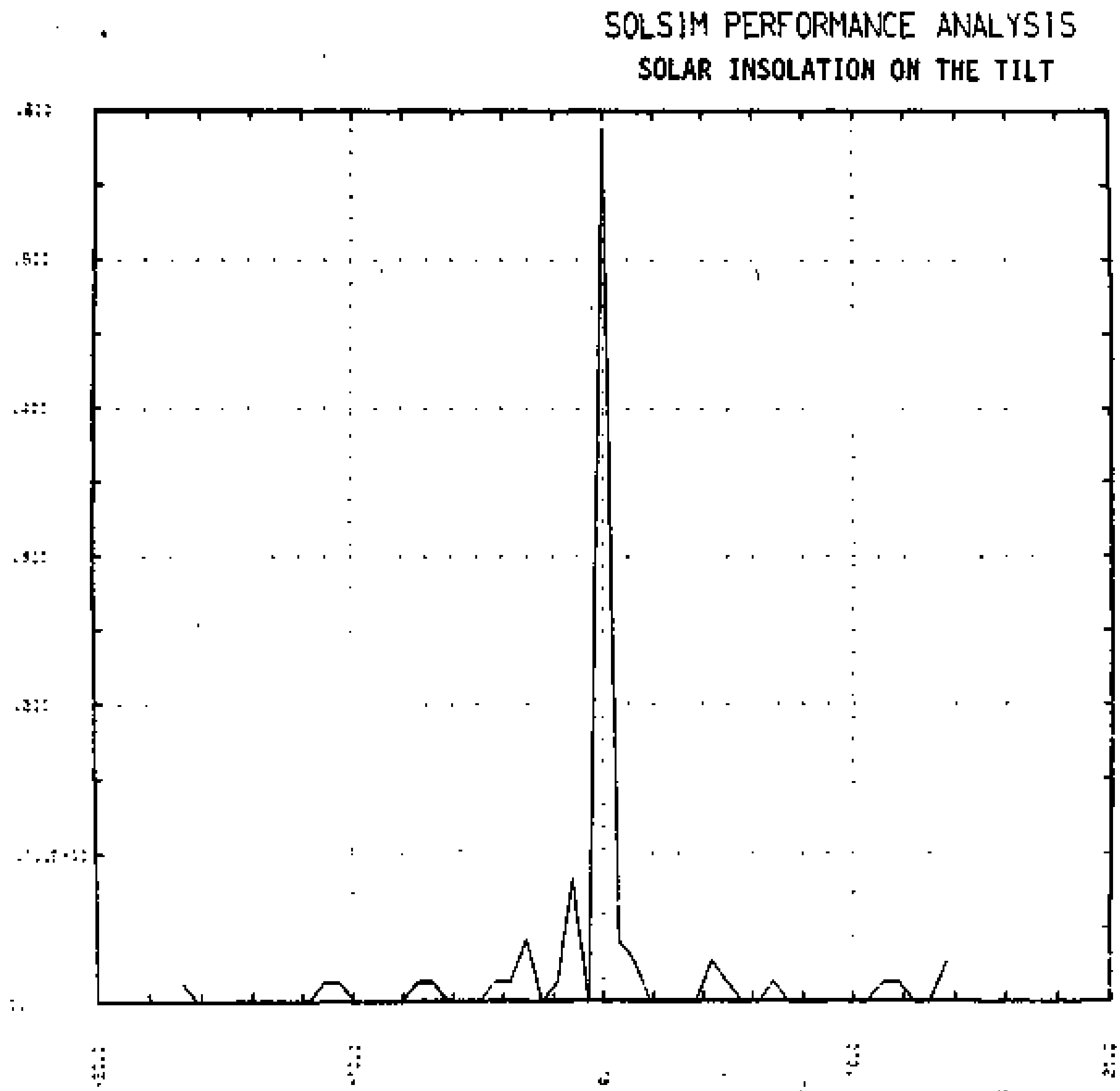

Figure B3.39 : RELATIVE FREQUENCY HISTOGRAM OF SIMULATION ERROR

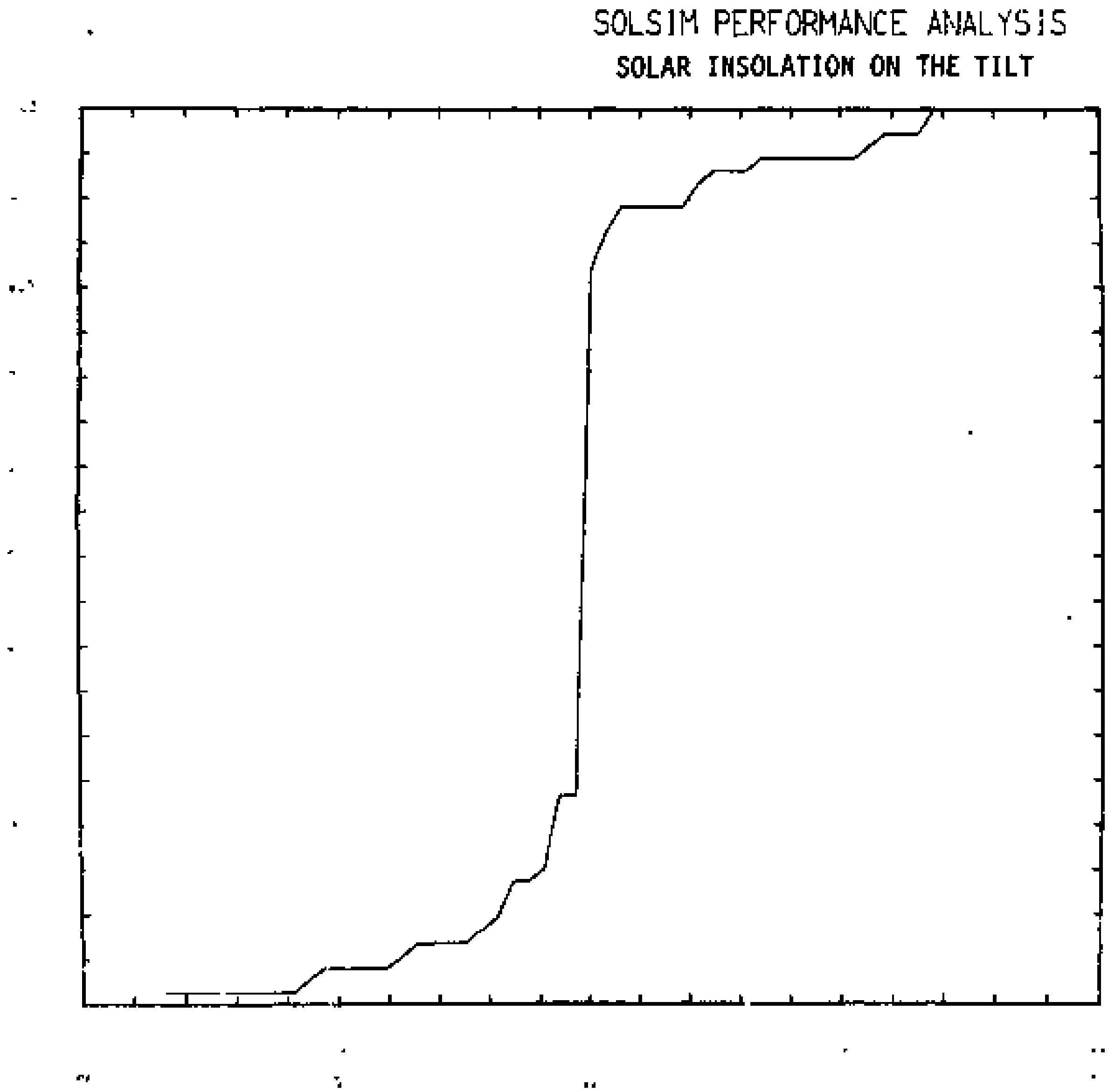

Figure B3.40: CUMULATIVE FREQUENCY DISTRIBUTION OF SIMULATION ERROR

APPENDIX B4

SAMPLE RESULTS OF SIMSHAC PERFORMANCE ANALYSIS FOR DECEMBER TRAINING PERIOD

SIMSHAC COMPONENTS

. Flat Plate Collector

. Evercated Tuble Collector

. Heat Exchanger

. Solar Service Hot Water

. Splitter Value

. Mixer Value

. Pump

. Lithium Bromide Unit

. Hot Water Storage

. Cool Water Storage

. Auxiliary Heater

. Auxiliary Boiler

. Baseboard Heater

. Heat Pump

. Heat Load Analysis

. Rock Bed Thermal Storage

. Control Units for

1. Water System
2. Air System
3. Conventional System
4. Heat Pump System

Figure B4.1

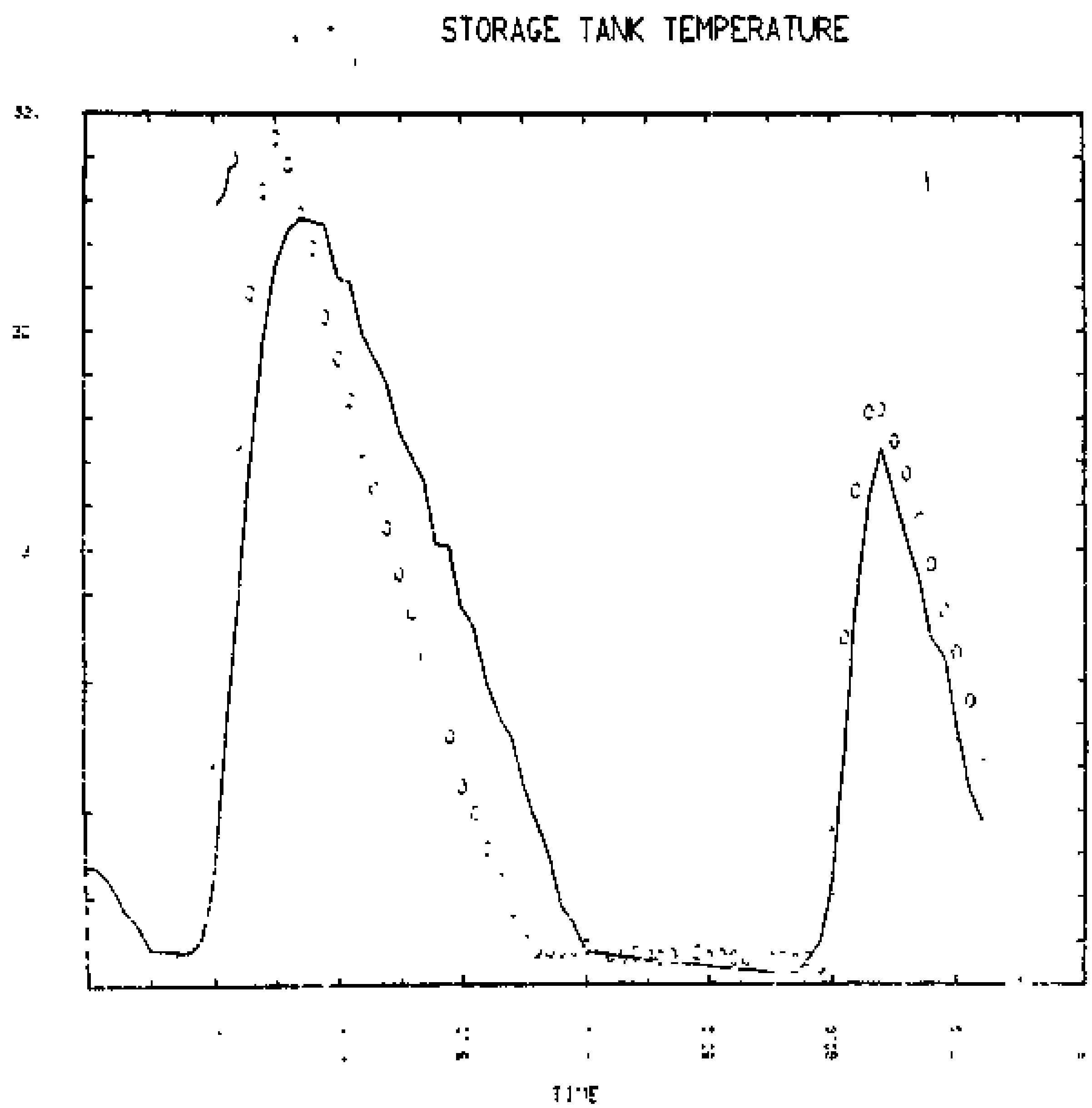

Figure B4.2 : SIMSHAC PERFORMANCE ANALYSIS

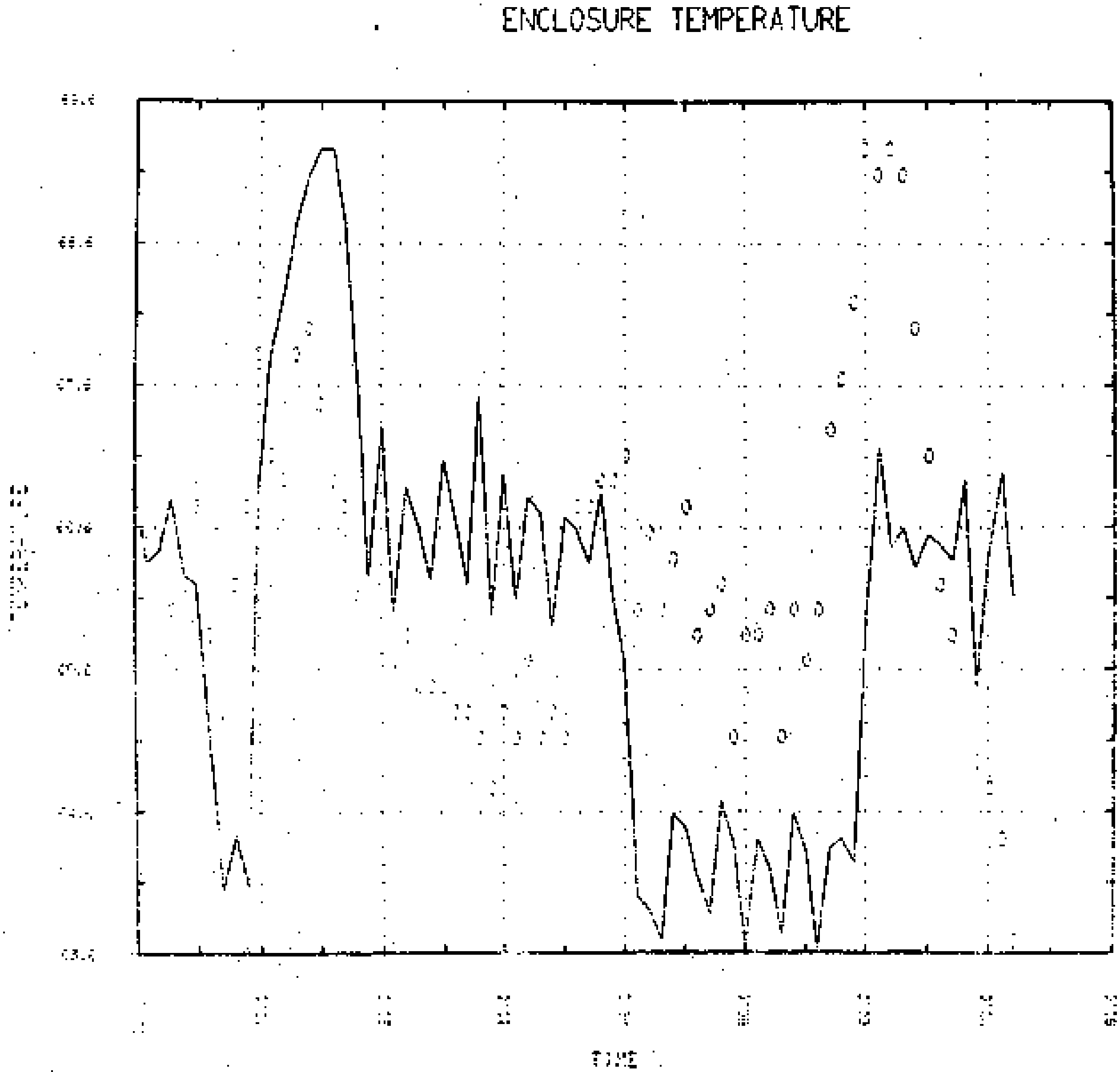

Figure B4.3 : SIMSHAC PERFORMANCE ANALYSIS

COLLECTOR INLET TEMPERATURE

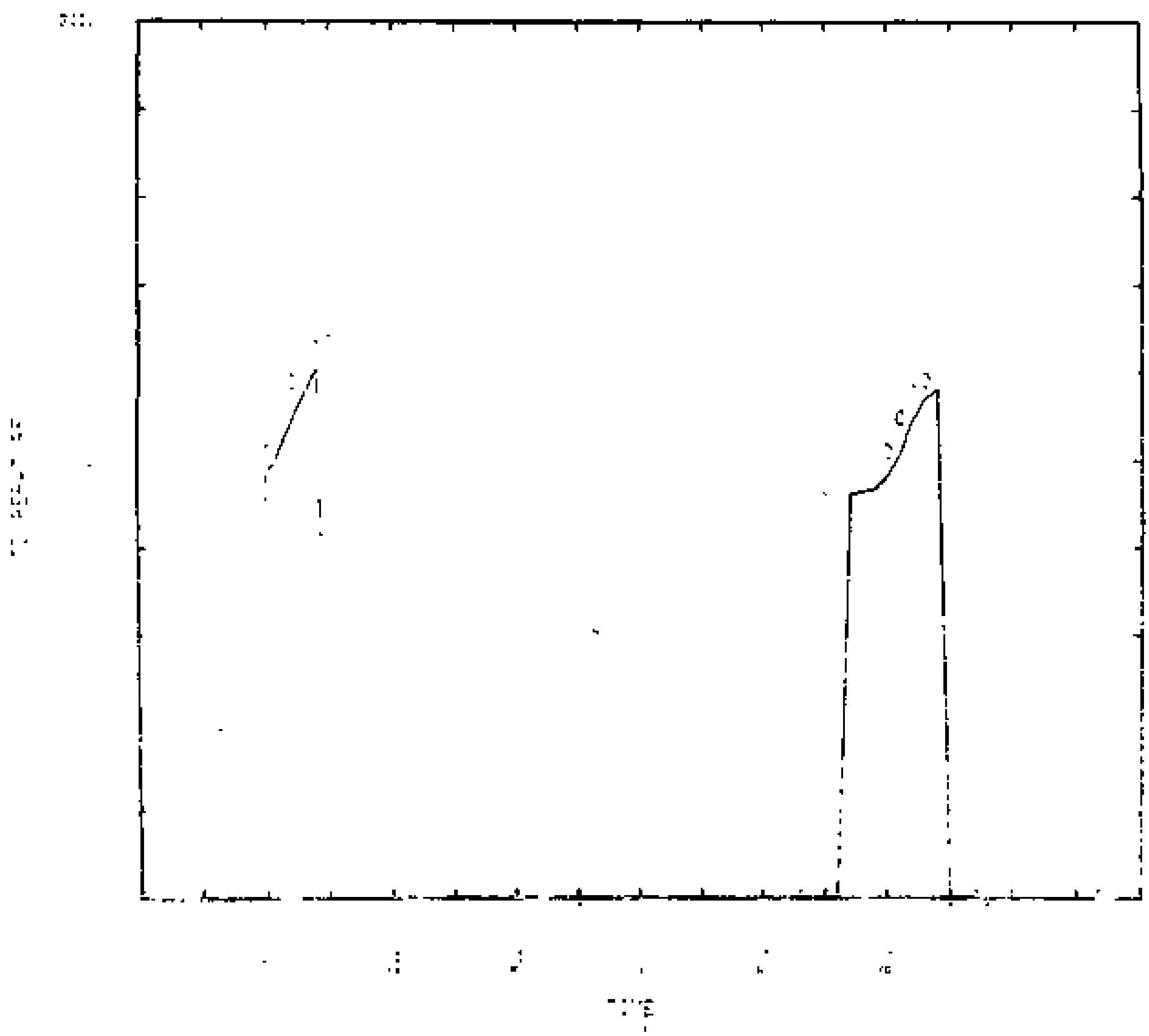

Figure B4.4: SIMSHAC PERFORMANCE ANALYSIS

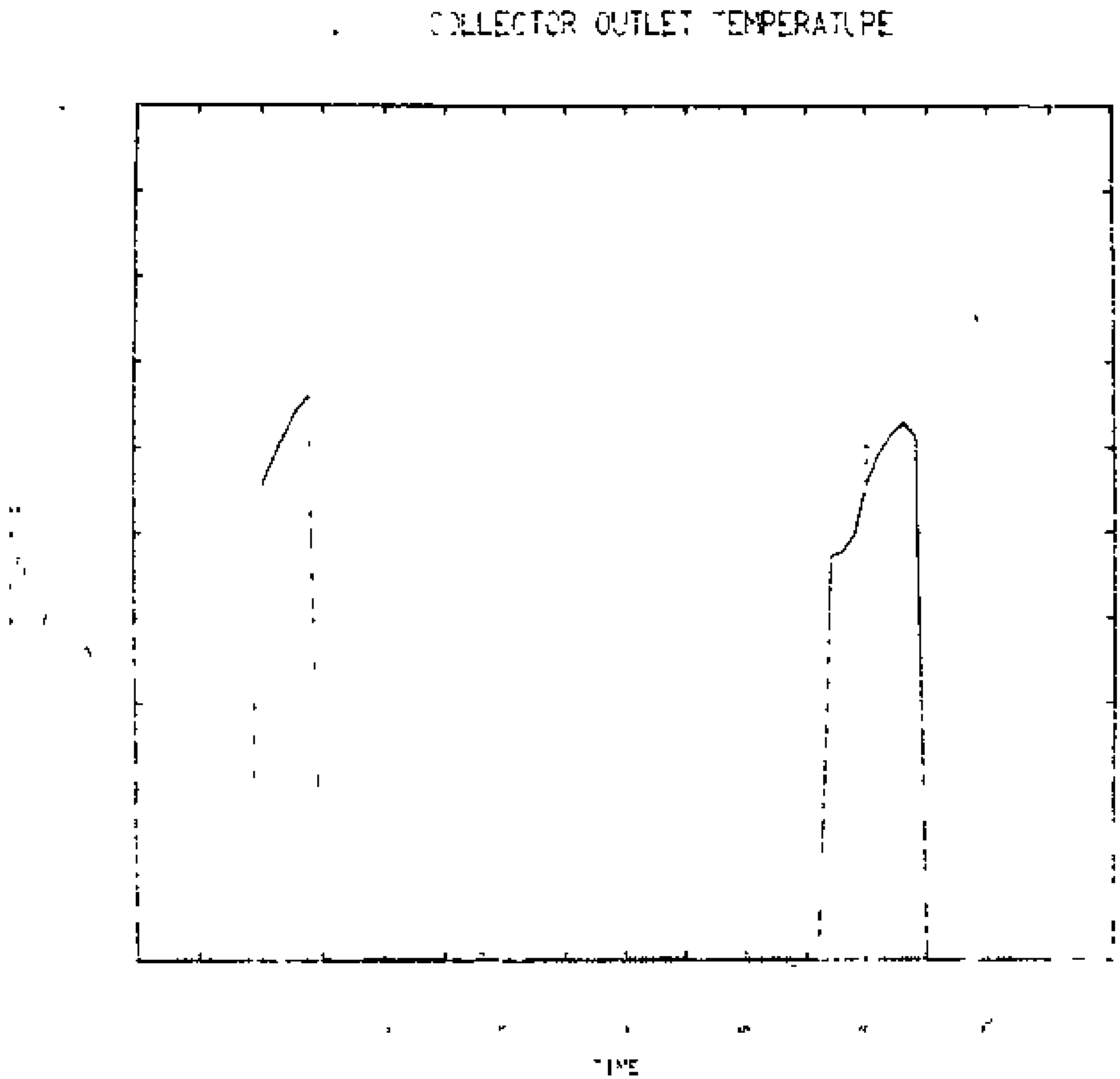

Figure B4.5 : SIMSHAC PERFORMANCE ANALYSIS

COLLECTOR FLOW RATE

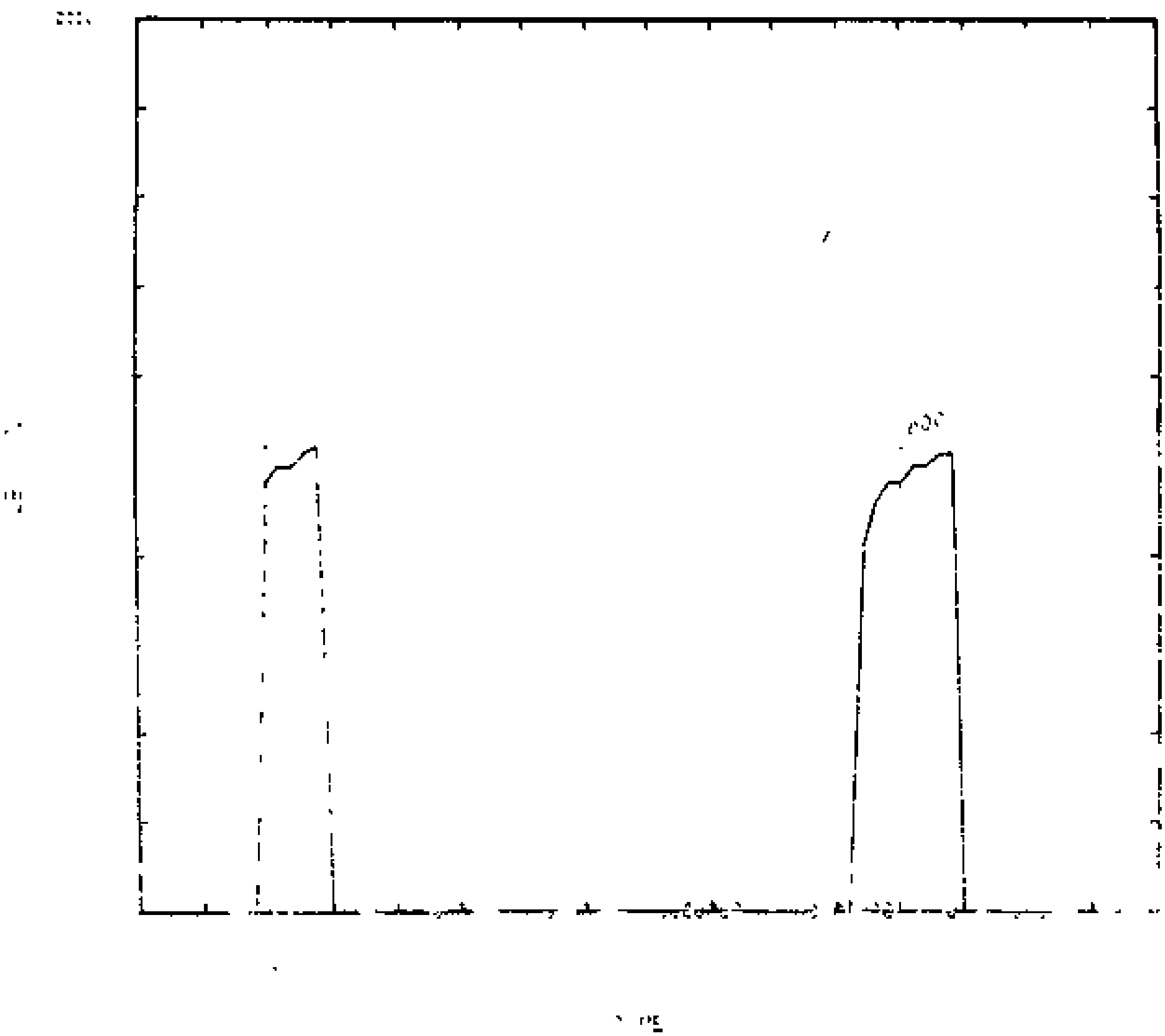

Figure B4.6 : SIMSHAC PERFORMANCE ANALYSIS

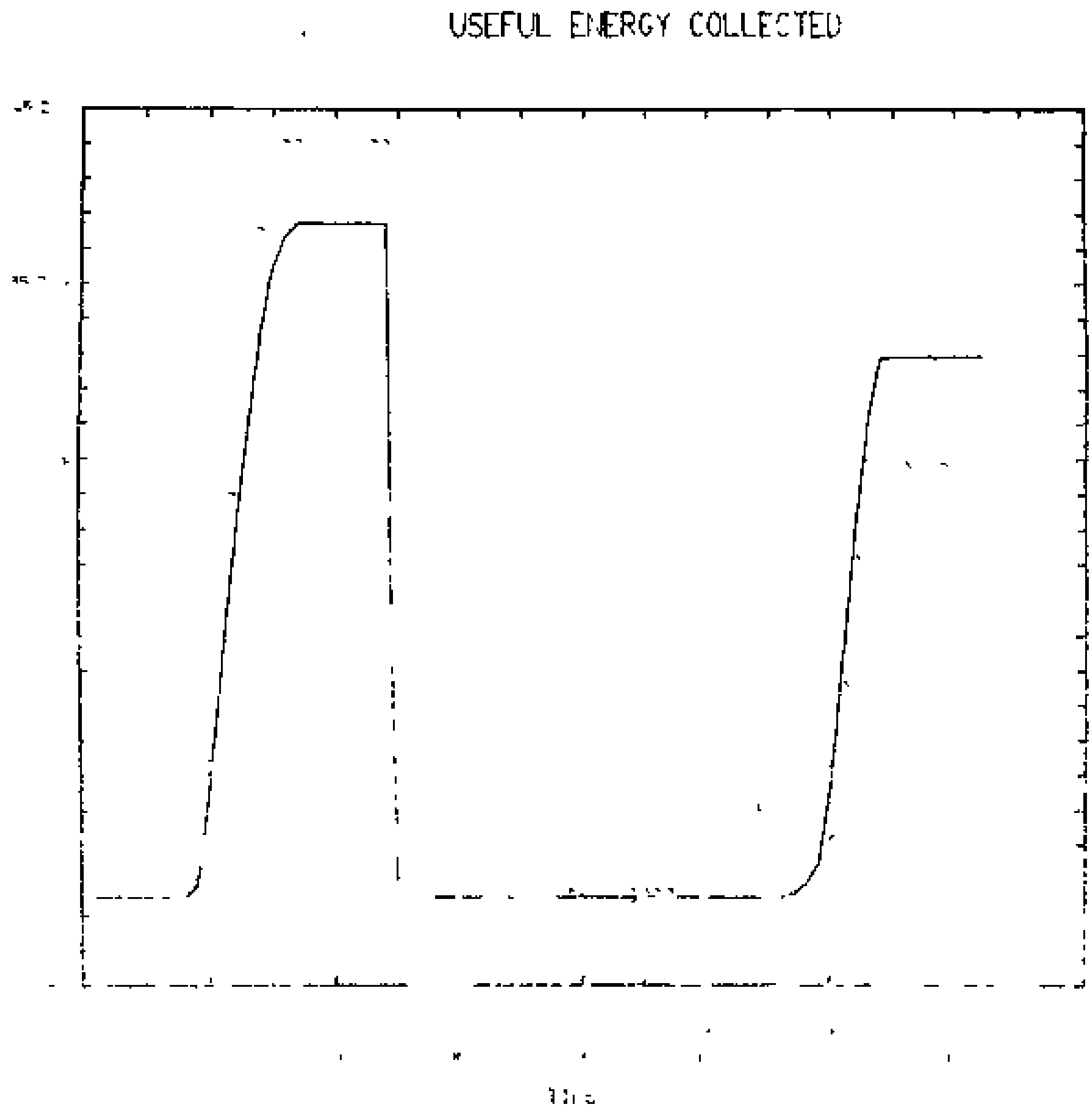

Figure B4.7 : SIMSHAC PERFORMANCE ANALYSIS

ENERGY DELIVERED

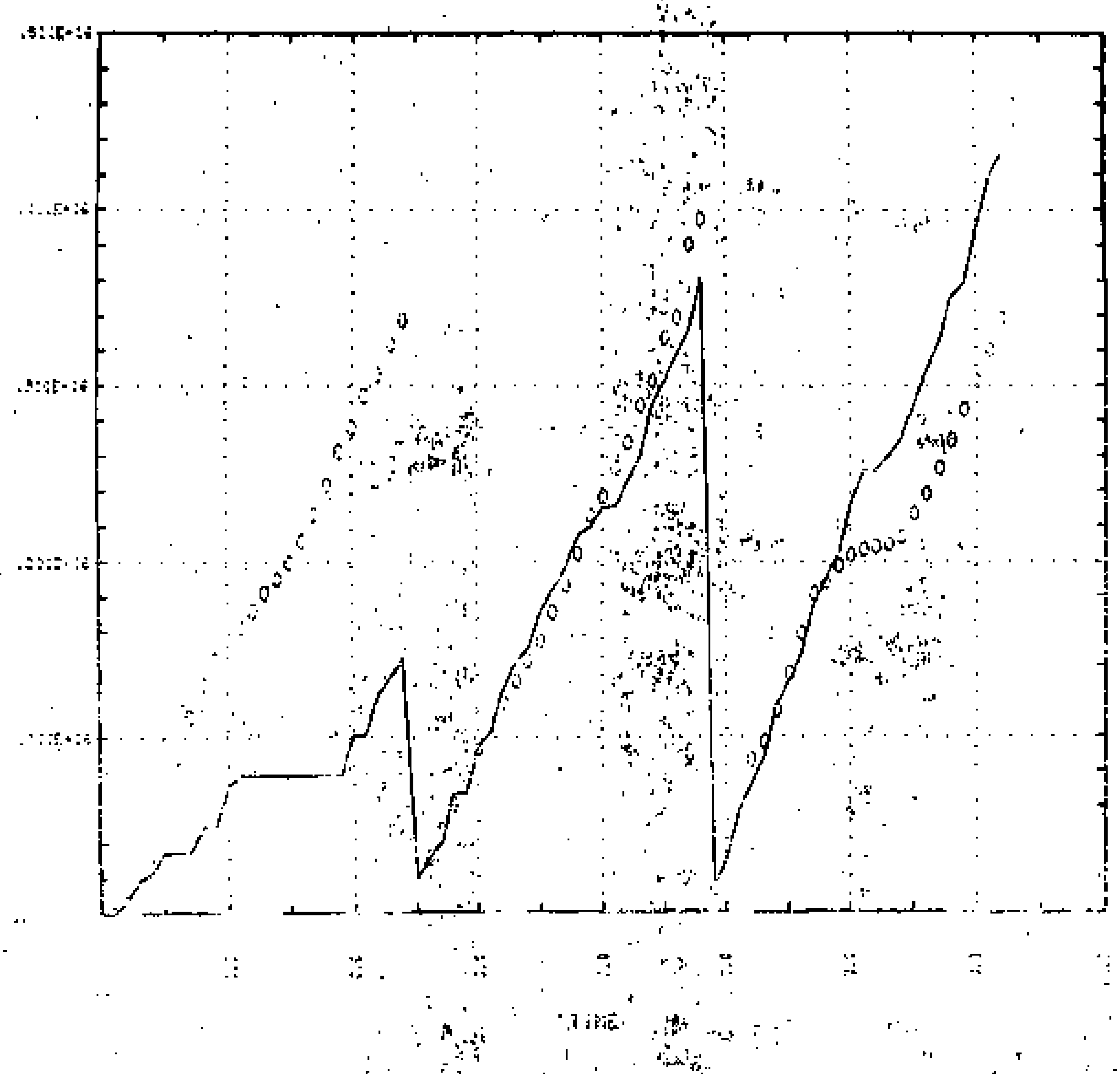

Figure B4.8 : SIMSHAC PERFORMANCE ANALYSIS

AUXILIARY ENERGY SUPPLIED

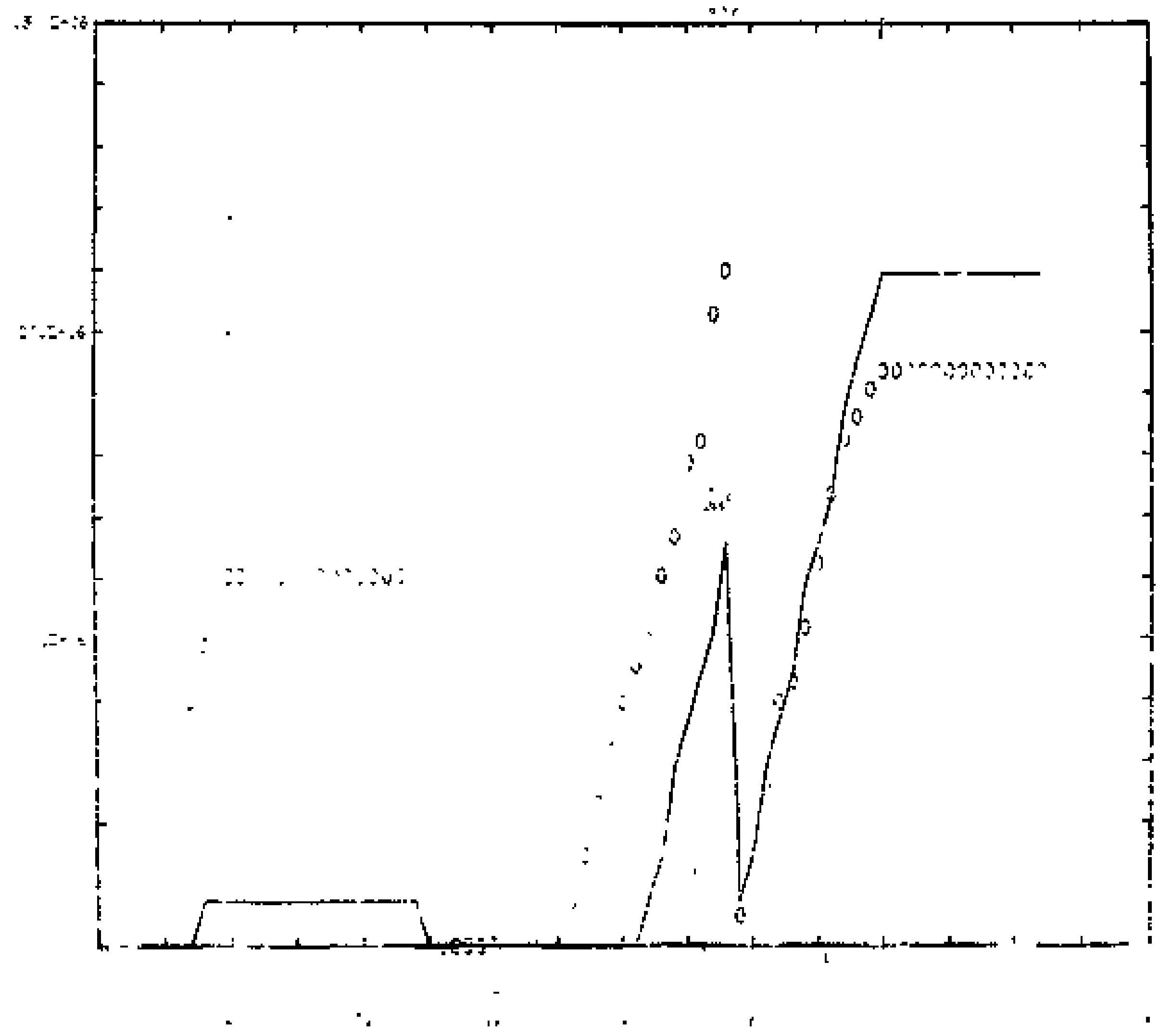

Figure B4.9 : SIMSHAC PERFORMANCE ANALYSIS

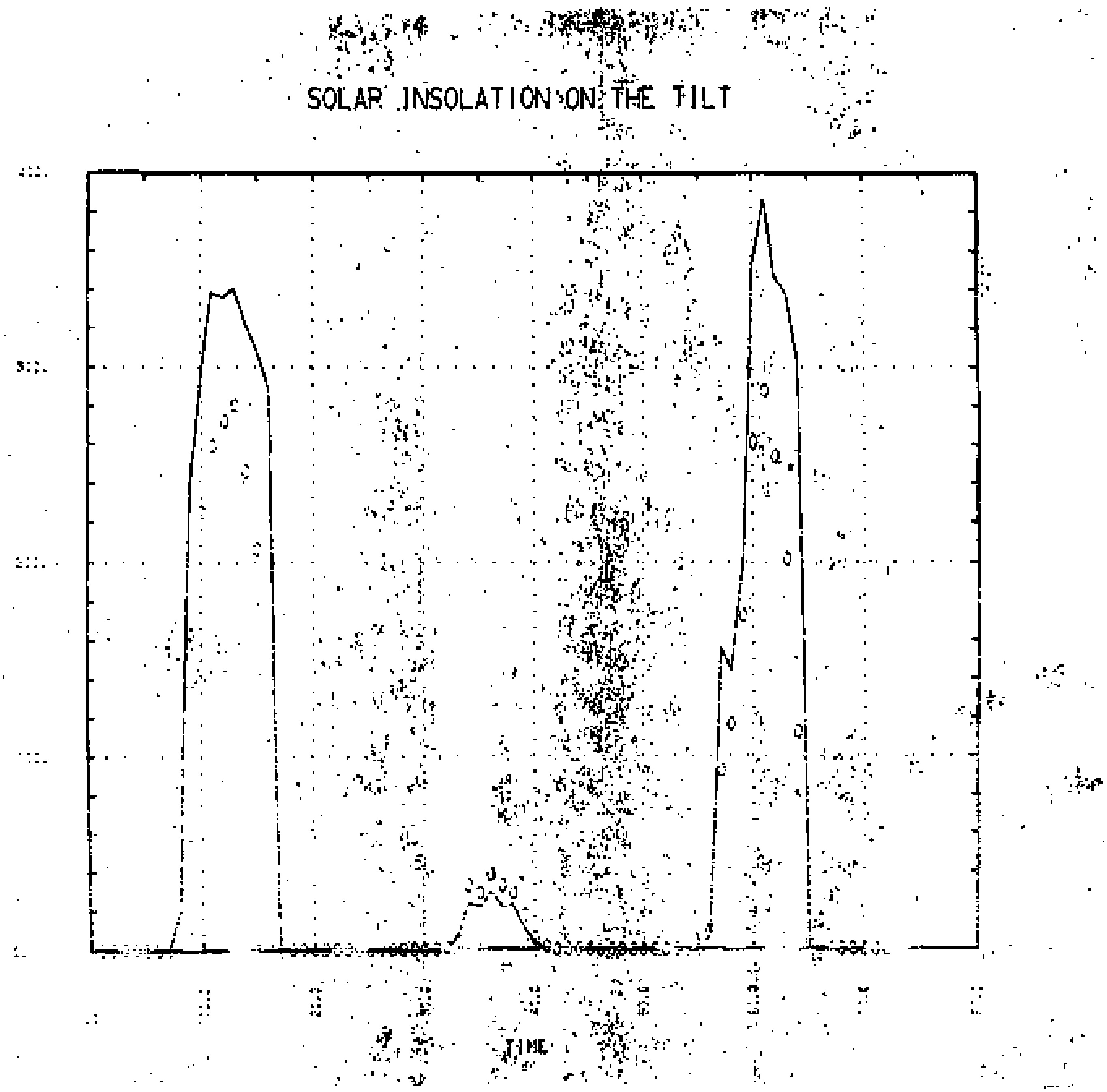

Figure B4.10 : SIMSHAC PERFORMANCE ANALYSIS

APPENDIX B5

SAMPLE RESULTS OF TRNSYS PERFORMANCE ANALYSIS FOR DECEMBER TRAINING PERIOD

TRNSYS COMPONENTS

- Flat Plate Collector
- On-Off Differential Controller with Hysteresis
- Pump
- Stratified Fluid Storage Tank
- Heat Exchanger (4 types)
- On-Off Auxiliary Heater
- ARKLA Absorption Air Conditioner
- Three-Stage Thermostat
- Rock Bed Thermal Storage
- Tee Piece, Flow Diverter and Flow Mixer
- Space Heating by Degree-Hour Approach
- Pressure Relief Valve
- Solar Radiation Processor
- Finite Element Wall Load Analysis
- Finite Element Roof Load Analysis
- Room and Basement Models
- Heat Pump
- Data Reader and Interpolator
- Time Dependent Forcing Function
- Algebraic Operator
- Integrator
- Printer
- Plotter

Figure B5.1

154

STORAGE TANK TEMPERATURE

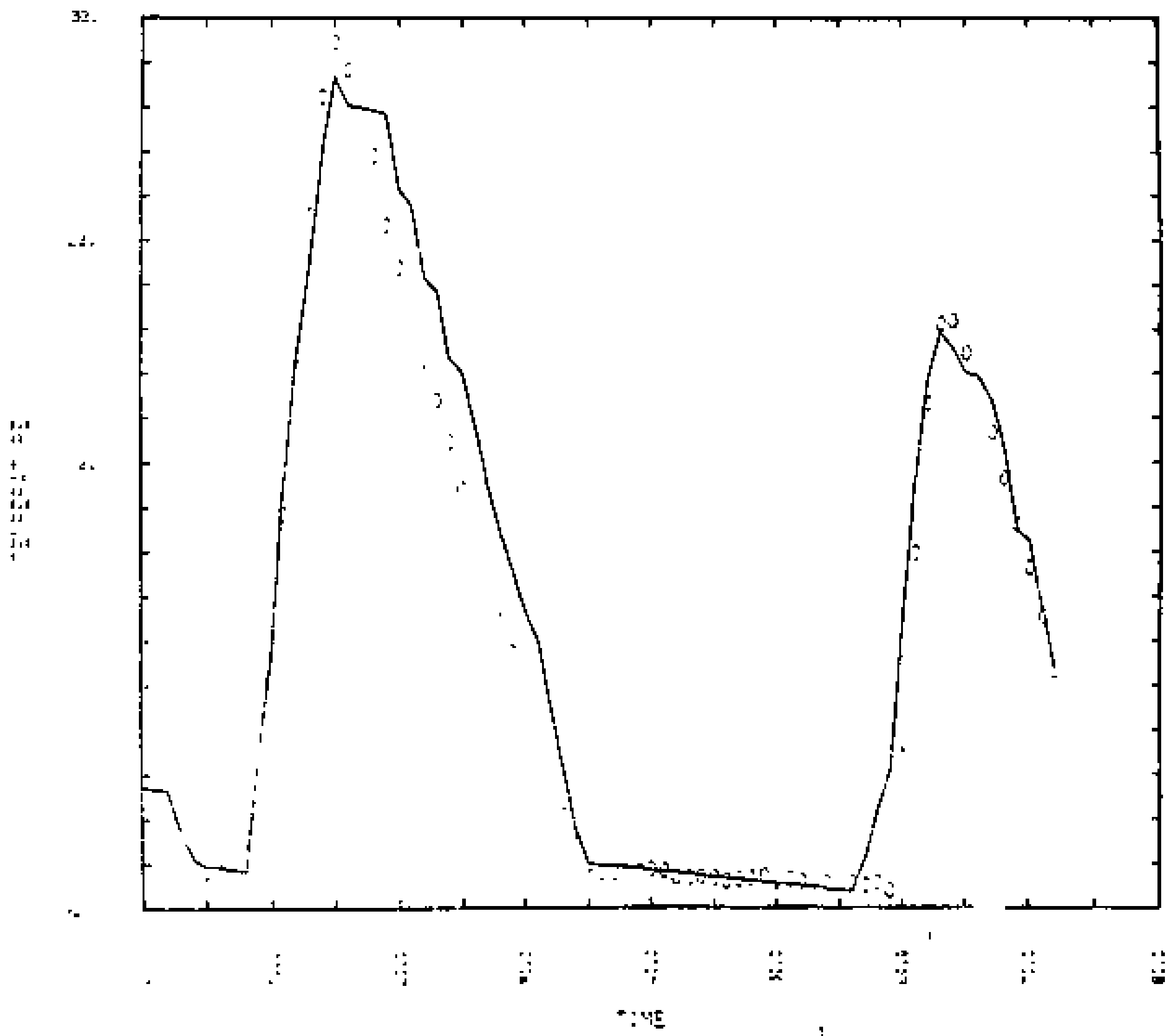

Figure B5.2 ; TRNSYS PERFORMANCE ANALYSIS

ENCLOSURE TEMPERATURE

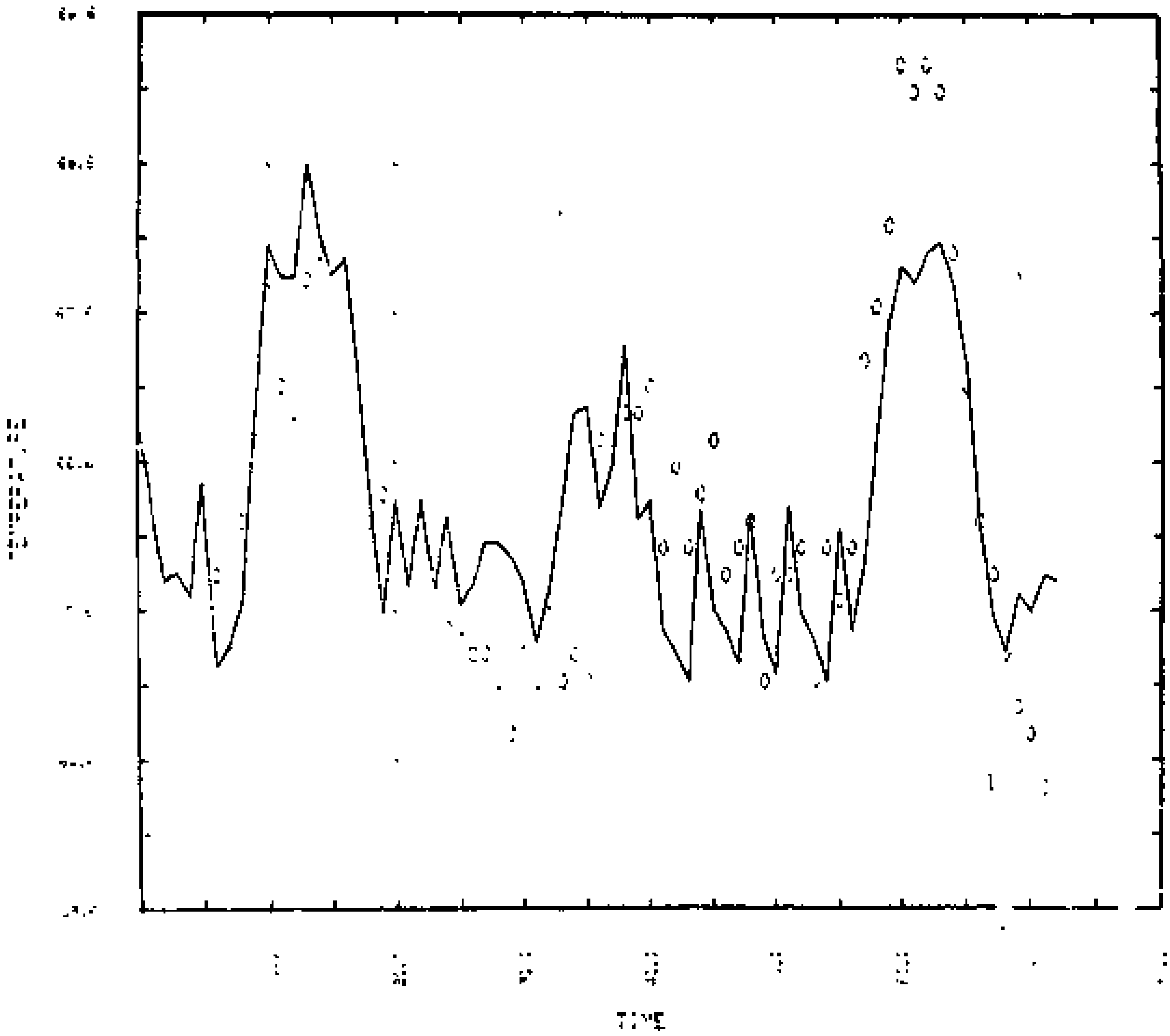

Figure B5.3 : TRNSYS PERFORMANCE ANALYSIS

COLLECTOR INLET TEMPERATURE

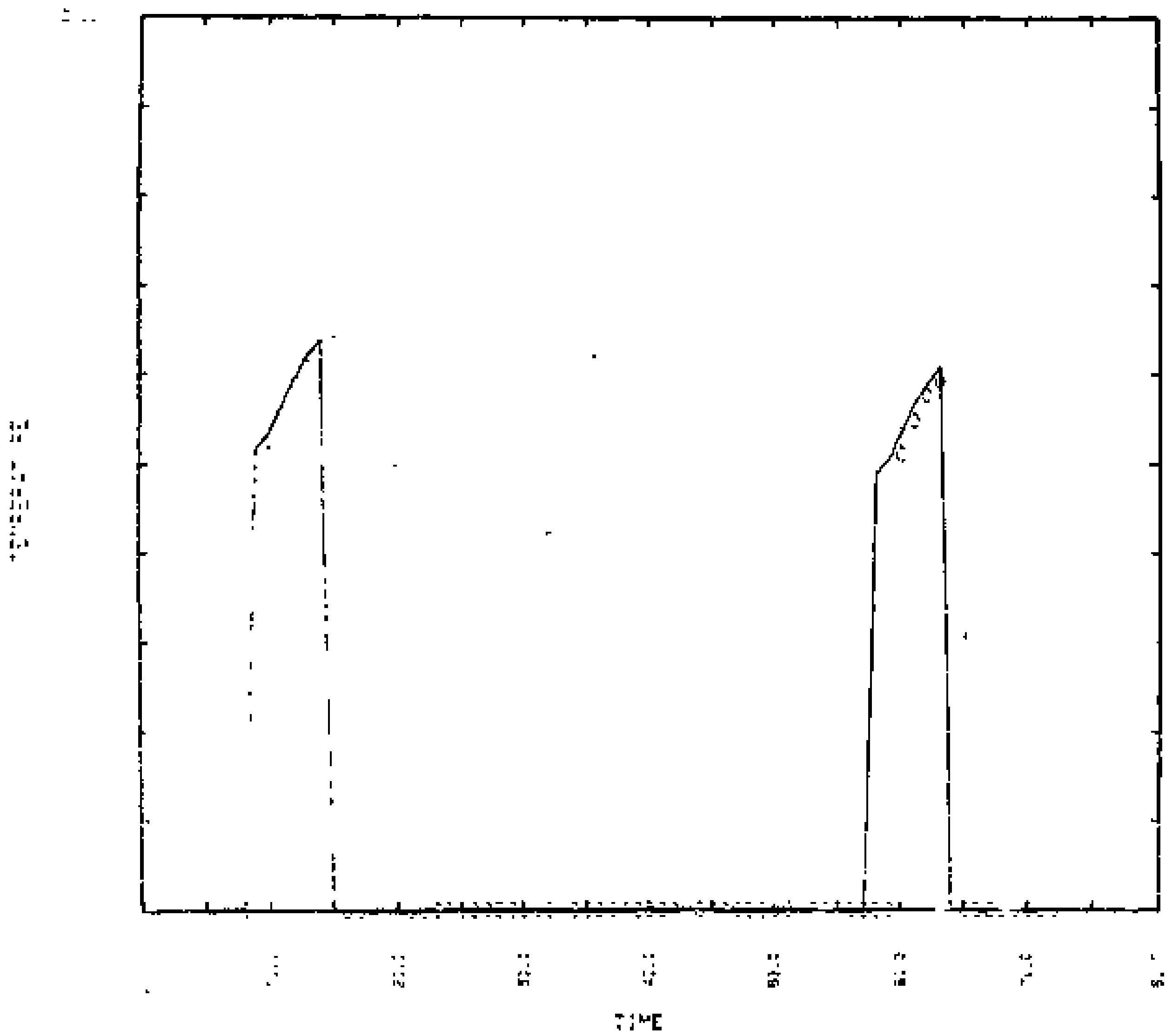

Figure B5.4 : TRNSYS PERFORMANCE ANALYSIS

COLLECTOR OUTLET TEMPERATURE

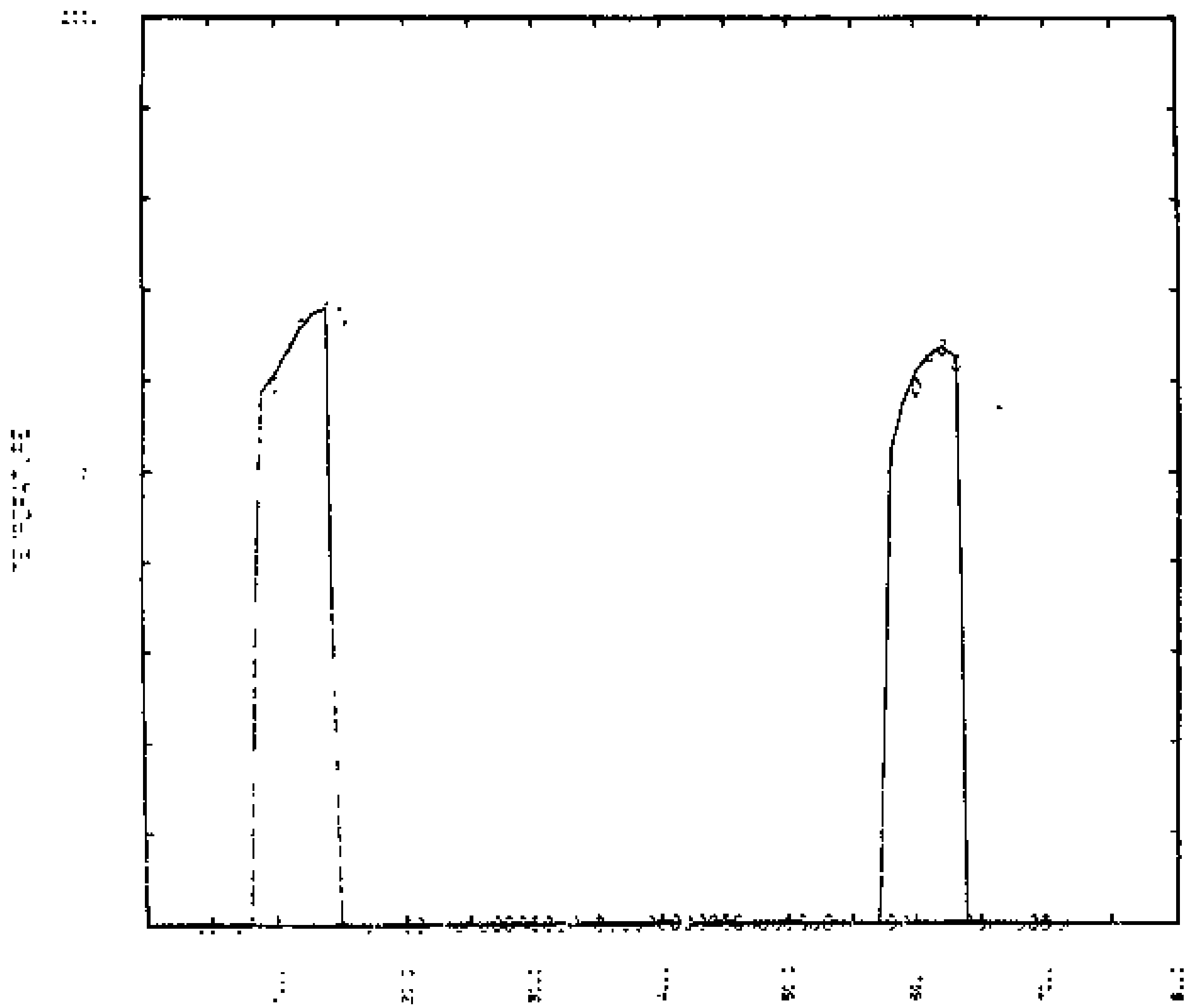

Figure B5.5 : TRNSYS PERFORMANCE ANALYSIS

COLLECTOR FLOW RATE

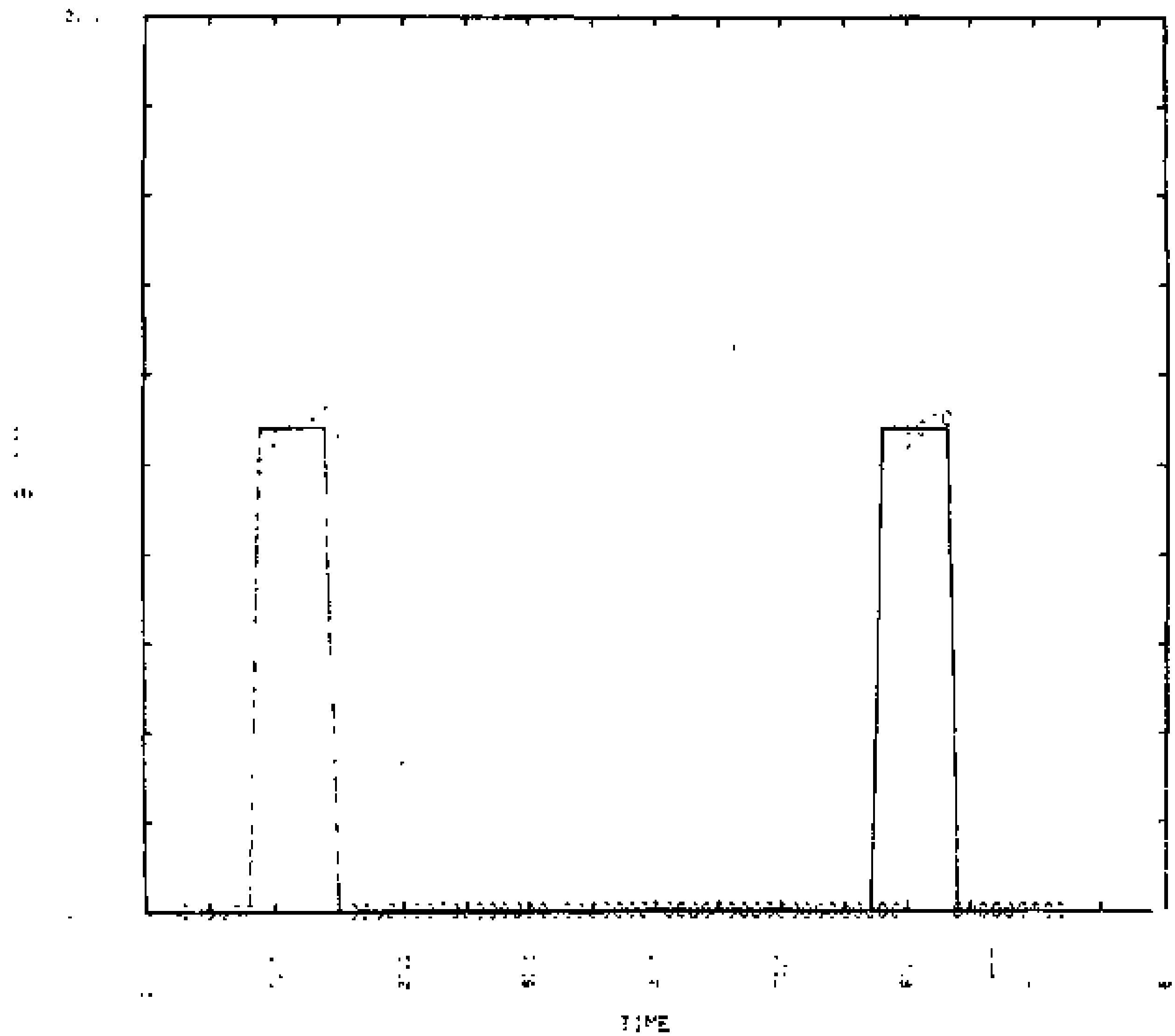

Figure B5.6: TRNSYS PERFORMANCE ANALYSIS

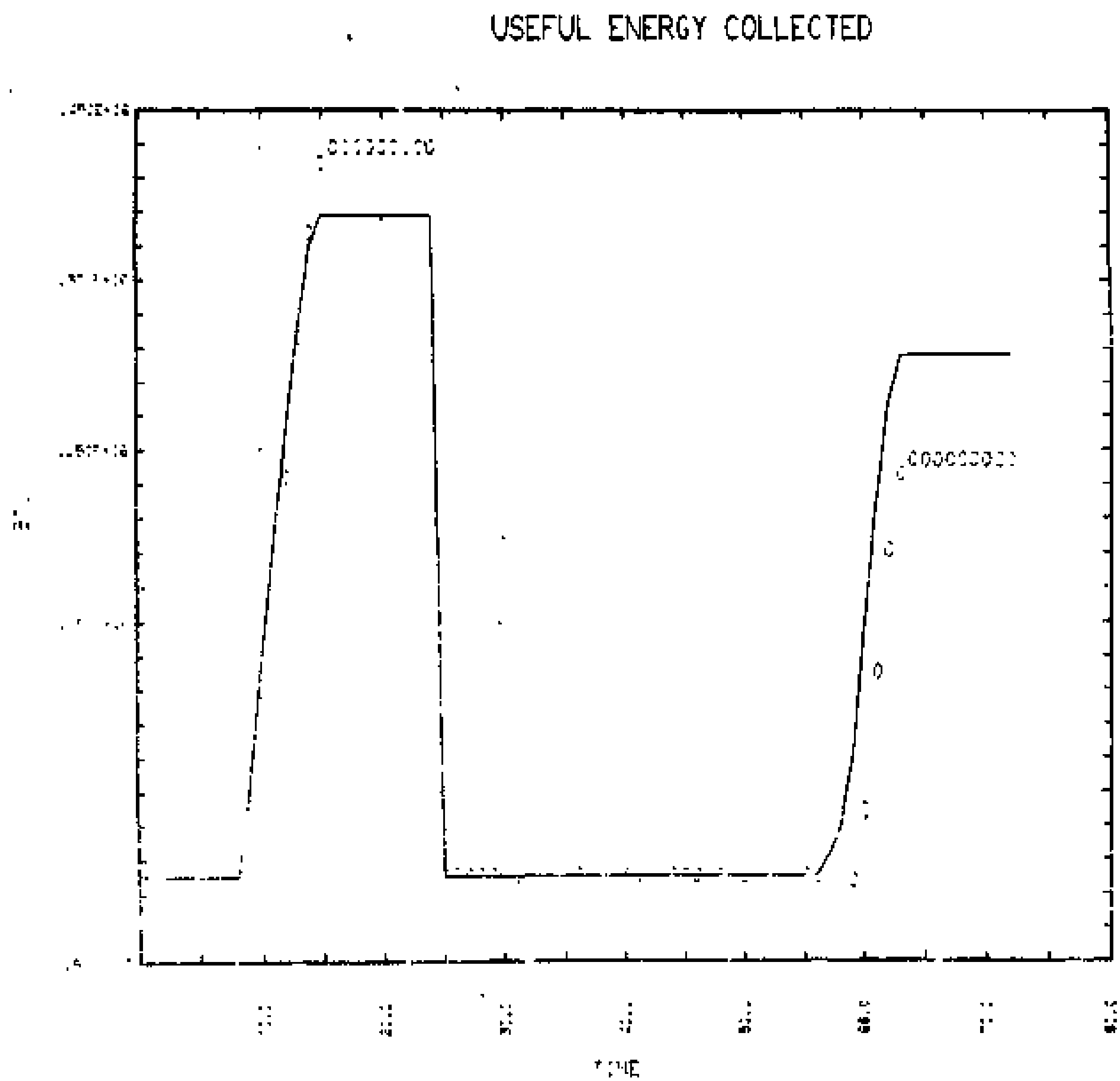

Figure B5.7 : TRNSYS PERFORMANCE ANALYSIS

ENERGY DELIVERED

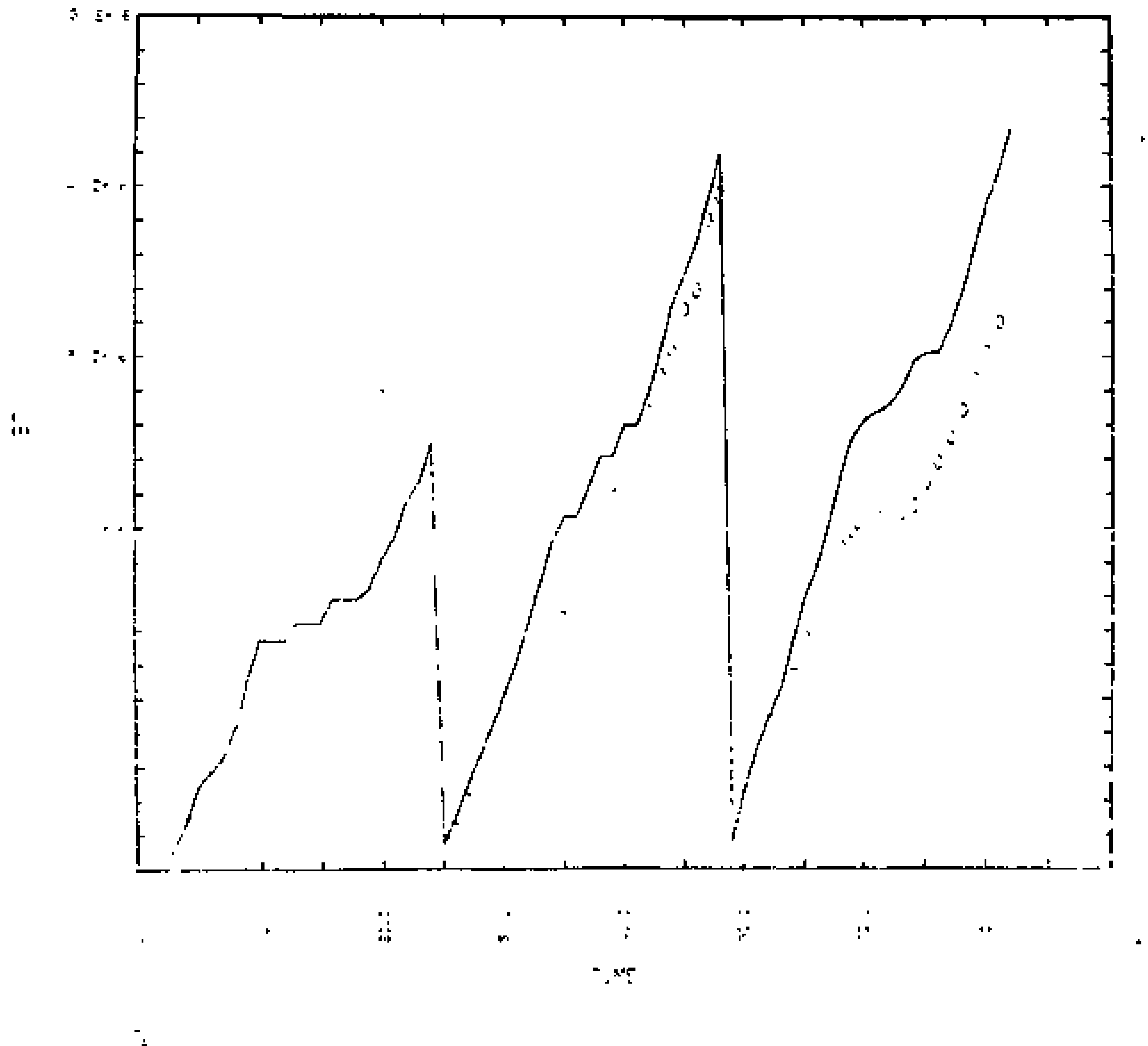

Figure B5.8 : TRNSYS PERFORMANCE ANALYSIS

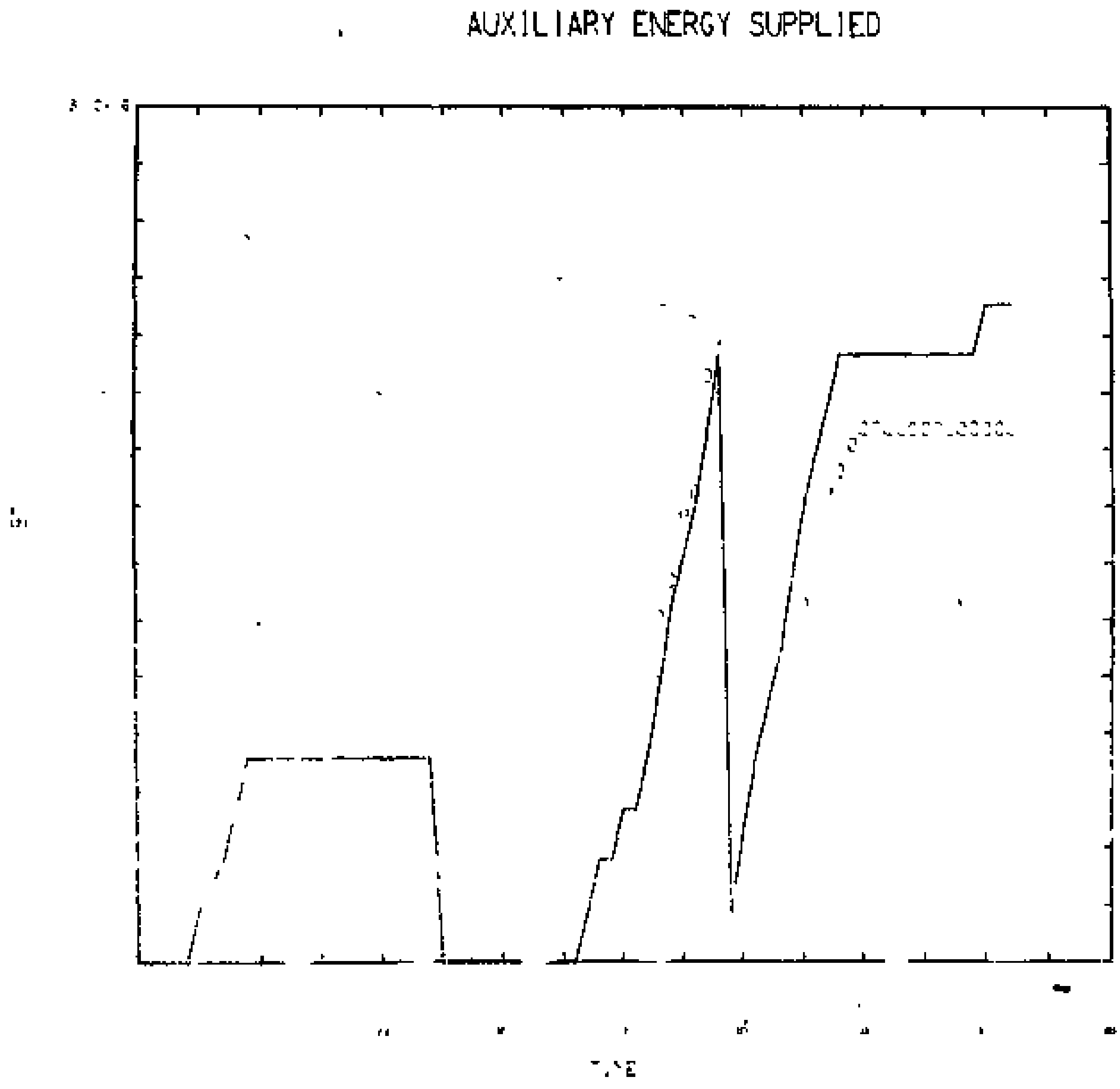

Figure B5.9 : TRNSYS PERFORMANCE ANALYSIS

SOLAR INSOLATION ON THE TILT

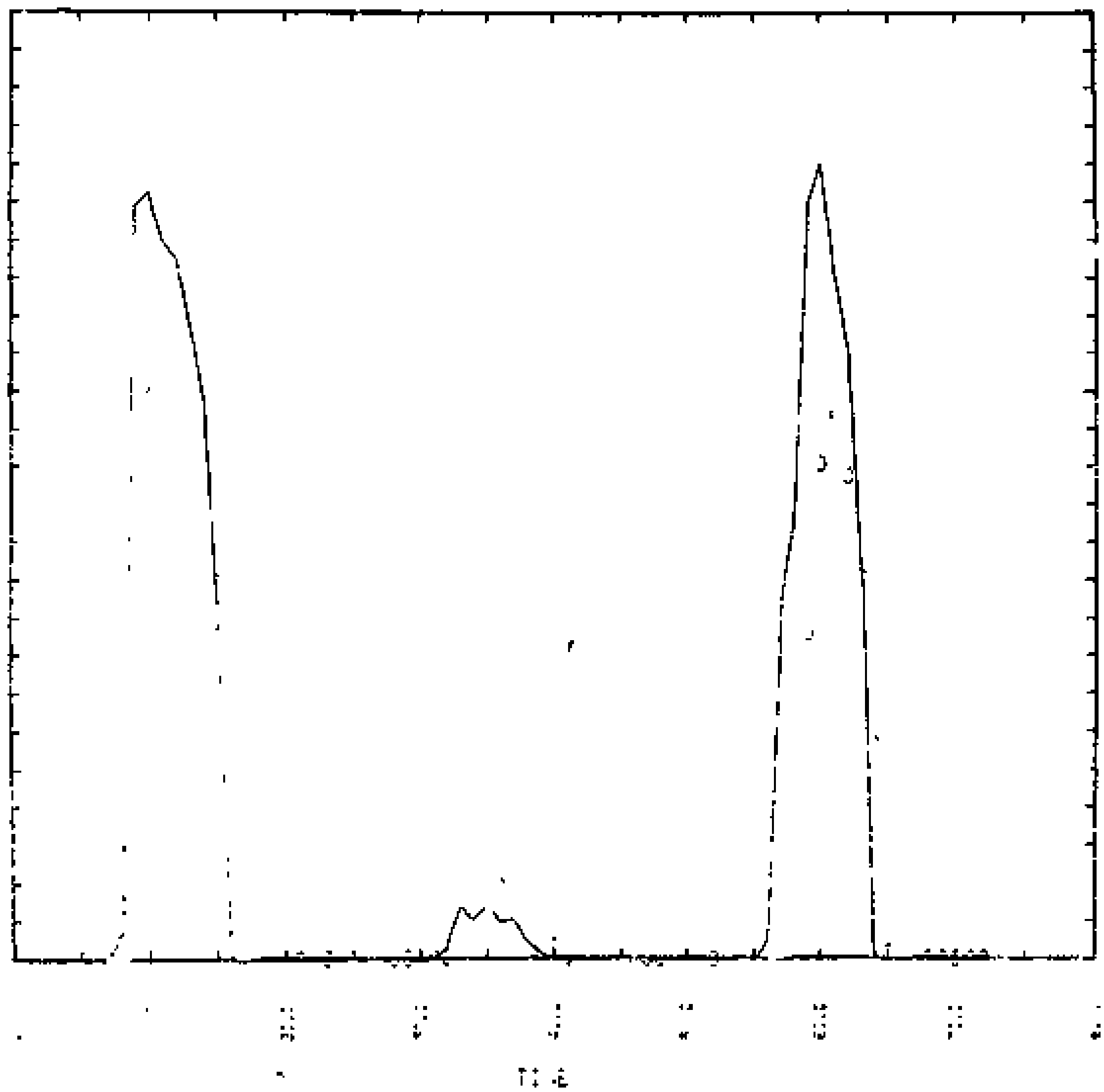

Figure B5.10: TRNSYS PERFORMANCE ANALYSIS