

THERMAL ANALYSIS FOR THE DESIGN OF AN  
INDUSTRIAL PROCESS WATER HEATING SYSTEM  
UTILIZING WASTE HEAT RECOVERY AND SOLAR ENERGY

by

MICHAEL DEANE ARNY

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## ABSTRACT

The transient simulation program TRNSYS is used to evaluate the thermal performance of design options for an industrial process water heating system in an Oscar Mayer meat packing plant. Two separate sets of evaluations are included. First of all, the thermal performance of design options for a system utilizing both an extensive waste heat recovery system and a large solar energy collection system are evaluated. Secondly, the thermal performance of a modified waste heat recovery system with no solar system is evaluated.

The system including solar energy collection was designed as part of the Low Temperature Solar Industrial Process Heat Demonstration Program funded by the Department of Energy and managed by the Solar Energy Research Institute. The Oscar Mayer plant has an extensive waste heat recovery system. This is an important factor in the thermal analysis of the system combining solar collectors and waste heat recovery since the energy outputs of both of these subsystems are dependent on their operating temperatures. The effect of the interaction of these two subsystems on their combined energy contribution to the process waste heating load is evaluated for

several system configurations.

The annual process water heating energy requirement for the meat packing plant is 47.3 TJ ( $11.9 \times 10^9$  BTU). The dominant source of energy to meet the load is the waste heat recovery system. For the four configurations, the fractions of the load met by waste heat recovery range from a high of 68 percent for the configuration without solar to a low of 53 percent for the series configuration with solar first. The configuration with parallel input of solar and waste heat recovery energy to storage has the smallest auxiliary energy requirement, even though this system has the smallest solar contribution of the three configurations with solar collectors. These results can be attributed to the dependence of the energy outputs of both the waste heat recovery subsystem and the solar subsystem on their respective operating temperatures and the relative magnitude of these energy outputs.

Once it was decided that the solar energy collection system would not be funded for construction, Oscar Mayer continued to investigate improvements for the waste heat recovery system. The existing waste heat recovery system is modeled and compared with system performance data. Then the effect of the proposed addition of two energy

uses to the waste heat recovery system is evaluated by simulating the modified system. The modified system was found to deliver to the load 32 GJ (30 MMBTU) more energy per production day than the existing system.

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## NOMENCLATURE

$IDN$	--	Direct normal solar flux.
$K$	--	Collector incident angle modifier.
$M_{BASE}$	--	Potable water flow rate through waste heat recovery heat exchanger when $Q_{BASE}$ data were collected at the Perry Plant.
$M_{WHR}$	--	Potable water flow rate through waste heat recovery heat exchanger.
$Q_{BASE}$	--	Energy transferred to potable water flow stream by waste heat recovery system based on data collected at the Perry Plant.
$Q_{WHR}$	--	Energy transferred to potable water flow stream by waste heat recovery system.
$T_{amb}$	--	Ambient temperature.
$T_{ave}$	--	Average collector fluid temperature.
$\theta$	--	Angle of incidence of beam radiation on collector.
$n$	--	Collector efficiency.

## 1.0 INTRODUCTION

### 1.1 The Use of Transient Simulations in the Design of Thermal Systems for Industrial Plants

The design of cost effective thermal systems requires the evaluation of the thermal performance of the various design options being considered. The thermal performance of systems involving steady state processes can easily be evaluated since operating conditions do not change over time. The evaluation of the thermal performance of systems involving transient processes is more complex since the conditions under which the system operates change over time and the thermal performance of the system may depend on previous as well as present operating conditions. Transient simulation is a method for evaluating the thermal performance of systems which operate under conditions which change over time. To carry out the transient simulation of a system, a mathematical model is developed from algebraic and differential equations which describe each of the components in the system. A schedule is developed for the variation over time of the conditions under which the system operates. Then some suitable techniques for solving sets of simultaneous equations is used to step the models through the schedule of operating conditions. In this way the system thermal performance under transient operating conditions can be

evaluated.

The transient computer simulation program TRNSYS (1) is a modular program written for the simulation of the thermal performance of such transient systems. Using this program, the model of the system is built up by specifying parameters for components from the TRNSYS component library and by specifying how these components are interconnected. In this thesis, TRNSYS was used to evaluate the thermal performance of design options for an industrial process water heating system in an Oscar Mayer meat packing plant. Two separate sets of evaluations were carried out. First of all, the thermal performance of design options for a system utilizing both an extensive waste heat recovery system and a large solar energy collection system was investigated. Secondly an investigation of the thermal performance of modified waste heat recovery system with no solar system was performed.

## 1.2 Thermal Analysis of an Industrial Process Water Heating System Utilizing Solar Energy and Waste Heat Recovery

A thermal analysis was carried out for an industrial process water heating system utilizing an extensive waste

heat recovery system and a large scale solar energy collection system. This system was designed for an Oscar Mayer Company meat packing plant in Perry, Iowa as part of the Low Temperature Solar Industrial Process Heat Demonstration Program funded by the Department of Energy and managed by the Solar Energy Research Institute. This program funded the design of low temperature solar industrial process heat systems for several industrial plants. The plants for which solar systems were designed included the Oscar Mayer meat packing plant, a food processing plant, a poultry processing plant, and a plant which manufactures sodium alginate from kelp. The solar system for each plant was designed by a separate design team.

The design team for the Oscar Mayer process water heating system was made up of the plant owners, the University of Wisconsin Solar Energy Laboratory, and TEAM Inc., an engineering design firm whose main office was located in West Virginia. These three groups had the following roles: Oscar Mayer provided data on the existing plant and carried out the economic analysis; the University of Wisconsin Solar Energy Laboratory provided system thermal analysis for the evaluation of design options; TEAM Inc. managed the design process and carried out the design of the mechanical system.

Progress through the design process was periodically reviewed by representatives of the Solar Energy Research Institute. The initial intent of the Department of Energy was to fund a substantial portion of the construction costs for the solar system designed for each plant if that design was accepted by the reviewers. By the end of the design phase, the funding for the demonstration program had been substantially reduced and as a result only one plant received partial funding for construction. The solar process water heating system designed for the Oscar Mayer Company plant was not funded for construction.

At the beginning of the design process, the Oscar Mayer plant had an extensive waste heat recovery system. This was an important factor in the thermal analysis. The energy output of both the waste heat recovery system and the solar energy collection system are dependent on their operating temperatures. The effect of the interaction of these two subsystems on their combined energy contribution to the process waste heating load was evaluated for several system configurations. In order to carry out these comparisons, several simulation component models not available in the TRNSYS component library were developed.



During the design of the process water heating system utilizing both a solar energy collection system and a waste heat recovery system, Oscar Mayer implemented or approved plans for energy conservation and waste heat recovery measures which would reduce process water heating requirements by thirty-five percent. These cost effective energy management projects produced an interest in the detailed simulation of the waste heat recovery system itself for design purposes.

### 1.3 Waste Heat Recovery System Design Simulations

Based on the reductions in the process water heating requirements during the design of the solar energy collection system, Oscar Mayer decided to find additional uses for the energy collected by the waste heat recovery system. Simulations were used for the evaluation of design modifications being considered for the existing waste heat recovery system. The existing waste heat recovery system in the plant was modeled using the simulation program TRNSYS, and the simulation results were compared with system performance data. Then the effect of proposed modifications to the waste heat recovery system was evaluated by simulating the modified system.

## 1.4 Objectives and Organization

The objective of this research was the evaluation of the thermal performance of industrial process systems in order to provide information for design decisions. The transient simulation program TRNSYS was used for modeling the thermal performance of the systems.

This thesis is organized into 2 main chapters. Chapter 2 describes the thermal analysis done for the design of the industrial process water heating system utilizing a waste heat recovery system and a solar energy collection system. Chapter 3 presents the evaluation of the effect of the addition of new energy uses to the waste heat recovery system. Chapter 4 consists of conclusions.

## 2.0 Evaluation of the Thermal Performance of the Oscar Mayer Solar Industrial Process Water Heating System

### 2.1 Plant Description

#### 2.1.1 Process Heat Requirements

The Perry plant requires process heat in the form of steam, hot water, and open flame. The steam is generated in a boiler fired with natural gas or fuel oil. The hot water is heated by the waste heat recovery system and steam heaters. The open flame used for singeing the hog carcasses is provided by the direct combustion of natural gas. Figure 2.1 (2) shows the types of thermal energy inputs required at various stages during the meat packing process and illustrates the energy intensive nature of the plant operation.

Steam is used in many processes throughout the plant. Inedible rendering is the largest user of steam. In this process inedible materials are rendered to recover greases, oils, and solid protein materials. The process water heating system is the second largest user of steam, even though the waste heat recovery system has reduced the steam requirements for this purpose. The amount and temperature of process water required vary

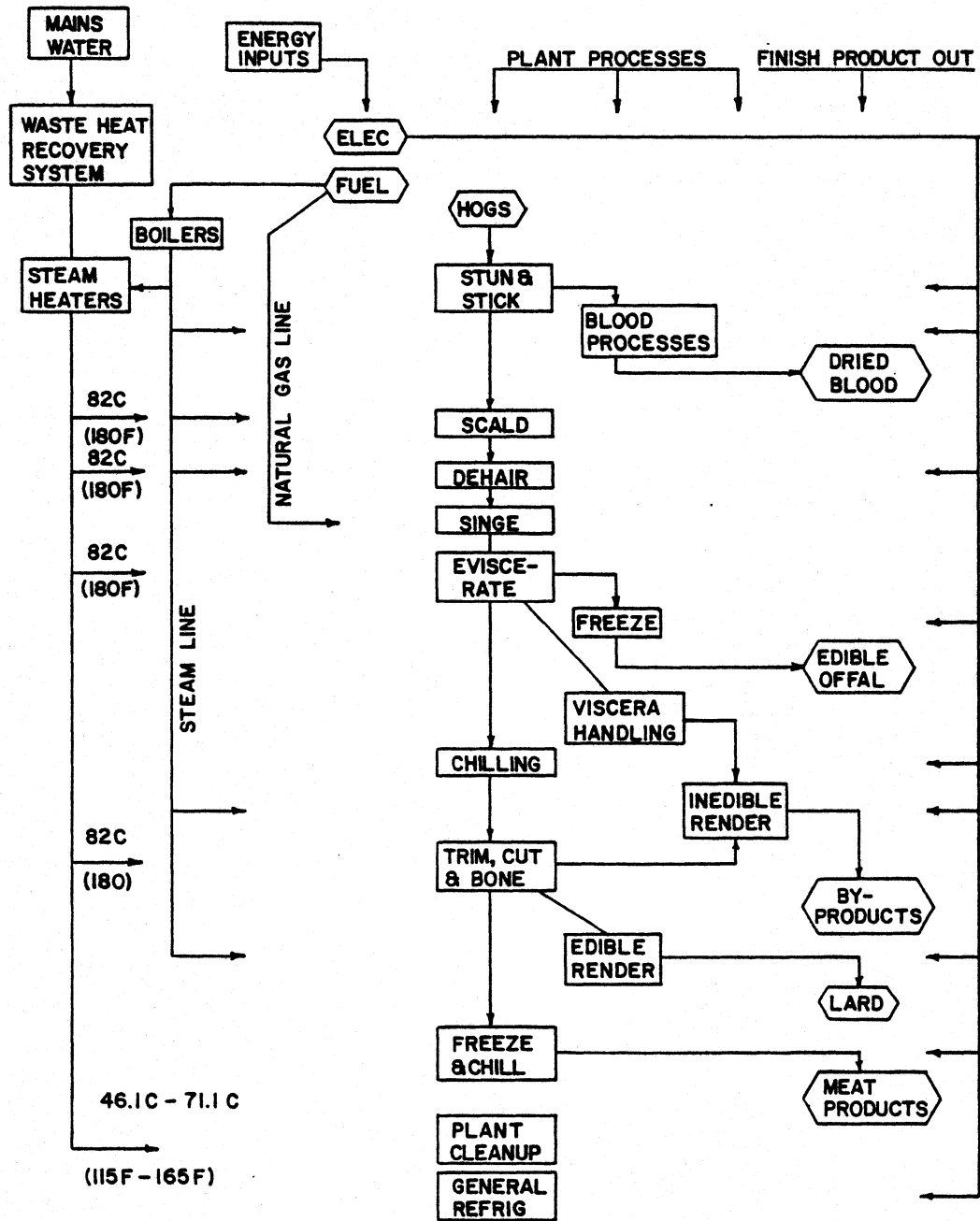


Figure 2.1 Energy Use in Pork Processing Plant Operations

over time. During the production day, 82.2 C (180 F) water is required by USDA regulations for sanitation at many stages of the meat packing process. To insure that the water is delivered to the points of use above this temperature during production, all process water is heated to 85 C (185 F). During non-production hours USDA regulations do not apply, but 60.0 C to 71.1 C (140 F to 160 F) water has been used for cleaning since high temperatures assist the removal of animal fats and proteins from equipment, floors, and walls. At the beginning of the design study for the solar system, the temperature of the cleaning water had been reduced to 62.8 C (145 F) as an energy conservation measure. Later it was determined that a cleaning water temperature of 46.1 C (115 F) was adequate if special cleaning compounds were used. Characterization of these fluctuating process water loads is discussed in section 2.3.3.

#### 2.1.2 The Waste Heat Recovery System

At the beginning of the design process, the Perry plant process water heating system (Figure 2.2), used an extensive waste heat recovery system and steam heaters. The waste heat recovery system collected energy from the hog singer exhaust economizer, the inedible rendering

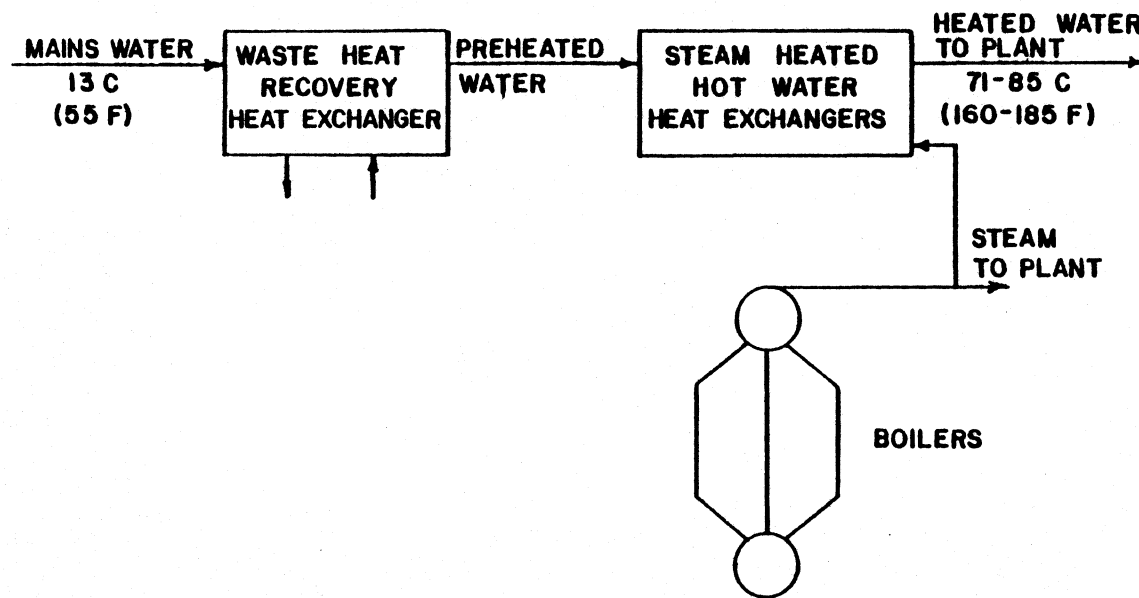


Figure 2.2 The Process Water Heating System Prior to the Addition of a Storage Tank

condensate heat exchanger, and from the ammonia desuperheaters. Early in the design process, a storage tank was added so that excess preheated water could be stored. Other waste heat recovery system modifications occurred later on during the design process and these are discussed in section 2.3.3.

## 2.2 The Proposed System

### 2.2.1 Introduction

Since the system was designed as part of the Solar Industrial Process Heat Demonstration Program, certain aspects of the design were specified in the Request for Proposals. This particular cycle of the program specified the design of systems which heated low temperature process water (62.8 to 85.0 C) (145 F to 185 F) using collector arrays of approximately 3700 square meters (40,000 square feet). The three different types of solar collectors initially considered for use in the system design were flat plate collectors, evacuated tubular collectors, and parabolic trough single axis tracking collectors. The parabolic trough collector type was selected by TEAM Inc. after evaluation of the economic merit for this project of the three collectors types. This evalua-

tion of economic merit was based on thermal performance results for a system with constant volume storage which was simulated early in the design process. The parabolic trough collector type was used in all of the simulations done for the comparison of the thermal performance of the final system configurations. Before system simulations began, the 45 cubic meter (98,000 gallon) storage tank was ordered for the waste heat recovery system and the solar system.

Given these basic system parameters and the extensive waste heat recovery system already in place, the goal of the analysis became the comparison of the thermal performance of various system configurations.

### 2.2.2 System Configurations

Four system configurations were considered: a system without solar collectors, a system with a separate parallel delivery of solar and waste heat energy into the storage tank, and two different systems with the waste heat recovery and solar subsystems in series supplying energy to the storage tank. One series system had the waste heat recovery subsystem first in series and the other had the solar subsystem first in series. The waste heat recovery loop and its three sources of energy are



shown in Figure 2.3. The ammonia desuperheater operates continuously, since it is needed to allow the plant refrigeration system to function efficiently. The other two sources in the secondary loop provides energy intermittently and can be bypassed. The proposed solar collector loop is shown in Figure 2.4.

The system without solar collectors, shown in Figure 2.5, had a constant volume of water for energy storage, (i.e., a constant volume tank). Energy was input to storage from the waste heater recovery system through the make-up water for the tank. A tempering valve mixed cold water with water from the tank when the temperature in the tank exceeded the load set temperature. An auxiliary steam heat exchanger boosted the temperature of the process water as required.

The parallel system configuration, shown in Figure 2.6, was the same as the system without solar collectors except for the addition of energy input to storage from the collector array through a recirculation loop. In the parallel system configuration the storage tank holds a constant volume of water (i.e., a "constant volume" tank). The control strategy used for this configuration operated the collector loop pump whenever the collector outlet temperature was marginally above the temperature at the bottom of the storage tank. This control strategy

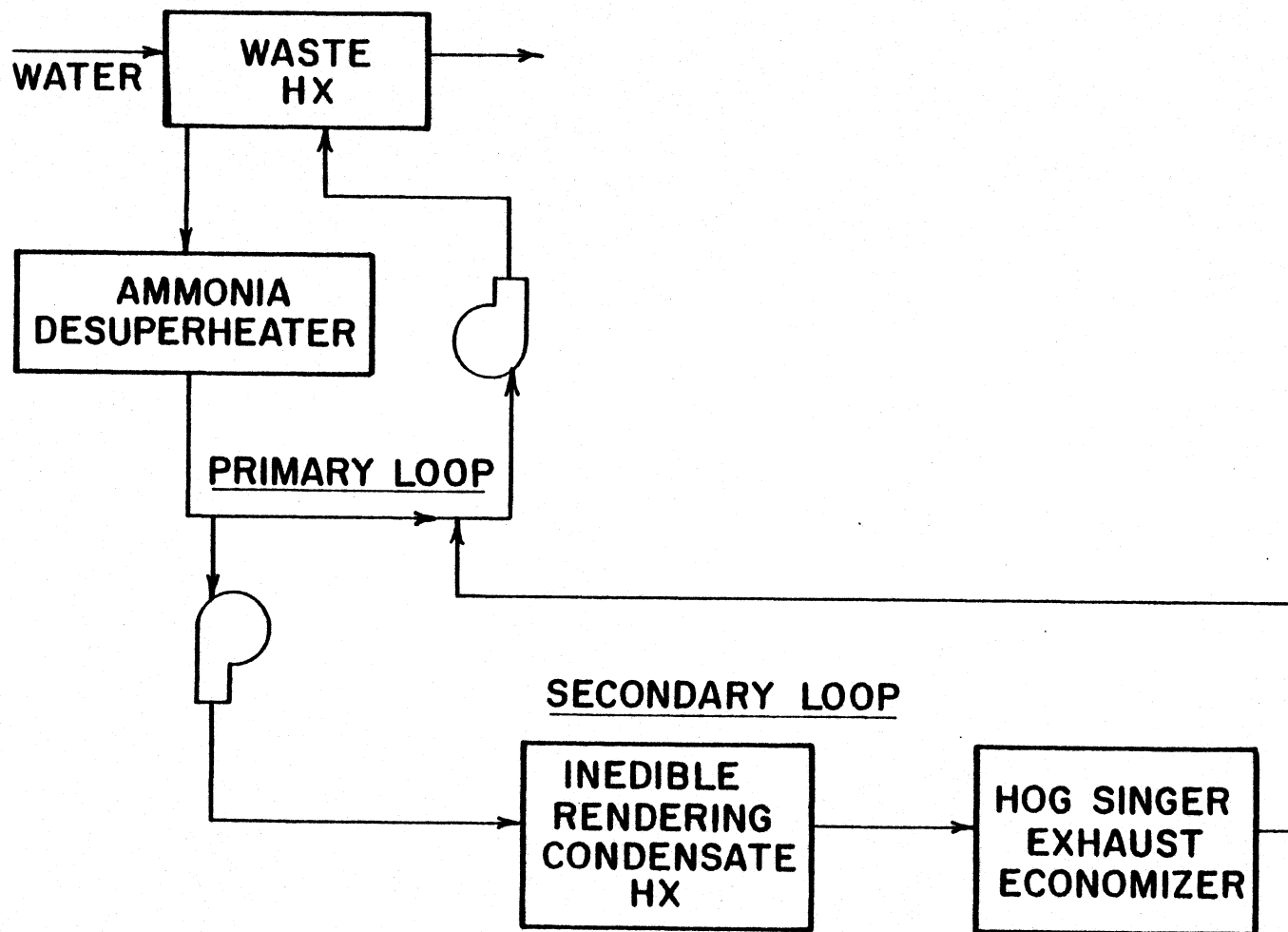


Figure 2.3 The Waste Heat Recovery Loop

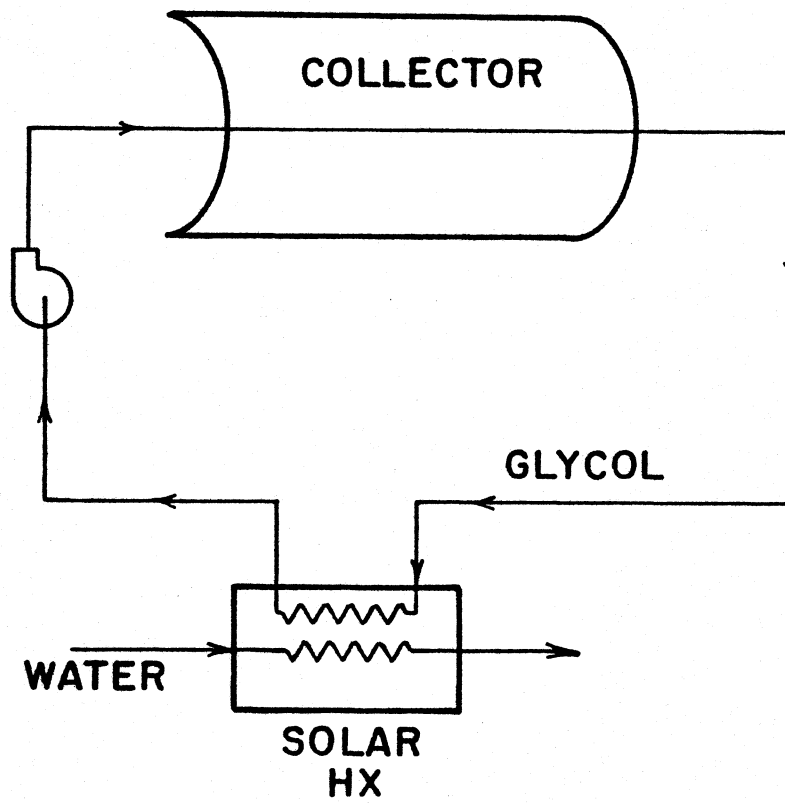


Figure 2.4 The Solar Collector Field Loop

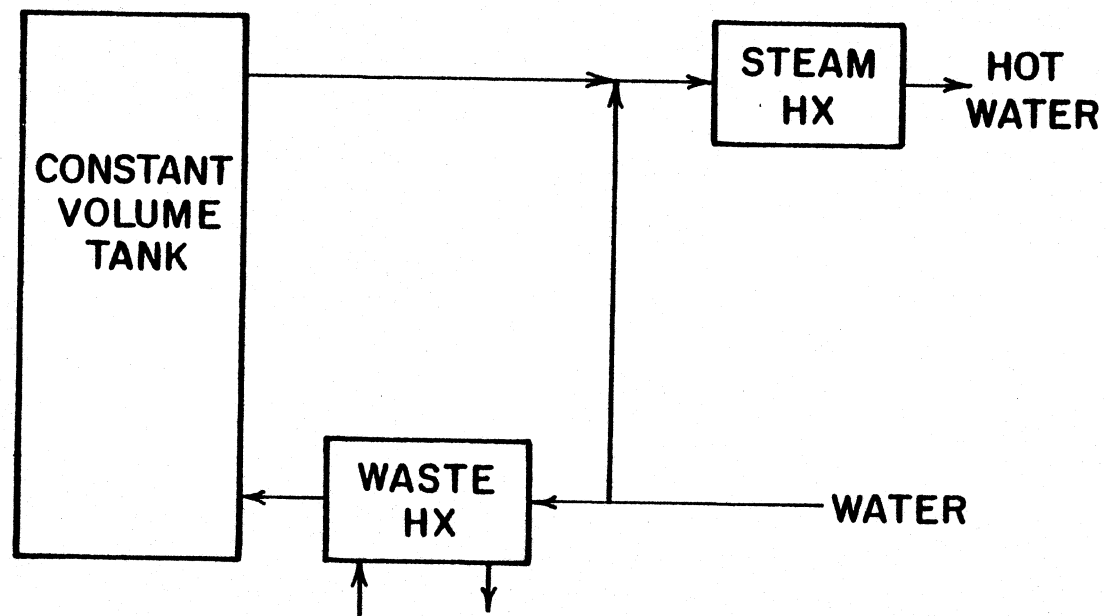


Figure 2.5 The Constant Volume Storage System Without Solar Collectors

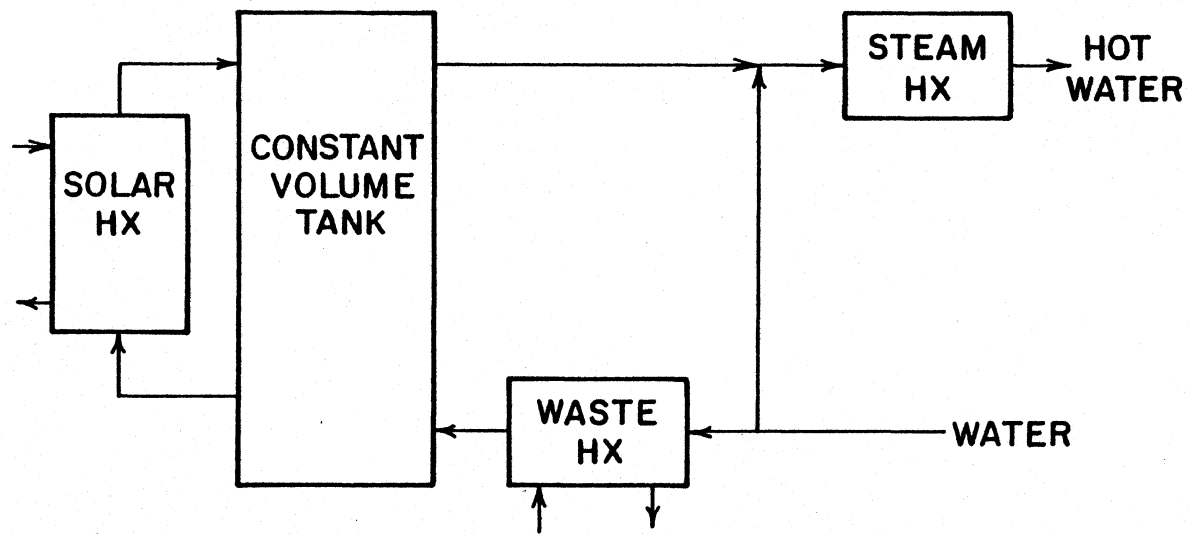


Figure 2.6 The Constant Volume Storage System With Solar Collectors

allows the addition of energy to the storage tank whenever there is sufficient energy gain. The control decision at any point in time is determined by the temperature at the bottom of the tank and the collector outlet temperature. This is simpler than the control strategy used for the system with variable volume storage discussed below which required prediction of subsequent energy flows in or out of the tank.

In the series system shown in Figure 2.7, the solar heat exchanger preceded the waste heat recovery heat exchanger in series. In the second variation, shown in Figure 2.8, the solar heat exchanger followed the waste heat recovery heat exchanger in series. In both series systems a tempering valve was used to mix cold water with water from the tank when the temperature in the tank exceeded the desired temperature. An auxiliary steam heat exchanger boosted the water temperature as required. These two variations of the series system configuration used a storage tank holding varying amounts of water, (i.e., a "variable volume" tank). In this system the make-up water flowed through the waste heat recovery and solar heat exchangers in series and then into the storage tank. The use of variable volume storage allows an additional freedom of choice for control strategies. The storage inlet temperature depends on the strategy chosen.

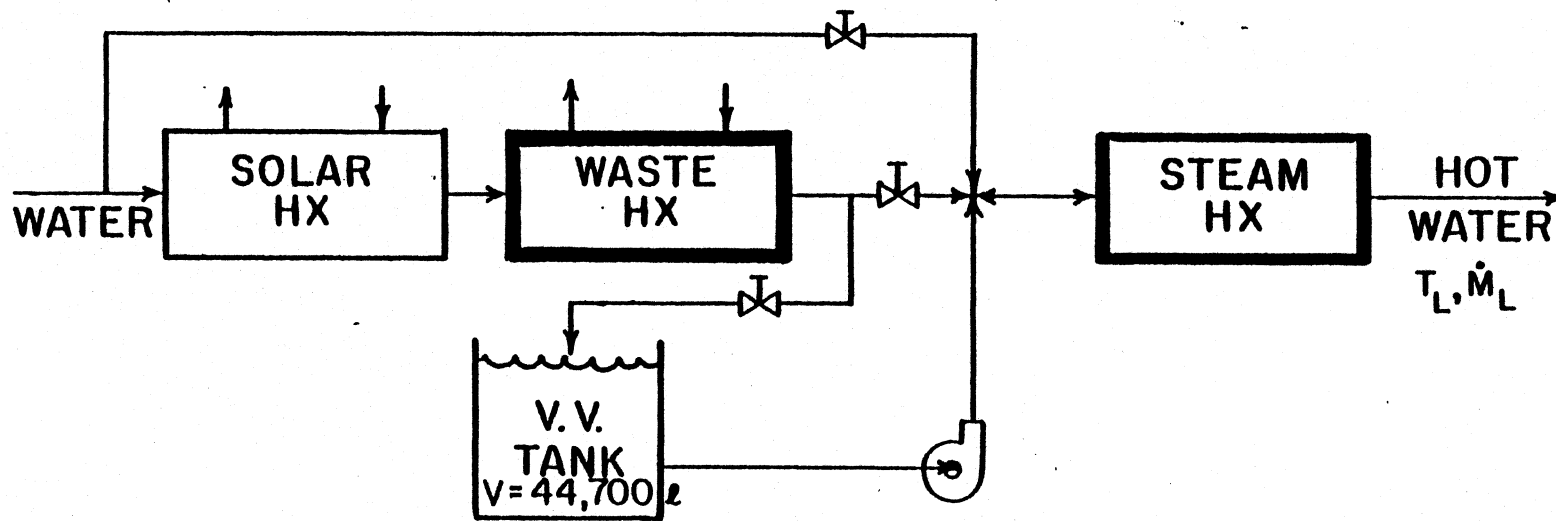


Figure 2.7 The Variable Volume Storage System With Solar First in Series

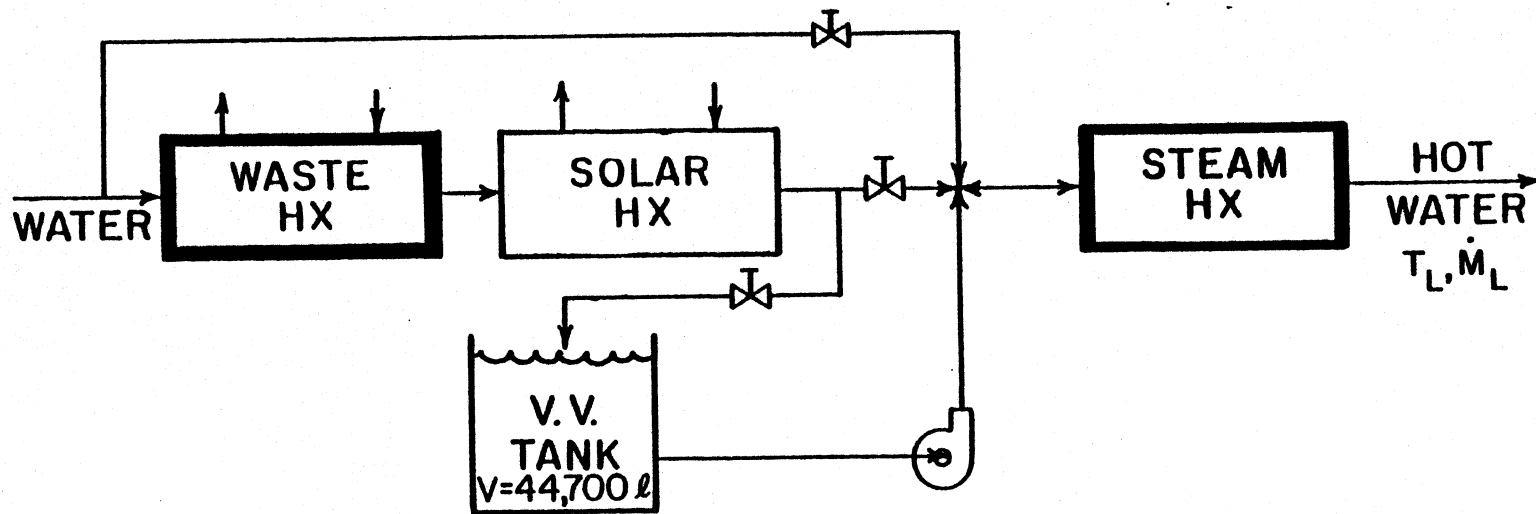


Figure 2.8 The Variable Volume Storage System With Solar Second in Series



Two system constraints affect the choice of control strategy. First, the total mass of water flowing into the tank over a day or longer must equal that leaving. Second, at any given point in time the solar and waste heat recovery sub-systems when considered together will deliver more energy to the potable water flow stream when there is a higher water flow rate and less energy when there is a lower water flow rate.

The optimum control strategy for this system is one which modulates the water flow rate into the tank so that the maximum amount of energy is delivered to the load. A predictive control strategy must be used to obtain optimal system thermal performance, since at any given point in time the optimal storage tank inlet temperature depends on subsequent energy flows in and out of the tank as well as conditions in the tank at that point in time.

In the control strategy used for the variable volume system simulations, the flow through the solar and waste heat recovery heat exchanger was modulated so that water entered the storage tank at a preselected temperature. This storage tank inlet temperature was selected so the flow rates were as high as possible without causing frequent tank overflow. Since the amount of energy collected by the collector array varies over the course of

a year, the storage inlet set temperature varied over the year to make efficient use of the storage. The storage inlet set temperatures were selected by trying various values in successive simulations until values were found which provided high energy transfers into the potable water flow stream but rarely caused the storage tank to overflow.

## 2.3 Method of Analysis of System Thermal Performance

### 2.3.1 Introduction

The Transient Simulation Program TRNSYS was used to investigate the thermal performance of the various proposed configurations for the solar industrial process water heating system. To carry out the system simulations it was necessary to model the various system components and to characterize the conditions under which the system would be operated. A number of new system component models were developed in the form of TRNSYS subroutines. These component models include: a variable volume tank, a variable volume pump, a temperature and flow rate dependent waste heat recovery system, a load profile sequencer, and shading for large collector arrays.

### 2.3.2 Weather Data

The proposed site for the solar industrial process heat system is in Perry, Iowa. The nearest location for which hourly SOLMET Typical Meteorological Year (TMY) (3) data are available is North Omaha, Nebraska, which is located 130 miles southwest of Perry. The annual global insolation values and the annual average temperatures calculated from monthly SOLMET data (4) for several Iowa sites near Perry and those calculated from hourly SOLMET data for North Omaha are listed in Table 2.1. The annual average temperature for North Omaha is 1.6 degrees C (2.9 degrees F) above the average of the annual average temperatures for the Iowa sites. The annual global insolation is 2.4 percent greater for North Omaha than the average for the Iowa sites. This similarity between the meteorological data for North Omaha and the Iowa sites is reassuring, but not conclusive, since the monthly SOLMET data were generated using modeling techniques combined with local meteorological data. The North Omaha TMY data were used for all of the system simulations.

Two diffuse correlations were considered for separating the global insolation data into beam and diffuse components: the Liu and Jordan correlation (5) and the Aerospace correlation (6). The Aerospace correlation provides

Table 2.1  
Weather Data Comparison

Type of Weather Data	City	State	Latitude (°North)	T <sub>amb</sub> Avg. (°F)	Annual Global Insolation (MMBTU/ft <sup>2</sup> )
Monthly SOLMET Data	Sioux City	IA	42.2	48.6	.479
	Mason City	IA	43.1	45.3	.471
	Des Moines	IA	41.3	49.4	.479
	Burlington	IA	40.5	51.3	.478
Hourly SOMMET TMY data	North Omaha	NE	41.2	51.5	.489

lower estimates of the beam fraction and was used to generate the direct normal radiation values appearing in the hourly TMY data. The choice of the diffuse correlation used to separate the radiation data into its beam and diffuse components is particularly significant when calculating the performance of concentrating collectors that only utilize beam radiation. The annual totals of insolation on a collector array in various orientations calculated with both diffuse correlations are shown in Table 2.2. The insolation values calculated from the hourly data show that for fixed arrays of collectors which utilize both beam and diffuse radiation, the two correlations produce similar estimates of the total incident solar radiation. The two correlations produce very different estimates of total incident solar radiation on tracking collectors which only utilize beam radiation. In the case of the north to south collector axis tracking collector, the Liu and Jordan correlation estimates 13 percent greater beam radiation incident on the collector aperture than the Aerospace correlation. Recent work by Erbs (7) has shown the Aerospace correlation to be relatively satisfactory, so it was used in the system simulations.

Table 2.2  
Diffuse Correlation Comparison

Diffuse Correlation Used to Evaluate Insolation	Annual Total Insolation on 40,320 ft <sup>2</sup> Collector Array (Billions of BTU)		
	Slope = 41.3 AZ = 0.0 No Tracking	Az = 0.0 E-W Axis Tracking	Slope = 0.0 N-S Axis Tracking
Liu & Jordan	22.6	24.9	28.6
Aero Space Corp.	22.2	23.6	24.8

### 2.3.3 Load Profiles

The simulation of the proposed system required the development of a schedule of the process water heating load throughout the year. For this purpose performance data for the existing system were collected by Oscar Mayer. These data were recorded during a typical week composed of five production days and a two-day weekend. During such a weekend some cleaning and routine maintenance occur, primarily on the first day after production ends. The performance data include values for the hot water demand temperature, the hot water demand flow rate, and the temperature of the potable water after it has passed through the water heat recovery system heat exchanger. These data are in the form of average values over two hour intervals. The existing system had a constant potable water inlet temperature of 12.8 C (55 F) to the waste heat recovery heat exchanger at a flow rate equal to the hot water demand flow rate.

For the purpose of generating an annual load profile the year was represented by a sequence of three types of days. These types were a production day, the first day after a production day, and the second day after a production day. The week of performance data was reduced to

daily load profiles for the three types of days. The average of the data for the five production days was used as the production load profile shown in Figure 2.9. The Saturday data were used as the daily load profile for the first day after a production day (Figure 2.10). The Sunday data were used as the daily load profile for the second or third day after a production day (Figure 2.11).

Next, the three types of daily load profiles were combined in several different sequences to produce weekly load profiles representative of the various weekly production schedules which occur during the year. These production week load profiles were a regular production week, a long production week, and a short production week.

The regular production week load profile represented a week with five working days and a two-day weekend. This regular production week profile was composed of a sequence of five production day profiles, one first day after a production day profile, and one second day after a production day profile.

The long production week load profile represented a week when the demand for a high level of production required six working days and a one day weekend. This long production week profile was composed of a sequence of six production day profiles and one first day after a



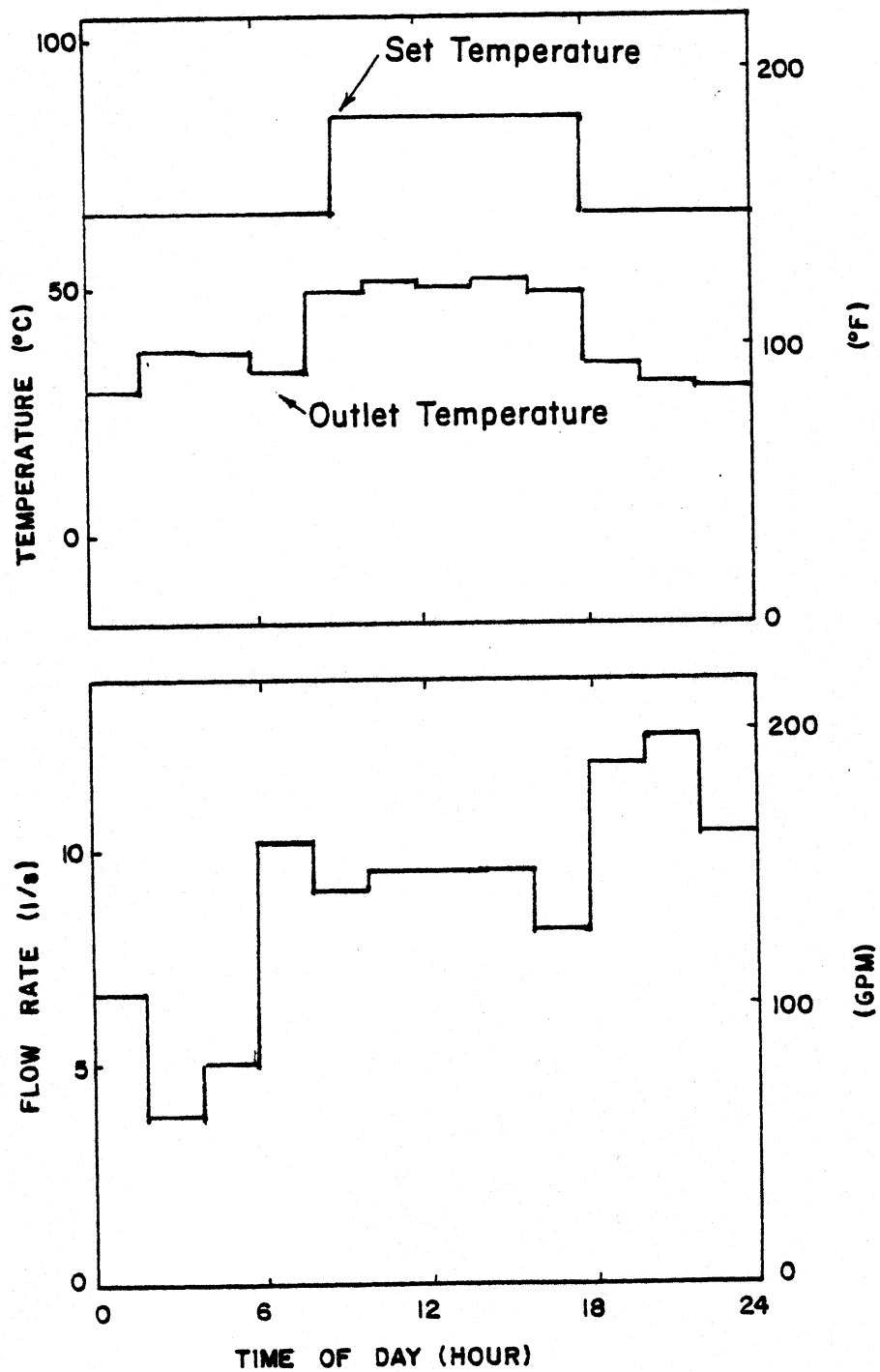


Figure 2.9 Production Day Load Profile 1

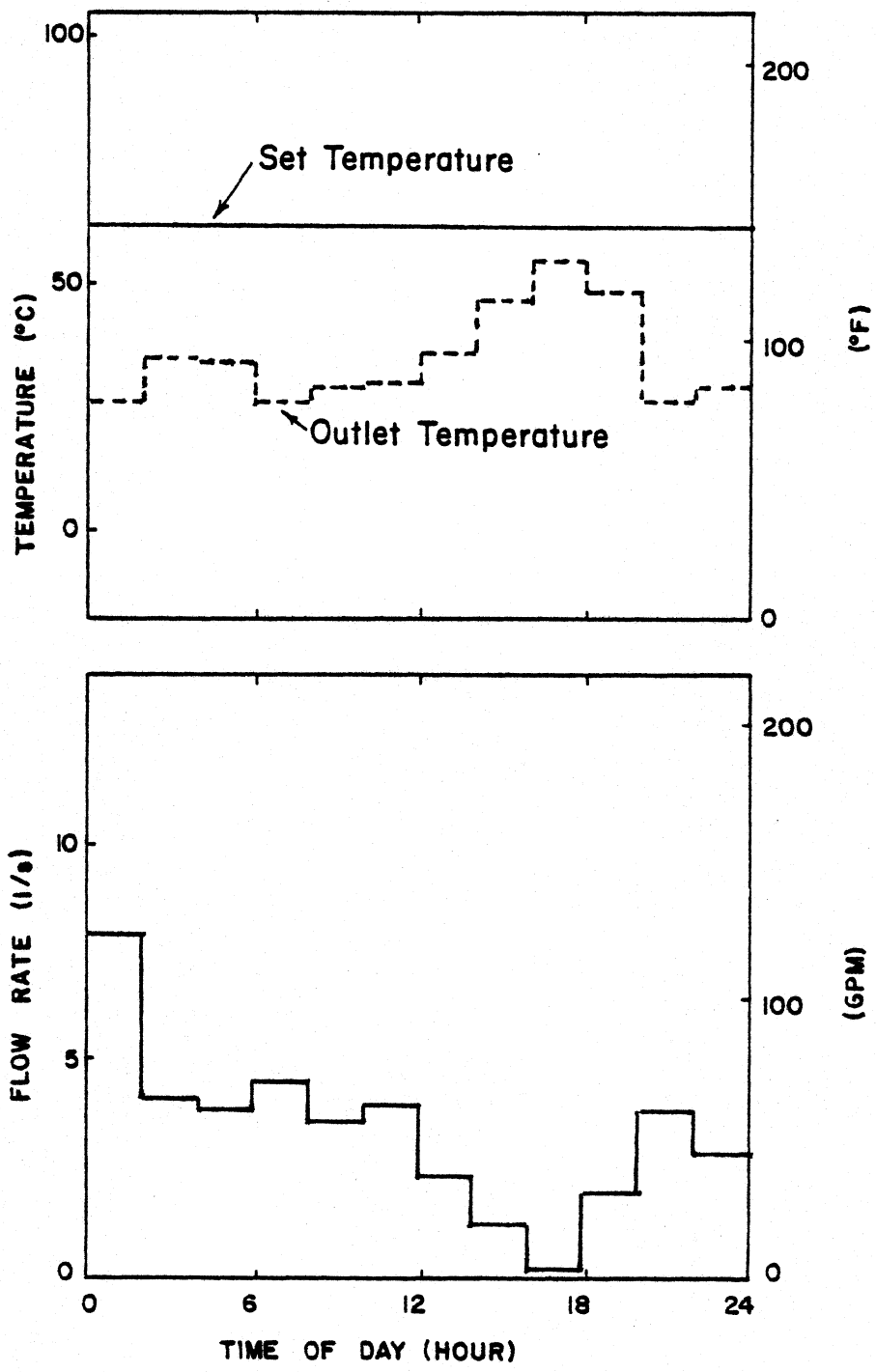


Figure 2.10 The First Day After a Production Day Load Profile

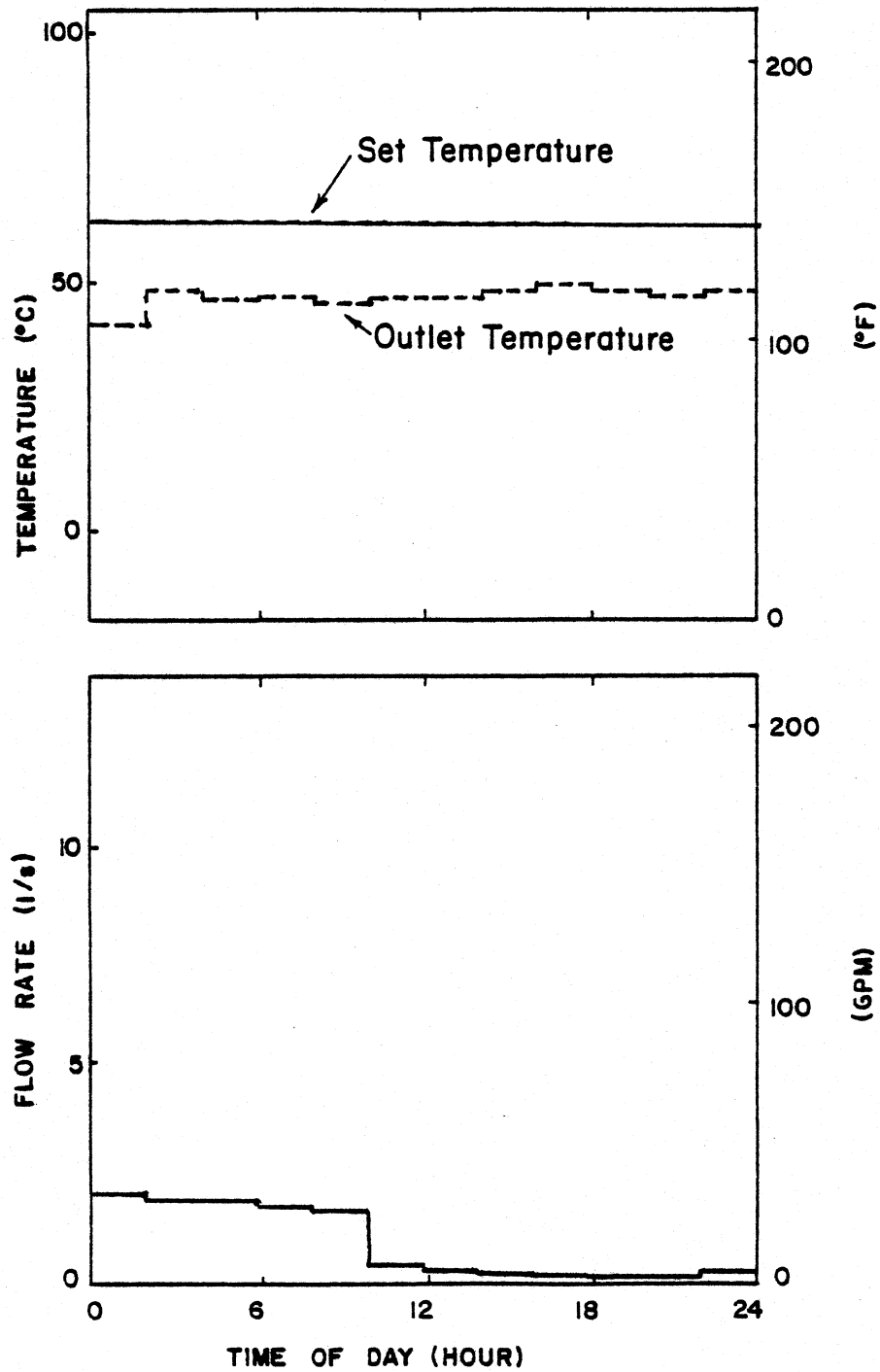


Figure 2.11 The Second Day After a Production Day Load Profile

production day profile.

The short production week load profile represented a holiday week with four working days and a three day week end. This short production week profile was composed of a sequence of four production day profiles, one first day after a production day profile and two second or third day after a production day profiles.

The annual load distribution for a typical year was represented by a sequence of the three types of production week load profiles. A typical year was viewed as having ten short holiday weeks distributed uniformly over the year and ten long work weeks also uniformly distributed over the year. Based on this pattern, Annual Load Profile 1 consisted of ten long production week profiles and ten short production week profiles, uniformly distributed over a year with regular production week profiles interspersed among them.

Prior to the completion of the conceptual design of the solar process water heating system, Oscar Mayer decided to modify the waste heat recovery system at the Perry plant. These modifications included the replacement of an inedible rendering condensate heat exchanger with a pressurized condensate return and the installation of a shell and tube vapor condenser for a new inedible cooking operation. The net effect of these

changes on the energy output of the waste heat recovery system was calculated by Oscar Mayer to be an increase of 50 MMBTU per production day. This additional energy would be available during production days only. The resulting temperatures of the potable water after it had passed through the heat exchanger of the modified waste heat recovery system were calculated and used in the modified production day load profile shown on Figure 2.12. Using the same annual distribution of days as for Annual Load Profile 1, this modified production day load profile was used with the previously described first day after a production day profile and the second day after a production day profile to generate Annual Load Profile 2.

The consideration of various system configurations for the Perry plant required that the waste heat recovery system performance model be extended to allow for operating conditions other than those at which the data were recorded. These extensions of the model allow for variation in the temperature and flow rate of potable water into the waste heat recovery system heat exchanger. Using performance data for the individual components in the waste heat recovery system, Oscar Mayer calculated the effect of these variations in operating conditions on the energy output of the waste heat recovery system. The results of these calculations were curve fit with the

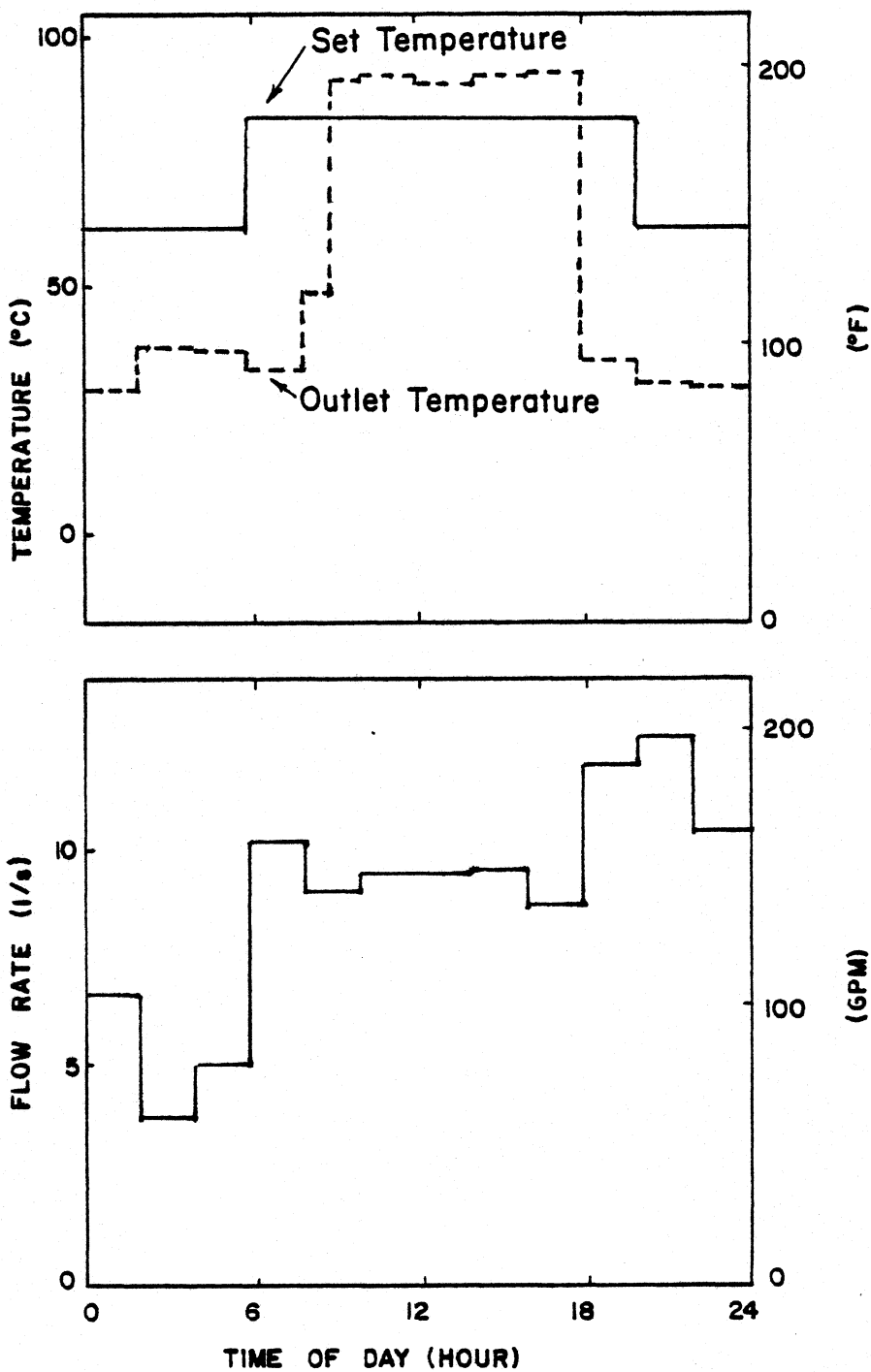


Figure 2.12 Production Day Load Profile 2

following equations.

$$Q_{WHR} = F1 \times F2 \times Q_{base} \quad \text{Equation 2.1}$$

$$\text{where } F1 = 0.8 \frac{M_{whr}}{M_{base}} + 0.2 \text{ for } \frac{M_{whr}}{M_{base}} \leq 1.3$$

$$F1 = 0.014 \times \frac{M_{whr}}{M_{base}} + 1.2218 \text{ for } \frac{M_{whr}}{M_{base}} > 1.3$$

and

$$F2 = \exp (-0.048x (\text{Tinlet} - \text{Tinlet base}))$$

Curves generated using these equations are shown in Figures 2.13 and 2.14. In Figure 2.13 the ratio of the delivered energy flow to the base value is plotted as a function of the ratio of the actual flow rate to the base flow rate for a range of water inlet temperatures. In Figure 2.14 the ratio of the delivered energy flow to the base value is plotted as a function of water inlet temperature for a range of ratios of actual flow rate to base flow rate. It can be seen from these two figures that the delivered heat flow is a fairly strong function of the temperature and flow rate of potable water into the primary waste heat recovery heat exchanger.

During the course of the development of the final system design, additional energy conservation measures were approved for the Perry plant. The measures included

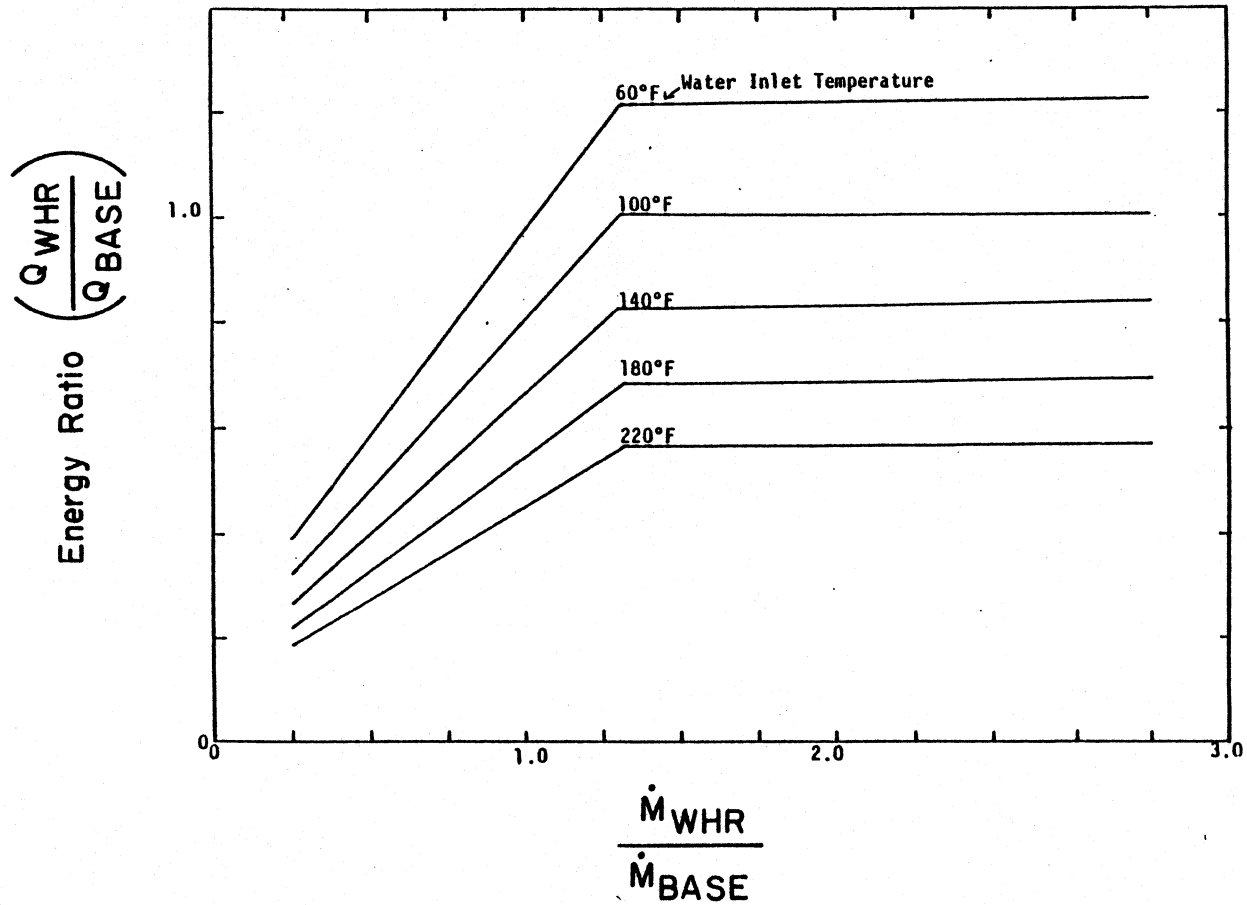


Figure 2.13 The Energy Transferred by the Primary Waste Heat Recovery Heat Exchanger as a Function of Flow Rate for a Range of Inlet Temperatures



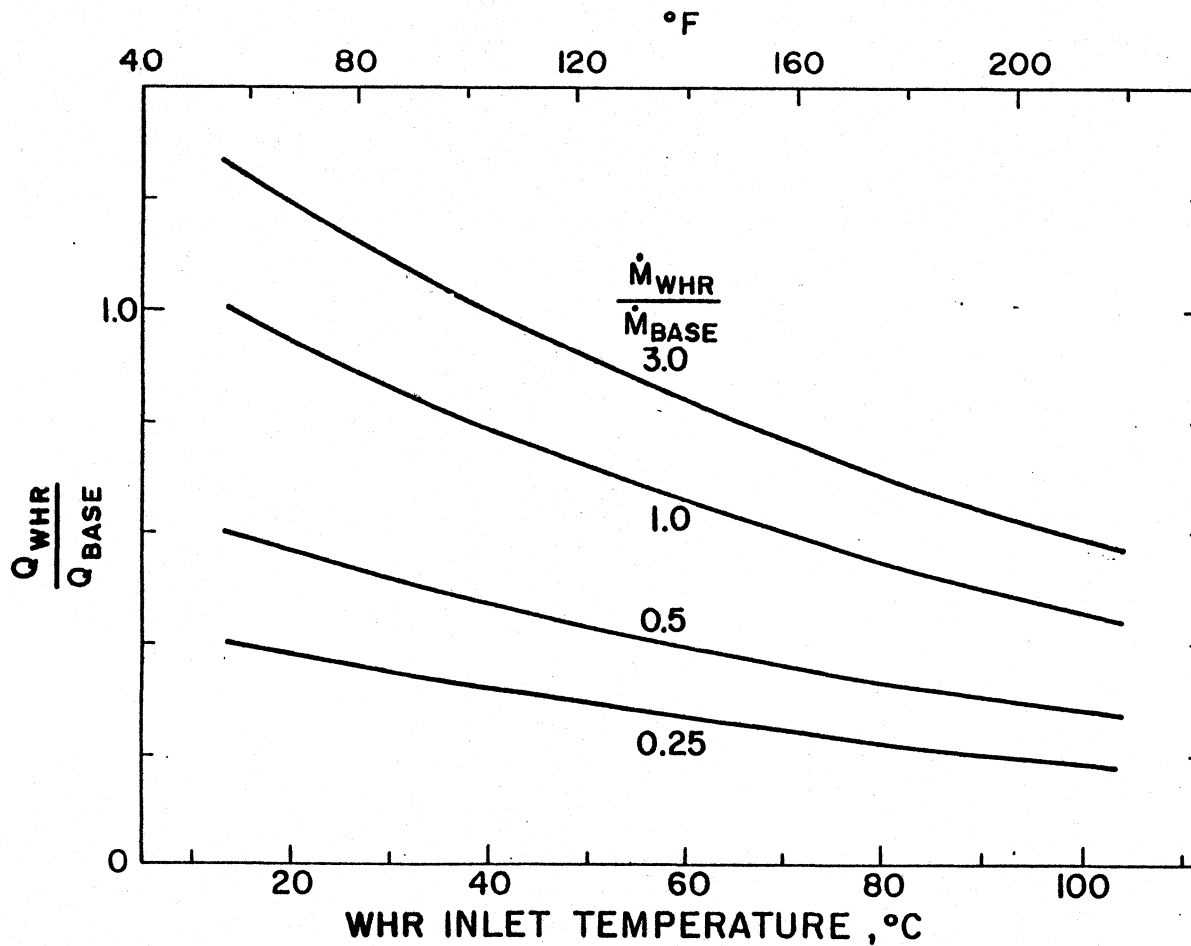


Figure 2.14 The Energy Transferred by the Primary Waste Heat Recovery Heat Exchanger as a Function of Inlet Temperature for a Range of Flow Rates

lowering the hot water set temperature from 62.8 C (145 F) to 46.1 C (115 F) during non-production hours and the use of some waste heat recovery energy for purposes other than heating hot water. These changes were incorporated into the third production day profile shown in Figure 2.15. Using the same distribution of days as for the other annual load profiles, Annual Load Profile 3 was generated using the production day load profile 3 and modified first and second day after a production day profiles. The non-production day profiles were the same as those used in the first two annual load profiles except that the hot water set temperature had been reduced from 62.8 C (145 F) to 46.1 C (115 F), (Figure 2.16 and Figure 2.17).

The characterization of the load and the waste heat recovery system energy output represented a major portion of the work expended on the simulation of the solar process water heating system. This type of detailed investigation of heating loads and waste heat recovery system performance can be useful for energy management purposes.

#### 2.3.4 Collector Performance

The single axis tracking parabolic trough collectors considered for this system were modeled using normal inci-

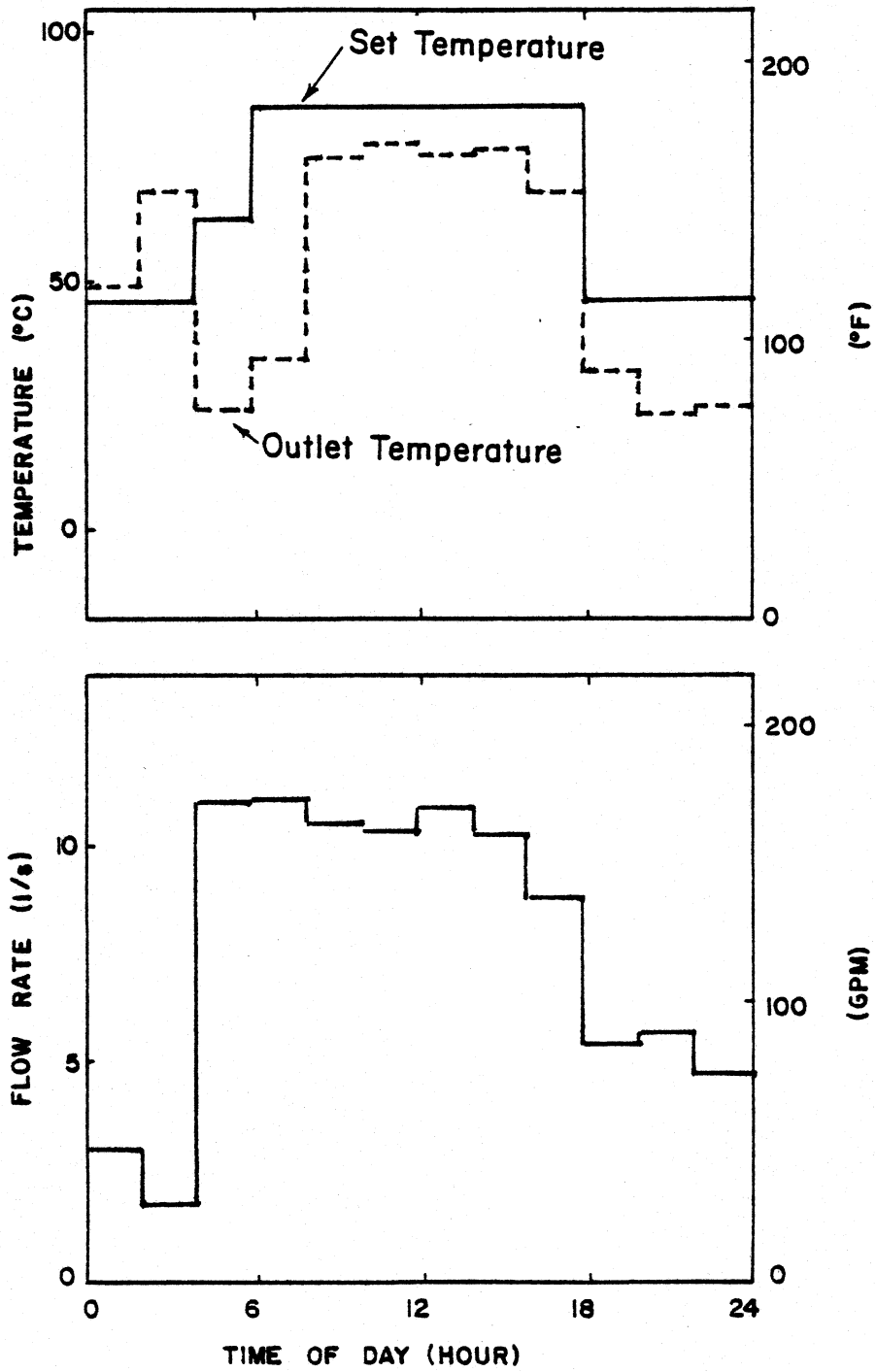


Figure 2.15 Production Day Load Profile 3

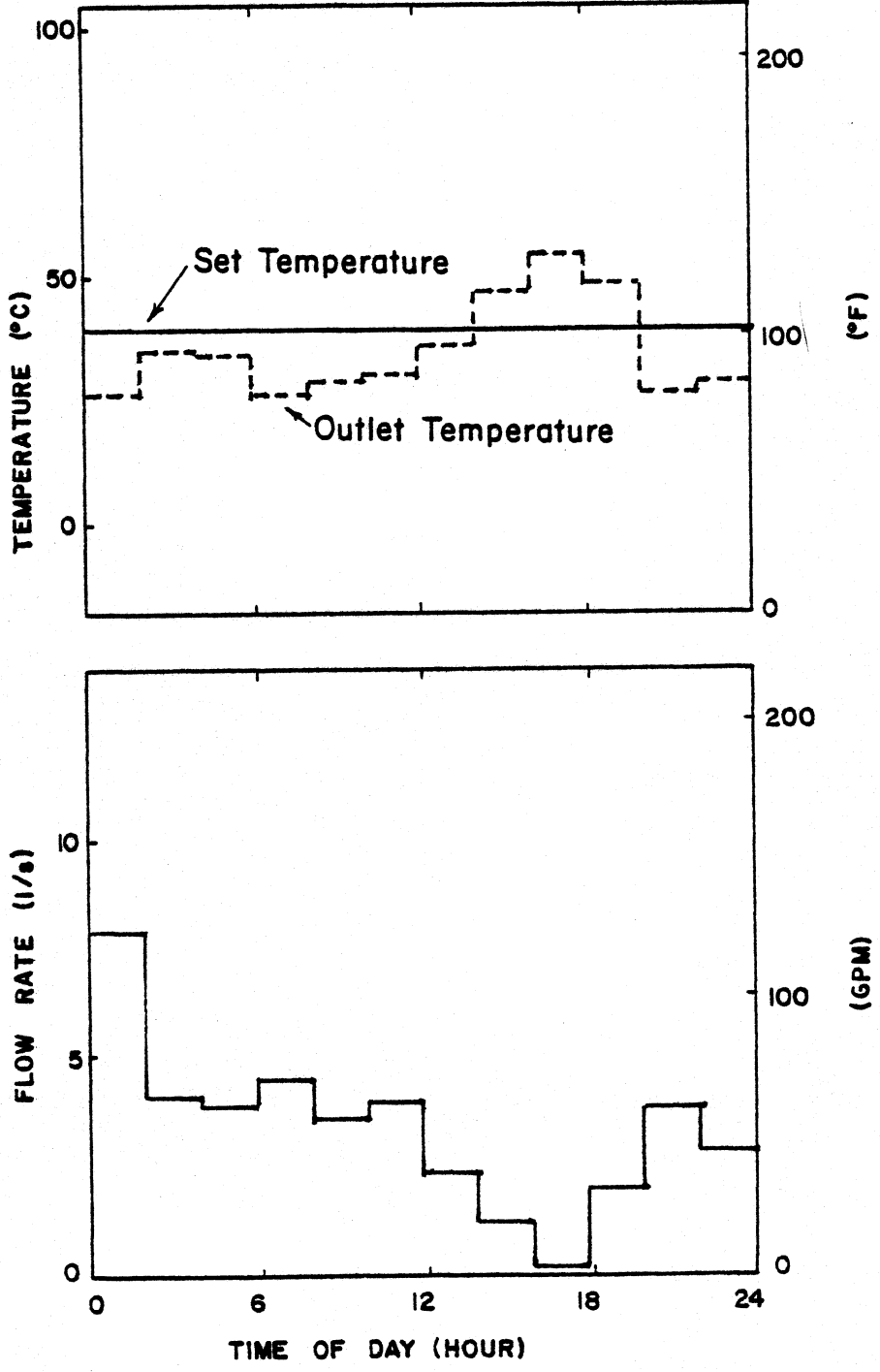


Figure 2.16 The First Day after a Production Day Load Profile With a Reduced Set Temperature

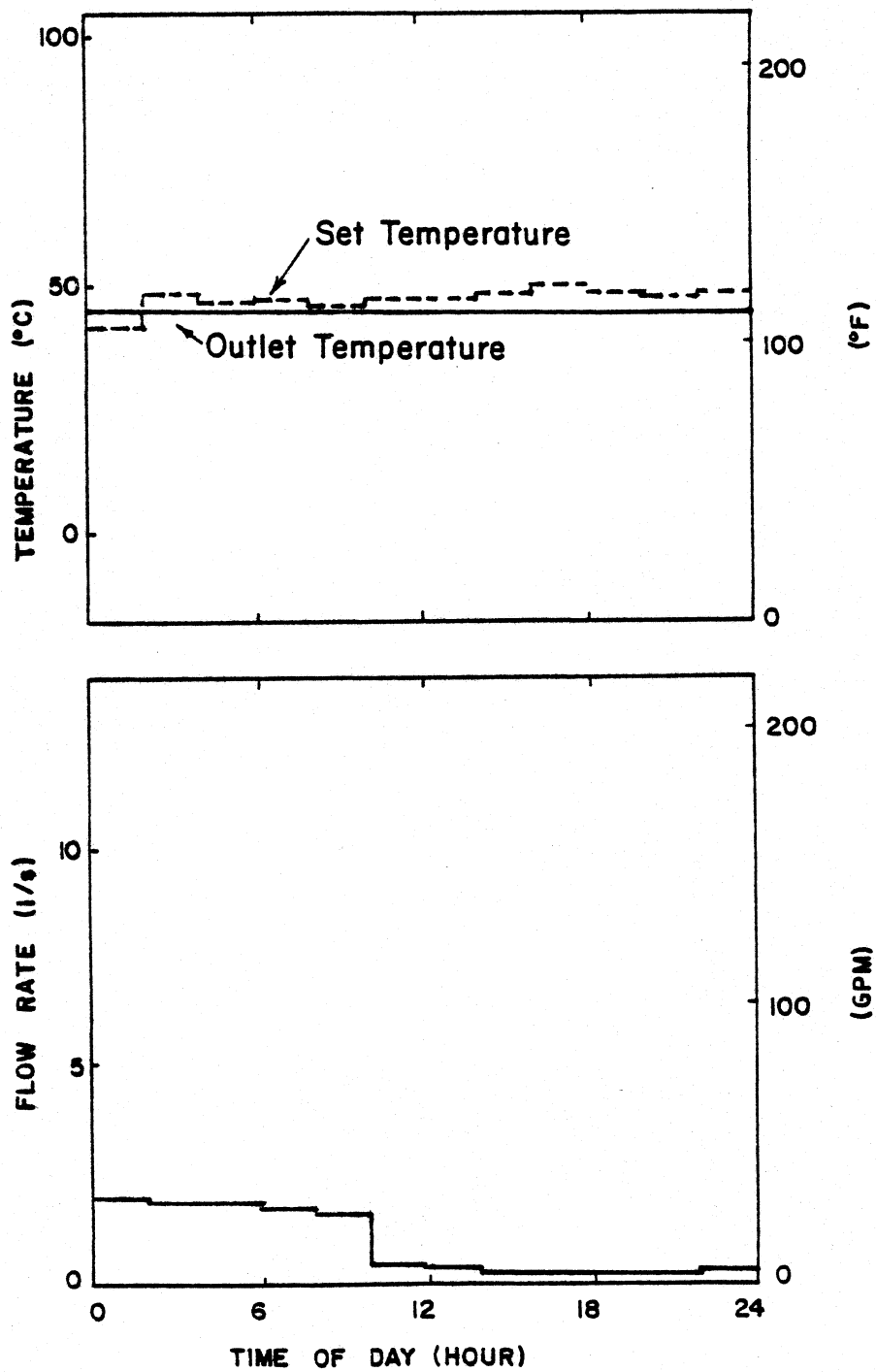


Figure 2.17 The Second Day after a Production Day Load Profile With a Reduced Set Temperature

dence instantaneous efficiency data and an incidence angle modifier (8). These data were input to the collector component model (TRNSYS collector model, mode 4) in tabular form. The equation for the collector efficiency curve is:

$$n = 0.66 - 0.41 \left( \frac{T_{ave} - T_{amb}}{IDN} \right) - 0.04 \left( \frac{T_{ave} - T_{amb}}{IDN} \right)^2$$

(English units, based on aperture area)

The equation for the collector incidence angle modifier curve is:

$$K = 1 + 3.81 \times 10^{-5} \theta^2 - 1.18 \times 10^{-6} \theta^3 - 6.85 \times 10^{-9} \theta^4$$

( $\theta$  in degrees)

For a given set of conditions, the model interpolates between the tabulated points representing each curve to find the values of the normal incidence efficiency and incidence angle modifier which are then used to calculate the instantaneous collector efficiency.

### 2.3.5 Method of System Simulation

Detailed simulation models of the various systems were developed using both standard and new TRNSYS component models. Appendices A and B contain listings of documentation for all new component models used in the system simulations. The parameters used in system simulations

are listed in Table 2.3. The constant volume storage system was modeled with standard components except for the temperature and flow rate sensitive waste heat recovery component and the shading component. A sample listing of a TRNSYS deck which models one of the constant volume systems simulated is included in Appendix C.

The variable volume storage systems required the use of several new component models. These components represent a variable volume storage tank, a tempering valve for a variable volume storage tank, a night time bypass for a variable volume storage tank, and a variable volume pump with a controller. A sample simulation deck for the variable volume system is included in Appendix C.

## 2.4 Results

### 2.4.1 Introduction

The simulations of the various system configurations provided a means of comparing the relative thermal performance of these configurations. The results presented here include the thermal performance of the four system configurations considered. The effects of collector axis orientation and collector array shading on system thermal performance are also presented.

Table 2.3

## Solar Energy Collection System Parameters

Collector array

Collector type - single axis tracking  
parabolic trough collectors

Collector axis slope - horizontal

Collector area - 3746 square meters

Heat transfer fluid - 55% glycol solution

Heat transfer fluid flow rate: minimum - 0.56 l/s  
maximum - 8.90 l/s

Heat exchanger

Type - plate

Effectiveness - 0.8

Piping

Location	diameter	length	insulation
in plant	7.6 cm	170 m	1.19 w/m <sup>2</sup> C
underground	7.6 cm	274 m	1.19 w/m <sup>2</sup> C
in collector field	7.6 cm	354 m	1.19 w/m <sup>2</sup> C

Storage tank

Volume - 447,000 liters

Insulation - .537 w/m<sup>2</sup> C



## 2.4.2 General System Thermal Performance

The annual integrated system performance results for the configurations evaluated are shown in Figure 2.18. The results shown are for three systems with solar energy collection systems and one system with no solar collectors. The systems with solar collectors all used single axis, tracking parabolic trough collectors with a north to south axis. The dashed horizontal line at 47.3 TJ ( $11.9 \times 10^9$  BTU) is the annual process water heating energy requirement for the meat packing plant. The bars labeled "WHR" represent the amount of energy provided by the waste heat recovery system for process water heating. The bars labeled "solar" represent the amount of energy which the solar system provides for process water heating. The bars labeled "AUX" represent the auxiliary energy provided by the steam process water heaters. The sum of the energy quantities represented by the bars for each system equals the annual process water heating requirement. The dominant source of energy to meet the load is the waste heat recovery system. For the four systems the fractions of the load met by waste heat recovery ranges from a high of 68 percent for the system without solar to a low of 53 percent for the series system with solar first. The parallel system has the smallest auxiliary energy require-

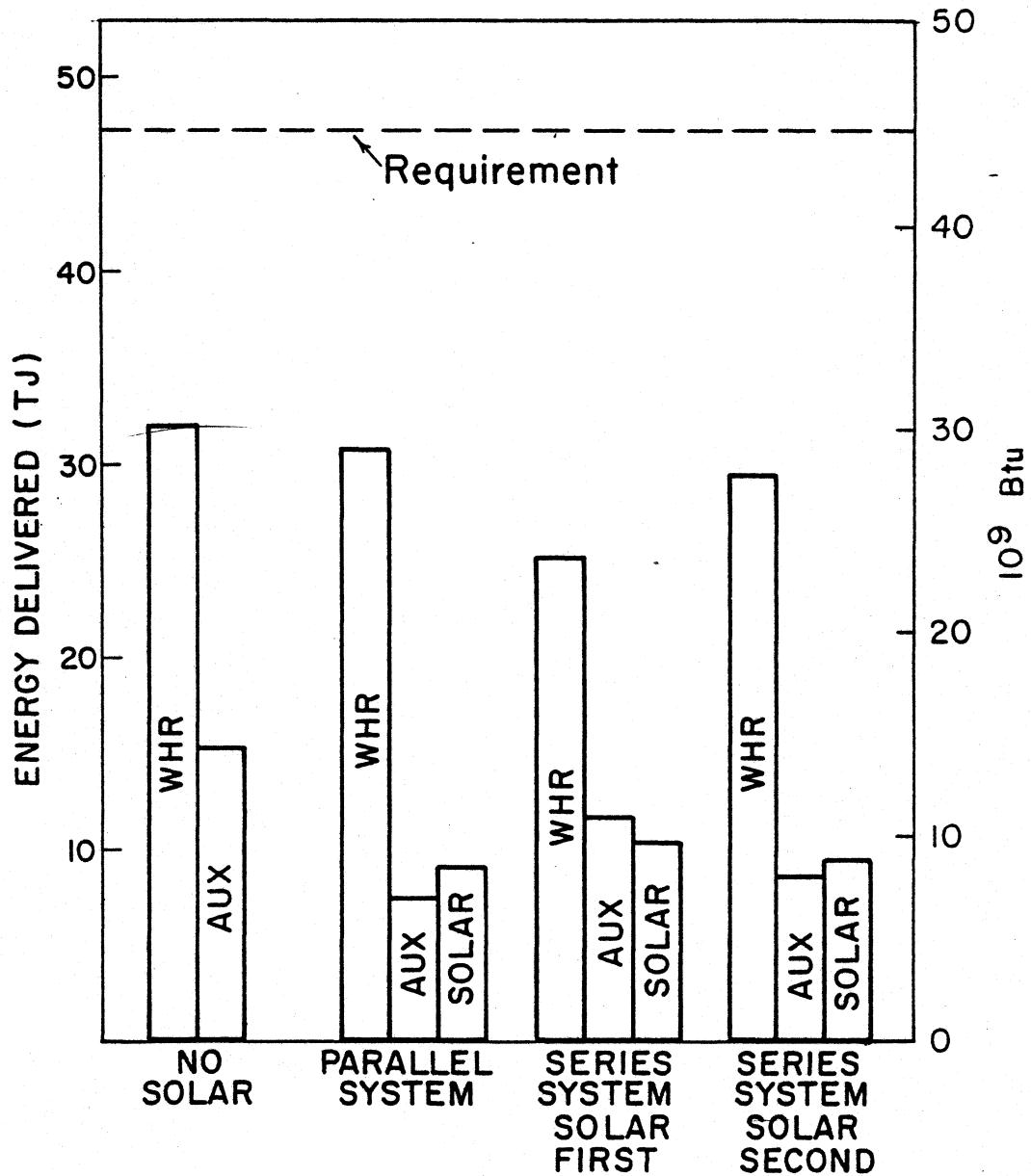


Figure 2.18 Process Water Heating System Simulation Results

ment even though this system has the smallest solar contribution of the three systems with solar collectors. These results can be attributed to the dependence of the energy outputs of both the waste heat recovery subsystem and the solar subsystem on their respective operating temperatures and the relative magnitude of these energy outputs.

#### 2.4.3 Detailed System Results

A detailed breakdown of the annual energy flows in the four configurations is presented in Table 2.4. These results can be best understood by considering the effect of the temperatures and flowrates of the water entering the waste heat recovery and solar heat exchangers. For both the waste heat recovery and solar sub-systems the heat exchanger inlet conditions effect the subsystem energy output.

The system without solar collectors had the largest waste heat recovery output because the inlet flow stream was at the mains water temperature and the flow rate was the load flow rate occasionally reduced by flow through the tempering valve. The annual auxiliary energy required was 15.3 TJ ( $3.9 \times 10^9$  BTU). The parallel system had slightly reduced waste heat recovery energy output relative to the system without solar collectors since the

Table 2.4  
Annual Process Water Heating System Performance Comparison  
(all energy quantities in TJ)

	System without Solar Collectors	Parallel System	Series System with Solar First	Series System with Waste Heat Recovery First
<u>Waste Heat Recovery</u>				
Q available at load flowrate	32.9	32.9	32.9	32.9
Q to storage	32.2	30.8	22.7	26.9
Q direct to load	---	---	2.4	2.4
<u>Solar</u>				
Insulation on Array	----	26.22	26.2	26.2
Q collected	----	10.6	11.2	10.8
Q loss from pipes				
--day	----	0.2	0.2	0.2
--night	----	0.3	0.1	0.2
Q to storage	----	10.1	10.9	10.4
<u>Storage</u>				
Q input	32.2	40.9	36.6	37.3
Q loss by overflow	----	----	0.1	0.6
Q UA loss	0.2	0.4	0.4	0.4
Q to load	32.0	39.9	33.1	36.3
<u>Q to Load</u>				
Q WHR direct to load	----	----	2.4	2.4
Q WHR and Q Solar from Storage	32.0	39.9	33.1	36.3
Q Auxiliary	15.3	7.4	11.8	8.6
TOTAL LOAD	47.3	47.3	47.3	47.3

addition of energy to storage from the solar collector recirculation loop resulted in a more frequent need to temper the water flowing to the load. There was a consequent reduction in the flow rate through the waste heat recovery heat exchanger. The water flowing into the primary waste heat recovery heat exchanger was at mains temperature just as in the system without solar collectors. The annual auxiliary energy requirement was 7.4 TJ ( $1.9 \times 10^9$  BTU).

The series system with the solar heat exchange before the waste heat recovery heat exchanger had the lowest waste heat recovery energy output, since the waste heat recovery heat exchanger had higher inlet temperatures and the flow rate was frequently reduced from the load flow rate in order to obtain the preselected inlet temperature to storage. The annual auxiliary energy requirement was 11.8 TJ ( $3.0 \times 10^9$  BTU).

The series system with the solar heat exchanger second had an intermediate waste heat recovery energy output, since the waste heat recovery heat exchanger had an inlet temperature equal to mains water temperature (like the parallel system) and a flow rate reduced to deliver water to storage at the preselected inlet temperature (like the series system with solar first). The annual auxiliary energy requirement was 8.6 TJ ( $2.2 \times 10^9$  BTU).

BTU).

The better performance of the parallel system relative to the series systems was in part due to the control strategy. The variable volume tank in the series system has water pumped into it at a preselected temperature chosen so that the flow rates into the tank were as high as possible without causing frequent tank overflow or bypass to the load at a temperature above the set temperature. High flow rates were desirable, since a larger energy output from the solar and waste heat recovery heat exchangers was produced, but if the flow rates were excessively high the tank would overflow and no further energy could be added to the tank. Since the quantity of energy available from the solar collector array varies over the year, the preselected tank inlet temperature had to be varied over the course of the year as well. As discussed in section 2.2.2, optimal system thermal performance for such a system requires some sort of predictive control strategy. The parallel system with constant volume storage did not have this control problem, since the solar heat exchanger was on a recirculation loop and energy could be added to storage whenever the collector outlet temperature permitted.

One area of concern during the design process was the significance of losses from the collector loop piping

both during collector operation and at night. From the results shown in Table 2.4 it can be seen that the day and night time energy losses from the piping in the solar loop are small (5 percent), relative to the amount of energy collected by the solar loop.

The effect of the collector axis orientation on the quantity of energy delivered to storage from the collector array is shown in Figure 2.19. The north to south axis collectors delivered more energy to storage on an annual basis, even though the annual distribution of solar energy collection was strongly skewed toward the summer months. The east to west axis collectors delivered less energy to storage on an annual basis but the solar energy collection was more evenly distributed over the year. While this difference in the annual distribution of solar energy into storage for the two collector orientations was of interest, the more important result was the annual auxiliary energy requirement for the two orientations. Since the north to south collector orientation required less auxiliary energy on an annual basis, it would be the preferable design choice for this system and location if there were no significant shading effects on the collector array.

It is possible for solar collector array shading effects to **have** a significant effect on solar collector

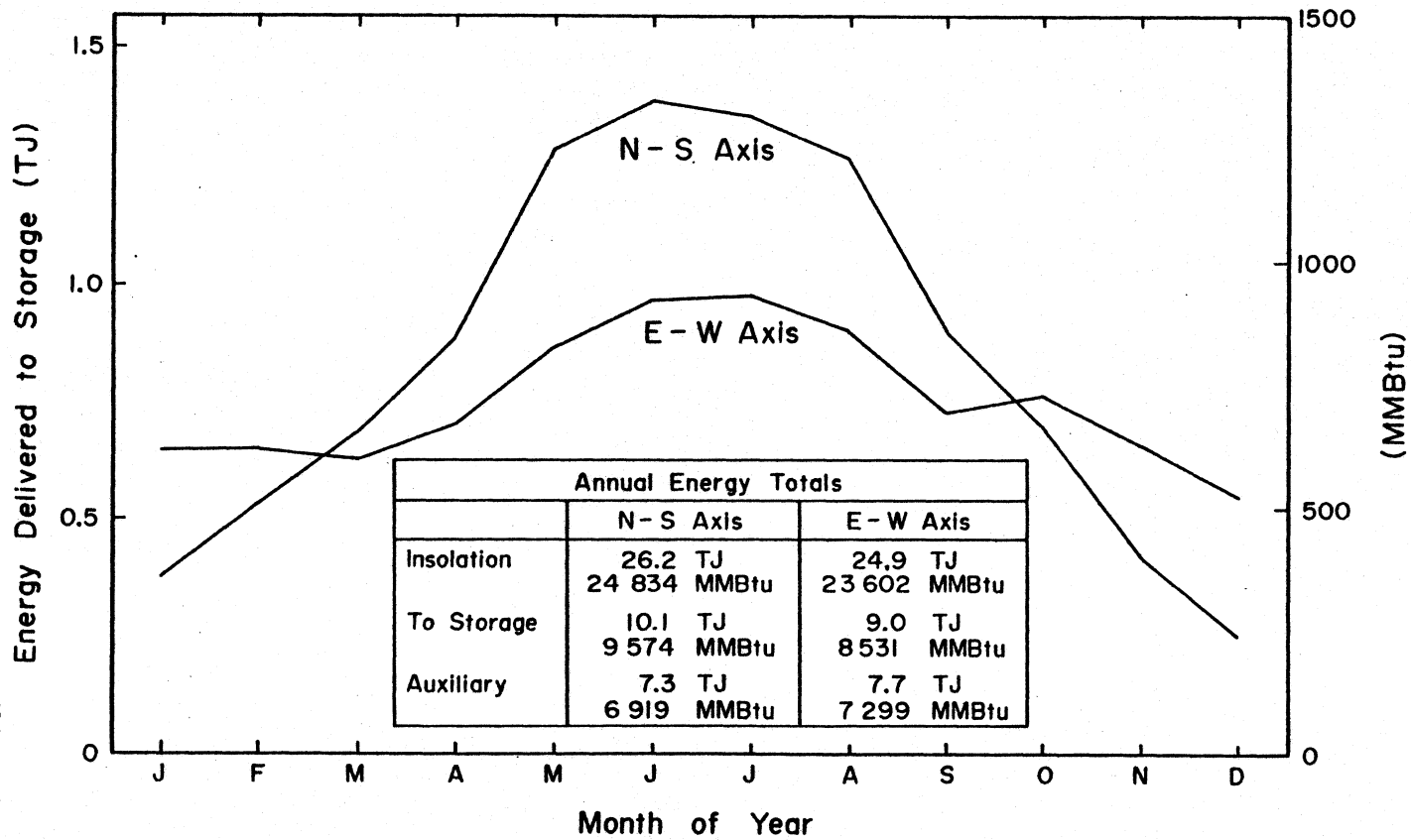


Figure 2.19 The Effect of Collector Axis Orientation on the Thermal Performance of Constant Volume Storage System



system thermal performance. In order to examine the effect of collector array shading, a model of shading for large collector arrays was developed and included in annual simulations of the parallel system. This system was simulated for both east to west collector axes and north to south collector axes using the proposed separation of collectors in the field. For the north to south collector axes case, the shading increased the annual auxiliary requirement by 5 percent. For the east to west collector axes case, the shading increased the annual auxiliary requirement by 1 percent. When shading was taken into account, the system with east to west collector axes had an annual auxiliary requirement within 1 percent of that of the system with north to south collector axes. These results indicate that when the shading effects for the proposed collector array are taken into consideration, there is not a significant difference between the auxiliary energy requirement of the constant volume tank configuration with north to south collector axes and the same configuration with east to west collector axes.

### 3.0 The Evaluation of Waste Heat Recovery System Design Modification Options Using System Simulations

#### 3.1 Introduction

After it was announced that the solar system construction would not be funded for the Perry plant, Oscar Mayer's continuing interest in energy management led to a consideration of various design options for the waste heat recovery system itself. The transient simulation program TRNSYS was used to model the existing waste heat recovery system in detail. The model was validated by comparing simulation results with performance data for the existing system. The simulation model was then used to evaluate the effect of adding two new energy uses to the waste heat recovery loop.

#### 3.2 The Present Waste Heat Recovery System

##### 3.2.1 System Description

The present waste heat recovery system is shown in Figure 2.2. It consists of a primary heat exchanger which transfers energy to the potable water flow stream and three secondary heat exchangers which transfer energy into the waste heat recovery loop. The three secondary heat exchangers include an ammonia gas desuperheater, an inedible rendering vapor condenser and a hog singer exhaust economizer. The ammonia desuperheater transfers

energy to the loop continuously, while the inedible rendering vapor condenser and the hog singer economizer only transfer energy during production hours. In order to reduce pumping power requirements, the latter two heat exchangers are bypassed when neither is transferring energy into the waste heat recovery loop.

### 3.2.2 Model of the present system

System performance data were collected during a production day in November. The inlet temperatures, outlet temperatures and flow rates were recorded for each of the heat exchanger flow streams in the system. These data were used in the calculation of the heat exchanger performance characteristics.

The system was modeled using components available in the TRNSYS library. The primary heat exchanger was modeled as a counter-flow heat exchanger with a constant overall heat transfer coefficient of  $976600 \text{ W/}^\circ\text{C}$  ( $6 \times 10^5 \text{ BTU/hr } ^\circ\text{F}$ ). The ammonia desuperheater was modeled as a counter flow heat exchanger with a constant overall heat transfer coefficient of  $6800 \text{ W/}^\circ\text{C}$  ( $4.2 \times 10^4 \text{ BTU/hr } ^\circ\text{F}$ ). Since the ammonia pressure and temperature at the heat exchanger inlet were fairly constant, the specific heat of the ammonia gas was assumed to be con-

stant at the heat exchanger inlet. The inedible rendering condenser was modeled as device with a constant effectiveness of 0.87. The hog singer exhaust economizer is a cross-flow air to liquid heat exchanger which was modeled as a device with a constant effectiveness of 0.55. The air temperature and flow rate into the economizer were assumed to be constant during production hours.

### 3.2.3 Comparison of Waste Heat Recovery System Thermal Performance Simulations with System Performance Data

The system was simulated using the data for the hot side inlet conditions of the secondary heat exchangers and the flow rate and inlet temperature of potable water into the primary heat exchanger. The parameters used in the heat exchanger models were adjusted so that the heat transfer rates calculated in the simulations of the existing system agreed with the data. The total energy transfer to the potable water flow stream over the day was 200 GJ ( $1.9 \times 10^8$  BTU).

### 3.3. Modified Waste Heat Recovery System

#### 3.3.1 Proposed Waste Heat Recovery System Modifications

Due to reductions in the process water heating loads through energy conservation and the increase in the energy available to the waste heat recovery loop from the inedible rendering process, Oscar Mayer feels that it is desirable to add new energy uses to the waste heat recovery loop. The waste heat recovery loop flow stream will be used to partially heat the hog scald tub and to concentrate glycol and water solution. This modified waste heat recovery system is shown in Figure 3.1.

The scald tub is used in the hog carcass dehairing process. The glycol and water solution is used for cooling in several plant processes and in these processes the solution absorbs water from the materials that it is in contact with. In the glycol concentrator, water is evaporated out of the solution until the desired glycol concentration is obtained. The energy requirements of both the scald tub and the glycol solution concentrator are presently met entirely with steam. A water temperature of 60°C (140°F) is maintained in the scald tub during production hours by circulating the water through a steam heat exchanger. In the proposed waste heat recovery system modification (Figure 3.1) a new heat exchanger will be added to this recirculation loop.

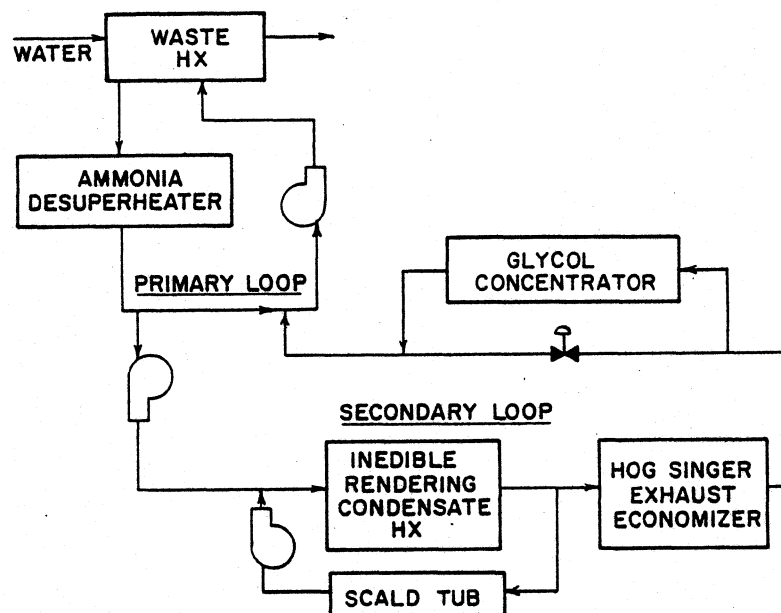


Figure 3.1 Waste Heat Recovery Loop with Two New Energy uses

Another recirculation loop will connect this new scald tub heat exchanger to the waste heat recovery loop. Water will be pumped out of the waste heat recovery loop after the inedible rendering condenser at a rate of 7.9 liters per second (125 gallons/minute). After flowing through the scald tub heat exchanger the water will be returned to the waste heat recovery loop before the inedible rendering heat exchanger. In this way the flow rate through the inedible rendering heat exchanger will be increased without increasing the flow rate through the rest of the waste heat recovery loop. This is advantageous because the pipe used for the rest of the loop is smaller so increasing the flow rate around the whole loop would require more pumping power.

The glycol concentrating system evaporates water out of the glycol solution used for cooling in several plant processes. Part of the waste heat recovery loop flow stream will be diverted after the hog singer exhaust economizer to deliver energy to the glycol concentrator loop. Flow from the waste heat recovery loop into the glycol concentrator is modulated so that the temperature does not exceed 82.2 C (180 F). Above this temperature too much glycol evaporates along with the water.

### 3.3.2 Modeling the New Energy uses in the Waste Heat Recovery Loop

The water flowing from the scald tub was assumed to enter the load side of the scald tub heat exchanger in the waste heat recovery loop at a constant temperature of  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ) and a constant flow rate of 19 liters per second (300 gpm) during production hours. This heat exchanger was assumed to have a constant effectiveness of 0.5. The glycol concentrator load was modeled as a heat exchanger with a constant effectiveness of 1.0 because in the proposed system water will be diverted from the loop to maintain the desired inlet temperature to the glycol concentrator. During production hours the load side of the heat exchanger had a constant inlet temperature of  $82^{\circ}\text{C}$  ( $180^{\circ}\text{F}$ ) and a constant flow rate of 15.8 liters per second (250 gpm).

### 3.3.3 The Modified Waste Heat Recovery Loop Simulations

The modified waste heat recovery loop was simulated for the production hours of one day. During a 24 hour period which included 10 production hours the simulation of the thermal performance of the modified waste heat recovery system calculated an increase in the energy de-



livered to the load 32 GJ (30 MMBTU) over the simulated energy transfer of the present system. The increase was primarily due to the increased waste heat recovery loop flow rate through the inedible rendering heat exchanger which allows more steam to be condensed. The TRNSYS decks for the existing system and the modified system are included in Appendix C.

## 4.0 Conclusions

### 4.1 The Oscar Mayer Process Water Heating System Using Waste Heat Recovery and Solar Collectors

The waste heat recovery system as planned for the Perry meat packing plant will provide more than 60 percent of the energy required for process water heating. For this reason the waste heat recovery system was a primary consideration in the evaluation of design options for the addition of solar collectors to the process water heating system. Simulation results showed that the thermal performance of the constant volume storage system provided the most energy for process water heating on an annual basis. In this configuration the waste heat recovery system added energy to the make up water flowing into the tank and the solar collector array added energy to storage through a recirculation loop. This configuration provided a means of incorporating solar collectors into the process water heating system without causing a large reduction in the energy output of the waste heat recovery system.

Another system configuration considered had variable volume storage which allowed the amount of water in storage to fluctuate. The waste heat recovery heat ex-

changer and solar loop heat exchanger were in series along the flow stream into the tank and this flow stream would be modulated to control the inlet temperature to storage. Since the criteria used for evaluating system performance was total energy supplied to process water heating it was of no benefit to modulate the flow rate into storage to obtain temperature above the one which allowed the maximum delivery of energy to the load from the tank. In fact adding water to storage at a higher than necessary temperature actually reduced the amount of energy delivered to the load since it caused a reduction in the energy output of both the waste heat recovery system and the solar energy collection system.

The solar collectors chosen for the system were parabolic trough single axis tracking collectors which can be used to produce steam as well as hot water. During the design process for the solar energy system, projects were implemented or approved which will reduce the auxiliary energy required for process water heating by 35 percent and further reductions will probably occur. For this reason in a solar system designed for such an industrial plant it can be advantageous to use collectors suitable for delivering energy to higher temperature energy uses if most of the low temperature energy requirements may eventually be met by waste heat recovery

systems.

#### 4.2 The Oscar Mayer Waste Heat Recovery System Modification Evaluation

The proposed modifications to the waste heat recovery system will allow it to supply energy for scald tub heating and glycol concentration as well as process water heating. These changes were found to increase the energy output of the waste heat recovery system by 32 GJ (30 MMBTU) during a 24 hour period which included 10 production hours.

#### 4.3 Thermal Energy Management in Industry

It is useful to investigate energy use throughout the plant when evaluating design options for thermal systems. Each energy use should be examined to determine if the energy requirement could be reduced or if it is a potential source or sink for waste heat recovery. It is in the context of such a broad investigation of energy options for a plant that the potential for solar or other renewable energy sources should be evaluated. Based on the results of thermal performance evaluations economic comparisons of the design options can be car-

ried out to determine which ones best fit the economic requirements of the plant owners

#### 4.4 Transient Simulation as a Design Tool for Industrial Thermal Processes

Transient simulation can be an effective aid in the design of industrial thermal systems. This approach to thermal analysis is particularly useful when system operating conditions vary over time and there is a significant thermal interaction between system components. For such systems transient simulation can provide the thermal performance information needed for design decisions.

## APPENDIX A

## TRNSYS Subroutine Documentation

- Variable Volume Pump
- Variable Volume Tank
- Tempering Valve for Flow Out of Variable Volume Tank
- Load Profile Sequencer
- Low Temperature Night Storage Bypass Valve Controller
- Oscar Mayer Perry Plant System Specific Temperature and Flow Rate Dependent Waste Heat Recovery System
- General Cascaded Waste Heat Recovery Loop
- Collector Array Shading

## APPENDIX A

## VARIABLE VOLUME PUMP

This subroutine models a controlled variable volume pump which modulates the flow rate through one or more heat exchangers in order to deliver the specified outlet temperature.

Inputs 6

- 1 pump inlet temperature
- 2 pump mass flow rate in
- 3 temperature out of heat exchanger
- 4 mass flow rate out of heat exchanger (to be modulated)
- 5 set temperature relative to which the temperature out of the heat exchanger is being regulated
- 6 control function (if equal to 0, no flow)

Parameter 6

- 1 number of iterations flow is fixed in on-mode
- 2 number of iterations before outputs of subroutine are stuck
- 3 minimum mass flow rate
- 4 maximum mass flow rate
- 5 delta mass flow rate [each timestep the initial guess of mass flow rate equals Par (3) + Par (5)]
- 6 delta Temperature [In (3) is controlled to equal In (5) + Par (6)]

Outputs 4

- 1 pump outlet temperature
- 2 pump outlet mass flowrate
- 3 -----
- 4 -----

## VARIABLE VOLUME TANK

This subroutine models a vertical cylindrical tank, which contains a variable quantity of liquid, using analy-

tically solved differential equations. The level of the liquid in the tank is allowed to vary between user specified high and low level limits. When the high level limit is exceeded additional flow into the tank is dumped and the level indicator is set equal to +1. When the liquid level falls below the low level limit, further flow out of the tank ceases and the tank level indicator is set equal to -1.

Since the flow rates into and out of the tank are not necessarily the same, both flowrates are specified as tank model inputs.

#### Inputs 4

- 1 inlet temperature
- 2 inlet mass flowrate
- 3 outlet mass flowrate
- 4 ambient temperature

#### Parameters 11

- 1 tank volume
- 2 tank diameter
- 3 wetted tank wall - U value
- 4 dry tank wall - U value
- 5 minimum liquid volume in tank
- 6 maximum liquid volume in tank
- 7 specific heat of liquid
- 8 density of liquid
- 9 reference temperature (usually mains water temperature)
- 10 initial temperature of liquid in tank
- 11 initial mass of liquid in tank

#### Outputs 17

- 1 outlet temperature
- 2 outlet mass flowrate
- 3 mass flowrate of liquid added to tank ( $\dot{m}$  inlet -  $\dot{m}$  dump)
- 4 Q dumped (tank overflow)
- 5 Q loss by conduction
- 6 change in internal energy in tank from initial conditions
- 7 tank level: +1 for liquid volume  $>$  max volume  
0 for min volume  $\leq$  liquid volume  $\leq$  max volume  
-1 for liquid volume  $\leq$  min volume



8 tank temperature at beginning of timestep  
 9 mass in tank at beginning of timestep  
 10 tank temperature at end of timestep  
 11 mass in tank at end of timestep  
 12 -----  
 13 -----  
 14 Q in - Energy added to tank by flow in  
 15 Q out - Energy removed from tank by flow out  
 16 energy stored in tank  
 17 change in mass in tank from initial conditions

#### TEMPERING VALVE FOR FLOW OUT OF VARIABLE VOLUME TANK

This subroutine models equipment which draws liquid out of the variable volume tank in order to deliver the specified liquid flowrate to the load. The liquid drawn out of the tank is tempered to the load set temperature with liquid from a lower temperature source (usually mains water) as necessary.

#### Inputs 7

1 temperature of hot source (storage tank)  
 2 mass flowrate from hot source  
 3 temperature of cold source (mains water)  
 4 mass flowrate from cold source  
 5 load set temperature  
 6 load mass flow rate  
 7 tank level indicator to indicate when liquid can be drawn from hot source (-1 indicates liquid is not available)

#### Parameters 2

1 N-stick-after N-stick calls to this subroutine in a timestep the outputs fixed.  
 2 Mode - this specifies from which source the load will be met if both sources are at temperatures above the load set temperature.

1: all flow from hot source  
 2: all flow from cold source  
 3: all flow from lower temperature source  
 4: all flow from higher temperature source

Outputs 6

- 1 temperature out of tempering valve
- 2 mass flow rate out of tempering valve
- 3 temperature from hot source
- 4 mass flowrate from hot source
- 5 temperature from cold source
- 6 mass flowrate from cold source

## LOAD PROFILE SEQUENCER

This subroutine combines a number of daily load profiles in a user specified sequence to form an annual load profile. Each daily profile is composed of values for three variables input either as constants or variable values from TYPE 15 forcing functions.

To form a standard weekly load profile the user specifies which load profile is to be used for each day of the week.

The standard weekly load profile is repeated to produce a 365 day annual load profile.

To allow variation from the standard weekly profile throughout the year, one of up to three non-standard daily load profiles can be specified to replace a day in the standard weekly profile on any day of the year. Any of the daily load profiles input by the user can be specified as one of the non-standard daily load profiles.

Inputs

(for  $1 \leq I \leq N$ , where  $N$  = total number of daily load profiles specified)

$((I-1) \times 3) + 1$  variable #1 of daily load profile #I

$((I-1) \times 3) + 2$  variable #2 of daily load profile #I

$((I-1) \times 3) + 3$  variable #3 of daily load profile #I

Parameters

- 1 #1 of daily load profile to be used for the first

day of the standard week  
 2 #I of daily load profile to be used for the second  
 day of the standard week  
 3 #I of daily load profile to be used for the third  
 day of the standard week  
 4 #I of daily load profile to be used for the fourth  
 day of the standard week  
 5 #I of daily load profile to be used for the fifth  
 day of the standard week  
 6 #I of daily load profile to be used for the sixth  
 day of the standard week  
 7 #I of daily load profile to be used for the seventh  
 day of the standard week  
 8 Number of days first nonstandard daily profile  
 occurs during the year  
 9 Number of first nonstandard daily load profile  
 ((+1) to (9+PAR(8))) - days of year when first nonstandard  
 load profile occurs.  
 (10+PAR(8)) - number of days second nonstandard daily  
 profiles occurs during the year  
 (11+PAR(8)) - number of second nonstandard daily load  
 profile  
 (12+PAR(8)) to (PAR(10+PAR(8)) + (11+PAR(8)))  
 - days of year when second nonstandard pro-  
 file occurs  
 (PAR(10+PAR(8)) + 12+PAR(8))  
 - number of days third nonstandard daily  
 load profile occurs during the year  
 (PAR(10+PAR(8)) + 13+PAR(8))  
 - number of third nonstandard daily load  
 profile  
 [PAR(10+PAR(8)) + 14+PAR(8) to end of parameter list]  
 - days of year when third nonstandard pro-  
 file occurs

### Outputs

1 variable 1  
 2 variable 2  
 3 variable 3  
 4 input source of variable 1

- 5 input source of variable 2
- 6 input source of variable 3
- 7 day of week (1-7)
- 8 day of year (1-365)
- 9 week of year (1-53)

#### LOW TEMPERATURE NIGHT STORAGE TANK BYPASS VALVE CONTROLLER

This component is used with the variable volume tank in a system where the load set temperature varies with the time of day. At night liquid is sent directly to the load if the set temperature is below a specified value rather than being raised to the tank inlet temperature by reducing the flowrate. This can be advantageous when the energy provided by the heat source increases with increased mass flowrate.

#### Inputs 6

- 1 temperature out of the energy source at load mass flowrate
- 2 load mass flowrate
- 3 -----
- 4 insolation on collector surface
- 6 tank inlet temperature

#### Parameters 6

- 1 low set temperature of load
- 2 high set temperature of load
- 3 -----
- 4 minimum insolation for collector operation
- 5 -----
- 6 Nstick (number of iterations per timestep before outputs are fixed)

#### Outputs 8

- 1 temperature desired from energy source
- 2 I valve: 0 - all flow to tank  
          1 - divert all flow to load
- 3 -----
- 4 -----
- 5 -----
- 6 -----

7 -----  
8 -----

#### OSCAR MAYER PERRY PLANT SYSTEM SPECIFIC TEMPERATURE AND FLOWRATE DEPENDENT WASTE HEAT RECOVERY SYSTEM

This component models the dependence of the waste heat recovery system energy output on the temperature and flowrate of the fluid entering the cold side of the WHR heat exchanger. Separate functional relationships between these two variables and the WHR energy output are used to calculate the combined effect. The functional relationships used in the model are:

$$Q \text{ delivered} = F_1 F_2 Q_{\text{base}}$$

( $F_1$  = flowrate factor)

( $F_2$  = inlet temperature factor)

( $Q_{\text{base}}$  = energy transferred at operating conditions when data were taken)

where  $x = (\text{flowrate}/\text{data flowrate})$  and

$$x \leq 1.3 \quad F_1 = A_1 X + A_2$$

$$x > 1.3 \quad F_1 = B_1 X + B_2$$

$$\text{and } F_2 = \exp C_1 (T_{\text{inlet}} - C_2)$$

These relations may be changed inside the subroutine by re-programming other relations.

#### Inputs 4

- 1 inlet temperature
- 2 inlet mass flowrate
- 3 energy transferred at operating conditions when data were taken
- 4 mass flowrate at which data were taken

#### Parameters 8

- 1  $A_1$
- 2  $A_2$
- 3  $B_1$

4 B<sub>2</sub>  
 5 C<sub>1</sub>  
 6 C<sub>2</sub>  
 7 maximum outlet temperature  
 8 minimum mass flowrate

#### Outputs 6

1 outlet temperature  
 2 outlet mass flowrate  
 3 energy transferred  
 4 -----  
 5 -----  
 6 energy which would have been transferred at operating conditions when data were taken

TYPE 41: GENERAL WASTE HEAT RECOVERY SUBSYSTEM

#### General Description

Cascaded waste heat recovery systems (WHR) in industrial plants can have the configuration shown in Figure 1. The waste heat recovery loop is composed of one primary heat exchanger, several secondary heat exchangers, a pump and controllers.

#### The Heat Exchanger Model

The analysis used to model each heat exchanger is identical to that of the Type 5 heat exchanger. The user is referred to the description of that component for the mathematical description of the heat exchanger analysis and the description of the 4 modes.

#### Control Strategies

Three possible heat exchanger control strategies for the primary and secondary heat exchangers are:

- 1) No control - the rate of energy transfer across the heat exchanger (either positive or negative is calculated when ever there is flow on both sides of the heat exchanger.
- 2) Energy transfer into the WHR loop only - Energy is transferred only when the inlet temperature on the

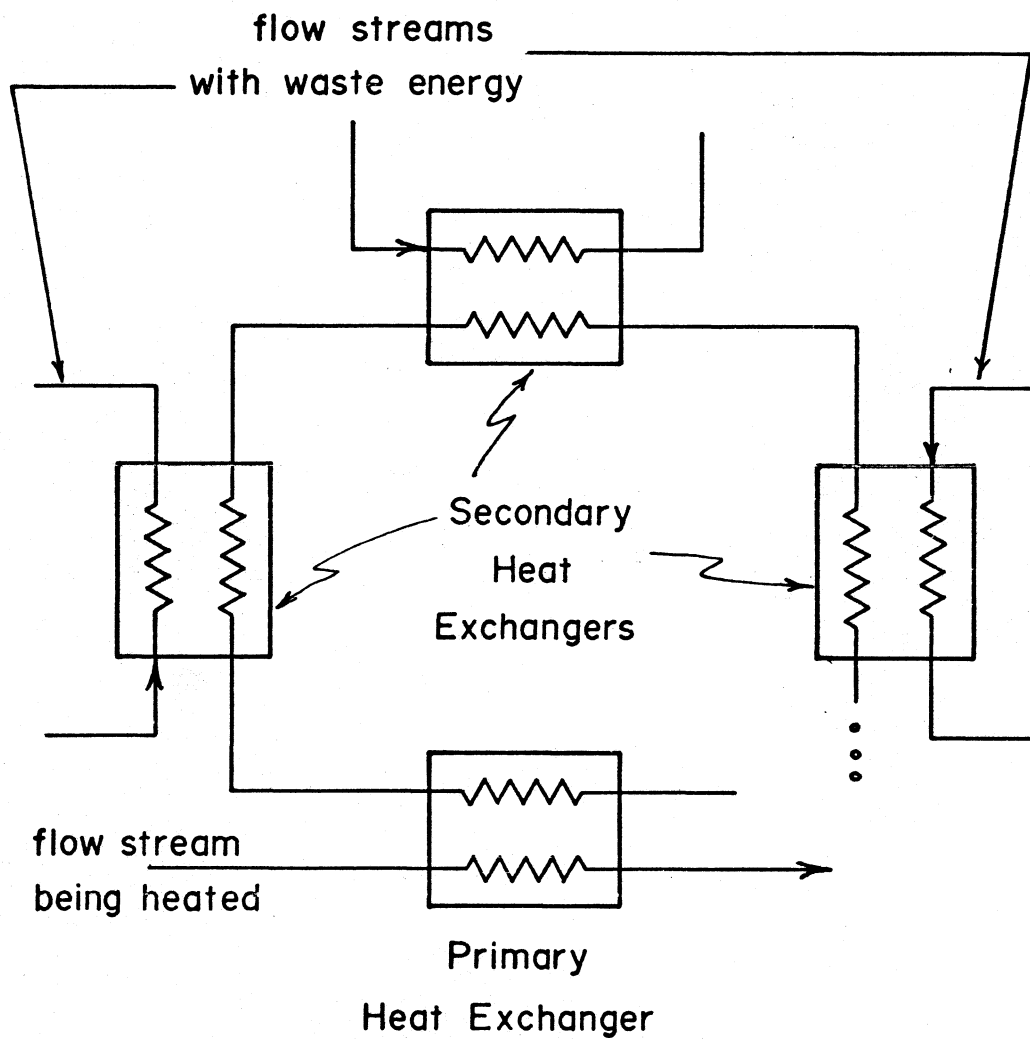


Figure 1 Cascaded Waste Heat Recovery System

WHR loop side of the heat exchanger is more than  $\Delta T_{MIN}$  below the inlet temperature on the other side of the heat exchanger. ( $\Delta T_{MIN}$  is the user specified minimum temperature difference between HX inlet temperatures).

- 3) Energy flow out of the WHR loop only - Energy is transferred only when the inlet temperature on the WHR loop side of the heat exchanger is more than  $\Delta T_{MIN}$  above the inlet temperature on the other side of the heat exchanger.

### Specifying the Control Strategy for each Heat Exchanger

For the main heat exchanger only control strategies 1 or 3 can be specified. For the secondary heat exchangers control strategies 1, 2 or 3 can be specified. The control strategy for each heat exchanger is specified by setting the parameters  $CONTRL$  and  $\Delta T_{MIN}$  as follows:

- 1) No control - set  $CONTRL = 1$   
-  $\Delta T_{MIN}$  IS IGNORED
- 2) Energy transfer into WHR loop only  
- set  $CONTRL = 2$   
- set  $\Delta T_{MIN} =$  the minimum difference between heat exchanger inlet temperatures for which heat transfer is permitted.
- 3) Energy transfer out of WHR loop only  
- set  $CONTRL = 3$   
- set  $\Delta T_{MIN} =$  the minimum difference between heat exchanger inlet temperatures for which heat transfer is permitted.

The controlled heat exchangers specified by setting  $CONTRL = 2$  or  $CONTRL = 3$  can each represent two different physical configurations:

- 1) One heat exchanger with a bypass valve operated by a differential controller (see Figure 2). In this case the heat exchanger performance parameters specified should be for the individual heat exchanger.
- 2) Two heat exchangers connected by a flow loop with a pump regulated by a differential controller (see Figure 3).

In this case the heat exchanger parameters specified



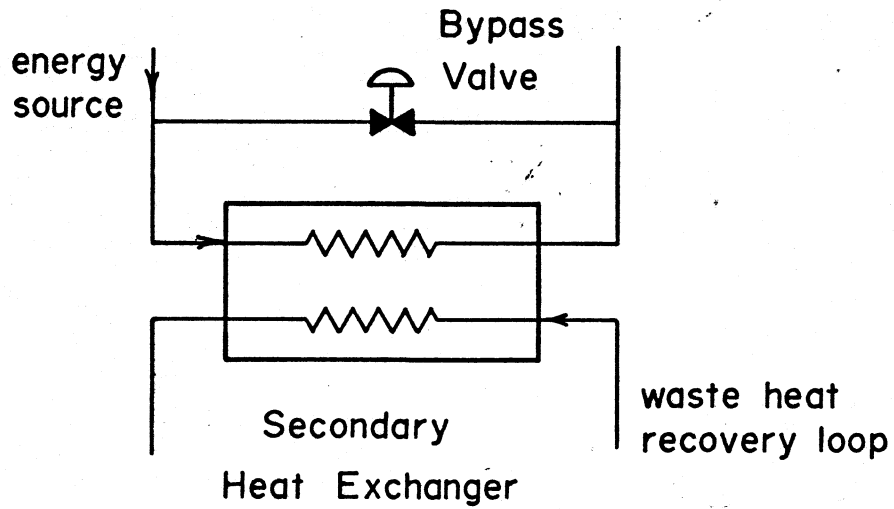


Figure 2 Secondary Heat Exchanger with Controlled Bypass

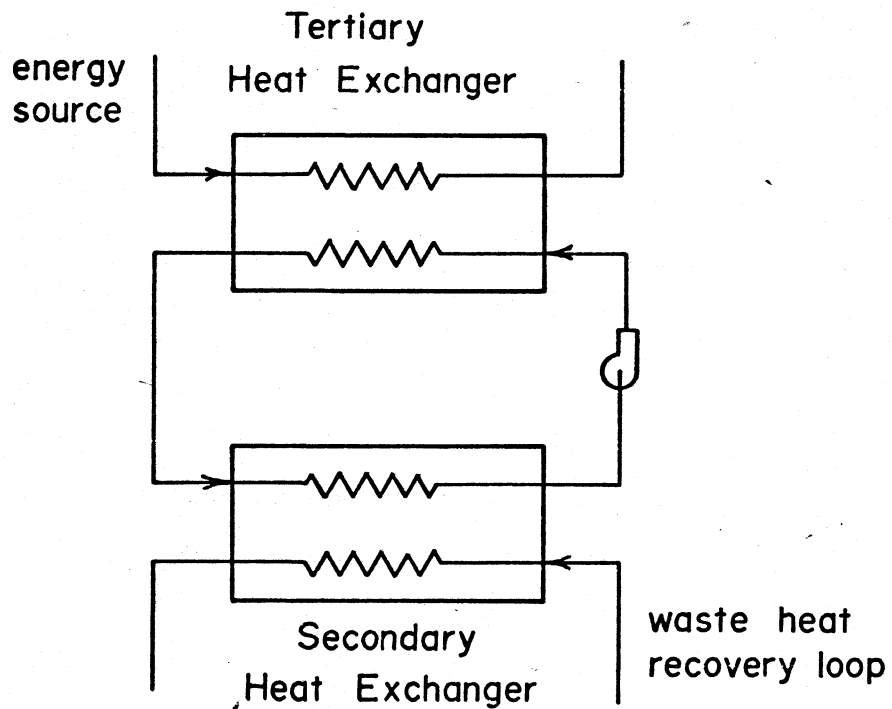


Figure 3 Secondary Heat Exchanger Connected to a Tertiary Heat Exchanger by a Loop with a Controlled Pump

should represent the combined performance of the two heat exchangers. The combined performance parameters can be determined either analytically using the equations given for the appropriate mode of the TYPE 5 heat exchanger component or experimentally.

### Calculation Procedure

The WHR loop model iteratively solves the system of algebraic equations representing the heat exchangers. Iteration continues until the hot side outlet temperature of the main heat exchanger changes less than the specified error tolerance between successive iterations. If this degree of convergence has not occurred after the specified N-stick iterations, convergence is promoted by turning off pumps which oscillate on and off.

During the last timestep of the simulation, a summary of WHR subroutine errors is printed out if errors occurred in more than 5 percent of the timesteps. The summary includes the percentage of simulation timesteps during which N-stick was exceeded and the percentage of simulation timesteps during which the temperatures in the primary loop failed to converge after N-stick + 5 iterations.

### Output

Either brief or detailed output modes can be specified. Both modes output complete performance information for the main heat exchanger, the lack of closure in the WHR loop energy balance, and the number of internal iterations during the last call of the timestep.

After these first 8 outputs the brief mode outputs only the total energy transfer rate across each primary loop heat exchanger from HX#2 through HX #NHX.

The detailed mode, on the other hand, outputs complete performance information for each heat exchanger in the primary loop from HX#2 through HX #NHX.

Since the standard version of TRNSYS limits the number of outputs per component to 20, the brief output allows up to 12 heat exchangers in the primary loop and the detailed output allows up to 3. If a greater number of heat exchangers is required, the standard version of TRNSYS must be modified to allow more parameters. The number of parameters required is:

for brief output, N outputs = 8 + NHX

for detailed output, N outputs = 2 + (6 x NHX).

### TRNSYS Component Configuration

<u>Parameter Number</u>	<u>Description</u>
1	NHX - number of heat exchangers in primary WHR loop
2	$m_{WHR}$ - mass flow rate in primary WHR loop when pump is on
3	$Cp_{WHR}$ - specific heat of fluid in primary WHR loop
4	Nstick - number of iterations allowed for convergence of WHR loop before convergence is promoted
5	TOL - error tolerance for convergence of WHR loop temperatures
6	OUTPUT - if > 0 brief output if < 0 detailed output

(parameters for HX #1 - the main heat exchanger in the primary loop)

7	Mode - 1 for parallel flow - 2 for counter flow - 3 for cross flow - 4 for constant effectiveness
	UA - overall heat transfer coefficient of HX (modes 1, 2, and 3)
	E - HX effectiveness (mode 4)

<u>Parameter Number</u>	<u>Description</u>
9	C <sub>pc</sub> - specific heat of cold side fluid
10	CONTRL - 1 for no control - 3 for heat transfer out of WHR loop only
11	$\Delta T_{min}$ - if $< 0$ HX is not controlled - if $\geq 0$ HX energy transfer rate set to zero if $\Delta T$ between hot and cold inlet temperatures is less than $\Delta T_{min}$

(parameters for HX #IHX from HX #2 through HX #NHX)

<u>Parameter Number</u>	<u>Description</u>
$((IHX) \times 5) + 2$	Mode <sub>(IHX)</sub> - as above
$((IHX) \times 5) + 3$	UA <sub>(IHX)</sub> or E <sub>(IHX)</sub> - as above
$((IHX) \times 5) + 4$	C <sub>PH(IHX)</sub> - specific heat of hot side fluid
$((IHX) \times 5) + 5$	CONTRL - 1 for no control - 2 for heat transfer in to WHR loop only - 3 for heat transfer out of WHR loop only
$((IHX) \times 5) + 6$	$\Delta T_{min(IHX)}$ - as above

### Inputs

<u>Input Number</u>	<u>Description</u>
1	T <sub>Ci</sub> - main HX cold side inlet temperature
2	$\dot{m}_c$ - main HX cold side mass flow rate

(for HX #IHX from HX #2 through HX #NHX)

<u>Output Number</u>	<u>Description</u>
$((\text{IHX}-1)\times 2) + 1$	$T_{hi}(\text{IHX})$ - hot side inlet temperature to HX #IHX
$((\text{IHX}-1)\times 2) + 2$	$\dot{m}_n$ - hot side mass flow rate through HX #IHX

Outputs

<u>Output Number</u>	<u>Description</u>
	(for HX #1)
1	$T_{ho}(1)$ - main HX hot side outlet temperature
2	$\dot{m}_n(1)$ - main HX hot side mass flow rate
3	$T_{co}(1)$ - main HX cold side outlet temperature
4	$\dot{m}_c(1)$ - main HX cold side mass flow rate
5	$\dot{Q}_T(1)$ - total energy transfer rate across main HX
6	$E(1)$ - effectiveness of main HX
7	EBERR - lack of closure in WHR loop energy balance
8	ITER - number of iterations during last call of the timestep

After output number 8 the brief and detailed modes have different outputs.

Brief Output Mode

	(for HX #IHX from HX #2 through HX #NHX)
$\text{IHX} + 8$	$Q_T(\text{IHX})$ - total energy transfer rate across HX #IHX

Detailed Output Mode

(for HX #IHX from HX #2 through HX #NHX)

<u>Output Number</u>	<u>Description</u>
$[(\text{IHx}-1)\times 6] + 9$	$T_{\text{ho}}(\text{IHx})$ - hot side outlet temperature for HX #IHx
$[(\text{IHx}-1)\times 6] + 10$	$\dot{m}_{\text{h}}(\text{IHx})$ - hot side mass flow rate for HX #IHx
$[(\text{IHx}-1)\times 6] + 11$	$T_{\text{co}}(\text{IHx})$ - cold side outlet temperature for HX #IHx
$[(\text{IHx}01)\times 6] + 12$	$\dot{m}_{\text{co}}(\text{IHx})$ - cold side mass flow rate for HX #IHx
$[(\text{IHx}-1)\times 6] + 13$	$\dot{Q}_{\text{T}}(\text{IHx})$ - total energy transfer rate across HX #IHx
$[(\text{IHx}-1)\times 6] + 14$	$E(\text{IHx})$ - effectiveness of HX #IHx

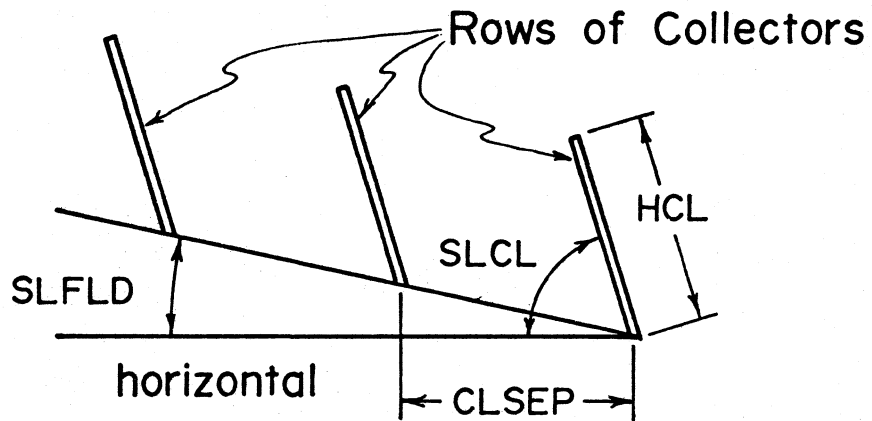
## COLLECTOR ARRAY SHADING DOCUMENTATION

The collector shading subroutine has several modes which calculate the reduction in insolation incident on the collector surfaces due to shading by other collectors in the array. Two types of arrays are considered.

## SAW TOOTH FLAT PLATE COLLECTOR ARRAYS (MODE 1)

The reduction in insolation incident on the array surface due to shading of one row of collectors by another is calculated. It is assumed that the collector rows are all of equal length and situated to form a rectangular collector field. The reduction in beam radiation on the array surface is calculated two ways and both values are output, one assumes infinite collector row length and the other takes into account the length of the collector rows. For the calculation of the reduction in the incident diffuse radiation however, it is assumed that the collector rows are infinitely long. The dimensions and angles required in the parameter list are illustrated in Figure 1.

side view



top view

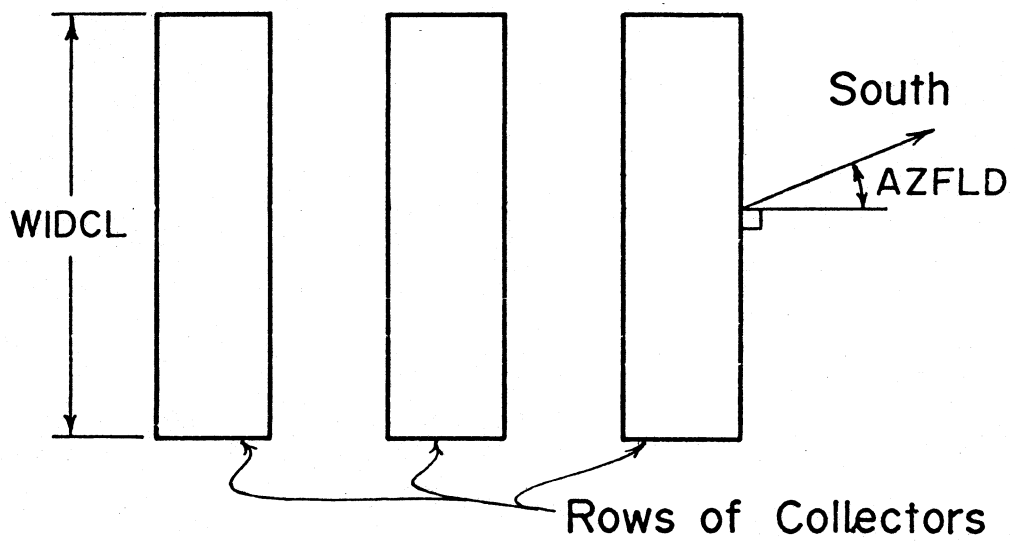


Figure 1



## PARABOLIC TROUGH ARRAY SHADING (MODE 2)

The reduction in insolation incident on the array surface due to shading of one parabolic trough by another is calculated. It is assumed that the parabolic troughs are all of equal length, have parallel axis of rotation and are situated to form a rectangular field. It is also assumed that the collector axes are parallel to one of the two axis of a rectangular collector field.

When the projections of the collector axes into the horizontal are parallel to the collector field azimuth set parameter ARMODE = 1. When the projections of the collector axes into the horizontal are normal to the collector field azimuth set parameter ARMODE = 2. For the calculation of the reduction in the incident beam radiation the troughs are assumed to be infinitely long. The reduction of incident diffuse radiation is not calculated. The dimensions and angles required for the parameter list are illustrated in Figure 2.

Parameters

1 - MODE

- 1 - saw tooth flat plate array
- 2 - parabolic trough array

for mode = 1

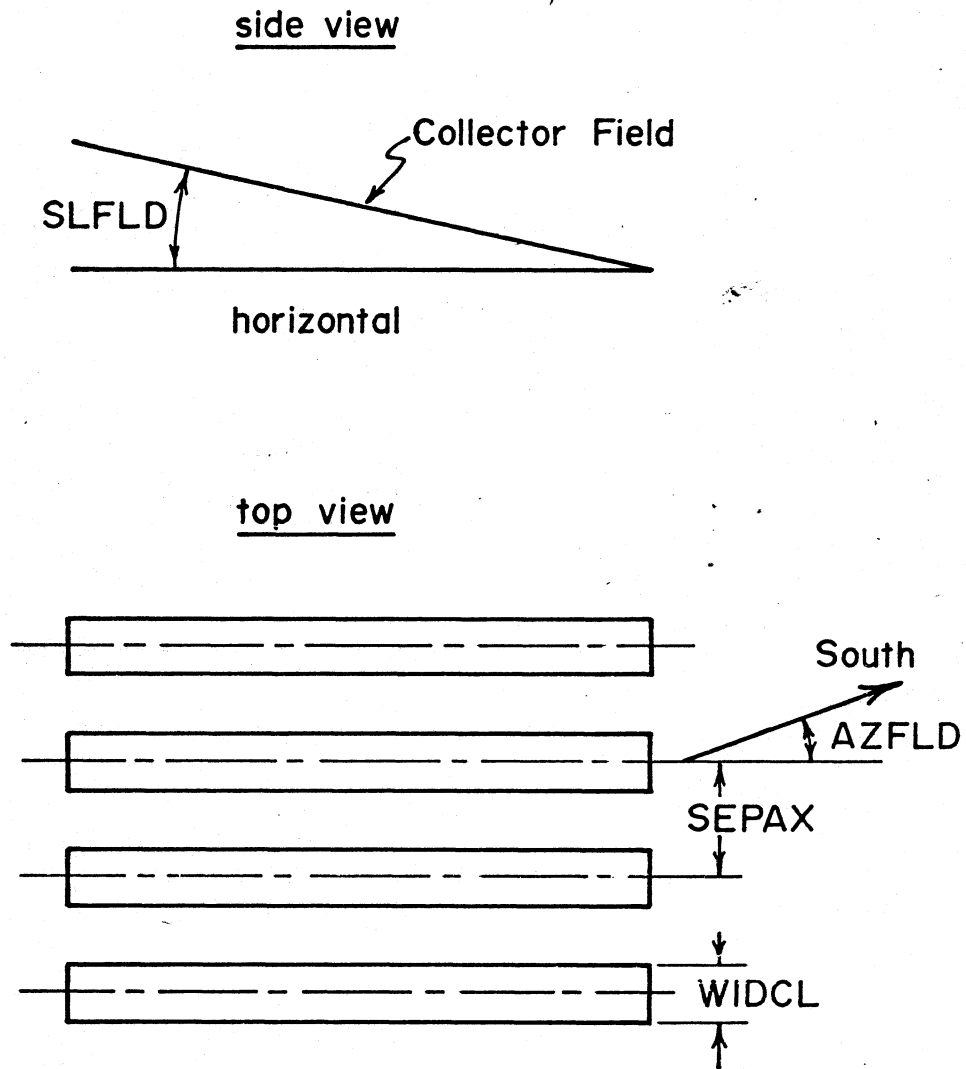


Figure 2

Parameters

- 2 - collector height
  - 3 - collector row length
  - 4 - collector slope (relative to horizontal)
  - 5 - collector row separation (projection into horizontal plane)
  - 6 - number of collector rows
  - 7 - azimuth of collector field
  - 8 - slope of collector field
- for Mode = 2
- 2 - slope of collector field
  - 3 - azimuth of collector field
  - 4 - collector axis orientation mode
    - 1 - projection of collector axis into horizontal plane **is** parallel to collector field azimuth
    - 2 - projection of collector axis into horizontal plane is normal to collector field azimuth.
  - 5 - separation of collector axes
  - 6 - width of collector aperture
  - 7 - number of rows of collectors.

Inputs

- for Mode = 1
- 1 - Total solar flux on unshaded collector surface

Inputs

- 2 - Beam solar flux on unshaded collector surface
- 3 - diffuse solar flux on unshaded collector surface
- 4 - -----
- 5 - -----
- 6 - -----
- 7 - solar zenith angle
- 8 - solar azimuth angle
- 9 - total solar flux on horizontal surface
- 10 - diffuse solar flux on horizontal surface
- 11 - beam solar flux on unshaded ground between  
collectors
- 12 - albido of ground  
from Mode = 2
- 1 - beam solar flux on collector aperture
- 2 - slope of aperture surface
- 3 - solar azimuth angle

Outputs

Mode 1

- |                       |   |  |
|-----------------------|---|--|
| 1 - total radiation   | } | beam calculation<br>based on<br>specified<br>collector<br>length |
| 2 - beam radiation    |   |  |
| 3 - diffuse radiation |   |  |

Outputs

4 - total radiation	}	beam calculations based on infinite collector length
5 - beam radiation		
6 - diffuse radiation		

Mode 2

1 - beam radiation incident of collector aperture  
2 - fraction unshaded collector area.

MATHEMATICAL DESCRIPTION OF  
PARABOLIC TROUGH SHADING MODEL

It is assumed that the collectors are infinitely long. The important collector dimensions and angles are shown in Figure 3.

$$XNSEP = \cos(ETA) \times SEPAX$$

$$\text{where } \cos(ETA) = \frac{\cos(THETA1)}{\cos(SLAX)}$$

THETA1 = slope of collector surface

SLAX = slope of collector axis of rotation

$$SFRAC = \frac{WIDCL - XNSEP}{XNSEP}$$

where WIDCL = collector aperture width.

If SFRAC > 1.0, SFRAC is set to 1.0.

If SFRAC < 0.0, SFRAC is set to 0.0.

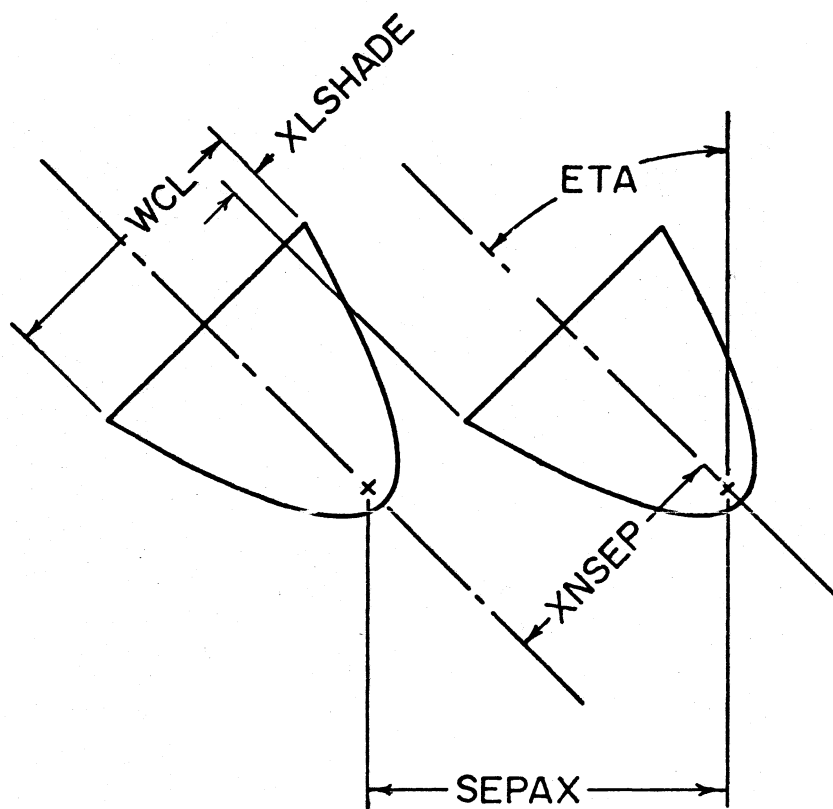


Figure 3

Fraction of array aperture that is unshaded

$$FUSARR = \frac{(1.0 + ((XNROW - 1.0) \times (1.0 - SFRAC)))}{XNROW}$$

Average beam solar flux on collector array aperture area after shading is taken into account is calculated by multiplying the solar radiation incident on the collector aperture without shading by FUSARR.

MATHEMATICAL DESCRIPTION OF  
SAW TOOTH COLLECTOR ARRAY SHADING MODEL

General definitions

$$BB = (SEPCL \times \tan (SLFLD)) - (HLL \times \sin(SLCL))$$

$$SEP = SEPCL \div \cos (SLFLD)$$

$$D = (SEP^2 + HCL^2 - (2 \times (SEP) \times (HCL)) \\ \times \cos (SLCL - SLFLD))^{\frac{1}{2}}$$

$$THETA6 = (THETA1 - SLFLD)$$

where,

$$THETA1 = \text{ARCOS} ((SEP^2 + D^2 - HCL^2) \div (2 \times SEP \times D))$$

$$\text{IF } SEP \leq 0, \text{ THETA1} = \pi - SLCL$$

$$ALF = SLCL - SLFLD$$

$$ALB = \text{albido of the ground}$$

$$ALT = \underline{\pi} - ZENAZ$$

$$\text{where } ZENAZ = (\sin l / \cos l)$$

$$\cos l = \cos(ZEN)$$

$$ZEN = \text{Solar zenith angle}$$

$$\sin l = (\cos(DELTAZ)) \times (\sin(ZEN))$$

$$DELTAZ = \text{absolute value } (AZSOL - AZCL)$$

$$AZSOL = \text{Solar azimuth angle}$$

$$AZCL = \text{Collector azimuth angle}$$

$$HTHOR = \text{Total radiation flux on horizontal}$$

$$HDHOR = \text{Diffuse component of radiation flux on horizontal}$$



HBHOR = Beam component of radiation flux on horizontal

HBSLFL = Beam component of radiation flux on surface  
with a slope equal to that of the collector  
field.

1. The calculation of average diffuse radiation flux.

Using the cross-uncrossed string method the following  
equations were obtained:

A. Shaded collector view factor of ground in front  
of array

$$L5 = CLSEP$$

$$L7 = CLSEP \div \cos(SLFLD)$$

$$L6 = CLSEP - (HCL \times \cos(SLCL))$$

$$L8 = (BB^2 + L6^2)^{\frac{1}{2}}$$

$$\text{If } BB \leq 0 \text{ then } L6 = L8$$

$$USUFGR = (1 - \cos(SLCL)) \div 2$$

$$SVFGR = ((L6 - L5) + (L7 - L8)) \div (2 \times HCL)$$

$$ARUFGR = (SVFGR \times (XNROW - 1)) + USVFGR \div XNROW$$

B. Shaded collector view factor of sky

$$USVFSK = (1 + \cos(SLCL)) \div 2$$

$$SVDSK = FAB - SVFGR$$

$$ARVFSK = ((SUFVSK \times XNROW - 1) + USVFSK) \div XNROW$$

where

$$FAB = ((HCL + SEP) - D) \div (2 \times HCL)$$

SVFGR as defined in section A.

C. Beam radiation incident on ground between collector rows which reaches collector aperture as diffuse (DFBBC)

$$DFBBC = VFB1 \times HBSLFL \times ALB \times ((XNROW - 1) \div XNROW)$$

1. If ground between collector rows shaded by row in front.

$$\text{If } (ALT) < THETA6, \text{ GRUS} = 0.$$

$$\text{If } (\pi - SLCL) > ALT > THETA6$$

$$ANGLE2 = ZENAZ + \frac{\pi}{2} - SLCL$$

$$ANGLE3 = \pi - ANGLE2 - ALF$$

$$\begin{aligned} \text{GRUS} &= \text{SEP} - \text{HCL} \times (\text{Sin}(ANGLE2)) \\ &\div (\text{sin}(ANGLE3)) \end{aligned}$$

$$\text{If } ALT = - SLCL$$

$$\text{GRUS} = \text{SEP}$$

$$VFB1 = (\text{HCL} + \text{GRUS} - \text{CC}) \div (2 \times \text{HCL})$$

where

$$\begin{aligned} \text{CC} &= (\text{HCL}^2 + \text{GRUS}^2 - (2 \times (\text{HCL}) \\ &\times (\text{GRUS}) \times \cos(\pi - ALF)))^{\frac{1}{2}} \end{aligned}$$

2. If ground between rows shaded by row behind

$$\text{If } ANGLE15 \geq ALT \geq (\pi - SLCL)$$

$$\text{where: } ANGLE15 = \pi - \text{ARCTAN} (\text{NA15} \div \text{DA15})$$

$$\text{NA15} = \text{sin}(SLCL) \times \text{HCL}$$

$$+ (\text{TAN}(SLFLD) \times \text{SEPCL})$$

$$\text{DA15} = (\text{cos}(SLCL) \times \text{HCL} + \text{SEPCL})$$

$$VFB1 = ((SEP + EE) - (BB + S)) \div (2 \times HCL)$$

If ALT > ANGLE15

$$VFB1 = 0.0$$

where,

$$ANGL11 = ABS (ZENAZ) - \frac{\pi}{2} - SLCL$$

$$ANGL12 = \pi - SLCL - SLFLD$$

$$ANGL13 = SLFLD + (2 \times SLCL) + \frac{\pi}{2} - ABS (ZENAZ)$$

$$EE = HCL \times \sin(ANGL12) \div \sin(ANGL13)$$

$$S = HCL \times \sin(ANGL11) \div \sin(ANGL13)$$

- D. Diffuse radiation incident on the ground between collector rows which reaches the collector as diffuse (DFDBC).

$$DFDBC = ((VFD1) \times (VFD2) \times (HDHOR) \times (ALB) \\ \times (XNROW - 1) \div XNROW$$

1. View factor from ground between collector rows to sky.

$$VFD1 = (BB + D + (2 \times HCL)) \div (2 \times SEP)$$

2. View factor from collector aperture to ground between collector rows.

$$VFD2 = (HCL + SEP - BB) \div (2 \times HCL)$$

2. Beam shading of collector array.

$$\text{If } ALT > (\pi - SLCL) \text{ FCLBIN} = 0.0$$

$$\text{If } (\pi - SLCL) \geq ALT \geq \text{THETA6}, \text{ FCLBIN} = 1.0$$

$$\text{If } ALT < \text{THETAG}$$

$$HB = SEP \times ((\sin(ALT + SLFLD)) \div \sin(THETA2))$$

$$\text{and } THETA2 = \pi - ALF - (SLFLD + ALT)$$

$$\text{If } (HB > HCL), FCLBIN = 1.0$$

$$\text{If } (HB < HCL), FCLBIN = 1 - (WIDCL \times XL1) \div A$$

where

$$A = HH \times WIDCL$$

$$HH = HCL \times \cos(SLCL)$$

$$XL1 = HS \times \cos(SLCL)$$

$$HS = HCL - HB$$

$$FHBIN = (1 + (FCLBIN \times (XNROW - 1))) \times XNROW$$

3. Combined beam and diffuse radiation flux on collector array

$$\text{In } HT1S = HD1S + INHB1S$$

where,

$$HD1S = HDHOR \times ARVFSK + HTHOR \times ARVFG \times ALB \\ + DFBBC + DFDBC$$

$$INHB1S = HB1 \times FHBIN$$

## APPENDIX B

## TRNSYS Subroutine Listings

- Variable Volume Pump
- Variable Volume Tank
- Tempering Valve for Flow Out of Variable Volume Tank
- Load Profile Sequencer
- Low Temperature Night Storage Bypass Valve Controller
- Oscar Mayer Perry Plant System Specific Temperature and Flow Rate Dependent Waste Heat Recovery System
- General Cascaded Waste Heat Recovery Loop
- Collector Array Shading

```

      SUBROUTINE TYPE29(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C THIS SUBROUTINE MODELS A VARIABLE VOLUME PUMP WHICH
C MODULATES A FLOW STREAM THROUGH ONE OR MORE HEAT
C EXCHANGERS TO PRODUCE THE DESIRED OUTLET TEMPERATURE
      DIMENSION PAR(6),XIN(6),OUT(4),INFO(10)
      REAL MIN,MOUT,MDMIN,MDMAX
      IF(INFO(7) .GT. -1) GO TO 5
      OUT(1) = 55.0
      OUT(2) = MDMIN + DELM
      OUT(3) = 1.0
      OUT(4) = 1.0
5 CONTINUE
      NI = 6
      NP = 6
      ND = 0
      INFO(6) = 4
      INFO(9) = 1
      CALL TYPECK(1,INFO,NI,NP,ND)
C SET PARAMETERS
      NSTK1 = INT(PAR(1) + 0.1)
      NSTK2 = INT(PAR(2) + 0.1)
      MDMIN = PAR(3)
      MDMAX = PAR(4)
      DELM = PAR(5)
      DTMP = PAR(6)
C READ INPUTS
      TIN = XIN(1)
      MIN = XIN(2)
      TOUT =XIN(3)
      MOUT = XIN(4)
      TSET = XIN(5) + DTMP
      XI = XIN(6)
      TINLST = OUT(1)
C FOR ITERATION -1 GO TO 50 WITH INNITAIL VALUES FOR OUTPUTS
      IF(INFO(7) .EQ. -1) GO TO 50
C CHECK FOR ON CONTROL FUNCTION
      IF (XI .LT. 0.001) GO TO 10
C CHECK FOR TOO MANY ITERATIONS
      IF (INFO(7) .GT. NSTK1) GO TO 40
C FOR FIRST NSTIK 2 ITERATIONS SET MDOT .GT. MDMIN
C EITHER EQUAL TO MDMIN+DELM OR MDOT FROM PREVIOUS
C TIME STEP
      IF (INFO(7) .GT. NSTK2) GO TO 7
      MOUT = MDMIN + DELM
      BETA = (MOUT)/MDMAX
      GAMMA = BETA
      GO TO 50
7 CONTINUE
      IF(TOUT .LT. TINLST) GO TO 10

```

```
      GO TO 20
C NO FLOW (MDOT .LT. MDMIN)
  10 CONTINUE
      MOUT = 0.0
      BETA = 0.0
      GAMMA = 0.0
      GO TO 50
C MAXIMUM FLOW (MDOT .GE. MDMAX)
  15 CONTINUE
      GAMMA = 1.0
      MOUT = MDMAX
      BETA = 1.0
      GO TO 50
  20 CONTINUE
C USE COLLECTOR T-IN AND T-OUT FROM PREVIOUS ITERATION
      TEST = TSET - 0.1
      IF(TINLST .GE. TEST) GO TO 15
      GAMMA = (TOUT - TINLST) / (TSET - TINLST)
      MOUT = MOUT * GAMMA
      IF(MOUT .GT. MDMAX) MOUT = MDMAX
      IF(MOUT .LT. MDMIN) MOUT = 0.0
      BETA = MOUT/MDMAX
      GO TO 50
C FIX OUTPUTS AFTER ISTIK ITERATIONS
  40 CONTINUE
      TIN = OUT(1)
      MOUT = OUT(2)
      BETA = OUT(3)
      GAMMA = OUT(4)
  50 CONTINUE
      OUT(1) = TIN
      OUT(2) = MOUT
      OUT(3) = BETA
      OUT(4) = GAMMA
      RETURN
      END
```

;

```

SUBROUTINE TYPE32(TIME,XIN,OUT,T,DTDI,PAR,INFO)
C THIS SUBROUTINE MODELS A VARIABLE VOLUME TANK WHICH
C HAS UPPER AND LOWER VOLUME LIMITS
  DIMENSION PAR(11),XIN(4),OUT(17),INFO(10)
  REAL MIN,MOUT,LHTAV,MFIN,MAV,MFST,MZERO
  COMMON/SIM/TIME0,TFINAL,DELT
  DELTA = DELT
  DATA TUNE/10000.0/
  IF(INFO(7),GT,-1) GO TO 10
  NI = 4
  NP = 11
  ND = 0
  CALL TYPECK(1,INFO,NI,NP,ND)
C SET PARAMETERS
  VOL = PAR(1)
  DIA = PAR(2)
  UM = PAR(3)
  UD = PAR(4)
  VMIN = PAR(5)
  VMAX = PAR(6)
  CP = PAR(7)
  DEN = PAR(8)
  THAINS = PAR(9)
  TFST = PAR(10)
  MFST = PAR(11)
C PRELIMINARY TANK LOSS CALCULATIONS
  AEND = (3.1416*(DIA**2.0))/4.0
  HEIGHT = VOL/AEND
  CIRC = 3.1416 * DIA
C SET T-ZERO AND M-ZERO FOR DELTA-E CALCULATION
  TZERO = TFST
  MZERO = MFST
10 CONTINUE
  IF(INFO(7) .NE. 0 ) GO TO 15
C SET T INITIAL AND M INITIAL
  TFST = OUT(10)
  LEVEL = 0
  MFST = OUT(11)
15 CONTINUE
C READ INPUTS
  TIN = XIN(1)
  MIN = XIN(2)
  MOUT = XIN(3)
  TAMR = XIN(4)
  QDUMP = 0.0
C CHECK FOR MAXIMUM OR MINIMUM LIQUID VOLUME
  VFTEST = (MFST+(DELTA*(MIN-MOUT)))/DEN
  IF(VFTEST .LT. VMAX) GO TO 17
  QDUMP = MIN * CP * (TIN - THAINS)

```



```

    MIN = 0.0
    LEVEL = 1
    GO TO 20
17 IF(VFTEST .GT. VMIN) GO TO 20
    MOUT = 0.0
    LEVEL = -1
20 CONTINUE
C CALCULATE FINAL AND AVERAGE FOR TANK FLUID MASS AND VOLUME
    MFIN = MFST + DELTA*(MIN-MOUT)
    MAV = (MFST+MFIN)/2.0
    VOLFIN = MFIN/DEN
    VOLAV = MAV/DEN
    LHTAV = VOLAV/AEND
C CALCULATE AVERAGE TANK UA BASED ON DRY AREA AND WETTED AREA
    UAW = UW * (AEND+CIRC * LHTAV)
    UAD = UD * (AEND + CIRC * (HEIGHT - LHTAV))
    UA = UAW + UAD
C CHECK FOR MIN = MOUT
    CHECK = ABS(MIN-MOUT)
    XXTEST = (MIN + UA/CP)/TUNE
    IF(CHECK .LT. XXTEST) GO TO 75
C CHECK FOR NO FLOW
    IF(MIN .LT. 0.001 .AND. MOUT .LT. 0.001) GO TO 75
C EQUATIONS FOR FLOW CONDITION
50 CONTINUE
    B = MIN + UA/CP
    C = MIN - MOUT
    D = MIN * TIN + (UA/CP) * TAMB
    CC = MFST - D/B
    DD = (1+(C*DELTA)/MFST)**(-B/C)
    TFIN = CC*DD/D/B
    AA = (TFST - D/B)/(C-B)
    BB = (1+(C*DELTA)/MFST)**(1-B/C)
    TAV = AA*(MFST/DELTA)*(BB-1.0) + D/B
    GO TO 150
75 CONTINUE
C EQUATIONS FOR MIN = MOUT CONDITION
    B = MIN + UA/CP
    D = MIN * TIN + (UA/CP) * TAMB
    G = -B/MFST
    H = 1.0/(DELTA*(-B))
    A1 = D - B*TFST
    E = A1 * EXP(DELTA*G)
    TFIN = (E-D)/(-B)
    TAV = H*((E-A1)/G)+D/B
    GO TO 150
150 CONTINUE
    DE = CP*((TFIN-TMAINS)*MFIN - (TZERO-TMAINS)*MZERO)
    DM = MFIN - MZERO
    QTKIN = CP*MIN*(TIN-TMAINS)

```

```
QTKOUT = CP*MOUT*(TAV-TMINS)
ETKAV = CP*MAV*(TAV-TMINS)
QLOSS = UA*(TAV - TAMB)
MFIN = MFIN
C SET OUTPUTS
OUT(1) = TAV
OUT(2) = MOUT
OUT(3) = MIN
OUT(4) = QDUMP
OUT(5) = QLOSS
OUT(6) = DE
OUT(7) = LEVEL
OUT(8) = TFST
OUT(9) = MFST
OUT(10) = TFIN
OUT(11) = MFIN
OUT(12) = DELTA
OUT(13) = VFTEST
OUT(14) = QTKIN
OUT(15) = QTKOUT
OUT(16) = ETKAV
OUT(17) = DM
RETURN
END
```

```

      SUBROUTINE TYPE34(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C THIS SUBROUTINE MODELS A TEMPERING VALVE WHICH
C MODULATES HOT AND COLD FLOW STREAMS SO THAT
C TSET IS NOT EXCEEDED AND THE DEMAND FLOW RATE IS DELIVERED
      DIMENSION PAR(2),XIN(7),OUT(7),INFO(10)
      REAL MH,MC,MLD,MOUT
      IF(INFO(7) .GT. -1) GO TO 10
      NI = 7
      NP = 2
      ND = 0
      CALL TYPECK(1,INFO,NI,NP,ND)
10 CONTINUE
C SET PARAMETERS
      NSTIK = INT(PAR(1) + 0.1)
      MMM = INT(PAR(2) + 0.1)
C READ INPUTS
      TH = XIN(1)
      MH = XIN(2)
      TC = XIN(3)
      MC = XIN(4)
      TSET = XIN(5)
      MLD = XIN(6)
      XL = XIN(7)
C IF N STICK EXCEEDED FIX MH AND MC
      IF(INFO(7) .LT. NSTIK) GO TO 15
      TH = TH
      MH = MH
      TC = TC
      MC = MC
      MOUT = MH + MC
      TOUT = (TH*MH + TC*MC)/MOUT
      GAMMA = MH/MLD
      GO TO 50
15 CONTINUE
C IS HOT SOURCE AVAILABLE ?
      IF(XL .LT. -0.5) GO TO 35
      IF (MLD .GT. 1.0) GO TO 25
      TOUT = TH
      MOUT = MLD
      MH = MLD
      MC = 0.0
      GO TO 50
25 CONTINUE
C ARE BOTH SOURCES ABOVE TSET ?
      IF(TH .GE. TSET .AND. TC .GE. TSET) GO TO 45
C IS ONE SOURCE ABOVE TSET ?
      IF(TH .GT. TSET .OR. TC .GT. TSET) GO TO 40
C IS COLD SOURCE ABOVE TSET ?
      IF(TC .GE. TH) GO TO 35

```

```
C FLOW OUT ALL FROM HOT SOURCE
 30 CONTINUE
   TOUT = TH
   MOUT = MLD
   TH = TH
   MH = MLD
   TC = TC
   MC = 0.0
   GAMMA = 1.0
   GO TO 50
C FLOW OUT ALL FROM COLD SOURCE
 35 CONTINUE
   MH = 0.0
   MC = MLD
   MOUT = MC
   TOUT = TC
   GAMMA = 0.0
   GO TO 50
C FLOW OUT MIXED FROM HOT AND COLD SOURCES
 40 CONTINUE
   TEST = ABS(TH-TC)
   IF(TEST .LT. 1.0) GO TO 45
   GAMMA = (TSET-TC)/(TH-TC)
   MH = GAMMA * MLD
   MC = MLD - MH
   MOUT = MH + MC
   TOUT = (TH*MH + TC*MC)/(MOUT)
   GO TO 50
C BOTH SOURCES ABOVE TSET
 45 CONTINUE
C MODE 1, ALL FLOW FROM HOT SOURCE
   IF(MMM .EQ. 1) GO TO 30
C MODE 2, ALL FLOW FROM COLD SOURCE
   IF(MMM .EQ. 2) GO TO 35
   IF(MMM .EQ. 4) GO TO 47
C MODE 3, ALL FLOW FROM LOWER TEMPERATURE SOURCE
   IF(TH .LE. TC) GO TO 30
   GO TO 35
C MODE 4, ALL FLOW FROM HIGHER TEMPERATURE SOURCE
 47 CONTINUE
   IF(TH .GE. TC) GO TO 30
   GO TO 35
 50 CONTINUE
   OUT(1) = TOUT
   OUT(2) = MOUT
   OUT(3) = TH
   OUT(4) = MH
   OUT(5) = TC
   OUT(6) = MC
   OUT(7) = GAMMA
```

RETURN  
END

;

```

      SUBROUTINE TYPE30(STIME,XIN,OUT,T,DTDT,PAR,INFO)
C
C THIS SUBROUTINE SELECTS SPECIFIED DAILY LOAD PROFILES
C FOR EACH DAY OF THE WEEK PROFILES ARE SPECIFIED FOR
C FLOW RATE, INLET TEMPERATURE, AND SET TEMPERATURE
C IF SO DESIRED EACH DAY OF THE WEEK CAN HAVE DIFFERENT LOAD PROFILES
C ANY ONE OF THREE SETS OF LOAD PROFILES CAN ALSO BE
C FOR ANY DAY OF THE YEAR
C
      DIMENSION XIN(30),OUT(9),PAR(50),INFO(10)
      IF(INFO(7) .GT. -1) GO TO 5
      NI = INFO(3)
      NO = 9
      NP = INFO(4)
      CALL TYPECK(1,INFO,NI,NP,0)
5 CONTINUE
      IF(XIN(1) .GE. 0.0) GO TO 7
      TIME = STIME
      GO TO 9
7 CONTINUE
      TIME = XIN(1)
9 CONTINUE
C
C CALCULATE: DAY OF THE YEAR, WEEK OF THE YEAR, DAY OF WEEK
C
      BTIME = TIME + 0.01
      NDAYYR = (BTIME / 24.0) + 1.0
      NWKYR = BTIME / 168.0
      NDAYWK = NDAYYR - (NWKYR * 7)
      IF(NP .LT. 8) GO TO 40
C
C IS IT A NON STANDARD DAY 1
C
      ND1 = INT(PAR(8) + 0.1)
      NPROF = INT(PAR(9) + 0.1)
      NPARAM = 9
      DO 20 J=1,ND1
      NPARAM = NPARAM + 1
      LD1 = INT(PAR(NPARAM) + 0.1)
      IF (LD1 .EQ. NDAYYR) GO TO 90
20 CONTINUE
      NTEST2 = 8 + 2 + ND1
      IF(NP .LT. NTEST2) GO TO 90
C
C IS IT A NON STANDARD DAY 2
C
      ND2 = INT(PAR(NTEST2) + 0.1)
      NPARAM = NTEST2 + 1
      NPROF = INT(PAR(NPARAM) + 0.1)

```

```
DO 30 J=1,ND2
  NPARAM = NPARAM + 1
  LD2 = INT(PAR(NPARAM) + 0.1)
  IF (LD2 .EQ. NDAYYR) GO TO 90
30 CONTINUE
  NTEST3 = NTEST2 + 2 + ND2
  IF(NP .LT. NTEST3) GO TO 90
C
C IS IT A NON STANDARD DAY 3
C
  ND3 = INT(PAR(NTEST3) + 0.1)
  NPARAM = NTEST3 + 1
  NPROF = INT(PAR(NPARAM) + 0.1)
  DO 40 J=1,ND3
    NPARAM = NPARAM + 1
    LD3 = INT(PAR(NPARAM) + 0.1)
    IF (LD3 .EQ. NDAYYR) GO TO 90
  40 CONTINUE
  NPROF = INT(PAR(NDAYWK) + 0.1)
  90 CONTINUE
C
C SET OUTPUTS TO APPROPRIATE DAY OF WEEK PROFILES
C
  NTS = (NPROF * 3) + 1
  NMD = NTS + 1
  NTD = NTS + 2
  100 CONTINUE
C
C SET OUTPUTS
C
  OUT(1) = XIN(NTS)
  OUT(2) = XIN(NMD)
  OUT(3) = XIN(NTD)
  OUT(4) = NTS
  OUT(5) = NMD
  OUT(6) = NTD
  OUT(7) = NDAYWK
  OUT(8) = NDAYYR
  OUT(9) = NWKYR
  RETURN
  END
```

:

```

      SUBROUTINE TYPE23(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C THIS SUBROUTINE MODELS A LOW TEMPERATURE BYPASS AROUND
C THE STORAGE TANK
      DIMENSION PAR(6),XIN(5),OUT(8),INFO(10)
      REAL MOUTDA,MDPOT,LTSET
      IF(INFO(7) .GT. 0.0) GO TO 40
      IF(INFO(7) .GT. -1) GO TO 5
      NI = 6
      NP = 6
      ND = 0
      INFO(6) = 8
      CALL TYPECK(1,INFO,NI,NP,NI)
C SET PARAMETERS
C PARAMETERS 1,2,3,5 ARE NOT BEING USED
      LTSET = PAR(1)
      HHTSET = PAR(2)
      TTEST = PAR(3)
      RTEST = PAR(4)
      FLTEST = PAR(5)
      ITERAT = PAR(6)
      5 CONTINUE
C READ INPUTS
C INPUT 4 IS NOT BEING USED
      TOUTDA = XIN(1)
      MOUTDA = XIN(2)
      TSETDA = XIN(3)
      MDPOT = XIN(4)
      RAD = XIN(5)
      TNKTMP = XIN(6)
C INITIALIZE TEST VALUES TO 0
C   IF(INFO(7) .GT. 0.0) GO TO 10
      ITOUT = 0
      ITSET = 0
      IRAD = 0
      IFLOW = 0
      I = 0
      IRF = 0
C 10 CONTINUE
C TEST VALUES OF VARIABLES
      IF(TOUTDA .LE. TSETDA) ITOUT = 1
      IF(RAD .LT. RTEST) IRAD = 1
      I = ITOUT*IRAD
C LOW SET TEMPERATURE
      IF(I .EQ. 0) GO TO 30
      TSET = TSETDA
      IVALVE = 1
      GO TO 40
      30 CONTINUE
      TSET = TNKTMP

```



```
        IVALVE = 0
C SET OUTPUTS
  40 CONTINUE
      OUT(1) = TSET
      OUT(2) = IVALVE
      OUT(3) = ITOUT
      OUT(4) = ITSET
      OUT(5) = IRAD
      OUT(6) = IFLOW
      OUT(7) = IRF
      OUT(8) = I
      RETURN
      END
```

;

```

      SUBROUTINE TYPE38(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C THIS SURROUTINE MODELS A TEMPERATURE SENSITIVE SOURCE
C SUPPLYING ENERGY TO A HEAT EXCHANGER
      DIMENSION PAR(8),XIN(4),OUT(6),INFO(10)
      REAL MCIN,MDATA,MDMIN
      IF(INFO(7) .GT. -1) GO TO 5
      NI = 4
      NP = 8
      ND = 0
      INFO(6) = 6
      CALL TYPECK(1,INFO,NI,NP,ND)
C SET PARAMETERS
      A1 = PAR(1)
      A2 = PAR(2)
      B1 = PAR(3)
      B2 = PAR(4)
      C1 = PAR(5)
      C2 = PAR(6)
      THAX = PAR(7)
      MDMIN = PAR(8)
      5 CONTINUE
C READ INPUTS
      TCIN = XIN(1)
      MCIN = XIN(2)
      QDATA = XIN(3)
      MDATA = XIN(4)
C CHECK FOR NO FLOW
      IF(MCIN .LT. 0.001) GO TO 20
      IF(MDATA .LT. 0.001) GO TO 20
C CALCULATE Q-WHR
      IF(MCIN .GT. MDMIN) GO TO 7
      IF(MDATA .GT. MDMIN) GO TO 7
      FEF = 1.0
      GO TO 15
      7 CONTINUE
C CALCULATE F-EFFECTIVENESS
      X = MCIN/MDATA
      IF(X .GT. 1.3) GO TO 10
      FEF = A1 * X + A2
      GO TO 15
      10 CONTINUE
      FEF = B1 * X + B2
      15 CONTINUE
C CALCULATE F-DELTA T
      IF(TCIN .GT. 55.0) GO TO 17
      FDT = 1.0
      GO TO 18
      17 CONTINUE
      FDT = EXP(C1*(TCIN-C2))

```

```
18 CONTINUE
C CALCULATE Q
  Q = QDATA*FEF*FDT
  TCOUT = TCIN + Q / MCIN
  IF(TCOUT .GT. TMAX) TCOUT = TMAX
  GO TO 30
C NO FLOW CONDITION
20 CONTINUE
  TCOUT = TCIN
  MCIN = MCIN
  Q = 0.0
  FEF = 0.0
  FDT = 0.0
C SET OUTPUTS
30 CONTINUE
  OUT(1) = TCOUT
  OUT(2) = MCIN
  OUT(3) = Q
  OUT(4) = FEF
  OUT(5) = FDT
  OUT(6) = QDATA
  RETURN
  END
```

```

C
C      SUBROUTINE TYPE30(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C
C      THIS SUBROUTINE SIMULATES A WASTE HEAT RECOVERY SYSTEM MADE UP OF
C      N SENSIBLE HEAT EXCHANGERS CONNECTED IN A SERIES LOOP WHICH
C      INCLUDES A CONSTANT VOLUME PUMP WITH AN ON-OFF PUMP CONTROLLER.
C
C      THE FIRST HEAT EXCHANGER DESCRIBED IS THE "MAIN" HEAT EXCHANGER
C      WHICH TRANSFERS THE ENERGY COLLECTED BY THE WHR LOOP TO ANOTHER
C      FLOW STREAM.
C
C      EACH HEAT EXCHANGER IN THE LOOP IS SIMULATED IN THE ORDER SPECIFIED
C      USING THE HEAT EXCHANGER MODEL SPECIFIED BY THE MODE PARAMETER.
C      MODES 1,2,3, AND 4 SIGNIFY PARALLEL, COUNTERFLOW, CROSS FLOW, AND
C      CONSTANT EFFECTIVENESS MODELS RESPECTIVELY. FOR MODE 4, THE HEAT
C      EXCHANGER EFFECTIVENESS MUST BE SUPPLIED AS A PARAMETER.
C
C      VARIABLE NAMES
C      UA      - OVERALL TRANSFER COEFF PER UNIT TEMP DIFFERENCE
C      CPH     - SPECIFIC HEAT OF HOT SIDE FLUID
C      CPC     - SPECIFIC HEAT OF COLD SIDE FLUID
C      THI     - HOT SIDE INLET TEMP
C      FLWH    - HOT SIDE FLOW RATE
C      TCI     - COLD SIDE INLET TEMP
C      FLWC    - COLD SIDE FLOW RATE
C      DTMIN   - IF GREATER THAN 0.0, THIS IS THE MINIMUM DELTA-T BETWEEN
C                THI AND TCI FOR HX OPERATION. BELOW THIS VALUE THE HX IS
C                BYPASSED OR THE PUMP IN THE SECONDARY LOOP IS TURNED OFF.
C                - IF LESS THAN 0.0, HX IS ALWAYS IN OPERATION.
C
C      LOOP PARAMETER NAMES
C      NHX     - NUMBER OF HX IN LOOP
C      WHRFLW  - ON MASS FLOW RATE IN WHR LOOP
C      CPWHR   - SPECIFIC HEAT OF FLUID IN WHR LOOP
C      NSTICK  - MAXIMUM NUMBER OF ITERATIONS TO CALCULATE T-WHR INTO
C                MAIN HX WITHIN THE ERRTOL, BEFORE THIS TEMPERATURE IS STUCK
C      ERRTOL  - ACCEPTABLE DIFFERENCE BETWEEN VALUES OF T-WHR INTO
C                PRIMARY HX CALCULATED FOR SUCCESSIVE ITERATIONS
C                ( THE USE OF 0.01 IS THE RECOMMENDED )
C      OUTPUT  - BRIEF OUTPUT IF GREATER THAN 0.0
C                - DETAILED OUTPUT IF LESS THAN 0.0
C
C      LOOP CONTROL VARIABLE NAMES
C      STUCK1  - INDICATES THAT NSTICK ITERATIONS HAS BEEN EXCEEDED AND FOR
C                5 ADDITIONAL ITERATIONS THE CONTROLLED SECONDARY HX'S
C                ARE ALLOWED TO TURN OFF ONLY
C      STUCK2  - INDICATES THAT THE 5 ADDITIONAL ITERATIONS AFTER STUCK1
C                FAILED TO PRODUCE CONVERGENCE AND FOR 2 ADDITIONAL
C                ITERATIONS THE MAIN HX'S CHECKED TO SEE IF IT SHOULD BE
C                TURNED OFF

```

```

DIMENSION XIN(24),PAR(54),OUT(20),INFO(10)
DIMENSION XTHD(12),XFLWH(12),XTCO(12),XFLWC(12),XDT(12),
SXEFF(12),XPUMP(12)
INTEGER CONTRL
COMMON /STORE/ NSTORE,IAV,S(200)
COMMON /SIM/ TIME0,TIMEF,DELT
IF (INFO(7).GE.0) GO TO 1
C ***** START * FIRST CALL INITIALIZATION
C FIRST CALL OF SIMULATION
  INFO(6)=20
  INFO(9)=0
  INFO(10) = 4
  NHX = IFIX(PAR(1) + .1)
  NI = NHX * 2
  NP = NHX * 5 + 6
  CALL TYPECK(1,INFO,NI,NP,0)
  DO 300 INX=1,NHX
    NNPAR = 7 + (INX - 1) * 4
    MODE=IFIX(PAR(NNPAR)+.1)
    IF (MODE.GE.1.AND.MODE.LE.4) GO TO 300
    CALL TYPECK(4,INFO,0,0,0)
  RETURN
300 CONTINUE
C INITIALIZE XTHD(1)
  OUT(1) = XIN(1)
C INITIALIZE ERROR COUNTERS
  ISTORE = INFO(10) -1
  S(ISTORE+1) = 0.0
  S(ISTORE+2) = 0.0
  S(ISTORE+3) = 0.0
  S(ISTORE+4) = 0.0
C ***** END * FIRST CALL INITIALIZATION
1 CONTINUE
C ***** START * SIMULATION ERROR COUNTERS
  ISTORE = INFO(10) -1
C COUNT NUMBER OF TIMES NSTIK WAS EXCEEDED AND NUMBER
C OF TIMES THE CONVERGENCE CRITERIA WAS NOT MET
  IF(INFO(7).EQ.0.AND.S(ISTORE+1).GT.0.5)S(ISTORE+3)=S(ISTORE+3)+1.
  IF(INFO(7).EQ.0.AND.S(ISTORE+2).GT.0.5)S(ISTORE+4)=S(ISTORE+4)+1.
C INITIALIZE ERROR CODES ON EACH CALL
  S(ISTORE+1) = 0.0
  S(ISTORE+2) = 0.0
C WRITE NUMBER OF TIMES NSTIK WAS EXCEEDED AND NUMBER
C OF TIMES THE CONVERGENCE CRITERIA WAS NOT MET
  TLTEST=TIMEF-(DELT/2.0)
  IF(TIME .LT. TLTEST) GO TO 590
  IF(INFO(7) .NE. 0) GO TO 590
  IF(XITFRC .LT. 0.05 .AND. ERFRAC .LT. 0.05) GO TO 590
  XNSTEP = (TIMEF - TIME0)/DELT
  XITFRC = (S(ISTORE+3)/XNSTEP)*100.0

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ERFRAC = (S(ISTORE+4)/XNSTEP)*100.0
WRITE(*,520)
WRITE(*,530)
WRITE(*,540)S(ISTORE+3),XITFRD
WRITE(*,550)
WRITE(*,560)S(ISTORE+4),ERFRAC
520 FORMAT('0','WASTE HEAT RECOVERY SUBROUTINE ERROR SUMMARY')
530 FORMAT('0','NUMBER OF TIMES NSTICK WAS EXCEEDED ON',
5' FINAL CALL OF TIME STEP')
540 FORMAT('0','N = ',1PE11.3,' PERCENT OF TIME STEPS = ',F6.3)
550 FORMAT(' ','NUMBER OF TIMES CONVERGENCE CRITERIA WAS NOT MET',
5' ON FINAL CALL OF TIME STEP')
560 FORMAT(' ','N = ',1PE11.3,' PERCENT OF TIME STEPS = ',F6.3)
C ***** END * SIMULATION ERROR COUNT
590 CONTINUE
C ***** START * WHR LOOP *****
C SET WHR LOOP PARAMETERS
NHX = IFIX(PAR(1)+.1)
WHRFLW = PAR(2)
CPWHR = PAR(3)
NSTIK = IFIX(PAR(4)+.1)
ERKTOL = PAR(5)
OUTPUT = PAR(6)
C INITIALIZE HOT SIDE OUTLET CONDITIONS OF HX(1)
C ON EACH CALL OF SUBROUTINE
XTHD(1) = OUT(1)
XFLWH(1) = WHRFLW
XPUMP(1) = 1.0
C CHECK FOR XFLWC(1) = 0.0
XFLWC(1) = XIN(2)
IF(XFLWC(1) .LE. 0.0) XFLWH(1) = 0.0
C INITIALIZE CONTROLS AS NOT STUCK
STUCK1 = 0.0
STUCK2 = 0.0
C INITIALIZE ITERATION COUNTER AND CONVERGENCE TEST TEMP.
2 CONTINUE
T1LAST = XTHD(1)
ITER = 0
C BEGIN EACH ITERATION THROUGH WHR LOOP WITH HX2
3 CONTINUE
IHX = 1
ITER = ITER + 1
C SET INPUTS AND PARAMETERS FOR HX(2) THROUGH HX(N)
4 CONTINUE
IHX = IHX + 1
IF(STUCK1 .LT. 0.5) XPUMP(IHX) = 1.0
C SET HX PARAMETERS FOR HX(N)
NNPAR = 6 + (IHX-1) * 5
MOUE=IFIX(PAR(NNPAR + 1)+.1)
UA=PAR(NNPAR + 2)

```

```

CPH=PAR(NNPAR + 3)
CPC=CPWHR
CONTRL = IFIX((PAR(NNPAR + 4)) + 0.1)
DTMIN=PAR(NNPAR + 5)
C SET HX INPUTS
  NNXIN = (IHX - 1) * 2
C SET HOT SIDE INLET CONDITIONS FOR HX(2) THRU HX(N)
  THI = XIN(NNXIN + 1)
  FLWH = XIN(NNXIN + 2)
C SET COLD SIDE INLET CONDITIONS FOR HX(2)
  IF(IHX .GT. 2) GO TO 5
  TCI = XTHD(1)
  FLWC = XFLWH(1)
  GO TO 6
C SET COLD SIDE INLET CONDITIONS FOR HX(3) THROUGH HX(N)
  5 CONTINUE
  TCI = XTCD(IHX-1)
  FLWC = XFLWC(IHX-1)
  6 CONTINUE
C TEST FOR HX BYPASS
  IF(CONTRL .EQ. 1) GO TO 8
C AFTER NSTICK ITERATIONS CONTROLLED HX'S ONLY ALLOWED TO
C TURN OFF
  IF(XPUMP(IHX) .LT. 0.5 .AND. STUCK1 .GT. 0.5) GO TO 98
  IF(CONTRL .EQ. 2) DELTAT = (THI - TCI)
  IF(CONTRL .EQ. 3) DELTAT = (TCI - THI)
  IF(DELTAT .GE. DTMIN) GO TO 8
  XPUMP(IHX) = 0.0
  GO TO 98
C *****
C BEGINING OF HX MODEL
C *****
  8 CONTINUE
C SET PARAMETERS AND INPUTS PRIOR TO ENTERING HX MODEL
C PARAMETER AND INPUT VARIABLE LIST
  IF (MODE.EQ.4) EFF=UA
C CALCULATE MINIMUM AND MAXIMUM CAPACITY RATES
  CH=CPH*FLWH
  CC=CPC*FLWC
  CMAX = AMAX1(CC,CH)
  CMIN = AMIN1(CC,CH)
  IF (CMIN .LE. 0.) GO TO 98
  IF (MODE.EQ.4) GO TO 40
C MODES 1-3
  RAT=CMIN/CMAX
  UC=UA/CMIN
  EFF=1.0-EXP(-UC)
  IF((CMIN/CMAX) .LE. 0.01) GO TO 38
  GO TO (10,20,30), MODE
C PARALLEL FLOW

```

```

10  EFF=(1.0-EXP(-UC*(1.0+RAT)))/(1.0+RAT)
    GO TO 38
C   COUNTER FLOW
20  CHECK=ABS(1.0-RAT)
    IF(CHECK .LT. .01) GO TO 25
    EFF=(1.0-EXP(-UC*(1.0-RAT)))/(1.0-RAT*EXP(-UC*(1.0-RAT)))
    GO TO 38
25  EFF=UC/(UC+1.0)
    GO TO 38
C   CROSSFLOW, HOT SIDE UNMIXED
30  GAM=1.0-EXP(-UC*RAT)
    EFF=1.0-EXP(-GAM/RAT)
    IF(CMAX .EQ. CH) GO TO 38
    GAM=1.0-EXP(-UC)
    EFF=(1.0-EXP(-GAM*RAT))/RAT
38  THO=THI-EFF*(CHIN/CH)*(THI-TCI)
    TCO=EFF*(CHIN/CC)*(THI-TCI)+TCI
    QT=EFF*CHIN*(THI-TCI)
    GO TO 88
C   MODE 4
40  QMAX=CHIN*(THI-TCI)
    QT=EFF*QMAX
    THO=THI-QT/CH
    TCO=TCI+QT/CC
C   SET OUTPUTS --
C   THO-OUTLET TEMP ON HOT SIDE, TCO-OUTLET TEMP ON COLD SIDE, QT-TOTAL
C   INSTANTANEOUS ENERGY TRANSFER ACROSS EXCHANGER, EFF-EFFECTIVENESS
88  XTHO(IHX)=THO
    XFLWH(IHX)=FLWH
    XTCD(IHX)=TCO
    XFLWC(IHX)=FLWC
    XQT(IHX)=QT
    XEFF(IHX)=EFF
    GO TO 400
C   MINIMUM CAPACITY RATE IS .I.E. 0.
98  XTHO(IHX)=THI
    XFLWH(IHX)=FLWH
    XTCD(IHX)=TCI
    XFLWC(IHX)=FLWC
    XQT(IHX)=0.0
    XEFF(IHX)=0.0
C *****
C END OF HX MODEL
C *****
400 CONTINUE
    IF(IHX .EQ. 1) GO TO 105
    IF(IHX .LT. NHX) GO TO 4
C SET UP INPUTS AND PARAMETERS FOR HX(1)
    IHX = 1
    MODE = IFIX(PAR(6+1)+.1)

```



```

      UA = PAR(6+2)
      CPH = CPWHR
      CPC = PAR(6+3)
      CONTRL = IFIX((PAR(NNPAR + 4)) + 0.1)
      DTMIN = PAR(6+5)
C INPUTS
      THJ=XTCO(NHX)
      FLWH=XFLWC(NHX)
      TCI=XIN(1)
      FLWC=XIN(2)
      GO TO 8
105 CONTINUE
C TEST FOR CONVERGENCE OF LOOP AND MAXIMUM NUMBER OF ITERATIONS
      TEST = ABS( TILAST - XTHO(1) )
      TILAST = XTHO(1)
      IF(ITER .GT. NSTIK) GO TO 99
      IF(TEST .GT. ERRTOL) GO TO 3
C SHOULD WHR LOOP PUMP BE ON?
100 CONTINUE
      IF(XPUMP(1) .LT. 0.5) GO TO 110
      IF(CONTRL .EQ. 1) GO TO 110
      IF(CONTRL .EQ. 2) DELTAT = XIN(1) - XTCO(NHX)
      IF(CONTRL .EQ. 3) DELTAT = XTCO(NHX) - XIN(1)
      IF(DELTAT .GE. DTMIN) GO TO 110
      XFLWH(1) = 0.0
      XPUMP(1) = 1.0
      GO TO 3
99 CONTINUE
      IF(STUCK1 .GT. 0.5) GO TO 700
      STUCK1 = 1.0
      NSTICK = NSTICK + 5
      S(ISTORE+1) = 1.0
      GO TO 3
700 CONTINUE
      IF(STUCK2 .GT. 0.5) GO TO 110
      STUCK2 = 1.0
      NSTIK = NSTIK + 2
      S(ISTORE+2) = 1.0
      GO TO 100
C ***** END * WHR LOOP *****
110 CONTINUE
C ENERGY BALANCE FOR WHR LOOP
      QIN = 0.0
      DO 115 IEBHX = 2,NHX
      QIN = QIN + XQT(IEBHX)
115 CONTINUE
      EBERR = QIN - XQT(1)
C ***** START * SET OUTPUTS *****
C SET OUTPUTS
C SET OUTPUT FOR PRIMARY HX

```

```
OUT(1)=XTHO(1)
OUT(2)=XFLWH(1)
OUT(3)=XTCO(1)
OUT(4)=XFLWC(1)
OUT(5)=XQT(1)
OUT(6)=XEFF(1)
OUT(7) = EBERR
OUT(8) = ITER
IF(OUTPUT ,LE. 0.0) GO TO 150
DO 130 IOHX=2,NHX
IO = 7 + IOHX
OUT(IO) = XQT(IOHX)
130 CONTINUE
GO TO 170
C SET DETAILED OUTPUT
150 CONTINUE
DO 160 IOHX = 2,NHX
NN = (IOHX-2) * 6 + 8
OUT(NN+1)=XTHO(IOHX)
OUT(NN+2)=XFLWH(IOHX)
OUT(NN+3)=XTCO(IOHX)
OUT(NN+4)=XFLWC(IOHX)
OUT(NN+5)=XQT(IOHX)
OUT(NN+6)=XEFF(IOHX)
160 CONTINUE
170 CONTINUE
C ***** END * SET OUTPUTS *****
RETURN
END
```

```

SUBROUTINE TYPE34(TIME,XIN,OUT,T,DTHT,PAR,INFO)
DIMENSION XIN(24),PAR(54),OUT(20),INFO(10)
REAL INHB1S,INHT1S
RAD = (2.0 * 3.1416) / 360.0
C CHECK NODE
MODE = PAR(1)
IF(MODE .EQ. 1) GO TO 1
IF (MODE .EQ. 2) GO TO 500
C MODE 1 - FLAT PLATE COLLECTOR ARRAY
1 CONTINUE
IF (INFO(7) .GE. 0) GO TO 5
C FIRST CALL OF SIMULATION
INFO(6)=20
INFO(9)=0
NP = 8
NI = 12
CALL TYPECK(1,INFO,NI,NP,0)
5 CONTINUE
C SET PARAMETERS
HCL = PAR(2)
WIDCL = PAR(3)
SLCL = PAR(4)*RAD
SEPCL = PAR(5)
XNROW = ABS(PAR(6))
AZCL = PAR(7) * RAD
SLFLD = PAR(8) * RAD
PCHECK = PAR(6)
C SET INPUTS
HT1 = XIN(1)
HB1 = XIN(2)
HD1 = XIN(3)
THETA1 = XIN(4) * RAD
BETA1 = XIN(5) * RAD
W = XIN(6) * RAD
ZEN = XIN(7) * RAD
AZSOL = XIN(8) * RAD
HTHOR = XIN(9)
HDHOR = XIN(10)
HBSLFL = XIN(11)
ALB = XIN(12)
IF(INFO(7) .GE. 0.0) GO TO 30
C CHECK FOR OUT OF RANGE PARAMETERS
IF(SLFLD.GE.0.0 .AND. SLFLD.LE.SLCL .AND.
SSLFLD.LT.1.50) GO TO 7
WRITE(*,6)
6 FORMAT('0',' FIELD SLOPE IS OUT OF RANGE')
CALL TYPECK(4,INFO,NI,NP,0)
7 CONTINUE
IF(SLCL .GE. 0.0 .AND. SLCL .LT. 1.58) GO TO 9

```

```

WRITE(*,8)
8 FORMAT('0',' COLLECTOR SLOPE IS OUT OF RANGE')
CALL TYPECK(4,INFO,NI,NP,0)
9 CONTINUE
C CALCULATE COLLECTER VIEW FACTORS OF SKY AND GROUND
C UNSHADED COLLECTERS
USVFGR=(1.-COS(SLCL))/2.0
USVFSK=(1.+COS(SLCL))/2.0
C SHADED COLLECTERS
SEP=SEPCL/COS(SLFLD)
D=(SEP**2.+HCL**2.-2.*SEP*HCL*COS(SLCL-SLFLD))**0.5
THETA1=ACOS((SEP**2.+0**2.-HCL**2.)/(2.*SEP*D))
IF(SEP .LT. 0.001) THETA1 = 180.0*PI-SLCL
THETA6 = THETA1 - SLFLD
ALF = SLCL-SLFLD
XL5 = SEPCL
XL7 = SEP
XL6 = SEPCL - (HCL * COS(SLCL))
BB = SEPCL * TAN(SLFLD) - HCL * SIN(SLCL)
XL8 = (BB**2. + XL6**2.)**0.5
IF(BB .LE. 0.0) XL6 = XL8
SVFGR1 = ((XL6-XL5) + (XL7-XL8)) / (2.*HCL)
BB = (HCL**2.+SEP**2.-2.*HCL*SEP*COS(180.*PI-ALF))**0.5
SVFGR2 = (HCL+SEP-BB)/(2.*HCL)
SVGR12 = SVFGR1 + SVFGR2
SVFSK = (((HCL + SEP) - D) / (2.*HCL)) - SVFGR1
SVFGR = SVFGR1
C AVERAGE FOR ARRAY
ARVFSK=(SVFSK*(XNR0W-1.0)+USVFSK)/XNR0W
ARVFGR=(SVFGR*(XNR0W-1.0)+USVFGR)/XNR0W
C CALCULATE COLLECTOR ARRAY ANGLES
HH=HCL*COS(SLCL)
SS=SEPCL-HH
TSL=ABS(SLFLD-SLCL)
IF(SS .GE. 0.0 ) GO TO 25
CALL TYPECK(4,INFO,NI,NP,0)
C ERROR INSUFFICIENT COLLECTOR SEPARATION
WRITE(*,27)
27 FORMAT('0','ERROR: INSUFICIENT COLLECTOR ROW SEPARATION')
25 CONTINUE
OUT(7) = D
OUT(8) = THETA1
OUT(9) = SVFGR
OUT(10) = SVFSK
OUT(11) = USVFGR
OUT(12) = BB
OUT(13)=ALF
OUT(14)=ARVFGR
OUT(15)=ARVFSK
OUT(16)=HH

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    OUT(17)=SS
    OUT(19) = SEP
    OUT(20) = THETA6
30 CONTINUE
    D = OUT(7)
    THETA1 = OUT(8)
    RB = OUT(12)
    ALF = OUT(13)
    ARVFCR = OUT(14)
    ARVFSK = OUT(15)
    HH = OUT(16)
    SS = OUT(17)
    SEP = OUT(19)
    THETA6 = OUT(20)
C CALCULATE INCIDENT ANGLE IN PLANE OF COLLECTOR AZIMUTH
    IF (HT1 .LE. 0.0) GO TO 300
    IF(ZEN .GE. 1.570) ZEN = 1.570
    DELAZ = ABS(AZSOL - AZCL)
    SIN1 = COS(DELAZ) * SIN(ZEN)
    COS1 = COS(ZEN)
    IF(COS1 .LT. 0.01 .AND. SIN1 .GE. 0.0) GO TO 40
    IF(COS1 .LT. 0.01 .AND. SIN1 .LT. 0.0) GO TO 41
    ZENAZ = ATAN(SIN1/COS1)
    GO TO 50
40 ZENAZ = 90.0*RAD
    GO TO 50
41 CONTINUE
    ZENAZ = -90.0*RAD
50 CONTINUE
    ALT = 90.0*RAD - ZENAZ
    THETA6 = THETA1 - SLFLD
    IF(ALT .GT. 180.0*RAD-SLCL) GO TO 230
    IF(ALT .GE. THETA6) GO TO 210
C CALCULATE ARRAY BEAM IRRADIATED FRACTION
    IF(SLFLD+ALT .LE. 0.0) GO TO 55
    THETA2 = RAD*180.0 - ALF - (SLFLD + ALT)
    HB = SEP * ((SIN(ALT+SLFLD)) / (SIN(THETA2)))
    IF(HB .GT. HCL) GO TO 210
    GO TO 57
55 CONTINUE
    HB=0.0
57 CONTINUE
    HS = HCL - HB
    XL2 = ABS(SS*TAN(DELAZ))
    IF(XL2 .GE. WIDCL) GO TO 210
C CHECK FOR SLCL = 90.0 DEGREES
    IF(SLCL .GE. 89.99*RAD) GO TO 200
    XL1 = HS * COS(SLCL)
    XL3 = ABS((SS+XL1)*TAN(DELAZ))
C CALCULATE SHADED COLLECTOR FRACTION

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A = HH*WIDCL
IF(XL3 .GE. WIDCL) GO TO 195
AS=(WIDCL-((XL3+XL2)/2.0))*XL1
GO TO 197
195 CONTINUE
ST1 = WIDCL-XL2
ST2 = ABS( ST1*TAN(90.0*RAD-DELAZ))
AS = (ST1*ST2)/2.0
197 CONTINUE
FCLB=1.0-AS/A
FCLBIN = 1.0 -(WIDCL*XL1)/A
GO TO 220
200 CONTINUE
A = HH*WIDCL
AS = (WIDCL-XL2)*XL1
FCLB=1.0-AS/A
FCLBIN = 1.0 - (WIDCL*XL1)/A
GO TO 220
C NO BEAM SHADING
210 CONTINUE
FCLR = 1.0
FCLBIN = 1.0
220 CONTINUE
FHB = (1.0 +FCLB * (XNRW - 1.0)) / XNRW
FHBIN = (1.0 +FCLBIN * (XNRW - 1.0)) / XNRW
GO TO 240
230 CONTINUE
FHR = 0.0
FHBIN = 0.0
240 CONTINUE
HB1S=HB1*FHB
INHB1S=HB1*FHBIN
C GO TO 260
C 250 CONTINUE
C HB1S = HB1
C 260 CONTINUE
C CALCULATE BEAM RADIATION REFLECTED TO COLLECTORS FROM GROUND
C BETWEEN COLLECTOR ROWS
IF(ALT .LT. THETA6) GO TO 270
NA1S = (SIN(SLCL))*HCL + (TAN(SLFLD))*SEPCL
DA1S =(COS(SLCL))*HCL + SEPCL
ANGL15 = 180.*RAD-ATAN(NA1S/DA1S)
IF(ALT .GT. ANGL15) GO TO 274
ANGL14 = 180.0*RAD - SLCL
IF(ALT .GT. ANGL14) GO TO 273
C SHADING OF GROUND BETWEEN COLLECTOR ROWS FROM BEAM
C RADIATION WHEN ALT .LT. 180 - SLCL
ANGL1 = 180.0*RAD - 90.0*RAD - SLCL
IF(ALT .GT. 90.0*RAD + ANGL1) GO TO 269
ANGL2 = ANGL1 + ZENAZ

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ANGL3 = 180.0*RAD - ANGL2 - ALF
GRS = HCL*(SIN(ANGL2))/(SIN(ANGL3))
GRUS = SEP - GRS
GO TO 271
269 CONTINUE
GRUS = SEP
GO TO 271
270 CONTINUE
GRUS = 0.0
271 CONTINUE
C CALCULATE VIEW FACTOR HCL TO GRUS
CC = (HCL**2.0+GRUS**2.0-2.0*HCL*GRUS*COS(180.*RAD-ALF))**.5
VFB1 = (HCL+GRUS-CC)/(2.0*HCL)
GO TO 275
273 CONTINUE
C SHADEING OF GROUND BETWEEN COLECTOR ROWS FROM BEAM
C RADIATION WHEN ALT .GT. 180 - SLCL
ANGL10 = 180.*RAD-90.*RAD-SLCL
ANGL11 = ABS(ZENAZ)-ANGL10
ANGL12 = 180.*RAD-SLCL+SLFLD
ANGL13 = 180.*RAD-ANGL11-ANGL12
EE=HCL*SIN(ANGL12)/SIN(ANGL13)
S = HCL*SIN(ANGL11)/SIN(ANGL13)
VFB1 = ((SEP+EE)-(BB+S))/(2.0*HCL)
IF(S .GT. SEP) VFB1=0.0
IF(VFB1 .LT. 0.0) VFB1=0.0
GO TO 275
274 CONTINUE
VFB1 = 0.0
275 CONTINUE
DFBFC = (VFB1*HBSLFL*ALB*(XNRDOW-1.0))/XNRDOW
C CALCULATE DIFFUSE RADIATION REFLECTED TO COLLECTOR SURFACE
C FROM GROUND BETWEEN COLLECTORS
C CALCULATE VIEW FACTOR SEP TO SKY
VFD1 = (BB+D-(2.0*HCL))/(2.0*SEP)
C CALCULATE VIEW FACTOR HCL TO SEP
VFD2 = (HCL+SEP-BB)/(2.0*HCL)
DFBFC = (VFD1*VFD2*HDHOR*ALB*(XNRDOW-1.0))/XNRDOW
HGRBCL = DFBFC + DFBFC
OUT(18) = HGRBCL
C CALCULATE ARRAY DIFFUSE IRRADIATED FRACTION
HD1S = HDHOR*ARVFSK + HTHOR*ARVFGGR*ALB + HGRBCL
C CALCULATE HT ON SHADED ARRAY
HT1S=HD1S+HR1S
INHT1S=HD1S+INHR1S
GO TO 400
300 CONTINUE
OUT(1) = XIN(1)
OUT(2) = XIN(2)
OUT(3) = XIN(3)

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      OUT(4) = XIN(1)
      OUT(5) = XIN(2)
      OUT(6) = XIN(3)
      RETURN
400 CONTINUE
      OUT(1) = HT1S
      OUT(2) = HB1S
      OUT(3) = HD1S
      OUT(4) = INHT1S
      OUT(5) = INHB1S
      OUT(6) = HD1S
      IF(PCHECK .LT. 0.0) GO TO 806
      WRITE(*,800)
800 FORMAT('0',' HH , SS , DELAZ , COS1 , SIN1 , ZENAZ ')
      WRITE(*,*)HH,SS,DELAZ,COS1,SIN1,ZENAZ
      WRITE(*,801)
801 FORMAT('0',' ALT , THETA2 , HR , HS , XL2')
      WRITE(*,*)ALT,THETA2,HR,HS,XL2
      WRITE(*,802)
802 FORMAT('0',' XL1 , XL3 , A , AS , ST1')
      WRITE(*,*)XL1,XL3,A,AS,ST1
      WRITE(*,803)
803 FORMAT('0',' ST2 , FCLB , FCLBIN , FHB , FHBIN ')
      WRITE(*,*)ST2,FCLB,FCLBIN,FHB,FHBIN
      WRITE(*,804)
804 FORMAT('0',' CC VFB1 DFBC VFD1 VFD2 DFDBC HGRBCL')
      WRITE(*,*)CC,VFB1,DFBC,VFD1,VFD2,DFDBC,HGRBCL
      WRITE(*,805)
805 FORMAT('0',' ANGL10 ANGL11 ANGL12 ANGL13 ANGL14 EE S ')
      WRITE(*,*)ANGL10,ANGL11,ANGL12,ANGL13,ANGL14,EE,S
806 CONTINUE
      RETURN
500 CONTINUE
C MODE 2 - LINEAR CONCENTRATING COLLECTOR ARRAY
      IF (INFO(7) .GE. 0) GO TO S10
C PARAMETER DEFINITIONS
C ASFLD = SLOPE OF CONCENTRATOR AXIS OF ROTATION
C AZFLD = AZIMUTH OF CONCENTRATOR AXIS
C WIDCL = WITH OF CONCENTRATOR APPERTURE
C XNROW = NUMBER OF ROWS OF CONCENTRATORS IN ARRAYU
C
C INPUT DEFINITIONS
C HM1 = UNSHADED BEAM RADIATION FALLING ON APPERTURE
C THETA1 = SLOPE OF APPERTURE SURFACE
C AZSOL = SOLAR AZIMUTH
C
C OUTPUT DEFINITIONS
C HB1S= SHADED BEAM RADIATION FALLING ON ARRAY APPERTURE
C FUSARR = FRACTION OF UNSHADED ARRAY APPERTURE AREA
C COSETA = COSINE OF PSEUDO INCIDENCE ANGLE

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C XNSEP = SEPARATION OF AXIES PROJECTED INTO PLANE OF APPERTURE
C FIRST CALL OF SIMULATION
  INFO(6)=5
  INFO(9)=0
  NP = 7
  NI = 3
  CALL TYPECK(1,INFO,NI,NP,0)
  RAD = (2.0 * 3.1416) / 360.0
510 CONTINUE
C SET PARAMETERS
  SLFLD = PAR(2) * RAD
  AZFLD = PAR(3) * RAD
  MODEAX = INT(PAR(4) + 0.1)
  SEPAX = PAR(5)
  WIDCL = PAR(6)
  XNROW = PAR(7)
C SET INPUTS
  HB1 = XIN(1)
  THETA1 = XIN(2) * RAD
  AZSOL = XIN(3)
C CHECK FOR NO RADIATION
  IF(HB1 .GT. 0.00001) GO TO 520
  HB1S = HB1
  FUSARR = 1.0
  XIHB1S = HB1
  XIFUSA = 1.0
  COSETA = 1.0
  XNSEP = SEPAX
  GO TO 550
520 CONTINUE
C CHECK FOR AXIS MODE
  IF(MODEAX .NE. 1) GO TO 524
  SLAX = SLFLD
  AZAX = AZFLD
  GO TO 528
524 CONTINUE
  IF(MODEAX .NE. 2) GO TO 526
  SLAX = 0.0
  AZAX = AZFLD - 0.7854
  GO TO 528
526 CONTINUE
  CALL TYPECK(4,INFO,NI,NP,0)
  WRITE(*,527)
527 FORMAT('0','ERROR: NONEXISTANT MODE SPECIFIED')
  GO TO 550
528 CONTINUE
C CALCULATE SHADING
  IF(SLAX .GT. 1.56 .AND. SLAX .LT. 1.58) GO TO 530
  COSETA = COS(THETA1) / COS(SLAX)
  GO TO 540

```

```

530 COSETA = COS(AZSOL-AZAX)
540 CONTINUE
C CHECK FOR AXIS MODE
  IF(MODEAX .EQ. 2) COSETA = COSETA - COS(SLFLD)
C FOR ETA GREATER THAN 90 DEGREES SET ETA = 90 DEGREES
  IF(COSETA .LT. 0.0) COSETA = 0.0
  XNSEP = COSETA * SEPAX
  A = WIDCL - XNSEP
  SFRAC = A / WIDCL
  IF(SFRAC .LE. 0.0) SFRAC = 0.0
  IF(SFRAC .GE. 1.0) SFRAC = 1.0
  FUSARR = (1.0+(XNROW-1.0)*(1.0-SFRAC))/XNROW
  HR1S = HB1*FUSARR
  XIFUSA = 1.0 - SFRAC
  XIHR1S = XIFUSA * HB1
550 CONTINUE
C SET OUTPUTS
  OUT(1) = HR1S
  OUT(2) = FUSARR
  OUT(3) = COSETA
  OUT(4) = XNSEP
  OUT(5) = A
  OUT(6) = SFRAC
  OUT(7) = SLAX
  OUT(8) = AZAX
  OUT(9) = HB1
  OUT(10) = THETA1
  OUT(11) = AZSOL
  OUT(12) = MODE
  OUT(13) = SLFLD
  OUT(14) = AZFLD
  OUT(15) = MODEAX
  OUT(16) = SEPAX
  OUT(17) = WIDCL
  OUT(18) = XNROW
  OUT(19) = XIHR1S
  OUT(20) = XIFUSA
  RETURN
  END

```

APPENDIX C  
TRNSYS DECKS

- I. Solar System Evaluation
  - Variable volume tank system with the solar heat exchanger after the waste heat recovery heat exchanger in series
  - Constant volume tank system with collector array shading
- II. Waste Heat Recovery Only System Evaluation
  - Existing system
  - Modified system 1

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*****
*
* OSCAR MAYER SIMULATION STUDY
*
* LINEAR CONCENTRATING COLLECTORS
* SERIES SYSTEM, SOLAR HX BEFORE WHR HX IN SERIES
* COMBINED STORAGE FOR SOLAR SYSTEM AND WHRS
*****
SIMULATION 1.0 8760.0 0.25
TOL -.1 -.1
LIM 25 40 23
CONSTANTS 48
* COLLECTOR
LAT = 41.3 SHF = -5.9 SER = 24.0
DCL = 61.56 CCL = 0.90 CAZ = -1000.0 SLOPE = 0.0
ACL = 40320.0 / SER MCL = 1131.0 * DCL
HCL = DCL * 1131.0 / 16.0 DOD = HCL DTC = 20.0 SET = 185.0
* PIPING
* --S = SUPPLY, --R = RETURN
* LA- = OUTSIDE
* LB = BURIED
* LR = INSIDE
LAS = 940.0 LAR = 220.0 LRM = 280.0
LBB = 450.0
UAS = LAS * 0.21 UAR = LAR * 0.21 URM = LRM * 0.21
UBB = LBB * 0.21
CAP = CCL * DCL * 0.0513 + 0.83
*CAP = 0.0
CAS = LAS * CAP CAR = LAR * CAP CRM = LRM * CAP
CBB = LBB * CAP
*PUMP TO TANK
MTP = 200000.0 TTP = 0.0 DMP = 80000.0 LTP = 5.0
* TANK
SVL = 15775.0 DTK = 62.4 CTK = 1.0
DIA = 21.0 IZT = 157.0
* HEAT EXCHANGER
MHX = 2.0 * MCL
* GENERAL
TRM = 60.0 TZA = 32.0 STK = 5 SKC = 1 TII = 0.0 DTP = 0.5
DPT = 0.5 SIP = 0.0 FTP = 24.0 SSP = -1 PTF = 24.0 TMS = 55.0
UNIT 1 TYPE 9 LOAD DATA READER
PARAMETER 4
10 1 9 4
(F10.4,6(1PE11.3)/3(1PE11.3))
UNIT 2 TYPE 9 DATA READER
PAR 13
3 1 1 0.08811 0.0 2 0.08811 0.0 3 0.18 32.0 -5 5
(T20,F4.0,T25,F4.0,T30,F4.0)
*(T17,F2.0,T20,F4.0,T31,F5.1)

```

UNIT 3 TYPE 16 RADIATION PROCESSOR  
 PARAMETERS 6  
 5 1 LAT 428, SHF -1  
 INPUTS 7  
 2,2 2,1 2,19 2,20 0,0 0,0 0,0  
 0.0 0.0 1.0 2.0 .2 SLOPE CAZ  
 UNIT 36 TYPE 15 DUMMY LOAD SELECTOR  
 PAR 18  
 0 -4 0 -4 0 -4 0 -4 0 -4 0 -4 0 -4  
 INPUTS 9  
 1,2 1,3 1,4 1,5 1,6 1,7 1,8 1,9 1,10  
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
 UNIT 37 TYPE 15 CHANGE LOAD GPM TO LBM. PER HR  
 PAR 8  
 0.0 -1 8.34 1 -1 60.0 1 -4  
 INPUTS 1  
 36,2  
 0.0  
 UNIT 39 TYPE 15 Q WASTE HEAT RECOVERY  
 PAR 13  
 0 0 4 8 -13 1 -4 -14 -12 4 -13 1 -4  
 INPUTS 4  
 36,1 0,0 37,1 36,3  
 160.0 TMS 0.0 145.0  
 UNIT 16 TYPE 14 ANNUAL VARIATION IN T TO TANK  
 PAR 40  
 0.0 150.0 744.0 150.0  
 744.0 155.0 1416.0 155.0  
 1416.0 177.0 2160.0 177.0  
 2160.0 186.0 2880.0 186.0  
 2880.0 192.0 5088.0 192.0  
 5088.0 188.0 5832.0 188.0  
 5832.0 188.0 6552.0 188.0  
 6552.0 177.0 7296.0 177.0  
 7296.0 165.0 8016.0 165.0  
 8016.0 160.0 8761.0 160.0  
 \*3624.0 189.0 4344.0 189.0  
 \*4344.0 190.0 5088.0 190.0  
 UNIT 18 TYPE 23 LOW TEMPERATURE BY PASS  
 PAR 6  
 115.0 185.0 115.5 0.001 100.0 30  
 INPUTS 6  
 36,1 37,1 36,3 5,2 3,7 16,1  
 185.0 1000.0 185.0 1000.0 0.0 145.0  
 \*TRACE 2.0,2.5  
 UNIT 5 TYPE 29 VVPUMP TO TANK  
 PAR 6  
 18 0 LTP MTP DMP TTP  
 INPUTS 6  
 0,0 0,0 7,1 7,2 18,1 0,0

TMS 500.0 TRM 500.0 SET 1.0  
\*TRACE 135,138  
\*\* COLLECTOR LOOP PUMP  
UNIT 14 TYPE 33 COLLECTOR LOOP PUMP - VARIABLE VOLUME  
PAR 6  
18 0 HCL MCL DDD DTC  
INPUTS 6  
22,1 22,2 6,1 6,2 18,1 0,0  
TRM 0.0 TRM 0.0 SET 1.0  
\*TRACE 135,138  
UNIT 6 TYPE 1 LINEAR CONCENTRATING COLLECTORS  
PARAMETERS 9  
5 ACL CCL -10 18 SER 11 19 60.0  
INPUTS 6  
14,1 14,2 2,3 3,7 3,7 3,9  
TZA 0.0 0.0 0.0 0.0 0.0  
UNIT 8 TYPE 13 PRESSURE RELIEF VALVE  
PARAMETERS 2  
500.0 CCL  
INPUTS 3  
6,1 6,2 6,1  
TZA 0.0 TZA  
UNIT 10 TYPE 31 RETURN PIPE OUTSIDE  
PARAMETERS 4  
UAR CAR CCL TZA  
INPUTS 3  
8,1 8,2 2,3  
TZA 0.0 TZA  
UNIT 24 TYPE 31 RETURN PIPE BURRIED  
PARAMETERS 4  
UBB CBB CCL TZA  
INPUTS 3  
10,1 10,2 0,0  
TZA 0.0 50.0  
UNIT 11 TYPE 31 RETURN PIPE INSIDE  
PARAMETERS 4  
URM CRM CCL TRM  
INPUTS 3  
24,1 24,2 0,0  
TRM 0.0 TRM  
UNIT 12 TYPE 5 COLLECTOR HEAT EXCHANGER  
PAR 4  
4 0.8 CCL CTK  
INPUTS 4  
11,1 11,2 5,1 5,2  
TRM 0.0 TZI 0.0  
\*TRACE 135,138  
UNIT 7 TYPE 38 WHK HX -- TEPERATURE SENSITIVE  
PAR 8  
0.8 0.2 0.014 1.2218 -0.0048 55.0 2000.0 0.0

INPUTS 4  
 12,3 12,4 39,1 37,1  
 TMS 100.0 1000.0 100.0  
 \*TRACE 135,138  
 UNIT 4 TYPE 11 FLOW DIVERTER  
 PAR 1  
 2  
 INPUTS 3  
 7,1 7,2 18,2  
 185.0 1000.0 0.0  
 \*TRACE 2.0,2.5  
 UNIT 20 TYPE 15  
 PAR 17  
 -13 -4 -14 -12 4 8 -4 -12 -12 -14 4 8 -3 -11 -4 4 -4  
 INPUTS 4  
 4,3 4,4 36,3 37,1  
 0.0 0.0 145.0 1000.0  
 UNIT 13 TYPE 2 COLLECTOR LOOP CONTROLLER  
 PAR 3  
 SKC 6 3  
 INPUTS 3  
 6,1 0,0 13,1  
 TZA SET 0.0  
 UNIT 21 TYPE 31 SUPPLY PIPE INSIDE  
 PAR 4  
 URM CRM CCL TRM  
 INPUTS 3  
 12,1 12,2 0,0  
 TRM 0.0 TRM  
 UNIT 25 TYPE 31 RETURN PIPE BURRIED  
 PARAMETERS 4  
 URB CRB CCL TZA  
 INPUTS 3  
 21,1 21,2 0,0  
 TZA 0.0 50.0  
 UNIT 22 TYPE 31 SUPPLY PIPE OUTSIDE  
 PAR 4  
 UAS CAS CCL TZA  
 INPUTS 3  
 25,1 25,2 2,3  
 TZA 0.0 TZA  
 UNIT 26 TYPE 15 ADD PIPE LOSSES  
 PAR 12  
 0 0 0 3 3 -4  
 0 0 0 3 3 -4  
 INPUTS 6  
 10,4 24,4 25,4 10,3 24,3 25,3  
 0.0 0.0 0.0 0.0 0.0 0.0  
 UNIT 23 TYPE 15 ADD PIPE DELTA E AND LOSSES  
 PAR 29

```

0 0 0 0 3 3 3 -4
0 0 0 0 3 3 3 -4
-15 8 -16 8 -17 8 -18 3 3 3 -19 1 -4
INPUTS 9
26,1 11,4 21,4 22,4 26,2 11,3 21,3 22,3 13,1
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
UNIT 17 TYPE 32 VV TANK
PAR 12
SVL DIA 0.0945 0.0945 668.0
15099.0 CTK DTK TMS SET 436800.0 10000.0
INPUTS 4
4,1 4,2 19,4 2,3
TMS 100.0 100.0 TZA
*TRACE 135,138
UNIT 19 TYPE 34 TEMPERING VALVE
PAR 2
18 1
INPUTS 7
17,1 17,2 0,0 19,6 36,3 20,2 17,7
TZT 1.0 TMS 1.0 1.0 1.0 1.0
*TRACE 135,138
UNIT 34 TYPE 11 MIXING T-PIECE
PAR 1
1
INPUTS 4
20,4 20,5 19,1 19,2
145.0 1000.0 100.0 100.0
*TRACE 2.0,2.5
UNIT 46 TYPE 15 AUXILIARY STEAM HEAT + AV TEMPS + QU S
PAR 39
0 0 4 8 -13 1 -4
-14 -1 0.001 9 -15 1 -4 -16 -14 -1 0.001 9 1 -4 -17
-18 3 -19 3 -4 -14 -1 0.001 9 -20 1 -4 -14 -1 0.001 9 -4
INPUTS 10
36,3 34,1 34,2 14,3 22,1 8,1 0,0 0,0 0,0 7,1
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
UNIT 15 TYPE 15 PUMP ON TIME + TOUT WHR
PAR 22
-12 -1 0.001 9 -3
-13 -1 0.001 9 -3 1 -21
-11 -31 1 -4 -14 -31 1 -4 -31 -4
INPUTS 4
7,1 14,3 5,3 12,3
1.0 1.0 1.0 1.0
*****
*
* RESULTS
*
*****
*
```



## \* COLLECTOR RESULTS

\*

## UNIT 47 TYPE 28 COLLECTOR RESULTS

PAR 35

SSP TII 8760.0 -1

0 -1 ACL -1 SER 1 1 -3

0.0 -3 -7 2 -4

-13 -4 -14 -4 -15 -4

-16 -14 2 -4 -17 -14 2 -4 -18 -4 -19 -4

INPUTS 9

3,6 6,3 8,3 46,6 12,5 46,2 46,3 23,3 15,2

LABELS 10

HTAC QU COLEFF QBOIL CLPUMP QHX TAVCLI TAVCLO

OFFLOS HRFLOW

## UNIT 9 TYPE 27 COLLECTOR TEMPERATURE HISTOGRAMS

PAR 36

1 -1 -1 0.0 8760.0

50.0 250.0 20 50.0 510.0 23 50.0 250.0 20 0.0 1.0 20

0.0 1.0 20 50.0 250.0 20 0.0 900000.0 24

50.0 250.0 20 0.0 1.0 20 50.0 250.0 20 -5

INPUTS 10

46,2 46,3 17,1 14,3 5,3 4,1 17,11 15,3 5,3 4,3

TINCL TClOUT TTANK HMDCLX CMDCLX TINTNK MASINK

CTICLX MDWHR TDIVER

## UNIT 35 TYPE 27 COLLECTOR TEMPERATURE HISTOGRAMS

PAR 36

1 8760.0 8760.0 0.0 8760.0

50.0 250.0 20 50.0 510.0 23 50.0 250.0 20 0.0 1.0 20

0.0 1.0 20 50.0 250.0 20 0.0 900000.0 24

50.0 250.0 20 0.0 1.0 20 50.0 250.0 20 -5

INPUTS 10

46,2 46,3 17,1 14,3 5,3 4,1 17,11 15,3 5,3 4,3

TINCL TClOUT TTANK HMDCLX CMDCLX TINTNK MASINK

CTICLX MDWHR TDIVER

\*

## \* PIPING LOSSES

\*

## UNIT 48 TYPE 28 PIPING LOSSES

PAR 28

SSP TII 8760.0 -1

0 -3 0 -3 0 -3 0 -3 0 -3 3 3 3 3 3 -4

0 -4 0 -4 0 -4

INPUTS 9

10,3 24,3 11,3 21,3 25,3 22,3 37,1 39,1 39,2

LABELS 10

RPOLOS RPBLOS RPILOS SPILOS SPBLOS SPOLOS TOTLOS

MLD QWHNTS QLD

\*

## \* TANK RESULTS

\*

```

UNIT 49 TYPE 28 TANK RESULTS
PAR 27
SSP TII 8760 -1 3
0 -4 0 -4 0 -4 0 -4 0 -4 0 -4
-17 -4 -18 -2 2 -4
-19 -4 -20 -4
INPUTS 10
23,2 17,6 17,17 17,15 17,5 17,14 17,4 17,1 17,3 17,2
LABELS 10
DEP DETK DMTNK QOUT QLOSS QIN QDUMP TAVIKH MASSIN MASSOUT
CHECK 0.10 6 -2 -4 -5
CHECK 0.10 9 -10 -3
*XXX TYPE 25 PRINTER
*PAR 4
*0.25 134.0 140.0 -5
*INPUTS 10
*5,1 5,2 5,3 5,4 7,1 7,2 12,1 12,2 12,3 12,4
*TEMP MASSP
*BETA GAMMA TXWHR MXWHR CLXTH CLXMH CLXTC CLXMC
*XXX TYPE 25 PRINTER
*PAR 4
*1 0.0 168.0 -5
*INPUTS 10
*18,1 18,2 18,3 18,4 18,5 18,6 18,7 18,8
*17,1 17,2
*ITSET IVALVE ITOUT ITSET IRAD IFLOW IRF I
*ITOUTIK MOUTIK
**INPUTS 10
*17,1 17,2 17,3 17,4 17,5 17,6 17,7 17,8 17,9 17,10
*ITAV MOUT MIN QDUMP QLOSS DE LEVEL TFST MFST IFIN
*UNIT 38 TYPE 25 PRINTER
*PAR 4
*1 0.0 168.0 -5
*INPUTS 10
*12,3 12,4 4,1 4,2 4,3 4,4 36,3 37,1 20,1 20,2
*ITOUTHX MOUTHX ITOTK MTOTK TBYP MBYP TLD MLD
*ITLDEFF MLDEFF
*UNIT 48 TYPE 25 PRINTER
*PAR 4
*1 0.0 168.0 -5
*INPUTS 10
*36,3 37,1 4,3 4,4 19,5 19,6 19,3 19,4 34,1 34,2
*ITLD MLD TBYP MBYP TCLD MCLD THOT MHOT ITOLD MTOLD
*INPUTS 6
*17,11 17,12 17,13 17,14 17,15 17,16
*ITFIN DELTA VFTST QTKIN QTKOUT ETKAV
*UNIT 17TYPE 25 PRINTER
*PAR 4
*1 0.0 168.0 -5
*INPUTS 9

```

```

*19,1 19,2 19,3 19,4 19,5 19,6 19,7 36,3 37,1
*TOUT MOUT IH MH TC MC GAMMA TSET MLD
*UNIT 17X TYPE 25 PRINTER
*PAR 4
*1 5040.0 5712.0 -5
*INPUTS 7
*15,3 12,5 39,1 7,3 46,1 3,6 6,3
*TTANK QHX QWHR QBOILT QAUX HTAC QU
*UNIT 32 TYPE 26 PLOTTER
*PAR 4
*1 5040.0 5376.0 -5
*INPUTS 5
*15,3 12,5 39,1 7,3 46,1
*TTANK QHX QWHR QBOILT QAUX
*
* LOAD RESULTS
*
UNIT 50 TYPE 28 LOAD RESULTS
PAR 36
SSP TII 8760 -1
0 -3 0 -3 3 0 -3 3 -3 -22 -11 -32 2 -4 -12 -32 2 -4
-13 -32 2 -4
-14 -16 2 -4 -15 -16 2 -4 -17 -4
INPUTS 7
46,1 12,5 7,3 15,3 15,4 15,5 3,7
LABELS 10
QAUX QSOL QWHR QLOAD AUXFRC SOLFRC WHRFRC ZTCXIN
ZTXCOT HTBEAM
*UNIT 45 TYPE 28 RESULTS
*PAR 26
*SSP TII 8760 -1
*0 -4 0 -4 0 -4 0 -4 0 -4 0 -2 2 -4
*0 -4 0 -4 0 -4 0 -4
*INPUTS 10
*37,1 19,4 19,6 20,5 17,2 2,2 12,4 20,2 34,2 20,3
*LABELS 10
*MLD HOTMLD CLDMLD WRMLD TKHOTH HGLOBE
*NWHRCL MLDEFF HTOLD MEXCES
*CHECK 0.10 1 -5 -3 -4
*CHECK 0.02 2 -5
END
;
```

```

*****
*
* OSCAR MAYER SIMULATION STUDY
* SYSTEM CVTANK E-W AXIS
* LINEAR CONCENTRATING COLLECTORS
* COMBINED STORAGE FOR SOLAR SYSTEM AND WHRS
* TEMPERATURE SENSITIVE WHR + BYPASS
* PLUS COLLECTOR ARRAY SHADING
*****
SIMULATION 1.0 8760.0 0.125
TOL -.1 -.1
LIM 40 50 39
CONSTANTS 44
* COLLECTOR
LAT = 41.3 SHF = 0.0 SER = 24
DCL = 61.56 CCL = 0.90 CAZ = 90.0 SLOPE = 0.0
ACL = 40320.0 / SER MCL = 1131.0 * DCL
MODEAX = 1.0 SEPAX = 20.0 WIDCL = 7.4 XNR0W = 16
* PIPING
* --S = SUPPLY, --R = RETURN
* LA- = OUTSIDE
* LB = BURRIED
* LR = INSIDE
LAS = 940.0 LAR = 220.0 LRM = 280.0
LBB = 450.0
UAS = LAS * 0.21 UAR = LAR * 0.21 URM = LRM * 0.21
UBB = LBB * 0.21
CAP = CCL * DCL * 0.0513 + 0.83
*CAP = 0.0
CAS = LAS * CAP CAR = LAR * CAP CRM = LRM * CAP
CBB = LBB * CAP
* TANK
SVL = 15775.0 DTK = 62.4 CTK = 1.0
SHT = 45.55 IZT = 137.0
* HEAT EXCHANGER
MHX = 2.0 * MCL
* GENERAL
TRM = 60.0 IZA = 32.0 STK = 5 SKC = 1 TII = 0.0 ITP = 0.5
DPT = 0.5 SYP = 0.0 FTP = 24.0 SSP = -1 PTF = 24.0 TMS = 55.0
UNIT 1 TYPE 9 LOAD DATA READER
PARAMETER 4
10 1 9 4
(F10.4,6(1PE11.3)/3(1PE11.3))
UNIT 2 TYPE 9 DATA READER
PAR 13
3 1 1 0.08811 0.0 2 0.08811 0.0 3 0.18 32.0 -5 5
(T20,F4.0,T25,F4.0,I30,F4.0)
*(T17,F2.0,T20,F4.0,T31,F5.1)
UNIT 3 TYPE 16 RADIATION PROCESSOR

```

PARAMETERS 7  
 5 3 1 LAT 428. SHF -1  
 INPUTS 7  
 2,2 2,1 2,19 2,20 0,0 0,0 0,0  
 0.0 0.0 1.0 2.0 .2 SLOPE CAZ  
 UNIT 30 TYPE 34 SHADE  
 PAR 7  
 2 SLOPE CAZ MODEAX SEPAX WJXCL XNROW  
 INPUTS 3  
 3,7 3,10 3,3  
 0.0 0.0 0.0  
 UNIT 36 TYPE 15 DUMMY LOAD SELECTOR  
 PAR 18  
 0 -4 0 -4 0 -4 0 -4 0 -4 0 -4 0 -4  
 INPUTS 9  
 1,2 1,3 1,4 1,5 1,6 1,7 1,8 1,9 1,10  
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
 UNIT 37 TYPE 15 CHANGE LOAD GPM TO LBM. PER HR  
 PAR 8  
 0.0 -1 8.34 1 -1 60.0 1 -4  
 INPUTS 1  
 36,2  
 0.0  
 UNIT 39 TYPE 15 R WASTE HEAT RECOVERY  
 PAR 13  
 0 0 4 8 -13 1 -4 -14 -12 4 -13 1 -4  
 INPUTS 4  
 36,1 0,0 37,1 36,3  
 160.0 TMS 0.0 145.0  
 UNIT 5 TYPE 11 MIXING VALVE  
 PAR 2  
 5 5  
 INPUTS 4  
 0,0 37,1 15,3 36,3  
 TMS 0.0 TZT 145.0  
 UNIT 4 TYPE 33 MHR HX -- TEPERATURE SENSITIVE  
 PAR 8  
 0.8 0.2 0.014 1.2218 -0.0048 55.0 2000.0 0.0  
 INPUTS 4  
 5,1 5,2 39,1 37,1  
 TMS 100.0 1000.0 100.0  
 UNIT 6 TYPE 1 LINEAR CONCENTRATING COLLECTORS  
 PARAMETERS 9  
 5 ACL CCL -10 18 SER 11 19 60  
 INPUTS 6  
 22,1 22,2 2,3 30,1 30,1 3,9  
 TZA 0.0 0.0 0.0 0.0 0.0  
 UNIT 8 TYPE 13 PRESSURE RELIEF VALVE  
 PARAMETERS 2  
 500.0 CCL

INPUTS 3  
6,1 6,2 6,1  
TZA 0.0 TZA  
UNIT 10 TYPE 31 RETURN PIPE OUTSIDE  
PARAMETERS 4  
UAR CAR CCL TZA  
INPUTS 3  
8,1 8,2 2,3  
TZA 0.0 TZA  
UNIT 24 TYPE 31 RETURN PIPE BURRIED  
PARAMETERS 4  
UBB CBB CCL TZA  
INPUTS 3  
10,1 10,2 0,0  
TZA 0.0 50.0  
UNIT 11 TYPE 31 RETURN PIPE INSIDE  
PARAMETERS 4  
URM CRM CCL TRM  
INPUTS 3  
24,1 24,2 0,0  
TRM 0.0 TRM  
UNIT 12 TYPE 5 COLLECTOR HEAT EXCHANGER  
PAR 4  
4 0.8 CCL CTK  
INPUTS 4  
11,1 11,2 19,1 19,2  
TRM 0.0 Tzt 0.0  
UNIT 13 TYPE 2 COLLECTOR LOOP CONTROLLER  
PAR 3  
SKC 15 5  
INPUTS 3  
6,1 15,1 13,1  
TZA Tzt 0.0  
UNIT 14 TYPE 3 COLLECTOR LOOP PUMP  
PAR 1  
MCL  
INPUTS 3  
12,1 12,2 13,1  
TRM 0.0 0.0  
UNIT 21 TYPE 31 SUPPLY PIPE INSIDE  
PAR 4  
URM CRM CCL TRM  
INPUTS 3  
14,1 14,2 0,0  
TRM 0.0 TRM  
UNIT 25 TYPE 31 RETURN PIPE BURRIED  
PARAMETERS 4  
UBB CBB CCL TZA  
INPUTS 3  
21,1 21,2 0,0

TZA 0.0 50.0  
UNIT 22 TYPE 31 SUPPLY PIPE OUTSIDE  
PAR 4  
UAS CAS CCL TZA  
INPUTS 3  
25,1 25,2 2,3  
TZA 0.0 TZA  
UNIT 26 TYPE 15 ADD PIPE LOSSES  
PAR 12  
0 0 0 3 3 -4  
0 0 0 3 3 -4  
INPUTS 6  
10,4 24,4 25,4 10,3 24,3 25,3  
0.0 0.0 0.0 0.0 0.0 0.0  
UNIT 23 TYPE 15 ADD PIPE DELTA E AND LOSSES  
PAR 29  
0 0 0 0 3 3 3 -4  
0 0 0 0 3 3 3 -4  
-15 8 -16 8 -17 8 -18 3 3 3 -19 1 -4  
INPUTS 9  
26,1 11,4 21,4 22,4 26,2 11,3 21,3 22,3 13,1  
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
UNIT 17 TYPE 2 TANK LOOP CONTROLLER  
PAR 3  
STK 3.0 1.0  
INPUTS 3  
11,1 15,1 17,1  
TZA IZT 0.0  
UNIT 19 TYPE 3 TANK LOOP PUMP  
PAR 1  
MHX  
INPUTS 3  
15,1 15,2 17,1  
TZT 0.0 0.0  
UNIT 7 TYPE 13 PRESSURE RELIEF VALVE  
PARAMETERS 2  
212.0 CTK  
INPUTS 3  
12,3 12,4 15,3  
TZT 0.0 IZT  
UNIT 15 TYPE 37 STORAGE TANK  
PARAMETERS 7  
SVL SHT CTK DTK 0.0945 1 TZT  
INPUTS 5  
7,1 7,2 4,1 4,2 2,3  
TRM 0.0 TMS 0.0 TZA  
UNIT 40 TYPE 11 TEMPERING FLOW MIXER  
PAR 1  
1  
INPUTS 4

```

15,3 15,4 5,3 5,4
0.0 0.0 0.0 0.0
*UNIT 40 TYPE 25 PRINTER
*PAR 4
*DTP STP FTP -5
*INPUTS 9
*24,1 25,1 26,1 28,1 29,1 30,1 32,1 33,1 30,1
*WKTIN WKMDOT WKTSET SINTIN SIMDOT SITSET SNTIN SNMDOT SNTSET
*UNIT 41 TYPE 25 PRINTER
*PAR 4
*DTP STP FTP -5
*INPUTS 9
*36,1 36,2 36,3 36,4 36,5 36,6 36,7 36,8 36,9
*TIN MDOT TSET NTS NMD NTD NDAYWK NDAYR NWKYR
*XXXX TYPE 27 HISTOGRAM PLOTTER
*PARAMETERS 8
*2 24 24 STP FTH 0 24 24
*INPUTS 3
*36,1 36,2 36,3
*TIN MDOT TSET
*XXXXX TYPE 27 HISTOGRAM PLOTTER
*PARAMETERS 8
*2 24 24 STP FTH 0 24 24
*INPUTS 9
*24,1 25,1 26,1 28,1 29,1 30,1 32,1 33,1 30,1
*WKTIN WKMDOT WKTSET SINTIN SIMDOT SITSET SNTIN SNMDOT SNTSET
*TYPE 2 TYPE 2 HEAT EXCHANGER CONTROLLER
*PARAMETER 3
*STK 5 10
*INPUTS 3
*15,3 36,1 38,1
*0.0 TZT 0.0
UNIT 46 TYPE 15 AUXILIARY STEAM HEAT + AV TEMPS + QUS
PAR 15
0 0 4 8 -13 1 -4
-14 -15 1 -4 -16 -14 1 -4
INPUTS 6
36,3 40,1 40,2 13,1 22,1 8,1
0.0 0.0 0.0 0.0 0.0 0.0
UNIT 33 TYPE 15 ADD QU S
PAR 2
0 -4
INPUTS 1
6,3
0.0
*****
*
* RESULTS
*
*****

```



```

*
* COLLECTOR RESULTS
*
UNIT 47 TYPE 28 COLLECTOR RESULTS
PAR 35
SSP TII 8760.0 -1
0 -1 ACL -1 SER 1 1 -3
0.0 -3 -7 2 -4
-13 -4 -14 -4 -15 -4 -16 -4
-17 -14 2 -4 -18 -14 2 -4 -19 -4
INPUTS 9
3,6 33,1 8,3 13,1 12,5 17,1 46,2 46,3 23,3
LABELS 10
HTAC QU COLEFF QROIL CLPUMP QHX TKPUMP TAVCLI TAVCLO
OFFLOS
UNIT 9 TYPE 27 COLLECTOR TEMPERATURE HISTOGRAMS
PAR 15
1 -1 -1 0.0 8760.0
50.0 250.0 20 50.0 510.0 23 50.0 250.0 20 -5
INPUTS 3
46,2 46,3 15,3
TINCL TCloud TTANK
UNIT 35 TYPE 27 COLLECTOR TEMPERATURE HISTOGRAMS
PAR 15
1 8760.0 8760.0 0.0 8760.0
50.0 250.0 20 50.0 510.0 23 50.0 250.0 20 -5
INPUTS 3
46,2 46,3 15,3
TINCL TCloud TTANK
*
* PIPING LOSSES
*
UNIT 48 TYPE 28 PIPING LOSSES
PAR 28
SSP TII 8760.0 -1
0 -3 0 -3 0 -3 0 -3 0 -3 3 3 3 3 3 -4
0 -4 0 -4 0 -4
INPUTS 9
10,3 24,3 11,3 21,3 25,3 22,3 37,1 39,1 39,2
LABELS 10
RPOLOS RPBLOS RPILOS SPILOS SPRLOS SPOLOS TOTLOS
MLD QWHNTS QLD
*
* TANK RESULTS
*
UNIT 49 TYPE 28 TANK RESULTS
PAR 33
SSP TII 8760 -1 1
0 -4 0 -4 0 -4 0 -4
-15 -4 -16 -2 2 -4

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-17 -4 -18 -4 -19 -4
-20 -1 ACL 1 -1 SER 1 -4
INPUTS 10
15,7 15,6 15,5 12,5 7,3 15,3 5,2 15,4 37,1 30,1
LABELS 10
DETK QOUT QLOSS QHX QBOILT TAVIKH MASSIN MASSOUT MLD SBEAM
CHECK 0,10 4 -1 -2 -3 -5
*UNIT 34 TYPE 25 PRINTER
*PAR 4
*1 5040.0 5712.0 -5
*INPUTS 7
*15,3 12,5 4,3 7,3 46,1 3,6 6,3
*TTANK QHX QWHR QBOILT QAUX HTAC QU
*UNIT 33 TYPE 26 PLOTTER
*PAR 4
*1 5040.0 5376.0 -5
*INPUTS 5
*15,3 12,5 39,1 7,3 46,1
*TTANK QHX QWHR QBOILT QAUX
*
* LOAD RESULTS
*
UNIT 50 TYPE 28 LOAD RESULTS
PAR 36
SSP TII 8760 -1
0 -3 0 -3 3 0 -3 3 -3 -22 -11 -32 2 -4 -12 -32 2 -4
-13 -32 2 -4
-14 -2 2 -4 -15 -2 2 -4 -16 -4
INPUTS 6
46,1 15,6 4,3 4,1 7,1 5,4
LABELS 10
QAUX QTNK QWHR QLOAD AUXFRC TNKFRC WHRFRC TAVIN TAVOUT
MDTEMP
*UNIT 45 TYPE 28 SYSTEM ENERGY BALANCE
*PAR 21
*SSP TII 8760.0 -1 2
*0 0 3 -4 0 -4 0 0 3 -4 0 -18 3 -4 0 -4 0 -4
*INPUTS 9
*23,1 15,7 6,3 8,3 23,2 15,5 15,6 7,3
*LABELS 6
*DETOT QUCL TOTPLS QLOSST QTANK QTRANS
*CHECK ,10 2 -1 -3 -4 -5 -9
END
:

```

```

SIM 0.0 24.0 1
TOL -.001 -0.001
LIK 30 10 29
CONSTANTS 10
TIF = 80.0 TON = 0.0 TOF = 24.0 MD = 123513 DT = 1
HFG = 970.3 CPN = 0.63 TS = 212.0
* CONSTANTS FOR RENDERING VAPOR CONDENSER
DTW = 91.0 ICA = 117.0
UNIT 5 TYPE 9 CARD READER 1
PAR 19
7 1 -3 .5 0 -4 1 0 -5 1 0 -6 1 0 -7 1 0 11 -1
*
*INPUTS: 1-DAY,2-HOUR,
*
*NH3 DESUPERHEATER
*
*INPUTS: 3-MDOT NH3,4-TIN NH3,5-TOUT NH3,
*INPUTS: 6-TIN H2O,7-TOUT H2O
*
UNIT 6 TYPE 9 CARD READER 2
PAR 16
6 1.0 -3.0 0.4165 0 -4 1 0 -5 1 0 -6 1 0 12 -1
*
*INPUTS: 1-DAY,2-HOUR,
*
* INEDIBLE RENDERING VAPOR CONDENSER
*
*INPUTS: 3-MDOT STEAM TOTAL, 4-TOUT STEAM,, 5-TIN H2O, 6-TOUT H2O
*
UNIT 7 TYPE 9 CARD READER 3
PAR 22
8 1 -3 2.046 0 -4 1 0 -5 1 0 -6 1 0 -7 1 0 -8 4.10 0 13 -1
*
*INPUTS          1-DAY, 2- HOUR,
*
* SINGER EXHAUST ECONOMISER
*
*INPUTS: 3-MDOT AIR, 4-TIN H2O,5-TOUT H2O,
*
* SCALD TUB
*
*INPUTS: 6-HOURS OF OPERATION
*
* GLYCOL CONCENTRATOR
*
*INPUTS: 7-HOURS OF USE
*
* PRIMARY HEAT EXCHANGER
*

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*INPUTS: 8-MDOT PROCESS WATER
*
UNIT 8 TYPE 15 CONDENSER MDOTS
PAR 7
0 -3 0 4 -4 -12 -4
INPUTS 2
6,3 0,0
0,0 0,0
*
* OUTPUTS: 1- MDOT STEAM TOTAL, 2- MDOT STEAM WHR CONDENSER
* 3 - MDOT STEAM JET CONDENSER
*
UNIT 12 TYPE 5 HX-1 PRIMARY HX
PAR 4
2 600000.0 1 1
INPUTS 4
26,3 26,4 0,0 7,8
206.0 123513.0 55.0 14085.0
TRACE 8, 9,
UNIT 15 TYPE 5 HX-2 AMMONIA DESUPERHEATER HX
PAR 4
2 42000.0 CPN 1
INPUTS 4
0,0 5,3 12,1 12,2
220.0 0.0 200.0 MD
UNIT 17 TYPE 3 LOOP PUMP
PAR 1
MD
INPUTS 3
15,3 15,4 0,0
TIF MD 1,0
UNIT 20 TYPE 15 HX3 INEDIBLE REDERING STEAM CONDENSER
PAR 62
-1 0,0 -4
-1 TS -13 4 -1 .87 1 -14 -15 -1 1.0 9 1 1
-1 1065.3 2 -3 -21
-1 TS -13 4 -1 .87 1 -14 -15 -1 1.0 9 1 1
-14 2 -13 3 -4 -14 -4
-1 TS -13 4 -1 .87 1 -14 -15 -1 1.0 9 1 1
-4
-15 -31 4 -4
INPUTS 5
0,0 0,0 15,3 17,2 6,3
TS TIF 0,0 0,0 MD
*UNIT 23 TYPE 5 HX-3 INEDIBLE RENDERING CONDENSATE SUBCOOLING
*PAR 4
*4 0.8 1 1
*INPUTS 4
*20,1 20,2 20,3 20,4
*TIF 0.0 TIF MD

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UNIT 26 TYPE 5 HX-4 HOG SINGER ECONOMIZER
PAR 4
4 .55 0.253 1.0
INPUTS 4
0,0 7,3 20,3 20,4
700.0 0.0 TIF 0.0
TRACE 8, 9.
UNIT 45 TYPE 28 SIM SUM
PAR 12
DT TON TOF -1
0 -4 0 -4 0 -4 0 -4
INPUTS 4
12,5 15,5 20,5 26,5
LABELS 4
Q1 Q2 Q3 Q4
*CHECK 0.10 1 - 2 - 3 - 4
UNIT 44 TYPE 28
PAR 12
DT TON TOFF -1
0 -4 0 -4 0 -4 0 -4
INPUTS 4
49,5 49,3 49,7 49,1
LABELS 4
Q1D Q2D Q3D Q4D
*UNIT 46 TYPE 28 SIM SUM
*PAR 21
*DT TON TOF -1 8
*0 -4 0 -4 0 -4 0 -4 0 -4
*0 -4 0 -4 0 -4
*INPUTS 8
*26,3 7,5 12,1 5,6 15,3 6,5 20,3 7,4
*LABELS 8
*TH11 TH11D TCI2 TCI2D TCI3 TCI3D TCI4 TCI4D
*UNIT 47 TYPE 28 SIM SUM
*PAR 21
*DT TON TOF -1 8
*0 -4 0 -4 0 -4 0 -4
*0 -4 0 -4 0 -4 0 -4
*INPUTS 8
*12,1 12,3 15,1 15,3 20,1 20,3 26,1 26,3
*LABELS 8
*TH01 TC01 TH02 TC02 TH03 TC03 TH04 TC04
UNIT 48 TYPE 28 SIM SUM
PAR 20
DT TON TOF -1
0 -4 0 -4 0 -4 0 -4 0 -4 0 -4 0 -4
INPUTS 8
12,2 12,4 15,2 15,4 20,2 20,4 26,2 26,4
LABELS 8
MH1 MC1 MH2 MC2 MH3 MC3 MH4 MC4

```

## UNIT 49 TYPE 15 HX- EFFECTIVENESS CALCULATION

PAR 73

0 0 4 -1 MD 1 -3 -1 6470 -1 700 -12 4 -1 0.0001 3 1 2 -4  
 0 0 4 -1 MD 1 -3 0 -1 CPN 0 -14 4 -1 0.0001 3 1 1 2 -4  
 -11 0 4 -1 MD 1 -3 0 -11 -1 55 4 -1 0.0001 3 1 2 -4  
 0 0 4 -1 MD 1 -3 -1 MD -1 212 -20 4 1 2 -4

INPUTS 10

7,5 7,4 5,7 5,6 5,3 5,4 5,6 7,8 6,6 6,5  
 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0

UNIT 39 TYPE 25 PRINTER

PAR 4

DT TON TOF -1

INPUTS 8

49,1 49,2 49,3 49,4 49,5 49,6 49,7 49,8

Q4D E4D Q2D E2D Q1D E1D Q3D E3D

UNIT 43 TYPE 25 DATA READER 1

PAR 4

DT TON TOF -1

INPUTS 10

5,1 5,2 5,3 5,4 5,5 5,6 5,7 12,1 12,3 15,3

DAY HR MNH3 TINH3 TONH3 TIH20 TOH20 SHX1CO SHX1HO SHX2CO

UNIT 42 TYPE 25 DATAREADER 2

PAR 4

DT TON TOF -1

INPUTS 10

6,1 6,2 6,3 6,4 6,5 6,6 15,1 20,3 26,3 26,1

DAY HR MSIM TOSTM TIH20 TOH20

SHX2HO SHX3CO SHX4CO SHX4HO

UNIT 41 TYPE 25 DATA READER 3

PAR 4

DT TON TOF -1

INPUTS 8

7,1 7,2 7,3 7,4 7,5 7,6 7,7 7,8

DAY HR MAIR TIH20 TOH20 SIHRS GCHRS MPROC

END

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```

SIM 0.0 24.0 1
TOL -.001 -0.001
LIH 30 10 29
CONSTANTS 10
TIF = 80.0 TON = 0.0 TOF = 24.0 MD = 123513 DT = 1
HFG = 970.3 CPN = 0.63 TS = 212.0
* CONSTANTS FOR RENDERING VAPOR CONDENSER
DTW = 91.0 TCA = 117.0
UNIT 5 TYPE 9 CARD READER 1
PAR 19
7 1 -3 .5 0 -4 1 0 -5 1 0 -6 1 0 -7 1 0 11 -1
*
*INPUTS: 1-DAY,2-HOUR,
*
* NH3 DESUPERHEATER
*
*INPUTS: 3-MDOT NH3,4-TIN NH3,5-TOUT NH3,
*INPUTS: 6-TIN H2O,7-TOUT H2O
*
UNIT 6 TYPE 9 CARD READER 2
PAR 16
6 1.0 -3.0 0.4165 0 -4 1 0 -5 1 0 -6 1 0 12 -1
*
*INPUTS: 1-DAY,2-HOUR,
*
* INEDIBLE RENDERING VAPOR CONDENSER
*
*INPUTS: 3-MDOT STEAM TOTAL, 4-TOUT STEAM,, 5-TIN H2O, 6-TOUT H2O
*
UNIT 7 TYPE 9 CARD READER 3
PAR 22
8 1 -3 2.046 0 -4 1 0 -5 1 0 -6 1 0 -7 1 0 -8 4.10 0 13 -1
*
*INPUTS          1-DAY, 2- HOUR,
*
* SINGER EXHAUST ECONOMISER
*
*INPUTS: 3-MDOT AIR, 4-TIN H2O,5-TOUT H2O,
*
* SCALD TUB
*
*INPUTS: 6-HOURS OF OPERATION
*
* GLYCOL CONCENTRATOR
*
*INPUTS: 7-HOURS OF USE
*
* PRIMARY HEAT EXCHANGER
*

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```

*INPUTS: 8-MDOT PROCESS WATER
*
UNIT 8 TYPE 15 CONDENSER MDOTS
PAR 12
0 -3 0 4 -4 -12 -4 -1 MD -13 1 -4
INPUTS 3
6,3 0,0 7,7
0.0 0.0 0.0
*
* OUTPUTS: 1- MDOT STEAM TOTAL, 2- MDOT STEAM WHR CONDENSER
* 3 - MDOT STEAM JET CONDENSER
*
UNIT 12 TYPE 5 HX-1 PRIMARY HX
PAR 4
2 600000.0 1 1
INPUTS 4
27,1 27,2 0,0 7,8
206.0 123513.0 55.0 14085.0
TRACE 8. 9.
UNIT 15 TYPE 5 HX-2 AMMONIA DESUPERHEATER HX
PAR 4
2 42000.0 CPN 1
INPUTS 4
0,0 5,3 12,1 12,2
220.0 0.0 200.0 MD
UNIT 17 TYPE 3 LOOP PUMP
PAR 1
MD
INPUTS 3
15,3 15,4 0,0
TIF 0.0 1.0
UNIT 18 TYPE 11 T-PIECE
PAR 1
1
INPUTS 4
15,3 17,2 22,1 22,2
0.0 0.0 0.0 0.0
UNIT 20 TYPE 15 HX3 INFEDIBLE REDERING STEAM CONDENSER
PAR 62
-1 0,0 -4
-1 TS -13 4 -1 .87 1 -14 -15 -1 1.0 9 1 1
-1 1045,3 2 -3 -21
-1 TS -13 4 -1 .87 1 -14 -15 -1 1.0 9 1 1
-14 2 -13 3 -4 -14 -4
-1 TS -13 4 -1 .87 1 -14 -15 -1 1.0 9 1 1
-4
-15 -31 4 -4
INPUTS 5
0,0 0,0 18,1 18,2 6,3
TS 0.0 TIF 0.0 0.0

```



UNIT 21 TYPE 15 SCALD TUB LOOP PUMP AND DIVERTER

PAR 11

0.0 -4 0.0 -4 -11 -4 0.0 -1 61760 1.0 -4

INPUTS 3

20,3 17,2 7,6

0.0 0.0 0.0

UNIT 22 TYPE 5 SCALD TUB HX

PAR 4

4 .5 1 1

INPUTS 4

21,3 21,4 0,0 0,0

0.0 0.0 140.0 150000.0

UNIT 26 TYPE 5 HX-4 HOG SINGER ECONOMIZER

PAR 4

4 .55 0.253 1.0

INPUTS 4

0,0 7,3 21,1 21,2

700.0 0.0 TIF 0.0

UNIT 27 TYPE 5 GLYCOL CONCENTRATOR

PAR 4

4 1 1 1

INPUTS 4

26,3 26,4 0,0 8,4

0.0 0.0 180.0 MD

UNIT 45 TYPE 28 SIM SUM

PAR 18

DT TON TOF -1

0 -4 0 -4 0 -4 0 -4 0 -3 0 -3 3 -4

INPUTS 6

12,5 15,5 20,5 26,5 22,5 27,5

LABELS 7

Q1 Q2 Q3 Q4 RSCALD RGLYCL QS+QG

CHECK 0.10 1 - 2 - 3 - 4 + 7

UNIT 44 TYPE 28

PAR 12

DT TON TOFF -1

0 -4 0 -4 0 -4 0 -4

INPUTS 4

49,5 49,3 49,7 49,1

LABELS 4

Q1D Q2D Q3D Q4D

\*UNIT 46 TYPE 28 SIM SUM

\*PAR 21

\*DT TON TOF -1 8

\*0 -4 0 -4 0 -4 0 -4 0 -4

\*0 -4 0 -4 0 -4

\*INPUTS 8

\*26,3 7,5 12,1 5,6 15,3 6,5 20,3 7,4

\*LABELS 8

\*TH11 TH11D TCI2 TCI2D TCI3 TCI3D TCI4 TCI4D

```

*UNIT 47 TYPE 28 SIM SUM
*PAR 21
*DT TON TOF -1 8
*0 -4 0 -4 0 -4 0 -4
*0 -4 0 -4 0 -4 0 -4
*INPUTS 8
*12,1 12,3 15,1 15,3 20,1 20,3 26,1 26,3
*LABELS 8
*TH01 TCO1 TH02 TCO2 TH03 TCO3 TH04 TCO4
UNIT 48 TYPE 28 SIM SUM
PAR 20
DT TON TOF -1
0 -4 0 -4 0 -4 0 -4 0 -4 0 -4 0 -4
INPUTS 8
12,2 12,4 15,2 15,4 20,2 20,4 26,2 26,4
LABELS 8
MH1 MC1 MH2 MC2 MH3 MC3 MH4 MC4
UNIT 49 TYPE 15 HX- EFFECTIVENESS CALCULATION
PAR 73
0 0 4 -1 MD 1 -3 -1 6470 -1 700 -12 4 -1 0.0001 3 1 2 -4
0 0 4 -1 MD 1 -3 0 -1 CPN 0 -14 4 -1 0.0001 3 1 1 2 -4
-11 0 4 -1 MD 1 -3 0 -11 -1 55 4 -1 0.0001 3 1 2 -4
0 0 4 -1 MD 1 -3 -1 MD -1 212 -20 4 1 2 -4
INPUTS 10
7,5 7,4 5,7 5,6 5,3 5,4 5,6 7,8 6,6 6,5
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
UNIT 39 TYPE 25 PRINTER
PAR 4
DT TON TOF -1
INPUTS 8
49,1 49,2 49,3 49,4 49,5 49,6 49,7 49,8
Q4D E4D Q2D E2D Q1D E1D Q3D E3D
*UNIT 43 TYPE 25 DATA READER 1
*PAR 4
*DT TON TOF -1
*INPUTS 10
*5,1 5,2 5,3 5,4 5,5 5,6 5,7 12,1 12,3 15,3
*DAY HR MNH3 TINH3 TONH3 TIH20 TOH20 SHX1H0 SHX1C0 SHX2C0
*UNIT 42 TYPE 25 DATAREADER 2
*PAR 4
*DT TON TOF -1
*INPUTS 10
*6,1 6,2 6,3 6,4 6,5 6,6 15,1 20,3 26,3 26,1
*DAY HR MSTH TOSTH TIH20 TOH20
*SHX2H0 SHX3C0 SHX4C0 SHX4H0
UNIT 43 TYPE 25
PAR 4
DT TON TOF -1
INPUTS 10
15,3 15,4 17,1 17,2 18,1 18,2 20,3 20,4 21,1 21,2

```

```
T MHX2 T MPUMP T MTOUT T MHX3CO T MYLOOP
UNIT 42 TYPE 25
PAR 4
DT TON TOF -21
INPUTS 10
21,3 21,4 22,1 22,2 26,3 26,4 27,1 27,2 27,3 27,4
T MYSCLD T MSCLD T MSING TH MHCONC TC MCONC
UNIT 41 TYPE 25 DATA READER 3
PAR 4
DT TON TOF -1
INPUTS 10
7,1 7,2 7,3 7,4 7,5 7,6 7,7 7,8 22,3 27,1
DAY HR MAIR TIH20 TOH20 STHRS GCHRS MPROC TOSCLD TOGLYC
END
:
```

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