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Manual for the Solar Total Energy System Evaluation Program

B. L. McFarland

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MANUAL
FOR THE
SOLAR TOTAL ENERGY SYSTEM
EVALUATION PROGRAM

By
B. L. McFARLAND



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8900 DeSoto Avenue
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FOREWORD

This is the computer manual for the Solar Total Energy System Evaluation Program (STESEP), developed under the Department of Energy (DOE) Contract EY-76-C-03-1210 [formerly, Energy Research and Development Administration (ERDA) Contract E(04-03)-1210]. The contract effort was performed by Rockwell International Corporation's Atomics International (AI) Division, and was monitored by Dr. R. W. Harrigan, of Sandia Laboratories, under the direction of Mr. J. E. Rannels, DOE Program Manager.

This documentation of the STESEP Code was funded by Sandia Laboratories, Albuquerque, New Mexico, through Federal Agency Order (FAO) 07-6971, and was written by Mr. B. L. McFarland, with contributions by Dr. E. P. French, of Rockwell's Space Division, and by Mr. S. J. Nalbandian, who was the AI Program Manager.

The TMY subroutine to read the National Climatic Center's typical meteorological year data tape was written and incorporated into the code by Herbert Anderson of Sandia Laboratories.

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1.0 INTRODUCTION

The purpose of this report is to present a computer manual for the Solar Total Energy System Evaluation Program (STESEP) which was previously developed as part of DOE Contract EY-76-C-03-1210 [formerly ERDA Contract E(04-3)-1210]^{(1)*} for evaluation of the potential commercial application of solar total energy systems.

1.1 SOLAR TOTAL ENERGY SYSTEMS

A solar total energy system uses solar energy as the primary source to provide a combination of electrical and thermal power to the user to supplement or replace conventional energy sources. Figures 1 and 2 show the generic concepts considered during the study. Both can be evaluated by the STESEP computer program to determine the equipment sizes and control methodology bestsuited to applications in the commercial sector.

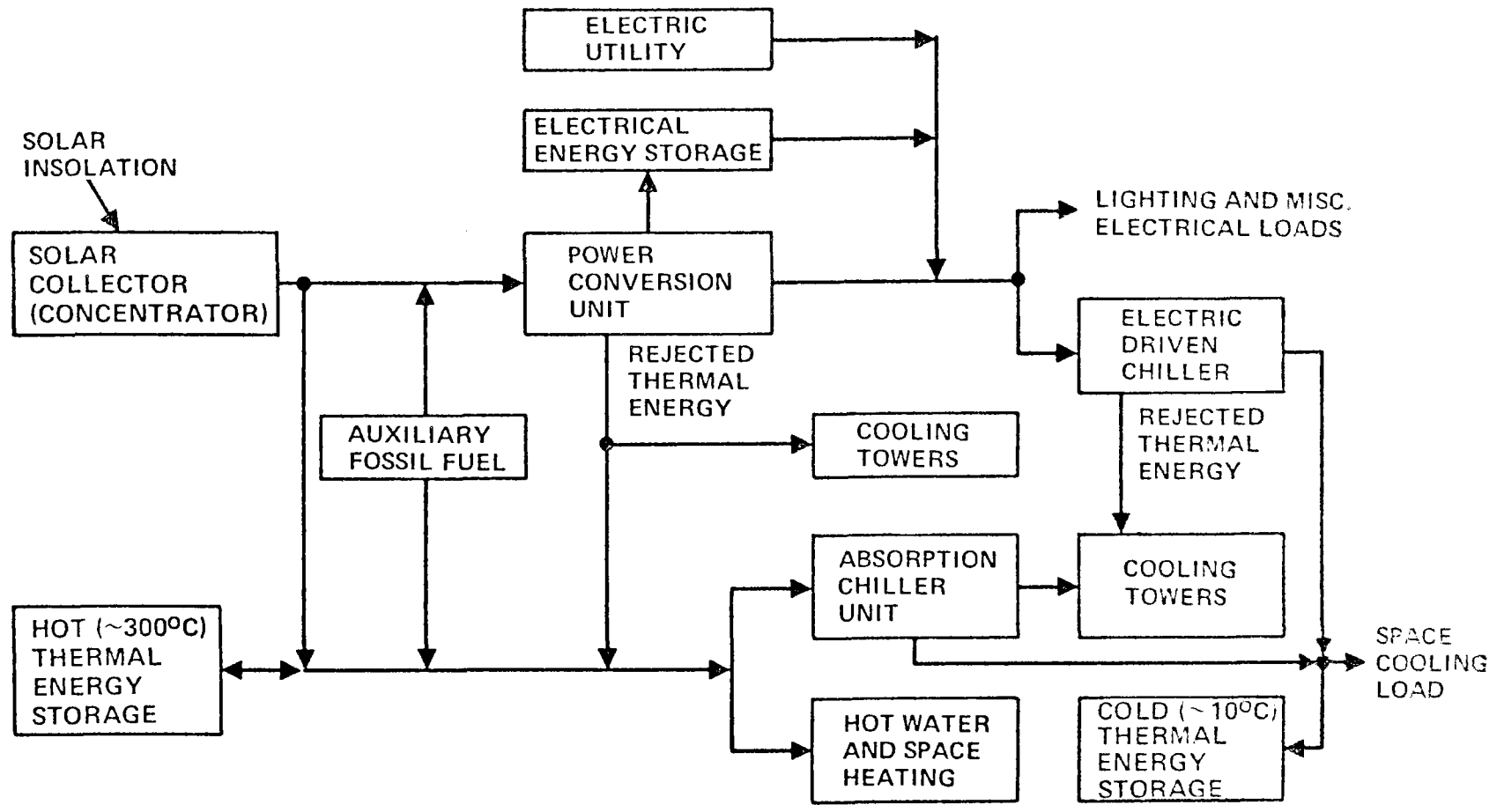
As indicated in Figure 1, a thermal STES utilizes a concentrating solar collector to produce a high-temperature fluid which supplies energy to a power conversion system (PCS) and/or hot thermal energy storage for later use to power the PCS. The electrical energy produced by the PCS is used to supply the user's electrical demand loads (lighting, vapor compression chillers) and/or an electrical energy storage system. Rejected thermal energy from the PCS can be cascaded to supply the user's heating loads and/or absorption chiller refrigeration loads with all excess energy exhausted to the atmosphere through a cooling tower.

Figure 2 shows schematically how a photovoltaic STES can consist of (1) direct conversion of the solar energy to electricity by photovoltaic arrays, which may or may not involve concentrators, and (2) collection of low-grade thermal energy either from the cooling of concentrating photovoltaic arrays or by separate flat plate collectors which supply the user's thermal demand loads.

Figures 1 and 2 show energy storage in several places to indicate the numerous options possible in configuring the systems and which need to be evaluated to determine the most economical configuration for a given application. This

^{*}Superscript numbers in parentheses refer to references.

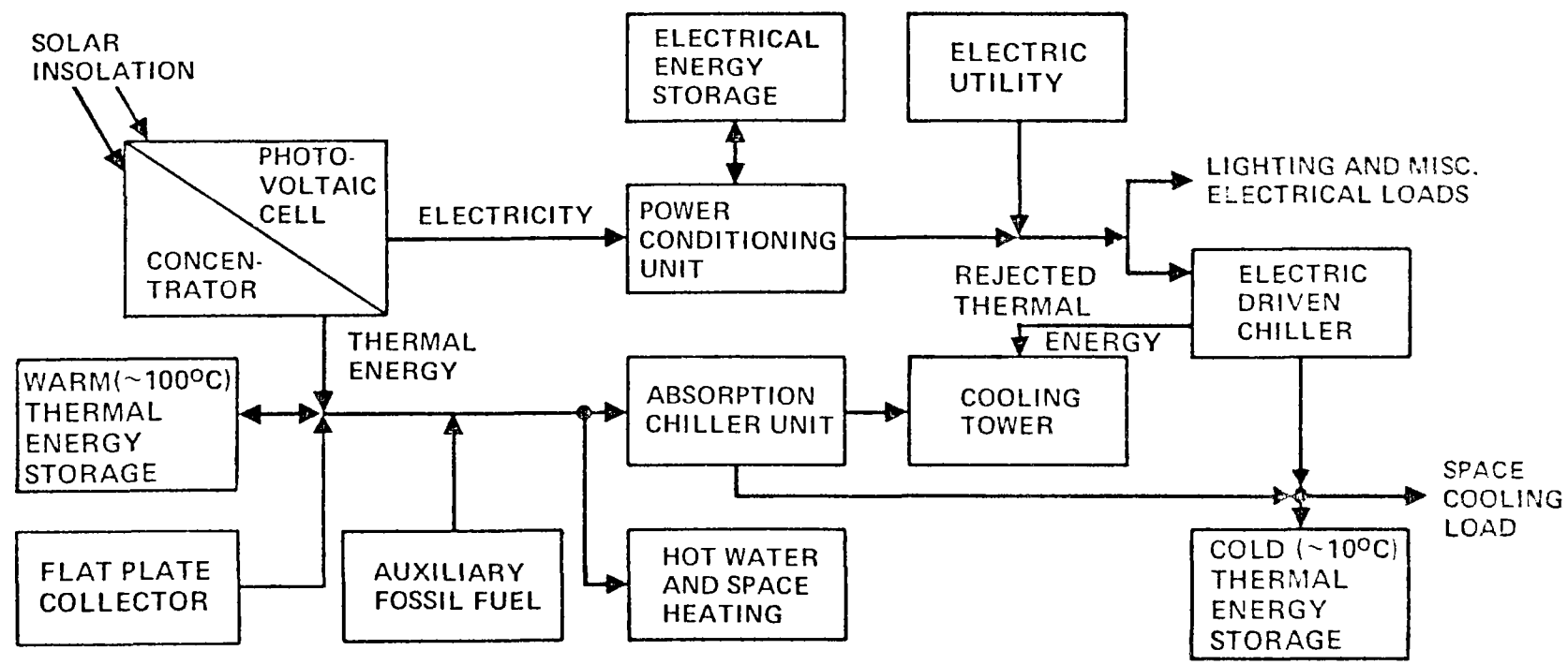
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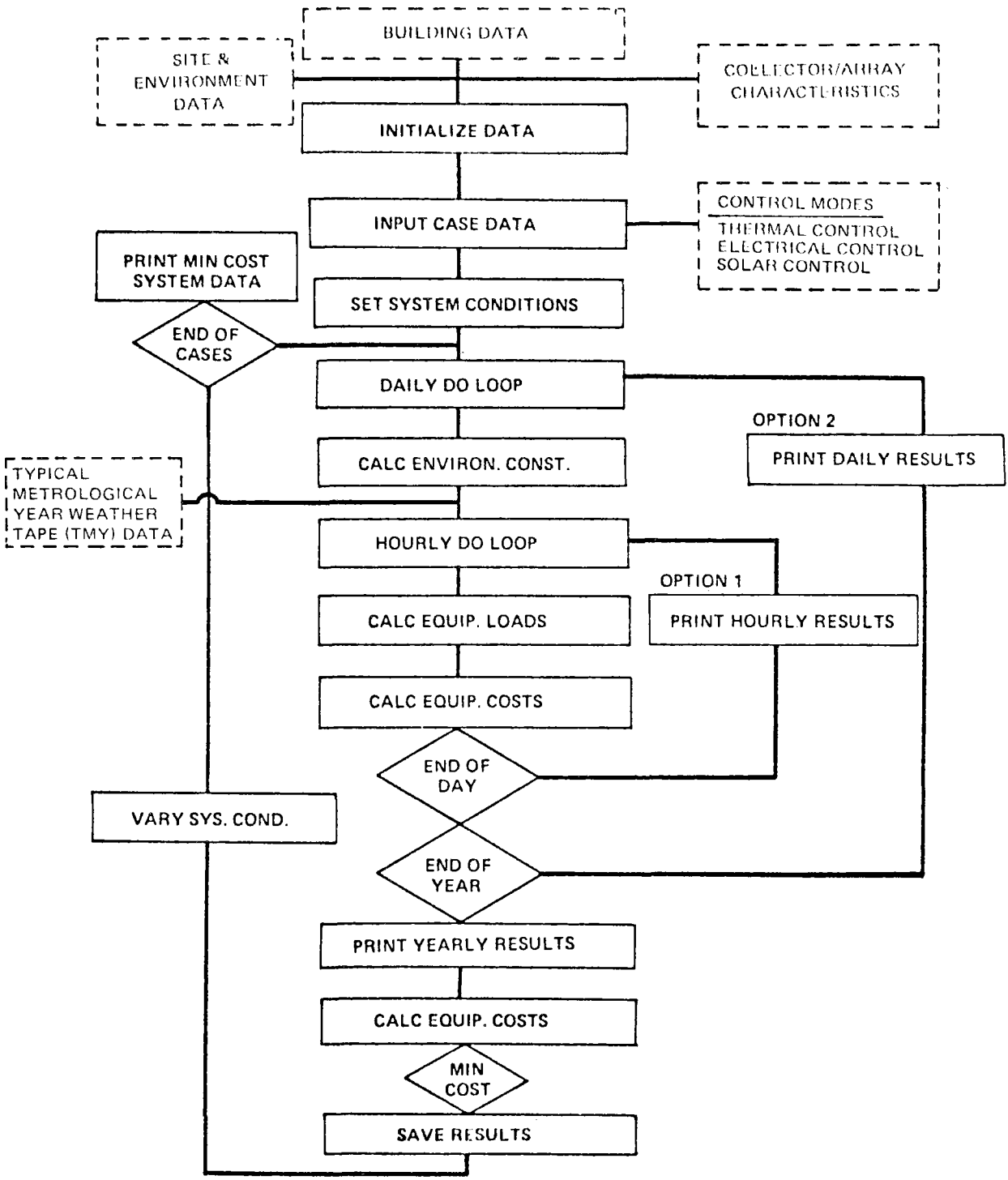
Figure 1. Solar Thermal STES Concept Block Diagram

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Figure 2. Photovoltaic STES Concept Block Diagram



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Figure 3. STESEP Logic Diagram

evaluation can be expensive if a detailed computer program such as SOLSYS,⁽²⁾ PVSOLSYS,⁽³⁾ or modified TRNSYS⁽⁴⁾ is used. Thus an alternate method of developing the economical optimum STES configuration was needed.

1.2 SOLAR TOTAL ENERGY SYSTEM EVALUATION PROGRAM (STESEP)

The STESEP Computer Program was developed for a quick evaluation of trade-offs related to (1) cascading of thermal power conversion systems, (2) determination of optimum collector sizes and operating conditions (make or buy decisions for auxiliary energy), and (3) comparison of solar total energy concepts in various parts of the country and in various types of commercial buildings to assess their future economic potential for various economic scenarios.

The logic of the STESEP Computer Program is shown in simplified form in Figure 3. Environmental and building data are combined with component performance and cost characteristics to evaluate the effect of system performance by hourly energy balances of calculated building loads as a function of environmental temperatures, solar energy collection and one of three possible generic control modes for the system that are discussed in Section 2.2.

The individual component-subsystem models are of necessity simplified and are used together with a deterministic model⁽¹⁾ of the solar-environmental condition to enable screening calculations to be made inexpensively. Provision for using more detailed weather tape data is discussed in Section 3.4. The results from these screening calculations define the economics of the system and can be used directly for conceptual trend studies. The component sizes selected for the system also form a good starting point for more detailed preliminary design studies using the larger SOLSYS⁽²⁾, PVSOLSYS⁽³⁾, or modified TRNSYS⁽⁴⁾ computer programs.

TABLE 1
COMPARISON OF STES CONCEPTS

Power Conversion System Concept	Advantages	Disadvantages
Organic Rankine	<ol style="list-style-type: none"> 1. Distributed Collector Can be Used 2. Can be Cascaded for Thermal Load 	<ol style="list-style-type: none"> 1. Requires Licensed Operator or Automatic Safety Controls 2. Fire Hazard 3. Low Performance
Steam Rankine	<ol style="list-style-type: none"> 1. High Performance Potential when superheated steam is used 	<ol style="list-style-type: none"> 1. Requires Licensed Operator or Automatic Safety Controls 2. Requires Point Focus Receiver (higher temperature) 3. Fire Hazard Because of Second Fluid for Storage 4. Large Performance Loss to Cascade
Brayton Cycle (High Pressure)	<ol style="list-style-type: none"> 1. High Performance Potential 2. Can be Cascaded for Thermal Load 	<ol style="list-style-type: none"> 1. Requires Licensed Operator 2. Requires Point Focus Receiver (higher temperature) 3. Current Concepts of Thermal Storage Not Feasible for STES 4. Fluid Leakage Problems
Brayton Cycle (Low Pressure)	<ol style="list-style-type: none"> 1. High Performance Potential 2. Can be Cascaded for Thermal Load 3. No Operator Required 4. Thermal Storage Feasible for STES 	<ol style="list-style-type: none"> 1. Requires Advanced Central Receiver Concept 2. Probably Requires Fossil Fuel Topping Cycle to Produce Needed Turbine Inlet Temperatures
Photovoltaic	<ol style="list-style-type: none"> 1. High Performance Potential 2. Simple Control Systems 3. No Operator Required 	<ol style="list-style-type: none"> 1. High Cost of Array 2. Cascading Inefficient

2.0 PROGRAM DESCRIPTION

This section describes the mathematical models used by the STESEP program and briefly discusses how the systems were selected.

2.1 TOTAL ENERGY SYSTEM SELECTION

The STESEP program was developed for analyzing Rankine cycle STES of the type shown in Figure 4,* and photovoltaic systems of the type shown in Figure 5.

During the contractual effort reported in Reference 1, several other STES concepts were compared before selection of the Rankine and photovoltaic systems for the STESEP computer program. Table 1 compares these STES concepts which were evaluated⁽¹⁾ for application to the commercial sector. While the Brayton cycle was felt to have a high potential, the development of a suitable collector lags far behind the development of collectors for Rankine systems where test data are available.⁽⁵⁻¹⁴⁾ Consequently, only Rankine cycle solar thermal systems have been included in the program.

The STESEP program determines component demand loads, based on an hourly steady-state energy balance for each of the various components as indicated in Figures 4 and 5, to meet the input users requirements for electrical, heating, ventilating, and air conditioning (HVAC), and process heat demand loads. Component sizes and utilization factors are estimated based on the input of environmental conditions. System capital and recurring costs are evaluated to determine the annualized cost⁽¹⁵⁾ for the system.

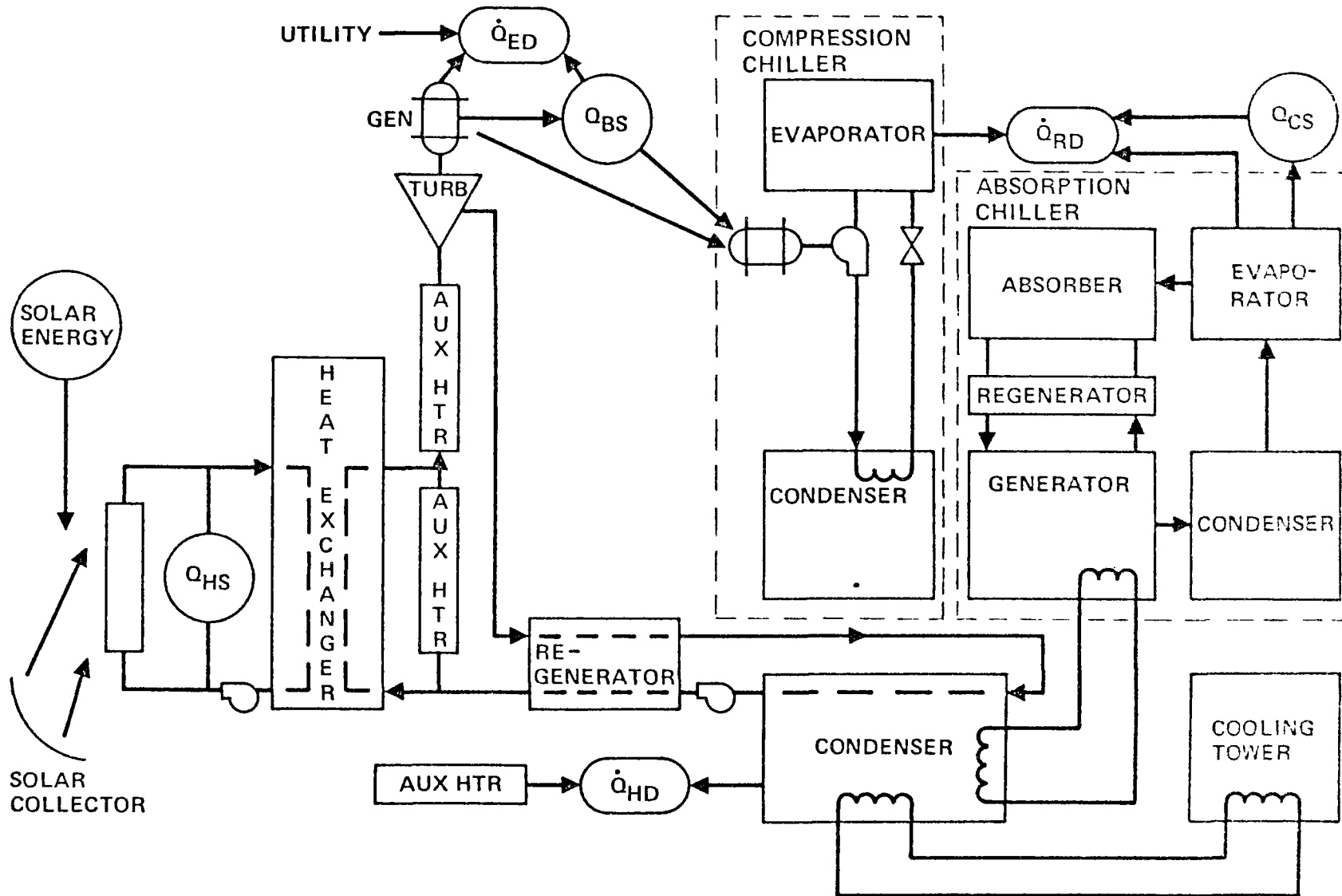
2.2 CONTROL MODES

The performance of the STES is dependent on the control logic used to operate the system. In addition, the type of energy storage also depends on this control logic. There are three generic methods of control of the STES, which are considered (at the users option) by the STESEP computer program. These determine how the power conversion system (PCS) is operated and are as follows:

- 1) Thermal Control -- When the power conversion system (PCS) is sized and operated to provide the building HVAC and process heating demand load

*See list of symbols.

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Figure 4. Diagram of Solar Thermal STES Concept

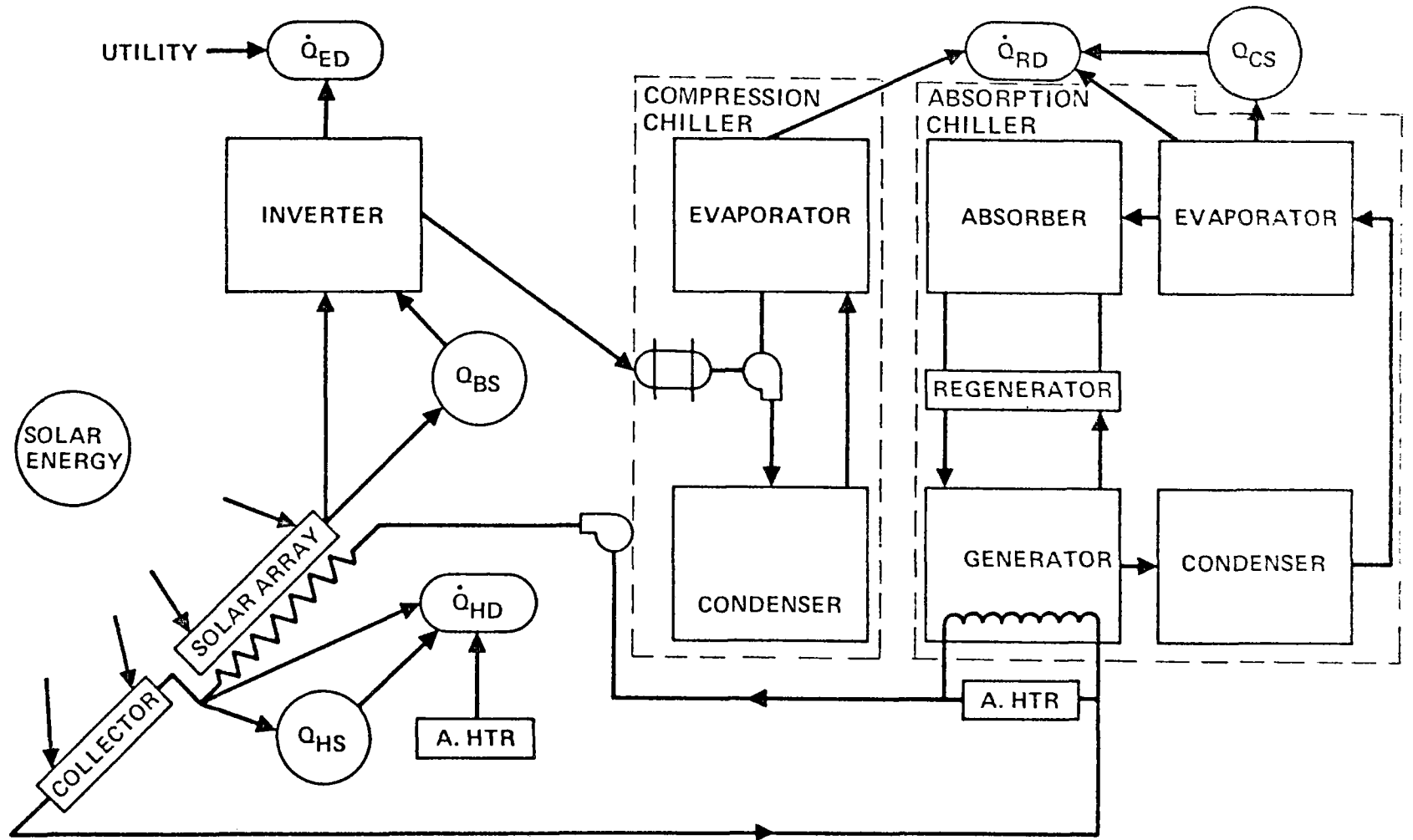


Figure 5. Diagram of Photovoltaic STES Concept

(using reject heat), the system is controlled by the thermal load. In this mode, the PCS always operates to provide enough reject thermal energy for the heating and cooling (thermal) loads. Electricity is used to meet any unsatisfied building electrical load.

- 2) Electrical Control – The PCS is operated to provide the entire electrical load for the building. Auxiliary fossil-fired boilers are used in conjunction with the solar collector to provide sufficient energy to the PCS to make the system stand alone with no electricity purchased from the utility.
- 3) Solar Control – The PCS is sized and operated to utilize the solar energy collected by the system. Utility electricity is used to meet any unsatisfied building electrical or cooling load while fossil fuel is burned to meet any unsatisfied building heating requirements.

Solar thermal systems can be operated in any one of the three control modes (i.e., electrical, thermal, solar) and can use either hot thermal storage or battery storage for energy storage in conjunction with cold storage for refrigeration needs. The photovoltaic STES (nonconcentrator system) should only be operated in the solar control mode since the flatplate collectors used for meeting the building thermal loads decouple the electrical and thermal requirements.

STESEP is intended to compare the cost of operation in each of the control modes so that preliminary appraisals of the suitability of the solar system can be made.

2.3 COMPONENT MODELS

To evaluate the STES concepts discussed above, the component and subsystems shown in Figures 4 and 5 have been characterized in terms of their performance and cost parameters.

The following discussion describes the derivation of the major components models selected for use in this computer program.

2.3.1 Concentrating Solar Collectors

An STES that produces electricity from a heat engine must achieve temperatures beyond the range of flat-plate collectors and will require a tracking, concentrating collector to efficiently heat the working fluid to the necessary temperature range of 230 to 400°C for Rankine cycles STES or 700 to 900°C for Brayton cycle STES. Unfortunately, collector designs suitable for use with the Brayton cycle⁽¹⁶⁻¹⁸⁾ are in a conceptual design period and were not considered to be in hardware development stage suitable for use in commercial buildings for the present study. The combination of a gaseous coolant and extremely high turbine temperature requirements resulted in deletion of Brayton cycle solar collectors from the study program. Collectors suitable for use with the Rankine cycle STES are being developed in both distributed and central receiver configurations. While the configurations discussed below cannot yet be considered "state-of-the-art," the hardware development programs currently in progress should ensure their commercial availability.

2.3.1.1 Distributed Concentrating Collectors

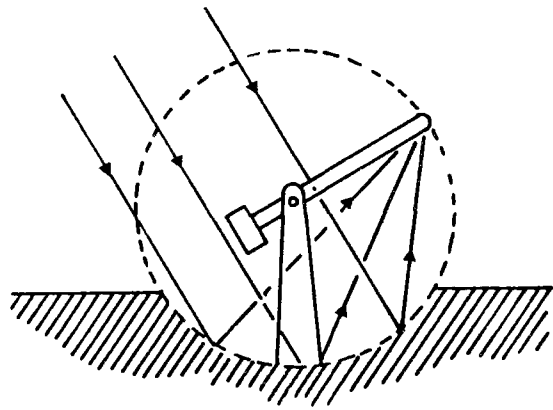
Four basic concepts of distributed concentrating collectors being developed for liquid coolants are shown in Figure 6.⁽⁵⁻¹⁴⁾ For these collectors, the optical and thermal losses determine their operating efficiencies and are somewhat different for each concept. For the evaluation of the STES concepts, the losses can be represented by:^{*}

$$q_{\text{use}} = \eta_{\text{oc}} I A_c - U A_a (\bar{T} - T_a) - \sigma \epsilon_c A_a (\bar{T}^4 - T_a^4) \quad \dots(1)$$

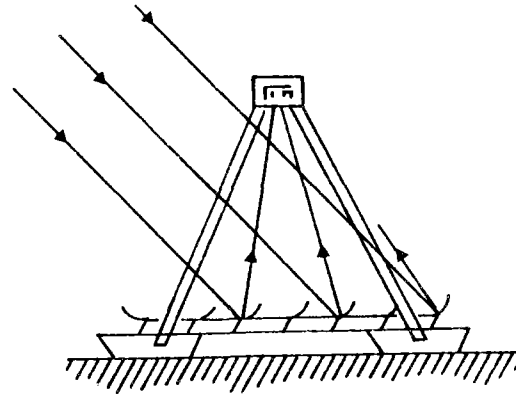
Data from References 5 through 14 have been used for preliminary evaluation of the loss coefficients for these collectors. These are listed in Table 2 and can be used if data are not available for the collector being analyzed.

Using the deterministic insolation model discussed in Section 2.3.6 in conjunction with Equation (1) allows one or two axis tracking collectors to be simulated accurately as well as nontracking distributed collectors based on the solar declination angle, θ_z , as shown in Figure 7.

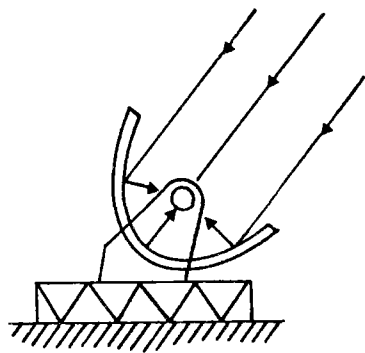
*See List of Symbols on Page 153 and also Glossary of Terms, Section 4.3, for equivalent STESEP variable name.



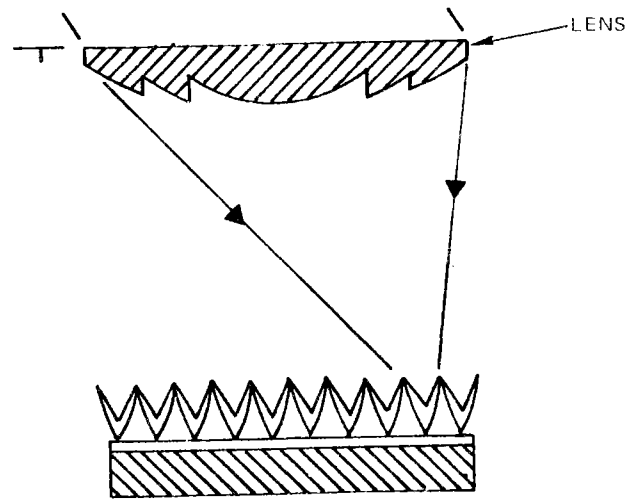
(a) Fixed Stepped Mirror Concept
(General Atomic)



(c) Segmented Mirror Concept
(Sheldahl)



(b) Parabolic Trough Concept
(Honeywell)



(d) Fresnel Lens Concept
(JPL)

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Figure 6. Distributive Collector Concepts

TABLE 2
SOLAR CONCENTRATING COLLECTORS

Concept Source	Reference	Concentration Ratio (A_c/A_a)	Optical Efficiency, η_{oc} (%)	Receiver** Emissivity ($\frac{\epsilon_c A_r}{A_a}$)	Receiver Convective Loss Coefficient (U)	
					W/m ² -h-°C	Btu/ft ² -h-°F
Segmented Mirror						
Sheldahl-Planar	6, 7	30	64(67)*	1.5	8.5	1.5
Sheldahl-V [†]	6, 7	30	(71)	0.37	8.2	1.44
Itek	6, 8	46	(75)	1.2	1.4	0.24
Parabolic						
Honeywell (NSC) [§]	6, 9	31	63	1.8	5	0.89
Honeywell (SC) [§]	6, 9	31	60	0.39	5	0.89
Sandia (NSC) [§]	10, 11	42	(65)	2	14.1	2.5
Sandia (SC) [§]	10, 11	42	(64)	0.3	14.1	2.5
JPL [†]	12	16.8	65	1.0	0.6	0.1
Fresnel Lens						
McDonnell Douglas	13, 14	(40)	(63)	(1)	(5.6)	(1)
Fixed Mirror	6, 15	41	65	(0.3)	(5.6)	(1)

*Numbers in parentheses are estimated values.

†Evaluated from transient data — solid absorber.

§NSC = nonselective coating, SC = selective coating.

**Value used in Equation 1 and which contains area correction term to account for different radiating area, A_r , and illuminated area, A_a , on the receiver.

- APPLIES ANALYTICAL EXPRESSIONS FOR PREDICTABLE EFFECTS
 - SUN POSITION (ZENITH ANGLE θ_z) AS FUNCTION OF LATITUDE, TIME OF DAY, AND SEASON
 - TRANSMISSION THROUGH THE STANDARD ATMOSPHERE AS FUNCTION OF SEASON:

$$A \cdot \exp(-B/\cos \theta_z)$$

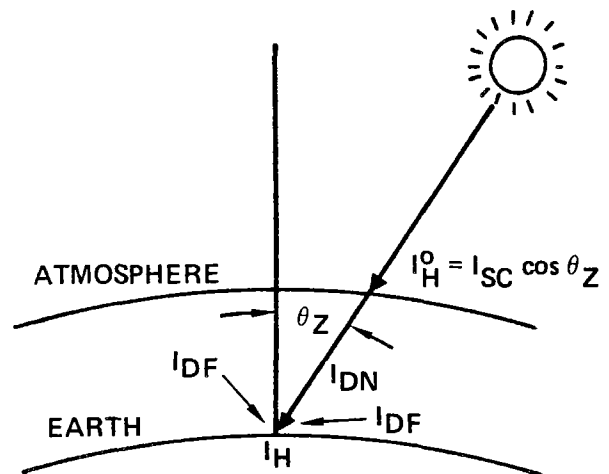
- DERIVES AVERAGE LOCAL CORRECTIONS BASED ON MEASURED DIRECT AND HORIZONTAL RADIATION

- RADIATION IS OBSCURED BY CLOUDS FOR $(1 - CF)$ FRACTION OF THE TIME
- WHEN NOT CLOUDED, LOCAL ATMOSPHERIC EFFECTS ATTENUATE RADIATION BY THE CLEARNESS FACTOR, CN

$$I_{DN} = CN \cdot A \cdot \exp(-B/\cos \theta_z)$$

- TOTAL HORIZONTAL RADIATION I_H (DIRECT AND DIFFUSE) ESTIMATED BY LINEAR FORMULA,

$$I_{DN} = \alpha'(I_H/I_H^0) + \beta'$$



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Figure 7. Deterministic Insolation Model

The direct normal insolation predicted by this insolation model is used directly in Equation (1) for two-axis tracking systems, while for one-axis east-west oriented tracking systems, the incident insolation is given by:

$$I = I_{DN} (1 - \sin^2 h \cos^2 \delta)^{1/2} \quad \dots(2a)$$

and for a N-S orientation:

$$I = I_{DN} \cos \delta \quad \dots(2b)$$

For nontracking nonconcentrating collectors, the incident insolation is given by:

$$I = \frac{I_{DN} + 0.384 I_c}{1.33} [\cos \delta \cos(\phi - T) \cos h + \sin(\phi - T) \sin \delta] \quad \dots(3)$$

The total horizontal insolation is:

$$I_{HT} = \frac{I_{DN} + 0.384 I_c}{1.33} \cos \theta_z \quad \dots(4)$$

where

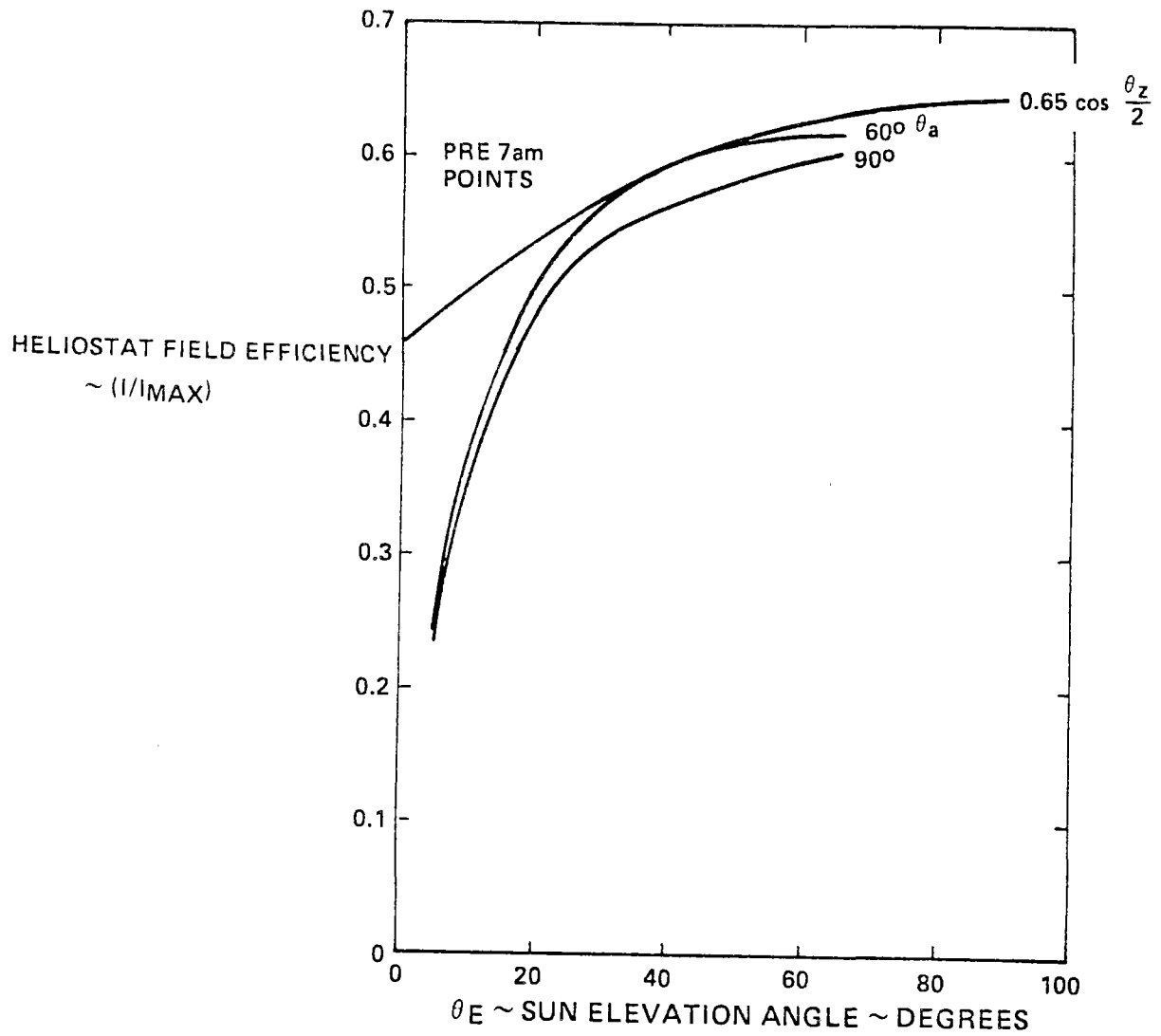
$$\theta_z = \cos \delta \cos \phi \cos h + \sin \phi \sin \delta \quad \dots(5)$$

2.3.1.2 Central Receivers

Equation (1) also accurately represents the behavior of central receivers if the incident insolation on the absorber is known. The multiple reflection paths from the mirror field precludes the use of simple expressions⁽¹⁹⁻²¹⁾ to accurately represent the incident insolation such as those described above. In this program, the direct horizontal insolation has been used in conjunction with cosine of half of the solar angle in Equation (1) to approximate the behavior of the central receiver.

$$I = I_{DN} \cos 0.5\theta_z = I_{DN} \sqrt{0.5(1 + \cos \theta_z)} \quad \dots(6)$$

Performance test data for central receivers are not yet available, although the 5-MWt facility at Sandia should soon be testing several of the central receiver concepts under development.



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Figure 8. Comparison of Sandia and Cosine Law Results for Barstow 10 MWe Pilot Plant

Predictions of the heliostat efficiency of the 10-MWe plant to be installed at Barstow, California⁽²²⁾ are shown in Figure 8, along with Equation 6 to indicate that this simple expression gives reasonable predictions for the field cosine losses for 5 hr either side of solar noon. Since the sun will not normally be acquired at azimuth angles below 20 deg, this inaccuracy will not normally affect the numbers generated by STESEP.

Estimates for the optical efficiency of small central receivers vary from 0.65⁽²²⁾ to 0.72.⁽²³⁾ Probable concentration ratios will vary from 250 to 1000. Convective losses⁽²¹⁾ will be 2 to 4 times that of distributed systems and the receiver surface emissivity will be above 0.9. These values are recommended for use with Equation (1).

2.3.1.3 Coolant Pressure and Thermal Losses

Both the distributed and central receiver solar collector systems must be actively cooled. The high temperatures needed for efficient power conversion system operation $\sim 300^{\circ}\text{C}$ ($\sim 600^{\circ}\text{F}$) severely limits the type of coolant that can be used. Based on the results of the extensive study reported in Reference 19, Caloria HT-43 has been used for coolant calculations in the STESEP Computer Program. Equation (1) is used to predict the energy absorbed by the coolant, and a coolant velocity necessary to limit the wall-to-coolant temperature difference to a specified value (DTW) is computed using the turbulent Nusselt equation with bulk properties of the fluid.

$$N_{Nu} = 0.023 N_{Pr}^{1/3} N_{Re}^{0.8} \quad \dots(7)$$

The hydraulic power to produce 20 velocity heads for the coolant flow with a 70% efficient pump is used as the pumping loss for distributed collectors. For central receivers, an additional head is required equal to the tower height.

For distributed collector systems, a thermal energy loss equal to 5% of the collected energy is assumed to account for the piping loss between the collectors and power conversion system.

2.3.1.4 Photovoltaic Array Performance

Photovoltaic cells convert solar energy directly into electricity but must be connected in arrays to produce easily useable power. One hundred to several

hundred cells will normally be connected in series to produce voltage levels compatible with commercial equipment. Consequently, estimating array performance can be a complicated process. The user must input the reference efficiency of the array. An array packing factor of 0.95 is assumed by the STESEP Computer Program, and the photovoltaic array performance is corrected for cell temperature excursions by the equation:

$$\text{array efficiency} = [1 - \beta (T_{\text{cell}} - T_{\text{ref}})] \eta_{\text{oc}} \quad \dots(8)$$

The performance of the photovoltaic array is based on the input array efficiency at 28°C (15% conversion efficiency would be typical). Equation (1) is used to compute the passively cooled cell temperature each hour based on the ambient air temperature and the input linear loss coefficient. The cell performance is corrected for temperature effects by the linear coefficient.

Since many of the commercial buildings considered for STES application have all electric power systems, the photovoltaic STES concept is a likely candidate for retrofit conversion to solar power. However, the use of electricity for space and process heating is both uneconomical and wasteful of energy so that the program assumes conversion of the building heating system to use a thermal source of energy. This also enables direct comparison to be made of photovoltaic and solar thermal total energy systems since the base or original operating cost for the building is the same for either system.

2.3.1.5 Land Utilization Effects

Commercial buildings are normally located in relatively high-cost land areas (\$10/m² to \$50/m² or more) and consequently do not normally have a large parking area. Multi-tiered parking is common where land costs favor multi-story buildings. Data from Reference 24 indicates that parking areas are usually less than the total building floor areas for shopping centers, while the parking area is considerably smaller for office buildings (particularly true for high-rise buildings).

Because of the land utilization factor and high land cost surrounding commercial buildings, the purchase of additional land for collector use would add an incremental cost of \$40/m² to \$120/m² to the capital investment for the additional collectors. Since the reference cost for concentrating collectors

was assumed at \$100/m² (see Section 2.4), the cost of land for these additional collectors could be considered as doubling the collector cost.

With all collector (and array) systems, the land utilization efficiency affects both the cost of connecting piping, etc., and the total amount of energy that can be captured on a fixed amount of land. Shadowing effects are important for all designs and must be considered in establishing the field construction for a specific application. The shadowing analyses from Reference 24 are considered to be sufficiently accurate for conceptual design sizing studies and have been used to establish the land utilization efficiencies used in the STESEP program to set the usable daily collection period for the collector and array systems (see 2.3.6).

Several assumptions were made in the analysis for two axis tracking systems in Reference 24 which need to be repeated for clarity.

- 1) North-south (N-S) spacing should be made to prevent shadowing at any time since this could reduce the winter output during the entire day.

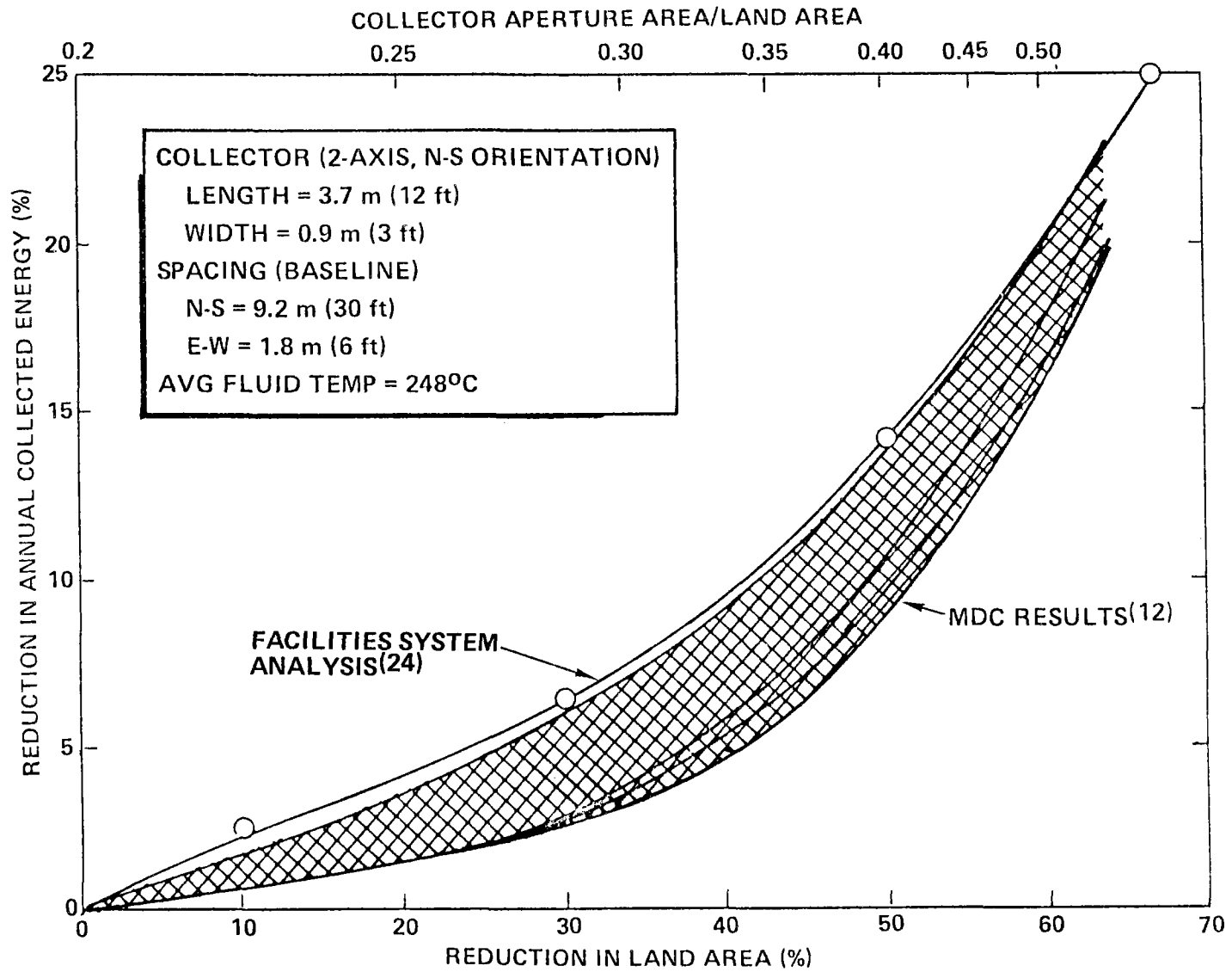
$$\frac{Y}{L_c} = \frac{\text{N-S spacing}}{\text{collector length}} = \cos \phi + \frac{\sin \phi}{\tan(90 - \delta_{\max} - \phi)} \quad \dots(9)$$

- 2) The angle to prevent E-W shadowing is approximated by:

$$\cos \theta_z \geq \frac{W_c}{X} = \frac{\text{collector width}}{\text{E-W spacing}} \quad \dots(10)$$

Based on this analysis, the STESEP Computer Program uses a default value for the east-west (E-W) spacing ratio of 0.4 for tracking collectors which gives a 20 to 25% land utilization depending on the site latitude.

For tracking collectors, Figure 9 from Reference 12 shows the effect of collector spacing on performance for comparison with the simplistic analysis results from Reference 24. These studies indicate that collector area-to-land area ratios will probably be kept below 1/3 for distributed systems to prevent excessive shadowing losses. References 22 and 25 indicate the similar result for central receivers, since shadowing losses for both types of systems increase rapidly as the collector spacing is decreased. When area requirements for power conversion systems, energy storage, etc., are considered, an overall land utilization



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Figure 9. Effect of Collector Spacing

efficiency for STES using tracking collectors of 1/4 appears reasonable and should be used for estimating an upper limit for collector areas to be considered.

Nontracking flat plate collectors and photovoltaic arrays can more effectively utilize the available area, since shadowing effects are minimized although cosine losses are large. Equation 9⁽²⁴⁾ indicates that flat plate collector area-to-land area ratios of 0.6 can be obtained without shadowing losses at 34 deg latitude so that an overall land utilization efficiency of 0.5 is reasonable and can usually be assumed to estimate the maximum array areas of interest.

It is recognized that these spacings have not been optimized for cost effectiveness, but are used to form preliminary estimates of what system constraints are likely to be found in commercial application of STES concepts.

2.3.2 Energy Storage Subsystems

Energy storage is necessary for STES concepts to:

- 1) Prevent interruption of power due to intermittent cloud cover (smooth out the solar profile).
- 2) Extend the usable period of operation of the system to nonsunlight periods.

The amount of storage capability will depend upon the application and type of backup or auxiliary energy available. Both the thermal and battery storage systems can be considered by the STESEP.

The thermal energy can be stored in the collector fluid or in a secondary material (and/or fluid). For STESEP it has been assumed that the additional system complexity required to use a secondary fluid for the storage subsystem would not be cost effective, and only systems using the collector fluid as the transfer medium have been considered.

Three types of thermal storage systems suitable for single fluid use have been considered. They are: (1) the double (multiple) tank system of in-line storage, (2) the neat fluid thermocline system of off-line storage, and (3) the dual media thermocline (hot rocks and oil) system of the off-line storage.

For systems requiring a large amount of thermal storage (such as the 100-MWe system described in Reference 19), the cost of the fluid eliminates thermocline and multiple tank storage in favor of dual media storage. However, when only a small amount of energy storage is possible (see Section 2.3.7), the oil cost does not influence the selection, and efficiency becomes the governing criterion.

Double (multiple) tank storage was selected for the STESEP Computer Program on this basis.

2.3.2.1 Multiple Tank Thermal Storage

Because of the large operational temperature range of the collector fluid, expansion tanks are required to accommodate the volume changes of the fluid. The double tank storage concept uses separate tanks and pumps for the hot and cold legs of the system with a ullage volume equivalent to one of the tanks.

During system operation, the hot leg pump is controlled by PCS demand and the cold leg pump by the collector outlet temperature so that one of the tanks is filling while the other tank is emptying. Thus, both the PCS and collector thermal condition are matched and a separate expansion tank eliminated. The two tanks are designed for complete mixing (i.e., thermal capacitor operation) and, therefore, have only small temperature changes as they fill and empty out of phase with each other. The inert cover gas system can be coupled to minimize makeup gas requirements and trace heaters can even be used to maintain tank temperatures during long outage periods or to preheat the tanks during startup.

The primary loss from this type of storage is that occurring through the insulation and tank supports. This is a function of the tank geometry and duration of storage at temperature, so that an average thermal efficiency⁽¹⁾ can be estimated as follows:

Flat Head Tanks:^{*}

$$\eta_{st} = 1 - \frac{(q/A)_{ins} t}{\rho c_p (T_{co} - T_{ci})} \frac{2}{D} (2 + D/L) \quad \dots(11)$$

Spherical Head Tanks:

$$\eta_{st} = 1 - \frac{(q/A)_{ins} t}{\rho c_p (T_{co} - T_{ci})} \frac{12}{D} \frac{1 + L/D}{2 + 3 L/D} \quad \dots(12)$$

Normally, spherical tanks (L/D = 0) will be preferred for double tank storage systems even with low system pressure to minimize thermal losses and aid complete mixing in the tanks.

^{*}See list of symbols.

For cold and warm thermal energy storage, a separation bladder in the tank enables the same results to be obtained with a single tank (and pump) so that Equations (11) and (12) apply equally well for hot and cold thermal systems when appropriate thermal conditions are used.

2.3.2.2 Hot Oil Thermal Stability

An important aspect of the cost of organic Rankine concepts is the thermal stability of the oil used as the heat transfer fluid. Consequently, the thermal stability data developed at Rocketdyne^(26,27) has been incorporated into the analysis effort of this study. An Arrhenius-type equation is used to relate the decomposition of the oil to the peak system temperature and used with the Rocketdyne estimate⁽²⁶⁾ of the average storage temperature. Decomposition data for both Therminol 66 and Caloria HT-43 were obtained (and are in reasonable agreement with the data reported in Reference 28) and used to compare the storage system costs for the two fluids. Caloria HT-43 was found to be less expensive and, therefore, was the fluid used for this study effort.

The decomposition rate equation used for Caloria HT-43 in the presence of solids is as follows:

$$dr = 1.53 \times 10^6 \exp(21,000/T_{co}) \quad \dots(13)$$

where $dr = \text{wt \%}/\text{hr}$ and T_{co} is in $^{\circ}\text{K}$.

The experimental decomposition rates were found to be only slightly different without the presence of solids for Caloria HT-43 so the same decomposition rate can be used for either. This decomposition rate is divided by the same time factor of 6.4 from Reference 26 to obtain the predicted loss rate for the system. Replacement costs are then considered as recurring costs in the analysis.

2.3.2.3 Battery Storage System

A survey of the literature on battery storage systems has been made, but did not turn up specific information on either system efficiency or costs. Table 3 from Reference 29 indicates the type of information found during the survey. Cycle life data and performance data in the literature is not relatable to either charge/discharge ratio or to the depth of discharge. Consequently, a fixed (0.85) battery efficiency factor is used in STESEP which is independent of the

TABLE 3
CHARACTERISTICS OF STORAGE BATTERIES

Batteries			Performance							
Systems	Electrolytes	Temperature (°F)	Current (April 1976)				Projected			
			Wh/kg	W/kg (peak)	Life (No. of Cycles)	Cost (\$/kWh)	Wh/kg	W/kg	Cycle Life	Cost (\$/kWh)
<u>Near Term (1-2 years)</u>										
Lead/Acid (SOA)	Aqueous H ₂ SO ₄	Ambient	22	50	1000	80	22	50	>1750	45
<u>Intermediate Term (3-5 years)</u>										
Lead/Acid (Advanced)	Aqueous H ₂ SO ₄	Ambient	-	-	-	-	50	50	>1500	50
Zn/Cl ₂	Aqueous ZnCl ₂	Ambient	<66	<60	<100	>2000	130	100	>1000	50
<u>Long Term (5 years)</u>										
Li/MS	LiCl-KCl eutectic	400-450	100	120	<250	>2000	150	150	>1000	40
Na/S	β-alumina	300-350	90	100	<200	>2000	170	120	>1000	40
Na/SbCl ₄	β-alumina + NaAlCl ₄	200	-	-	5000*	>2000	110	70	>1000	40
Redox	Aqueous Ti/Fe chloride	Ambient	22	-	50	-	55	50	>1000	30

*2-Wh laboratory cell.

charge/discharge rate and depth of discharge. This yields an overall in/out energy efficiency for the battery storage system of 0.722 (i.e. 0.85²). The dc-to-ac inverter efficiency is assumed to be 0.95. Based on an optimistic estimated life of 7 years, a recurring cost of 20% of the battery cost has been assumed to include both battery replacement and maintenance of the battery system.

2.3.3 Rankine Power Conversion Systems

The Carnot efficiency of a thermal power conversion system is defined by the upper and lower cycle temperature limits and represents the maximum efficiency attainable for those limits. Practical systems such as the Rankine system included in the STESEP program will operate at a fraction of this efficiency so that the efficiency of a Rankine cycle power conversion system can be represented by*

$$\eta_{PCS} = R_c \left(\frac{T_t - T_{cnd}}{T_t} \right) \quad \dots(14)$$

where R_c will be about 0.5.⁽³⁰⁾

The condensed working fluid will be heated by turbine exhaust gases in organic Rankine systems in a recuperator, which normally will be 90 to 95% effective. The recuperator model used in STESEP to determine the working fluid temperature at the inlet to the main heat exchanger is derived from an energy balance for a fixed effectiveness recuperator. It can be expressed as:

$$T_{ei} = T_t - 1.1 R_c (T_t - T_{cnd}) \quad \dots(15)$$

This assumes equal vapor and liquid specific heat with a 90% recuperator effectiveness and given a reasonable estimate of the conditions for operation of the interconnecting heat exchanger (IHx) between the collector fluid and the turbine working fluid.

2.3.4 HVAC Systems

Reject energy from the Rankine PCS can be cascaded to an absorption chiller system to provide cooling for the building. A simplified model of the absorption

*See List of Symbols

system coefficient of performance (COP) is used as a fixed fraction of the Carnot refrigeration cycle in the same manner as used for the PCS.⁽¹⁾ A nominal 35% ratio⁽¹⁾ is used in STESEP giving:

$$\text{COP} = 0.35 \frac{T_{cs} T_{ct} - T_a - \Delta T_{cnd}}{T_{ct} T_a + \Delta T_{cnd} - T_{cs}} \quad \dots(16)$$

Because of efficiency problems with lithium bromide-water absorption systems, a PCS condenser temperature of greater than 105°C (220°F) is required to include the absorption refrigeration system in the analysis. The cold thermal energy storage system discussed in Section 2.3.2 is automatically included in the analysis when absorption refrigeration systems are analyzed to provide maximum utilization of the energy.

When the Rankine cycle PCS is operated at condenser temperatures below 105°C (220°F), the reject PCS energy is exhausted through the dry cooling tower discussed in Section 2.3.5 and an electrically driven vapor compression refrigeration system is used to meet the refrigeration demand load of the building. The COP for the vapor compression refrigeration system is assumed to be 4.5.

The building heating system is assumed to use the PCS reject energy at the condenser temperature with 100% efficiency. Fossil fuel is assumed to be used during periods when the building heating and process heat (hot water) demand exceeds the energy available from the PCS. The fossil fuel is assumed to be utilized with a 75% thermal efficiency.

2.3.5 Heat Exchangers

Heat exchangers for Rankine cycle STES application are state-of-the art, as are control techniques for the exchangers.

The main heat exchanger serves as high-pressure boiler for the turbine working fluid (which can either be a saturated or superheated vapor) using collector fluid as the energy source. An additional complication is the provision for firing the boiler with fossil fuels, which should not increase the cost significantly over conventional boilers.

The cooling tower requirement will probably be met with an air-cooled heat exchanger, either as a direct condenser for the turbine vapor or as an indirect

heat dump using a liquid coolant. Both techniques are in use, with selection made based on the relative location of the turbine and cooling tower.

To model the cooling tower, an air flow rate was assumed that gave an effectiveness of 0.7 for direct condensation of the excess turbine exhaust, which was not required for the building load.

For simplicity in simulation of the main heat exchanger operation, the effective mean temperature difference (MTD) for the heat exchanger was specified as 5.5°C (10°F) and the overall heat transfer coefficient (U) was based on the calculated heat transfer coefficient for collectors calculated from Equation 7. Using equal thermal capacity streams for both the turbine and collector fluids allows a simple estimate to be made for the area required for the heat exchanger since:

$$q_{\text{use}} = U \cdot A_x \cdot \text{MTD} \quad \dots(17)$$

For supercritical systems, the "pinchpoint" does not present any problems and the solar collector inlet (T_{ci}) and outlet (T_{co}) temperatures are directly calculated.

2.3.6 Deterministic Insolation Estimates for STES Performance Evaluation⁽¹⁾

Performance predictions for solar energy systems require a mathematical model of the energy incident on the collectors. It is possible to model the long-term behavior of a solar energy system using actual hourly insolation data recorded for the location in question (site) as an input to a transient simulation program like TRNSYS.⁽⁴⁾ Such an approach probably gives the best estimate of the performance of a specified solar system. However, it can be expensive if many sites require evaluation, since the simulation must extend over a long period of time to have meaningful predictive value.

A second difficulty with the use of hourly insolation data is its limited availability. Complete hourly data for both total horizontal* and direct normal† radiation at 33 sites over a 2-year period has been prepared on tape by the Aerospace Corporation⁽³¹⁾ and 26 sites by Sandia.⁽³²⁾ The two sets overlap to a

*Sum of direct (beam) and diffuse radiation falling on a horizontal surface.

†Direct (beam) radiation falling on a surface normal to the sun's direction.

large extent, giving a total of 41 sites for which detailed hourly data is available. While these sites are fairly well distributed geographically, they do not cover all regions of possible interest. For example, Southern California is represented by seven sites, but there are none for the San Francisco bay area (Northern California).

Data on total horizontal radiation exists for many other sites. However, it is often incomplete and covers variable periods of time. Moreover, hourly values of direct normal radiation must be estimated analytically from the total horizontal values.

In summary, detailed hourly data is conveniently available for only a limited number of sites, and even for those, application of the data is a costly process requiring large computer facilities. It has been judged inappropriate to the requirements of the Reference 1 study of commercial application of STES where the primary objective was concept evaluation and system definition.

At the other extreme, solar energy input to a system can be estimated from average values obtained by numerical integration of the hourly data referred to above. Both the Sandia Laboratories and Aerospace Corporation tape data have been processed to yield daily averages of total horizontal and direct normal radiation on a monthly basis.^(32,33) More extensive tables are available for average daily values of total horizontal radiation in Reference 34 (80 sites) and Reference 35 (117 sites). The Climatic Atlas⁽³⁵⁾ also contains maps from which insolation can be estimated for any site in the United States.

In order to evaluate the useful energy input from average daily values, the latter must be modified by factors which account for the effect of collector aperture orientation and thermal efficiency. These factors can be estimated well enough to carry out preliminary screening. They depend, however, on site location, the time of year, and the detailed systems configuration in a complicated way. Any attempt to define optimum configurations or to assess the influence of component parameters requires a more detailed approach.

The method described here is eclectic, incorporating the features of several methods already in use. It attempts to make maximum use of predictable factors,

introducing random factors associated with local weather in the simplest way possible. This approach lends itself to a formulation using simple mathematical expressions suitable for use by hand calculators and small computers.⁽³⁶⁾

2.3.6.1 Insolation Model

2.3.6.1.1 Extraterrestrial Solar Radiation

Solar radiation reaching the top of the earth's atmosphere may be predicted quite accurately. Its intensity is a near constant, I_c , modified only by a small correction, R , which takes into account the effect of seasonal variations in the earth-sun distance. According to Reference 37, this distance correction is approximately:

$$R = 1.0 + 0.033 \cos (360 n'/365) \quad \dots(18)$$

where n' is the day of the year. Monthly values of R are also given in Table 4.

The angle of incidence on a horizontal surface (the zenith angle θ_z) depends upon the geographic location (latitude ϕ), the solar declination δ , and the local solar time, as measured by the hour angle h .

$$\cos \theta_z = \sin \delta \sin \phi + \cos \delta \cos \phi \cos h \quad \dots(19)$$

The solar declination is a function of the day of the year and is given approximately by:

$$\delta = 23.45 \sin [284 + n' (360/365)] \quad \dots(20)$$

The declination is also given in Table 4.

TABLE 4
SEASONALLY VARYING SOLAR RADIATION PARAMETERS

Date	R	δ (degree)	A/I _c	B
January 21	1.031	-20.0	0.909	0.142
February 21	1.021	-10.8	0.897	0.144
March 21	1.006	0.0	0.876	0.156
April 21	0.989	+11.6	0.839	0.180
May 21	0.975	+20.0	0.815	0.196
June 21	0.968	+23.45	0.804	0.205
July 21	0.969	+20.6	0.801	0.207
August 21	0.979	+12.3	0.818	0.201
September 21	0.999	0.0	0.850	0.177
October 21	1.011	-10.5	0.881	0.160
November 21	1.026	-19.8	0.902	0.149
December 21	1.033	-23.45	0.911	0.142

2.3.6.1.2 Estimation of Direct (Beam) Radiation During Noncloudy Times

On noncloudy days, most of the extraterrestrial radiation penetrates the atmosphere with small change in direction. A portion of the initial radiation is absorbed by molecular atmospheric constituents; another fraction is scattered out of the beam direction by molecules, droplets, and suspended solid particles. The attenuation, which depends upon the concentration of absorbers and scatterers in the atmosphere, can be considered to have a local component and a general component which exhibits systematic seasonal variations.

The ASHRAE Handbook of Fundamentals⁽³⁸⁾ presents a semitheoretical expression for direct normal radiation, I_{DN} , which follows this approach. It is expressed in terms of an apparent extraterrestrial irradiation A and an extinction coefficient B based on air mass.

$$I_{DN} = CN \cdot A \cdot \exp \left(-B / \cos \theta_z \right) \quad \dots(21)$$

where I_{DN} is the irradiation on a surface normal to the beam. The term A includes both the effects of upper atmosphere absorption and of variable earth-sun distance.

Table 4 gives monthly values of A and B based upon empirical data from Refer-
 enct 38. These values have been used in the numerical results reported here.
 The factor CN is a "clearness number" which characterizes the average local trans-
 mittance of the atmosphere. It may exhibit seasonal variations.

2.3.6.1.3 Estimation of Diffuse Radiation

A certain amount of the radiation scattered by atmospheric constituents and
 cloud surfaces reaches ground level from directions other than that of the direct
 beam. The amount of this diffuse radiation received is a complicated function of
 the state of the atmosphere, the sun's position, ground reflectance, and surface
 orientation. The difuse component is estimated by means of two simplifying
 assumptions: (1) that the diffuse radiation is independent of the orientation
 of the receiving surface and (2) that the direct normal radiation is linearly
 related to the "percent possible," the fraction of total (direct plus diffuse)
 radiation falling on a horizontal surface at ground level compared with the extra-
 terrestrial value. These assumptions result in the following relationship
 between direct and diffuse radiation intensities:

$$I_{DN} = \alpha' \frac{I_{DN} \cdot \cos \theta_z + I_{DF}}{I_c \cdot R \cdot \cos \theta_z} + \beta' \quad \dots(22)$$

The coefficients α' and β' are empirically determined by linear regression analysis
 of simultaneous measurements of both total and direct components. Although they
 are found to depend to some extent on site location and time of day, they are
 treated as constants in the present application.

2.3.6.1.4 Effect of Cloud Cover

Solar radiation exhibits periods of reduced intensity associated with the
 obscuration of sunlight by clouds. The effects range from long-term overcasts,
 which may last for days, to broken cloud cover, which may block the sun for only
 a fraction of an hour. The net effect of cloud cover is to reduce the average
 radiation measured at a given site below the unclouded values. Cloud effects
 are dependent on local atmospheric characteristics and vary seasonally. In the
 present method, the effect of cloud cover is approximated very simply. On the
 average, for each hour of the day, the proportion of unclouded time is assumed
 to be a constant, CF. During the remaining fraction (1-CF), solar radiation is
 considered to be nil.

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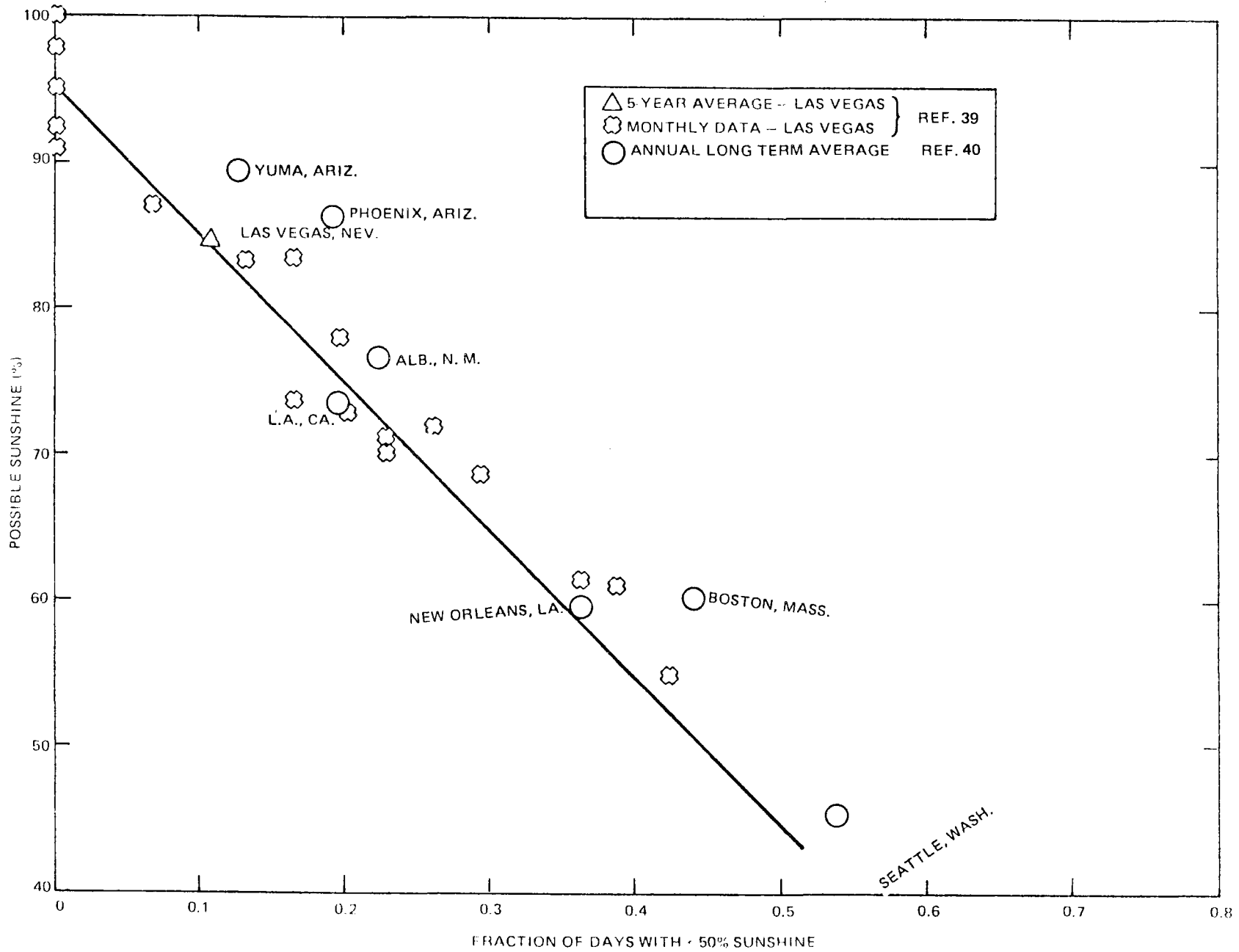


Figure 10. Sunfall Outage Correlation

2.3.6.2 Approximation of Solar Insolation Usable by Concentrating Systems

The deterministic method of approximating solar insolation described above allows the STESEP to evaluate flat plat, 1-axis, and 2-axis tracking-distributed collectors directly, but cannot directly predict weather outages as described in References 39 to 41.

To estimate realistically the usable energy collected by the STES, the analysis approach used in Reference 39 has been adopted and is based on the percent possible sunshine (PP) data for the site. For conceptual design purposes, days having ~50% of possible sunshine (PP) will allow this decrease in energy production for the STES caused by weather outages to be estimated. Reference 40 also presents this type of information and agrees reasonably well with Reference 39, when the number of cloudy days per month is used as the parameter as shown in Figure 10. The curve from Figure 10 is used to estimate outage losses in STESEP, based on the monthly PP data for each site, and to provide good predictions of the energy displacement over the life of the system.

$$\text{Fraction Sunny Days (FSD)} = 0.05 + \text{PP}/100 \quad \dots(23)$$

This methodology allows a number of conceptual designs to be evaluated, at minimum expense, to determine the proper operating strategy, in addition to determining equipment sizes, costs, and energy output. Because of the weather outages, a significant amount of the design load for the building will have to be supplied by conventional means. The standby fossil fuel system can provide this load, or it can be obtained from the utility during off hours, stored, and used as needed during high-load periods. The "make or buy" decision is dependent on the relative costs of fuel and electricity at the site, as well as on the STES design itself. The STESEP Program analyzes both "making" and "buying" of this energy, to determine the most cost effective way to produce the site load profile as described in the following sections.

2.3.7 Approximation of Auxiliary Energy Requirements

A maximum value could be specified for the electric energy purchased from the utility, which requires the STESEP program to size the PCS to produce all demands greater than this value with use of fossil fuel augmenting the solar energy available to meet these demand loads. A minimum can also be specified for the energy purchased

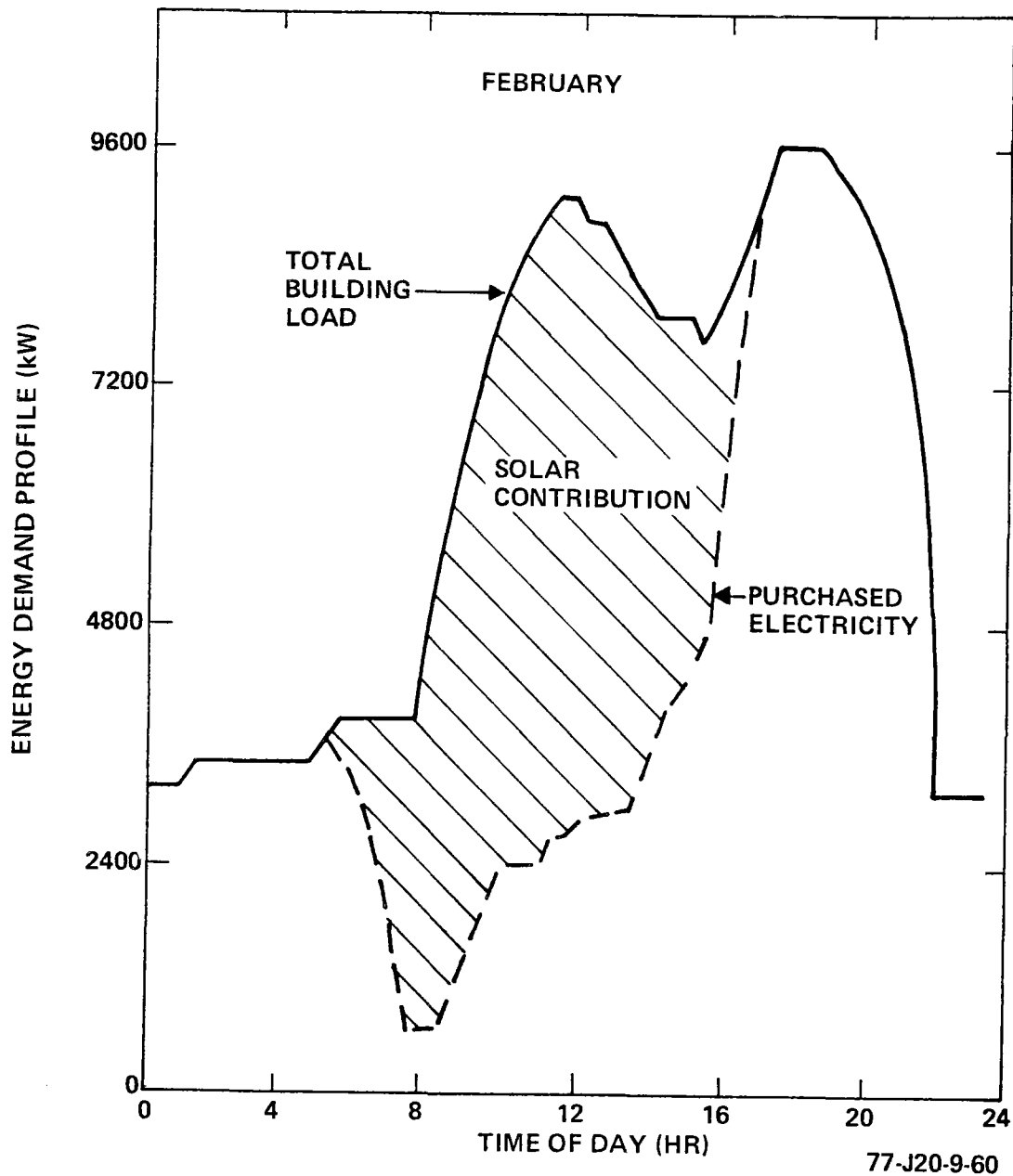


Figure 11. Typical Hourly Load Variation

from the utility which requires the STESEP program to size batteries and collectors to generate and store excess energy overnight for use during the following day. The STESEP program is, therefore, capable of evaluating a wide range of make or buy conditions for each STES design concept. This feature of the program was found to be necessary in order to maintain credibility for the conceptual STES designs, which tend to produce very poor load profiles from the utilities' point of view, as discussed in Reference 42. The weather outages discussed previously are the primary cause of this problem, since they prevent the peak demand load of the building from being reduced by the STES and required that the utility add additional power generation capability. This has been recognized as a problem by all investigators⁽³⁹⁾ and must be considered as part of the evaluation method.

STES sized to provide 40% or less solar contribution may not generate enough energy to cost effectively utilize either thermal or battery storage (as illustrated in Figure 11 for a photovoltaic STES concept) for an average winter day. It can be seen that the peak purchased power for a day in February, for example, has not been reduced by the STES; although a 30% reduction in total energy has been accomplished. Even with current utility contracts, the demand charge will significantly increase the cost of electricity to the user for the full ratchet period of 1 to 12 months. This problem applies to all STES concepts considered thus far and, additionally, a period of clouds (low insolation) will occur every year with a high probability of requiring purchase of all electric energy for several days a year. A 6- or 12-month ratchet in the utility contract would, therefore, make the cost of energy prohibitive to the facility operator if peak sharing use of auxiliary energy is not used.

2.4 COST ALGORITHMS

A number of algorithms, based on 1976 price estimates, have been developed for the capital costs of candidate capital equipment and items, redundancy effects, and operations and maintenance costs. They are discussed in the following paragraphs.

2.4.1 Capital Equipment Costs

Algorithms for the installed costs for the several candidate capital equipment items considered were obtained from References 43-49 and are presented in Table 5. Preliminary computations indicate that the collector, storage, and power conversion systems will approach 90% of the initial capital outlays.

TABLE 5
COST ALGORITHMS FOR CAPITAL EQUIPMENT

Unit	Size Range	Algorithm	Reference
1. Collector:			
a) Distributive	—	\$100/m ²	47
b) Heliostats		\$65/m ²	47
2. Storage:			
a) Hot Storage	150 - 150,000 ft ³	Cost = \$352 (vol, ft ³) ^{0.515} + \$12 (vol, ft ³)	44,49
b) Cold Storage	150 - 150,000 ft ³	Cost = \$352 (vol, ft ³) ^{0.515}	49
c) Battery	—	Cost = \$50 (size, kWh) + \$75 (system size, kW)	43
3. Packaged Steam Boilers	10 ⁴ - 10 ⁵ lb Steam/h-Unit	Cost/Unit = \$3690 (lb Steam/ h Unit) ^{0.32}	43
4. Refrigeration:			
a) Centrifugal Chillers (Electric)	250-2000 tons	Cost/Unit = \$4240 (tons/ Unit) ^{0.61}	43
b) Centrifugal Chillers (Engine)	500-2000 tons	Cost/Unit = \$2270 (tons/ Unit) ^{0.745}	43
c) Absorption Chillers (Steam)	250-1200 tons	Cost/Unit = \$2194 (tons/ Unit) ^{0.7}	43
5. Power Conversion Systems:			
a) Sunstrand Organic Rankine Cycle	100-1000 kW	Cost = \$3815 (kW/Unit) ^{0.66}	45
b) Rankine Cycle — Steam	1-1000 kW	Cost = \$22,700 + \$350 (kW)	46
c) Rankine Cycle — Steam	1000-1,000,000 kW	Cost = \$2150 (kW) ^{0.825}	46
6. Shell & Tube Heat Exchangers	20-2000 ft ²	Cost/Unit = \$300 (Area, ft ²) ^{0.56}	48
7. Cooling Towers — Dry	—	Cost/Unit = \$40 (Area, ft ²) ^{0.6}	49

The several power conversion system cost algorithms have been compared for a 1-MWe unit. The costs ranged from \$365,000 to \$375,000. (Costs for equivalent "conventional" fossile fuel-fired gas turbine and 900-rpm reciprocating engine installations, derived from Reference 43, were \$357,000 and \$500,000.)

2.4.1.1 Estimated Cost of Small Central Receivers and Towers

In order to compare the performance of small central receivers with distributive collectors for STES commercial applications, algorithms for cost of the receiver and tower are required. In Reference 46, it was suggested that \$100/m² should be used for the installed cost of distributed collectors and \$65/m² for the heliostats used in a central receiver system. The cost of the receiver/tower was not given.

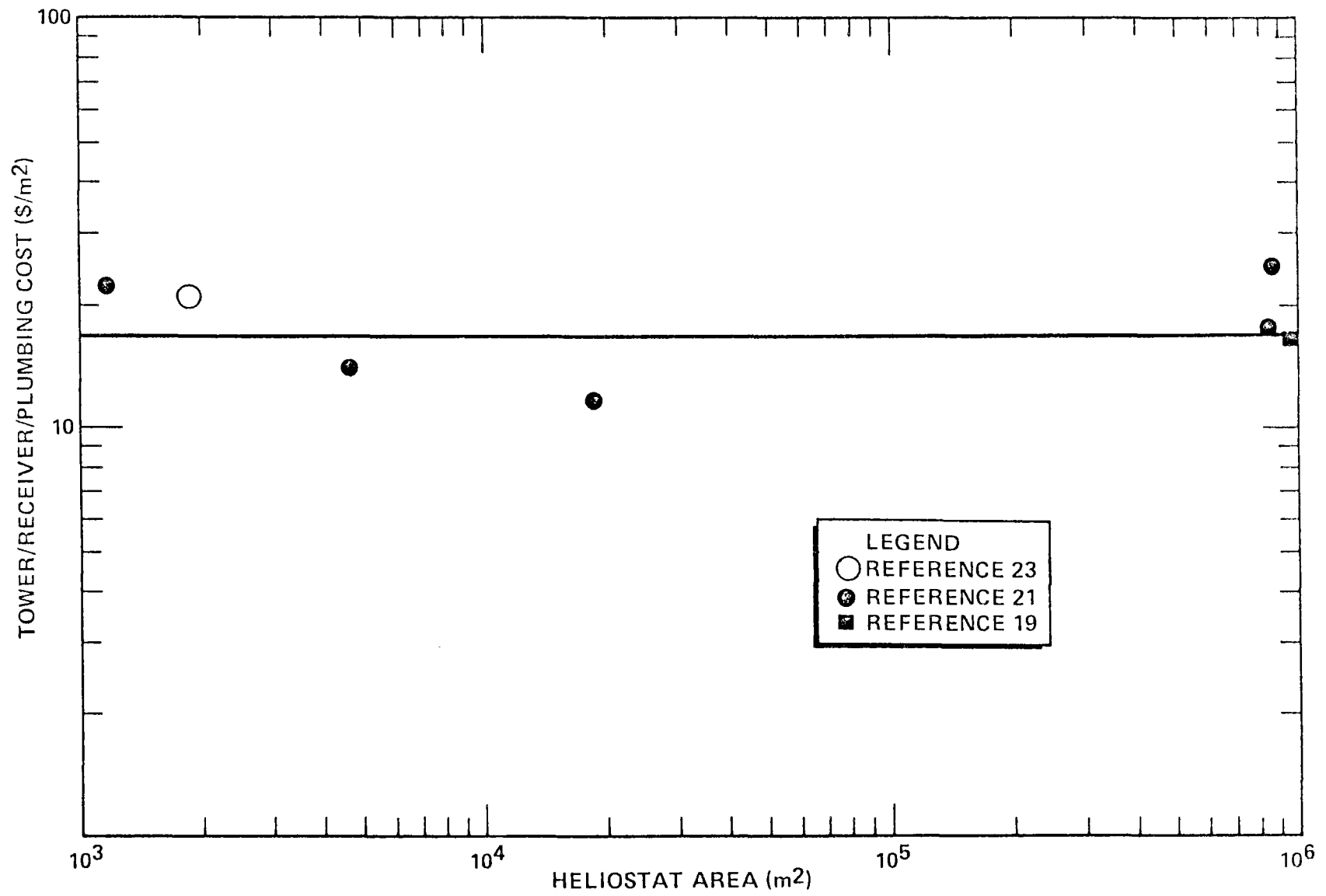
Reference 21 gives estimates for three small systems designed at the University of Houston and refers to previous analyses of large systems (100-200 MWe). Reference 19 describes one of these large systems in detail and has been used in conjunction with References 21 and 23 as the basis for this cost estimate.

In Reference 25, the height requirement for the central receiver tower is discussed. It is shown that the tower height will be approximately proportional to the square root of the heliostat area.

The cost of the tower itself will be proportional to the height of the tower raised to a power greater than unity. If the cost is assumed proportional to the square of the height, then the tower cost will be proportional to the heliostat area. Since the absorber area is also proportional to the heliostat area for a given concentration ratio, the total costs of the tower/receiver/plumbing should be related directly to the heliostat area.

Figure 12 shows the unit costs (\$/m²) presented in References 21 and 19 for six systems ranging in size from a heliostat area of 1,100 to 855,000 m². These data indicate that 17 \$/m² is a reasonable cost estimate over this range. The central receiver reference costs can, therefore, be related to the heliostat area by the algorithm:

$$\text{Central Receiver Cost} = (65 + 17) \$/\text{m}^2 = 82 \$/\text{m}^2 \quad \dots(24)$$



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Figure 12. Effect of System Size on Central Receiver Cost

2.4.1.2 Effect of Redundancy of Subsystem Capital Costs

A scaling relationship was developed and the effect of selected subsystem redundancy on cost was assessed. Figure 13 shows the approximate effect of the number of units used to provide redundancy on the capital cost of a system when the unit costs are a power law function of the component size. That is,

$$\text{Unit Cost} \cong (\text{Unit Size})^n \quad \dots(25)$$

The exponent, n , normally varies between 0.5 and 0.7.⁽⁴³⁾ To provide redundancy, one extra unit is assumed to be needed in the system so that the total cost is given by:

$$\text{Total Cost} \cong \left(\frac{\text{Design Capacity}}{\text{Unit Size}} + 1 \right) (\text{Unit Size})^n \quad \dots(26)$$

As indicated in Figure 13, the cost of the redundant system is approximately double that of the nonredundant system independent of the number of components used with very little effect indicated for the power law exponent on the system cost.

2.4.2 Operations and Maintenance Costs

The operations and maintenance cost algorithms for both attended and "unattended" organic Rankine cycle plants were estimated based on the analyses of Reference 43. The data were developed by allocating supervision, operations, and maintenance labor as a function of plant size and operating hours in accordance with the guidelines suggested in Reference 43. Current quotations were used for labor rates (indirect, direct, and contract maintenance); materials and supply costs were estimated as a function of the number of kilowatt hours generated annually. Table 6 presents the allocations by category for attended Rankine cycle plants while Table 7 presents the allocation for unattended Rankine cycle plants. Figure 14 shows the effect of installed capacity on the operation and maintenance cost contribution to the cost of electricity from the plant.

COST ~ (NO. UNITS) (SIZE)

OR

$$\frac{C_2}{C_1} \sim \frac{N_2}{N_1} \left(\frac{S_2}{S_1} \right)^n$$

WHERE:

	SIZE	N	
S = 100		1	N ₁
}	100	2	N ₂
	50	3	
	33	4	
	25	5	

AND n = 0.5; 0.6; 0.7

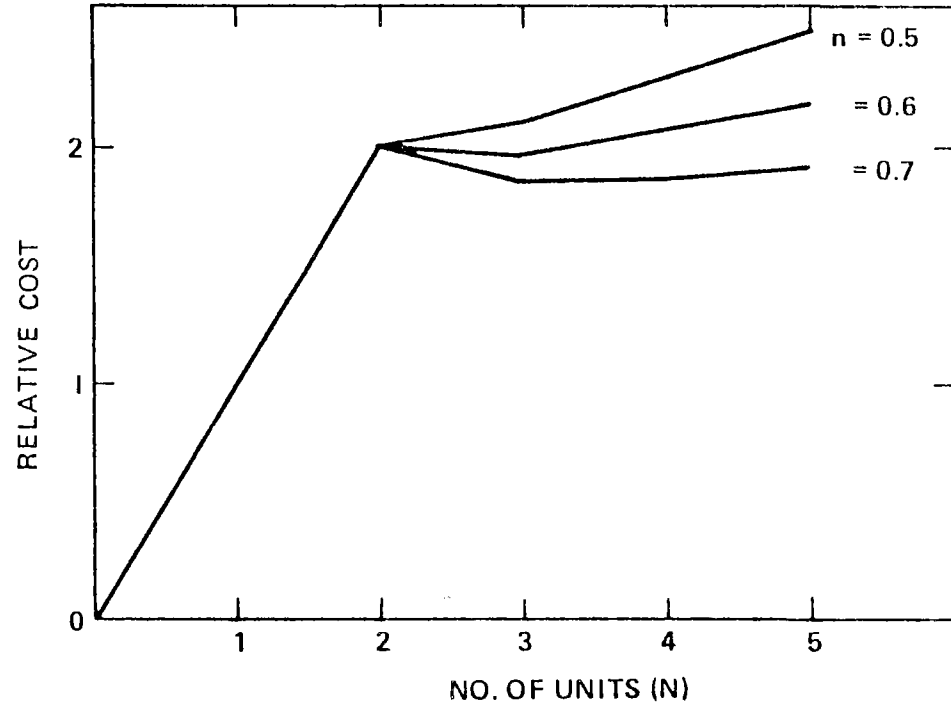


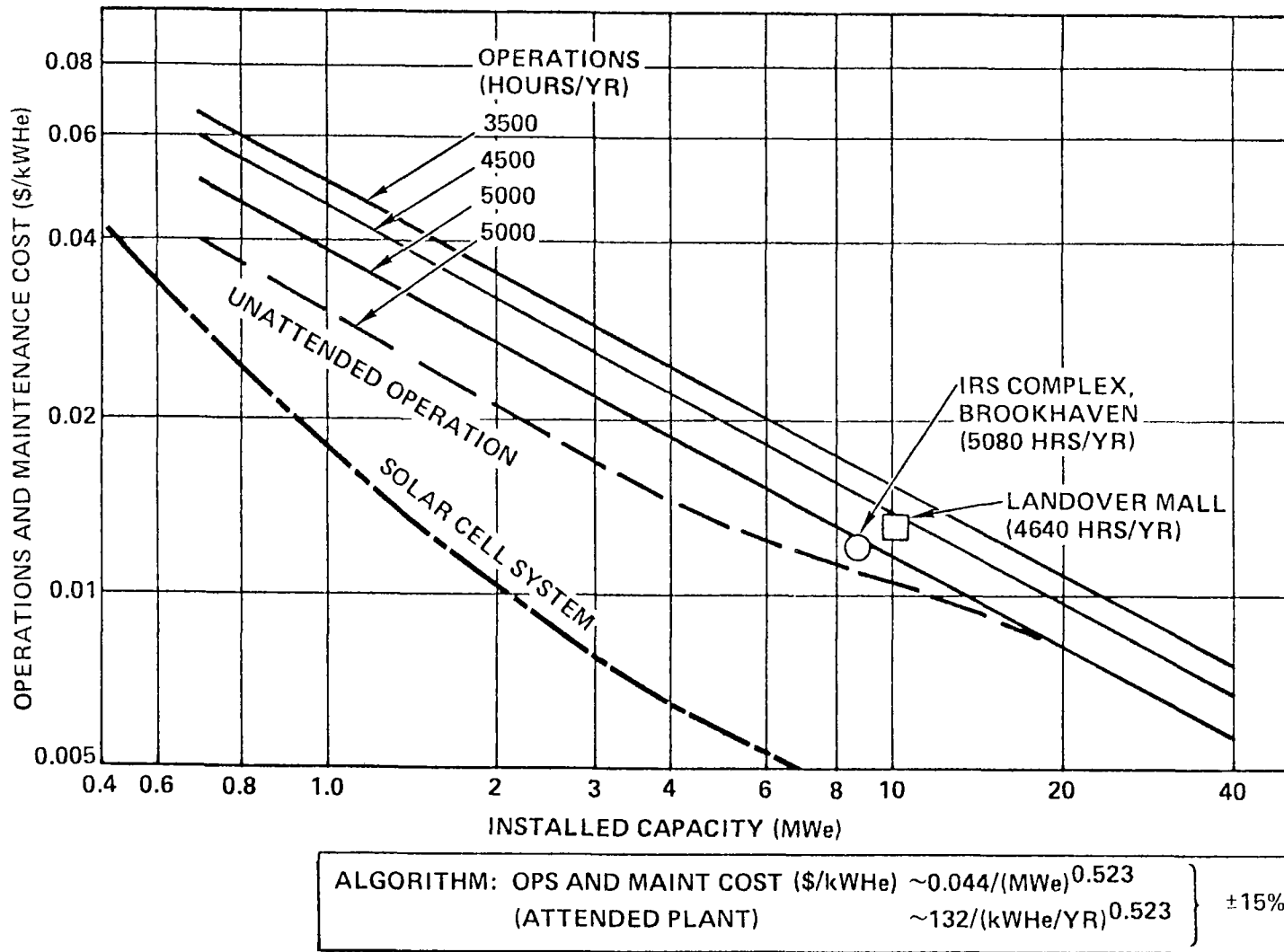
Figure 13. Effect of Redundancy on System Cost

TABLE 6
OPERATIONS AND MAINTENANCE COSTS — FULLY ATTENDED RANKINE CYCLE

Installed Capacity (Nom.) (MWe)	Power Generated (kWh x 10 ⁶ /yr)	Materials & Supplies (\$1000/yr)	Operators		Supervision (\$1000/yr)	Maintenance		Cost (\$/kWh)
			Number	Cost (\$1000/yr)		Direct (\$1000/yr)	Contract (\$1000/yr)	
0.6	3	12	3	81	35	33	14	5.8
1.0	5	20	3	81	35	33	23	3.8
5.0	25	100	4	108	35	99	46	1.6
10.0	50	200	5	135	35	165	92	1.3
20.0	100	400	5	135	35	165	138	0.87
40.0	200	800	5	135	35	165	138	0.64

TABLE 7
OPERATIONS AND MAINTENANCE COSTS — "UNATTENDED" RANKINE CYCLE

Installed Capacity (Nom.) (MWe)	Power Generated (kWh x 10 ⁶ /yr)	Materials & Supplies (\$1000/yr)	Operators		Supervision (\$1000/yr)	Maintenance		Cost (\$/kWh)
			Number	Cost (\$1000/yr)		Direct (\$1000/yr)	Contract (\$1000/yr)	
0.6	3	12	0	0	35	66	14	4.2
1.0	5	20	0	0	35	66	23	2.9
5.0	25	100	0	0	35	99	46	1.1
10.0	50	200	0	0	70	165	92	1.1
20.0	100	400	0	0	105	165	138	0.81
40.0	200	800	0	0	105	165	138	0.60



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Figure 14. Cost Algorithm (Operation and Maintenance)

The operations and maintenance costs for attended Rankine cycle plants are well represented by the equation:

$$\text{Cost/year} = 132 (\text{kWh/year})^{0.523} \quad \dots(27)$$

The operation and maintenance cost algorithm for a nontracking photovoltaic STES is also shown in Figure 14. The data were developed in a similar manner to the Rankine cycle plant costs by allocating supervision operations and maintenance labor as a function of plant size and operating hours as shown in Table 8. The algorithm for photovoltaic STES is given by:

$$\text{Cost/year} = 80,000 + 2.68 \times 10^{-3} (\text{kWh/year}) \quad \dots(28)$$

2.4.3 Approximation of Purchased Power Costs

The solution to potential load profile problems appears to lie in the combination of a peak-shaving system or a load-leveling system with the STES, so that purchased power in the evening and early morning may be stored if desired for use during low insolation periods whether in the evening or during cloudy days. The alternate approach is to generate the energy onsite with fossil fuel backup as part of the STES and reduce the peak purchased power as required. Either or both of these techniques can be used to produce load profiles that are acceptable to utilities; however, to evaluate the economic aspects requires definition of the cost of purchased electricity at specific sites fairly accurately. Reference 50 publishes a rate summary for commercial users of electricity which can be used to define the constants in an empirical equation of the form:

$$$/\text{kWh} = C_1 (\text{kW/kWh})^{C_2} / \text{kW}^{C_3} \quad \dots(29)$$

This type of equation acknowledges that current rate schedules have both a demand and energy charge and can, therefore, approximate the charges that will occur in the cost of purchased power as the load profile of the building changes. Figure 15 shows the variation in cost of electricity for the sites considered in this study. A sample determination of the coefficients (C_1, C_2, C_3) is given in 3.1.3.3.

2.4.4 System Annualized Costs

The figure of merit used by the STESEP Computer Program to evaluate the various STES concepts is the JPL/ERDA⁽¹⁵⁾ "annualized cost." This is, in effect,

TABLE 8
OPERATIONS AND MAINTENANCE COSTS — SOLAR PHOTOVOLTAIC CYCLE

Installed Capacity (Nom.) (MWe)	Power Generated (kWh x 10 ⁶ /yr)	Materials & Supplies (\$1000/yr)	Operators		Supervision (\$1000/yr)	Maintenance		Cost (\$/kWh)
			Number	Cost (\$1000/yr)		Direct (\$1000/yr)	Contract (\$1000/yr)	
0.6	3	6	0	0	35	33	14	2.93
1.0	5	10	0	0	35	33	14	1.84
5.0	25	50	0	0	35	33	28	.58
10.0	50	100	0	0	35	50	40	.45
20.0	100	200	0	0	35	75	60	.37
40.0	200	400	0	0	35	100	80	.31

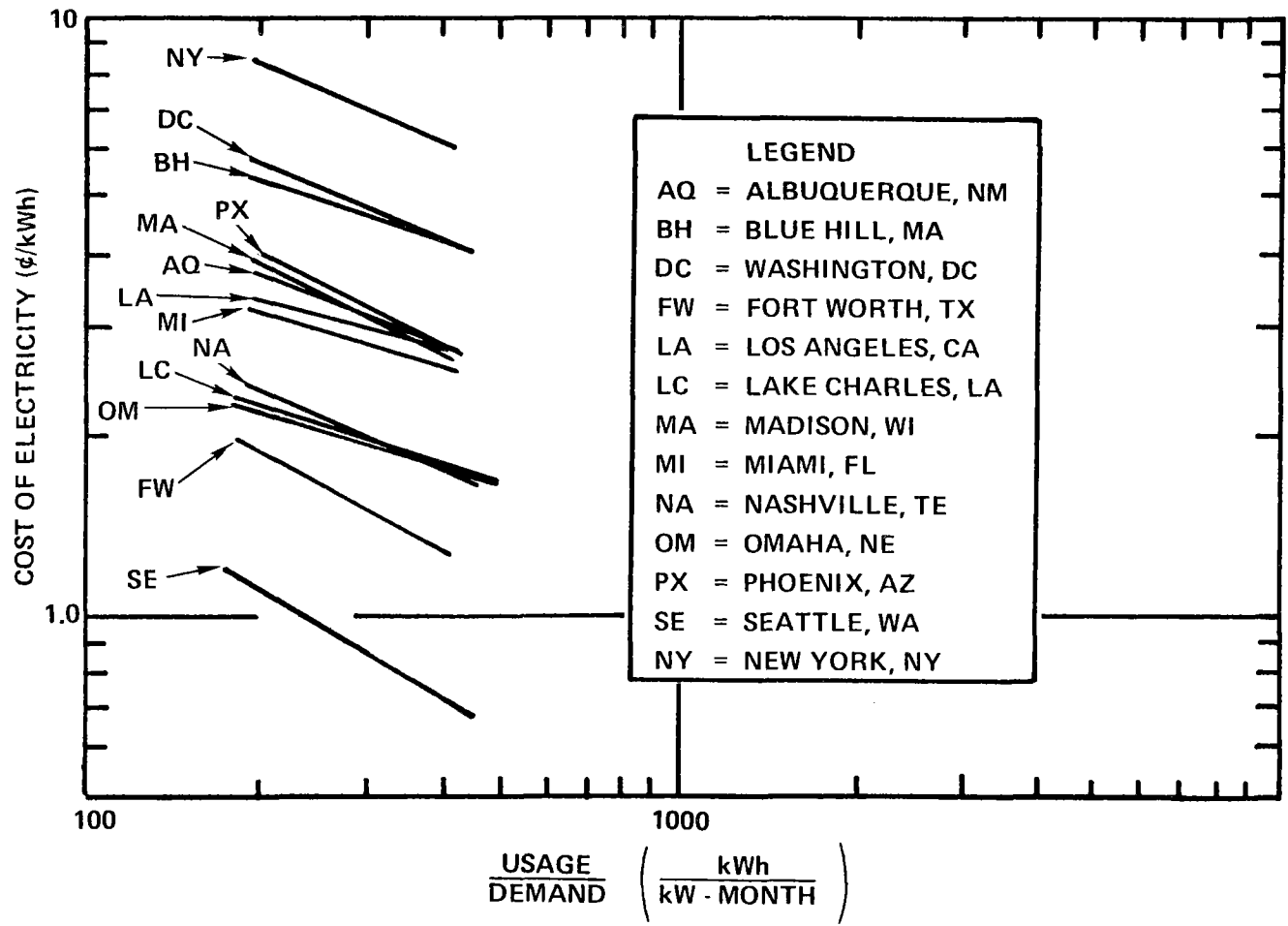


Figure 15. Present Cost of Electricity

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a present value analysis of the total system life cycle costs. This concept considers the effects of both inflation (g) of capital costs (CI) and escalation in the cost of fuel and operating expenses (g_f).

Reference 15 gives the complete development of this method, which relates the annualized cost of the systems to the following relationship between capital investment (CI) and recurring cost (RCC):

$$\overline{AC} = (\overline{FCR} \times CI_{pv} + CRF \times RCC_{pv}) / (1 + g)^P \quad \dots(30)$$

From the "annualized cost" of the building configuration without a solar total energy system, an incremental return on investment ($\Delta R.O.I.$) can be computed as:

$$\Delta R.O.I. = (\overline{AC}_0 - \overline{AC}_{STES}) / CI_{STES} \quad \dots(31)$$

In a like manner, the "breakeven" cost of electricity (B.E.C.E.) can be computed for each system as follows:

$$B.E.C.E. = \left(\frac{\$}{kWh} \right) \times \left[\frac{\overline{FCR}(CI_{STES} - CI_0)_{pv} + CRF(OPM_{STES} - OPM_0)_{pv}}{CRF(kWh_0 - kWh_{STES})_{pv}} \right] \quad \dots(32)$$

All of these cost parameters are sensitive to the specific cost parameters (g , g_f , k , system life, etc.) but are useful for comparing systems for fixed economic parameters. Limit analysis can then be used to evaluate the effects of uncertainties in the cost parameters.

2.5 SITE AND BUILDING DATA

Characterization of the environment at the site location and the building demand loads is necessary before the STESEP Computer Program can be used to evaluate the application of an STES to meet all or part of the building energy requirements.

2.5.1 Site Environment Characterization

Tables 9 through 20 illustrate the site information necessary as input parameters to the STESEP Computer Program. The locations in these 12 tables

CLIMATE AND INSOLATION SUMMARY

TABLL 9

SITE NAME ALBUQUERQUE, N.M. LATITUDE 35.05° LONGITUDE 106.62°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 8.3 °C, 94 °F;

WIND SPEED LOW

SUMMER - 2 1/2%

DRY BULB TEMP 34.4 °C, 94 °F;

WET BULB TEMP 18.3 °C, 65 °F

DESIGN RELATIVE HUMIDITY 20 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	513	389	331	156	32	0	0	0	4	121	342	496
°F	924	700	595	282	58	0	0	0	7	218	615	893
COOLING °C	0	0	0	3	37	162	236	200	89	4	0	0
°F	0	0	0	6	67	291	425	360	160	7	0	0

PERCENT POSSIBLE SUNSHINE:

70	72	72	76	79	84	76	75	81	80	79	70
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	8.0	11.2	14.9	20.6	25.7	31.4	32.9	31.1	27.9	21.5	13.4	9.1
°F	46.4	52.2	58.8	69.1	78.3	88.6	91.2	88.0	82.3	70.7	56.1	48.3
MIN D.B. °C	-4.7	-2.5	0.4	5.7	11.1	16.2	18.8	17.9	14.2	7.4	-0.5	-3.6
°F	23.5	27.5	32.7	42.2	51.5	61.1	65.8	64.3	57.6	45.3	31.1	25.6

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	3.58	4.50	6.00	7.30	8.29	8.63	7.39	7.23	5.87	6.23	3.80	3.48
Btu/ft ²	1136	1427	1903	2116	2630	2738	2343	2292	1861	1658	1205	1105
DIRECT kWh/m ²	6.77	7.11	8.48	9.10	10.00	10.40	8.43	8.90	7.37	8.19	6.90	7.23
Btu/ft ²	2149	2254	2591	2887	3172	3299	2691	2824	2337	2599	2189	2292

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.96	0.87	0.99	0.92	1.17	1.17	1.03	1.10	0.93	1.05	0.97	1.14
CLOUD FACTOR	0.84	0.85	0.85	0.87	0.89	0.92	0.87	0.866	0.90	0.89	0.89	0.84

CLIMATE AND INSOLATION SUMMARY

TABLE 10

SITE NAME BLUE HILL, MASS. LATITUDE 42.22° LONGITUDE 71.02°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -12.2 °C, 10 °F;

WIND SPEED HIGH

SUMMER - 2 1/2%

DRY BULB TEMP 31.1 °C, 88 °F;

WET BULB TEMP 23.3 °C, 74 °F

DESIGN RELATIVE HUMIDITY 50 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	668	583	513	312	151	30	3	8	62	203	378	608
HEATING °F	1203	1050	924	561	271	54	6	14	111	366	681	1094
COOLING °C	0	0	0	0	6	38	108	83	18	0	0	0
COOLING °F	0	0	0	0	10	69	195	150	33	0	0	0

PERCENT POSSIBLE SUNSHINE:

47	56	57	56	59	62	64	63	61	58	48	48
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AVERAGE AMBIENT TEMPERATURE RANGE:

	°C	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX D.B.	°C	2.8	2.8	7.2	13.3	20.	24.4	27.8	26.7	22.8	17.2	11.1	4.4
	°F	37	37	45	56	68	76	82	80	73	63	52	40
MIN D.B.	°C	-5	-5	-6	4.4	10	15	18.3	17.2	13.9	8.3	3.3	-2.8
	°F	23	23	31	40	50	59	65	63	57	47	38	27

AVERAGE DAILY INCIDENT RADIATION:

	Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HORIZ	kWh/m ²	1.87	2.68	4.03	5.07	6.00	6.33	5.71	5.23	4.17	3.35	1.71	1.90
	Btu/ft ²	593	850	1278	1608	1903	2008	1811	1659	1323	1063	542	603
DIRECT	kWh/m ²	4.06	4.64	5.94	6.33	7.03	7.10	6.42	6.42	5.60	5.48	3.42	4.26
	Btu/ft ²	1288	1472	1884	2008	2230	2252	2036	2036	1776	1738	1085	1351

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.74	0.61	0.75	0.82	0.91	0.92	0.79	0.81	0.81	0.92	0.62	1.05
CLOUD FACTOR	0.69	0.75	0.76	0.75	0.77	0.79	0.80	0.79	0.78	0.76	0.70	0.69

CLIMATE AND INSOLATION SUMMARY

TABLE 11

SITE NAME FT. WORTH, TEXAS LATITUDE 32.83° LONGITUDE 97.05°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -4.4 °C, 24 °F;

WIND SPEED HIGH

SUMMER - 2 1/2%

DRY BULB TEMP 37.8 °C, 100 °F;

WET BULB TEMP 25.6 °C, 78 °F

DESIGN RELATIVE HUMIDITY 40 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	348	253	186	49	0	0	0	0	0	33	159	294
	°F	626	456	335	88	0	0	0	0	0	60	287	530
COOLING	°C	0	0	14	52	131	260	341	343	212	78	6	0
	°F	0	0	25	94	236	468	614	617	381	141	11	0

PERCENT POSSIBLE SUNSHINE:

56	57	65	66	67	75	78	78	74	70	63	58
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AVERAGE AMBIENT TEMPERATURE RANGE:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX D.B.	°C	13.3	15.6	19.4	24.4	28.3	33.3	35.6	35.6	31.7	26.1	18.9	14.4
	°F	56	60	67	76	83	92	96	96	89	79	66	58
MIN D.B.	°C	1.7	3.9	6.7	12.2	17.2	21.7	23.9	23.9	20	13.3	6.7	2.8
	°F	35	39	44	54	63	71	75	75	68	56	44	37

AVERAGE DAILY INCIDENT RADIATION:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HORIZ	kWh/m ²	3.06	3.86	5.19	5.20	6.81	6.81	7.42	7.10	5.27	4.39	2.94	2.61
	Btu/ft ²	971	1224	1646	1649	2160	2160	2354	2252	1672	1393	933	828
DIRECT	kWh/m ²	5.10	5.61	6.71	5.67	7.55	7.58	8.65	8.74	6.47	6.42	4.61	4.55
	Btu/ft ²	1618	1779	2128	1799	2395	2404	2744	2772	2052	2052	1462	1443

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.78	0.75	0.81	0.66	0.97	0.87	1.0	1.02	0.79	0.81	0.66	0.71
CLOUD FACTOR	0.75	0.76	0.81	0.81	0.82	0.87	0.88	0.88	0.86	0.84	0.79	0.76

CLIMATE AND INSOLATION SUMMARY

TABLE 12

SITE NAME LAKE CHARLES, LA LATITUDE 30.12° LONGITUDE 93.22°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 0.6 °C, 33 °F;

WIND SPEED MEDIUM

SUMMER - 2 1/2%

DRY BULB TEMP 33.9 °C, 93 °F;

WET BULB TEMP 26.1 °C, 79 °F;

DESIGN RELATIVE HUMIDITY 60 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	231	170	111	14	0	0	0	0	0	20	98	188
°F	415	306	200	26	0	0	0	0	0	36	177	338
COOLING °C	12	16	30	79	176	262	299	296	223	106	18	4
°F	21	29	54	143	316	471	539	533	402	191	33	7

PERCENT POSSIBLE SUNSHINE:

49	50	57	63	66	64	58	60	64	70	60	46
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	17.8	19.4	21.7	25.6	28.9	32.2	32.8	32.8	30.6	26.7	21.1	18.3
°F	64	67	71	78	84	90	91	91	87	80	70	65
MIN D.B. °C	7.2	8.9	11.1	14.4	17.8	21.7	22.8	22.8	20.6	16.1	10	7.8
°F	45	48	52	58	64	71	73	73	69	61	50	46

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	2.42	3.68	4.55	5.20	6.48	5.87	6.23	5.68	5.00	4.48	3.06	2.52
Btu/ft ²	766	1167	1443	1649	2055	1862	1976	1802	1586	1421	971	799
DIRECT kWh/m ²	3.35	4.89	4.54	5.53	7.29	6.43	7.10	6.68	5.83	5.94	4.35	3.87
Btu/ft ²	1063	1551	1729	1754	2312	2040	2252	2119	1849	1884	1380	1228

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.48	0.70	0.68	0.67	0.90	0.77	0.96	0.85	0.77	0.76	0.64	0.69
CLOUD FACTOR	0.70	0.71	0.76	0.79	0.81	0.80	0.76	0.78	0.80	0.84	0.78	0.68

CLIMATE AND INSOLATION SUMMARY

TABLE 13

SITE NAME LOS ANGELES, CA. LATITUDE 34.05° LONGITUDE 118.23°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 6.7 °C, 44. °F;

WIND SPEED VERY LOW

SUMMER - 2 1/2%

DRY BULB TEMP 32.2 °C, 90. °F;

WET BULB TEMP 21.1 °C, 79. °F

DESIGN RELATIVE HUMIDITY 36 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	149	115	106	69	33	14	0	0	3	19	63	121
°F	268	207	190	124	60	25	0	0	5	35	113	218
COOLING °C	6	8	6	14	28	64	143	157	131	78	24	0
°F	10	14	10	25	51	115	258	282	236	140	44	0

PERCENT POSSIBLE SUNSHINE:

70	69	70	67	68	69	80	81	80	76	79	72
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B. °C	18.3	18.9	20.3	21.4	22.9	25.1	28.5	28.5	28.0	25.2	22.9	19.7
°F	65.0	66.0	68.6	70.6	73.3	77.1	83.3	83.3	82.4	77.3	73.3	67.5
MIN D.B. °C	8.1	9.0	10.1	11.7	13.3	14.9	17.0	17.2	16.3	14.1	11.2	9.3
°F	46.6	48.2	50.2	53.0	56.0	58.9	62.6	62.9	61.4	57.4	52.1	48.8

AVERAGE DAILY INCIDENT RADIATION:

HORIZ kWh/m ²	2.94	3.32	5.23	6.57	6.23	6.27	8.13	7.49	5.87	4.19	3.27	3.03
Btu/ft ²	931	1054	1658	2083	1975	1988	2579	2353	1861	1330	1036	962
DIRECT kWh/m ²	5.32	4.86	7.32	8.00	7.03	6.73	9.32	8.84	7.50	6.23	5.63	5.16
Btu/ft ²	1688	1541	2323	2538	2231	2136	2957	2804	2379	1975	1787	1637

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.64	0.49	0.79	0.99	0.82	0.81	1.15	1.07	0.92	0.73	0.70	0.83
CLOUD FACTOR	0.84	0.83	0.84	0.82	0.83	0.83	0.89	0.90	0.89	0.87	0.89	0.85

CLIMATE AND INSOLATION SUMMARY

TABLE 14

SITE NAME MADISON, WIS. LATITUDE 43.13° LONGITUDE 89.33°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -20.6 °C, -5 °F;
WIND SPEED MEDIUM

SUMMER - 2 1/2%

DRY BULB TEMP 31.1 °C, 88 °F;
WET BULB TEMP 23.9 °C, 75 °F } DESIGN RELATIVE HUMIDITY 53 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	830	696	599	328	165	40	8	22	96	263	505	742
°F	1494	1252	1079	591	297	72	14	39	173	474	909	1336
COOLING °C	0	0	0	0	10	53	96	86	8	3	0	0
°F	0	0	0	0	18	96	172	154	14	6	0	0

PERCENT POSSIBLE SUNSHINE:

44	49	52	53	58	64	70	66	60	56	41	38
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AVERAGE AMBIENT TEMPERATURE RANGE:

	°C	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX D.B.	°C	-3.3	-2.2	2.8	11.7	18.9	24.4	28.3	27.2	22.2	16.1	5.6	-1.1
	°F	26	28	37	53	66	76	83	81	72	61	42	30
MIN D.B.	°C	-12.2	-12.2	-6.1	1.7	7.2	13.9	15.6	15	10.6	4.4	-2.2	-8.9
	°F	10	10	21	35	45	57	60	59	41	40	28	16

AVERAGE DAILY INCIDENT RADIATION:

	Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HORIZ	kWh/m ²	1.77	2.46	3.68	5.47	6.03	7.13	6.71	6.16	4.50	3.26	1.80	1.56
	Btu/ft ²	563	780	1167	1734	1912	2260	2127	1953	1427	1033	571	495
DIRECT	kWh/m ²	3.52	4.18	5.10	6.90	7.29	8.67	8.19	7.97	6.30	5.26	3.43	3.35
	Btu/ft ²	1116	1325	1617	2187	2311	2448	2596	2526	1997	1667	1087	1062

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.78	0.62	0.72	1.00	0.94	1.09	0.98	1.04	0.96	0.94	0.86	1.00
CLOUD FACTOR	0.66	0.70	0.72	0.73	0.76	0.80	0.84	0.81	0.78	0.75	0.64	0.62

CLIMATE AND INSOLATION SUMMARY

TABLE 15

SITE NAME MIAMI, FLA. LATITUDE 25.80° LONGITUDE 80.27°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 8.3 °C, 47 °F;

WIND SPEED MEDIUM

SUMMER - 2 1/2%

DRY BULB TEMP 32.2 °C, 90 °F;

WET BULB TEMP 26.1 °C, 79 °F;

DESIGN RELATIVE HUMIDITY 65 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	29	37	9	0	0	0	0	0	0	0	7	31
	°F	53	67	17	0	0	0	0	0	0	0	13	56
COOLING	°C	67	81	118	167	224	267	298	308	278	221	127	88
	°F	121	145	212	300	403	480	536	555	501	397	229	159

PERCENT POSSIBLE SUNSHINE:

66	72	73	73	68	62	65	67	62	62	65	65
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	24.4	25.	26.7	28.3	29.4	31.1	31.7	32.2	31.1	29.4	26.7	25
	°F	76	77	80	83	85	88	89	90	88	85	80	77
MIN D.B.	°C	14.4	15.	16.1	18.9	21.1	23.3	23.9	23.9	23.9	21.7	18.3	15
	°F	58	59	61	66	70	74	75	75	75	71	65	59

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	3.81	4.79	5.90	6.67	6.68	5.97	6.42	5.71	4.80	4.90	3.80	3.65
	Btu/ft ²	1205	1518	1870	2114	2118	1892	2035	1810	1522	1553	1205	1157
DIRECT	kWh/m ²	5.52	6.50	7.32	7.47	7.55	6.63	7.19	6.10	5.27	6.48	5.20	5.58
	Btu/ft ²	1750	2061	2320	2368	2393	2102	2279	1934	1671	2054	1648	1769

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.69	0.70	0.80	0.89	0.93	0.83	0.92	0.76	0.68	0.86	0.71	0.76
CLOUD FACTOR	0.81	0.85	0.85	0.85	0.83	0.79	0.81	0.82	0.79	0.79	0.81	0.81

CLIMATE AND INSOLATION SUMMARY

TABLE 16

SITE NAME NASHVILLE, TENN. LATITUDE 36.12° LONGITUDE 86.68°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -8.9 °C, 16 °F;

WIND SPEED LOW

SUMMER - 2 1/2%

DRY BULB TEMP 35 °C, 95 °F;

WET BULB TEMP 25.6 °C, 78 °F;

DESIGN RELATIVE HUMIDITY 50 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	460	373	291	98	25	0	0	0	6	100	277	424
	°F	828	672	524	176	45	0	0	0	10	180	498	763
COOLING	°C	0	0	11	16	85	193	252	233	122	29	0	0
	°F	0	0	19	29	153	348	453	419	220	53	0	0

PERCENT POSSIBLE SUNSHINE:

42	47	54	60	65	69	69	68	69	65	55	42
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	9.4	10.6	15	21.7	26.7	31.1	32.8	32.2	29.4	23.3	15	10
	°F	49	51	59	71	80	88	91	90	85	74	59	50
MIN D.B.	°C	-0.6	0.6	3.9	8.9	13.9	18.9	21.1	20.0	16.1	9.4	3.3	0
	°F	31	33	39	48	57	66	70	68	61	49	38	32

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	1.97	2.89	3.71	5.07	6.13	5.77	5.90	5.61	4.37	3.87	1.94	1.84
	Btu/ft ²	625	917	1177	1608	1944	1830	1871	1779	1386	1228	615	584
DIRECT	kWh/m ²	3.26	4.04	4.48	5.63	6.68	5.90	6.19	6.23	5.03	5.39	2.90	3.06
	Btu/ft ²	1034	1281	1421	1786	2119	1871	1963	1976	1596	1710	920	971

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.56	0.61	0.56	0.71	0.84	0.69	0.76	0.79	0.65	0.80	0.40	0.64
CLOUD FACTOR	0.65	0.69	0.74	0.78	0.81	0.83	0.83	0.83	0.83	0.81	0.74	0.65

CLIMATE AND INSOLATION SUMMARY

TABLE 17

SITE NAME OMAHA, NEB. LATITUDE 41.37° LONGITUDE 96.02°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP -18.3 °C, -1 °F;

WIND SPEED MEDIUM

SUMMER - 2 1/2%

DRY BULB TEMP 34.4 °C, 94 °F;

WET BULB TEMP 25.6 °C, 78 °F;

DESIGN RELATIVE HUMIDITY 53 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	730	576	481	217	82	11	0	3	39	167	417	637
	°F	1314	1036	865	391	148	20	0	6	71	301	750	1147
COOLING	°C	0	0	0	6	48	131	210	186	61	11	0	0
	°F	0	0	0	10	86	236	378	334	110	19	0	0

PERCENT POSSIBLE SUNSHINE:

57	59	60	60	63	69	76	71	67	66	59	55
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	1.7	3.9	9.4	17.8	23.9	29.4	33.9	32.2	27.8	21.1	11.1	5
	°F	35	39	49	64	75	85	93	90	82	70	52	41
MIN D.B.	°C	-8.3	-6.7	-1.7	5	11.1	17.2	20.6	19.4	13.9	7.2	-0.6	-5.
	°F	17	20	29	41	52	63	69	67	57	45	31	23

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	2.45	2.89	4.19	5.33	5.84	6.90	6.84	5.94	4.67	3.84	2.40	2.10
	Btu/ft ²	777	916	1328	1690	1851	2187	2168	1883	1480	1217	761	666
DIRECT	kWh/m ²	5.58	4.68	5.90	6.60	6.55	7.83	7.90	7.32	6.10	6.29	4.77	4.81
	Btu/ft ²	1769	1484	1870	2092	2076	2482	2504	2320	1934	1994	1512	1525

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.94	0.64	0.75	0.84	0.81	0.97	0.93	0.90	0.88	0.99	0.89	1.02
CLOUD FACTOR	0.76	0.77	0.78	0.78	0.79	0.83	0.87	0.84	0.82	0.81	0.77	0.74

CLIMATE AND INSOLATION SUMMARY

TABLE 18

SITE NAME PHOENIX, ARIZ. LATITUDE 33.43° LONGITUDE 112.02°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 1.1 °C, 34 °F;

WIND SPEED VERY LOW

SUMMER - 2 1/2%

DRY BULB TEMP 41.1 °C, 106 °F;

WET BULB TEMP 24.4 °C, 76 °F

DESIGN RELATIVE HUMIDITY 27 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	238	162	103	33	0	0	0	0	0	9	101	216
	°F	428	292	185	60	0	0	0	0	0	17	182	388
COOLING	°C	0	8	12	78	197	327	451	415	313	133	14	0
	°F	0	14	21	141	355	588	812	747	564	240	26	0

PERCENT POSSIBLE SUNSHINE:

76	79	83	88	93	94	84	84	89	88	84	77
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	17.8	20	23.9	28.9	33.9	38.9	40.6	38.9	36.7	30.6	23.3	18.9
	°F	64	68	75	84	93	102	105	102	98	87	74	66
MIN D.B.	°C	1.7	3.9	6.1	10	13.9	18.9	23.9	22.8	19.4	12.8	5.6	2.8
	°F	35	39	43	50	57	66	75	73	67	55	42	37

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	3.61	4.50	5.97	7.23	8.00	8.10	7.74	6.87	5.93	5.13	3.74	3.42
	Btu/ft ²	1145	1427	1894	2293	2538	2569	2455	2179	1881	1627	1186	1085
DIRECT	kWh/m ²	6.42	6.86	8.16	8.97	9.65	9.67	9.19	8.26	7.43	7.81	6.39	6.65
	Btu/ft ²	2036	2176	2588	2845	3061	3067	2915	2620	2357	2477	2027	2109

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.83	0.76	0.85	0.92	0.96	0.96	1.02	0.91	0.84	0.89	0.82	0.92
CLOUD FACTOR	0.87	0.89	0.91	0.94	0.96	0.97	0.92	0.92	0.94	0.94	0.92	0.88

CLIMATE AND INSOLATION SUMMARY

TABLE 19

SITE NAME SEATTLE, WASH. LATITUDE 47.45° LONGITUDE 122.30°

ASHRAE DESIGN CONDITION:

WINTER - 97 1/2%

DRY BULB TEMP 6 °C, 32 °F;

WIND SPEED LOW

SUMMER - 2 1/2%

DRY BULB TEMP 26.1 °C, 79 °F;

WET BULB TEMP 18.3 °C, 65 °F;

DESIGN RELATIVE HUMIDITY 47 %

DEGREE DAYS:

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING	°C	410	319	329	238	143	69	31	32	68	184	297	372
	°F	738	574	592	429	258	124	56	57	123	332	534	670
COOLING	°C	0	0	0	0	0	12	50	38	10	0	0	0
	°F	0	0	0	0	0	22	90	69	18	0	0	0

PERCENT POSSIBLE SUNSHINE:

27	34	42	48	53	48	62	56	53	36	28	24
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AVERAGE AMBIENT TEMPERATURE RANGE:

MAX D.B.	°C	6.7	8.3	10.6	14.4	18.9	21.1	24.4	23.9	22.8	15.6	10.0	7.8
	°F	44.	47.	51.	58.	66.	70.	76.	75.	73.	60.	50.	46.
MIN D.B.	°C	0.6	1.7	2.2	5.0	7.2	10.0	12.2	12.2	8.3	6.7	3.3	2.2
	°F	33.	35.	36.	41.	45.	50.	54.	54.	47.	44.	38.	36.

AVERAGE DAILY INCIDENT RADIATION:

HORIZ	kWh/m ²	1.19	1.96	3.10	4.20	5.94	6.00	6.19	5.13	4.03	2.19	1.10	0.84
	Btu/ft ²	379	623	982	1332	1883	1903	1965	1627	1279	696	349	266
DIRECT	kWh/m ²	2.68	3.46	4.52	5.10	7.00	6.97	7.45	6.45	5.70	3.48	2.20	1.90
	Btu/ft ²	849	1099	1433	1618	2220	2210	2364	2046	1808	1105	698	604

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.93	0.76	0.75	0.74	1.02	1.08	0.98	0.95	1.03	0.91	0.78	0.87
CLOUD FACTOR	0.52	0.58	0.65	0.69	0.73	0.69	0.79	0.75	0.73	0.60	0.53	0.49

CLIMATE AND INSOLATION SUMMARY

TABLL 20

SITE NAME WASHINGTON, D.C. LATITUDE 38.89° LONGITUDE 77.03°

ASHRAE DESIGN CONDITION:

WINTER -- 97 1/2%

DRY BULB TEMP -7.2 °C, 19 °F;

WIND SPEED MEDIUM

SUMMER -- 2 1/2%

DRY BULB TEMP 33.3 °C, 92 °F;

WET BULB TEMP 25.0 °C, 77 °F

DESIGN RELATIVE HUMIDITY 55 %

DEGREE DAYS:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HEATING °C	506	431	343	147	40	0	0	0	8	106	283	476
°F	911	776	617	265	72	0	0	0	14	190	510	856
COOLING °C	0	0	4	5	62	148	216	191	101	21	0	0
°F	0	0	8	9	111	267	388	344	181	37	0	0

PERCENT POSSIBLE SUNSHINE:

46	53	56	57	61	64	64	62	62	61	54	47
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AVERAGE AMBIENT TEMPERATURE RANGE:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MAX D.B. °C	6.7	7.8	12.2	18.9	24.4	28.3	30.6	29.4	26.1	20.	13.9	7.8
°F	44	46	54	66	76	83	87	85	79	68	57	46
MIN D.B. °C	-1.1	-1.7	2.2	7.8	13.3	18.3	20.6	20	16.1	10.	3.9	-0.6
°F	30	29	36	46	56	65	69	68	61	50	39	31

AVERAGE DAILY INCIDENT RADIATION:

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HORIZ kWh/m ²	2.20	2.90	4.20	5.20	5.70	6.40	5.90	5.40	4.60	3.50	2.30	2.00
Btu/ft ²	699	919	1331	1648	1807	2029	1870	1712	1458	1110	729	634
DIRECT kWh/m ²	3.80	4.10	5.00	5.70	5.60	6.40	5.50	5.50	5.20	4.70	3.60	3.60
Btu/ft ²	1205	1300	1585	1807	1775	2029	1744	1744	1648	1490	1141	1141

EFFECTIVE ATMOSPHERE FACTORS:

CLEARNESS NO.	0.78	0.62	0.74	0.81	0.79	0.90	0.82	0.83	0.85	0.80	0.73	0.85
CLOUD FACTOR	0.68	0.73	0.75	0.76	0.78	0.80	0.80	0.79	0.79	0.78	0.73	0.69

were selected⁽¹⁾ as representative of weather conditions over a large portion of the U.S.A. so that these parameters can be used for evaluation of conceptual design if better information is unavailable.

2.5.1.1 Temperature Data

The monthly maximum and minimum temperatures for the site location are used in approximating the thermal requirements of the building in the STESEP Computer Program. A sinusoidal variation in the air temperature is assumed to occur following the equation and gives very good agreement with heating and cooling degree day data (see results of check case, Figure 20):

$$T_a = T_{mn} - (T_{mx} - T_{mn})[1 + \cos(h + t_L)]/2 \quad \dots(33)$$

A lag (t_L) is introduced into the air temperature to compensate for building capacitance effects as discussed in the next Section (2.5.3).

2.5.2 Evaluation of Clearness Numbers and Cloud Factors

2.5.2.1 Application of the Insolation Model to Compute Daily Average Insolation

The insolation model (see Section 2.3.6) describes local insolation in terms of deterministic equations which contain the clearness number CN and the cloud factor CF.

The average daily direct normal radiation (with cloud effects considered) is obtained by integrating Equation (21) over the full day.

$$\begin{aligned} H_{DN} &= \int CF I_{DN} dt \\ &= CF \cdot CN \cdot \int A \exp(-B/\cos \theta_z) dt \quad \dots(34) \\ &= CF \cdot CN \cdot I_1 \end{aligned}$$

Similarly, the daily total horizontal radiation is found as follows:

$$\begin{aligned}
H_h &= \int CF (I_{DN} \cos \theta_z + I_{DF}) dt \\
&= \frac{CF \cdot CN \cdot R \cdot I_c}{\alpha'} \int A \exp(-B/\cos \theta_z) \cos \theta_z dt \\
&\quad - \frac{CF \cdot R \cdot I_c \beta'}{\alpha'} \int \cos \theta_z dt \\
H_h &= \frac{CF \cdot CN \cdot R \cdot I_2}{(\alpha'/I_c)} - \frac{CF \cdot R \cdot \beta' \cdot I_3}{(\alpha'/I_c)} \quad \dots(35)
\end{aligned}$$

Equation (35) is more compactly written:

$$\hat{H} = CF \cdot CN \cdot I_2 - CF \cdot \hat{\beta} \quad \dots(36)$$

where

$$\hat{\beta} = \beta' \cdot I_3$$

and

$$\hat{H} = \frac{H_h (\alpha'/I_{sc})}{R}$$

The integrals I_1 , I_2 , and I_3 are obtained by numerical integration. (I_3 can be integrated in closed form, but is grouped with the others for programming convenience.) Because of the symmetry about solar noon, all three can be expressed in the form:

$$I = 2 \int_0^{t_s} F(\cos \theta_z) dt \quad \dots(37)$$

where t is the time measured from solar noon, $t_s = \cos^{-1}(-\tan \delta / \tan \phi) / 15$ the sunset time, and $\cos \theta_z$ is a function of the hour angle $h = 15t$, from Equation (19). Equation (37) is evaluated by the trapezoidal rule, with ordinates evaluated at 30-min intervals. The numerical approximation becomes:

$$I \approx 0.5 F_0 + \sum_{i=1}^N F_i \quad \dots(38)$$

where N is the integer part of $2t_s - 1$.

Equation (38) slightly overestimates the contribution of the "tail" whenever the sunset time is not an even 1/2 h. The error is insignificant in the present application.

2.5.2.2 CN Evaluation from Daily Averages of Total Horizontal and Direct Insolation

The first module of the deterministic insolation program evaluates the clearness number CN in one of two ways. If no cloud factor CF is specified, it solves Equations (34) and (36) simultaneously for both CF and CN as follows:

$$CF = (H_{DN} \cdot I_2/I_1 - \hat{H})/\hat{\beta} \quad \dots(39)$$

$$CN = (\hat{H}/CF + \hat{\beta})/I_2 \quad \dots(40)$$

It may happen that the resulting value of CN is found to be unreasonably high. If so, a reasonable upper limit (say CN = 1.1) can be assigned and a revised value of CF can be calculated from Equation (36) as follows:

$$CF = \hat{H}/(CN \cdot I_2 - \hat{\beta}) \quad \dots(41)$$

2.5.3 Building Load Characterization

Although most industrial and commercial facilities can be classified as "thermally heavy," the variation in energy demands throughout the year as well as the variable solar energy availability must be considered in any application of STES. This is a function of both the building construction, shape and operational conditions as discussed in Reference 1, as well as the local environmental conditions which can vary enormously in different parts of the country.

Direct calculation of the building energy demands is extremely difficult and beyond the scope of a small computer program like STESEP and in the absence of actual data should be accomplished with a more elaborate program such as AXCESS⁽⁵¹⁾ or ECUBE⁽⁵²⁾.

As discussed in Reference 1, the energy demands of commercial buildings are primarily a function of the lighting and HVAC system of the building. Commercial

buildings are normally thermally "heavy" so that environmental effects are less important than the internal operating parameters (hours of operation, illumination/unit area, etc.) in determining the building loads. Prediction of the type of HVAC system which will be selected for commercial buildings in the 1985 to 2000 time frame is also difficult so, consequently, six typical commercial building configurations were selected during the development of STESEP to use when more definitive information is not available. The data for these building configurations was developed using the AXCESS computer program and is listed in Tables 21 to 26 in the format required by the STESEP computer program. The AXCESS program runs were made based on industry average daily profiles for electrical, occupancy (ventilation), and process heat loads, which are independent of weather conditions and are input parameters of STESEP. The AXCESS output defined the hourly, monthly, and yearly energy usage for heating and cooling as well as the electrical loads of the buildings. These loads were then used to define the coefficients in the simplified load equations used by the STESEP computer program and listed on Tables 21 to 26.

Since the building loads for commercial buildings are primarily a function of the way the building systems are operated, the yearly loads must also be available to allow adjustment of several program constants so that the electrical, heating, and cooling loads can be balanced. The STESEP program uses six constants to obtain the balance. These constants are CEL, CVR, CVH, CHD, CHL, CRL* and are used to obtain agreement between the STESEP predictions for hourly, monthly, and yearly loads with the values determined from a more exact source as discussed above.

The refrigeration and heating demand loads are related to the input hourly loads by the following equations:

*See List of Symbols, Page 153, or Glossary of Terms, Section 4.3.

TABLE 21

LOAD (EL) PROFILE APPROXIMATION FOR LARGE RETAIL STORE
 WITH A FLOOR AREA OF 18868.SQ.M
 LIGHTING LEVEL IS 0.102 KW/SQ.M FOR
 317.DAYS OF OPERATION A YEAR

DAILY OPERATIONAL PROFILE(% OF MAXIMUM)

HOUR OF THE DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LIGHTING LOAD(EL)	23.	23.	23.	23.	23.	12.	11.	13.	24.	68.	100.	100.	100.	100.	100.	99.	99.	100.	59.	48.	36.	35.	24.	23.
OCCUPANCY LOAD(OL)	0.	0.	0.	0.	0.	0.	0.	10.	30.	30.	10.	80.	80.	70.	50.	50.	50.	70.	70.	75.	60.	10.	0.	0.
PROCESS HEAT LOAD(HL)	0.	0.	0.	0.	0.	0.	0.	8.	8.	17.	17.	25.	92.	58.	58.	8.	8.	67.	100.	83.	50.	8.	0.	0.

LIGHTING HEAT RELEASE FACTOR(CEL)= 0.500
 VENTILATION COOLING FACTOR(CVR) = 1.30
 VENTILATION HEATING FACTOR(CVH) = 1.08
 HEAT LOSS COEFFICIENT(CHL) = 0.110E-01
 REFRIGERATION/HEATING RATIO(CRL) = 5.50

TABLE 22

LOAD (EL) PROFILE APPROXIMATION FOR LARGE SHOPPING CENTER
 WITH A FLOOR AREA OF 70755.SQ.M.
 LIGHTING LEVEL IS 0.081 KW/SQ.M. FOR
 338.DAYS OF OPERATION A YEAR

DAILY OPERATIONAL PROFILE(% OF MAXIMUM)

HOUR OF THE DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LIGHTING LOAD(EL)	23.	23.	12.	12.	12.	12.	11.	36.	67.	99.	99.	99.	98.	98.	98.	98.	98.	100.	69.	58.	46.	25.	14.	12.
OCCUPANCY LOAD(OL)	0.	0.	0.	0.	0.	0.	0.	10.	25.	35.	45.	80.	80.	75.	65.	70.	50.	80.	83.	80.	55.	10.	0.	0.
PROCESS HEAT LOAD(HL)	0.	0.	0.	0.	0.	0.	0.	11.	11.	17.	17.	22.	89.	55.	55.	11.	11.	61.	100.	78.	45.	11.	0.	0.

LIGHTING HEAT RELEASE FACTOR(CEL)= 0.600
 VENTILATION COOLING FACTOR(CVR) = 4.30
 VENTILATION HEATING FACTOR(CVH) = 1.88
 HEAT LOSS COEFFICIENT(CHL) = 0.100E-01
 REFRIGERATION/HEATING RATIO(CRL) = 7.50

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TABLE 23

LOAD (EL) APPROXIMATION FOR MEDIUM SHOPPING CENTER
 WITH A FLOOR AREA OF 42453.SQ.M
 LIGHTING LEVEL IS 0.094 KW/SQ.M FOR
 317.DAYS OF OPERATION A YEAR

DAILY OPERATIONAL PROFILE(% OF MAXIMUM)

HOUR OF THE DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LIGHTING LOAD(EL)	24.	24.	15.	15.	15.	10.	10.	37.	66.	96.	95.	95.	95.	95.	95.	100.	100.	71.	61.	51.	31.	15.	15.	
OCCUPANCY LOAD(OL)	0.	0.	0.	0.	0.	0.	0.	10.	28.	32.	24.	80.	80.	72.	56.	58.	58.	74.	78.	68.	29.	4.	0.	0.
PROCESS HEAT LOAD(HL)	0.	0.	0.	0.	0.	0.	0.	11.	11.	16.	16.	22.	89.	55.	55.	11.	11.	61.	100.	78.	45.	11.	0.	0.

LIGHTING HEAT RELEASE FACTOR(CEL)= 0.600
 VENTILATION COOLING FACTOR(CVR) = 4.02
 VENTILATION HEATING FACTOR(CVH) = 2.00
 HEAT LOSS COEFFICIENT(CHL) = 0.450E-01
 REFRIGERATION/HEATING RATIO(CRL) = 1.90

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TABLE 24

LOAD (EL) PROFILE APPROXIMATION FOR LRG. SHOP. CTR., ECR
 WITH A FLOOR AREA OF 70755.SQ.M
 LIGHTING LEVEL IS 0.040 KW/SQ.M FOR
 338.DAYS OF OPERATION A YEAR

DAILY OPERATIONAL PROFILE(% OF MAXIMUM)

HOUR OF THE DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LIGHTING LOAD(EL)	23.	23.	12.	12.	12.	12.	11.	36.	67.	99.	99.	99.	98.	98.	98.	98.	98.	100.	69.	58.	46.	25.	14.	12.
OCCUPANCY LOAD(OL)	0.	0.	0.	0.	0.	0.	0.	10.	25.	35.	45.	80.	80.	75.	65.	70.	50.	80.	83.	80.	55.	10.	0.	0.
PROCESS HEAT LOAD(HL)	0.	0.	0.	0.	0.	0.	0.	11.	11.	17.	17.	22.	89.	55.	55.	11.	11.	61.	100.	78.	45.	11.	0.	0.

LIGHTING HEAT RELEASE FACTOR(CEL)= 0.600
 VENTILATION COOLING FACTOR(CVR) = 4.27
 VENTILATION HEATING FACTOR(CVH) = 1.87
 HEAT LOSS COEFFICIENT(CHL) = 0.100E-01
 REFRIGERATION/HEATING RATIO(CRL) = 7.50

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TABLE 25

LOAD (EL) PROFILE APPROXIMATION FOR LOW RISE OFFICE BUILDING, C.H.
 WITH A FLOOR AREA OF 18868.SQ.M
 LIGHTING LEVEL IS 0.053 KW/SQ.M FOR
 255.DAYS OF OPERATION A YEAR

DAILY OPERATIONAL PROFILE(% OF MAXIMUM)

HOUR OF THE DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LIGHTING LOAD(EL)	0.	0.	0.	0.	0.	0.	0.	100.	100.	94.	94.	81.	47.	77.	92.	92.	99.	18.	19.	18.	14.	10.	0.	0.
OCCUPANCY LOAD(OL)	0.	0.	0.	0.	0.	0.	0.	100.	100.	100.	100.	80.	40.	80.	100.	100.	100.	10.	10.	10.	10.	0.	0.	0.
PROCESS HEAT LOAD(HL)	0.	0.	0.	0.	0.	0.	0.	60.	60.	54.	60.	100.	65.	88.	77.	82.	33.	35.	56.	5.	5.	0.	0.	0.

LIGHTING HEAT RELEASE FACTOR(CEL)= 0.500
 VENTILATION COOLING FACTOR(CVR) = 7.20
 VENTILATION HEATING FACTOR(CVH) = 1.78
 HEAT LOSS COEFFICIENT(CHL) = 0.600E-01
 REFRIGERATION/HEATING RATIO(CRL) = 1.00

TABLE 26

LOAD (EL) APPROXIMATION FOR LARGE SHOP. CTR., N.S. ,
 WITH A FLOOR AREA OF 70755.SQ.M
 LIGHTING LEVEL IS 0.014 KW/SQ.M FOR
 338.DAYS OF OPERATION A YEAR

DAILY OPERATIONAL PROFILE(% OF MAXIMUM)

HOUR OF THE DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
LIGHTING LOAD(EL)	23.	23.	12.	12.	12.	12.	11.	36.	67.	99.	99.	99.	98.	98.	98.	98.	98.	100.	69.	58.	46.	25.	14.	12.
OCCUPANCY LOAD(OL)	0.	0.	0.	0.	0.	0.	0.	10.	25.	35.	45.	80.	80.	75.	65.	70.	50.	80.	83.	80.	55.	10.	0.	0.
PROCESS HEAT LOAD(HL)	0.	0.	0.	0.	0.	0.	0.	11.	11.	17.	17.	22.	89.	55.	55.	11.	11.	61.	100.	78.	45.	11.	0.	0.

LIGHTING HEAT RELEASE FACTOR(CEL)= 0.600
 VENTILATION COOLING FACTOR(CVR) = 4.30
 VENTILATION HEATING FACTOR(CVH) = 1.88
 HEAT LOSS COEFFICIENT(CHL) = 0.100E-01
 REFRIGERATION/HEATING RATIO(CRL) = 7.50

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For $T_a > T_{SP}$

$$\dot{Q}_{RD} = \dot{Q}_T \left[CEL \cdot EL(t) + CVR \cdot OL(t) + CHL \cdot CRL \cdot (T_a - T_{SP}) \right] \dots(42a)$$

$$\dot{Q}_{HD} = \dot{Q}_T \left[CVH \cdot OL(t) - CEL \cdot EL(t) + CHD \cdot HL(t) \right] \dots(43a)$$

For $T_a < T_{SP}$,

$$\begin{aligned} \dot{Q}_{HD} = \dot{Q}_T \left[CVH \cdot OL(t) - CEL \cdot EL(t) + CHL \cdot (T_{SP} - T_a) \right. \\ \left. + CHD \cdot HL(t) \right] \dots(42b) \end{aligned}$$

$$\dot{Q}_{RD} = \dot{Q}_T \left[CEL \cdot EL(t) + CVR \cdot OL(t) \right] \dots(43b)$$

The electrical demand load is given by:

$$\dot{Q}_{ED} = \dot{Q}_T \cdot EL(t) \dots(44)$$

The coefficients in these equations are empirical constants for the building and are adjusted by the user to match demand loads for the building obtained from another source. Section 3.1.2 gives the procedure for adjusting the coefficients.

It should be noted that the building thermal capacitance does not appear in Equations (42) and (43) nor does a term representing the solar energy input. The thermal capacitance of the buildings is approximated by shifting the time of day when the maximum and minimum air temperatures occur [see Equation (33)]. This shifts the hourly variation of the building loads to approximate shift caused by wall and roof capacitance.

Shadow effects have been neglected since these shadow effects from the collectors depend strongly on their placements around (and on) the building and these locations are usually not known during conceptual analyses.

3.0 USER'S GUIDE

The preceding section detailed the mathematical models and some of the development history for the STESEP computer program. The discussion that follows defines the data input requirements, describes the output options and program limitations, and discusses sample problems that can be used to ensure proper program operation.

3.1 REQUIRED DATA INPUT

Table 27 lists the data input requirements for STESEP by generic type, which include: (1) building data, (2) environment data, (3) collector/array characteristics, and (4) operational data for the STES.

The STESEP computer code is written for use on a remote terminal with the data input obtained from a data file in free format form as shown in Figure 16. The input parameters for STESEP are entered in the order shown in Figure 17.

The following discussion describes each part of the input requirements and output options of the STESEP code. Figure 18 shows the section number where each portion of the input data is discussed and its relationship to the operation of the code. Table 28 gives a summary of the program options and flags that determine which operation will be used in the computation and/or output. This information is used to create a data file (or card deck for batch operation) to be used by the STESEP code and which is described in the following paragraphs.

TABLE 27
STESEP INPUT/OUTPUT PARAMETERS

Input Parameters	Output Parameters
Building Data	Load Profiles (Monthly and Hourly)
Environment (Site) Data	Component Sizes
Collector/Array Characteristics	Capital Investment
Operational Data	Recurring Costs
	Annualized Cost

```

LINE      PARAMETER VALUES

BUILDING DATA
00010  70755.09106,1.88,.6,4.3,.01,.075,7.5
00020  LARGE SHOPPING CENTER
00030  .23,.23,.1,.1,.1,.1,.1,.36,.67,1,1,1,1,1,1,1,1,.69,.58,.46,.25,.14,.1
00040  0,0,0,0,0,0,0,0,.1,.25,.35,.45,.8,.8,.75,.65,.7,.5,.8,.83,.8,.55,.1,0,0
00050  0,0,0,0,0,0,0,0,.1,.1,.17,.17,.22,.9,.55,.55,.1,.1,.6,1,.78,.45,.1,0,0
00060  336

SITE DATA
00070  42.22,1
00080  BLUE HILL, MASS.
00090  37,37,45,56,68,76,82,80,73,63,52,40
00100  21,21,29,39,49,58,64,62,56,45,36,25
00110  593,850,1278,1608,1903,2008,1811,1659,1323,1063,542,603
00120  47,56,57,56,59,62,64,63,61,58,48,48
00130  .3691,.3664,-.0022

COLLECTOR DATA
00140  42,.71,2.5,.3,2,0,0
00150  WITH A DISTRIBUTED COLLECTOR

OPERATIONAL DATA FOR
YEARLY RESULTS
00160  1,1,1,0,0
00170  .15,1.5,0,600,1000,50,50
00180  .15,1.5,0,600,1100,50,50
00190  .15,1.5,0,600,1160,50,50
00200  .25,1.5,0,600,1160,50,50
00210  .45,1.5,0,600,1160,50,50
00220  .65,1.5,0,600,1160,50,50
00230  .15,.2,0,690,900,50,50
00240  .15,.2,0,690,950,50,50
00250  .15,.2,0,690,1000,50,50
00260  .15,.2,0,690,1050,50,50
00270  .15,.2,0,690,1100,50,50
00280  .15,.2,0,690,1160,50,50
00290  .25,.2,0,690,1160,50,50
00300  .45,.2,0,690,1160,50,50
00310  .65,.2,0,690,1160,50,50
00320  .15,1.5,0,600,1000,0,50
00330  .15,1.5,0,600,1100,0,50
00340  .15,1.5,0,600,1160,0,50
00350  .25,1.5,0,600,1100,0,50
00360  .45,1.5,0,600,1100,0,50
00370  .65,1.5,0,600,1100,0,50
00380  .15,.2,0,690,900,0,50
00390  .15,.2,0,690,950,0,50
00400  .15,.2,0,690,1000,0,50
00410  .15,.2,0,690,1050,0,50
00420  .15,.2,0,690,1100,0,50
00430  .15,.2,0,690,1160,0,50
00440  .25,.2,0,690,1100,0,50
00450  .45,.2,0,690,1100,0,50
00460  .65,.2,0,690,1100,0,50
00470  11,0,0,690,1000,0,50

COLLECTOR AND OPERATIONAL DATA
FOR MONTHLY RESULTS
00480  42,.71,2.5,.3,2,0
00490  WITH A DISTRIBUTED COLLECTOR
00500  1,1,0,0,1
00510  .2,.5,0,690,1100,0,50

COLLECTOR AND OPERATIONAL DATA FOR
HOURLY RESULTS FOR THE 4TH MONTH
00520  42,.71,2.5,.3,2,0
00530  WITH A DISTRIBUTED COLLECTOR
00540  1,1,0,4,0
00550  .2,.5,0,690,1100,0,50

ARRAY DATA
00560  1,.15,2,.002,0,0
00570  WITH A PHOTOVOLTAIC ARRAY

OPERATIONAL DATA FOR YEARLY RESULTS
00580  1,1,1,0,0
00590  .2,.3,0,600,700,0,0
00600  .2,.25,0,600,700,0,0
00610  .2,.35,0,600,700,0,0
00620  .2,.4,0,600,700,0,0
00630  .3,.4,0,600,700,0,0
00640  .4,.4,0,600,700,0,0
00650  .5,.4,0,600,700,0,0
00660  .6,.4,0,600,700,0,0
00670  11,.4,0,600,700,0,0
00680  0,.4,0,600,700,0,0
END OF DATA

```

Figure 16. Sample Input Data Sheet

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INPUT VARIABLE LIST*

Input Parameter Order

Building Data

1. FA, PPSM, CVH, CEL, CVR, CHL, CHD, CRL
2. Building Name (24 characters) – BDL
3. EI Array of 24 Fractional Values
4. ØL Array of 24 Fractional Values
5. HL Array of 24 Fractional Values
6. DAØP

Site and Environmental Data

7. DEG, INSØ
8. Location Name (24 characters) – CIT
9. TU Array of 12 Values
10. TL Array of 12 Values
11. Either HH or CN Array of 12 Values
12. Either PP or CF Array of 12 Values
13. C1, C2, C3

Collector Data or Array Data

14. CR, EØC, UCØL, EM, NAXE, DTLT
15. System Name (24 characters) – STES

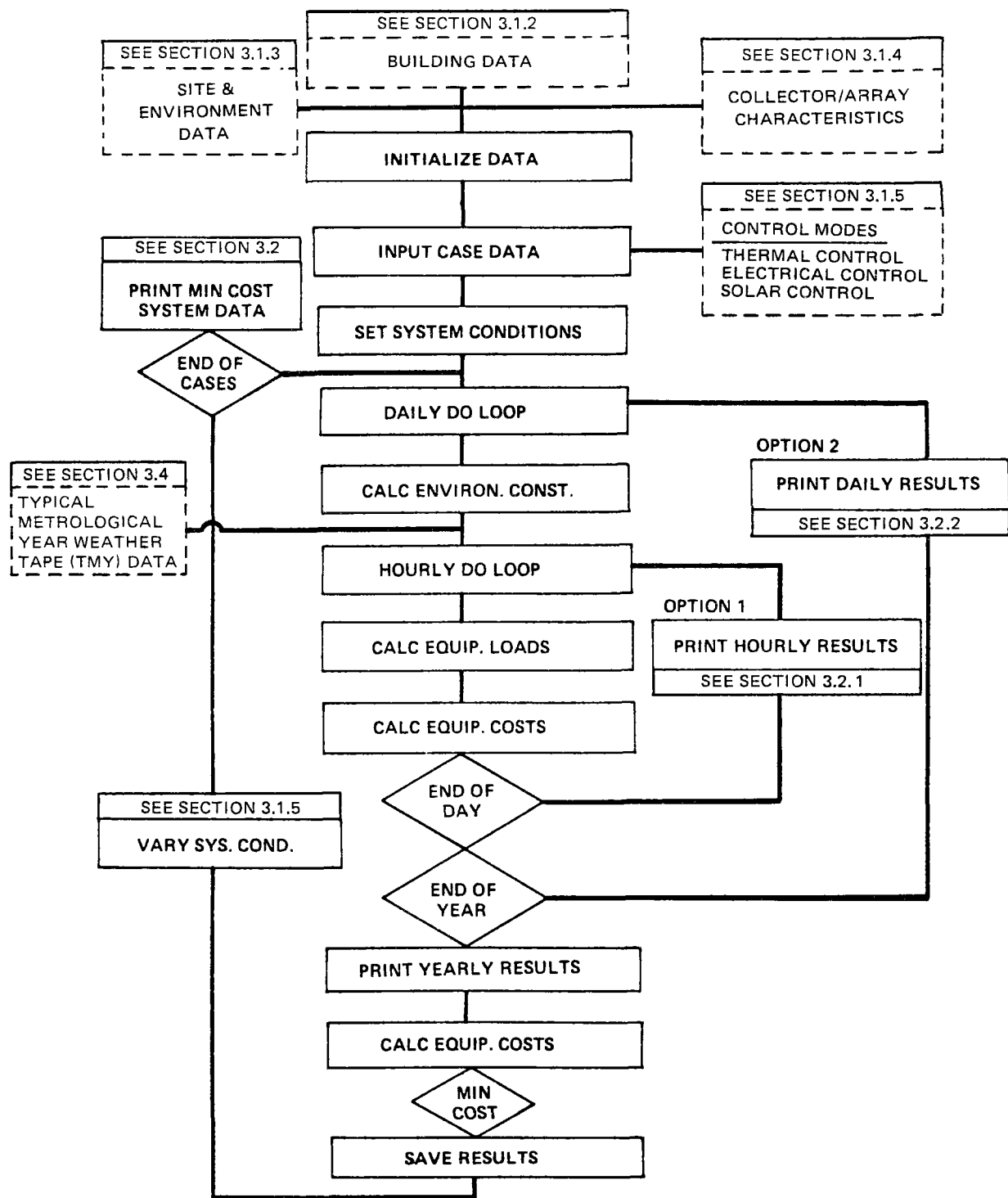
Operational and Control Data

16. EFT, BFT, MMAX, NMAX, LMAX
17. ARAT, RMAX, BUY, TØ, TT, DTAUX, DTW

Repeat 14 to 17 as required to consider different STES configuration, and end case with ARAT>8.

*See Glossary of Terms, Section 4.3

Figure 17. Sample Input Variable List



42400-10116C

Figure 18. STESEP Logic Diagram

TABLE 28
SUMMARY OF PROGRAM OPTIONS

Flag	Value	Discussed in Section	Program Result/Action
INSØ	0	3.1.1	Input CF& CN values
	1		Input HH&PP values
	2		Input HH&PP values and mount TMY tape
NAXE	-1	3.1.4	E-W oriented 1-axis tracking
	0		Nontracking
	1		N-S oriented 1-axis tracking
	2		2-axis tracking
	3		Central receiver
EFT	0	3.1.5.1	No purchased electricity used
	1		Purchase supplementary electricity
BFT(EFT=1)	0		Use thermal energy storage
	1		Use battery energy storage
MMAX	0	3.1.5.1	Adjust auxiliary energy to maintain load profile
	1		Use specified conditions
NMAX (LMAX=0)	0	3.1.5.1	Yearly calculation option
	1		Hourly calculation option for month specified by NMAX
LMAX (NMAX=0)	1	3.1.5.1	Monthly calculation option
EØC	≥0.3	3.1.1	Solar Thermal System used
	<0.3		Photovoltaic System used
RMAX (EØC<0.3)	0 >0.0	3.1.1	Array actively cooled Array passively cooled and flat plate thermal collectors used for heating load
ARAT	>8	3.1.1	Terminates cases - value determines next case input

3.1.1 Input Data File Format

Since the free format input option has been used for STESEP, the lines (cards) of the data input file must contain a value for each parameter separated by a comma delimiter as shown in Figure 16 where the check cases input data are listed. The suggested method of obtaining the numerical values for these parameters is discussed in Sections 3.1.2 through 3.1.6. The individual lines (cards) are discussed below to describe the parameters as defined in Figure 17 and illustrated in Figure 16.

The first six lines of the data input file define the building parameters and are input in metric units.

The first card contains the empirical coefficients for load calculations as discussed in 3.1.2 and shown as Line 10 (i.e. 00010) in Figure 16.

- FA -- Floor area of the building in m^2
- PPSM -- Power/ m^2 in W/m^2
- CVH -- Coefficient of heating ventilation
- CEL -- Coefficient of heat generation from lighting
- CVR -- Coefficient of cooling ventilation
- CHL -- Coefficient of heat loss
- CHD -- Coefficient of process heat
- CRL -- Coefficient for humidity effects

The second line (card), Line 20, is alphanumeric, BLD (8A4), and contains the building descriptor. The third line (card), Line 30, contains the hourly fractional electrical load, EL (24 values). It should be noted that two or more lines (cards) could be used if more significant figures are desired in the values for the profile as long as a comma delimiter is used between values. The fourth line (card), Line 40, contains the hourly fractional occupancy load, $\emptyset L$ (24 values), while the fifth line (card), Line 50, contains the hourly process heat load, HL (24 values). The sixth line, Line 60, contains only the number of days of operation per year for the building, DA $\emptyset P$.

The next seven lines, Lines 70-130, contain the site data as discussed in 3.1.3.

The first site line (card), Line 70, contains the site latitude, DEG, in degrees followed by an insolation flag, INSØ.

The next line (card), Line 80, is alphanumeric, CIT (8A4), and contains the site descriptor.

The next two lines, Lines 90 and 100, contain the monthly maximum temperatures for the site, TU (12 values), followed by the minimum temperatures, TL (12 values), in degrees F. If the INSØ flag is zero, the next two lines, Lines 110 and 120, contain the monthly CN numbers (12 values), followed by the monthly CF numbers (12 values). If the INSØ flag is 1, then the lines (cards) contain the monthly total horizontal, HH, insolation (12 values in either Btu/ft² or in kWh/m² Mo), followed by the monthly percent possible, PP, percentages (12 values). (See Sections 3.1.3.1 and 3.1.3.2 for suggested sources of these values.)

The last site input data line (card), Line 130, contains three empirical coefficients defining the local cost of electricity, C1, C2, C3, in dollars/kWh which are determined as described in 3.1.3.3.

The collector (or array) data is input on the next line (card), Line 140, and is discussed in 3.1.4.

- CR = Concentration ratio = A_c/A_a
- EØC = η_{oc} = Optical efficiency of system
- UCØL = Linear loss coefficient for system
- EM* = Radiation loss coefficient
- DTLT = Angular deviation of one axis N-S tracking and non-tracking system from an angle equal to the latitude

The data input lines described above have now defined the building requirements, the application location, the collector/array configuration, and local cost of electricity. The operational data is input on the remaining cards for a case, Lines 160 to 470.

The next line (card), Line 160, contains the operational and output flags that determine how the case will be run as discussed in Sections 3.1.5.1 and 3.2.3.

*For photovoltaic systems, the cell temperature loss coefficient is the input parameter.

EFT = Purchased electricity flag
BFT = Battery storage flag
MMAX = Flag to remove load profile restriction
NMAX = Output option flag for hourly results
LMAX = Output option flag for monthly results

The first variable is the purchased electricity flag, EFT, that sets the operation mode to the electric control mode if 0.0 or the thermal control mode if 1.0. This is followed by the battery storage flag that selects thermal storage of energy if 0.0 and battery storage of energy if 1.0, which converts the thermal control mode (Section 2.2) to the solar control mode. The next parameter is the load profile flag, MMAX, that can be set = 1 to eliminate the restriction that the load profile must be at least 60% of the original building profile. The next parameter is the hourly output flag, NMAX, which selects the hourly output option (3.2.1) and the month that the hourly results are computed for in the intermediate result mode.

The last parameter, LMAX, is the monthly output flag for intermediate (3.2.3) results to verify the load profiles developed by STESEP.

The next lines (cards), Lines 170 to 260, contain size and operating data for the STES as discussed in Section 3.1.5.

ARAT = Ratio of collector area to floor area = AC/FA
RMAX = Ratio of maximum purchased power to QT
BUY = Ratio of minimum purchased power to QT
T \emptyset = Turbine condenser temperature in $^{\circ}$ R
TT = Turbine inlet temperature in $^{\circ}$ R
DTAUX = Additional temperature increase from fossil fuel heating of collector output in $^{\circ}$ R
DTW = Temperature difference between wall and fluid in collector in $^{\circ}$ R

This last line is repeated for as many cases as desired for cost comparisons, varying the various parameters on the line. The last card on the case will have ARAT (the first parameter) >8 and will terminate the case.

Depending on the value of ARAT, the code will read successive case data differently according to the conditions listed as follows:

- If $8 < \text{ARAT} < 10$ Next case input starts with site data (Line 7, Figure 17)
- If $10 < \text{ARAT} < 20$ Next case input starts with collector data (Line 14, Figure 17) — If CR = 0 program execution stops (see line 680, Figure 16)
- If $20 < \text{ARAT} < 30$ Next case input starts with operational data (Line 16, Figure 17)
- If $30 < \text{ARAT}$ End execution after listing results

3.1.2 Building Data

As discussed in Section 2.5.3, evaluation of the demand loads for commercial buildings is beyond the scope of the STESEP computer program. Another source of this data must be used which can be actual metered data for the building under consideration, output from a computer program such as AXCESS⁽⁴⁸⁾ or ECUBE,⁽⁴⁹⁾ or even generalized energy requirements such as specified in Reference 49. These demand loads must be converted to the following forms:

- 1) Yearly lighting, heating, and cooling energy usage
- 2) Monthly lighting, heating, and cooling energy usage
- 3) Maximum lighting load (kW/m^2)
- 4) Hourly profiles as percent of the maximum lighting load:
 - a) Average lighting usage
 - b) Average occupancy of building
 - c) Average process heat usage.

Typical hourly profiles are listed in Tables 21 through 26 for these quantities. The loss coefficients (CEL, CVH, CVR, CHL, CHD, CHL) cannot be extracted directly from the building load profile, but instead are evaluated using the

STESEP program in the hourly and monthly option model (as discussed later in Section 3.2) to match the monthly and yearly building load data (from one of the sources discussed above) while using the average hourly demand profiles.

If Tables 21 through 26 are examined, the values for the loss coefficients do not vary much for the different types of buildings and consequently the following values are recommended for input values to start the iteration process.*

- 1) Lighting Heat Release Factor (CEL) -- 0.5-0.7
- 2) Ventilation Cooling Factor (CVR) -- 4
- 3) Ventilation Heating Factor (CVH) -- 1-2
- 4) Building Heat Loss Coefficient (CHL) -- 0.01-0.06
- 5) Refrigeration/Heating Ratio (CRL) -- 5.7
- 6) Maximum Lighting Load (PPSM) -- from data.

The complete set of building input parameters is shown in Figure 16 for the large shopping center data from Table 22.

Using the peak building lighting load to define PPSM and the hourly profiles from the external source, a computer run in the monthly option is made and PPSM is adjusted to obtain the smallest deviation from the monthly lighting loads (QELC). Computer runs are then made to adjust the values of CEL, CVR, CVH, CHL, and CRL to obtain the smallest deviation from the monthly heating and cooling loads (QHED and QRFD). This is a trial and error process, but normally will only require a few iterations. After agreement is obtained with the monthly loads, the code is ready for use in the yearly option to evaluate STES configurations.

For cases where the energy usage is independent of the weather conditions, the heat loss coefficient can be set equal to zero and the hourly profiles used to determine the energy usage.

3.1.3 Site and Environmental Data Input Values

The environmental data for twelve representative sites shown in Tables 9 to 20 provides all of the input parameters necessary for the STESEP computer program. Figure 16 shows the data from Table 10 for Blue Hill, Massachusetts

*In some cases it may be necessary to vary the energy lag factor, HLAG, (Line 790 in Appendix A) by reprogramming.

TABLE 29
SITE SURVEY: CLIMATIC SIMULATION ACCURACY

Site	STESEP Predicted HDD/yr*	Actual HDD/yr	Error (HDD)	STESEP Predicted CDD/yr†	Actual CDD/yr	Error (CDD)	Predicted Insolation§ (Btu/ft ² -Day)	Actual Insolation (Btu/ft ² -Day)	Error (%)
Lake Charles, LA	1211	1498	-0.79	2671	2739	-0.19	1764	1763	+0.06
Fort Worth, TX	2371	2382	-0.03	2766	2587	+0.49	2037	2053	-0.78
Blue Hill, MA	6051	6335	-0.78	636	457	+0.49	1750	1763	-0.74
Albuquerque, NM	4388	4292	+0.26	1437	1316	+0.33	2604	2615	-0.42
Washington, DC	4236	4211	+0.07	1285	1345	-0.16	1542	1551	-0.58
Seattle, WA	4720	4487	+0.64	279	199	+0.22	1496	1505	-0.60
Phoenix, AR	1869	1552	+0.87	3542	3508	+0.093	2508	2523	-0.59
Omaha, NB	5817	6049	-0.64	1346	1173	+0.47	1949	1964	-0.76
Miami, FL	186	206	-0.05	3958	4038	-0.22	2024	2029	-0.25
Madison, WI	7737	7729	+0.02	620	460	+0.44	1838	1828	+0.55
Los Angeles, CA	1441	1245	+0.54	1168	1185	-0.05	2156	2166	-0.46
Nashville, TN	3632	3696	-0.18	1807	1694	-0.31	1538	1554	-1.03

*HDD = Heating Degree Days

†CDD = Cooling Degree Days

§Direct Normal Insolation

transcribed for input to STES. Table 29 shows good agreement between the predicted heating and cooling degree day values compared with the actual (from Tables 9-20) for each of the twelve representative sites. A comparison of the predicted and actual insolation values at each site is also provided in this table.

Similar data can be obtained for any location in the USA from Reference 50 for local electricity rates and from Reference 35 for direct horizontal radiation and the percent possible sunshine.

3.1.3.1 Ambient Temperature Data

Maximum and minimum temperatures for each month are graphically presented on Pages 1-25 of Reference 35 for the entire USA. As noted in Reference 35, some care must be used in interpolating values from these figures because of local geography effects.

3.1.3.2 Insolation Data

The direct horizontal radiation available in each month of the year throughout the USA is graphically shown on Pages 69-70 of Reference 35, while the percent possible sunshine is graphically presented on Pages 65-66 of the same reference. Tabular values for these parameters are given for 156 specific cities on Pages 66 and 70 of Reference 35. As discussed in Section 2.5.1, other sources exist for more detailed information over a shorter time period, which can be used if desired by the user.

3.1.3.3 Local Electricity Cost

Reference 50 gives the cost of electricity to industrial users in cities of over 50,000 population for two energy usage rates (200 and 400 kWh/kW-month) for each of several billing demands.

The ratio of the two energy usage rates at a fixed billing demand determines the coefficient, C_2 , in Equation (29), Section 2.4.3. The coefficient, C_3 , is determined by the ratio of either the 200 or 400 kWh/kW-month at two billing demands and the coefficient, C_1 , is then found from the actual cost of electricity at any billing demand and energy usage rate.

For the sample case, Reference 50 gives the following cost data for Boston, Massachusetts (Blue Hill), which is shown in parentheses in Table 30. Examination of Table 30 shows how the four cost values can easily be used to define the constants C_1 , C_2 , and C_3 .

TABLE 30
COEFFICIENT CALCULATION FROM ELECTRIC COST DATA
FOR BOSTON, MASSACHUSETTS

	Billing Demand (G-3/11 Schedule)			
	150 kW		1000 kW	
	\$	\$/kWh	\$	\$/kWh
200 kWh/mo-kW	(1604)	0.0535	(10,762)	0.0538
400 kWh/mo-kW	(2494)	0.0416	(16,697)	0.0417
$\frac{\ln(0.0538/0.0417)}{\ln(2)} = C_2$				0.3664
$\frac{\ln(0.0417/0.0416)}{\ln(0.15)} = C_3$				-0.0022
$0.0417(1000)^{-0.0022}(400)^{0.3664} = C_1$				0.3691

3.1.4 Collector/Array Characteristics Input Values

The STESEP program has built-in default values for characterization of most of the system component/subsystems which are changed only by reprogramming. These characteristics have been described in Section 2.0 and will not be repeated here.

The characteristics of the solar collector/array must be input by the user in the form shown in Figures 16 and 17. For solar thermal systems, the concentration ratio (CR) of the collector is entered in the first columns followed by the reference (optical) efficiency ($E_{\theta C}$), the convective loss coefficient ($UC_{\theta L}$), the radiative loss coefficient (EM), and the number of axes used in tracking, NAXE. NAXE = 1 selects a N-S oriented 1-axis tracker while NAXE = -1 selects an E-W oriented 1-axis tracker. NAXE = 2 selects a 2-axis tracker and NAXE = 3

selects the central receiver option. If a nontracking collector is used (NAXE = 0) or a N-S 1-axis tracker, the default attitude is a tilt equal to the latitude in a N-S orientation. Input of a tilt deviation (DTLT) allows this to be varied. For solar photovoltaic systems, the radiative loss coefficient (EM) is replaced by the thermal loss coefficient (BETA)* for the solar cells with the remaining collector inputs staying the same for both types of systems.

3.1.5 Operational Data

The primary purpose of the STESEP computer program is to evaluate the effect of component operating conditions and size on the economics of the system so that the input data described in this section is used to optimize the STES design according to the user's ground rules.

The operational data input format is shown at the bottom of Figure 16 and consists of output option and control mode flags followed by the size and performance data.

3.1.5.1 Output Option and Control Mode Flags

As discussed in 3.2, the STESEP computer program output can take three forms:

- 1) Leaving EFT and BFT = 0 produces the electrical load control mode for solar thermal systems. Setting EFT = 1 produces the thermal load control mode operation with hot thermal energy storage. Setting BFT = 1 produces the solar load control mode with battery energy storage. Photovoltaic systems set BFT = 1 automatically.
- 2) Setting NMAX to +1 removes the local profile requirements (2.3.7).
- 3) Setting NMAX to a value greater than zero produces an hourly printout for the month determined by the value of NMAX.
- 4) Setting LMAX to one and NMAX = 0 produces a monthly energy usage printout.

3.1.5.2 Solar Thermal Systems

The input data for solar thermal systems are:

*See 2.3.1.4

- 1) ARAT — Collector size divided by floor area
- 2) RMAX — The maximum demand rate allowed divided by QT*
- 3) BUY — The minimum purchased energy usage rate allowed divided by QT*
- 4) T \emptyset — The condenser temperature for the PCS subsystem ($^{\circ}$ R)
- 5) TT — The turbine inlet temperature for the PCS subsystem ($^{\circ}$ R)

3.1.5.3 Photovoltaic Systems

The input data for photovoltaic operational conditions are:

- 1) ARAT — Array area divided by floor area
- 2) AFPR † — Flat plate collector area divided by floor area
- 3) BUY — The minimum purchased energy usage rate divided by QT
- 4) T \emptyset — The flat plate collector outlet temperature or if AFPR = 0, the coolant inlet temperature for the array ($^{\circ}$ R)
- 5) The outlet temperature of the array coolant ($^{\circ}$ R)

3.1.6 Run Termination Input

The STESEP computer program will continue to accept operational data input until a collector/array area ratio (ARAT) greater than eight is entered. Then, the program prints out the system size summary and will accept new component data for multiple runs, as shown in Table 28.

3.2 PROGRAM OUTPUT

Prior to making production runs with the STESEP computer program, data checkout runs need to be made to ensure that proper hourly and monthly (daily) results are obtained with the data being used. For this purpose, the run option flags NMAX and LMAX are used. For NMAX greater than zero, hourly results are obtained; for LMAX greater than zero and NMAX = 0, monthly results are obtained; while for NMAX = LMAX = 0 (default condition) yearly results are obtained.

*Building Tighting load defined in Equations 42-44.

† If AFPR = 0, then the array is assumed to be actively cooled.

3.2.1 Hourly Results

When NMAX is nonzero, the STESEP computer program conditions are set to the month defined by NMAX and the hourly energy balance is printed out as shown in Figure 19. This allows verification of the building hourly load profile.

3.2.2 Monthly Results

When NMAX is zero and LMAX nonzero, the STESEP computer program will print-out the monthly building energy usage as the average daily usage for that month as shown in Figure 20.

3.2.3 System Descriptions and Yearly Results

The default output option for the STESEP computer program is the selection of the minimum annualized cost system from a number of user-selected variations in the operational parameters following checkout of the input data.

For a solar thermal STES for a large shopping center, Figure 21 shows typical intermediate output from each case considered by the STESEP computer program while Figure 22 shows the system size summary for the minimum annualized cost system considered in the cases analyzed. Figure 23 shows the equivalent intermediate printout for a photovoltaic STES, and Figure 24 shows the sizes for the minimum annualized cost system.

3.2.3.1 Intermediate Prinouts

The intermediate printouts show the changes in annualized cost produced by the operational conditions considered by the user.

Figure 20 shows a line of intermediate output for each case considered (Lines 170 to 250 of Figure 16) giving the annualized cost of the case considered, ACST, of the system; the minimum annualized costs of all prior cases, OCST; the operating cost, OPCST, and capital investment, CINV; the average daily solar energy input, QSØLAR; the energy usage/kW, USE/DEMAND; and the two estimates for the breakeven cost of electricity from the system, \$/kWh HIGH and LOW.

These results are useful to: (1) examine how sensitive the results are to the range of parameters considered and (2) improve the guesses used if a re-submission is necessary.

LARGE SHOPPING CENTER BLUE HILL, MASS.

MO/HR	QELC KW	QRFD KW	QHED KW	QAUX KW	QBUY KW	QCOL KW	QDMP KW	QRFA KW	QVCR KW
401	308.9	791.5	556.9	2209.7	1010.3	0.0	0.0	791.5	0.0
402	326.6	791.5	634.4	2336.7	992.5	0.0	0.0	791.5	0.0
403	337.8	344.1	1130.5	2416.5	235.8	0.0	0.0	344.1	0.0
404	341.6	344.1	1147.1	2443.7	232.0	0.0	0.0	344.1	0.0
405	337.8	344.1	1130.5	2416.5	235.8	0.0	0.0	344.1	0.0
406	326.6	344.1	1081.8	2336.7	246.9	0.0	0.0	344.1	0.0
407	308.9	344.1	1004.3	2209.7	264.7	0.0	0.0	344.1	0.0
408	1107.4	3705.1	1129.9	5049.2	957.3	2155.5	0.0	3705.1	0.0
409	2298.3	8471.2	1562.9	13172.6	1544.4	2452.9	0.0	8471.2	0.0
410	3088.2	12073.0	1409.5	18605.5	2647.2	2616.5	0.0	12073.0	0.0
411	3871.1	14539.2	2361.6	24093.2	1864.3	2702.0	0.0	14539.2	0.0
412	6662.2	23171.0	6039.4	44022.3	0.0	2731.5	4046.2	19000.5	4170.5
413	6704.7	23171.0	6230.9	44354.5	0.0	2710.7	4232.0	18809.0	4362.0
414	6260.2	21937.9	5463.8	41277.5	0.0	2633.3	2291.3	19576.1	2361.8
415	5453.3	19471.7	4336.8	35713.5	282.1	2476.7	0.0	19471.6	0.0
416	5808.9	20704.8	4665.7	38646.6	0.0	2184.6	320.8	20374.1	330.6
417	4191.2	15772.3	2525.9	29985.8	1544.2	0.0	0.0	15772.3	0.0
418	6658.8	23171.0	6024.4	47640.4	0.0	0.0	4031.6	19015.5	4155.5
419	6897.6	22844.1	7664.2	49348.5	0.0	0.0	12836.3	9613.3	13230.7
420	6643.9	21725.7	7725.6	47533.5	0.0	0.0	14483.1	6797.6	14928.1
421	4648.8	15147.2	5418.5	33259.7	0.0	0.0	8777.6	6099.8	9047.3
422	1051.6	3326.5	1264.7	7523.7	382.2	0.0	0.0	3326.5	0.0
423	258.8	481.8	648.1	1851.6	544.2	0.0	0.0	481.8	0.0
424	285.7	344.1	903.3	2044.2	287.8	0.0	0.0	344.1	0.0

Figure 19. Hourly Result Printout Format

LARGE SHOPPING CENTER BLUE HILL, MASS.

MONTH	QELC KWH	QRFD KWH	QHED KWH	QAUX KWH	QRUY KWH	QCOL KWH	QDMP KWH	QRFA KWH	QVCR KWH
1	6662.7	21113.4	8127.1	46602.2	785.4	799.4	4952.6	16008.6	5104.8
2	6662.7	21113.4	8127.1	46206.7	785.4	1096.0	4952.6	16008.6	5104.8
3	6454.6	21113.4	7209.5	43767.9	925.0	1808.6	4653.6	16316.8	4796.6
4	6181.6	21113.4	6005.0	41707.6	1106.0	1888.6	4251.6	16731.2	4382.2
5	6008.7	21552.2	4804.5	39682.0	1225.6	2480.5	4019.4	17409.3	4215.6
6	6567.5	24495.9	4366.7	43562.4	1162.5	2568.4	6183.2	18122.9	6486.2
7	7688.7	28081.3	4351.6	52620.0	826.9	1791.7	9613.2	18172.7	9908.6
8	7229.4	26730.5	4351.6	49166.4	957.4	1917.1	8177.6	18301.7	8428.9
9	6298.7	23230.6	4433.7	43098.3	1251.7	1474.4	5400.6	17665.1	5565.5
10	6012.5	21113.4	5259.4	41188.8	1218.2	1370.7	4003.6	16986.7	4126.7
11	6272.5	21113.4	6406.5	44481.1	1047.6	296.6	4393.9	16584.4	4529.0
12	6571.6	21113.4	7725.6	46656.6	849.2	269.6	4833.1	16131.8	4981.6

Figure 20. Monthly Result Printout Format

LARGE SHOPPING CENTER BLUE HILL, MASS.

CASE	ACST \$	OCST \$	OPCST \$	CINV \$	USE/DEM. KWH/M/KW	\$/KWH LOW	\$/KWH HIGH
1	.2987E+08	.1000E+36	.2873E+07	.6646E+07	301.6	.6648E-01	.7709E-01
2	.2845E+08	.2989E+08	.2728E+07	.6729E+07	289.6	.6067E-01	.7120E-01
3	.2789E+08	.2845E+08	.2671E+07	.6790E+07	283.0	.5842E-01	.6896E-01
4	.2814E+08	.2789E+08	.2684E+07	.7498E+07	278.1	.5922E-01	.7150E-01
5	.2875E+08	.2789E+08	.2722E+07	.8933E+07	263.2	.6108E-01	.7672E-01
6	.2974E+08	.2789E+08	.2794E+07	.1055E+08	238.6	.6388E-01	.8290E-01
7	.2726E+08	.2789E+08	.2598E+07	.7454E+07	450.8	.5297E-01	.6133E-01
8	.2577E+08	.2726E+08	.2442E+07	.7910E+07	408.8	.4928E-01	.5839E-01
9	.2508E+08	.2577E+08	.2370E+07	.8072E+07	327.3	.4758E-01	.5682E-01
10	.2474E+08	.2508E+08	.2334E+07	.8183E+07	266.8	.4675E-01	.5606E-01
11	.2448E+08	.2474E+08	.2308E+07	.8209E+07	237.4	.4615E-01	.5544E-01
12	.2424E+08	.2448E+08	.2282E+07	.8327E+07	214.8	.4558E-01	.5502E-01
13	.2444E+08	.2424E+08	.2290E+07	.9052E+07	213.8	.4605E-01	.5671E-01
14	.2494E+08	.2424E+08	.2316E+07	.1055E+08	210.7	.4722E-01	.6041E-01
15	.2542E+08	.2424E+08	.2339E+07	.1205E+08	205.2	.4834E-01	.6403E-01
16	.2987E+08	.2424E+08	.2871E+07	.6646E+07	303.4	.6646E-01	.7709E-01
17	.2849E+08	.2424E+08	.2731E+07	.6729E+07	289.2	.6083E-01	.7141E-01
18	.2801E+08	.2424E+08	.2683E+07	.6790E+07	280.0	.5892E-01	.6951E-01
19	.2869E+08	.2424E+08	.2740E+07	.7437E+07	287.2	.6146E-01	.7382E-01
20	.2925E+08	.2424E+08	.2773E+07	.8887E+07	277.1	.6326E-01	.7918E-01
21	.3000E+08	.2424E+08	.2823E+07	.1036E+08	258.9	.6541E-01	.8460E-01
22	.2729E+08	.2424E+08	.2600E+07	.7441E+07	451.6	.5303E-01	.6138E-01
23	.2580E+08	.2424E+08	.2444E+07	.7901E+07	409.4	.4934E-01	.5843E-01
24	.2511E+08	.2424E+08	.2372E+07	.8065E+07	327.8	.4763E-01	.5686E-01
25	.2477E+08	.2424E+08	.2337E+07	.8178E+07	267.3	.4681E-01	.5611E-01
26	.2452E+08	.2424E+08	.2312E+07	.8204E+07	237.8	.4624E-01	.5552E-01
27	.2434E+08	.2424E+08	.2292E+07	.8323E+07	215.2	.4581E-01	.5525E-01
28	.2469E+08	.2424E+08	.2317E+07	.8921E+07	237.0	.4663E-01	.5714E-01
29	.2511E+08	.2424E+08	.2335E+07	.1039E+08	235.2	.4761E-01	.6060E-01
30	.2553E+08	.2424E+08	.2353E+07	.1187E+08	231.2	.4860E-01	.6409E-01
THE BEST CASE WAS 12; THE ORIGINAL ANNUALIZED COST WAS						.2446E+08	

Figure 21. Intermediate Results for Yearly Calculations

STES EQUIPMENT SIZES FOR A LARGE SHOPPING CENTER
 LOCATED IN BLUF HILL, MASS. FLOOR AREA IS 70755.SQ.M
 ELECTRICAL DEMAND IS 136176.KWH/DAY AT 309.KWH/KW
 BASED ON INSOLATION OF 446.LANG./DAY, HDD/YR OF 5917, CDD/YR OF 655.

ASSUMPTIONS

FOR A 2006 START OF OPERATION, COST PARAMETERS ARE
 FCR=0.159 K=0.080 G=0.050 GF=0.100 N= 20 FUEL= 2.37\$/GJ, ELECT=12.80\$/GJ(1976\$)
 RANKINE CYCLE STES, CONTROL BY SOLAR LOAD WITH A DISTRIBUTED COLLECTOR

EQUIP	SIZE	EFF	TIN	TOUT	ENERGY	INST'LD	CSI	CAP. INV.	REC'G	CST.
			DEG C	DEG C	KWH/DAY	\$/UNIT	SIZE	K\$	K\$	
COLLECT.	10621.SM	0.241	233.	349.	12918.	100.		1062.		57.
BATTSTO.	0.KWH	0.723	0.	0.	0.	0.		0.		3.
HEAT EX.	14156.SM	0.954	349.	233.	425662.	14.		204.		0.
AUX.HTG.	59510.KW	0.750	228.	371.	550335.	3.		182.		1588.
PCS	9042.KW	0.203	371.	110.	86233.	345.		3116.		479.
V.C.RFG.	6009.TON	4.500	0.	0.	86640.	285.		1712.		0.
AB. RFG.	5796.TON	0.717	108.	8.	185237.	327.		1895.		0.
PRO.HTG.	8801.KW	1.000	110.	19.	0.	11.		99.		0.
COOL TWR	6705.SM	0.700	110.	108.	80971.	5.		33.		0.
COLD STO	110.CM	0.700	8.	17.	0.	227.		25.		0.
AUX.ELEC	1147.KW	0.0	0.	0.	8748.	0.		0.		155.

COST ANALYSIS RESULTS

SOLAR ENERGY FURNISHES 27.2% OF LOAD, UTILITY 6.5%, AND FOSSIL FUEL 66.3%
 TOTAL CAP. INV. IS \$.83275E+07 WITH YEARLY REC'G. COSTS, .2282E+07
 ANNUALIZED COST OF \$.2424E+08 WITH A YEARLY SAVING OF .2174E+06 DROI= 0.9%

Figure 22. System Size Printout (Solar Thermal)

LARGE SHOPPING CENTER BLUE HILL, MASS.

CASE	ACST \$	OCST \$	OPCST \$	CINV \$	USE/DEM. KWH/M/KW	\$/KWH LOW	\$/KWH HIGH
1	.2331E+08	.1000E+36	.2244E+07	.4963E+07	288.2	-.1009E-01	.7143E-01
2	.2358E+08	.2331E+08	.2275E+07	.4751E+07	288.2	.3397E-02	.7737E-01
3	.2316E+08	.2331E+08	.2226E+07	.5172E+07	288.2	-.1723E-01	.7174E-01
4	.2304E+08	.2316E+08	.2210E+07	.5380E+07	288.2	-.2348E-01	.7288E-01
5	.2273E+08	.2304E+08	.2167E+07	.6133E+07	277.6	-.1008E-01	.7143E-01
6	.2241E+08	.2273E+08	.2123E+07	.6887E+07	267.0	-.3348E-02	.7059E-01
7	.2212E+08	.2241E+08	.2081E+07	.7650E+07	256.4	.1027E-02	.7044E-01
8	.2181E+08	.2212E+08	.2038E+07	.8414E+07	245.9	.3904E-02	.7017E-01
THE BEST CASE WAS 8							THE ORIGINAL ANNUALIZED COST WAS .24450E+08

Figure 23. Intermediate Results for Yearly Calculations (Photovoltaic)

STES EQUIPMENT SIZES FOR A LARGE SHOPPING CENTER
 LOCATED IN BLUE HILL, MASS. FLOOR AREA IS 70755.SQ.M
 ELECTRICAL DEMAND IS 136176.KWH/DAY AT 309.KWH/KW
 BASED ON INSOLATION OF 483.LANG./DAY, HDD/YR OF 5917, CDD/YR OF 655.

ASSUMPTIONS

FOR A 2006 START OF OPERATION, COST PARAMETERS ARE
 FCR=0.159 K=0.080 G=0.050 GF=0.100 N= 20 FUEL= 2.37\$/GJ, ELECT=12.80\$/GJ (1976\$)
 PHOTOVOLTAIC STES, CONTROL BY SOLAR LOAD WITH A PHOTOVOLTAIC ARRAY

EQUIP	SIZE	EFF	TIN	TOUT	ENERGY	INST'LD	CST.	CAP. INV.	REC'G	CST.
			DEG C	DEG C	KWH/DAY	\$/UNIT	SIZE	K\$		K\$
PV ARRAY	42484.SM	0.127	0.	0.	29497.	100.	4248.	0.		
BATTERY	467.KWH	0.723	0.	0.	152.	50.	23.	5.		
AUX.ELEC	12394.KW	1.000	0.	0.	108198.	0.	0.	1834.		
BLDG.HT.	430.KW	1.000	19.	19.	68634.	25.	11.	93.		
INVERT.	4104.KW	0.950	0.	0.	0.	65.	267.	107.		
V.C.RFG.	8525.TON	4.500	0.	0.	271877.	249.	2119.	0.		
AB. RFG.	0.TON	0.650	0.	0.	0.	0.	0.	0.		
PRO.HTG.	8371.KW	1.000	0.	0.	2534.	4.	38.	0.		
FP COLI.	28302.SM	0.440	60.	69.	68044.	54.	1523.	0.		
HEAT STO	25376.CM	0.700	69.	60.	0.	7.	185.	0.		

COST ANALYSIS RESULTS

SOLAR ENERGY FURNISHES 19.6% OF LOAD, UTILITY 76.6%, AND FOSSIL FUEL 3.9%
 TOTAL CAP. INV. IS \$.84137E+07 WITH YEARLY REC'G. COSTS, .2038E+07
 ANNUALIZED COST OF \$.2181E+08 WITH A YEARLY SAVING OF .2640E+07 DROI= 10.8%

Figure 24. System Size Printout (Photovoltaic)

3.2.3.2 System Size Summary Printout

The primary output of the STESEP computer program is the list of equipment sizes producing the minimum annualized cost system as shown in Figures 22 and 24. The equipment sizes, efficiencies, and operating conditions can serve as input to more detailed analysis programs⁽²⁻⁴⁾ or can be used directly in system comparisons. The capital investment and recurring cost summaries show which component systems are influencing the economic feasibility of the system.

3.3 PROGRAM LIMITATIONS

The STESEP computer program is a screening device intended to be used in conceptual design studies, feasibility studies, and as a preprocessor for more detailed programs.

Attempting to predict the energy usage of buildings is dangerous at best, since only previous environmental and customer usage traits are known. Different operational hours in the future as well as change in climatic conditions make extrapolation of present day standards questionable. However, to use long-term climatic conditions instead of actual weather conditions for a specific year probably increases the accuracy of the results when energy usage over the system lifetime (rather than any one specific year) is the criteria.

The STESEP program cannot be used to evaluate:

- 1) Daily startup procedures
- 2) Response to cloud formations
- 3) Internal HVAC systems configurations
- 4) Building thermal requirements
- 5) Effects of time variable cost parameters
- 6) Solar thermal systems other than superheated Rankine power conversion systems
- 7) Thermal storage systems using a second fluid
- 8) Phase change thermal storage systems.

3.4 TYPICAL METEOROLOGICAL YEAR WEATHER TAPE (TMY)

In addition to using the Deterministic Insolation Model⁽³⁶⁾ for the local environmental conditions, the STESEP code can utilize the Typical Meteorological Year Weather Tapes developed by Sandia Laboratories for National Oceanic and Atmospheric Administration (NOAA) from the SOLMET⁽⁵³⁾ tapes.

These tapes must be obtained directly from NOAA, Computer Products Branch at the National Climatic Center in Ashville, North Carolina, and are expected to be available for the original 26 SOLMET cities in either IBM or CDC compatible format (EBDIC or BCD). The cost of these tapes is not known at this time but is expected to be close to the \$60 per reel currently charged for the SOLMET⁽⁵³⁾ tapes.

The typical meteorological year tape for the site of interest must be mounted (special instructions may be required) and defined as UNIT 1 to use this computing option (INSØ=2). The TMY subroutine then reads the insolation and air temperature data from the tape for use in the STESEP code.

3.5 SAMPLE PROBLEMS

Figure 16 lists the input for the STESEP sample problems which consider a solar total energy system application to a large shopping center located in Blue Hill, MA. For this application, a Rankin solar thermal STES is analyzed, first yielding the intermediate results listed in Figure 21, and which relate to the operating conditions listed as lines 00160 to 00460 in Figure 16. In these cases, both total cascading of the PCS energy (lines 230-310 and 380-460) and partial cascading (lines 170-220 and 320-370) are considered along with using fossil fuel to add additional energy to the working fluid (lines 170-310) versus no additional energy addition (lines 370-460). The STESEP code then selected the most cost effective case from those analyzed and produced the system size summary shown in Figure 22. As indicated at the bottom of Figure 21, the best case was the 12th case considered (line 280) and indicated that in this application, total cascading of the PCS reject energy was desirable using only enough collectors to meet the building daily load without a significant amount of storage. The monthly use to demand ratio was decreased from 309 kwh/mo-kW to 215 kwh/mo-kW which may or may not be acceptable to the utility within the existing rate structure. From Figure 21, it can be seen that several other systems considered have annualized costs that are lower than the original reference cost and hence are also cost effective systems (e.g. cases 11, 13, 27) and which may be worth further consideration by a more detailed model of the system along with the selected case. These cases were selected based on the high fuel cost escalation rate assumptions and correspond therefore to the \$/kWh LOW breakeven cost of electricity listed in Figure 21. The comparative breakeven cost of electricity for the low fuel cost escalation rate is also shown in Figure 21 as \$/kWh high and indicates that Case 12 would also have been selected for those economic conditions.

For evaluation of the annualized cost of the system under other economic assumptions, Figure 21 also lists the operating costs and capital investment for each case that can be used with the Reference 6 analysis to compute the annualized system cost under different economic assumptions. The monthly result sample problem (input lines 480 to 510 in Figure 16) for this building gives the results shown in Figure 20 where the average daily energy usage for the month is listed in kWh for the lighting (QELC), cooling (QRFD), and heating (QHED) demand loads.

The average daily use of fossil fuel (QAUX), purchased electricity (QBUY), collected solar energy (QCOL), and cooling tower energy rejection (QDMP) are also shown for each month. The last two columns of the printout shows the cooling available from cascading the PCS reject energy (QRFA) and the required additional cooling from a vapor compression chiller system (QVCR) so that $QRFA + QVCR$ equals QRFD.

The hourly result for the sample problem (input lines 520 to 550) is shown in Figure 19 and gives hourly usage for the same parameters as the monthly result. In addition to checkout usage, the hourly result format can give insight into the effects of the daily demand profile on both auxiliary energy usage and purchased electricity.

The final sample case (input lines 560 to 680 in Figure 16) considers a non-tracking, non-concentrating photovoltaic array STES using flat plate collectors for the building heating load. Fewer cases are considered for this application where only the array area and flat plate collector area are varied. The intermediate results are shown in Figure 23 and indicate that a fairly large array would be desirable as considered in Case 8 (input line 660 in Figure 16). The system sizes for this case are shown in Figure 24. For the economic condition selected (high fuel cost escalation rate), the photovoltaic STES is better than the solar thermal STES (Figure 22) but examination of the breakeven costs of electricity listed in Figures 23 and 21 show that under conditions of low fuel cost escalation the solar thermal STES has a lower breakeven cost of electricity and hence would be more cost effective. Consequently the results of the analysis must be related to the economic assumptions used to compare the systems.

4.0 PROGRAMMER'S INFORMATION

The Solar Total Energy Systems Evaluation Program (STESEP) consists of a main program and four subroutines, which are listed in Appendix A. The code is available for either IBM or CDC usage and uses 76 kilobytes of memory during operation.

The code is intended for use through remote terminals and uses free-form input data read from tape - file 5, while output from the code uses tape - file 6. Since these are the default input - output files, no special file designation is required for operation of the code on either an IBM or CDC computer.

A detailed flow diagram of the STESEP code is given in Section 4.2 and a glossary of the code symbols is listed in Section 4.3. The code itself is described sequentially below in Section 4.1.

4.1 PROGRAM DESCRIPTION

Input data for the site and building characterization are read from file 5 in free format at the beginning of the code. The numerical constants and code default values for STES equipment are defined between statements 10 and 15. Between statements 15 and 20, the code can optionally ($INS\emptyset = 1$) calculate monthly CF and CN values from total horizontal insolation and percent possible sunshine as described in Section 2.3.6. The default annualized cost parameters are located between statements 30 and 35. Initialization of problem parameters occurs between statements 35 and 50. The start of successive problems can start at statement numbers 10, 35, 45, or 50, depending on the value of the parameter ARAT (see Section 3.1.7)

Input data for STES parameters is read from file 5 in free format between statements 35 and 55 and is not printed out on file 6. Default fluid properties are evaluated between statements 60 and 65 with the start of yearly calculations just before statement 70.

Insolation calculations occur between 75 and 80 followed by either:(1) photovoltaic array calculations from just before 65 to 75, or (2) solar thermal collector calculations between 75 and 95.

Control option calculations occur between statements 90 and 240 followed by energy storage calculations between 240 and 260. Hourly usage parameter data is stored in the Z array between 260 and 270 and is followed by a thermal (QBAL) and electrical (EBAL) energy balance to ensure proper operation of the code. Between statements 270 and 290, daily energy usage and maximum parameter values are determined.

From 300 to 450, photovoltaic array cost calculations are made. Annualized cost for the system is calculated using subroutine TAC. Parameters for the minimum annualized cost system are stored in the R array for later use. From 450 to 500, the same computations are made for solar thermal systems and from 500 to 600 the saved results are converted for printout usage.

The primary code output is defined between statements 650 and 999 where a one-page summary of equipment sizes and energy usage is written in file 6. The primary code output is defined between statements 650 and 999 where a one-page summary of equipment sizes and energy usage is written in file 6. The code then either terminates or returns to statements 10, 35, 45, or 50, depending on the value of the parameter ARAT.

4.2 PROGRAM FLOW CHART

The following pages present the flow diagram of the STESEP Code which was described in Section 4.1. The first 25 pages cover the main program while the last 8 pages cover the four subroutines TAC, PRINT, PRINTV, and TMY.

08/21/78

AUTOFLOW CHART SET - STESEP STESEP CODE FLOWCHART

PAGE 01

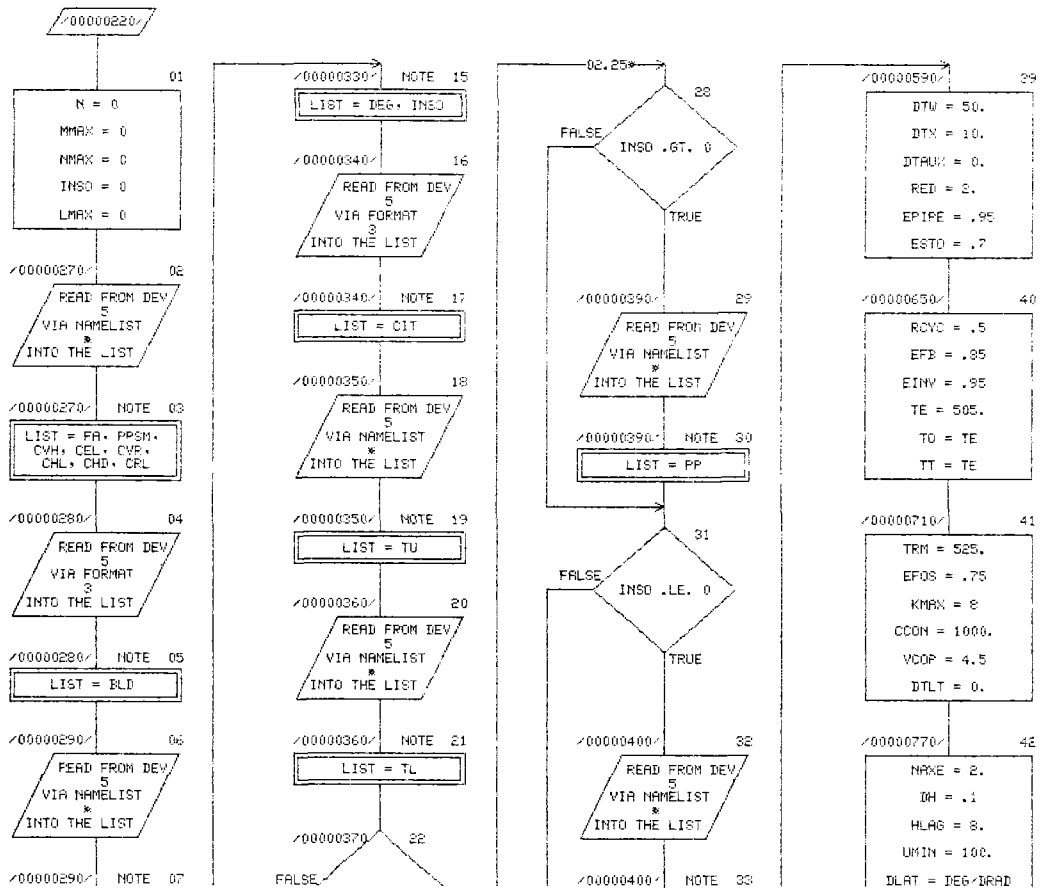
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THE QUESTION MARK REFERS TO TAPE ID NO. FROM LIBRARY
THE TOTAL HOR. AND PP OPTION MUST BE USED AS BACKUP

JUNE 20,1978

CHART TITLE - PROCEDURES



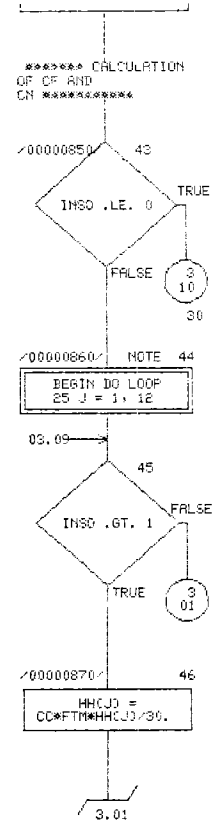
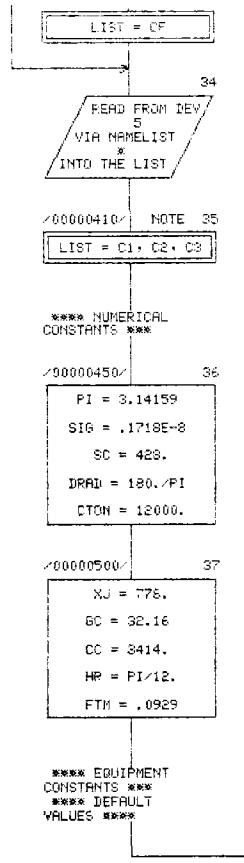
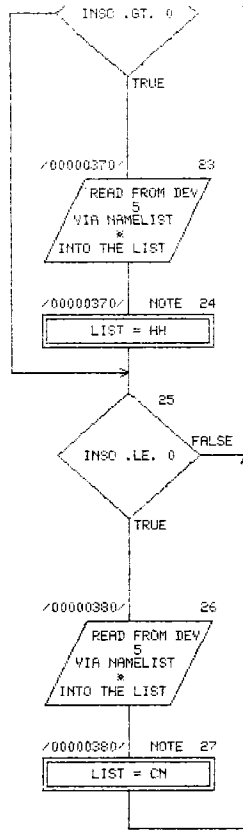
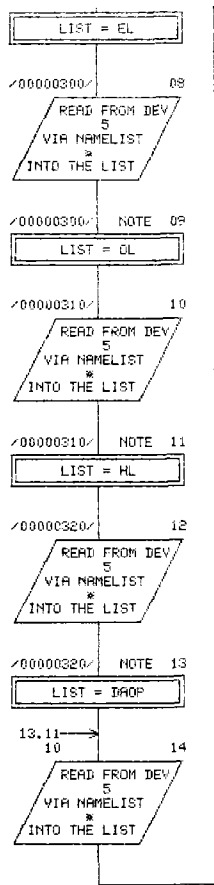
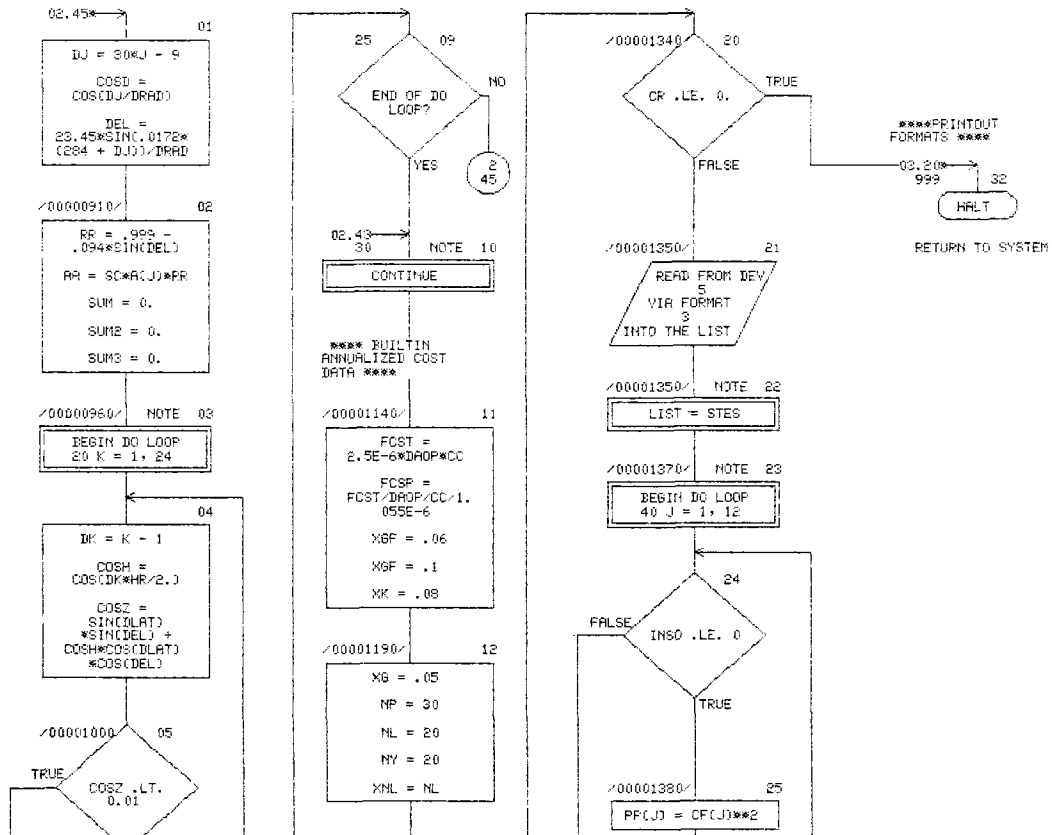


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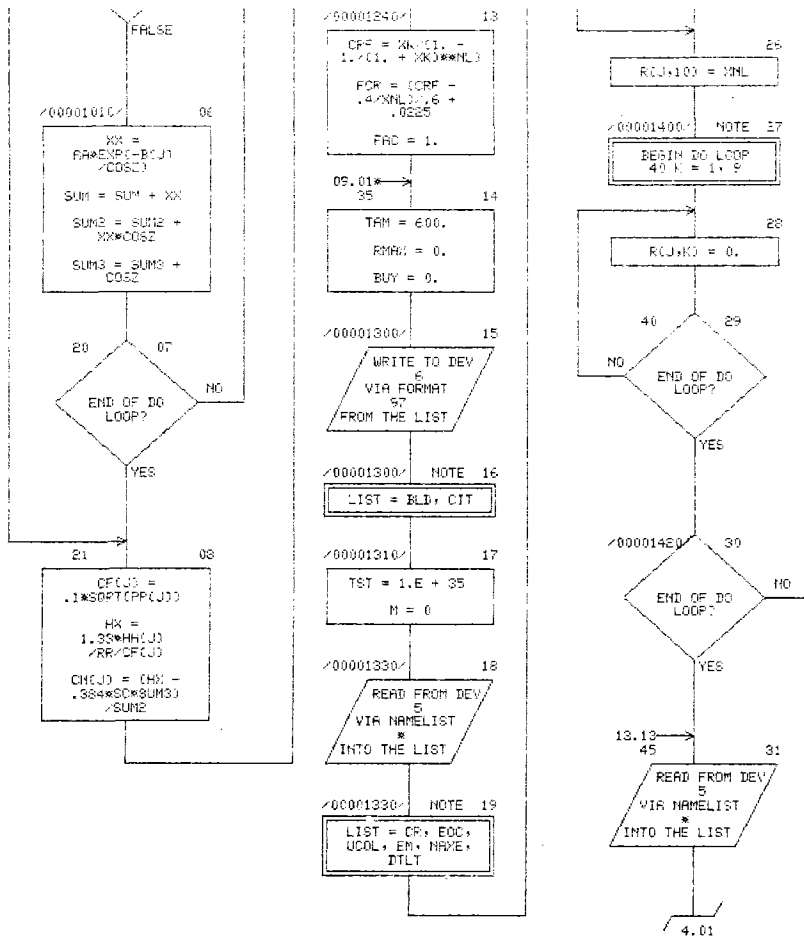
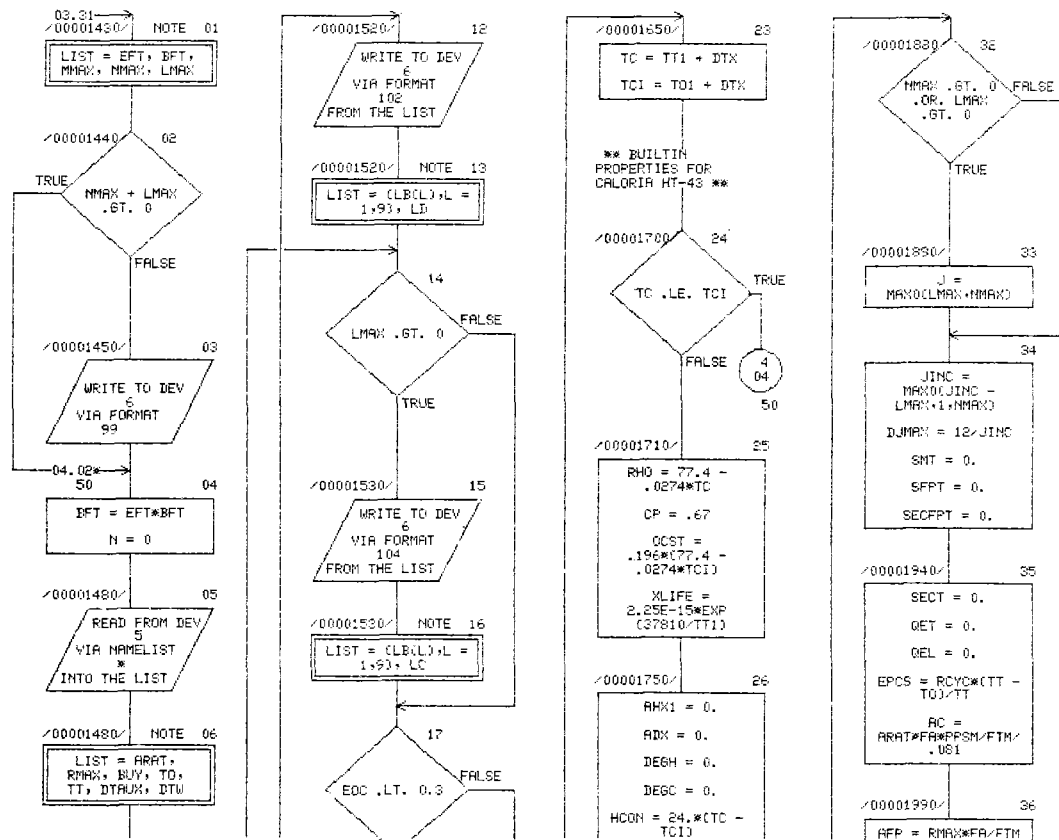


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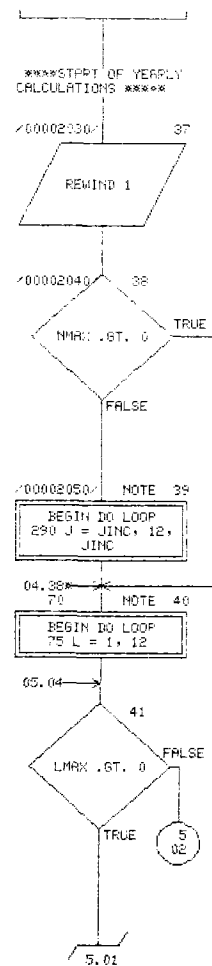
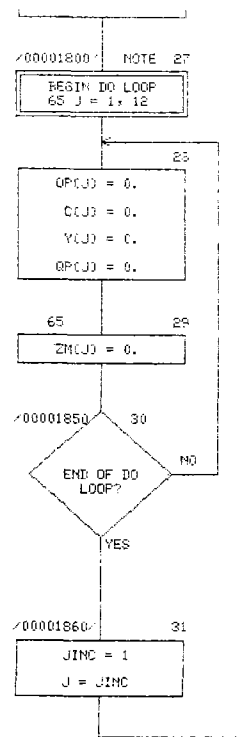
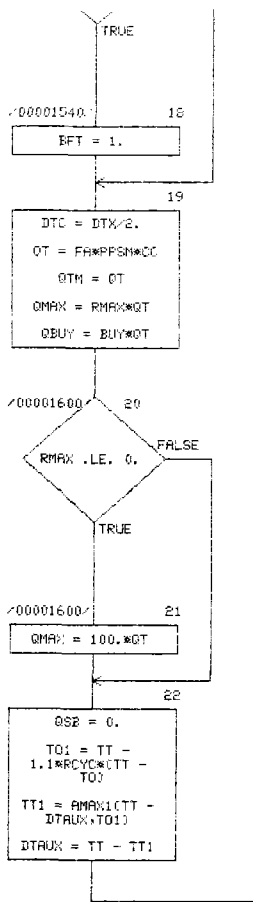
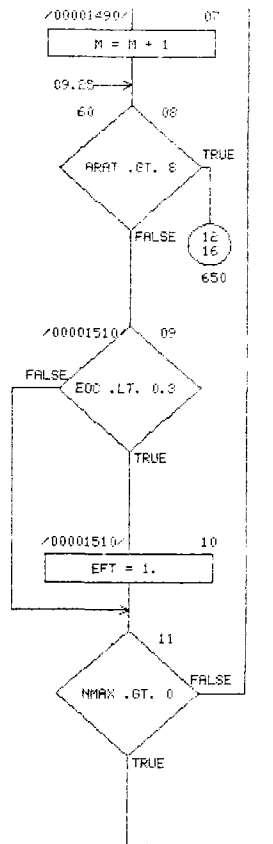
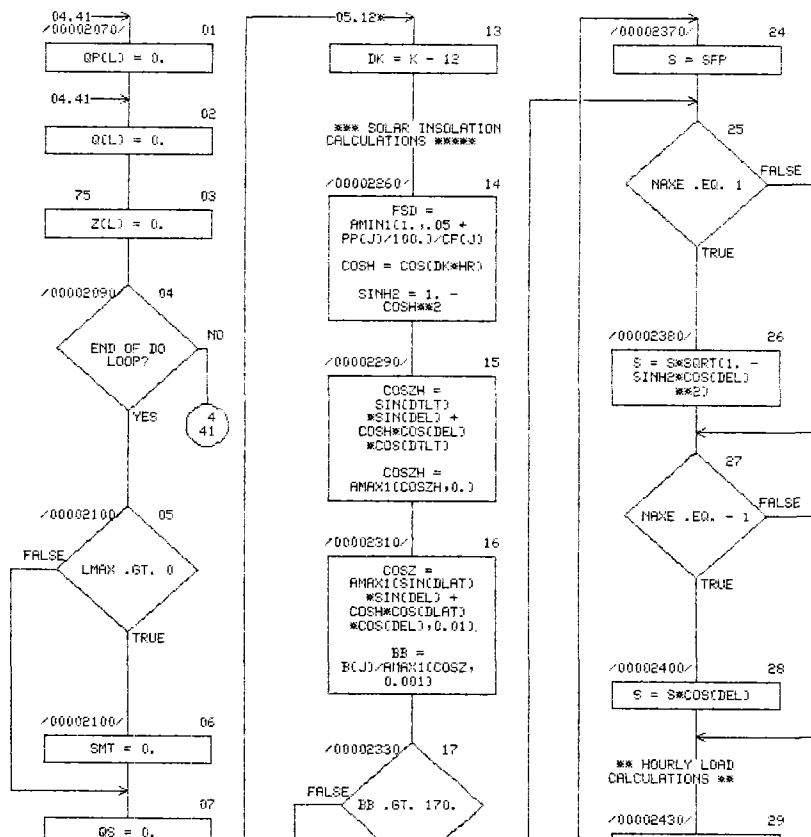


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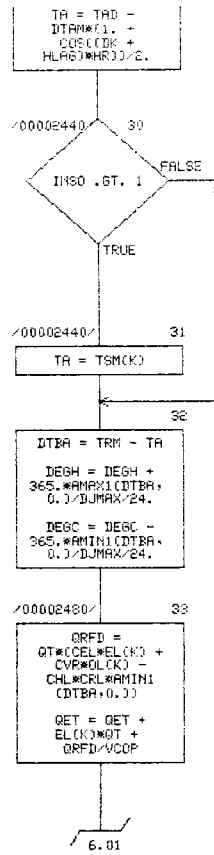
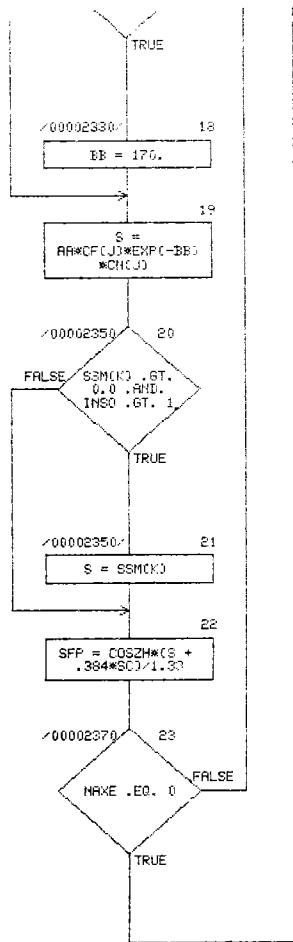
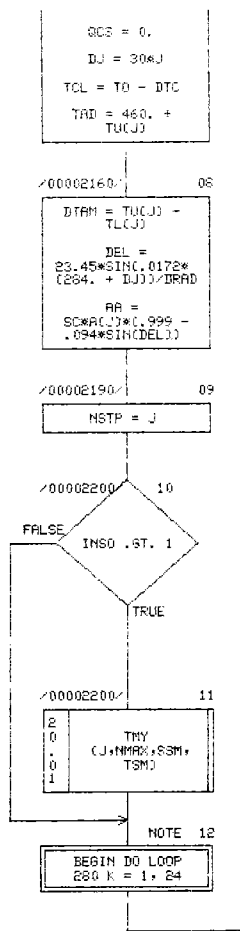
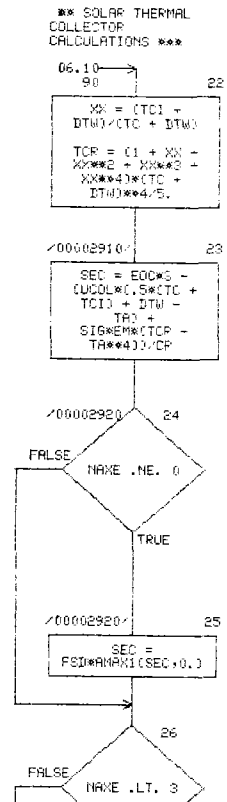
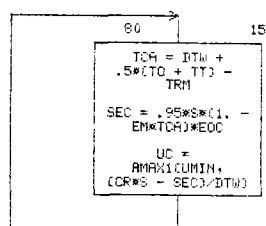
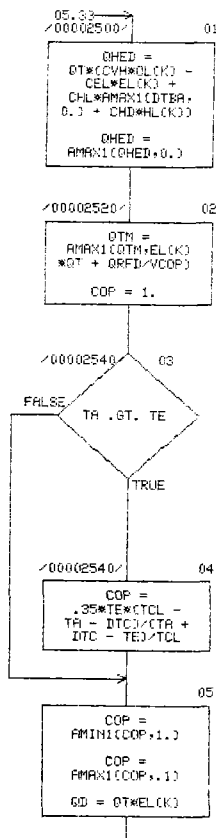


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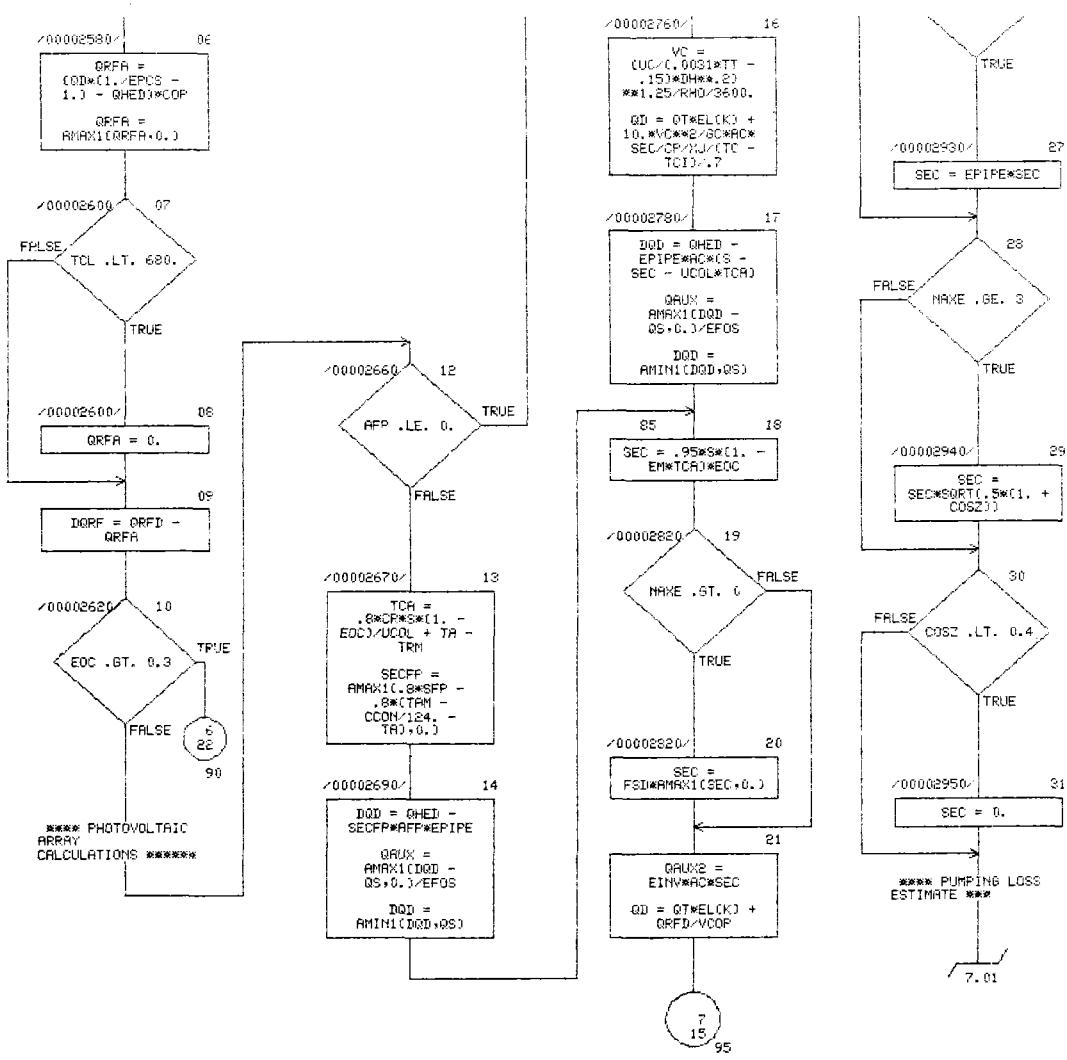
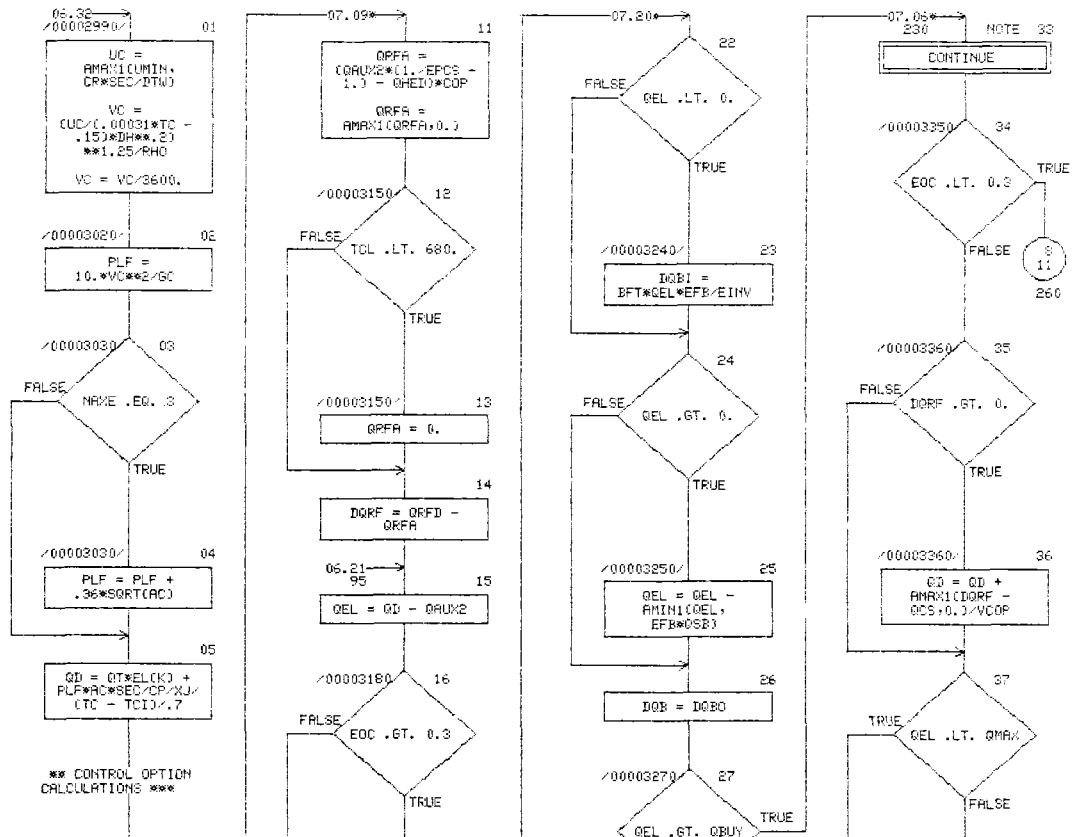


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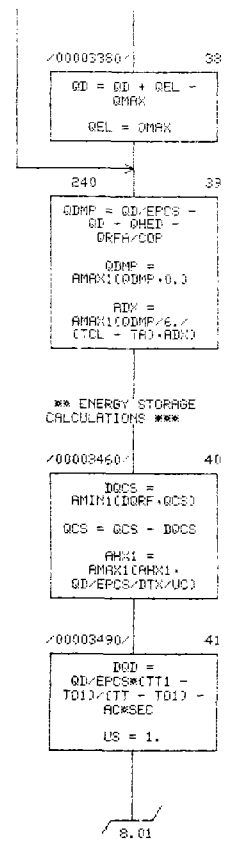
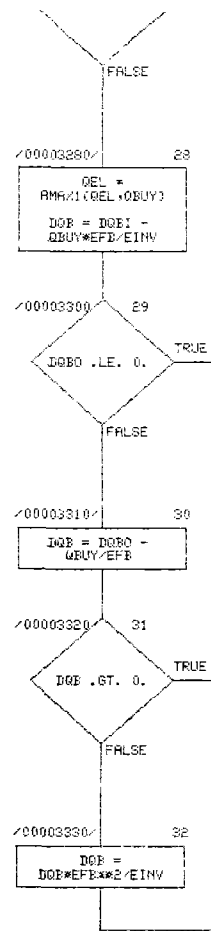
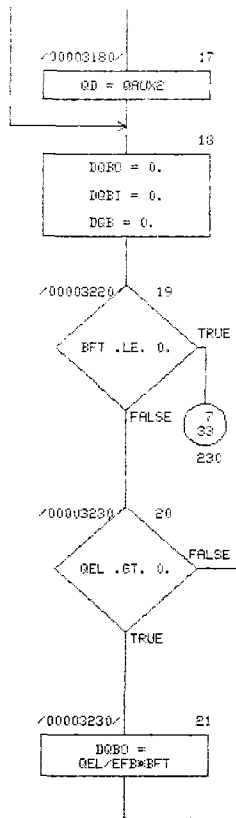
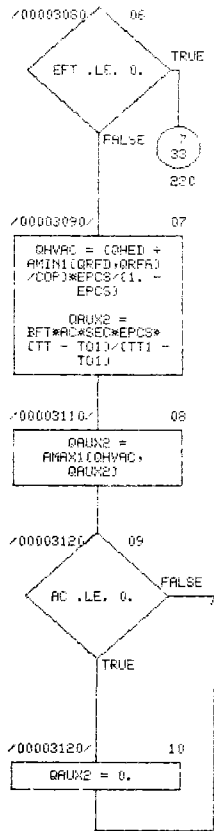
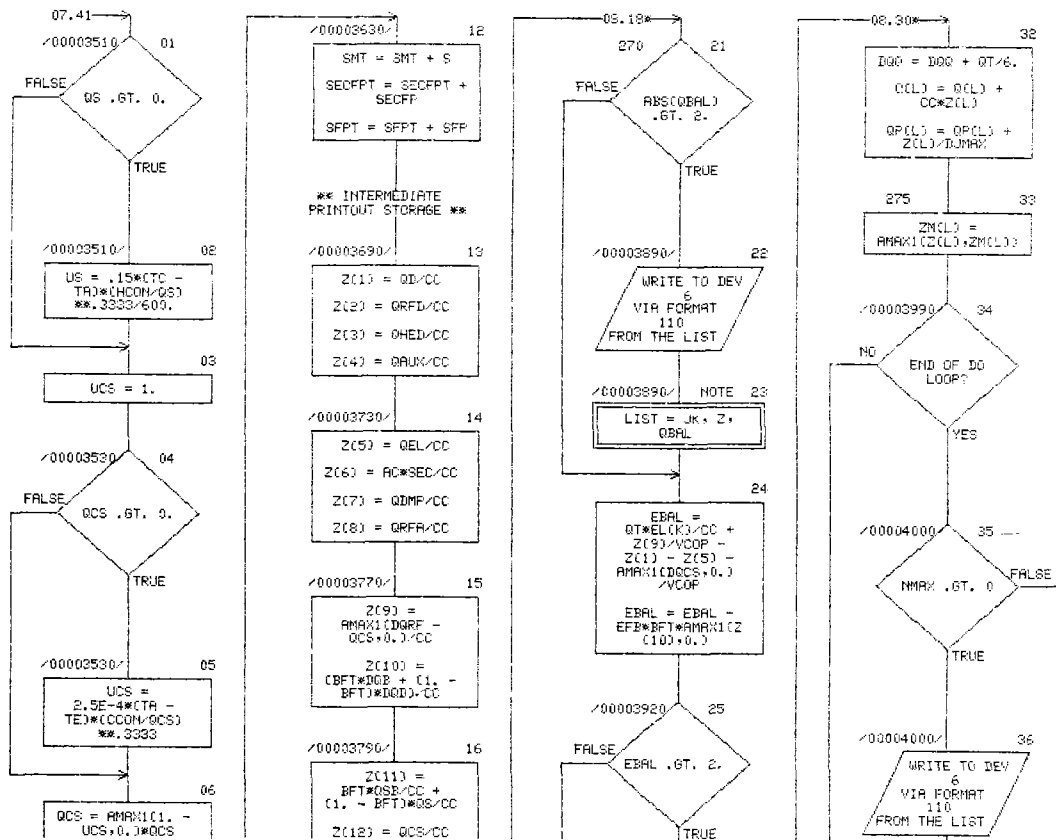


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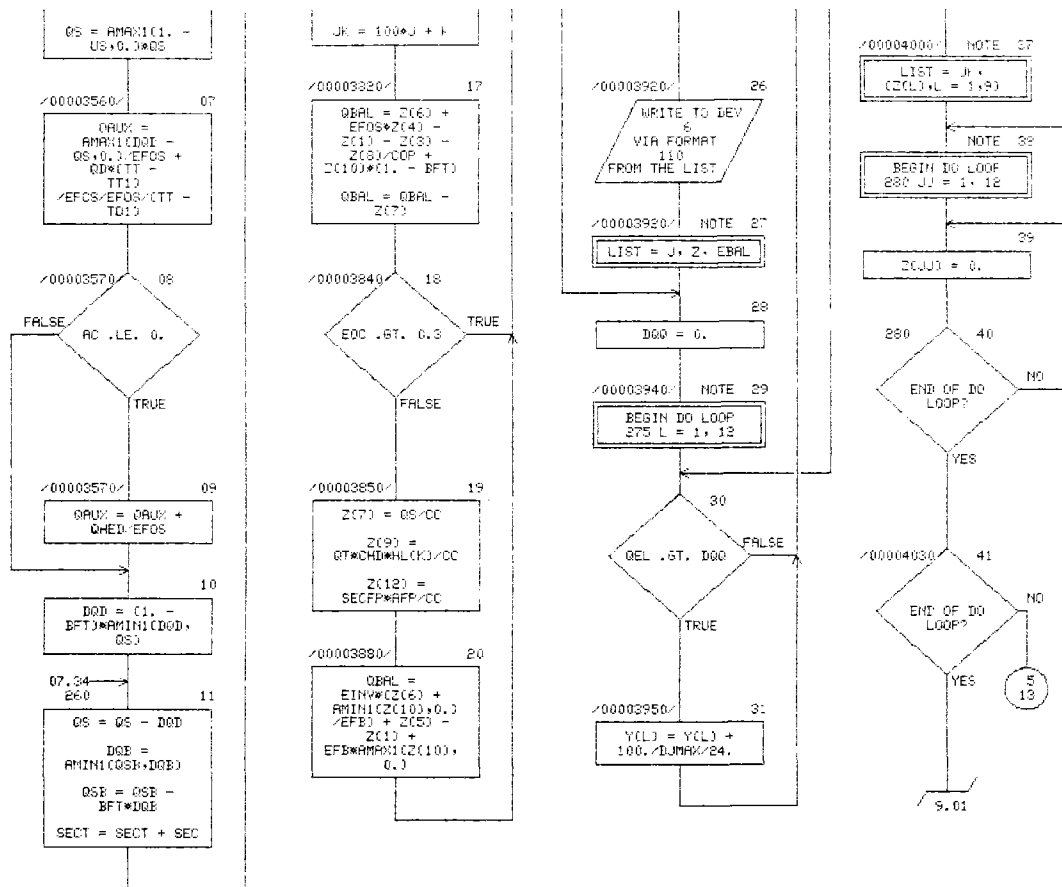
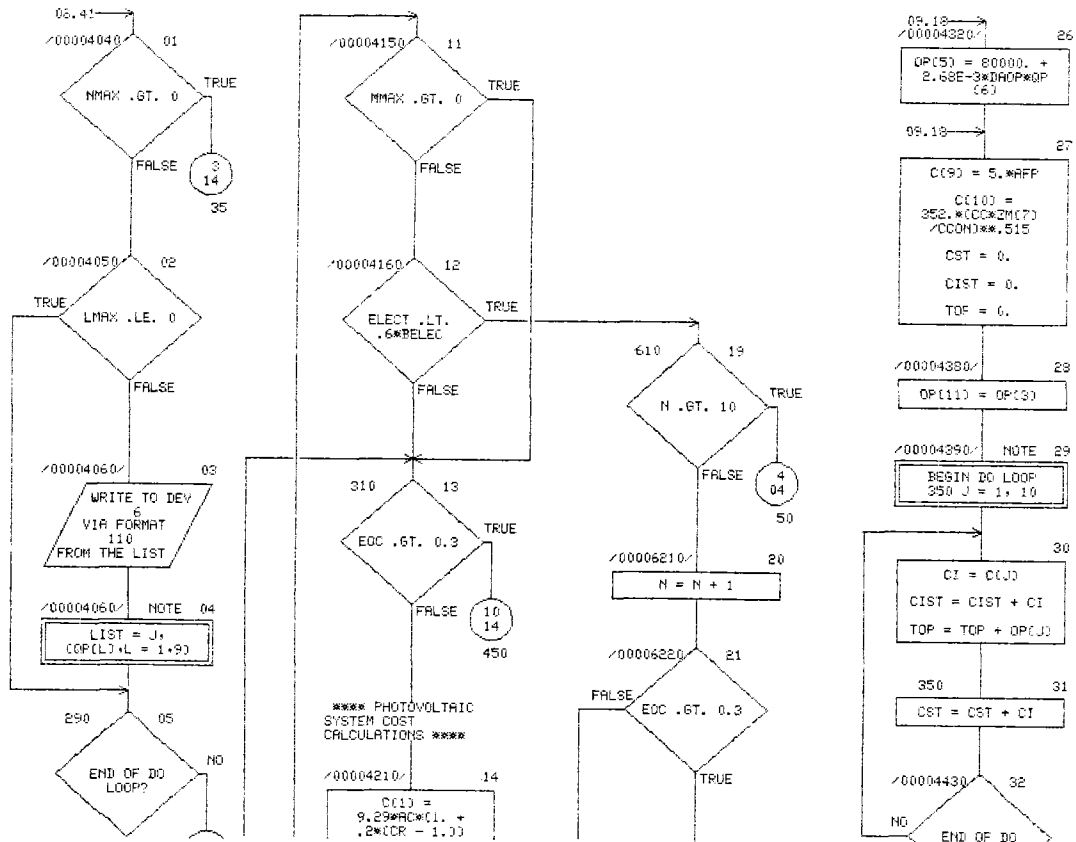


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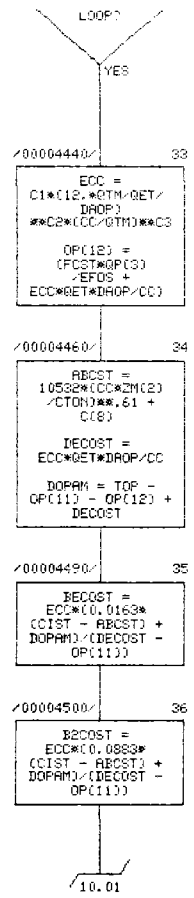
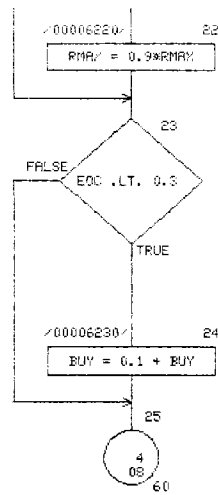
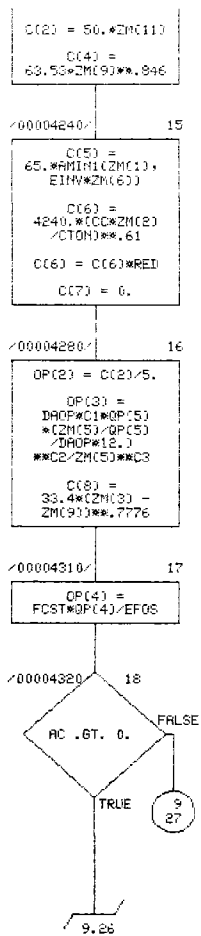
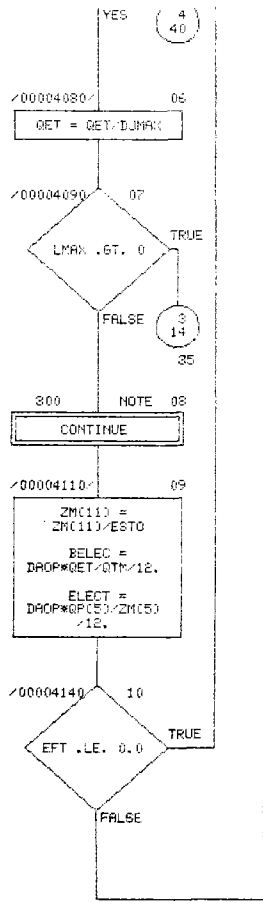
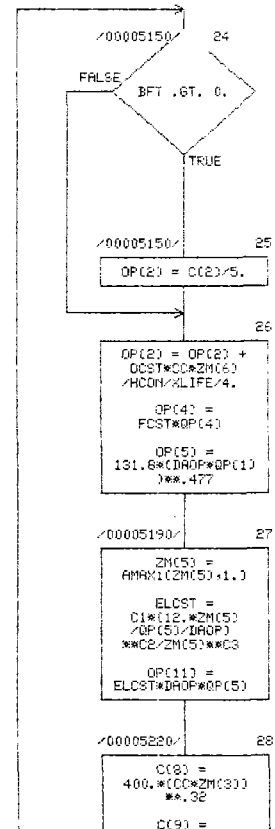
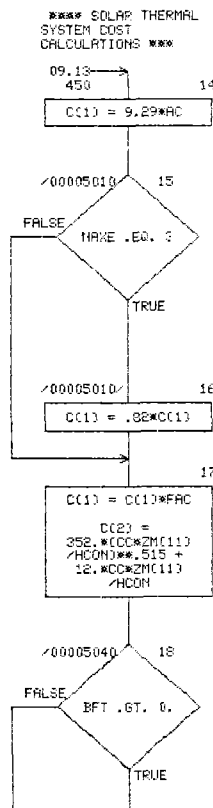
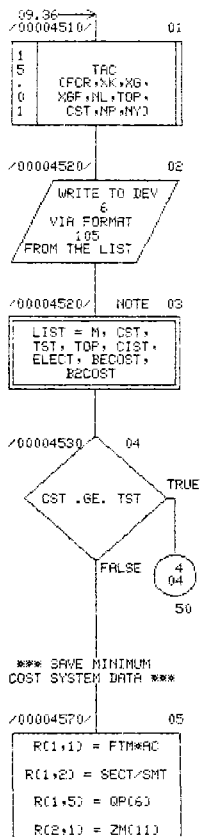


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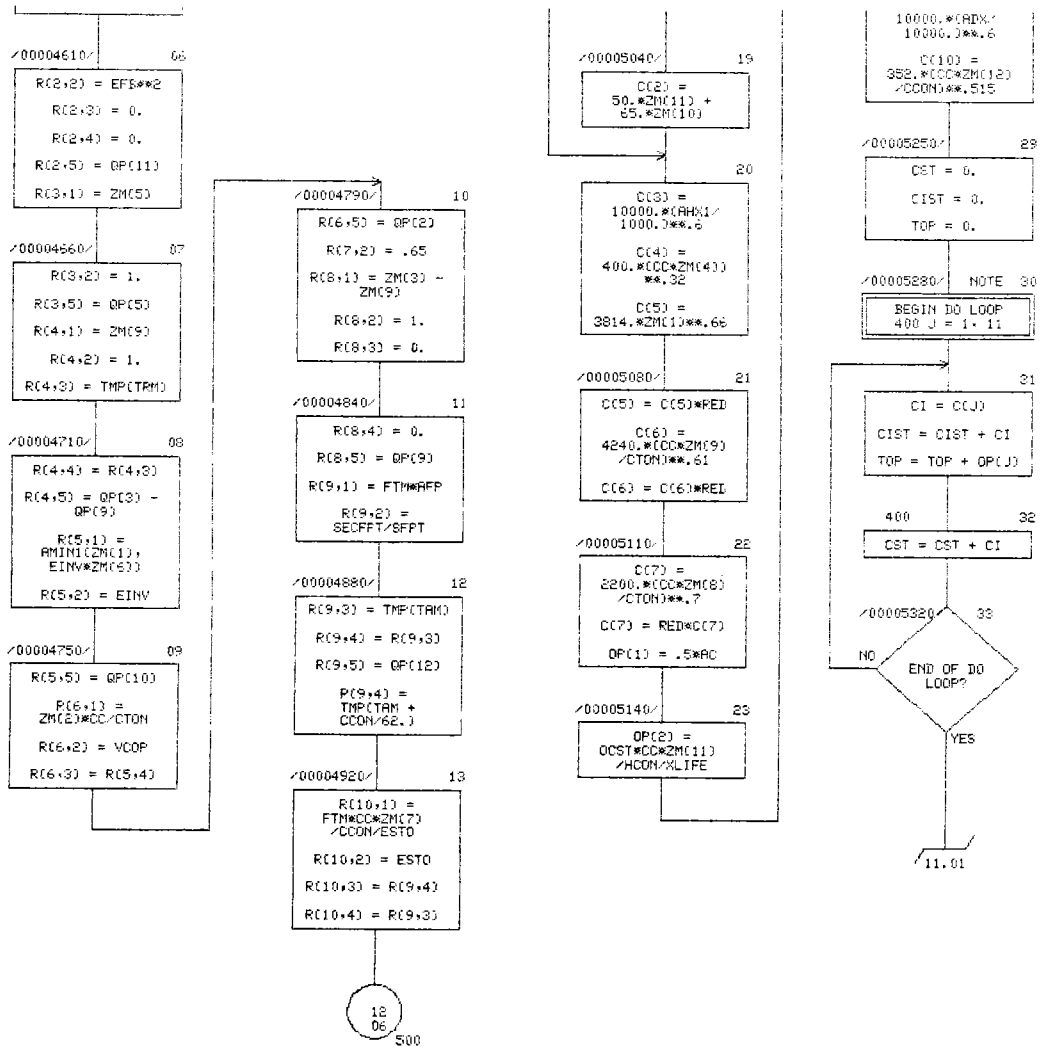
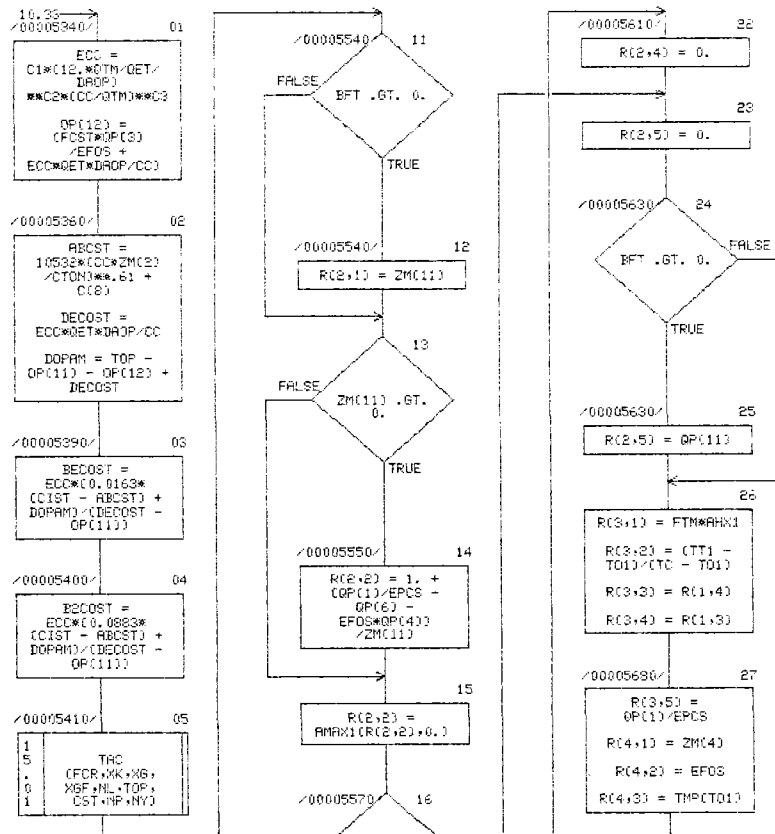


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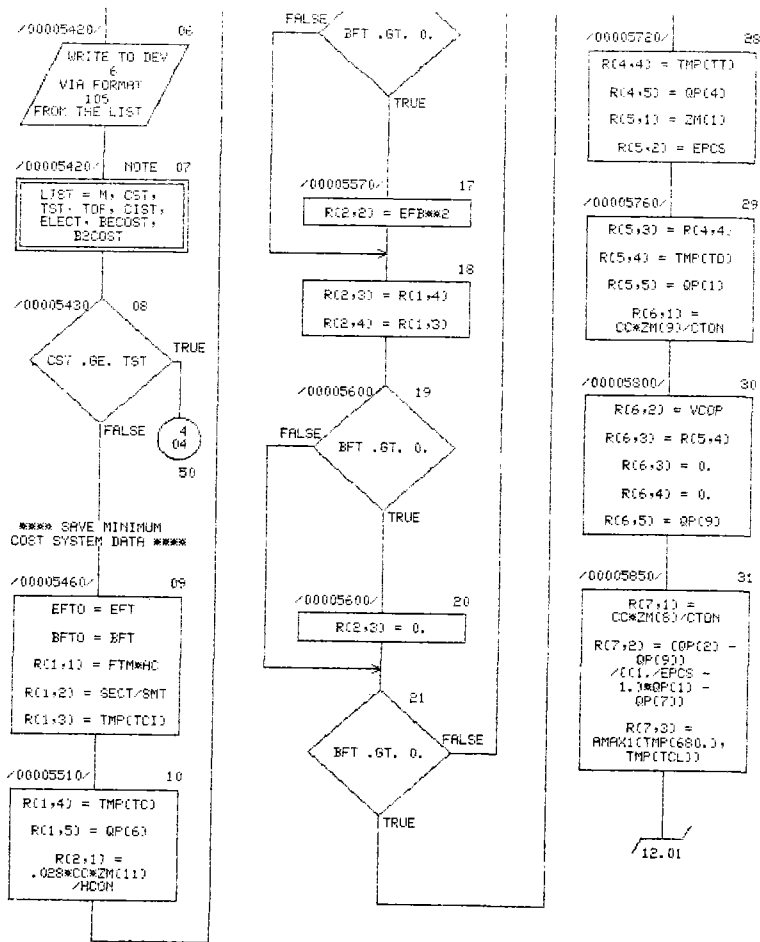
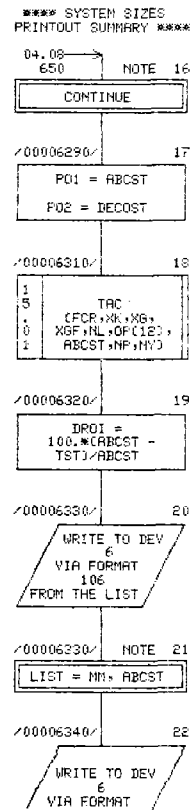
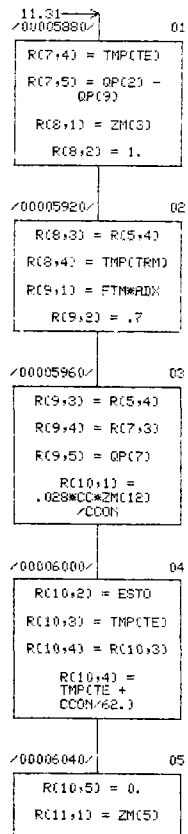


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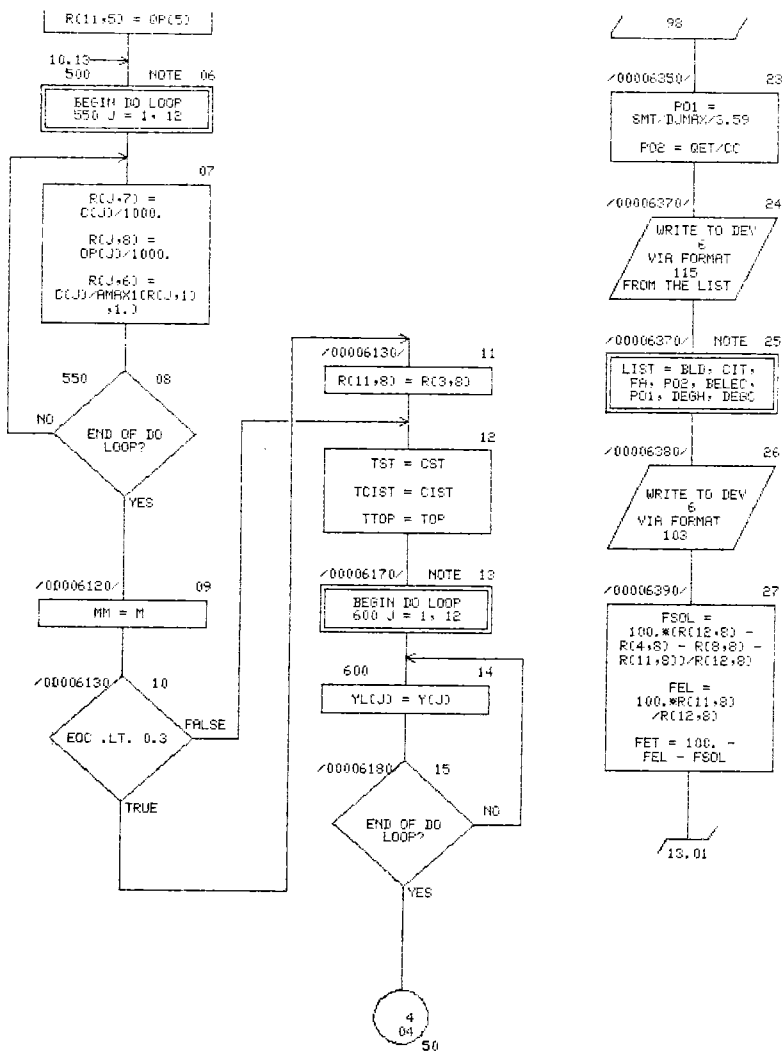
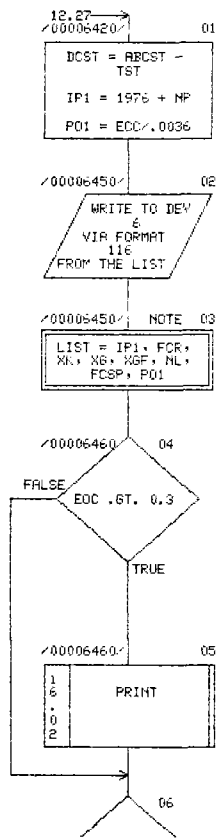


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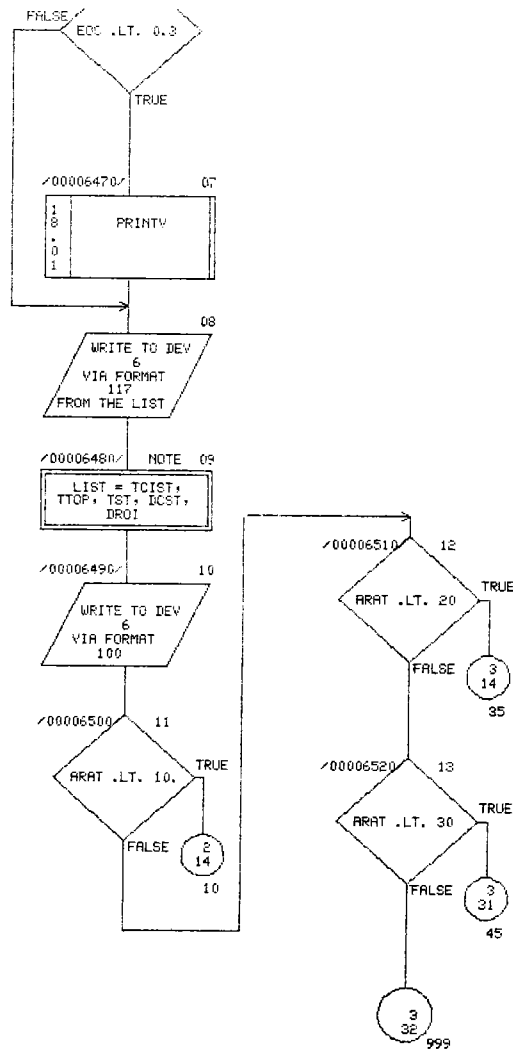
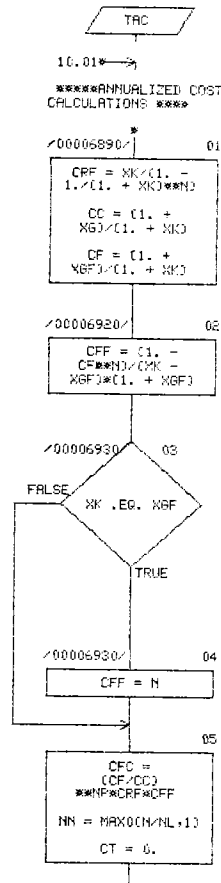


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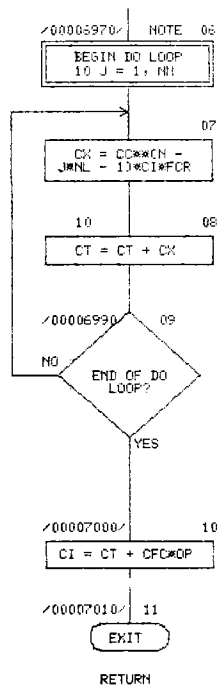
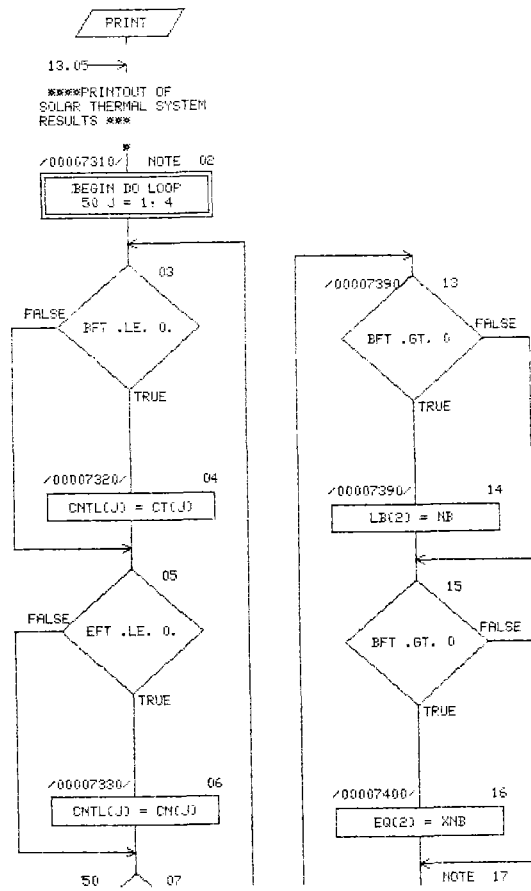


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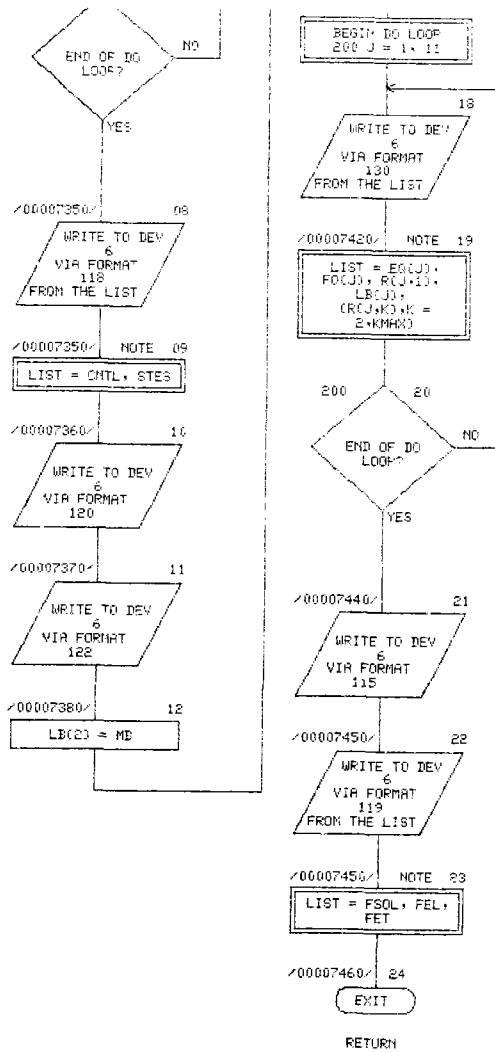
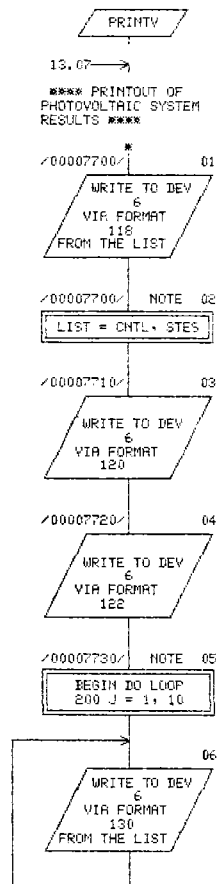


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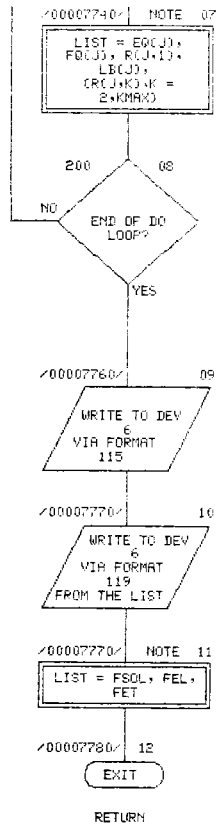
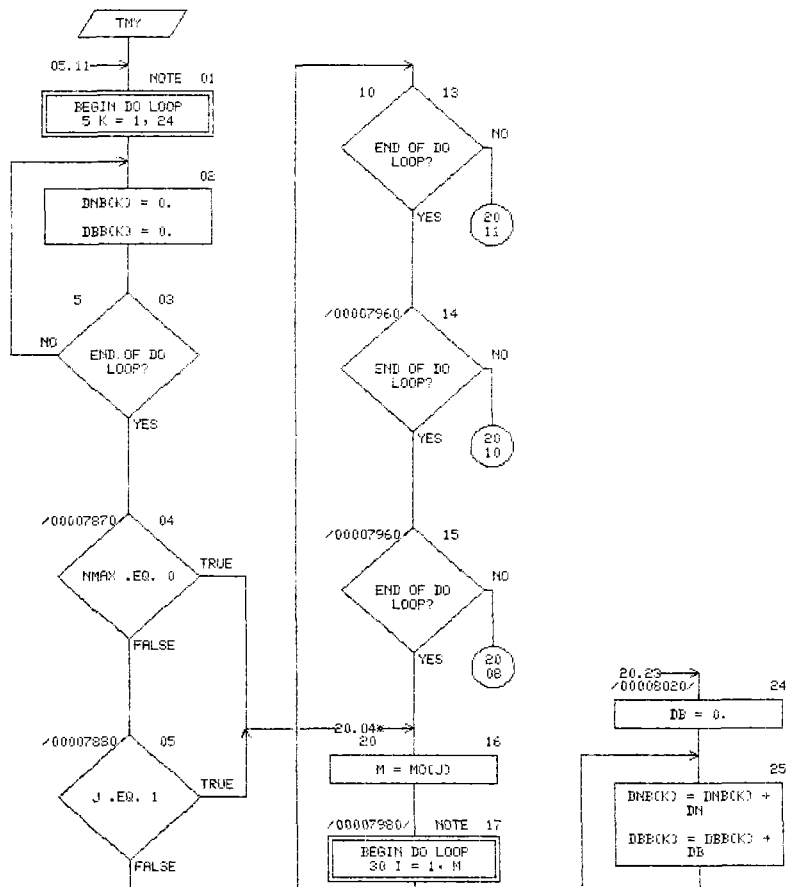
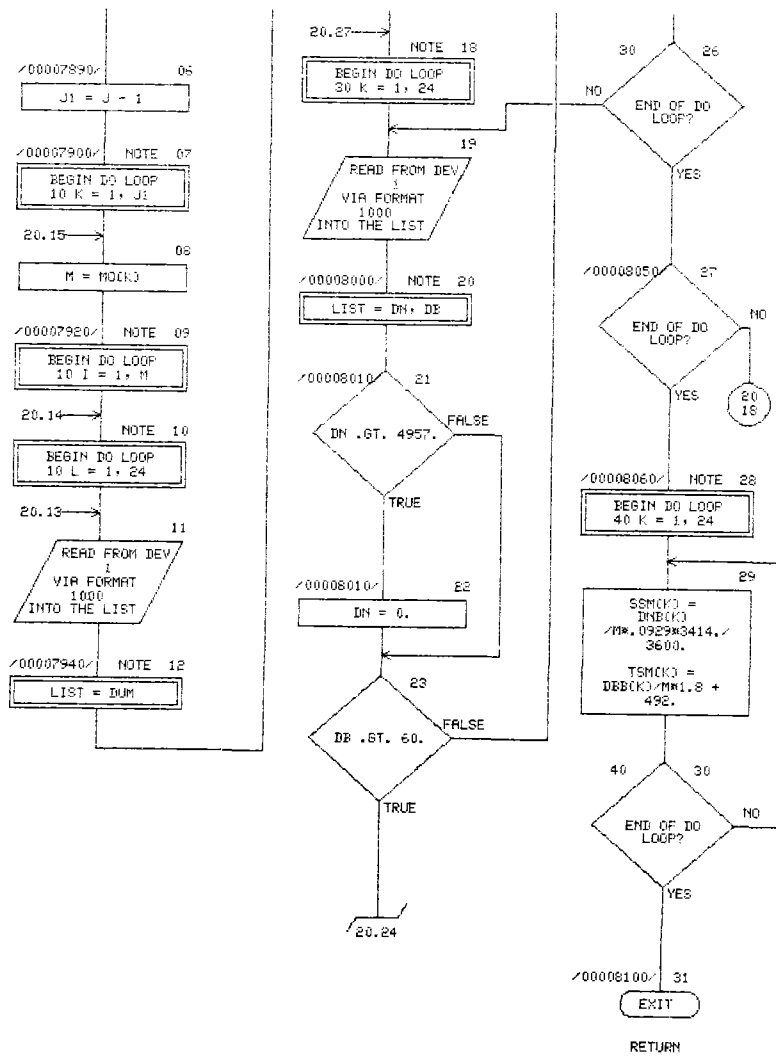


CHART TITLE - SUBROUTINE TM(CJ,NMAX,SSM,TSM)





4.3 GLOSSARY OF TERMS

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
A			
AA	Monthly Isolation Constant	Btu/h-ft ²	A
ABCST	Annualized Cost for Building Energy	\$	—
AC	Array or Collector Area	ft ²	A _c
ADX	Dump HEX Area	ft ²	A _x
AFP	Flat Plate Collector Area	ft ²	—
AHX1	Main HEX Area	ft ²	A _x
A(J)	Monthly Solar Factor	—	A/I _{sc}
ARAT	Fraction of Floor Area for Collectors	—	A _a
B			
BB	Monthly Isolation Constant	—	—
BELEC	Building Electrical Demand Ratio	—	—
BFT,BFTØ	Flag for Battery Energy Storage	—	—
B(J)	Monthly Solar Constant	—	B
BLD(6)	Alphanumeric Building Name	—	—
BUY	Minimum Electricity Fraction Purchased	—	—
BECØST, B2CØST	Breakeven Cost of Electricity	\$/kWh	—
C			
C1,C2,C3	Electricity Cost Constants (See Table 30)	—	C ₁ ,C ₂ ,C ₃
CC	Conversion Constant kW to Btu/h	Btu/kW-h	—
CCØN	Cold Thermal Storage Constant	Btu/ft ³	—
CEL	Coefficient of Heat Generation for Lighting	—	CEL
CF(J)	Monthly Cloud Factor	—	CF
CHD	Coefficient of Process Heat	—	CHD
CHL	Coefficient of Heat Loss	—	CHL
CI	Temporary Variable	—	—
CIST	STES Capital Investment Cost	\$	—
CIT(6)	Alphanumeric Location Name	—	—

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
	C		
C(J)	Component Capital Investment Cost	\$	—
CN(J)	Monthly Clearness Number	—	CN
CØP	Absorption Chiller Coefficient of Performance	—	—
CØSD	Internal Variable	—	—
CØSH } CØSZ } CØSZH }	Internal Variables for Isolation Calculations	—	$\text{Cos } \theta_z$
CP	Oil Specific Heat	Btu/lb- ⁰ R	C_p
CR	Concentration Ratio = A_c/A_a	—	—
CRF	Cost Recovery Factor	—	CRF
CRL	Coefficient for Humidity Effects	—	CRL
CST	Annualized STES Cost	\$	—
CTØN	Conversion Factor	—	—
CVH	Coefficient of Heating Ventilation	—	CVH
CVR	Coefficient of Cooling Ventilation	—	CVR
	D		
DAYØP	Yearly Days of Operation	—	—
DCST	STES Cost Saving Differential	\$	—
DEGC	Cooling Degree Days	—	—
DECØST	Temporary Variable	—	—
DEGH	Heating Degree Days	—	—
DEL	Monthly Solar Inclination Angle	radians	δ
DH	Hydraulic Diameter	ft	—
DJ	Monthly Internal Index Variable	—	—
DJMAX	Conversion Factor	—	—
DK	Internal Hourly Variable	—	—
DLAT,DEG	Location Latitude	radians	ϕ
DØPAM	Temporary Variable	—	—

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
D			
DQBI, DQBØ DQB	Battery Storage Variables	—	—
DQD, DQCS	Thermal Storage Variable	—	—
DQQ	Internal Variable	—	—
DQRF	Vapor Compression HVAC Demand	kW	—
DRAD	Conversion Factor	deg/radians	—
DRØI	Incremental Return on Investment	%	—
DTAM	Daily Temperature Change	°R	—
DTAUX	Temperature Increase by Topping	°R	—
DTBA	Building-to-Air ΔT	°R	—
DTC	PCS Condenser Fluid-to-Fluid ΔT	°R	—
DTLT	Collector Angle from Latitude	radians	—
DTW	Collector Wall to Fluid ΔT	°R	—
DTX	HEX Fluid-to-Fluid ΔT	°R	—
E			
EBAL	Internal Electrical Energy Balance	kW	—
ECC	Electrical Power Rate	\$/kWh	—
EFB	Battery Efficiency Factor	—	—
EPCS	PCS Efficiency	—	η_{pcs}
EFØS	Fossil Fuel Efficiency	—	—
EFT, EFTØ	Flag to Purchase Electricity	—	—
EINV	Inverter Efficiency	—	—
ELCST	Print Variable	—	—
ELECT	Electric Use for Building	kW	—
EL(J)	Hourly Building Electrical Factor	—	—
EM	Emissivity of Receiver	—	ϵ_c
EØC	Reference Solar Efficiency	—	—
EPIPE	Energy Transfer Efficiency	—	—
EQ(J)	Component Alphanumeric Label	—	—
ESTØ	Storage Volumetric Efficiency	—	—

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
	F		
FA	Building Floor Area	ft ²	—
FAC	Collector Cost Multiplier	—	—
FRC	Fixed Charge Rate	—	—
FCSP	Fossil Fuel Cost for Printout	\$/Gj	—
FCST	Fossil Fuel Cost	\$/kWh/day	—
FEL	Fraction of Load from Electricity	—	—
FET	Fraction of Load from Thermal	—	—
FSD	Fraction Sunny Days	—	—
FSØL	Fraction of Load by Solar	—	—
FTM	Conversion Factor	—	—
	G		
GC	Gravitational Constant	ft/s ²	g _c
	H		
HCØN	High Temperature Volumetric Storage Constant	Btu/ft ³ -°R	—
HH(J)	Daily Total Horizontal Insolation	Btu/ft ²	—
HLAG	Variable Shift Hourly Temperature	h	t _L
HL(J)	Hourly Building Process Heating Load	—	HL(t)
HR	Temporary Variable	radians	—
HX	Temporary Variable	—	—
	I		
INSØ	Flag for Data Input	—	—
IPI	Start Year for System	—	—
	J		
J, JJ	DØ Loop Indices	—	—
JINC	Month Skip Variable	—	—
JK	Month and Hour Index	—	—
	K		
K	DØ Loop Index	—	—
KMAX	Print Limit	—	—

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
	L		
L	DØ Loop Index	—	—
LB,LC,LD	Alphanumeric Labels	—	—
LMAX	Flag for Checkout Calculations	—	—
	M		
M	Index	—	—
MM	Lowest Annualized Cost Case Index	—	—
MMAX	Flag for Removing Load Profile Restriction	—	—
	N		
N	Internal Index	—	—
NAXE	Number of Tracking Axes	—	—
NL,R(J,10)	Component Life	yr	—
NMAX	Flag for Checkout Calculations	—	—
NP	Increment for Start Year	yr	—
NY	System Life	yr	—
	Ø		
ØCST	Oil Cost	\$/ft ³	—
ØL(J)	Building Occupancy Load	—	OL(t)
ØP(K)	Operating Cost for Year	\$	—
	P		
PI	Constant	—	—
PLF	Pressure Loss Estimate	—	—
PL(K)	Building Occupancy Factor	—	—
PØ1	Printout Variable	—	—
PØ2	Printout Variable	—	—
PP	Monthly Percent Possible Sunshine	%	PP
PPSM	Electrical Power/Square Meter	kW/m ²	—

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
	Q		
QUAX	Energy from Fossil Fuel	kWh	—
QAUX2	Temporary Variable	kWh	—
QBAL	Thermal Balance	kWh	—
QBUY	Lower Limit for Purchased Power	kWh	—
QCS	Thermal Storage (Cold)	kWh	Q _{CS}
QD	Building Electrical Load	kWh	Q _{ED}
QEL	Purchased Electricity	kW	—
QET	Original Building Electrical Usage	kW	—
QHED	Building Heating Demand	kW	Q _{HD}
QHVIC	Energy for HVAC System	kW	—
Q(J),OP(J)	Result Storage Arrays		—
QMAX	Upper Limit for Purchased Power	kW	—
QDMP	Energy Lost by Dump HEX	kWh	—
QRFA	Cooling Available from Chiller	kW	—
QRFD	Building Cooling Load	kW	Q _{RD}
QRFV	Solar Cooling Used	kW	—
QS	Thermal Storage (Hot)	kWh	—
QSB	Battery Storage	kWh	Q _{BS}
QT	Input Building Load Constant	kW	Q _T
QTM	Maximum Original Demand	kW	—
	R		
RCYC	Ratio of PCS to Carnot Efficiency	—	R _C
RMAX	Ratio of Maximum Purchased Power to QT	—	—
RED	Redundancy Factor	—	—
RHØ	Coolant Density	lb/ft ³	—
R(J,K)	Minimum Cost System Data	\$	—
RR	Relative Solar Distance	—	R

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
	S		
S	Direct Normal Insolation	Btu/ft ² -h	—
SC	Solar Constant	Btu/ft ² -h	I _{sc}
SEC,SECFP	Collected Solar Energy	Btu/ft ² -h	—
SFP	Solar Insolation on Flat Plate	Btu/ft ² -h	—
SIG	Stephan-Boltzman Constant	Btu/ft ² -h-°R ⁴	—
SINH2	Internal Variable	—	—
SMT,SFPT, SECT,SECFPT	Summation of Insolation	Btu/ft ²	—
STES	Alphanumeric Case Name	—	—
SUM,SUM2, SUM3	Temporary Variables	—	—
	T		
TA	Hourly Ambient Temperature	°R	T _a
TAD,TU(J)	Monthly Maximum Air Temperature	°R	T _{mx}
TAM	Flat Plate Collector Average Temperature	°R	—
TC	Collector Outlet Temperature	°R	T _{co}
TCA	Photovoltaic Cell Temperature	°R	—
TCI	Collector Inlet Temperature	°R	T _{ci}
TCIST	Total Capital Investment Cost	\$	—
TCL	PCS Condenser Coolant Temperature	°R	T _{end}
TCR	Collector Radiation Temperature	°R	—
TE	Cold Storage Temperature	°R	—
TL(J)	Monthly Minimum Air Temperature	°R	T _{mn}
TMP(X)	Temperature Conversion Function	—	—
TØ	Turbine Outlet (Condenser) Temperature	°R	—
TØ1	RCS Regenerator Outlet Temperature	°R	—
TØP,TTØP	Total Operating Cost for System	°R	—
TSM	Air Temperature from TMY Tape	°R	—
TRM	Building Set Point Temperature	°R	T _{SP}

STESEP Code Variable Name	Description	Units Used in Code	Analysis Variable Name
	T		
TST	Internal Cost Variable	1975 \$	—
TT	Turbine Inlet Temperature	^o R	T _t
TT1	HEX Outlet Temperature	^o R	—
	U		
UC	Collector Coolant Heat Transfer Coefficient	Btu/ft ² -h- ^o F	U
UCØL	Collector Convective Loss Coefficient	Btu/ft ² -h- ^o F	U
UCS	Cold Thermal Storage Loss Coefficient	Btu/ft ² -h- ^o F	U
UMIN	Minimum Allowable Heat Transfer Coefficient	Btu/ft ² -h- ^o F	—
US	Hot Thermal Storage Loss Coefficient	Btu/ft ² -h- ^o F	U
	V		
VC	Collector Coolant Velocity	ft/s	—
VCØP	Vapor Compression COP	—	—
	X		
XG	Inflation Rate	—	g
XGF	Fuel Escalation Rate	—	g _f
XJ	Mechanical Equivalent of Heat	ft/lb-Btu	—
XK	Cost of Capital	—	—
XLIFE	Decomposition Rate	%/year	—
XNL,NL	System Lifetime	—	—
XX	Temporary Variable	—	—
	Y		
YL(J),Y(J)	Load Profile Variable	—	—
	Z		
Z(J)	Intermediate Storage	—	—
ZM(J)	Maximum Usage Value Any	—	—

4.4 INSTALLATION ENVIRONMENT REPORT

The Rockwell computer facilities used for development of STESEP are described on the following pages.

Rockwell International
CORPORATE COMPUTING MANUAL

Computing Services

SECTION 151.3

COMPUTER SOFTWARE

RESPONSIBILITY

The Computing Services Operating Systems group is responsible for identifying and controlling changes to the software configuration baseline. The Systems Assurance group is responsible for ensuring that the configuration of software is described therein on a current basis at all times.

SOFTWARE LIST

Following is the software configuration baseline at Computing Services for both the Western Computing Center (WCC) and Eastern Computing Center (ECC). Except as noted, all software originated with IBM.

Western Computing Center

1. Operating System

OS/VS, Release 1.7 (5-CPU's)

2. Support Processor

ASP Version 3.2, on computers as follows:

168A Real Main
 168B LASP
 168C Real Main
 168E Real Main
 168F Real Main

3. Batch Processor and Libraries

a. Standard Release with OS/VS 1.7
 (unless noted otherwise)

COBOL, LCP Release 1.6
 RPG (OS Release 21.8)
 Scientific Subroutine Package (SSP)

b. Standard Release with MVS 3.7

Macro Library
 Linkage Editor
 Loader
 OS/VS Assembler F

c. Program Products (leased/purchased)

Assembler, Level H (Version 5.0)
 COBOL, Version 4, Release 1.4
 (including library)
 FORTRAN IV H Extended, Release 2.2
 FORTRAN IV G1, Release 2.0
 FORTRAN IV Library, Mod II, Release 2.
 PL/I Optimizing Compiler, Version 1,
 Release 3.0
 PL/I Checkout Compiler, Version 1,
 Release 3.0
 PL/I Optimizing Resident Library,
 Version 1, Release 3.0
 PL/I Optimizing Transient Library,
 Version 1, Release 3.0 (execution)
 OS/VS Sort/Merge, Version 2.2

4. Special Applications Programs

AUTOFLOW II, Version 6.0
 Automatic Flow Charting Program
 (Applied Data Research)

CSMP III, Version 1, Mod Level 2
 Continuous Modeling System Program

CUE/PPE
 System and Program Performance
 (Boole and Babbage)

FORTUNE
 FORTRAN Tuner - Analyzes a FORTRAN
 program to aid in optimization. (Capex)

GPSS V, Version 1, Model Level 3
 General Purpose Systems Simulator

International Mathematical and Statistical
 Library (IMSL) 1, Edition 6, 1976
 Statistical Subroutine Library
 (International Mathematical and
 Statistical Libraries, Inc.)

LIBRARIAN/VS, Version 1.1
 Source Program Library System
 (Applied Data Research)

Rockwell International
CORPORATE COMPUTING MANUAL

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Computing Services

MARK IV, Release 6, VS2 Version
File Management System, Model 270
(Informatics, Inc.)

MetaCOBOL, Version 6.2
COBOL Preprocessor
(Applied Data Research)

PMS IV, Version 1, Mod Level 4
Project Management System

5. On-Line and Time Sharing Systems

- a. Information Management System (IMS)
IMS/VS, Release 1.1.3 - Class A
Program Product
- b. Administrative Terminal System (ATS)
(DSL-0101 - Comtext, Inc.)
- c. A Programming Language (APL)
Services provided by Proprietary
Computer Systems
- d. Cost/Scheduling Planning & Control System
(COSPAC)
- e. Honeywell G440, Time Sharing, resides at
Rockwell Division, Canoga Park, Calif.

1. Time Sharing Option (TSO). The following
processors are available for use with TSO:

1. ANS COBOL Version 4, Release 1.4
(invoked by COBOL Prompter, Rel. 1.4)
2. OS/VS Assembler (invoked by
Assembler Prompter, Rel 2.0)
3. Code and Go FORTRAN, Release 3.0
4. FORTRAN IV, G1, Release 2.0
(invoked by FORTRAN Prompter Rel 1.1)
5. FORTRAN IV H Extended, Release 2.2
6. PL/I Checkout Compiler, Version 1,
Release 3.0
7. PL/I Optimizing Compiler, Version 1,
Release 3.0
8. TSO Data Utilities
9. FORTRAN Interactive Debug, Rel. 2.1
10. COBOL Interactive Debug, Rel. 1.3
11. VSBASIC Compiler, Release 3.0
12. Structured Programming Facility (SPF),
Release 2.0

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LIST OF SYMBOLS

A, a, b, B,	Equation constants	T_{cnd}	Condenser temperature
C_1, C_2, C_3		T_{ci}	Collector inlet temperature
A_a	Absorber area that is illuminated	T_{co}	Collector outlet temperature
A_c	Collector area	T_{ei}	Heat exchanger inlet temperature
A_r	Absorber area that radiates	T_{eo}	Heat exchanger outlet temperature
A_x	Heat exchanger area	T_{cs}	Cold storage temperature
C, c_p	Specific heat	T_{ct}	Cooling tower temperature
CEL	Coefficient of heat generation from electrical lighting	T_{mn}	Monthly minimum air temperature
CF	Cloud factor	T_{mx}	Monthly maximum air temperature
CHD	Coefficient of process heat	T_{SP}	Building internal temperature setpoint
CHL	Coefficient of heat loss	T_t	Turbine inlet temperature
CN	Cloud number	U	Overall heat transfer coefficient
CRL	Coefficient for humidity effects	V_{sm}	Single media fluid volume
CVH	Coefficient of heating ventilation	\dot{W}	Fluid mass flow rate
CVR	Coefficient of cooling ventilation	W_c	Collector (heliostat) width
COF	Coefficient of performance	W	Weight
D	Diameter	X	E-W collector (heliostat) spacing
dr	Decomposition rate of oil	x	Quality
E-W	East-West	Y	N-S collector (heliostat) spacing
EL(t)	Fraction of maximum electrical as a function of time	y	Distance coordinate
F_o	Eigenfunction of matrix temperature	y_d	Submersion depth of diffuser
g_c	Gravitational constant	<u>GREEK</u>	
h	Solar hour angle	α, β, γ	Insolation constants
HL(t)	Fraction of maximum process heat as a function of time	ρ	Absorptivity
H_{DN}	Daily total direct normal insolation	β	Solar cell temperature loss coefficient
H_h	Daily total horizontal insolation	γ	Specific heat ratio
I_c	Solar constant	δ	Solar declination angle
I_1, I_2, I_3	Insolation integrals	ϵ	Void fraction of matrix material
I	Direct insolation	ϵ_c	Emissivity
I_{DN}	Direct normal insolation	η	Efficiency
I_h	Total horizontal insolation	η_{PCS}	Power conversion efficiency
J	Mechanical equivalent of heat	η_{st}	Storage tank thermal efficiency
k	Thermal conductivity	η_{oc}	Optical efficiency
L	Length	μ	Viscosity
L_c	Collector (heliostat) length	ρ	Density
MTD	Mean temperature difference	σ	Stefan-Boltzman constant
N-S	North-South	τ	Transmissivity
N_{Nu}	Nusselt number	Δ	Incremental change
n^*	Day of year	<u>CAPITAL</u>	
N_{Pr}	Prandtl number	θ_a	Solar azimuth
N_{Re}	Reynolds number	θ_E	Solar elevation angle
OL(t)	Fraction of maximum occupancy load	θ_Z	Zenith angle
p	Wetted perimeter	ϕ	Site latitude
PP	Percent possible sunshine	<u>ECONOMIC PARAMETERS</u>	
P	Pressure	AC	Annualized cost
Q	Energy	BECE	Breakeven cost of electricity
q	Heat transfer rate	CJ	Capital investment
Q_{BS}	Battery electrical storage energy	CRF	Capital recovery factor
Q_{CS}	Cold thermal storage energy	FCR	Annualized fixed charge rate
\dot{Q}_{ED}	Electrical load demand	g	General inflation
\dot{Q}_{HD}	Heat load demand	g_f	Fuel escalation rate
Q_{HS}	Hot thermal storage energy	k	After tax cost of money
$(q/A)_{ins}$	Insulation heat transfer loss rate	n	Power law exponent
\dot{Q}_{RD}	Cooling load demand	N	Number of years of system life
\dot{Q}_T	Maximum load constant for building	NO	Number of units
q_{use}	Usable heat transfer rate	OPM	Recurring cost — electricity cost
R	Solar distance ratio	p	Years to start of operation
R_c	Cycle efficiency ratio	RCC	Recurring cost
r	Reflectivity	R.O.I.	Return on investment
τ	Collector tilt angle	Y_{co}	First year of operation
\bar{T}	Average temperature	<u>Subscript</u>	
t	Time	pv	Present value
t_L	Building heating lag time	o	Original building
T_{cell}	Temperature of solar cell	STES	Solar total energy system
T_{ref}	Reference temperature of solar cell (nominally 28°C)	max	Maximum
T_a	Ambient temperature		

APPENDIX A

STESSEP COMPUTER CODE LISTING (IBM)

NOTE: This IBM Code Listing was not reproduced because the masters were of poor quality. Interested readers may contact B. L. McFarland of Rockwell International, Atomics International Division, 8900 DeSoto Avenue, Canoga Park, CA 91304 for this information.