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APPLICATION ANALYSIS OF SOLAR TOTAL ENERGY SYSTEMS TO THE RESIDENTIAL SECTOR

Volume III. CONCEPTUAL DESIGN

Project 8987 Final Report

Prepared by
Institute of Gas Technology
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Chicago, Illinois 60616

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Program Manager

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PREFACE

This is the final report of the Institute of Gas Technology (IGT) on "Application Analysis of Solar Total Energy Systems to the Residential Sector," sponsored by the Department of Energy under Contract No. EG-77-C-04-3787. The period of performance was from 1 February 1977 through 30 April 1978.

The work is reported in four volumes, as follows:

- Volume I. Executive Summary
- Volume II. Energy Requirements
- Volume III. Conceptual Design
- Volume IV. Market Penetration.

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HIGHLIGHTS

- 300° AND 600°F WORKING RANGE SELECTED FOR RESIDENTIAL SOLAR TOTAL ENERGY SYSTEMS (STES)
- ORGANIC RANKINE CYCLE (ORC) AND FLAT-PLATE WATER-COOLED PHOTOVOLTAIC ARRAYS SELECTED AS TECHNICALLY APPROPRIATE ENERGY CONVERTERS FOR RESIDENTIAL STES.
- PARABOLIC TROUGH COLLECTOR, ROOF-MOUNTED ON FLAT ROOFS, SUITABLE FOR 300° TO 600°F RESIDENTIAL STES: N-S HORIZONTAL BEST FOR SUMMER-PEAKING REGIONS AND POLAR MOUNT FOR OTHER REGIONS.
- HOURLY SIMULATION MODEL EVALUATED STE DESIGN BY BUILDING TYPE, REGION, COLLECTOR AREA, AND CONSERVATION MEASURE.
- 600°F THERMAL TRACKING DESIGN, USING PURCHASED ELECTRICAL POWER BACKUP, MORE ATTRACTIVE ORC-BASED RESIDENTIAL STES THAN 300°F DESIGN OR 600°F STAND-ALONE DESIGN.
- AT MAXIMUM COLLECTOR APERTURE AREA, 600°F DESIGN PROVIDES 50% OF RESIDENTIAL ELECTRICAL LOAD AND MOST OF THERMAL LOAD.

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LIST OF ABBREVIATIONS

CPC:	Compound parabolic concentrator solar collector
CR:	Central receiver (but in the case of the CPC collector, it stands for concentration ratio)
ET:	Evacuated tube solar collector
EW:	Orientation of a solar collector such that tracking is around a horizontal-axis oriented East-West
FPC:	Flat plate solar collector
LTS:	Low-temperature storage
NS-Hor: or NS	Orientation of a solar collector such that tracking is around a horizontal-axis oriented North-South
ORC:	Organic Rankine Cycle heat engine
PM:	Polar-mount orientation (tilt angle equal to local latitude) of a single-axis tracking solar collector
psia:	pounds per square inch, absolute
PT:	Parabolic trough solar collector
PV:	Photovoltaic
RPA:	Resource Planning Associates, Inc.
SFD:	Single-family detached
SLATS:	Solar Linear Array Thermal System
STE:	Solar total energy
STES:	Solar total energy system

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SUMMARY

A solar total energy system (STES) is defined as an energy system designed to maximize the efficient use of collected solar energy by supplying both the low-grade (low-temperature thermal) and high-grade (electrical and/or mechanical) energy needs of selected applications. DOE's Solar Total Energy Program is concerned primarily with those solar total energy systems that use heat engine or photovoltaic devices to produce electricity (and/or mechanical work) and apply the residual thermal energy from the conversion process to some useful purpose. The solar total energy is backed up and supplemented to the extent required by conventional fossil-fuel-derived energy for periods when solar-derived energy is inadequate.

This project analyzed the application of solar total energy to appropriate segments of the residential sector and determined the market penetration potential for STE systems.

This volume (Volume III) describes the work done to evaluate components that are suitable for residential solar total energy systems, the preparation and evaluation of conceptual designs for residential applications, and the factors that may affect the acceptance of such systems.

Screening of solar collectors for use in STES designs for the residential sector has been based upon the following:

1. The high value of residential property strongly indicates that solar collectors for residential systems should be sited <u>only</u> on the roofs of buildings.
2. Parabolic dish collectors are not appropriate for the residential sector, based upon projected costs versus performance.
3. Central receivers could be used for residential applications, but offer insufficient performance incentive at 600°F to justify use over parabolic troughs, in addition to presenting greater architectural difficulties.
4. Projected costs for parabolic troughs are approximately $20/sq ft for N-S horizontal mounting and approximately $22/sq ft for polar mounts. Lower costs are considered in sensitivity studies.
5. Unless otherwise noted, all projected costs are in terms of 1975 dollars.

Results of the collector screening study indicate the use of North-South horizontal parabolic troughs for Miami, Dallas, Charleston, and Phoenix and polar mount parabolic troughs in the other regions. Aperture areas permitted for

each residential building (excluding high-rise apartments, which were eliminated as a viable building type for STES) are: 460 sq ft for N-S horizontal mounted troughs on each single-family house and 284 to 341 sq ft for polar mounted troughs; 13,596 sq ft for N-S horizontal mounted troughs on each 36-unit townhouse complex and 8,400 to 10,058 sq ft for polar mounted troughs; 16,378 sq ft for N-S horizontal mounted troughs on each 48-unit low-rise apartment complex and 10,118 to 11,146 sq ft for polar mounted troughs. These values are based upon flat roofs, rather than pitched roofs.

Maximum collector areas for photovoltaic arrays are: 429 to 578 sq ft for each single-family house, 12,674 to 17,061 sq ft for each 36-unit townhouse complex, and 15,264 to 19,458 sq ft for each 48-unit low-rise apartment complex. All photovoltaic arrays are mounted on flat roofs, tilted to the site latitude; consequently, the largest array areas are for locations at the lowest latitudes, with locations in higher latitudes having the smallest array areas.*

Organic Rankine cycle (ORC) heat engines and flat-plate photovoltaic arrays are the preferred energy conversion devices for use in residential STE systems. Brayton cycle engines require higher temperatures and are more suitable for non-residential systems. Steam Rankine systems are less efficient than ORC systems and offer no advantages except possibly an environmental and safety advantage. Stirling systems are theoretically feasible for residential applications but are either not sufficiently developed in the 50 to 100 kW range or require temperatures much higher than the 600°F collector limitation of the parabolic trough.

Conceptual designs for the total energy systems in the residential sector are based on parabolic trough collectors in conjunction with a 100 kWe organic Rankine cycle heat engine or a flat-plate, water-cooled photovoltaic array. The ORC-based systems are designed to operate as either independent ("stand alone") systems that burn fossil fuel for backup electricity or as systems that purchase electricity from a utility grid for electrical backup. The ORC designs are classified as 1) a high temperature system designed to operate at 600°F and 2) a low temperature system designed to operate at 300°F. The 600°F ORC system that purchases grid electricity as backup utilizes the thermal tracking

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* Spacing of flat plate photovoltaic arrays and parabolic trough collectors did permit small amounts of shadowing during early morning and late afternoon hours.

principle and the 300°F ORC system tracks the combined thermal and electrical loads. Reject heat from the condenser supplies thermal energy for heating and cooling. All of the ORC systems utilize fossil fuel boilers to supply backup thermal energy to both the primary (electrical generating) cycle and the secondary (thermal) cycle. Space heating is supplied by a central hot water (hydronic) system and a central absorption chiller supplies the space cooling loads. A central hot water system supplies domestic hot water. The photovoltaic system uses a central electrical vapor compression air conditioning system for space cooling, with space heating and domestic hot water provided by reject heat from the water-cooled array. All of the systems incorporate low temperature thermal storage (based on water as the storage medium) and lead-acid battery storage for electricity; in addition, the 600°F ORC system uses a therminol-rock high temperature storage for the primary cycle.

The design performance was evaluated by means of a computer program (Section 4) that utilized load tapes from the energy requirements task (Volume II) and city-specific weather tapes as inputs to calculate a simulated hourly performance for the conceptual designs in different regions of the country. Design performance was determined for: an aggregated community of 36 single-family homes; a 36-unit townhouse complex; and a 48-unit low-rise apartment complex; high-rise apartments had been eliminated earlier because of low solar contributions to the building's total energy requirements. The effect of ASHRAE 90-75 conservation measures on the design performance was also determined. The simulation program determines the quantity of solar energy collected for each hour of the day (for 365 days), the amount of electricity and fossil fuel that must be purchased to meet the electrical and thermal demands for the building, and the thermal energy in both primary and secondary storage for each building type in each region. Monthly summaries were determined on a regional basis and used as part of the market analysis program. Simulations based on 5 different collector sizes were made, together with calculations on collector utilization at different collector areas, so the cost effectiveness of decreasing/increasing collector size could be determined.

The effect of health, safety, and environmental factors on residential market potential of solar total energy systems was addressed. Although STE systems are generally regarded as environmentally benign and safe, the possibility of a rupture causing toluene or freon release from an ORC unit gives rise to a potential toxicity hazard and, in units utilizing toluene, a potential fire hazard. This may be particularly important in residential areas.

The major effort in subsequent development efforts should be directed toward reducing capital costs of collectors, energy conversion devices, and conventional thermal distribution systems (fan coil units, particularly). Specific recommendations include the development of low cost central receiver type collectors that are specifically designed for roof-mounting on residential buildings and building designs that could permit lower cost central thermal distribution systems.

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Section 1.

INTRODUCTION

The objective of the work described in this volume was to conceptualize suitable designs for solar total energy systems for the following residential market segments: single-family detached homes, single-family attached units (townhouses), low-rise apartments, and high-rise apartments.

Specific constraints to the design task required that —

- The designs were to be based on well-developed components, thus excluding components that were only in the experimental stage.
- All designs were to be based on 50 kWe or greater, electrical generating capacity; this required that single-family houses be considered as aggregates connected to a central STES.
- Flat plate solar thermal arrays need not be considered.

The approach involved an evaluation of components, including cost and performance, to be used in the designs, followed by the construction of the conceptual designs based on the selected components and an evaluation of the designs by means of a computer simulation program. This approach is shown diagrammatically in Figure 1, which shows how the conceptual design task was integrated with the energy requirements and market penetration efforts.

An important point to be considered prior to selecting the design components was the siting of solar collectors for residential STES applications. Efficient 2-axis collectors, such as parabolic dishes and central receivers, can produce high temperatures for generating electricity by means of heat engines; however, these are most often considered for applications where they are ground-mounted, and it was necessary to establish whether ground-mounting would be appropriate for residential collector siting. Although it would be possible to mount solar collectors on land adjacent to residential buildings, the conclusion was reached that only roof-mounting of collectors would be appropriate in most residential applications for the following reasons:

- The high cost of residential property is forcing builders to maximize the number of dwelling units that can be built on a piece of property; this is particularly true in areas zoned for multi-family dwellings. Using part of this high priced land for siting solar collectors, rather than for constructing additional dwelling units, would not be economically attractive for a developer if conventional energy options were available.

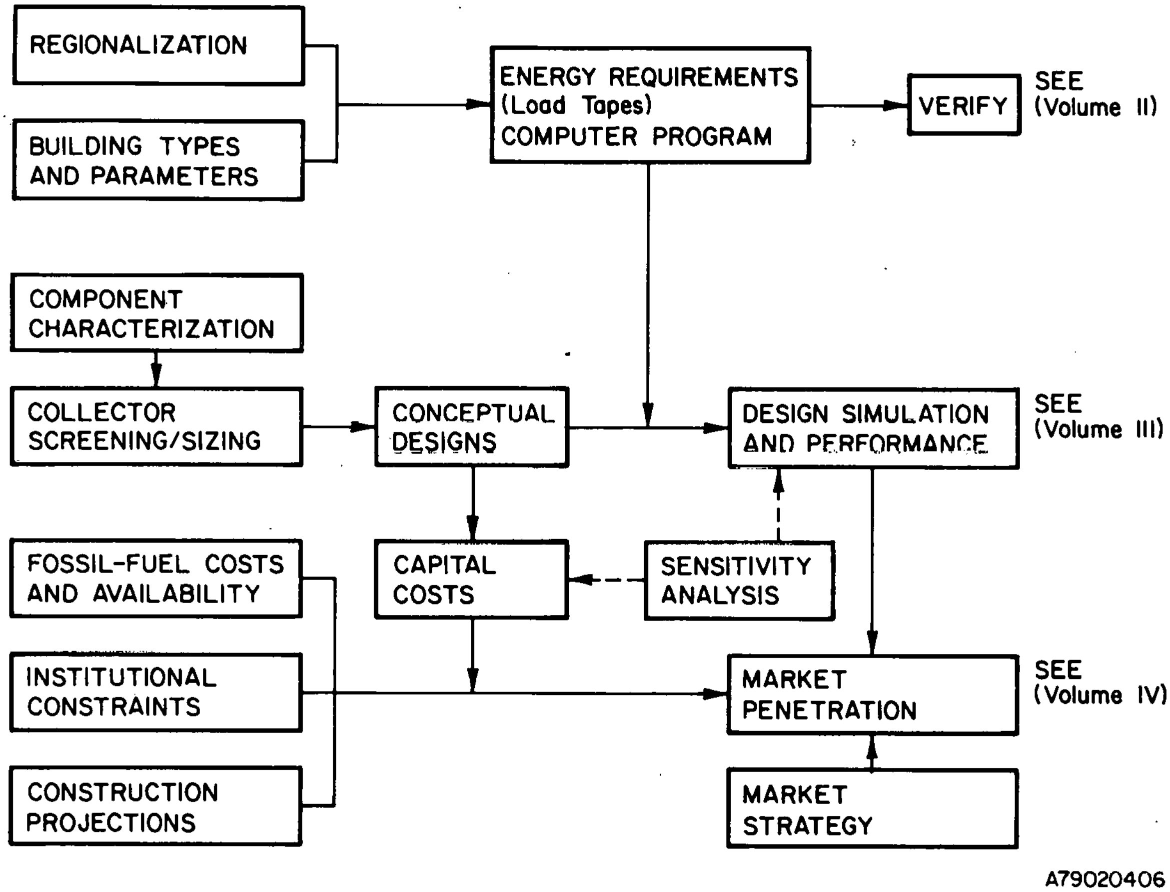

Figure 1. DIAGRAM OF PROGRAM APPROACH

- The installed cost of ground-mounted collectors would have to reflect the cost of the land, an additional expense that could add 1 to 3 dollars per square foot or more of collector area in many urban areas.
- Shadowing by buildings and trees would be a lesser problem for roof-mounted collectors than for ground-mounted collectors, particularly in residential areas of modest-sized lots.
- Siting on roofs placed over parking lots would also add appreciably to the cost of the collectors, since this additional cost must be assigned to the installed collector costs.

Section 2.
COMPONENTS

The initial efforts in the conceptual design effort were directed toward an assessment of the various possible components required for the design of operable solar total energy systems for the residential sector. By determining those components that are compatible with the guidelines of the program and that are considered feasible for the residential applications under study, the basic building blocks for inclusion in the conceptual designs were delineated.

Thermal systems consist of collectors, heat exchangers, pumps, high- and low-temperature sensible heat storage, heat engines, batteries and power conditioning equipment, cooling machinery such as absorption or vapor compression chillers, pipe and distribution networks to collect thermal energy and distribute hot and cold fluids for space conditioning, and controls.

In the following section we discuss components of solar total energy systems, characterizing these components both as to suitability for residential applications and for system modeling.

2.1 Solar Collectors

Two temperature levels were selected as representing the lower and upper limits of the range for residential total energy systems: 300°F and 600°F. These temperatures were considered achievable, at reasonable efficiencies, by intermediate priced collectors that are either currently commercially available or expected to be available in the near term. To achieve these temperatures thermal collectors may be characterized as concentrating or nonconcentrating; as fixed, seasonally tilted, or tracking; and also by output temperature. (See Appendix A.)

For temperatures of 300°F, reflector-augmented evacuated-tube collectors, compound parabolic concentrator (CPC) collectors of low concentration ratio (1.5 to 1.8X), or single-axis tracking parabolic troughs are appropriate. Evacuated tube and CPC collectors may be set at a fixed tilt angle and do not track (follow the sun). Evacuated-tube collectors are available from several manufacturers such as General Electric and Owens-Illinois.

CPC's will soon be available from at least one manufacturer (Steelcraft, Inc.) and designs with improved optical and thermal characteristics are under development at Argonne National Laboratory.

To achieve temperatures of 600°F, seasonally adjusted, non-tracking CPC's of moderate concentration ratios (5 to 6.5X), single-axis parabolic troughs in an East-West (E-W) horizontal orientation or in a polar mount, SLATS* or Russell-type collectors in E-W horizontal orientation, and two-axis parabolic troughs are appropriate. Moderate concentration ratio CPC collectors are currently under development; however, they should be available in the near term. Single-axis parabolic trough collectors are currently available from several manufacturers (Acurex Corporation, Hexcel Corporation, Solartec Corporation). Ongoing development efforts promise increases in optical efficiency and decreases in heat losses and costs. Polar-mounted troughs offer advantages over E-W troughs on an energy collected per unit collector aperture area basis. However, polar-mounted collectors may have problems with wind loads, shadowing of adjacent collectors reducing total effective aperture area for a given roof area, and applicability to single-family detached dwellings. Of course, E-W troughs have similar problems, and although they collect less energy per unit aperture than polar-mounted troughs, they may permit greater total unshadowed aperture area in a given roof area. The particular problems of applicability of trough-type collectors to single-family detached dwellings may indicate CPC's as the most appropriate collector for this application. The SLATS and Russell collectors may only be oriented in an E-W configuration. These collectors are commercially available (Shedahl manufactures the SLATS collector, the Russell collector is under continuing development at General Atomic Co. and is also available from Scientific Atlanta) but suffer drawbacks similar to those of the parabolic trough collectors when attempts are made to apply these collectors to single-family detached dwellings. Two-axis tracking parabolic troughs offer the advantage of collecting the maximum amount of insolation compared with single-axis trackers. However, these collectors are expected to have similar problems to polar-mounted troughs. Although they should be commercially available in the near term, these collectors appear to be inherently more complex than single-axis tracking collectors for an application where simplicity is a very important criterion in component selection.

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* Solar Linear Array Thermal System. (See Page A-14.)

Two-axis parabolic dish collectors, such as that under development at JPL, are appropriate and desirable for high temperatures to over 1500°F. They are suitable as heat sources for high-efficiency Brayton or Stirling heat engines. Problems of complexity, windloading, apparent difficulties in locating these collectors even on flat roofs, and probable low values of aperture area for a given roof area lead to the exclusion of this collector for residential total energy applications. (See section on parabolic dish collectors.)

Central receivers are capable of high-temperature collection and may be designed with thermal outputs comparable to the energy needs for a residential total energy system. However, because of the high cost of land on which to site a heliostat field and tower in a residential area (and, in general, to site any type of collector field), only roof areas are being considered for locating collectors or heliostats for residential STE application. This tentatively rules out central receivers from our residential STE designs. (See next section.)

A number of areas were pursued to validate our tentative collector choices and determine collector performance and cost. In the procedure for selecting appropriate generic collectors for the various temperature levels required, we identified generic characteristics (present and future) of the various collectors consistent with the collector performance models (including dirt effects on optical efficiency and cosine effects); we also identified allowable aperture areas of collectors on the various dwellings; and we determined current and projected installed and operating costs of the generic collector types. The amortized installed costs of the collector arrays were added to the estimated annual operation and maintenance costs, and annual energy collected in the various sites developed to establish an indicator (energy collected per year per dollar of annualized collector cost) for each collector type. Inputs from manufacturers were also solicited to assist in the determination of appropriate collectors. The Sheldahl people were contacted for a performance model of their collector.

Selection of collector field heat-transfer fluids is also important. The expense and complexity of piping a pressurized water heat collection system indicates the tentative choice of a heat-transfer oil as the collector heat-transfer fluid. (The choice of hot oil as a heat-transfer medium will be reviewed critically when the subjects of system safety and environmental considerations are addressed.) The fluid selected will probably be the same as the fluid used for sensible heat thermal storage, to avoid the requirement of a heat exchanger between collector and storage.

2.1.1 Small Central Receivers for STES Applications

The central receiver concept was considered for residential solar total energy applications. The central receiver concept, primarily considered for large-scale central electric power generation, may be scaled down to sizes corresponding to requirements for a residential solar total energy system. The primary effect of a reduction in system size is a reduction in receiver output temperature. This results from the fact that as the number of heliostats in the collector field is reduced, the flux of energy on the receiver is significantly decreased. If the system is run at high temperatures the heat losses from the receiver relative to the input flux increases in comparison to larger systems. To balance this effect, and thus maintain acceptable collector efficiencies, the temperature of the receiver must be reduced. In the size range of small central receivers for residential solar total energy applications, a collector outlet temperature of 600°F gives collector efficiencies comparable to much larger central receivers operating at significantly higher temperatures. Thus, central receivers have an operating temperature comparable to parabolic trough collectors.

The central receiver concept is probably not generally applicable to single-family detached dwellings, particularly in light of our roof-mounted criterion, unless the arrangement of housing is especially directed to be consistent with the requirements of a central receiver installation. This would correspond to an arrangement of houses spread in a northerly direction about a short receiver column located at the south end of the housing complex. The central receiver concept is adaptable to groupings of townhouses or th a receiver/heliostat system located on the roof of low-rise apartment dwellings.

The cost and performance characteristics were compared to the best performing parabolic trough collectors evaluated in the collector screening study. The parabolic trough collectors were used exclusively in the system performance analysis in order to produce results on a consistent basis for all sites evaluated. The results and assumptions from the evaluation of central receivers as alternative collectors to parabolic troughs are summarized in Table 1.

Table 1. ECONOMIC AND PERFORMANCE COMPARISON OF CENTRAL RECEIVERS AND PARABOLIC TROUGHS FOR RESIDENTIAL SOLAR TOTAL ENERGY APPLICATIONS

City	Dwelling Type	Collector Type	Unit Annual Output/ (Total Annual Output), (Btu/sq ft-yr)/ (Btu/yr X 10^7)	Collector Area 24 DU Basis, sq ft	Total Annual[5] Collector Cost I, $/yr	Total Annual[5] Collector Cost II, $/yr	Total Annual[5] Collector Cost III, $/yr
Boston	Low-Rise	PT1 – N-S	211,337/173.06	8,189	28,416	18,343	16,951
		PT1 – E-W	192,900/141.42	7,331	25,439	16,421	15,175
		PT1 – P-M	262,615/132.86	5,059	19,325	13,103	12,243
		CR[1]	/180.64[6]	5,292	17,781[7]	8,203	6,403
Albuquerque	Low-Rise	PT1 – N-S	332,630/272.44	8,189	28,416	18,343	16,951
		PT1 – E-W	284,046/242.29	8,530	29,599	29,599	17,657
		PT1 – P-M	382,333/208.28	5,448	20,811	14,110	13,184
		CR	/233.64	5,292	17,781	8,203	6,403
Chicago	Low-Rise	PT1 – N-S	216,010/176.89	8,189	28,416	18,343	16,951
		PT1 – E-W	186,375/139.67	7,494	26,004	16,787	15,513
		PT1 – P-M	258,150/133.00	5,152	19,681	13,344	12,468
		CR	/178.57	5,292	17,781	8,203	6,403
Dallas	Low-Rise	PT1 – N-S	255,018/208.83	8,189	28,416	18,343	16,951
		PT1 – E-W	211,482/189.70	8,970	31,126	20,093	18,568
		PT1 – P-M	289,603/165.22	5,705	21,793	14,776	13,806
		CR	/192.43	5,292	17,781	8,203	6,403

Common Data for All Cities

Collector Type	Unit Collector Cost I[5]/ (Annual Collector Cost I) $/sq ft/($/sq ft-yr)	Unit Collector Cost II/ (Annual Collector Cost II)	Unit Collector Cost III/ (Annual Collector Cost III)
PT1 – N-S	20.13[2]/(3.47)[3]	13.00[5]/(2.24)	12.00[5]/(2.07)
PT1 – E-W	20.13 /(3.47)	13.00 /(2.24)	12.00 /(2.07)
PT1 – P-M	22.13 /(3.82)	15.00 /(2.59)	14.00 /(2.42)
CR	19.50[4]/(3.36)	19.00 /(1.55)	7.00 /(1.21)

Notes:

1. CR = central receiver.
2. Capital cost estimate for trough collector from IGT-STES study.
3. Annual collector cost is 15% of capital cost. Annual O&M cost is 15% of annual capital cost. O&M cost estimate from Harrigan paper.
4. Corresponds to estimate from Harrigan paper of installed cost at $210/m^2$. Validated by personal communication from A.F. Hildebrandt estimate of $200/m^2$.
5. Cost I corresponds to expected collector costs in 1985 time frame. Cost II corresponds to collector costs in 1990 when large-scale production of collectors begins to impact significantly on collector production economics. Cost III corresponds to collector costs in the year 2000 when significant reductions in collector costs are expected to be realized due to large-scale deployment of collectors for many applications.
6. According to personal communication with A.F. Hildebrandt of Univ. of Houston Solar Energy Laboratory, performance of central receiver may be estimated as product of (600°F performance for small central receivers):
   a. Ground cover factor = 0.35
   b. Flat roof area = sq ft
   c. Annual average cosine loss factor = 0.8
   d. Clean heliostat reflectivity = 0.9
   e. Receiver absorbtivity = 0.9
   f. 600°F operating temperature heat loss = 0.9
   g. Correction for dirty optics = 0.9
   h. Annual direct normal beam radiation = Btu/sq ft-yr.

   Flat roof area, low-rise = 15,120 sq ft
   Annual output = (0.184)(beam radiation Btu/sq ft-yr)(flat roof area, sq ft)

City	Beam Radiation	Roof Area (24 DU basis)	Collector Area
Boston	650,337	15,120 sq ft	5,292
Albuquerque	841,151		
Chicago	642,870		
Dallas	692,761		

7. Total collector cost = (roof area)(ground cover factor, sq ft collector/sq ft roof)(unit collector cost).

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In the cities for which collector performance was evaluated, the central receiver generally shows a performance edge over the trough collectors, although on the basis of performance alone, the central receiver is not a clear winner. The central receiver produces about 36% more annual energy output than a polar mount trough in Boston; 12% more than a polar mount trough in Albuquerque; 34% more output than a polar mount trough in Chicago; but 8% less than the output of a N-S horizontal trough in Dallas, although the central receiver produces a more uniform output over the year than the N-S horizontal trough collector.

At the projected 1985 costs of central receivers versus performance, there is no advantage in the use of central receivers. An exception may be at lower latitudes, where the alternative is a relatively more expensive N-S horizontal collector installation. If the rather speculative costs of central receivers, which are strongly dependent upon the development of large-scale solar electric power plants, are realized in the 1990 to 2000 time frame, the central receiver shows a clear advantage over the trough collectors. The projected cost reductions of central receivers to $9/sq ft in 1990 and $7/sq ft in 2000 will certainly benefit STES economics. Because the performance of central receivers in comparable to the trough collectors, the results of the system economic evaluation in terms of required collector costs for breakeven economics may be viwed in terms of the anticipated future costs of central receivers.

2.1.2 Parabolic Dish Collectors for Residential STE Applications

Two-axis tracking parabolic dish collectors were considered for STES. A primary advantage of these collectors is their ability to operate at temperatures ($< 1000°F$) sufficient to drive steam Rankine cycle engines at good efficiencies. The essential disadvantage to parabolic dish collectors is that they are projected to have costs significantly higher than central receivers and parabolic troughs, and require large amounts of piping.

Our project team has projected installed cost of 73% efficient two-axis dishes at $35.50/sq ft ($22 collector plus $13.50 installation). With a similar ground cover factor to central receivers (0.35) to prevent shading of adjacent collectors, dish collectors do not offer any advantage in potential aperture area over alternative collectors. The benefits of increased collector efficiency and enhanced heat engine efficiency tend to be balanced by the high cost of the collector. A simple calculation which bears this out is given below in Table 2.

Table 2. CALCULATION OF PARABOLIC DISH COLLECTOR ECONOMICS

Parabolic Dish Annual Output = (ground cover factor)(roof area) X (total annual direct normal radiation) X (collector efficiency)(correction factor for more efficient heat engine performance)

Collector Annual Cost = (ground cover factor)(roof area) X [(annual capital charge factor) X (Collector cost) + (annual O&M)]

Ground Cover Factor = 0.35

Roof Area = 15,120 sq ft (low-rise)

Collector Efficiency = 73%

Correction Factor for Efficient Heat Engine Performance = ratio of heat engine efficiency at 1000°F/ heat engine efficiency at 600°F

= 26% (1000°F)/22% (600°F)

Annual Capital Charge = 15%

Annual O&M = $1/sq ft-yr

Annual Cost = $33,472.00/yr

City	Parabolic Dish Annual Output, 10^7 Btu/yr	Ratio of Annual Output Dish:Central Receiver	Ratio of Cost (1985) Dish:Central Receiver
Boston	297.0	1.6/1	1.9/1
Albuquerque	384.0	1.6/1	1.9/1
Chicago	294.0	1.6/1	1.9/1
Dallas	316.0	1.6/1	1.9/1

Although the increased annual output of the dish collector is desirable, the increased annual output is paid for in terms of a significant cost differential relative to the central receiver. A similar analysis would show substantially the same conclusion relative to trough collectors.

RPA* has projected[2] an installed cost of dish collectors of $13/sq ft. In comparison to projected central receiver costs of $7/sq ft, the cost of dish collectors becomes 2.4 times that of a central receiver for only a 60% increase in performance. However, if the cost reductions for dish collectors are realized they do offer a significant performance edge over the trough collectors, while providing the additional energy at the same capital cost as the troughs.

* Resource Planning Associates, Inc.

As a result of this evaluation, the dish collector is not considered a candidate for residential solar total energy applications, although if the projected cost reductions are achieved, it is worth another look, especially for single-family detached dwellings where central receivers are not applicable. Figure 2 shows a parabolic dish solar concentrator. (See Figure A-9.)

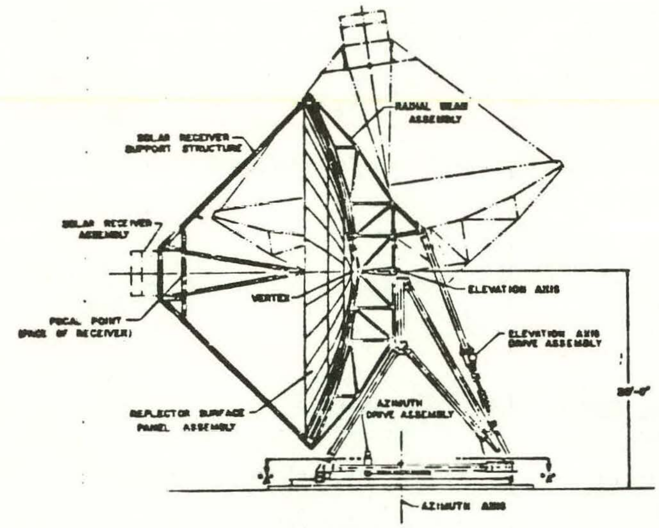

Figure 2. PARABOLIC DISH SOLAR CONCENTRATOR

2.1.3 Collector Areas

This section presents estimates of the maximum collector aperture areas, which could be used for several different residential structures under consideration. Seven types of housing were identified:

A. 1. Single-Family Detached, 4 bedroom, 2 story
   2. Single-Family Detached, 3 bedroom, 1 story
B. 3. Single-Family Attached, 3 bedroom, 2 story
   4. Multi-Family, 2 story concrete block
C. 5. Multi-Family, 2 story wood frame
   6. Multi-Family, 3 story wood frame
D. 7. Multi-Family, 15 story.

Only the 4 dwelling types labeled A, B, C, and D were selected for evaluation. The single-family attached dwelling (townhouse) was assumed to have 36 units. For each of the structures, the collectors were assumed to be roof mounted. No adjacent land area was assumed to be available for the collectors.

In the following discussion, roof areas are computed on the basis of sloped roofs for single-family detached, single-family attached, and low-rise structures. It is possible, however, that constraining the mounting of collectors to sloped roofs does not provide sufficient collector area. In order to increase potential collector area, collector areas were recalculated on the basis of flat roofs. Although in many regions of the United States flat roofs are not common construction, it is felt that this concession to conventional construction is vitally important to maximize the potential contribution of solar energy to satisfy the structure's energy requirements.

The first step in estimating the collector areas was to determine available roof area for each structure. Each of the first six types of housing has a sloped roof. The 15-story multi-family dwelling has a flat roof. The geometry of each structure was used to determine the roof area available. For example, the single-family detached, 4-bedroom, 2-story house plan view is shown in Figure 3 and the plan view for the townhouse is shown in Figure 4. The low-rise and high-rise plan views, with their dimensions, are shown in Figures 5 and 6. The house was assumed to have a south facing roof slope. For a 2-story home, a 1-story garage roof was assumed to be unusable since it would be shaded a large portion of the time. The roof area is simply found by the exterior house dimensions and an assumed roof slope. Normal construction techniques use a roof slope of approximately 20 degrees so that the normal roof area available for the single-family detached, 4-bedroom, 2-story home shown in Figure 3 is —

$$\text{Roof Area} = \frac{25.0'}{2} \times 34.0'/\cos 20° = 452 \text{ sq ft}$$

The collector area available can be estimated using the above values for the total available roof area. The collector area is impacted by the following considerations:

- Collector tilt angle
- Maintenance access
- Aperture area versus installation area
- Collector spacing to minimize shading

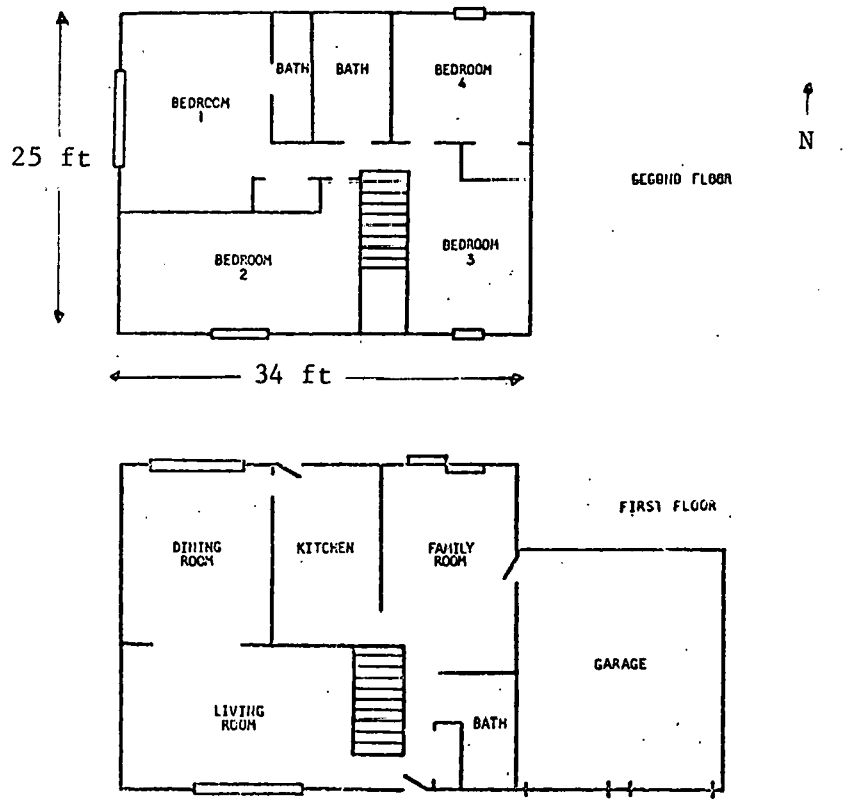

Figure 3. FLOOR PLAN FOR THE CHARACTERISTIC SINGLE-FAMILY, 4-BEDROOM, 2-STORY HOUSE

DIMENSIONS

Ceiling: W_c = 25 feet
L = 34 feet

Roof Slope = 20 degrees

Roof Dimensions for Collectors: (1/2 because only 50% of roof is south facing)
W = 25 feet/(COS 20°)(22) = 13.30
L = 34 feet

Sloped Roof Area for Collectors = 452 sq ft

Flat Roof Area for Collectors = 850 sq ft.

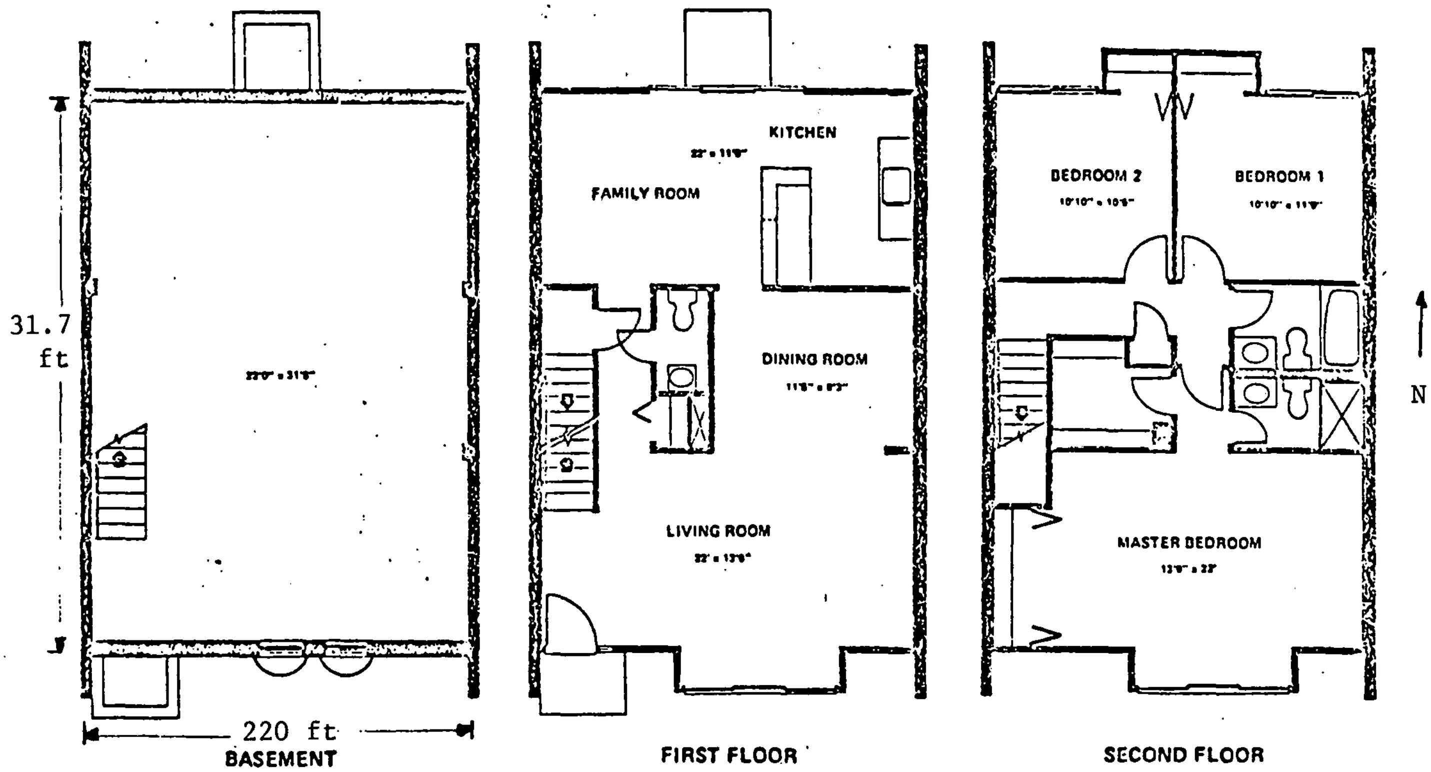

Figure 4. FLOOR PLAN FOR A 3-BEDROOM, 2-STORY TOWNHOUSE

DIMENSIONS

Ceiling: W_c = 31.7 feet
L = 22.0 feet

Roof Slope = 20 degrees

Roof Dimensions for Collectors/Roof Slope = 20°
W = 31.7/cos(20) · 2 = 16.87 feet
L = 22.0 feet/townhouse

Number of Townhouse Units = 36

L = (22.0 X 36) - 792 feet

Sloped Roof Area for Collectors = 13,359 sq ft

Flat Roof Area for Collectors = 25,107 sq ft.

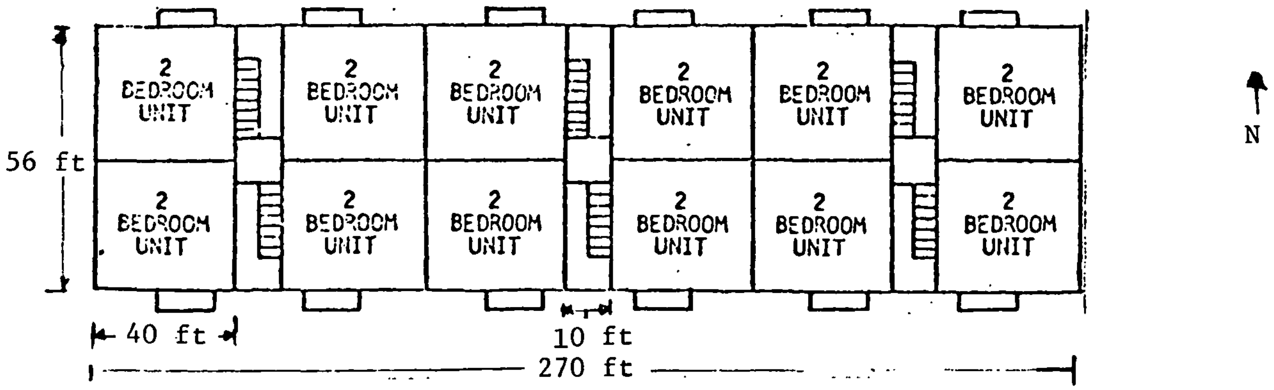

Figure 5. FLOOR PLAN FOR 2-STORY LOW-RISE

Two-Story Low-Rise

Number of Units = 24 (12 units/floor)*

DIMENSIONS

Ceiling: W_C = 56 feet
L' = 40 feet/apartment
L" = 10 feet/stairway

6 Apartments in long dimension

3 Stairways in long dimension

$$L = (6\ L') + (3\ L'')$$
$$= (6 \times 40) + (3 \times 10)$$
$$= 270 \text{ feet}$$

Roof Dimensions for Collectors/Roof Slope = 20 degrees
W = 56/(cos 20)(2) = 29.8 feet
L = 270 feet

Sloped Roof Area for Collectors = 8046 sq ft

Flat Roof Area for Collectors = 15120 sq ft.

* Two 24-unit apartment buildings were combined for the final design, thus producing a low-rise apartment assembly of 48 units. Roof area for the 48-unit assembly is double the areas indicated above for the 24-unit building.

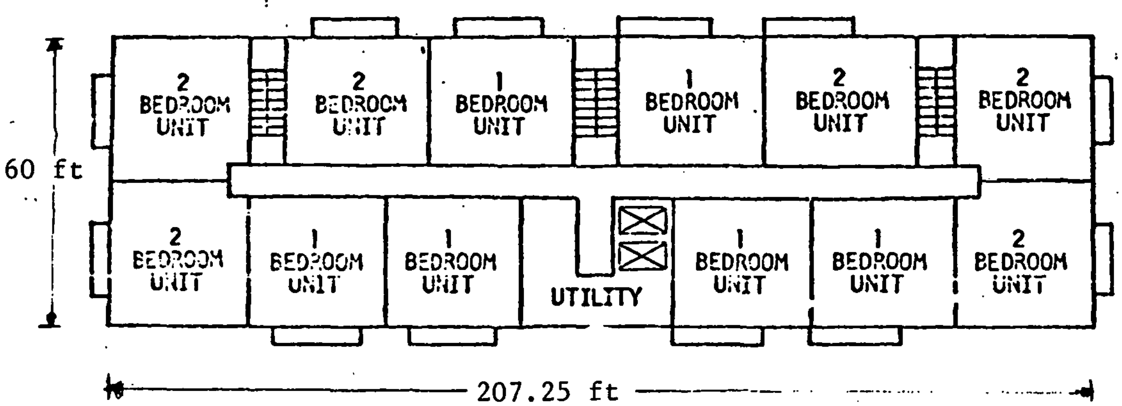

Figure 6. FLOOR PLAN FOR 15-STORY HIGH-RISE

15-Story High-Rise

Flat Roof Area Available for Collectors

4 Corner Apartments @ 884 sq ft/apartment	= 3536 sq ft
2 2-Bedroom Apartments @ 899 sq ft/apartment	= 1798 sq ft
6 1-Bedroom Apartments @ 754 sq ft/apartment	= 4524 sq ft
Hallways	= 1017 sq ft
Stairways/Elevator	= 1200 sq ft
Utility	= 360 sq ft
Total Roof Area for Collectors	= 12435 sq ft

Roof Dimensions for Collectors/Roof Slope - 0 degrees

W = 60 feet
L = 207.25 feet.

This procedure was followed for each housing type and the resulting roof areas are:

A. Single-family detached, 2-story = 452 sq ft
B. Single-family attached, 2-story = 8906 sq ft
C. Multi-family, 2-story = 8046 sq ft
D. Multi-family, 15-story* = 12435 sq ft.

* Note that the 15-story dwelling has a flat roof.

- Available collector sizes.

Each of these elements was addressed for a number of different classes of collectors.

Flat plate collectors, evacuated tubes, and compound parabolic concentrators (CPC), are all generally non-tracking and were evaluated as a class of collectors for estimating aperture area. There are basically three options for mounting these non-tracking collectors. These are —

1. Flat on normal roof
2. Tilted by new or pscudo roof
3. Tilted by individually rack mounting.

For Option 1, Figure 7 shows how the collectors would appear on a normally sloped roof structure. The available collector aperture area is less than the roof area because of required maintenance access area and because most non-tracking collectors have a smaller aperture area than the required installation area. Installation areas are greater than aperture areas because of the support structure surrounding the working surfaces of the collector. The ratio of actual aperture working area to total collector area varies from 0.85 to 0.93 depending upon the manufacturer's design. For example, a Lennox flat plate and a KTA evacuated tube both have approximately an effective aperture area of 0.86 times the required installation area. The required space for maintenance access was assumed to be 10% of the roof area. The effective available aperture area is then found by simply multiplying the roof area by 0.86 and 0.9; for a single-family detached, 2-story, we would get —

Collector Area = 452 X 0.9 X 0.86 = 350 sq ft (Mounting Option 1)

Mounting Options 2 and 3 would improve collector performance by tilting the collector to gather a greater portion of the available solar energy. Common practice is to use a tilt equal to the latitude of the site or the latitude plus or minus 10 to 15 degrees depending upon the distribution of the load. For a peak summer load, it may be desirable to tilt the collector to an angle equal to the latitude minus 10 degrees while a tilt of latitude plus 10 degrees would be better suited to a peak winter load. For a first approximation, we used a tilt angle equal to the latitude angle in estimating collector areas.

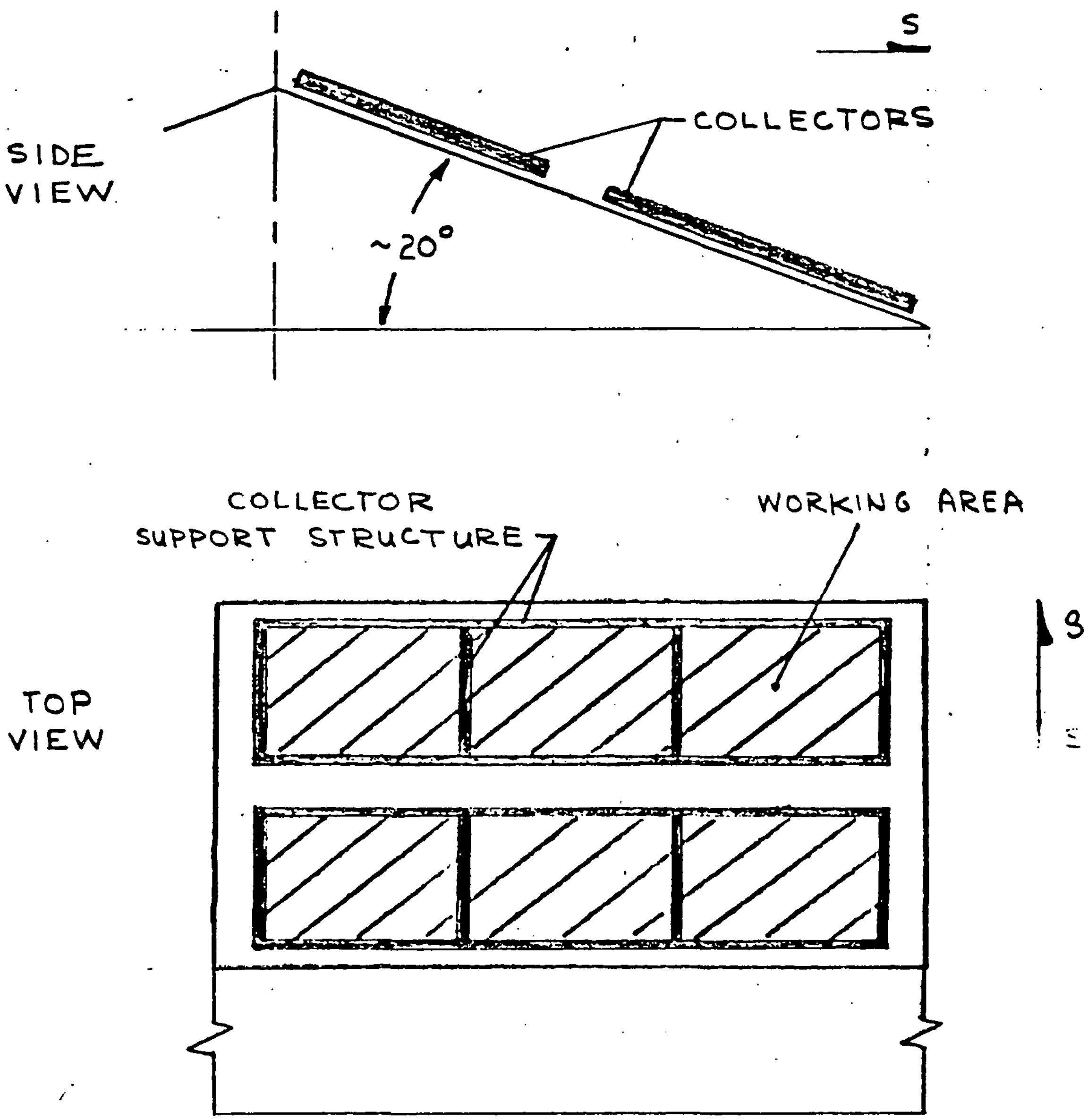

Figure 7. NON-TRACKING COLLECTORS MOUNTED ON A NORMALLY SLOPED ROOF

Option 1 is attractive as it allows a large aperture area because inter-row shading is minimized as compared with other mounting methods. However, a drawback exists for this mounting method because it results in very poor collector performance during the winter. Compensating for this drawback is very good performance in the summer, when the sun is nearly overhead. This collector is thus most suitable in areas with large loads during the summer, where its summer peaking performance may be effectively utilized. Option 3 gives good year-round collector performance and is the most appropriate manner of installation when roofs are not sloped at the desired angle. Collector areas have been established only for Options 1 and 3. Option 1 is only applied to tracking collectors, however.

Figure 8 shows how mounting Option 2 would be used. This is applicable to smaller dwellings and could be most practical for new housing where the roof slope could be originally constructed for the solar application. The available collector area is computed in essentially the same manner as for mounting Option 1 but modified by the factor [cos 20°/cos 0 lat] or in the single-family detached, 2-story example:

Collector Area = 350 X cos 20°/cos 0 lat (Mounting Option 2)

The third mounting option is to rack mount each collector to the desired tilt angle. Due to the flexibility of application of this approach and benefits of tilted collectors, collector areas were exclusively evaluated using this option. Figure 9 shows how this may be accomplished. For this option, the possible row-to-row collector shading can be avoided by properly spacing the collectors on the roof. For a south facing roof, the shading can be minimized by using the rule that there are no shadows at winter solstice noon.*
For winter solstice noon, the sun's elevation angle (β) is given by —

$$\sin \beta = \cos (\theta \text{ lat}) \cos (-23.45°) + \sin (\theta \text{ lat}) \sin (-23.45°)$$

The required spacing on a sloped roof is derived using Figure 10 for the geometry. Note that the required spacing also allows for maintenance access along rows. The ratio of collector length (CL) to roof length (CG) is:

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* Of course, during the winter there will be some shadowing because of the low altitude of the sun during morning and afternoon. These shadow losses are ignored in the estimates of collector performance.

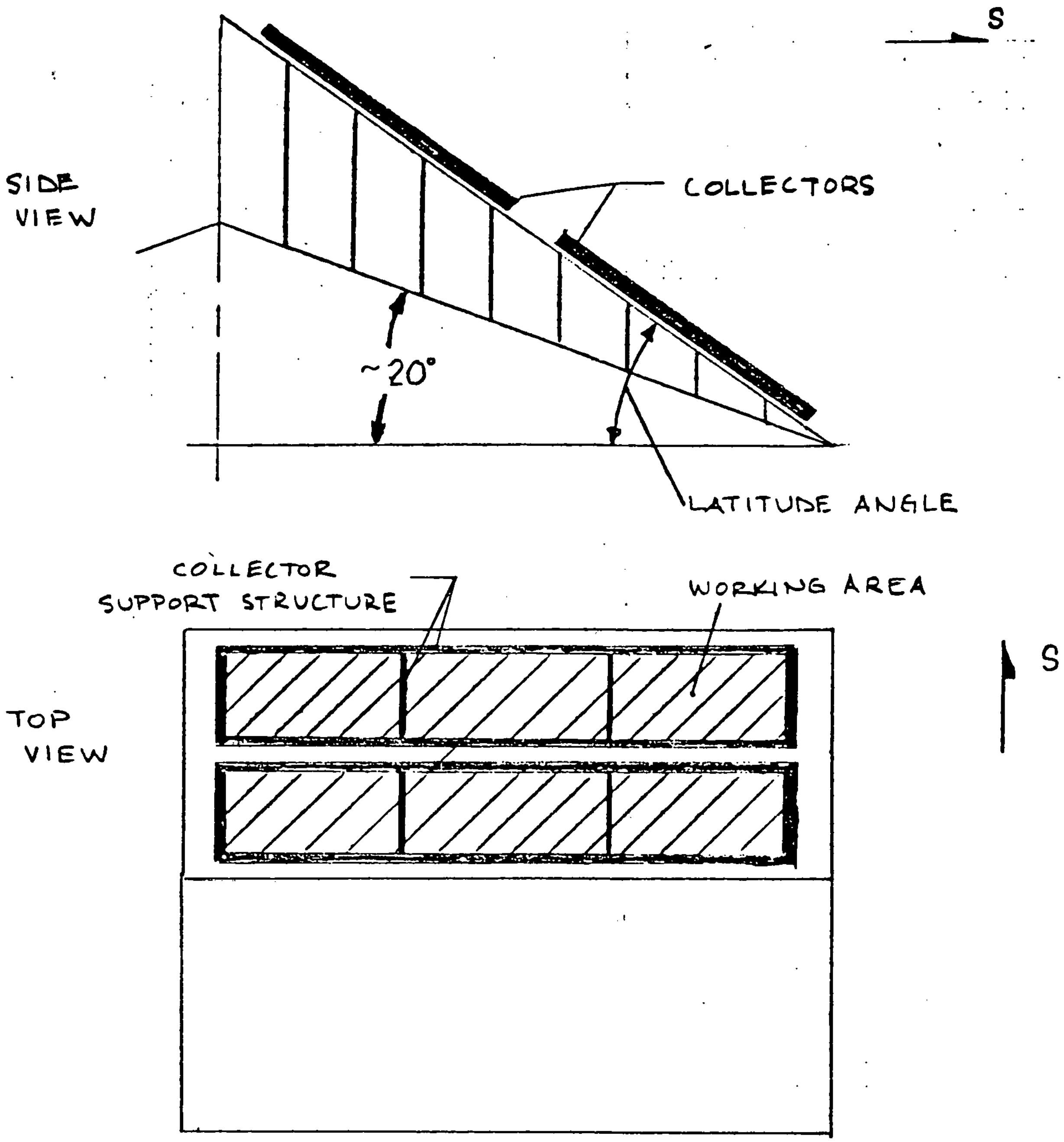

Figure 8. NON-TRACKING COLLECTOR MOUNTED AT LATITUDE ANGLE ON NEW OR PSEUDO ROOF

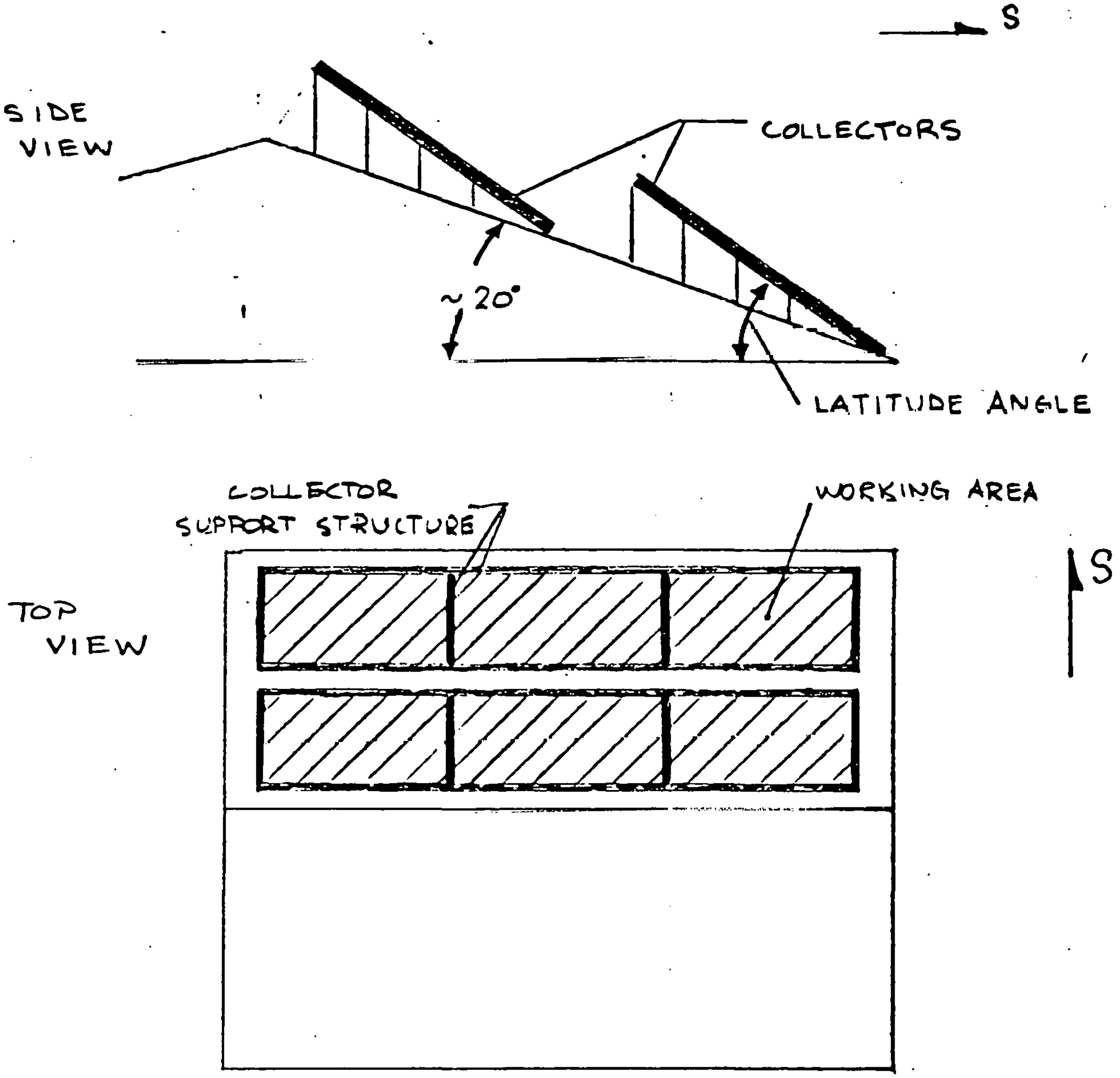

Figure 9. NON-TRACKING COLLECTOR RACK-MOUNTED INDIVIDUALLY

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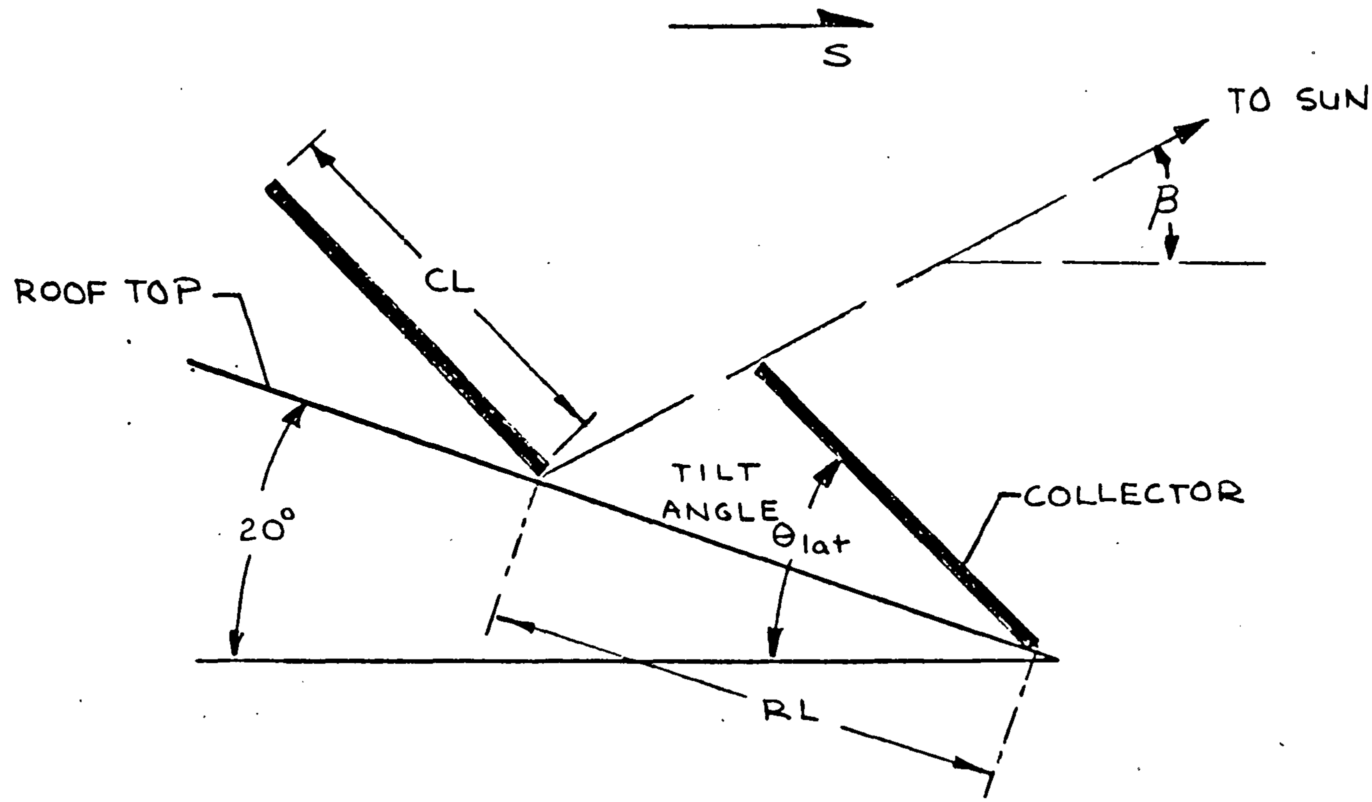

Figure 10. REQUIRED SPACING ON A SLOPED ROOF

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A) Applicable to EVAC TUBE, low CR CPC, polar mount trough, SLATS —

1.A. Collectors tilted at latitude (=θ) on flat roof:
$CL/CG^* = [\sin \theta/\tan \beta + \cos \theta]^{-1}$

2.A. Collectors tilted at latitude on sloped roof (20° slope):
$$CL/CG = [\frac{\sin (\theta - 20)}{\tan (\beta + 20)} + \cos (\theta - 20)]^{-1}$$

B) Applicable to high CR CPC and E-W trough:

1.B. Collector tilted at solar zenith angle on December 21, noon, on flat roofs:
$$CL/CG = [\cos(s) + \sin(s)/\tan \beta]^{-1}$$

where:

s = declination + latitude — December 21 declination = 23.45°

$= 90 - \beta$ — β = solar altitude

2.B. Collectors tilted at solar zenith angle on December 21, noon, on sloped roof (20°)
$$CL/CG = [\frac{\sin (s - 20)}{\tan (\beta + 20)} + \cos (s - 20)]^{-1}$$

Using the relations developed for collector spacing, the optimum collector length (CL) was developed that gave the maximum possible collector area. The collectors are assumed to be displayed such that the front row of the collector is at the roof edge and the last row is spaced a collector length away from the peak of the roof. The optimum collector length is thus:

$$CL = \frac{\text{roof width (measured in plane of roof slope — edge to peak)}}{[1 + \frac{N - 1}{(CL/CG)}]}$$

where N = number of rows.

The collector length is constrained to a reasonable value of between 5 and 20 feet. In the case of E-W trough collectors, the collector aperture is constrained to be between 5 and 10 feet. The optimum collector length is obtained with the minimum number of rows.

Polar mounted, tracking collectors will require more roof area per unit collector area to allow for shading within a collector row. The same 3 mounting alternatives exist but the roof mounting for a one-axis tracking collector may appear as shown in Figure 11. The east-west spacing of these collectors can reduce roof coverage allowable by anywhere from 30% to 70%. We recommend that a spacing of 0.57 be used as typical for polar mount trough collectors.

* CL = collector length, CG = spacing between collector rows.

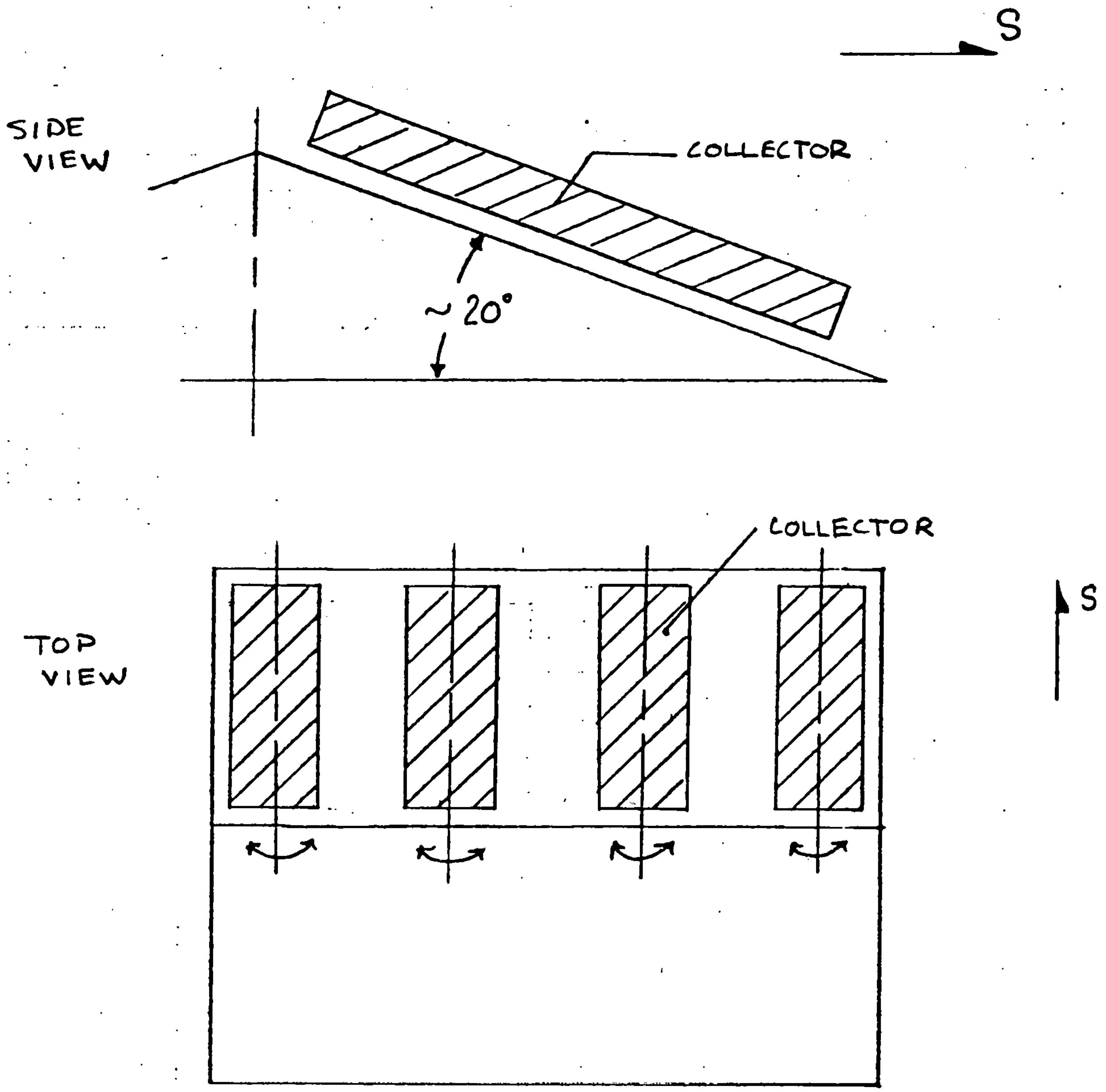

Figure 11. EXAMPLE OF ONE-AXIS TRACKER ROOF MOUNTING (TROUGH)

The collector area is found as the product of the optimum collector length, the optimum number of collector rows, the length of the roof in the east-west direction, the maintenance access factor, the aperture area reduction factor, and (where applicable) the polar mount reduction factor. These factors are summarized in Table 3, and the collector mounting options are summarized in Figure 12.

Table 3. COLLECTOR AREA ROOF COVERAGE FACTORS

Maintenance Areas Multiplying Factor (all orientation)	= 0.95
Aperture Area Reduction - Evacuated Tube and CPC	= 0.86
Aperture Area Reduction - SLATS	= 0.80
Aperture Area Reduction - East-West and Polar Mount Trough	= 1.0
Spacing Area Reduction - Polar Mount Trough	= 0.57

AREA = (N)(CL)(L)(Maintenance)(Aperture Reduction)(Polar Mount Reduction)

Note: Row spacing is sufficient to provide maintenance access along rows.

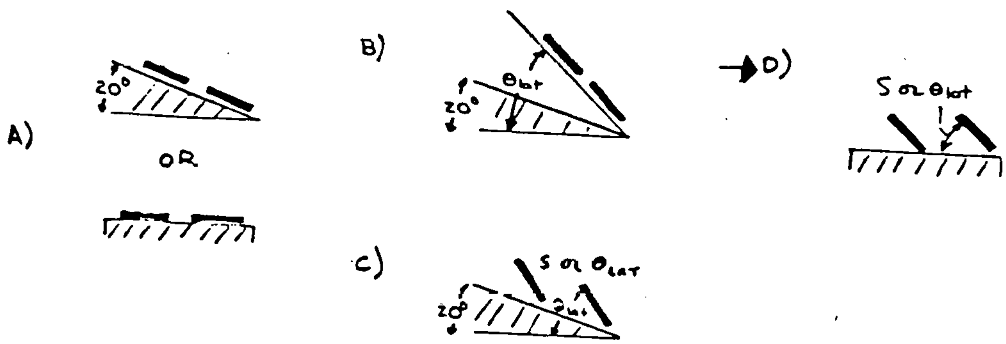

Figure 12. COLLECTOR MOUNTING OPTIONS

Collector areas are presented only for flat roof dwellings. Table 4 summarizes collector areas for north-south horizontal trough collectors. Tables 5 through 22 summarize collector areas for other collector types. (Collector areas for townhouses and low-rise apartments must be multiplied by 1.5 and 2.0 respectively, to coincide with final design criteria of 36 townhouses and 48 low-rise apartments.)

Table 4. COLLECTOR AREAS FOR NORTH-SOUTH HORIZONTAL TROUGHS

Application	Roof Area, sq ft	Collector Area, sq ft
Single-Family Detached (all cities)	850	460
Townhouse (24 Units)	16,738	9,064
Low-Rise (24 Units)	15,120	8,189

Assumptions:

Aperture Area Reduction Factor = 1.0
Intrarow Spacing Factor = 0.57
Maintenance Access Factor = 0.95

Collector Area = (Roof Area)(Aperture Area Reduction)(Intrarow Spacing)(Maintenance Access)

Table 5. COLLECTOR AREAS FOR EVACUATED TUBE, LOW CR-CPC COLLECTOR

Collector Type: Evacuated Tube, low CR-CPC

Application: Single-family detached

Flat Roof Option				
Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	578	850	0.68
Dallas/ Fort Worth	32.83	524	850	0.62
Charleston/ Raleigh	32.9	523	850	0.62
Phoenix	33.43	519	850	0.61
Los Angeles	34.0	514	850	0.61
Albuquerque	35.05	504	850	0.59
Nashville	36.12	494	850	0.58
Chicago	41.67	437	850	0.51
Boston	42.37	429	850	0.51

Table 6. COLLECTOR AREAS FOR POLAR MOUNT, TROUGH COLLECTOR

Collector Type: Polar Mount, Trough

Application: Single-family detached

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	383	850	0.45
Dallas/ Fort Worth	32.83	347	850	0.41
Charleston/ Raleigh	32.9	347	850	0.41
Phoenix	33.43	344	850	0.40
Los Angeles	34.0	341	850	0.40
Albuquerque	35.05	334	850	0.39
Nashville	36.12	327	850	0.38
Chicago	41.67	290	850	0.34
Boston	42.37	284	850	0.33

Table 7. COLLECTOR AREAS FOR EAST-WEST TROUGH COLLECTOR

Collector Type: East-West Trough

Application: Single-family detached

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	49.23	638	850	0.75
Dallas/ Fort Worth	56.28	576	850	0.68
Charleston/ Raleigh	56.35	576	850	0.68
Phoenix	56.88	570	850	0.67
Los Angeles	57.45	565	850	0.66
Albuquerque	58.5	555	850	0.65
Nashville	59.57	543	850	0.64
Chicago	65.12	479	850	0.56
Boston	65.82	470	850	0.55

Table 8. COLLECTOR AREAS FOR NORTH-SOUTH HORIZONTAL TROUGH COLLECTOR

Collector Type: North-South Horizontal Trough

Application: Single-family detached

Flat Roof Option

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	0.0	460	850	0.54
Dallas/ Fort Worth	0.0	460	850	0.54
Charleston/ Raleigh	0.0	460	850	0.54
Phoenix	0.0	460	850	0.54
Los Angeles	0.0	460	850	0.54
Albuquerque	0.0	460	850	0.54
Nashville	0.0	460	850	0.54
Chicago	0.0	460	850	0.54
Boston	0.0	460	850	0.54

Table 9. COLLECTOR AREAS FOR HIGH CR-CPC COLLECTOR

Collector Type: High CR-CPC

Application: Single-family detached

Flat Roof Option

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	49.23	549	850	0.65
Dallas/ Fort Worth	56.28	496	850	0.58
Charleston/ Raleigh	56.35	495	850	0.58
Phoenix	56.88	491	850	0.58
Los Angeles	57.45	486	850	0.57
Albuquerque	58.5	477	850	0.56
Nashville	59.57	467	850	0.55
Chicago	65.12	412	850	0.48
Boston	65.82	404	850	0.48

Table 10. COLLECTOR AREAS FOR SLATS COLLECTOR

Collector Type: SLATS

Application: Single-family detached

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	537	850	0.63
Dallas/ Fort Worth	32.83	487	850	0.57
Charleston/ Raleigh	32.9	487	850	0.57
Phoenix	33.43	483	850	0.57
Los Angeles	34.0	478	850	0.56
Albuquerque	35.05	469	850	0.57
Nashville	36.12	460	850	0.54
Chicago	41.67	407	850	0.48
Boston	42.37	399	850	0.47

Table 11. COLLECTOR AREAS FOR EVACUATED TUBE, LOW CR-CPC COLLECTOR

Collector Type: Evacuated Tube, low CR-CPC

Application: Single-family detached

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	11,374	16,738	0.68
Dallas/ Fort Worth	32.83	10,309	16,738	0.62
Charleston/ Raleigh	32.9	10,299	16,738	0.62
Phoenix	33.43	10,213	16,738	0.61
Los Angeles	34.0	10,116	16,738	0.60
Albuquerque	35.05	9,929	16,738	0.59
Nashville	36.12	9,727	16,738	0.58
Chicago	41.67	8,604	16,738	0.51
Boston	42.37	8,449	16,738	0.50

Table 12. COLLECTOR AREAS FOR EAST-WEST TROUGH COLLECTOR

Collector Type: East-West Trough

Application: Single-family attached (townhouse)

Flat Roof Option				
Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	49.23	11,741	16,738	0.70
Dallas/ Fort Worth	56.28	10,362	16,738	0.62
Charleston/ Raleigh	56.35	10,347	16,738	0.62
Phoenix	56.88	10,230	16,738	0.61
Los Angeles	57.45	10,112	16,738	0.60
Albuquerque	58.5	9,888	16,738	0.59
Nashville	59.57	9,647	16,738	0.58
Chicago	65.12	9,422	16,738	0.56
Boston	65.82	9,247	16,738	0.55

Table 13. COLLECTOR AREAS FOR POLAR MOUNT, TROUGH COLLECTOR

Collector Type: Polar Mount, trough

Application: Single-family attached (townhouse)

Flat Roof Option				
Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	7,579	16,738	0.45
Dallas/ Fort Worth	32.83	6,833	16,738	0.41
Charleston/ Raleigh	32.9	6,826	16,738	0.41
Phoenix	33.43	6,769	16,738	0.40
Los Angeles	34.0	6,705	16,738	0.40
Albuquerque	35.05	6,581	16,738	0.39
Nashville	36.12	6,447	16,738	0.39
Chicago	41.67	5,703	16,738	0.34
Boston	42.37	5,600	16,738	0.33

Table 14. COLLECTOR AREAS FOR NORTH-SOUTH HORIZONTAL, TROUGH COLLECTOR

Collector Type: North-South Horizontal, trough

Application: Single-family attached (townhouse)

Flat Roof Option				
Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	0.0	9,064	16,738	0.54
Dallas/ Fort Worth	0.0	9,064	16,738	0.54
Charleston/ Raleigh	0.0	9,064	16,738	0.54
Phoenix	0.0	9,064	16,738	0.54
Los Angeles	0.0	9,064	16,738	0.54
Albuquerque	0.0	9,064	16,738	0.54
Nashville	0.0	9,064	16,738	0.54
Chicago	0.0	9,064	16,738	0.54
Boston	0.0	9,064	16,738	0.54

Table 15. COLLECTOR AREAS FOR HIGH CR-CPC COLLECTOR

Collector Type: High CR-CPC

Application: Single-family attached (townhouse)

Flat Roof Option				
Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	49.23	10,804	16,738	0.65
Dallas/ Fort Worth	56.28	9,761	16,738	0.58
Charleston/ Raleigh	56.35	9,750	16,738	0.58
Phoenix	56.88	9,659	16,738	0.58
Los Angeles	57.45	9,567	16,738	0.57
Albuquerque	58.5	9,392	16,738	0.56
Nashville	59.57	9,201	16,738	0.55
Chicago	65.12	8,103	16,738	0.48
Boston	65.82	7,953	16,738	0.48

Table 16. COLLECTOR AREAS FOR SLATS COLLECTOR

Collector Type: SLATS

Application: Single-family attached (townhouse)

Flat Roof Option

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	10,581	16,738	0.63
Dallas/ Fort Worth	32.83	9,590	16,738	0.57
Charleston/ Raleigh	32.9	9,580	16,738	0.57
Phoenix	33.43	9,501	16,738	0.57
Los Angeles	34.0	9,410	16,738	0.56
Albuquerque	35.05	9,237	16,738	0.55
Nashville	36.12	9,049	16,738	0.54
Chicago	41.67	8,004	16,738	0.48
Boston	42.37	7,859	16,738	0.47

Table 17. COLLECTOR AREAS FOR EVACUATED TUBE, LOW CR-CPC COLLECTOR

Collector Type: Evacuated Tube, low CR-CPC

Application: Low-Rise Apartment

Flat Roof Option

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	9,729	15,120	0.64
Dallas/ Fort Worth	32.83	8,607	15,120	0.57
Charleston/ Raleigh	32.9	8,596	15,120	0.57
Phoenix	33.43	8,508	15,120	0.56
Los Angeles	34.0	8,409	15,120	0.56
Albuquerque	35.05	8,219	15,120	0.54
Nashville	36.12	8,787	15,120	0.58
Chicago	41.67	7,773	15,120	0.51
Boston	42.37	7,632	15,120	0.50

Table 18. COLLECTOR AREAS FOR POLAR MOUNT, TROUGH COLLECTOR

Collector Type: Polar Mount, trough

Application: Low-Rise apartment

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	6,449	15,120	0.43
Dallas/ Fort Worth	32.83	5,705	15,120	0.38
Charleston/ Raleigh	32.9	5,697	15,120	0.38
Phoenix	33.43	5,639	15,120	0.37
Los Angeles	34.0	5,573	15,120	0.37
Albuquerque	35.05	5,448	15,120	0.36
Nashville	36.12	5,824	15,120	0.39
Chicago	41.67	5,152	15,120	0.34
Boston	42.37	5,059	15,120	0.33

Table 19. COLLECTOR AREAS FOR HIGH CR-CPC COLLECTOR

Collector Type: High CR-CPC

Application: Low-Rise apartment

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	49.23	9,122	15,120	0.60
Dallas/ Fort Worth	56.28	8,818	15,120	0.58
Charleston/ Raleigh	56.35	8,808	15,120	0.58
Phoenix	56.88	8,725	15,120	0.58
Los Angeles	57.45	8,642	15,120	0.57
Albuquerque	58.5	8,484	15,120	0.56
Nashville	59.57	8,312	15,120	0.55
Chicago	65.12	7,320	15,120	0.48
Boston	65.82	7,184	15,120	0.48

Table 20. COLLECTOR AREAS FOR SLATS COLLECTOR

Collector Type: SLATS

Application: Low-Rise apartment

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	25.78	9,051	15,120	0.60
Dallas/ Fort Worth	32.83	8,006	15,120	0.53
Charleston/ Raleigh	32.9	7,996	15,120	0.53
Phoenix	33.43	7,915	15,120	0.52
Los Angeles	34.0	7,822	15,120	0.52
Albuquerque	35.05	7,646	15,120	0.51
Nashville	36.12	8,174	15,120	0.54
Chicago	41.67	7,230	15,120	0.48
Boston	42.37	7,100	15,120	0.47

Table 21. COLLECTOR AREAS FOR EAST-WEST TROUGH COLLECTOR

Collector Type: East-West Trough

Application: Low-Rise apartment

——— Flat Roof Option ———

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Miami	49.23	10,079	15,120	0.67
Dallas/ Fort Worth	56.28	8,970	15,120	0.59
Charleston/ Raleigh	56.35	8,756	15,120	0.58
Phoenix	56.88	8,847	15,120	0.58
Los Angeles	57.45	8,737	15,120	0.58
Albuquerque	58.50	8,530	15,120	0.56
Nashville	59.57	8,306	15,120	0.55
Chicago	65.12	7,494	15,120	0.50
Boston	65.82	7,331	15,120	0.48

Table 22. COLLECTOR AREAS FOR NORTH-SOUTH HORIZONTAL COLLECTOR

Collector Type: North-South Horizontal

Application: Low-Rise apartment

Geographic Location	Slope Angle	Collector Area (sq ft)	Roof Area Available For Collector (sq ft)	Ground Cover Factor
Flat Roof Option				
Miami	0.0	8,189	15,120	0.54
Dallas/ Fort Worth	0.0	8,189	15,120	0.54
Charleston/ Raleigh	0.0	8,189	15,120	0.54
Phoenix	0.0	8,189	15,120	0.54
Los Angeles	0.0	8,189	15,120	0.54
Albuquerque	0.0	8,189	15,120	0.54
Nashville	0.0	8,189	15,120	0.54
Chicago	0.0	8,189	15,120	0.54
Boston	0.0	8,189	15,120	0.54

2.1.4 Solar Collector Screening Methodology

To establish appropriate generic collector types for specific residential applications, a number of collectors were screened to determine which collectors offer most cost-effective performance after optical and thermal characteristics, and capital, installation, and maintenance costs are accounted for. Selection procedure applies only to future collector technology.

Procedures

- Establish performance of a 1 sq ft aperture for Albuquerque, Boston, Chicago, and Fort Worth, using one year's actual insolation data to produce a value for Btu collected/sq ft-yr at 300° and 600°F average collector temperatures. (Collector performance characteristics are summarized in Table 23. Cosine losses are not included.)

Table 23. GENERIC CHARACTERISTICS OF CANDIDATE COLLECTORS

$$\text{Collector Efficiency}^{**} = \eta_{opt} - \frac{A(Tc^{*} - Ta) + B(Tc^4 - Ta^4)}{I}$$

Collector	η_{opt} (clean)[a]	A[b]	B[c]	I[d]	Comments
Evacuated Tube					
ET 1	0.700	0.157	0.0	Total	Tilted at local latitude
ET 2	0.670	0.35	0.0	Total	
CPC					
CPC 1 (1.5X)	0.60	0.13	0.0	Total	Tilted at latitude/ Current Tech. (C.T.)
CPC 2 (5X)	0.48	0.12	0.0	Total	Tilted angle adjusted monthly/C.T.
CPC 1A (1.5X)	0.74	0.12	0.0	Total	Tilted at latitude/ Advanced Tech.
CPC 2A (5X)	0.67	0.084	0.0	Total	Tilt angle adjusted monthly/Ad. Tech.
SLATS	0.68	0.071	0.0	Direct	Performance from proprietary Sheldahl program
One-Axis Tracking					
PT 1	0.750	0.0663	$.445 \times 10^{-4}$	Direct	NS, Polar & E-W Mount/ TC = 300°F + 600°F
PT 2	0.620	0.080	$.50 \times 10^{-10}$	Direct	NS, Polar & E-W Mount/ TC = 300°F + 600°F
PT 3	0.700	0.55	0.0		NS, Polar & E-W Mount/ TC = 300°F

[a] Performance of collectors determined with an optical efficiency of 90% of clean optical efficiency (η_{opt}).

[b] Btu/sq ft of hr.

[c] Btu/sq ft °R^4 hr.

[d] Btu/sq ft hr.

[e] NS = North-South Horizontal.

[f] E-W = East-West.

[g] PM = Polar Mount.

* Yields conservative performance results because $T_c = \frac{T_{in} + T_{out}}{2}$, 300°F or 600°F, whereas T_c is always less than T_{out}. Typical values are: T_{in} (300°F) = 195°F, T_{in} (600°F) = 430°F.

** Cosine losses are figured in evaluation of insolation.

- Evaluate total Btu's collected per year for different collector types on different dwellings to account for effects of collector geometry on appropriate row spacing to minimize shadowing and hence on available collector area.

- For future technology collectors, establish —
  1. Annualized capital cost at 15%/yr
  2. Annualized installation cost of rack mounted collectors at 15%/yr
  3. Annual cost of collector maintenance and operation.
- For advanced technology collectors, improvements are modeled primarily as reductions in capital, installation, operation, and maintenance costs. A specific exception is the CPC collector for which Argonne National Laboratory has projected improvements in performance consistent with application of current- or near-term technology. Costs were taken from the section on collector costs. Cost data for current and future technology collectors are summarized in Tables 24 and 25.
- For advanced technology collectors, evaluate total Btu collected/yr and total annual cost for each collector, dwelling type, and geographical location.
- The advanced collectors showing greatest performance and cost effectiveness are carried over to system performance evaluation.
- Results are presented graphically as Btu/yr versus annual dollars. The best collector is the one showing the greatest annual output at lowest cost; since these characteristics are somewhat mutually exclusive, judgment is exercised to pick the most appropriate collector.

2.1.5 Collector Screening Study Results*

Results are presented in Tables 26 through 33 and Figures 13 through 20. The tables also summarize unit collector output (Btu/sq ft-yr), and collector areas on the various dwelling types. Although data have been developed for single-family detached and low-rise structures with flat roofs for Dallas and Chicago in addition to Albuquerque and Boston, results are considered reasonably representative of expected performance of collectors in other regions. It is to be emphasized that only a moderate level of detail is required in system performance estimation, and these results are considered of sufficient detail to allow a reasonable recommendation of appropriate collector types.

Low-Temperature (300°F) Tracking Collectors

- Performance results closely follow the changes in collector optical and heat loss characteristics. (Referring to Table 23, PT-1 is the best, with the highest optical efficiency and lowest heat loss coefficient, followed by PT-2 and PT-3.)

*This discussion is inferred primarily from results of collector performance and predicted future collector costs for Boston and Albuquerque. At 600°F, the performance differences between PT-1 and PT-2 are more significant because the improved heat loss characteristic of PT-1 becomes a more important factor in collector performance as operating temperature increases.

Table 24. ANNUAL INSTALLED COLLECTOR COSTS — CURRENT

Collector Type	Current Collector Cost, $/ft^2	Range, $/ft^2	Current Shipping Cost, $/ft^2	Current Installation Cost, $/ft^2	Current Total Cost, $/ft^2	Current Operation and Maintenance Cost, $/ft^2
ET 1	20.00 GC	20.00	0.25 GC	10.90 - All collectors are rack mounted on roofs.	31.15 GC	1.00
ET 2	12.00 GC	11 -18	0.25 GC	10.90	23.15 GC	1.00
CPC 1 - 1.5X	25 GC	25 (estimate,not on production)	0.35 GC	10.90	36.25 GC	1.25
CPC 2A - 5X (Tilt angle adjusted monthly)	25 GC	25 (estimate not on production)	0.35 GC	14.00 with tilt adjustment	39.35 GC	1.50 @ 25% O&M for fixed tilt
CPC 1A - 1.5X	32.5 GC @ 30% above state-of-the-art	Estimate	0.35 GC	10.90	43.75 GC	1.25
CPC 2A - 5X (Tilt angle adjusted monthly)	32.5 @ 30% above state-of-the-art	Estimate	0.35 GC	14.00 with tilt adjustment	46.85 GC	1.50
T1 - SLATS	20.00 GC	16 - 28	0.45	11.00	31.45 GC	0.75
PT 1	2500 GC	20 - 30	0.25	PM - 16.00 EW&NS-12.00	PM - 41.25 EW&NS - 37.25	PM - 1.00 EW&NS - 0.80 PM is more complex
PT 2	14.00 GC	13.70 - 14.50	0.25	PM - 16.00 EW&NS-12.00	PM - 30.25 EW&NS - 26.25	PM - 1.00 EW&NS - 0.80
PT 3	8.00 GC	7.80	0.25	PM - 16.00 EW&NS-12.00	PM - 24 EW&NS - 20	PM - 1.00 EW&NS - 0.80

Note: GC - Generic current.

Table 25. ANNUAL INSTALLED COLLECTOR COSTS — FUTURE

Collector Type	Future Collector Cost, $/ft^2	Range, $/ft^2	Future Shipping Cost, $/ft^2	Future Installation Cost, $/ft^2	Future Total Cost, $/ft^2	Future Operating and Maintenance Cost, $/ft^2/yr
ET 1	15.00 GF	5.80-14.00	0.10 @ 50% of current	All collectors are rock mounted on roof 5.45 @ 50% of current	20.58 GF	0.10
ET 2	9.00 GF	4.50-11.00	0.13	5.45	14.58 GF	0.10
CPC 1 - 1.5X	14.00 GF	10.00-20.15	0.18 @ 50% of current	5.45 @ 50% of current	19.63 GF	0.16
CPC 2 - 5X (Tilt angle adjusted monthly)	14.00 GF	10.00-20.15	0.18	7.00 with tilt Adjustments @ 50% of current	21.18 GF	0.20 @ 25% above O&M for fixed tilt
CPC 1A - 1.5X	15.40 GF @ 10% above state-of-the-art	estimate	0.18	5.45	21.02 GF	0.16
CPC 2A - 5X (Tilt angle adjusted monthly)	15.40 GF @ 10% above state-of-the-art	estimate	0.18	7.00 with tilt adjustments	22.58 GF	0.20
T1 - SLATS	14.00 GF	9.80-14.00	0.23 @ 50% of current	5.50 @ 50% of current	19.73 GF	0.15
PT 1	14.00 GF	12.00-14.50	0.13 @ 50% of current	PM = 8.00 EW & NS = 6.00 All at 50% of current	PM = 22.13 EW & NS = 20.13	PM = 0.20 EW & NS = 0.16
PT 2	12.00 GF	8.00-13.00	0.18	PM = 8.00 EW & NS = 6.00	PM = 20.13 EW & NS = 18.13	PM = 0.20 EW & NS = 0.16
PT 3	7.00 GF	--	0.13	PM = 8.00 EW & NS = 6.00	PM = 15.13 EW & NS = 13.13	PM = 0.20 EW & NS = 0.16

Table 26. COLLECTOR COSTS FOR 600°F SYSTEM (Boston) — LOW-RISE APARTMENT

City	Collector Type	Annual Collector Cost, $\$/ft^2$-yr	Annual Output ($Btu/ft^2/yr$)	Collector Area, ft^2	Total Annual Output, Btu/yr	$/Year
Boston	CPC2	3.38	36,092	7632	27.5454 X 10^7	25796
Flat Roof Option	CPC2A	3.59	96,868	7632	73.9297	27399
FUTURE COSTS	T1(SLATS)	3.11	106,590	7100	75.6789	22081
	PT1-EW	3.18	192,900	7331	141.4150	23313
	PT2-EW	2.88	36,367	7331	26.6606	21113
	PT1-PM	3.52	262,615	5059	132.8569	17808
	PT2-PM	3.22	53,808	5059	27.2215	16290
	PT1-NS	3.18	211,337	8189	173.0639	26041
	PT2-NS	2.88	31,525	8189	25.8158	23584

Table 27. COLLECTOR COSTS FOR 600°F SYSTEM (Boston) — SINGLE-FAMILY DETACHED

City	Collector Type	Annual Collector Cost, $/ft²-yr	Annual Output (Btu/ft²/yr)	Collector Area, ft²	Total Annual Output, Btu/yr	$/Year
Boston	CPC2	3.38	36,092	429	1.5483×10^7	1450.0
Flat Roof Option	CPC2A	3.59	96,868	429	4.1556	1540.1
FUTURE COSTS	T1(SLATS)	3.11	106,590	399	4.2529	1240.9
	PT1-EW	3.18	192,900	470	9.0663	1494.6
	PT2-EW	2.88	36,367	470	1.7092	1353.6
	PT1-PM	3.52	262,615	284	7.4583	999.7
	PT2-PM	3.22	53,808	284	1.5281	914.5
	PT1-NS	3.18	211,337	460	9.7215	1462.8
	PT2-NS	2.88	31,525	460	1.4502	1324.8

Table 28. COLLECTOR COSTS FOR 300°F SYSTEM (Boston) — SINGLE-FAMILY DETACHED

City	Collector Type	Annual Collector Cost, $\$/ft^2$-yr	Annual Output ($Btu/ft^2/yr$)	Collector Area, ft^2	Total Annual Output, Btu/yr	$/Year
Boston	ET1	3.19	111,168	429	4.7691×10^7	1368.5
Flat Roof Option	CPC1	3.11	154,958	429	6.6477	1334.2
FUTURE COSTS	ET2	2.29	52,391	429	2.2476	982.4
	PT3-PM	2.47	32,903	284	0.9344	701.48
	PT2-PM	3.22	220,994	284	6.2762	914.5
	PT1-PM	3.52	351,862	284	9.9929	999.7
	PT3-EW	2.13	22,367	470	1.0512	1001.1
	PT2-EW	2.88	162,744	470	7.6489	1353.6
	PT1-EW	3.18	269,561	470	12.6694	1494.6
	PT3-NS	2.13	19,416	460	0.8931	979.8
	PT2-NS	2.88	178,619	460	8.2165	1324.8
	PT1-NS	3.18	297,375	460	13.6793	1462.8
	SLATS	3.11	163,552	399	6.5257	1240.9
	CPC1A	3.32	220,026	429	9.4391	1424.3

Table 29. COLLECTOR COSTS FOR 300°F SYSTEM (Boston) — LOW-RISE APARTMENT

City	Collector Type	Annual Collector Cost, $\$/ft^2$-yr	Annual Output ($Btu/ft^2/yr$)	Collector Area, ft^2	Total Annual Output, Btu/yr	$/Year
Boston	ET1	3.19	111,168	7632	84.8434×10^7	24346
Flat Roof Option	CPC1	3.11	154,958	7632	118.2639	23735
FUTURE COSTS	ET2	2.29	52,391	7632	39.9848	17477
	PT3-PM	2.47	32,903	5059	16.64.56	12496
	PT2-PM	3.22	220,994	5059	111.8009	16290
	PT1-PM	3.52	351,862	5059	178.0070	17808
	PT3-EW	2.13	22,367	7331	16.3972	15615
	PT2-EW	2.88	162,744	7331	119.3076	21113
	PT1-EW	3.18	269,561	7331	197.6152	23313
	PT3-NS	2.13	19,416	8189	15.8998	17443
	PT2-NS	2.88	178,619	8189	146.2711	23584
	PT1-NS	3.18	297,375	8189	243.5204	26041
	SLATS	3.11	163,552	7100	116.1219	22081
	CPC1A	3.32	220,026	7632	167.9238	25338

Table 30. COLLECTOR COSTS FOR 300°F SYSTEM (Albuquerque) — SINGLE-FAMILY DETACHED

City	Collector Type	Annual Collector Cost, $/ft²-yr	Annual Output ($Btu/ft^2/yr$)	Collector Area, ft^2	Total Annual Output, Btu/yr	$/Year
Albuquerque	ET1	3.19	162,853	504	8.2078×10^7	1608
Flat Roof Option	CPC1	3.11	221,084	504	11.1426	1567
FUTURE COSTS	ET2	2.29	86,073	504	4.3381	1154
	PT3-PM	2.47	69,700	334	2.8748	825
	PT2-PM	3.22	321,758	334	10.7467	1075
	PT1-PM	3.52	478,095	334	15.9683	1176
	PT3-EW	2.13	47,409	555	2.6312	1182
	PT2-EW	2.88	239,831	555	13.3106	1598
	PT1-EW	3.18	370,351	555	20.5595	1765
	PT3-NS	2.13	47,657	460	21.9220	980
	PT2-NS	2.88	280,875	460	12.9203	1325
	PT1-NS	3.18	427,531	460	19.6664	1463
	SLATS	3.11	218,292	469	10.2379	1459
	CPC1A	3.22	302,267	504	15.2342	1623

Table 31. COLLECTOR COSTS FOR 300°F SYSTEM (Albuquerque) — LOW-RISE APARTMENT

City	Collector Type	Annual Collector Cost, $/ft²-yr	Annual Output (Btu/ft²/yr)	Collector Area, ft²	Total Annual Output, Btu/yr	$/Year
Albuquerque	ET1	3.19	162,853	8219	133.8489 X 10^7	26219
Flat Roof Option	CPC1	3.11	221,084	8219	181.7089	25561
FUTURE COSTS	ET2	2.29	86,073	8219	70.7434	18822
	PT3-PM	2.47	69,700	5448	37.9726	13457
	PT2-PM	3.22	321,758	5448	175.2938	17543
	PT1-PM	3.52	478,095	5448	260.4662	19177
	PT3-EW	2.13	47,409	8530	40.4399	18169
	PT2-EW	2.88	239,831	8530	204.5748	24566
	PT1-EW	3.18	370,351	8530	315.9094	27125
	PT3-NS	2.13	47,657	8189	39.0263	17443
	PT2-NS	2.88	280,875	8189	230.0085	23584
	PT1-NS	3.18	427,531	8189	350.1051	26041
	SLATS	3.11	218,292	7646	166.9061	23779
	CPC1A	3.22	302,267	8219	248.4332	26465

Table 32. COLLECTOR COSTS FOR 600°F SYSTEM (Albuquerque) — SINGLE-FAMILY DETACHED

City	Collector Type	Annual Collector Cost, $\$/ft^2$-yr	Annual Output ($Btu/ft^2/yr$)	Collector Area, ft^2	Total Annual Output, Btu/yr	$/Year
Albuquerque	CPC2	3.38	55,990	504	2.8219×10^7	1704
Flat Roof Option	CPC2A	3.59	132,559	504	6.6810	1809
FUTURE COSTS	T1(SLATS)	3.11	158,988	469	7.4565	1459
	PT1-EW	3.18	284,046	555	15.7646	1765
	PT2-EW	2.88	64,477	555	3.5785	1598
	PT1-PM	3.52	382,303	334	12.7689	1176
	PT2-PM	3.22	95,366	334	3.1852	1075
	PT1-NS	3.18	332,690	460	15.3037	1463
	PT2-NS	2.88	64,461	460	2.9652	1325

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Table 33. COLLECTOR COSTS FOR 600°F SYSTEM (Albuquerque) — LOW-RISE APARTMENT

City	Collector Type	Annual Collector Cost, $/ft²-yr	Annual Output (Btu/ft²/yr)	Collector Area, ft²	Total Annual Output, Btu/yr	$/Year
Albuquerque	CPC2	3.38	55,990	8219	46.0182×10^7	27780
Flat Roof Option	CPC2A	3.59	132,559	8219	108.9502	29506
FUTURE COSTS	T1(SLATS)	3.11	158,988	7646	121.5622	23779
	PT1-EW	3.18	284,046	8530	242.2912	27125
	PT2-EW	2.88	64,477	8530	54.9989	24566
	PT1-PM	3.52	382,303	5448	208.2787	19177
	PT2-PM	3.22	95,366	5448	51.9554	17543
	PT1-NS	3.18	332,690	8189	272.4398	26041
	PT2-NS	2.88	64,461	8189	52.7871	23584

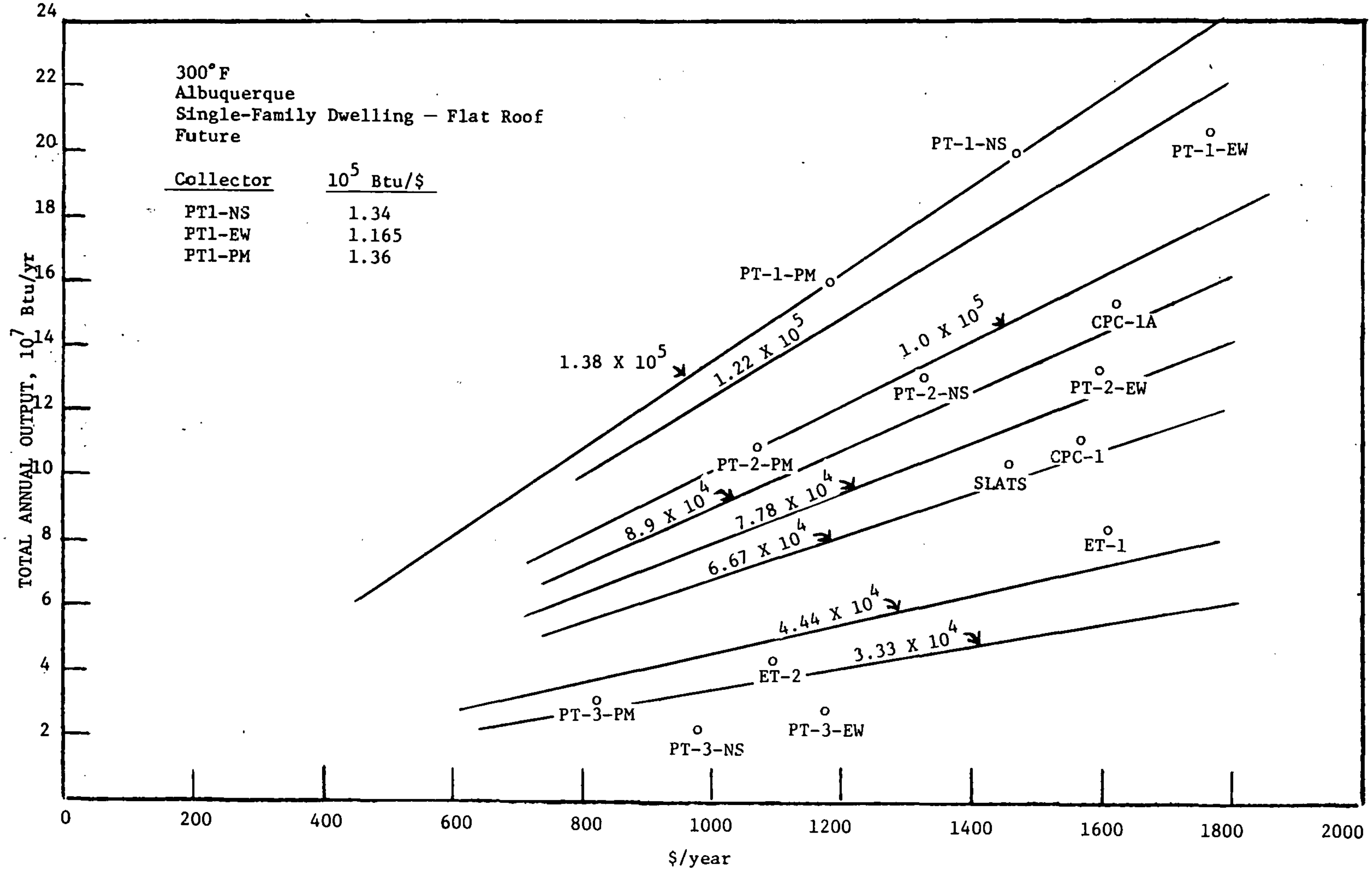

Figure 13. COLLECTOR COSTS VS. PERFORMANCE (300°F, Albuquerque)

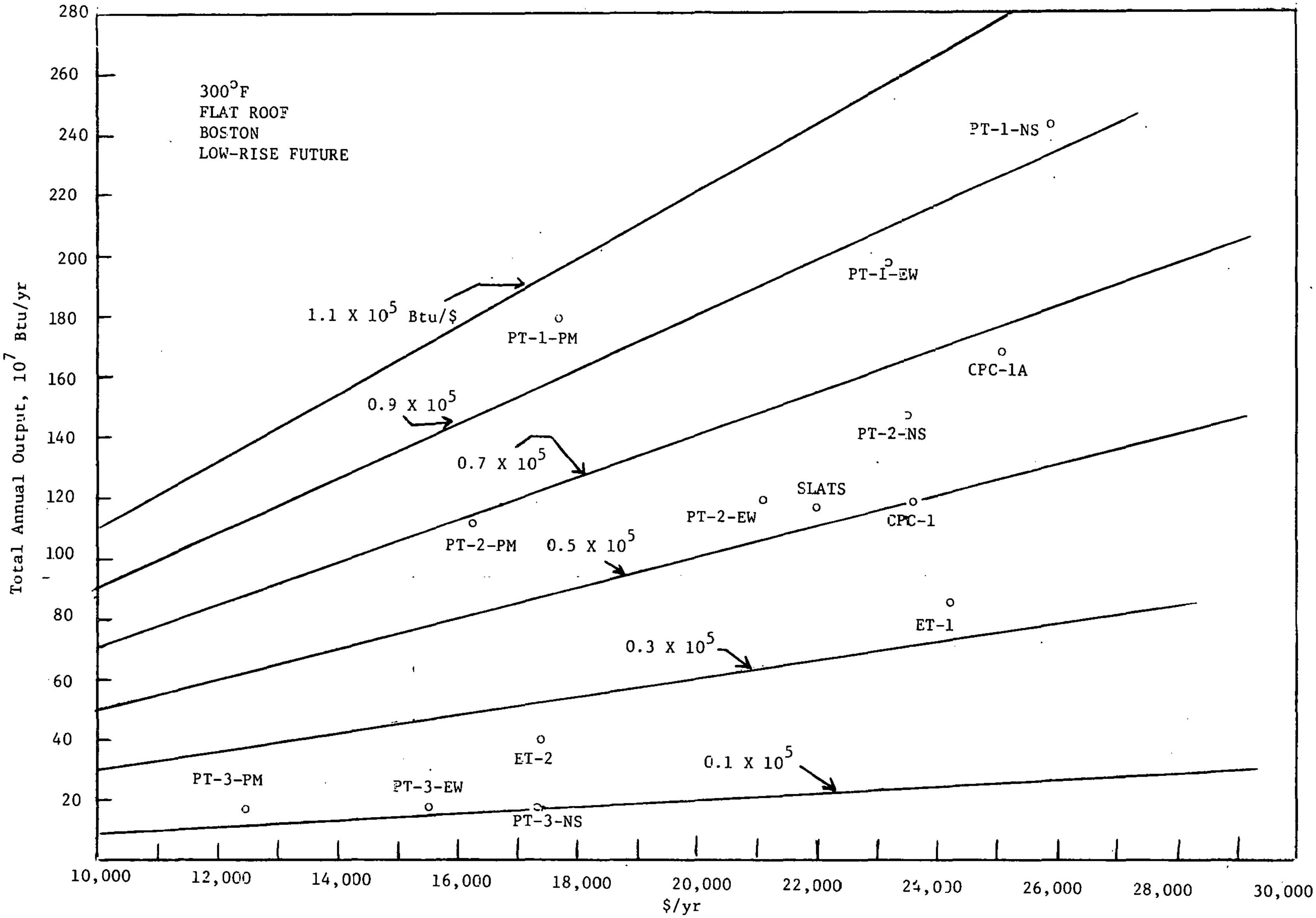

Figure 14. COLLECTOR COSTS VS. PERFORMANCE
(600°F, Boston)

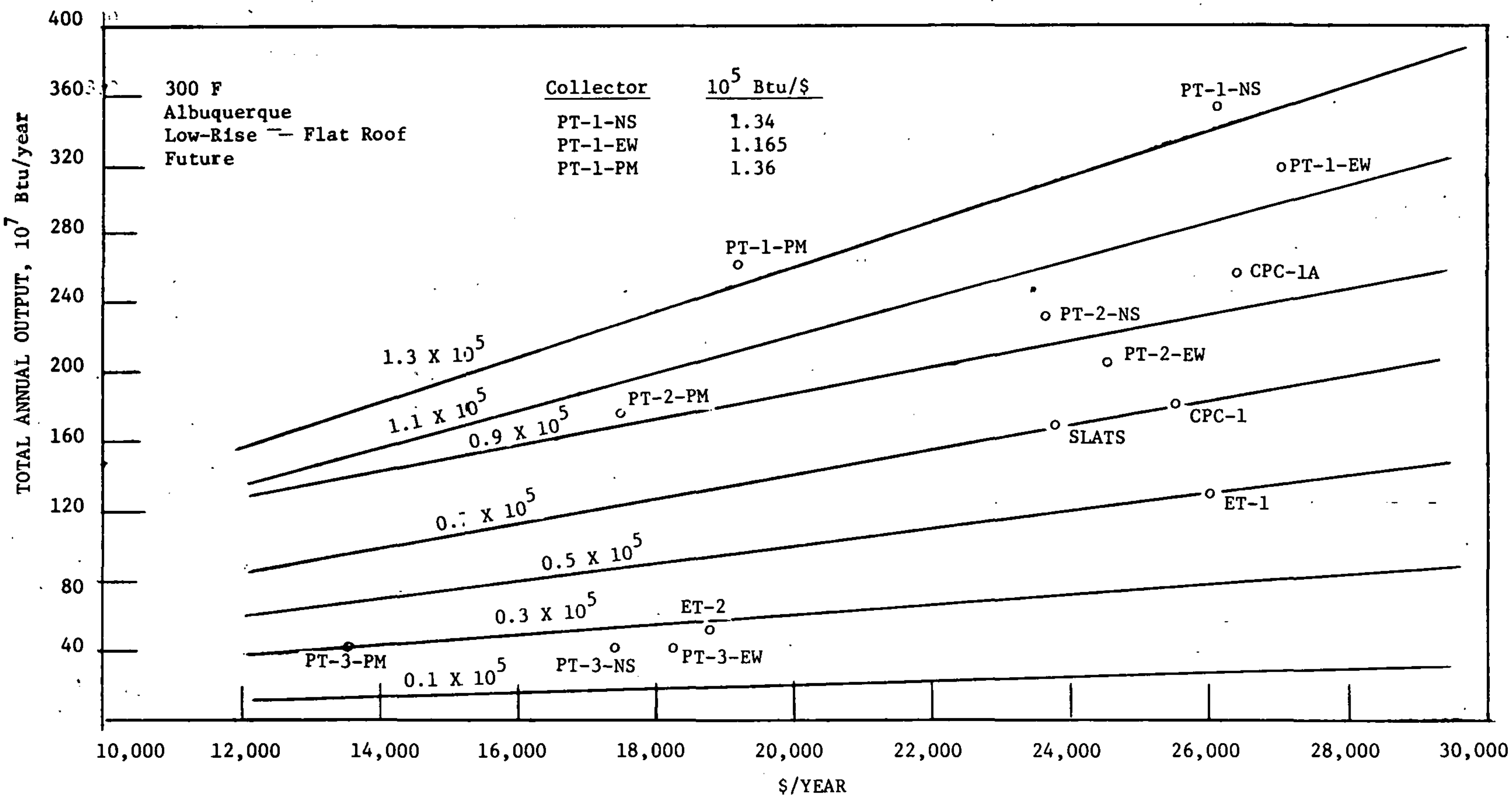

Figure 15. COLLECTOR COSTS VS. PERFORMANCE
(300°F, Boston)

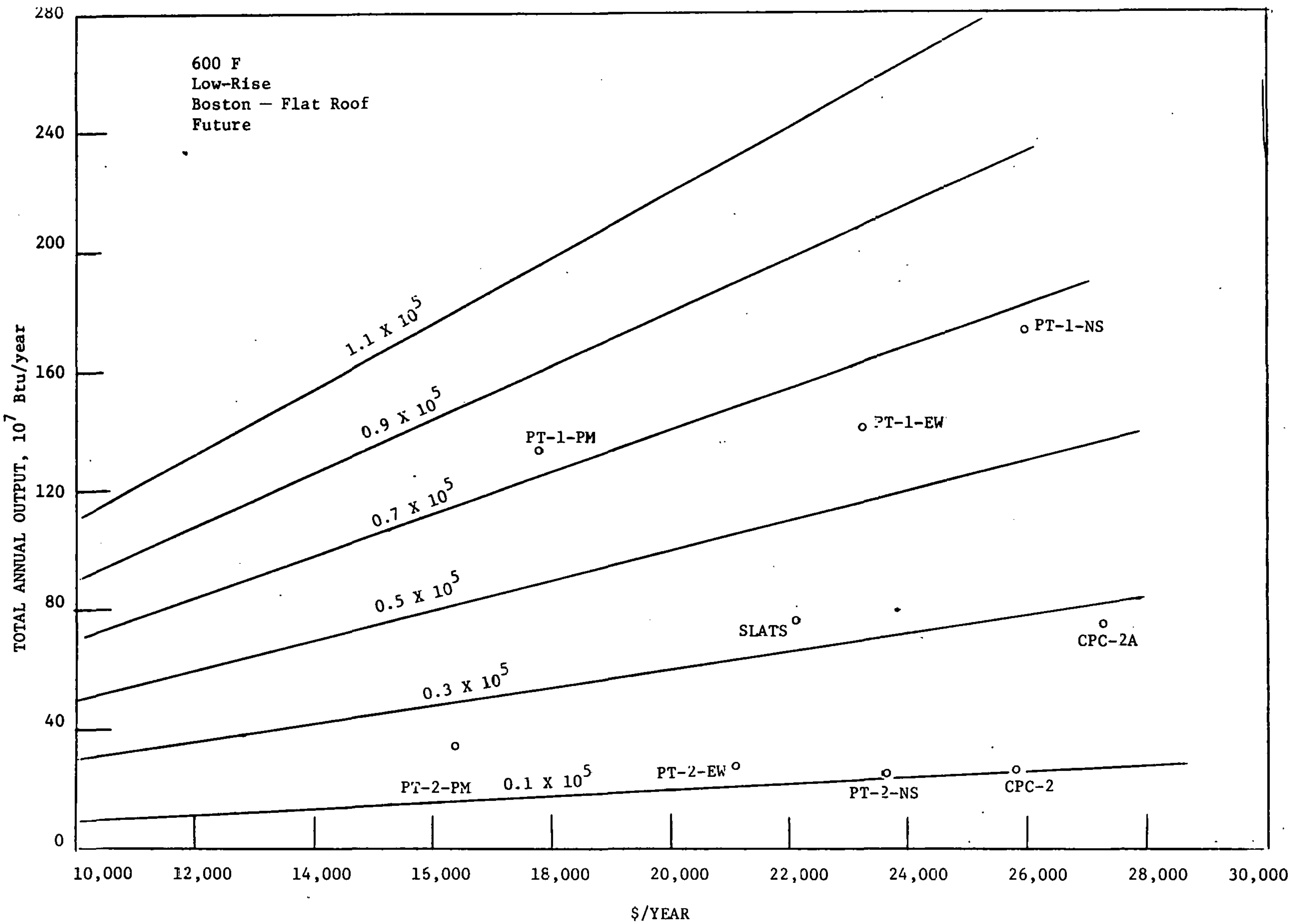

Figure 16. COLLECTOR COSTS VS. PERFORMANCE
(600°F, Albuquerque)

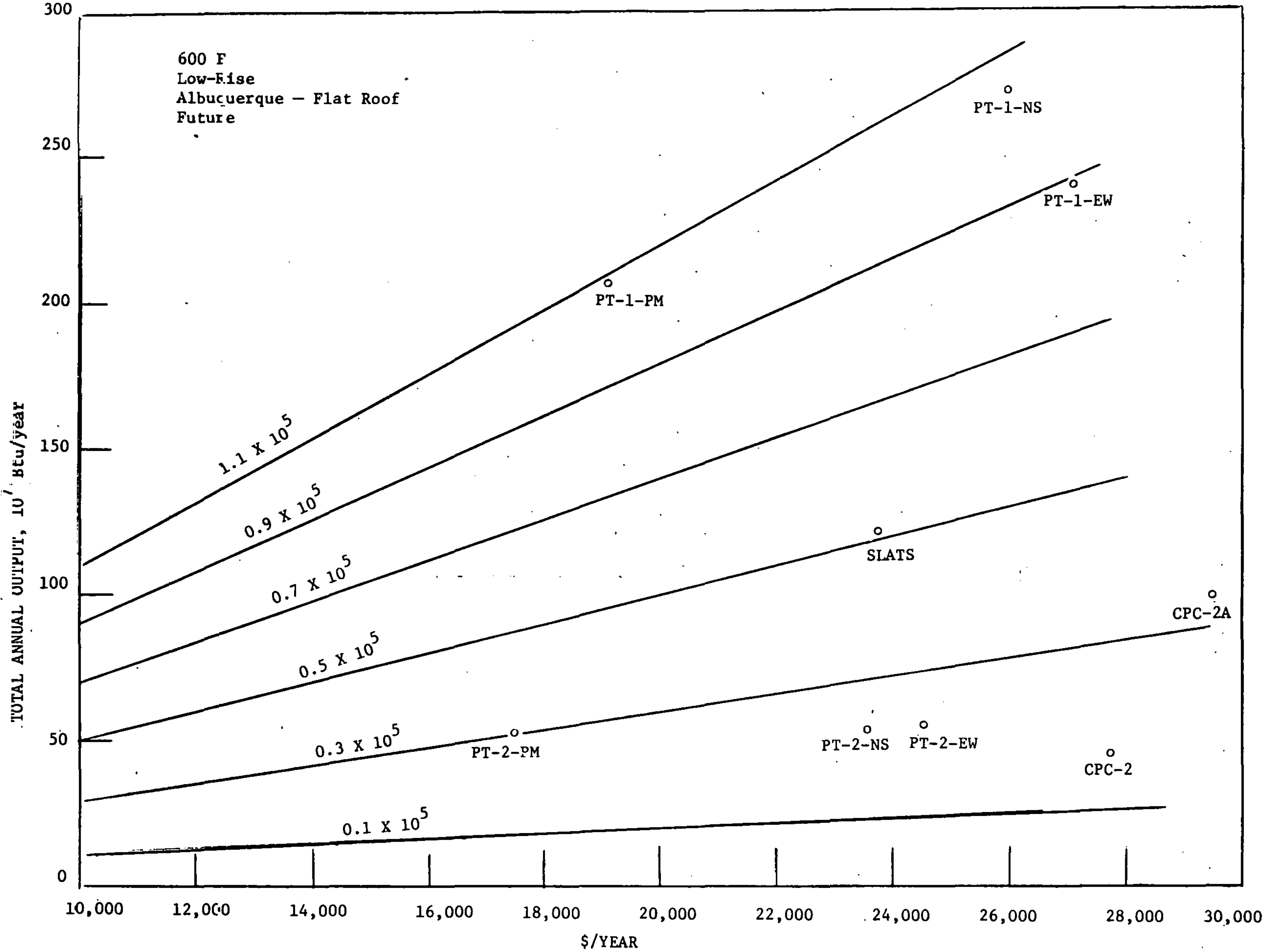

Figure 17. COLLECTOR COSTS VS. PERFORMANCE
(300°F, Albuquerque)

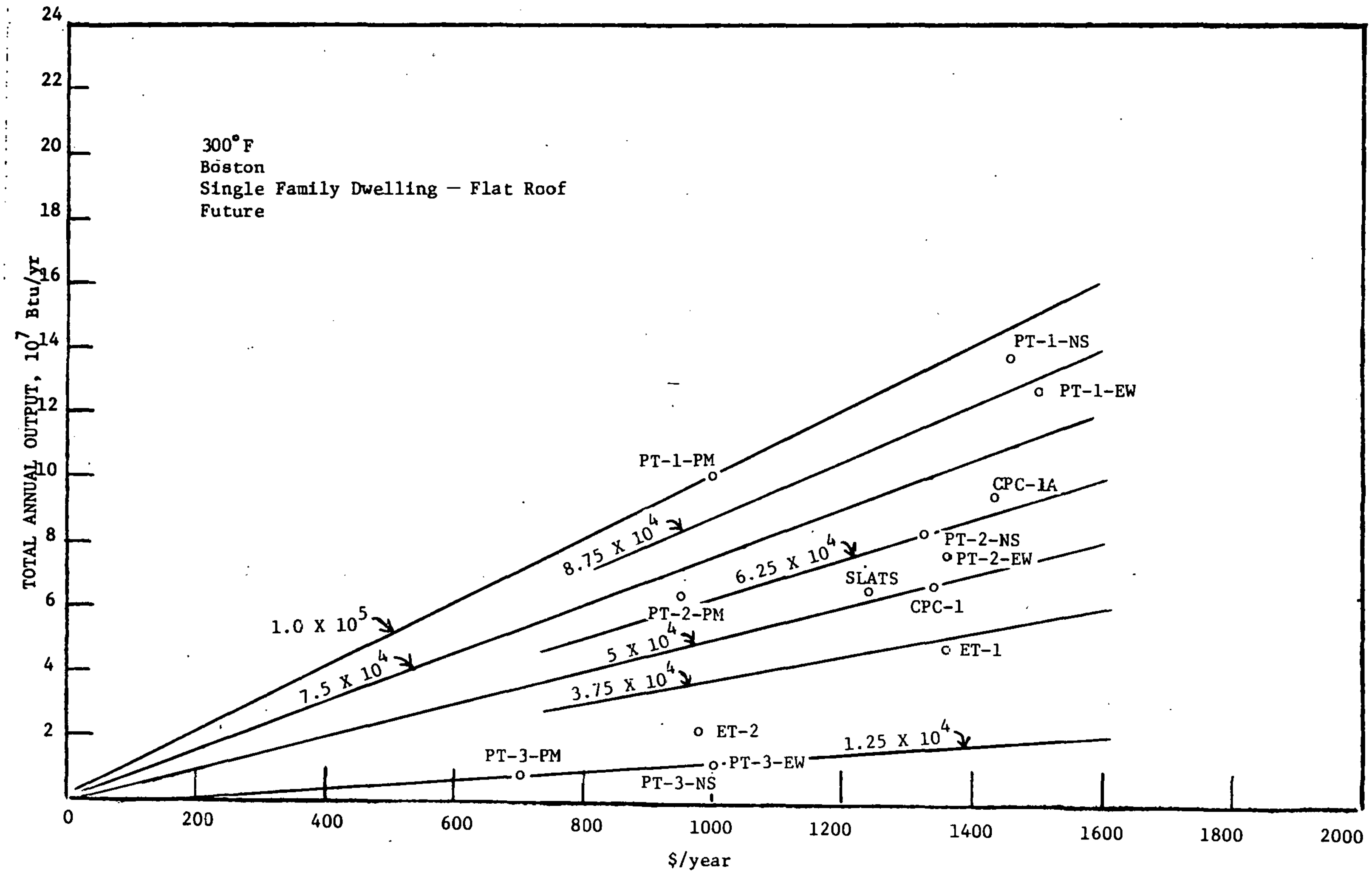

Figure 18. COLLECTOR COSTS VS. PERFORMANCE
(600°F, Albuquerque)

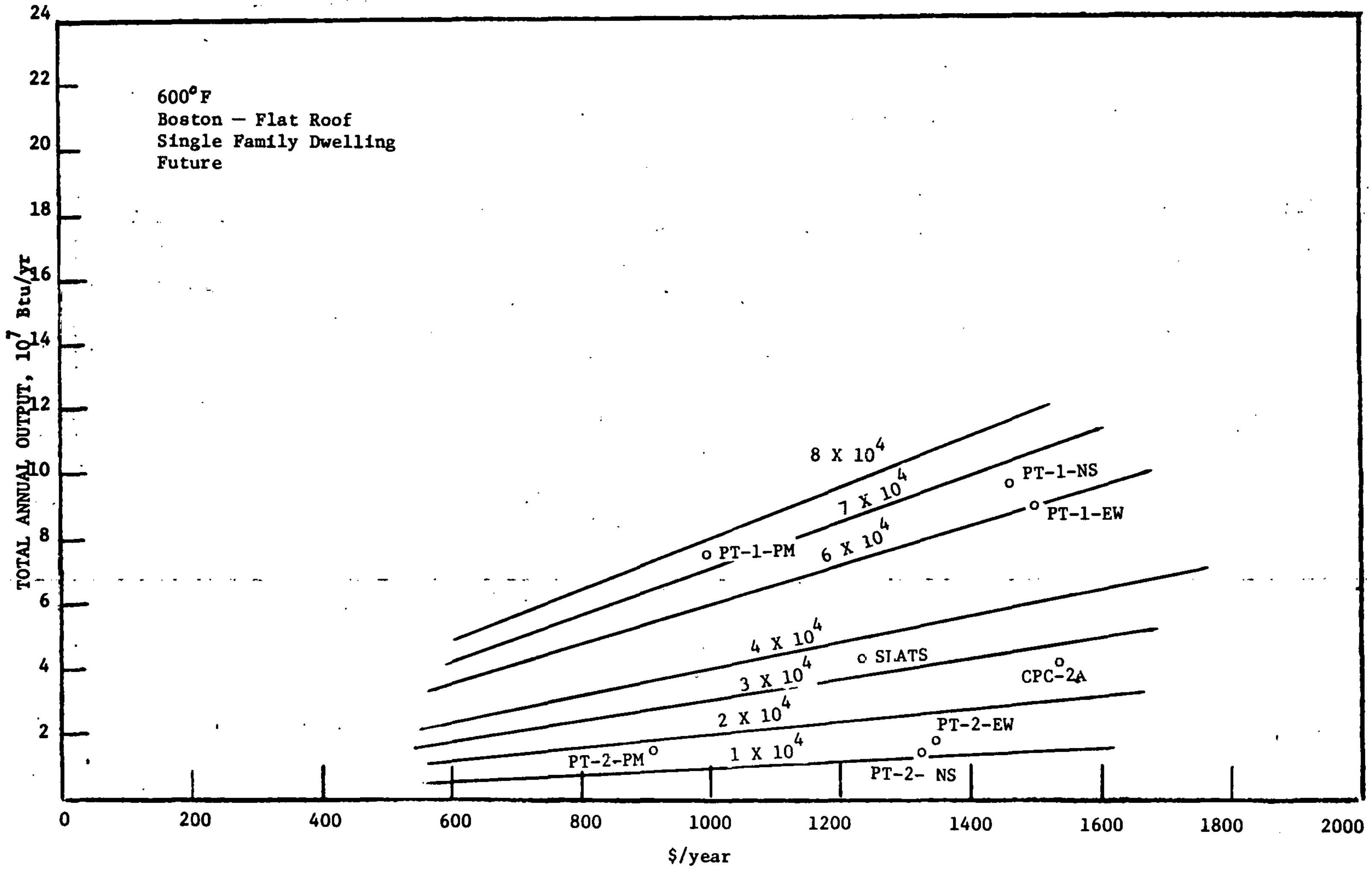

Figure 19. COLLECTOR COSTS VS. PERFORMANCE
(600°F, Boston)

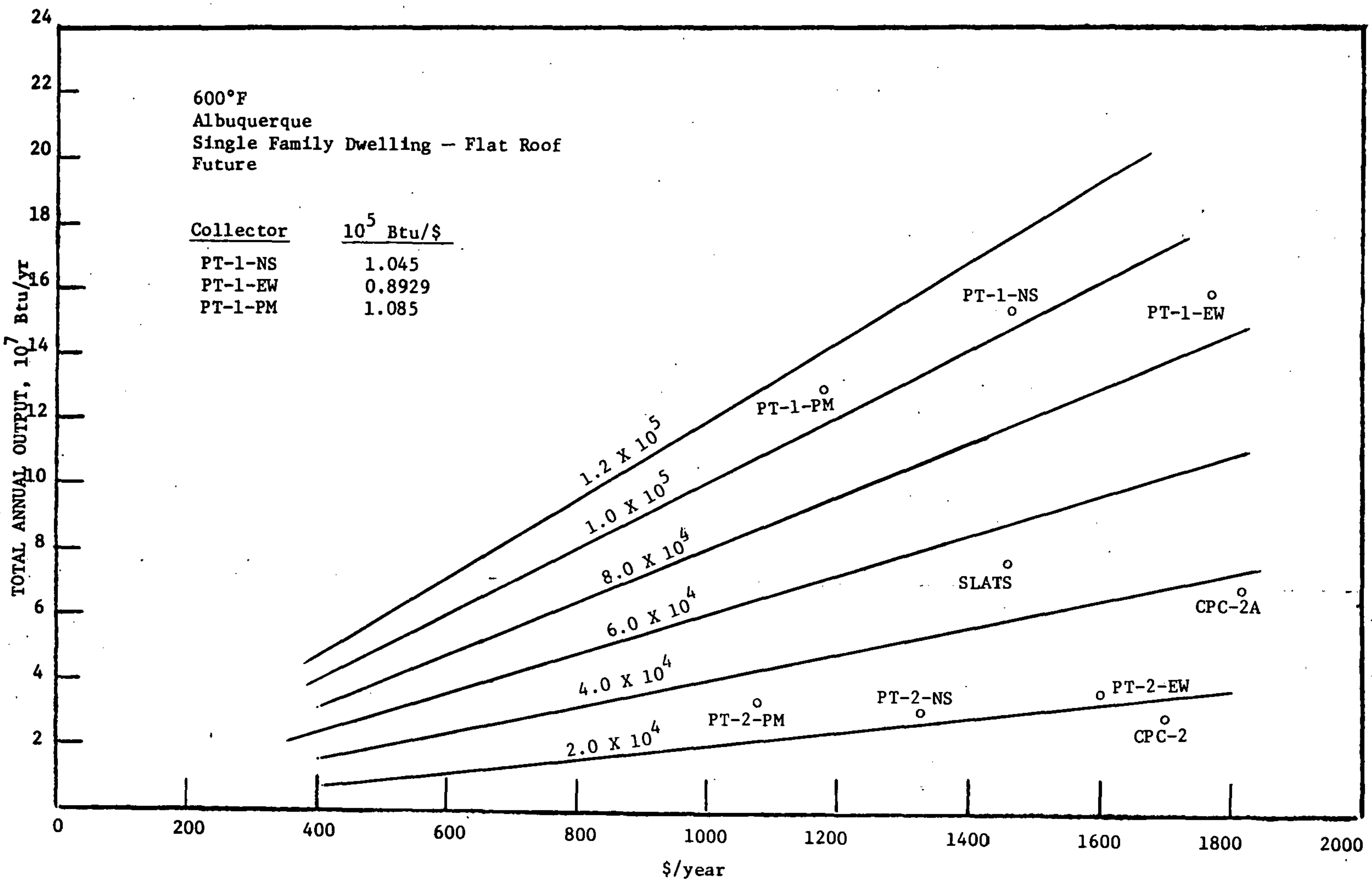

Figure 20. COLLECTOR COSTS VS. PERFORMANCE (300°F, Boston)

- The NS and EW horizontal orientations are fairly close both in cost and performance. Comparing results from Albuquerque and Boston, we can see how site-specific results are and the difficulty in finding a simple way to select a collector type. The PM orientation gives somewhat reduced performance at a reduced cost compared with other orientations. Because the NS orientation is a summer peaking alternative, EW and PM orientations are preferred for northern climates because their output is more even throughout the year. The ultimate collector orientation is best made by system simulation. For latitudes south of Albuquerque, the NS orientation may be preferred because of the significant summer cooling load. In an application demanding a more balanced annual output, the EW orientation might be preferred in lower latitudes, although the polar mount cannot be excluded. The EW orientation is somewhat more desirable than the PM orientation because it permits greater collector area and consequently greater annual output. For STES, the high-performance collector (PT-1) is the overall best choice, regardless of orientation.

High-Temperature (600°F) Tracking Collectors

- Performance results closely follow the changes in collector optical and heat loss characteristics. PT-1 is the best, followed by PT-2.

  The NS orientation usually gives superior performance to the EW, although cost effectiveness depends upon site and dwelling type. Which orientation gives the greatest performance in an STES application is a function of the enhanced summer collection of the NS orientation versus the more even output of the EW orientation and the relative collector areas available. NS collectors have large intrarow spacing; EW collectors have large interrow spacing. The PM gives decreased performance at reduced cost. The decision as to the most appropriate collector is dependent upon application; for STES, the high-performance collector (PT-1) is the overall best choice.

Low-Temperature CPC's Versus Tracking Collectors

Based upon future cost predictions, the state-of-the-art 1.5X CPC (CPC 1) is neither cost effective nor comparable in performance to tracking collectors with the exception of the rather poorly performing PT 3. The advanced technology 1.5X CPC (CPC 1A) is comparable in performance to PT 2 or PT 1 in PM orientation, although its cost effectiveness is only fair. If costs can be reduced, the advanced CPC might bear a second look for 300°F applications, especially if for some reason, tracking collectors are inappropriate.

High-Temperature CPC's

The state-of-the-art 5X CPC (CPC 2) is not a competitor to other collector types considered for high-temperature (600°F) applications. It is outperformed by every other collector. The advanced technology 5X CPC (CPC 2A), while showing better performance, is still not competitive on a cost basis.

Low-Temperature SLATS Versus Tracking Collectors Versus CPC's

The SLATS* collector is broadly representative of the class of collectors having either moving mirror-fixed focus (e.g., SLATS) or moving focus-fixed mirror, (e.g., General Atomic) geometries. The SLATS collector is inferior in performance to PT-1 and PT-2, and even to the CPC collectors. It is also non-competitive in cost with the tracking collectors, although it is competitive with the state-of-the-art 1.5X CPC. Its reduced output at reduced cost in comparison to the advanced 1.5X CPC (CPC 1A) might suggest it as an alternative choice in an application where the CPC collector might be used. However, in every case, PT 2 in a PM orientation gives comparable output at a lower cost.

High-Temperature SLATS

The SLATS collector is not competitive with the best of the tracking collectors, featuring significantly better performance. However, whereas at low temperatures, the SLATS collector was outperformed by PT 2, at high temperatures, it would be preferred over PT 2. The SLATS collector also is a more economic choice than the CPC collectors.

CPC Versus Evacuated Tube Collectors

The results indicate that, in every case, for 300°F applications, the CPC collectors significantly outperform evacuated tube collectors. The increased performance of the CPC collectors is obtained at costs comparable to the evacuated tube collectors.

Conclusions

From an approach based only upon collector output, the best collector for either 300° or 600°F output temperatures is PT 1 - NS. The drawback here is that a horizontal trough gives excellent performance in summer but very poor output in winter. In high north latitudes, a greater winter output is desirable because of significant winter loads. Thus, the choice is between PM

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* Of the class of tracking mirror/tracking receiver collectors, only the SLATS collector was modeled. (Sheldahl, Inc., the manufacturer of the SLATS collector, was kind enough to supply their computer program.) The General Atomic collector may be expected to have roughly comparable performance.

and E-W orientations. On an output/sq ft of aperture basis, the polar mount orientation looks best. However, roof area constraints yield greater collector area and, in this case, greater collector output for the E-W orientation.

The drawback of the PM orientation is that the ground cover factor allows less collector area.* The PM is also somewhat more expensive to install than other orientations. Despite these drawbacks, we see that the reduction in output over other orientations appears cost-effective in that the cost reduction is greater than the performance reduction. (See Table 34.) This happens because of the greater unit output (Btu/sq ft-yr) from the P-M orientation.

The final choice here is arbitrary; we get greater output from the E-W collector than the PM, but at greater cost in terms of Btu/dollars. Certainly, the best approach would be to evaluate system cost and performance using both collectors, but in the interest of obtaining a cost effective solar total energy system, the PM orientation for PT 1 is selected for both low and high temperature systems rather than the EW orientation. This is in consideration that the polar mount orientation is more cost effective (greater Btu/dollars) than the EW orientation with the only drawback being the somewhat reduced annual system output. The PM orientation of PT 1 will be used for Boston and Chicago; areas that clearly have large winter thermal loads. The PM orientation will also be used for Nashville, Albuquerque, and Los Angeles — cities with moderate heating and cooling requirements, and with the exception of Nashville, very good insolation availability. The cities of Charleston, Miami, Dallas, and Phoenix will use horizontal NS trough collectors because of their very large summer cooling loads.

2.1.6 Collector Areas — Thermal Solar Total Energy Systems

Table 35 summarizes the 100% collector areas used in evaluating the performance of thermal solar total energy systems. The table also indicates the orientation (N-S horizontal or P-M) selected for the single-axis tracking parabolic trough collectors used in the study. The 100% areas correspond to the

* All collector orientations are penalized somewhat because the collector layout minimizes shadowing. Although not pursued in this study, closer collector spacing can allow significant increases in collector area with small reductions in annual collector output and should be considered in detailed system design analyses.

Table 34. COST EFFECTIVENESS OF VARIATIONS IN COLLECTOR ORIENTATIONS

	300°F		600°F		
	Performance*	Cost**	Performance*	Cost**	Comments
Boston					
Single-Family Dwelling					
EW	1.27	1.50	1.22	1.50	EW does not appear cost effective.
PM	1.00	1.00	1.00	1.00	
Low-Rise Apartment					
EW	1.11	1.31	1.06	1.31	EW does not appear cost effective.
PM	1.00	1.00	1.00	1.00	
Albuquerque					
Single-Family Dwelling					
EW	1.29	1.50	1.24	1.50	EW does not appear cost effective.
PM	1.00	1.00	1.00	1.00	
Low-Rise Apartment					
EW	1.21	1.41	1.16	1.41	EW does not appear cost effective.
PM	1.00	1.00	1.00	1.00	

* Ratio of annual output of EW trough collector (PT-1) to PM trough collector (PT-1).

** Ratio of annualized cost of EW trough collector (PT-1) to PM trough collector (PT-1).

Table 35. 100% COLLECTOR AREA SUMMARY
(Thermal Solar Total Energy Systems)

Location	Orientation	Single-Family Detached	36-Unit Townhouse	48-Unit Low-Rise
		Area, sq ft		
Miami	North-South Horizontal	460/Unit	13,596	16,378
Dallas/ Fort Worth	North-South Horizontal	460/Unit	13,596	16,378
Charleston/ Raleigh	North-South Horizontal	460/Unit	13,596	16,378
Phoenix	North-South Horizontal	460/Unit	13,596	16,378
Los Angeles	Polar Mount	341/Unit	10,058	11,146
Albuquerque	Polar Mount	334/Unit	9,872	10,896
Nashville	Polar Mount	327/Unit	9,671	11,648
Chicago	Polar Mount	290/Unit	8,555	10,304
Boston	Polar Mount	284/Unit	8,400	10,118

maximum potential collector aperture area possible if the entire flat roof area of the dwellings is covered with collectors to the extent required to avoid shadowing. The sun's angle requires greater collector spacing at higher latitudes to avoid shadowing, thus accounting for less aperture area for Boston than for cities at lower latitudes.

2.1.7 Collector Area Sensitivity Studies

Of the nine cities for which STES economics were evaluated for the 100% collector area case, four cities were selected to explore the sensitivity of system economics to collector area. The collector areas explored were: 25, 50, 75, and 125% of the 100% collector areas permitted by the roof areas. (See Section 2.1.6 for summary of 100% collector areas.)

The nature of the selection process was somewhat arbitrary because it would be of interest to explore the effect of varying collector areas on system economics for all cities and all dwelling types. It was not possible to know which cities might benefit particularly from a change in collector area. The first decision was to explore the sensitivity for only low-rise, energy conservative dwellings. Because of the high cost of the collector pipefield for single-family detached dwellings, it was felt that the already poor economics of solar total energy for this application would not particularly benefit from a change in collector area. Low-rise and townhouse dwellings have similar loads so that the results are equally applicable to townhouses. The energy conservative dwelling, rather than the generic case, was selected because structures built in the time frame in which solar total energy may be economic are likely to be constructed to higher thermal standards than present construction practice.

The cities chosen for the sensitivity study were Boston, Los Angeles, Albuquerque, and Raleigh. The criteria used in judging the candidate cities for the sensitivity analysis were population density, insolation availability relative to local heating and cooling-degree days, estimates of how effectively the thermal energy produced at the ORC condenser was utilized for thermal requirements, and geographic representation. For example, Raleigh was selected for the southeast rather than Miami, which showed rather poor economics with the expectation that the economics would show little improvement if collector area was reduced. This results from the extremely high summer cooling loads and small winter thermal loads in Miami leading to poor economic utilization of expensive collector and power generation components. Boston was selected as a candidate for further evaluation because of the large population in the Northeast and results from the sensitivity study are roughly applicable to the Midwest also. Los Angeles represents the large population of the West Coast. Albuquerque is representative of STES in the "Sunbelt." Raleigh represents the Southeast, and results may be extended to Nashville also.

On the basis of the availability of insolation relative to local heating and cooling-degree-days as evaluated in the regionalization task, the cities selected bracket the kinds of climates characterizing the United States.

An important criterion for selection was how well the 100% collector area systems utilized the waste heat available at the heat engine condenser. It is generally considered that systems which reject the minimal extent of thermal energy, thus utilizing waste heat effectively, have correspondingly favorable economics. The four cities selected show a range of utilizations — Los Angeles and Charleston systems are clearly oversized because a substantial amount of thermal energy is wasted; Albuquerque wastes some thermal energy but shows improvement over Los Angeles and Charleston; Boston shows a rather good utilization suggesting that filling the roof with collectors is going to give about as good an economic result as possible. The effectiveness of utilization of thermal energy for the other cities are bracketed by the four cities selected.

In summary, the cities selected for the collector area sensitivity analysis were Boston, Los Angeles, Albuquerque, and Raleigh. The cities selected would be reasonable market targets if solar total energy economics are favorable; they have a reasonable range of insolation availabilities relative to thermal loads; and they bracket the range of how effectively the systems utilize reject thermal energy to satisfy thermal loads and hence reflect how close they are to the most economic system configuration.

<u>Pipefield Heat Loss Factors for Thermal STES</u>

Detailed calculations on the expected losses from insulated pipes connecting roof-top mounted solar collectors to the centrally located thermal storage and power generating facility were performed. Three inches of insulation were assumed on the exposed one inch pipes connecting roof top collectors to the large diameter buried pipeline. In the single-family detached application, buried pipeline was provided with 1.5-inches on insulation and the one-inch diameter buried pipes connecting each house to the large diameter pipeline also had one inch of insulation. All pipes in the low-rise and townhouse applications are exposed. The four-inch diameter main pipeline was provided with four inches of insulation. Three inches of insulation was provided for the one inch lines connecting the collectors to the main pipeline.

The results of heat loss calculations are summarized in Table 36 and are defined as the fraction of collected energy that ultimately reaches the storage facility.

Table 36. PIPEFIELD HEAT LOSS FACTORS FOR THERMAL STES

Application	Heat Loss Factor*	Solar Collector Outlet Temp
Single-Family Detached	0.85	300°F
	0.72	600°F
Townhouse	0.98	300°F
	0.94	600°F
Low-Rise	0.98	300°F
	0.94	600°F

$$\text{Heat Loss Factor} = \frac{\text{Heat Delivered to Storage From Collector Field}}{\text{Heat Collected by Solar Collector Field}}$$

2.1.8 Collector Areas for Photovoltaic STE Systems

The collector areas for photovoltaic solar total energy systems are equivalent to those determined for flat plate thermal collectors for thermal solar total energy systems. This is because both the thermal and combined photovoltaic collectors are of a conventional flat plate configuration, with a fixed tilt angle corresponding to the latitude of the site in which they are located. The collector areas for the 100% case, in which the maximum potential collector areas (if the dwelling's roof is filled with collectors), are given in Tables 37, 38, and 39. Collector area varies inversely with latitude to avoid shadowing.

Table 37. 100% COLLECTOR AREAS FOR PHOTOVOLTAIC SOLAR TOTAL ENERGY SYSTEMS APPLIED TO SINGLE-FAMILY DETACHED DWELLINGS
(Number of Dwelling Units = 36)

Geographic Location	Array Tilt	100% Collector Area sq ft /D.U. (Total)	Flat Roof Area Available for Collector sq ft /D.U. (Total)
Miami	25.78	578 (20808)	850 (30600)
Dallas/Fort Worth	32.83	524 (18864)	850 (30600)
Charleston/Raleigh	32.90	523 (18828)	850 (30600)
Phoenix	33.43	519 (18684)	850 (30600)
Los Angeles	34.00	514 (18504)	850 (30600)
Albuquerque	35.05	504 (18144)	850 (30600)
Nashville	36.12	494 (17784)	850 (30600)
Chicago	41.67	437 (15732)	850 (30600)
Boston	42.37	429 (15444)	850 (30600)

Note: If P.V. optimum is about 50% of 100% flat roof collector area, then we can recommend potential for sloped roof installation.

Table 38. 100% COLLECTOR AREAS FOR PHOTOVOLTAIC SOLAR TOTAL ENERGY SYSTEMS APPLIED TO TOWNHOUSE DWELLINGS
(Number of Dwelling Units = 36)

Geographic Location	Array Tilt	100% Collector Area, sq ft	Flat Roof Area Available for Collector, sq ft
Miami	25.78	17061	25107
Dallas/Fort Worth	32.83	15464	25107
Charleston/Raleigh	32.90	15449	25107
Phoenix	33.43	15320	25107
Los Angeles	34.00	15174	25107
Albuquerque	35.05	14894	25107
Nashville	36.12	14591	25107
Chicago	41.67	12906	25107
Boston	42.37	12674	25107

Table 39. 100% COLLECTOR AREAS FOR PHOTOVOLTAIC SOLAR TOTAL ENERGY SYSTEMS APPLIED TO LOW-RISE DWELLINGS
(Number of Dwelling Units = 48)

Geographic Location	Angle Slope	100% Collector Area, sq ft	Flat Roof Area Available for Collector, sq ft
Miami	25.78	19458	30240
Dallas/Fort Worth	32.83	17214	30240
Charleston/Raleigh	32.90	17192	30240
Phoenix	33.43	17016	30240
Los Angeles	34.00	16818	30240
Albuquerque	35.05	16438	30240
Nashville	36.12	17574	30240
Chicago	41.67	15546	30240
Boston	42.37	15264	30240

Pipefield Heat Loss Factors for Photovoltaic STES

It may be expected that, because of the much lower operating temperatures for the photovoltaic STE system than the thermal STE systems (130°F versus 300°F), the losses from piping which connects roof-top combined thermal and photovoltaic collectors to the central storage tank will be less than in the case of the thermal systems. Although detailed calculations were not performed, we have estimated the following pipefield efficiencies (Table 40) that represent the fraction of absorbed thermal energy that ultimately reaches the storage device with their already low losses. Little improvement is expected in pipefield efficiencies for townhouse and low-rise apartment applications.

Table 40. PIPEFIELD EFFICIENCY*

Application	300°F ORC System	130°F Photovoltaic/ Thermal System
Single-Family Detached	85%	90%
Townhouse	98%	98%
Low-Rise Apartment	98%	98%

* Pipefield efficiency is the percentage of collected thermal energy ultimately reaching storage.

Sensitivity Studies of Photovoltaic Collector Areas Versus System Economics

The sensitivity of photovoltaic system economics to variations in collector area was explored by investigating the performance of arrays of 20, 40, 60, 80, 100, and 125% of the maximum potential collector area on low-rise dwellings in four cities. The maximum potential collector area corresponds to a case in which the entire roof area is packed with as much collector area as possible. The 125% case was meant to explore the potential benefit, if any, of utilizing additional collector area, arrayed over garages of parking lots, on system economics. The results will indicate a collector area offering the most economic system configuration within the constraints of expected system component costs and backup energy costs.

The low-rise dwelling is considered a representative case, such that results of the sensitivity study can be applied to establish the economics of a single collector area in other cities and for other dwelling types.

The cities used in the sensitivity study were Boston, Los Angeles, Albuquerque, and Charleston/Raleigh. These are the same cities used in the sensitivity study for the thermal solar total energy system.

2.2 Storage

Two kinds of storage must be considered for solar total energy systems: electrical storage and thermal storage. Although many kinds of storage are possible candidates for electrical storage by large-scale STE systems (batteries, pumped hydro, compressed air, flywheels, hydrogen, etc.), only battery storage was regarded as sufficiently developed and appropriately sized for use in STE residential applications. In a similar sense, many different systems have been proposed for thermal storage, but only sensible thermal storage can be regarded as sufficiently developed for STE residential applications at this time.

2.2.1 Thermal Storage

Storage of thermal energy is necessary in a solar energy system because of the intermittent nature of the solar resource and because loads do not always coincide with solar availability. Thermal storage in a residential solar total energy system will be as the sensible heat of a fluid or fluid-solid system. Sensible heat storage is conceptually simple, and these storage systems are either commercially developed (in the case of low-temperature systems) or will be available in the near term (in the case of high-temperature systems).

Storage temperatures of 600°F for the high-temperature system concept, 300°F for the low-temperature concept, and 240°F or 180°F for space-conditioning thermal requirements were anticipated. These temperatures correspond to the heat engine cycle temperatures of 600°F or 300°F, an absorption cooling machine temperature requirement of 240°F, and the noncooling season space heating and domestic water heating requirement of 180°F.

For a system storing heat at 600°F, storage materials such as a composite of rock and a heat transfer oil such as Caloria HT-43 are appropriate. For storage at 300°F a lower cost heat-transfer oil or a rock/oil composite may be used. For storage of heat below 240°F, water storage will be used. The upper storage temperature will be adjusted seasonally, corresponding to the temperature level required (240°F, summer; 180°F, winter), to exploit benefits of reduced heat engine condenser temperatures when cooling is not required or to minimize the use of the heat engine in the non-regenerative operating mode. (See the discussion related to ORC system concepts.)

Storage was modeled as a stratified tank with constant outlet temperature until storage is 80% depleted. Storage behavior was modeled by a simple overall energy balance, accounting for standby losses as if the tank were fully charged and entirely at the upper storage temperature. Initially, storage components were sized to satisfy their 24-hour thermal demands, and reevaluated as system performance was evaluated.

The thermal storage subsystem involves all of the heat exchangers, water storage tanks, and associated equipment to utilize the reject heat from the solar cell array to provide for space heating and residential hot water needs. Thermal storage is designed to provide short-term reserve heating capacity.

In standard hydronic solar space heating systems, thermal storage capacity has been found to be economically sized at a capacity of around 15 pounds of water per square foot of collector.[3] This approach was adopted in our storage sizing but with a variation. Because the available storage temperature swing in the photovoltaic system is about 20°F rather than the 70°F or greater temperature swing available in standard solar heating systems, storage size was based on 50 pounds of water per square foot of collector.

Thermal storage costs of $0.60/gal of storage were used to estimate the cost of this system component.[4] Piping, fan coils, and controls costs are summarized in the section on system costs.

2.2.2 Battery Storage for the Residential Power System

The photovoltaic power system for the residential site requires electrical storage in the form of electrochemical batteries. The batteries are required to supplement the output of the solar array by providing load maintenance at high power drains for short time periods in addition to providing electrical energy when the solar array output drops off, at night for example. The battery would be expected to supply 5 to 10 kW per dwelling unit for periods of 5 to 10 minutes at any time. The high power demands are required for operation of appliances like ranges and dryers, and air conditioners. Westinghouse[5] estimates that the required total energy storage capacity of the battery is from 15 to 25 kWhr per dwelling unit, depending upon the site and the particular mission, especially if vapor compression air conditioning is required.

The battery system is charged from the array and delivers energy as required to provide power over and above what the array itself can supply. The combination of the array and battery system provides the energy and power requirements for a residential site in combination with utility line service.

Lead acid batteries are the only devices currently available for storing electrical energy in distributed storage systems. This section will briefly review the state-of-the-art of lead-acid battery systems capable of being integrated with an onsite photovoltaic power system.

Batteries store energy in reversible chemical reactions which use and discharge energy in the form of electricity. When a voltage is applied to a lead-acid battery, for example, energy is stored by converting the lead sulfate ($PbSO_4$) on the electrodes (which are suspended in acid) into a mixture of pure lead, lead dioxide (PbO_2), and sulfuric acid (H_2SO_4). When the battery is discharged, the reaction is reversed.

The technology of lead-acid batteries is mature and the systems are used in a variety of applications from automobile batteries to providing motive power for submarines. While the technology is mature, considerable progress can be expected in the next decade. For example, the amount of lead used can be reduced with more efficient designs.

Lead-acid batteries have a theoretical "energy density" of about 0.175 kWh/kg and thus a perfect battery would weigh about 12.6 pounds per kWh. Commercial batteries weigh more than this because of the need to provide packaging for the active materials and of design inefficiencies. Commercial lead-acid systems weigh about 100 pounds per kWh of storage capacity of which 60 to 80 pounds is lead. The cost of this rather substantial quantity of lead imposes a practical lower limit on the price of lead-acid batteries.

Most of the lead-acid batteries under consideration will be able to return between 70% and 80% of the energy sent to them for storage. The efficiency is dependent upon operating conditions. For purposes of analysis, it was assumed that all batteries had an efficiency of 80%.

Battery life is affected by the rate at which it is charged and discharged. Most lead-acid batteries can receive about 80% of their charge in 4 to 5 hours without shortening the system's life, but the remainder of the charge must be added much more slowly — requiring another 4 to 5 hours.

The life of a battery varies as a function of the "depth of discharge" or the fraction of the total storage capacity removed in a typical cycle. An ordinary automobile battery will last for 3 to 5 years, undergoing extremely shallow cycles several times a day, but would be capable of only 150 to 250 deep discharges. The electrodes in batteries used in golf carts, industrial forklifts, etc., are usually 2 or 3 times as thick as those used in automobile batteries and are typically capable of 300 to 500 deep cycles. Batteries capable of discharging 2000 times are currently available and this has become a design objective for residential storage batteries.

A practical limit to the depth of discharge, which can be obtained from a given battery design, can be obtained by watching the battery's voltage. This voltage drops slowly during discharge and then begins to fall sharply. If the battery is discharged beyond this point, its life is shortened substantially.

Battery life and capacity are also strongly affected by operating temperature. Optimum temperature for lead-acid batteries is typically 25°C (77°F). Battery life can be cut in half if the system is operated at temperatures of 35°C to 50°C (95° to 122°F) and the life and capacity are also reduced at cold temperatures.

The primary source of failure for lead-acid batteries is the corrosion of the battery electrodes. Some large battery systems are designed so that the positive electrode can be removed and replaced without rebuilding the entire battery.

In a residential application, the battery and its related equipment are designed to be essentially maintenance-free, requiring only periodic visual inspection for proper operation. In operation, the battery and its related systems must also be fail-safe with little or no hazard to other equipment or the surroundings.

A lead-acid battery suitable for residential photovoltaic systems and expected to be available by 1985 would have the following characteristics:

Cost:	\$60/kWh (1985) \$33/kWh (1990 and beyond)
Depth of Discharge:	70%
Lifetime:	10 to 15 years.

On the basis of data provided by Westinghouse,[6] we have sized the electrical storage capacity at 15 kWh/dwelling unit. This value is at the low end of the range of storage sizes found to be economic for single-family residences. The value of 15 kWh/dwelling is a reasonable figure for electrical storage capacity for groups of residences, especially in view of the diversification of loads characterizing groups of residences.

2.2.3 Power Conditioners

Battery storage systems require some kind of "power-conditioning" system to supervise their connection with sources of charging energy and with the loads they meet while discharging. This equipment can serve four functions:

1. Regulate the rate at which a battery is charged and discharged to protect the battery and extend its useful life.
2. Serve as a switching system, and determine whether the loads will be met from the photovoltaic array, from battery storage, from the utility, or from some combination of these. The utility connection is included for backup power and as a source of surge currents during motor starting transients.
3. Rectify alternating current received from the utility so that this energy can be used to charge the battery, if desired.
4. Invert the direct current produced by the battery or photovoltaic array, producing utility quality alternating current.

Older inverter units frequently were nothing more than a d.c. motor which drove an a.c. generator, but most modern devices use solid-state components based upon silicon-controlled rectifiers. The solid-state devices are usually more reliable and require less maintenance. Most of these systems are "line commutated" in that they rely on utility power to establish the phase and frequency of their a.c. generation.

The efficiency of modern solid-state inverters is in the range of 92% to 95% when the devices are operating at more than 25% of peak capacity. Below this point, the efficiency falls off quite sharply since a fixed amount of energy is required even at zero loads. An inverter efficiency of 93% was used in our study.

2.3 Power Generators

The devices available for generating electrical power by solar energy are usually classified as either direct conversion devices (photovoltaics) or heat engines (organic Rankine-cycle, steam Rankine-cycle, Brayton-cycle, or Stirling-cycle). For the purpose of this project, the cost and performance data for photovoltaic, or direct conversion, devices were taken from the final reports on photovoltaics by Westinghouse.[6] Similar cost/performance data for organic Rankine-cycle turbines were provided by Ormat Turbines, Ltd., of Israel, and Sundstrand Corp.

Current photovoltaic arrays are based on solar cells cut from silicon crystals, now costing about $15/watt of generating capacity in full sunlight. This is based on pure semiconductor grades of silicon costing about $65/kg, of which about 80% is wasted when the silicon is cut to make the solar cells. The DOE goal is $0.50 per peak watt for flat plate arrays of silicon cells by 1986, and current expectations are for cost reductions to about $1/watt as early as 1980. This will come about from several sources: 1) a sixfold decrease in the cost and a tenfold reduction in manufacturing energy for solar-grade silicon is deemed feasible, 2) new silicon crystal growing and slicing techniques (e.g., Texas Instruments' laser slicing) are being developed that could reduce wastage by 50%, 3) new automated cell manufacturing and assembly techniques are expected to replace current procedures that are carried out by hand, 4) new ion implantation techniques are expected to improve the controlled introduction of critical impurities in the silicon to create p-n junctions,

5) ribbons of crystalline silicon could obviate the need to grow and slice large single crystals of silicon, and 6) techniques for depositing semiconducting thin films may supercede the crystal growing and slicing technique for producing the solar cells.

In addition to these expected cost-cutting improvements, improvements in photovoltaic efficiency are also expected during the next decade. At the present time, the efficiencies of silicon cells currently on the market are 10% to 15%, with an average of about 13%. These efficiencies can probably be increased to about 20% by the use of better antireflective coatings, better quality silicon, careful cell manufacture, better grid lines, and the use of junctions with a gradient of doping material. Gallium arsenide cells have been produced with efficiencies as high as 23% and efficiencies of 19% have been achieved at concentration ratios of 1700 (i.e., through the use of concentrating solar collectors in conjunction with solar cells). Today there are no gallium arsenide cells that can be considered in commercial production; however, many organizations are studying GaAs photovoltaic cells and there does not appear to be any reason why GaAs cells with 20% efficiency could not be mass produced, except possibly the availability of gallium.

The only type of solar cell, other than silicon, currently available in commercial quantities is the cadmium sulfide cell. These cells have a semiconductor junction formed between cadmium sulfide and cuprous oxide. These cells are only about 3% efficient and have not been able to achieve efficiencies above 7.8% up to now; however, 10% efficiencies appear to be reachable and perhaps even as high as 16%. The reason why cadmium sulfide cells are of interest, despite their lower efficiencies, lies in the fact that they can be produced by thin-film techniques and production costs could be very low with high volume production and concomitant learning curves. Of course, the lower CdS cell efficiencies mean that the arrays must be considerably larger than the corresponding Si cells and installation costs would probably be higher. Nonetheless, near-term estimates of CdS cell production costs of less than $100/kW peak have been predicted.

2.3.1 Heat Engines

Organic Rankine-cycle (ORC) heat engines have been selected for residential total energy systems conceptual designs. Factors such as temperature of operation, cycle efficiency, and state of technical development and appropriateness to this application were considered. This work also involved the determination of the full- and part-load performance of the ORC engines as a function of condenser temperature in both regenerated and unregenerated modes of operation. Cost data for 10 to 150 kWe ORC heat engines and controls were developed, including vital considerations such as the need for operators and expected maintenance costs. Information on the suitability of Stirling engines for STE systems in the residential sector was also developed.

Organic Rankine Cycle (ORC) Units

The estimated cost and performance of ORC units* are summarized for four different sizes and two temperature levels in Table 41. These prices are based on an annual production level of 1000 units and do not include mark-up for selling costs, installation, or warranty. Larger units, 100 kW and 150 kW, are projected to cost 10% and 15% per kW less, respectively, and still larger units will cost even less per kW. Thus, the 100 kW unit is expected to cost (net selling f.o.b. factory) about $40,000 (250°F) and $30,000 (500°F) plus mark up for selling expenses, installation, and warranty, with the 150 kW unit estimated at about $57,000 (250°F) and $42,000 (500°F) under the same conditions. These values correspond approximately to the the $600/kW total installed cost generally quoted, and used in our economic evaluation.

Table 41. ORC FACTORY COSTS (1000units/yr)

	10 kW (Air Cooled)		50 kW (Water Cooled)	
Collector Temperature, °F	250	500	250	500
Efficiency, %	6	15	8	17
Turbine, Gearbox, and Alternator, $	1500	1500	5500	5500
Boiler, $	1000	500	4500	2250
Condenser, $	700	400	4000	2000
Preheater, $	400	200	1800	900
Regenerator, $	350	175	1400	700
Controls, $	500	500	1200	1200
Fluid, Startup, etc., $	1000	1000	4000	4000
Total, $	5450	4275	22,400	16,500

* Ormat Turbines Ltd., Israel.

For higher production levels of 10,000 units/year, the turbine, gearbox, and alternator costs should be reduced by 25%, cost of controls should be reduced by 18%, condenser costs should be reduced by 10%, and the boiler, preheater, and regenerator costs should be reduced by 17%. Thus, overall cost reductions in the 15% to 20% range might be expected at the 10,000 units/year level.

Development of new heat transfer surfaces (geometry, surface treatment, etc.) could reduce the cost of boilers, preheaters, regenerators, and miscellaneous items by 5% to 15%.

The selection of the correct working fluid is critical to determining the performance of the system. However, it is not only a significant technical problem, but an institutional problem, as well. Thus, a fluid that may increase the efficiency by several percentage points (e.g., 18% to 20%) may be environmentally unacceptable. This includes the freons which have desirable physical properties. Also included is toluene, which is a suitable, well-known fluid; however, it presents a potential fire and environmental hazard and it superheats during expansion, thus requiring a large regenerator.

Reliability of ORC units, with proper training of installation and maintenance personnel, should be comparable to air conditioning units. Redundancy was not included for ORC-based systems that depend upon purchased electricity for backup and which can depend upon the redundancy of the utility grid. However, any stand-alone system should include some redundancy in the ORC subsystem, perhaps by using three 50-kW units for a 100-kW design; this would permit one of the 50-kW units to serve as a backup unit.

Another independent projection of manufacturing costs for similar ORC units at three manufacturing levels (100, 1000, and 10,000 units/year), is summarized in Figure 20 (provided by Sundstrand as part of this study). Non-recurring cost is stated separately.

Figure 21 shows unit cost as a function of production rate for the two different units. The estimated non-recurring cost for the high production rate tooling is placed at $10,000,000. This cost includes a new plant and all the machinery and tooling necessary to build up to 10,000 units/year and includes the cost of designing and developing the unit. The non-recurring cost estimate for the low production rate plant, which would have the capacity to build up to 1,000 units/year, would be $7,000,000.

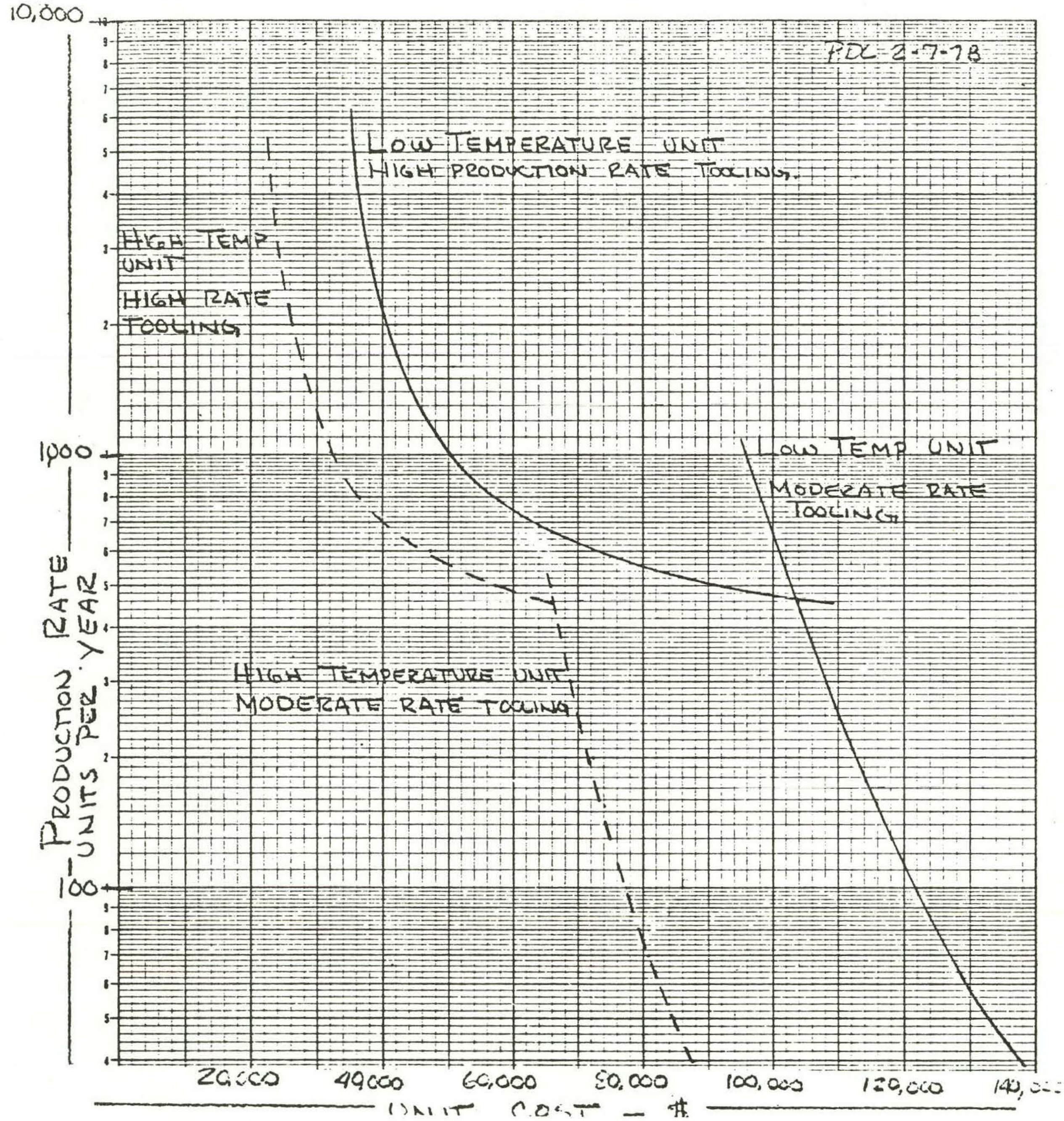

Figure 21. 100 kW ORC UNIT COSTS AS A FUNCTION OF PRODUCTION RATES

The ORC units are a complete system consisting of the following major components and all the associated auxiliary equipment and interconnecting piping and wiring:

- Turbine
- Gearbox
- Generator
- Circuit Breaker
- Switch Gear
- Feed Pump
- Boost Pump
- Regenerator (if needed)
- Condenser
- Cooling Tower
- Coolant Circulating Pump
- Non-Condensable Gas Removal System
- ORC Controls and Safeties

The vaporizer is not considered part of the ORC. The cost of installing the units is independent of the unit cost and production rate. There will be one to several units installed at any one site, and the installation costs will be dependent more on the number of units installed at a site rather than the production rate of the ORC.

The cost of installing a single 100 kW ORC unit is estimated at $10,000. This includes foundations and hook-up of the following ORC interfaces:

- Vaporizer
- Cooling Tower
- Electrical Output
- ORC Controls
- Electrical Switch Gear

If multiple units are installed at a site, the installation costs should decrease slightly for each unit.

Steam Rankine Cycles and Rankine-Cycle Working Fluid Selection

Numerous studies[7] have indicated that, for the Rankine cycle upper temperatures that are lower than 400°F, or for turbine sizes smaller than 5 MW, steam as a working fluid may be far from an economic choice.

These studies have also indicated that organic fluids will result in better thermal efficiency and less complicated equipment when the upper temperature is below 700°F and the turbine size is below 1 MW. Given the upper temperature limitation (600°F) imposed on the residential STES and given the total electrical demand of the community served by a single STES (<1 MW), organic fluids are preferred over steam as Rankine-cycle working fluids. The rationale for this preference is reviewed as follows:

1. Under given initial temperature and pressure and given condenser temperature, steam has a larger enthalpy drop per pound and larger volumetric flow variation compared with organic fluids. Moreover, steam condenses during the expansion. These aspects will result in lower cycle efficiency with steam as a working fluid (See Figure 22.) To raise the steam turbine efficiency, the number of stages must increase. This is not desirable at low power output levels as it results in more complicated machinery and higher costs per unit power output. The low adiabatic enthalpy drop of organic fluids allows the use of a single-stage turbine. This is a simpler turbine with no stage matching and interstage leakage problems.

2. Single wheel condensing turbines work with a poor bucket velocity ratio, resulting in poor efficiency. The introduction of additional wheels overcomes this difficulty, but results in high costs for small steam turbines. The total losses, therefore, for a small steam turbine are relatively high, as compared with large units. Heavy organics will make possible a single wheel turbine with the proper bucket velocity ratio.

3. For a given power level, the size and performance of a power system is influenced by the working fluid. System initial cost and performance can be optimized with respect to the working fluid and other design variables. The characteristics of the optimal working fluid may be far from those of steam. Therefore, allowance should be made for the use of other fluids to enhance the cost and energy effectiveness of the Rankine power plant. Below 700°F, several stable organics provide better performance and cost effectiveness than steam.

Stirling Engines

For many years, Stirling-cycle technology was virtually the private domain of the Philips Laboratories, Eindhoven, Holland. This company perfected Stirling-type cryogenic refrigeration machines to a production level and Stirling engines to a near-production level. Because this company has been oriented more to research than manufacturing, and because of the predisposition of engine manufacturers to favor the development of internal combustion rather than external combustion engines, the Philips Stirling engines have never reached a competitive position with their Otto or Diesel counterparts.

However, the need for higher efficiency engines, which has become more and more pronounced in the last 10 years, has stimulated development work on Stirling-cycle prime movers at many other laboratories. The interest has remained divided between automotive and stationary applications but the main emphasis has remained on the development of automotive engines. General Motors has apparently stopped their program, but the latest achievements of the Ford Company have been quite impressive. These results indicate that in the near

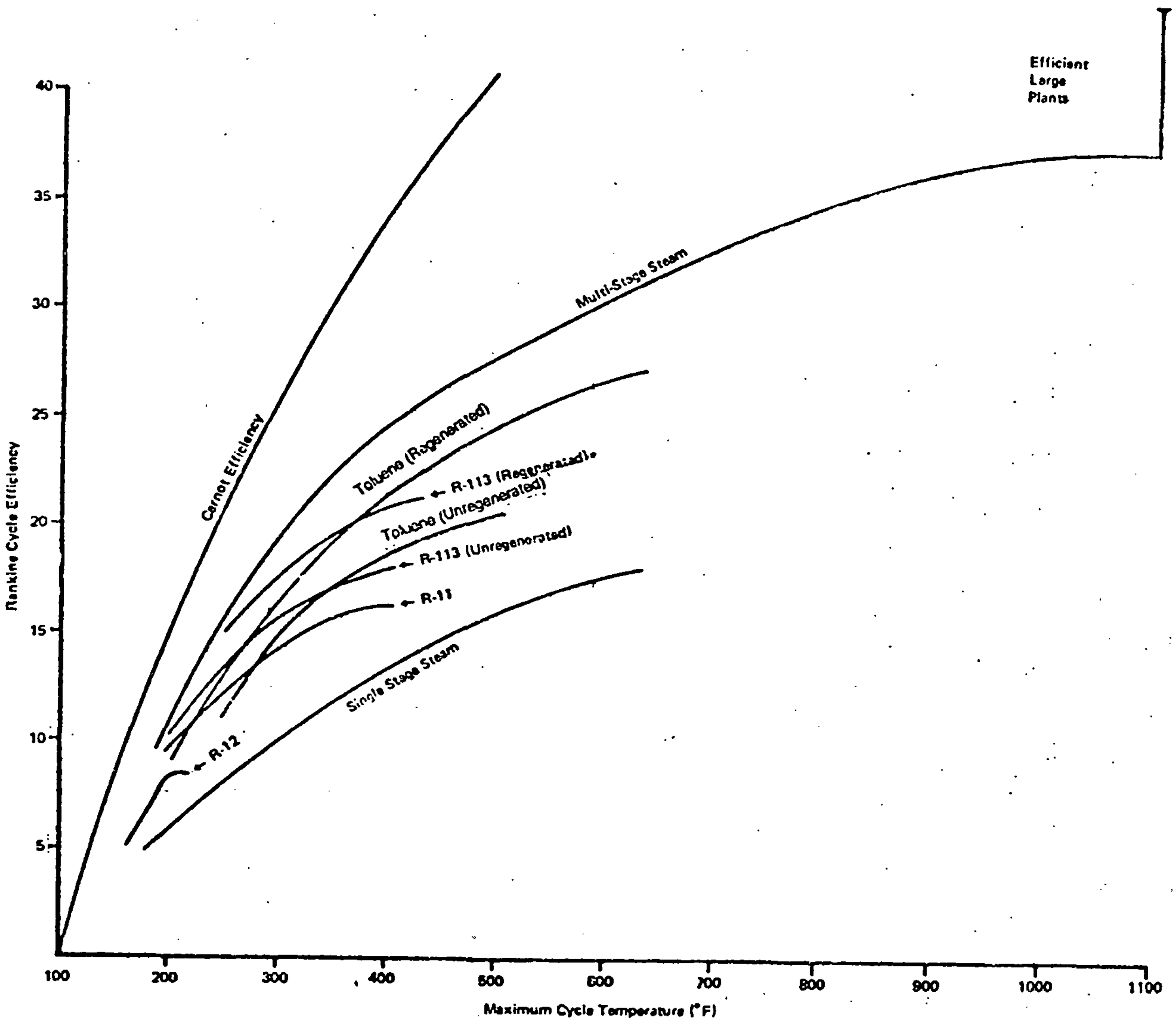

Figure 22. EFFICIENCY OF RANKINE-CYCLE SYSTEMS WITH DIFFERENT WORKING FLUIDS

future (within 15 to 20 years), we might expect to see external combustion engines used commercially in automobiles; however, this does not apply to the development of stationary engines. Although some of the development results are transferable to the stationary designs, the design characteristics of automotive engines are basically incompatible with the requirements of stationary engines. There are differences in life expectancy, reliability, and maintainability. Short-life automotive engines are limited by weight and size constraints; they have unique torque and efficiency characteristics; their manufacturing costs are dictated by the specific marketing requirements of the automotive industry, and their environmental impact aspects are of utmost importance. An automotive power plant cannot be properly used as a stationary engine. The application criteria for stationary Stirling engines are different from those of automotive power plants. Different problems must be confronted, especially in applying Stirling engines as stationary equipment for residential and light commercial service. For example, training of service personnel and user acceptance of the stationary power plant could be an easier task since it would involve a relatively smaller group of qualified people. From this point of view, the market penetration of stationary versions of the Stirling engine would be easier.

Research and development of stationary Stirling engines has seen comparatively much less funding. The important efforts have followed two independent routes. In both cases, the aim was to develop an engine that would be competitive with other types of stationary engines of the same size. This required approaching the design to simplify it in totally new ways. One approach, based on a regular piston-type mechanism has been pursued by the founders of the Swedish United Stirling Company (FFV Industrial Products Division, Eskilstuna, Sweden). The other approach is the free-piston embodiment invented and developed by Professor William Beale, who recently established the Sunpower Corp., Athens, Ohio. For the first time in the history of Stirling power plants these two concepts are now being qualified by experts as practical engines. Each, in its own category of capacities, has promise for becoming a competitive prime mover in stationary service.

The FFV engine, which has been developed to drive small electric power generators, has a nominal output of 10 kW. It is a single cylinder, V-type engine with multi-fuel capability, and it operates at approximately 1200°F input temperature level. This design, which uses several automotive components, is certainly more mature than the design of the free-piston engine. It has accumulated at least 20,000 hours of life-cycle testing for critical components and at least 4000 hours of engine operating time. As such, it could be considered a candidate for solar total energy systems if either the temperature of energy input to the engine could be increased to above 1000°F, or an overall efficiency of about 10% could be accepted at 600°F input. The FFV Company, which has recently formed a new subsidiary, Stirling Power Systems Corporation with principal offices in Ann Arbor, Michigan, will soon have tested the engine over enough operating hours to demonstrate its acceptability as a heavy duty, stationary power plant.

The limitations of Professor Beale's free-piston, Stirling engine with respect to its potential application as a power plant for solar total energy systems are different. Because of the free-piston embodiment, this oscillating engine can be visualized only in small sizes, probably limited to power outputs below 5 kW. Direct transmission of concentrated solar energy through a quartz window to power the cycle would further limit the size of the engine down to about 1 kW output. This engine concept has been found to be reliable and recently it has been accepted as a prime mover for two important government-sponsored R&D projects. These are —

1. The gas engine-driven, residential heat pump, being developed by General Electric.
2. The 2-kW, free-piston Stirling engine/linear alternator energy conversion system being developed by Mechanical Technology, Inc. (MTI).

Because of very low mechanical losses, the engine is inherently efficient. It is expected to reach an overall efficiency of 30% at 1200°F input temperatures. At 600°F it could probably reach an efficiency of 18%, which is highly attractive relative to other candidate prime movers for STE systems. However, two problems are associated with the application of this type of system. The linear engine/alternator concept is only in early stages of development, and it may, in our judgement, be limited to small capacity systems.

As of now, the potential improvements in both designs can be best judged by the two respective manufacturers (FFV and MTI) with whom we have had extensive contacts. Their prognostications of future trends can be summarized as follows:

- The Stirling Power Systems Corp. (FFV) will most likely succeed in raising the V-engine efficiency. Improvement by five percentage points in the near future would not be surprising.
- MTI recently initiated a new program to demonstrate the feasibility of the linear concept in sizes up to 10 or 20 kW electric output. So far the company is confident of positive finds from this program.

We have identified three main concept groups of systems with Stirling engines (Table 43):

1. Systems operating with maximum cycle temperature of 600°F, given as maximum temperature of solar thermal storage. Since there is no known development program addressing the design of low-temperature Stirling engines, we would have to assume that engines with high temperature design point would be applied. At 600°F maximum cycle operating temperature level, these engines would show relatively poor efficiency. However, if designed for low cycle temperature, efficiencies of up to 30% are being predicted for free-piston machines. No planned activity in this area and lower level of confidence in predicted efficiency values are our reasons for not considering this class of machines for future evaluation. In comparison with the ORC turbine, the merits of low source temperature Stirling engines could, however, rise for other than technical reasons. We are referring here to questions of public acceptance and safety of ORC machinery as well as to its compatibility with local codes. Together with one of the manufacturers of these systems, the Sundstrand Co., we believe that ORC systems designed to operate with toluene are comparatively safe and that no serious problems should arise from the current institutional barriers. Therefore, the low source temperature Stirling engine would have to be reconsidered only if "institutional" advantages of low-temperature Stirling engines versus ORC turbine would become highly important in view of newly imposed codes and regulations.

2. Systems operating above 600°F, with solar thermal storage also operating at higher temperatures. As can be seen in Table 42, engines that would be available for applications in STES and would operate from solar thermal storage at temperature levels above 600°F are those currently being developed as external combustion engines. Such engines would be easily adaptable to indirect heat input, their efficiency will be attractive and most probably appropriate sizes will be available already in 1985. One major consideration prevented us however from considering these machines as prime candidates for STE systems. It is the need for high-temperature storage greatly in excess of 600°F, which we feel is inappropriate for residential consideration at this time.

3. Directly solar irradiated systems operating at temperatures higher than 600°F (most probably at 1200°F) without thermal storage. Technically, engines that would operate directly from concentrated solar energy are the most attractive candidates for the STES application. The availability of such engines and other technical information as shown in Table 42 indicate again that within the constraints of our conditions it would be too speculative to extrapolate from what little is known about these engines and use it in our marketing assessment.

Brayton Engines

Brayton-cycle heat engines were considered for applicability to residential STE systems. However, as a consequence of limiting collector temperatures to 600°F, because the more sophisticated collector types are considered inappropriate for this application, we have ruled out Brayton machinery for our STES

Table 42. CHARACTERISTIC DATA FOR STATIONARY, POWER GENERATING STIRLING ENGINES

	SOLAR ENERGY SOURCE	DESIGN	ENGINE: PERFORMANCE		ENGINE: MANUFACTURING			
	Temperature,* °F and Concept	Mechanism and Temperature,** °F	Capacity, kW	Efficiency, %	Year Available	Projected Cost,† $/kWe: 10,000 units/yr	Projected Cost,† $/kWe: 100,000 units/yr	Note
System I	600, with thermal storage	Kinematic Drive 1200 - 1500	10 - 100		1983			
		Free Piston 1200 - 1500	1 - 10	30 predicted at 600°F if designed for 600°F	1983 - 85			MTI
			10 - 50		1993 - 95			
System II	600, with thermal storage, indirect heating or external combustion	Kinematic Drive 1200 - 1500	10 - 100		1983			MTI
			10	20 demonstrated for a competitive heavy duty engine	1979			Stirling Power Systems
		Free Piston 1200 - 1500	1 - 10	32 achieved experimentally at 1200°F	1983 - 85	240	170	
			10 - 50		1993 - 95			
		Constant Volume 1200 - 1500	Fractions - 15		Only heart assist projects active			
System III	600, no thermal storage, directly irradiated	Free Piston 1200	1	38/85	Small production run of about 50 available in 1979			Sunpower Corp.
		12 - 1500	20 - 50		1995 - 2000			MTI

* Source temperature = engine operating temperature.

** We do not know of any development of lower design temperature Stirling engines.

† Engine/generator set.

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residential designs. Brayton machinery follows similar thermodynamic limitations on efficiency as Rankine machinery as cycle temperature is reduced. In fact, practical considerations strongly affect Brayton engine performance as turbine inlet temperature is reduced. In particular, the optimum pressure ratio for the Brayton cycle decreases with decreasing inlet temperature. This results in a low net power output per pound of mass flow. Indeed, when air is the working fluid, the ideal net power output per unit of mass flow is an order of magnitude less than that from steam or organic fluid power cycles. As a result, it is generally recognized that Brayton machinery is uneconomical to operate at the temperature level available in our solar total energy system concepts for residential applications.

Cooling Machines

Only absorption cooling machines were used for the residential STE conceptual designs that incorporated ORC units to generate electricity. Vapor compression cooling machines were used in the STE conceptual designs based on photovoltaics.

Section 3.

CONCEPTUAL DESIGN OF SOLAR TOTAL ENERGY SYSTEMS FOR RESIDENTIAL APPLICATIONS

Three different conceptual designs have been selected: 1) a 300°F ORC design, 2) a 600°F ORC design, both using parabolic trough collectors, and 3) a photovoltaic design using water-cooled, flat plate silicon photovoltaic arrays.

3.1 STES Design Based Upon ORC Heat Engines

Two upper temperature levels were selected for the Rankine cycle operation based upon two solar collector outlet temperatures: 300°F and 600°F. An outlet temperature of 600°F can be achieved with reasonable efficiency and cost by commercially (or near-term) available parabolic trough collectors and allows for heat extraction from the condenser at seasonally varied temperatures to sustain the thermal loads. Alternatively, systems using parabolic trough collectors supply low-temperature (300°F) heat to the power cycle. In the 300°F system, the heat available at the condenser is rejected to the cooling tower and to the cold water entering the domestic water heating system. The thermal loads in the 300°F system are sustained by a heat exchanger placed in parallel with the Rankine cycle boiler. Heat engine cycle inlet temperatures will, of course, be somewhat below collector outlet temperatures. The 300° and 600°F temperature levels were selected because they represent the lower and upper limits that are considered appropriate for residential solar total energy systems.

3.1.1 Definitions of Variables and Parameters

The variables and parameters are classified under the following headings:

- Flow temperatures
- Component efficiencies
- Loads and insolation parameters
- Flow rates
- Storage charge rates and capacities
- Heat extraction rates.

These variables and parameters are either selected in the design procedure, predetermined from a previous analysis, or calculated using the current procedures.

The variables and parameters that are design selected are determined by analyzing the solar (primary) cycle, the ORC, and the secondary thermal cycle.

These are specified below under Flow Rates and Storage Change Rates. The predetermined variables, such as the loads, are the result of the energy requirements effort. These are used as inputs to the analysis algorithms. The calculated variables are those determined by the algorithms described in Appendix E.

Flow Temperatures

Temperatures are defined in Table 43 and indicated in Figure 23 for low-temperature systems. Comments pertinent to these variables are given in Table 43. (A more detailed discussion is given in Subsections 3.1.2 and 3.1.3.)

Table 43. DEFINITIONS OF TEMPERATURE VARIABLES

Variable	Definition	Comments
Tc_1	Supply temperature from the solar collector.	Controlled and computed variable (see discussion on operation)
Tc_2	Minimum value of Tc_1	Set at 200°F for low-temperature ORC; 550°F for high-temperature ORC
Ts_1	Supply temperature from storage	Controlled at approximately the maximum value of Tc_1
T_2	Return temperature to collector	Calculated variable
Ts_2'	Storage cut-off temperature	Slightly greater than T_2 (using stratified temperature storage)
Ts_2	Return temperature from storage	Approximately equal to T_2
Te_2	Input temperature to ORC boiler (heat exchanger No. 1)	Design selected based on ORC operation (varies with load)
Tx_1	Outlet temperature from heat exchanger No. 1 (see Figure 22)	Design selected depending on Te_2
Tcond	Condenser temperature	Design selected
Te_1	Supply temperature to turbine	Design selected (varies with load)
Th_1	Supply temperature to thermal loads at design point from heat exchanger No. 2	Design selected (varies with load)
Th_2	Return temperature to heat exchanger No. 2	Design selected (varies with load)
Tamb	Outdoor dry bulb temperature	Predetermined variable
Tx_2	Outlet temperature from heat exchanger No. 2 (see Figure 22)	Design selected

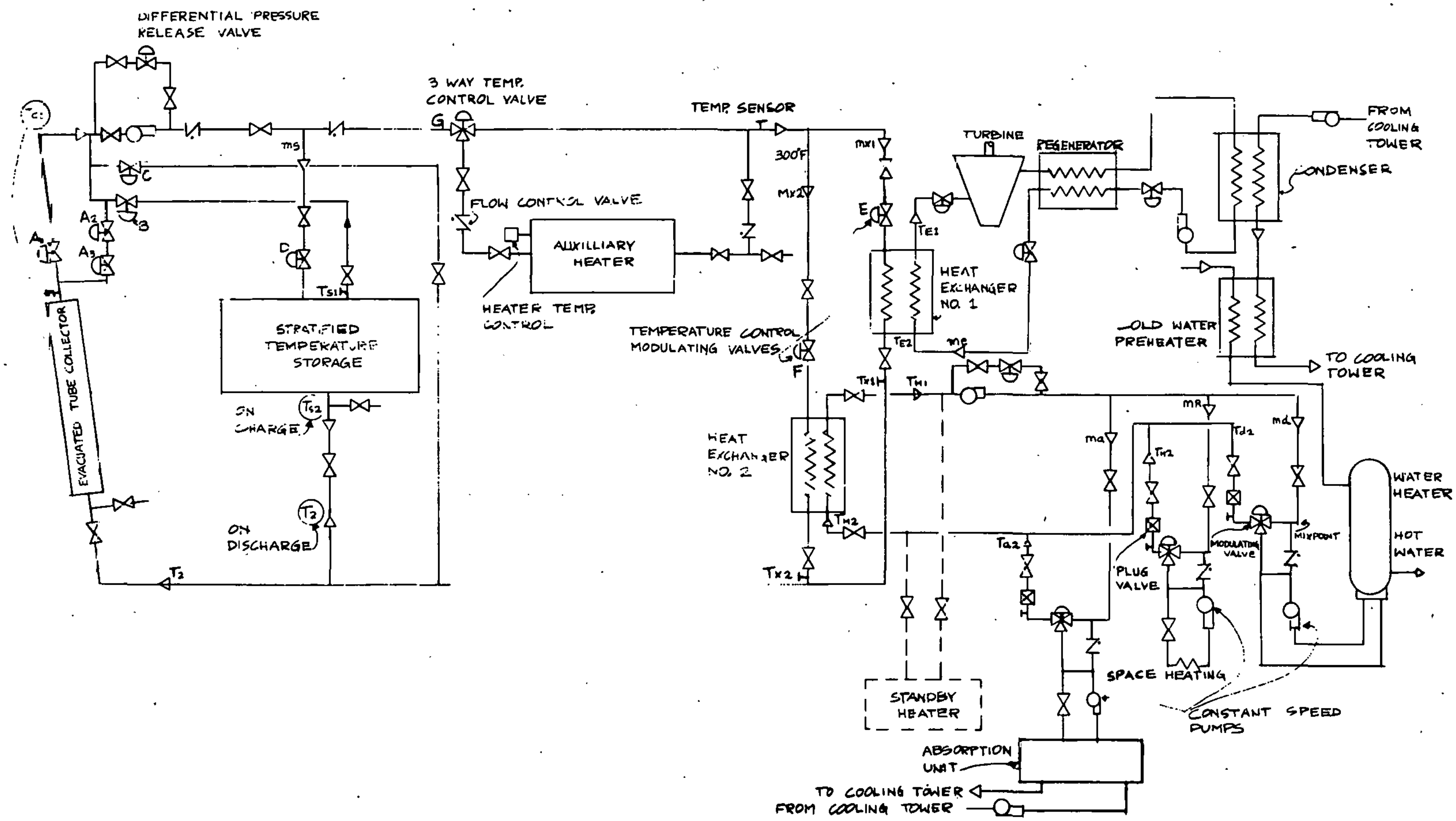

Figure 23. LOW-TEMPERATURE STES CONCEPTUAL DESIGN USING ORC

Component Efficiencies

Table 44 gives the definitions of component efficiencies used in the analysis. These efficiencies will depend upon the operating conditons which vary with time. For this reason, the efficiencies have been expressed as functions of time — t_{ij}. The subscript i indicates the hour of the day and the subscript j indicates the day of the year. The variable t_{ij} is therefore the hour to which the analysis applies.

Table 44. DEFINITIONS OF COMPONENT EFFICIENCIES

Variable	Definition	Comments
$\eta_c(t_{ij})$	Solar collector efficiency	Function of T_{c1}, T_2, $T_{ambient}$, and insolation
$\eta_e(t_{ij})$	Electric generation efficiency	Depends upon Rankine cycle operation and on turbine performance
$\eta_T(t_{ij})$	Turbine efficiency	Measure of turbine performance (work output relative to isentropic enthalpy change across turbine)
$\eta_a(t_{ij})$	Absorption chiller efficiency (excluding auxiliary power)	Depends on cooling tower design and chilled water temperature
$\eta_h(t_{ij})$	Space heating efficiency (excluding pump and fan power)	Depends on pipe heat losses
$\eta_d(t_{ij})$	Domestic water heating efficiency	Depends on pipe and standby heat losses and on amount of recovered heat from condenser (see Figure 22)
$\eta_b(t_{ij})$	Primary circuit boiler efficiency	Depends on firing rate and on standby losses
$\eta_{ea}(t_{ij})$	Mechanical chiller efficiency (excluding auxiliary power)	Depends on cooling tower design and chilled water temperature

Loads and Insolation Parameters

Table 45 shows definitions of pertinent loads and insolation paramenters. The loads are either results of previous analyses or calculated based upon the operating schedules discussed in Subsections 3.1.2 and 3.1.3.

Table 45. DEFINITIONS OF LOADS AND INSOLATION PARAMETERS

Variable	Definition	Comments
A	Collector aperture area	Determined in the design procedure
$S(t_{ij})$	Insolation available per unit area	Predetermined variable
S_{min}	Minimum insolation level for collector operation	Design selected corresponding to minimum collector flow rate
$E'(t_{ij})$	Total electrical load	Predetermined variable including base plus HVAC auxiliary power (see Subsection 3.1.2)
$ha(t_{ij})$	Cooling load	Predetermined variable
$h_h(t_{ij})$	Space heating load	Predetermined variable
$hd(t_{ij})$	Domestic water heating load	Predetermined variable
$E(t_{ij})$	Plant net electrical power output	Depends on operating schedule (see Subsections 3.1.2 and 3.1.3)
$Ep(t_{ij})$	Purchased power	Calculated variable depending on operating schedules
$b(t_{ij})$	Low-temperature design boiler load	Calculated variable
$b_1(t_{ij})$	High-temperature design boiler load of primary circuit	Calculated variable
$b_{th}(t_{ij})$	High-temperature design secondary boiler load	Calculated variable

Flow Rates

Table 46 shows definitions of the flow rates used in Subsections 3.1.2 and 3.1.3.

Table 46. DEFINITIONS OF FLOW RATES

Variable	Definitions	Comments
Mx_1	Primary flow rate through heat exchanger No. 1 (see Figure 22)	Calculated variable
Mx_2	Primary flow rate through heat exchanger No. 2 (see Figure 22)	Calculated variable
M	Total primary flow rate	Calculated variable
M_s	Flow to storage on charging	Calculated variable

Storage Charge Rates and Capacities

Table 47 defines the variables pertinent to the storage systems. These storage systems are sized for electrical generation as well as for heating and cooling when these loads are sustained by recovered heat from the power cycle.

Table 47. DEFINITIONS OF STORAGE CHARGE RATES AND CAPACITIES

Variable	Definition	Comments
$C(t_{ij})$	Primary storage charge or discharge rate	Calculated variable
C_{ij}	Primary storage heat capacity at time t_{ij}	Calculated variable
C_{min}	Minimum primary storage heat capacity (discharge cut-off point)	Design selected
$C_{th}(t_{ij})$	Charge/discharge rate of thermal storage for thermal system (high-temperature ORC system)	Calculated variable
$C_{th\,ij}$	Heat capacity of thermal storage for thermal system (high-temperature ORC system)	Calculated variable
$C_{th}max$	Maximum heat capacity of thermal storage for thermal system (high-temperature ORC system)	Design selected
Cmax	Maximum primary storage capacity	Design selected parameter
Ls	Storage loss rate factor	Specified parameter

Heat Extraction Rates

Table 48 lists the definitions of heat extraction rates discussed in Subsections 3.1.2 and 3.1.3.

3.1.2 Low-Temperature System General Description

The schematic diagram of a solar total energy system using an ORC heat engine operating at a cycle temperature of 300°F is shown in Figure 22. We have distinguished two backup alternatives: 1) a self-sustaining system ("stand-alone" system), and 2) a "purchased power" system. In the stand-alone system, no power is purchased; in the purchased power system, utility electricity makes up any shortfall in electric power required and fossil fuel is consumed to satisfy thermal needs. With the auxiliary energy source in series with the collector,

Table 48. DEFINITIONS OF HEAT EXTRACTION RATES

Variable	Definition	Comments
$H_{ch}(t_{ij}) = 1.347\ B_h E(t_{ij})^*$	Heat removed from condenser at higher value of Tcond	B_h, B_L and B_t are design selected parameters, and $E(t_{ij})$ is defined in Table 46. Parameters apply to high-temperature design
$H_{cL}(t_{ij}) = 1.347\ B_L E(t_{ij})^*$	Heat recovered from condenser at lower value of Tcond	
$H_{ct}(t_{ij}) = 1.347\ B_t E(t_{ij})^*$	Heat rejected from condenser when low-temperature storage is full	
$B_1 E(t_{ij})$	Heat rejected at condenser (low-temperature design)	Depends on condenser temperature
$H_{e1}(t_{ij})$	Heat extracted from heat exchanger No. 1	Calculated variable
$H_2(t_{ij})$	Total thermal demand for heating and cooling	Calculated variable

* The value 1.347 indicates the ratio of shaftpower to plant electrical power output, taking into account gear box and generator inefficiencies and solar and PCS parasitics.

under certain conditions the collector temperature is allowed to drop below 300°F in order to collect heat, albeit at reduced temperature, and the auxiliary energy source boosts the temperature of fluid going to the heat engine boiler to 300°F. In operation, if the thermal and electrical loads are satisfied from collected energy at 300°F, thermal energy is added to storage. Stratified storage is used because it features a constant outlet temperature until it is nearly depleted. Multiple storage tanks may also be used to achieve constant outlet temperature operation. Constant temperature output is desirable for efficient heat engine operation. When collected energy at 300°F is insufficient to meet thermal loads, they are met from collected energy supplemented from storage. When storage is discharged and collector temperature is allowed to drop, loads are met from the collected thermal energy boosted to 300°F by the auxiliary heater. In the stand-alone system, when storage is depleted and solar energy is unavailable, the entire load is met from the auxiliary heater. If the system is backed up by utility electricity, when loads have been satisfied by collected energy, excess energy is stored in the storage tank. When collected energy is insufficient to meet the loads, the storage tank is discharged to supplement collected energy to satisfy the load. When storage is depleted and solar energy is available, a fossil-fuel-fired auxiliary is used to help meet the combined thermal and electric loads. When an electric auxiliary is used, it supplements the solar contribution satisfying electrical loads. When storage is depleted and solar energy is unavailable (at night or during cloudy periods), auxiliary energy, fossil and utility electricity, is used to meet the loads. The heat engine is sized to maximum diversified electrical demand. Heat available at the condenser is rejected (at 110°F) to the cold water entering the domestic water heating system and to a cooling tower. ORC efficiency is 10%.

Operation

This system operates with a nominal upper temperature of 300°F. The schematic diagram is shown in Figure 23. The modes of operation are as follows:

- Mode 1

  As long as the collector temperature, T_{c1}, is slightly above 300°F, control valves A_1 and D will remain open, and control valves A_2, B, and C will remain closed. Valve D will modulate to prevent T_{c1} from rising excessively over 300°F, in effect storing excess energy in the stratified temperature tank. Primary fluid will flow through the collector toward storage tanks and toward three-way valve G.

  Thermodynamically, this mode is applicable whenever the solar energy being provided by the collector (ηAS) is in excess or equal to the sum of the thermal (H_2) and power generator (E/η_e) loads.

  All of these quantities are given as constants or functional values, including the storage lower temperature level T_{S2} which is, for simplification, assumed to be equal to the flow-weighted average of T_{X1} and T_{X2}.

  The solar fluid flow rate M is a calculated variable depending, in magnitude, upon the exit temperature from the collector. The fluid, leaving the collector at 300°F, is divided into three parallel flows with flow rates m_S, m_{X1}, and m_{X2}. These flow rates are again variable and the exiting heat exchanger temperatures T_{X1} and T_{X2} are assumed constant.

  Fluid flow in Mode 1 is shown schematically in Figure 24.

- Mode 2

  When T_{c1} drops below 300°F but remains over a specified value, T_{c2}, valve D will prevent flow-through storage, diverting it entirely toward valve G. The auxiliary heater will ensure a supply temperature of 300°F to the heat exchangers.

  Fluid flow in Mode 2 is shown schematically in Figure 25.

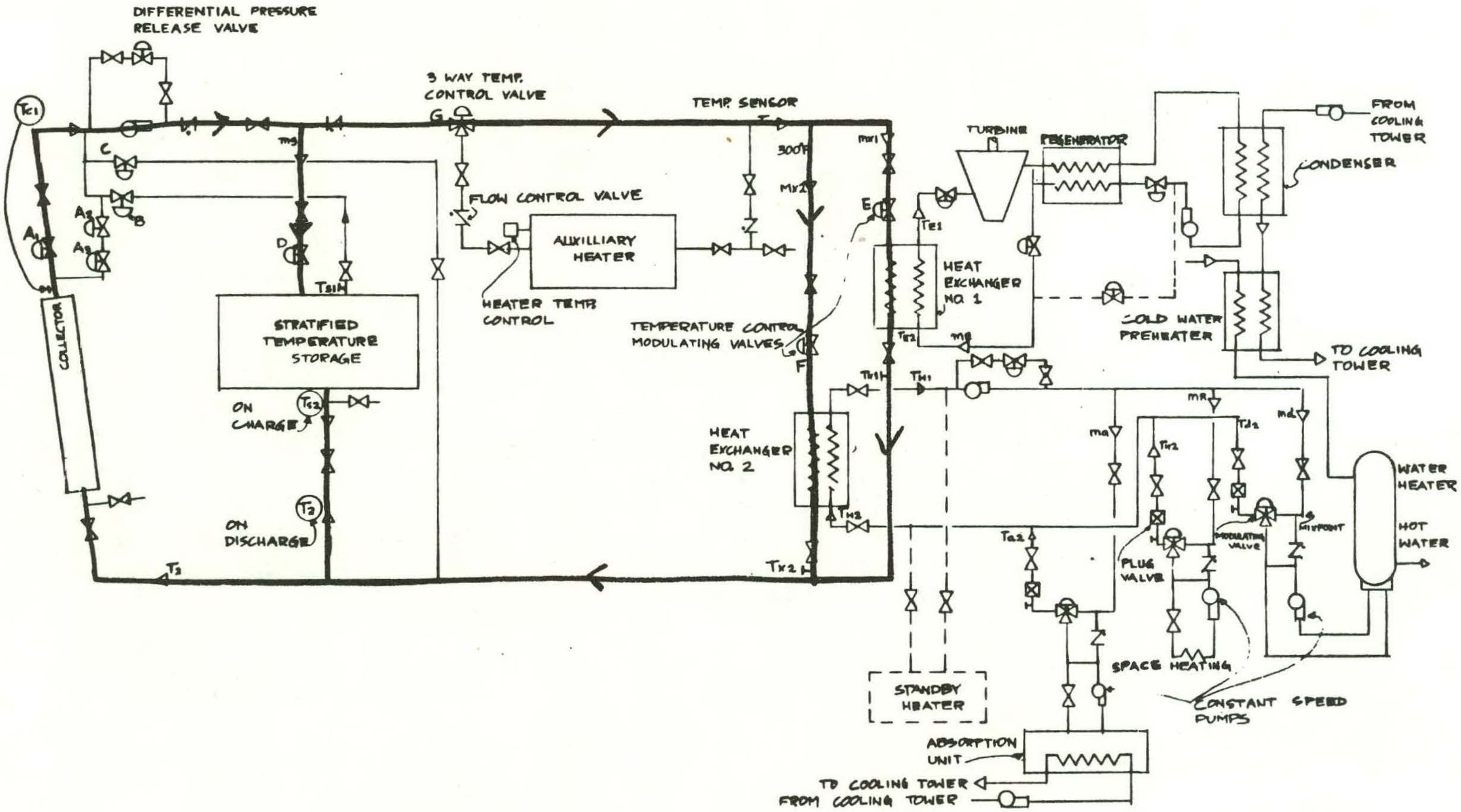

Figure 24. LOW-TEMPERATURE STES CONCEPTUAL DESIGN USING ORC — MODE 1

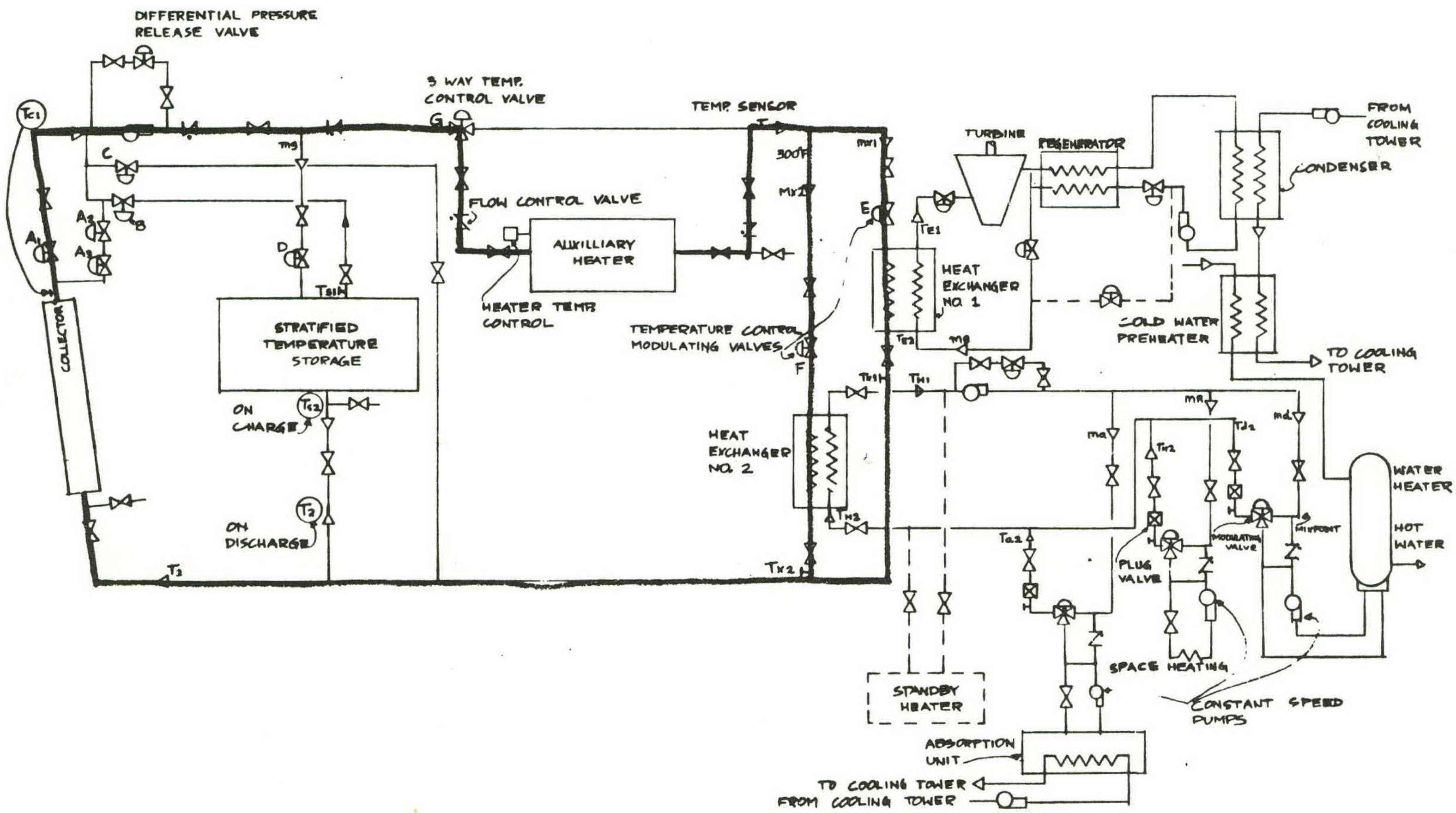

Figure 25. LOW-TEMPERATURE STES CONCEPTUAL DESIGN USING ORC — MODE 2

- Mode 3

When temperature T_{c1} drops below T_{c2} under Mode 2 conditions, system goes into Mode 3 operation and valves B and A_2 open, valves A_1 and D will close, and valve A_3 will maintain T_{c1} at 300°F (or slightly below 300°F). As long as the storage temperature T_{s1} is above a specified value (T'_{S2}), and as long as T_{c1} is slightly below 300°F, the pump will discharge liquid from storage and collector and toward valve G. The pump will discharge liquid entirely from storage if the collector flow rate reaches a specified minimum value determined by

$$Mc_{min} = \frac{\eta_c A \, S_{min}(t_{ij})}{(300 - T_2)}$$

where S_{min} (t_{ij}) is the value of insolation below which the collector system shuts off. If T_{c1} exceeds 300°F, valve A_1 will open, valves B and A_2 will close, and Mode 1 or Mode 2 will resume operation, depending upon the insolation level. However, if T_{s1} is less than T'_{S2}, implying that storage is discharged, valve C will open, valve B will close, and supplementary energy will be supplied by the auxiliary heater (Mode 4).

Fluid flow in Mode 3 is shown schematically in Figure 26.

- Mode 4

As long as T_{s1} is below T_{s2} (storage is discharged), and as long as the collector flow is through valve A_2 (controlled by T_{c1}), valve C will remain open and valves B, D, and A_1 will remain closed. Valve G will allow full flow through the auxiliary heater. In this mode, valve E will remain open if solar energy is to be supplemented by auxiliary fuel for electric power generation. On the other hand, valve E will remain closed in this mode if power is to be purchased from the utilities.

Fluid flow in Mode 4 is shown schematically in Figure 27.

- Secondary Circuits

The Rankine cycle receives energy through Heat Exchanger No. 1. The turbine inlet temperatures, T_{e1}, will be less than 300°F. The turbine exhausts to the regenerator for feed liquid heating.

The thermal loads are sustained by Heat Exchanger No. 2. Each of the three thermal circuits utilize primary/secondary pumping, whereby the secondary supply temperatures and the secondary and primary flow rates remain constant, while the primary supply and return temperatures vary with the load.

3.1.3 High-Temperature System, General Description

This system operates at an upper temperature level of 600°F. The schematic diagram is shown in Figure 28. In the absence of cooling (indicated by the ambient temperature not exceeding 70°F), the system operates at a condenser temperature of about 160°F as long as the low-temperature storage is not full. In the cooling season (indicated by the ambient temperature exceeding 70°F),

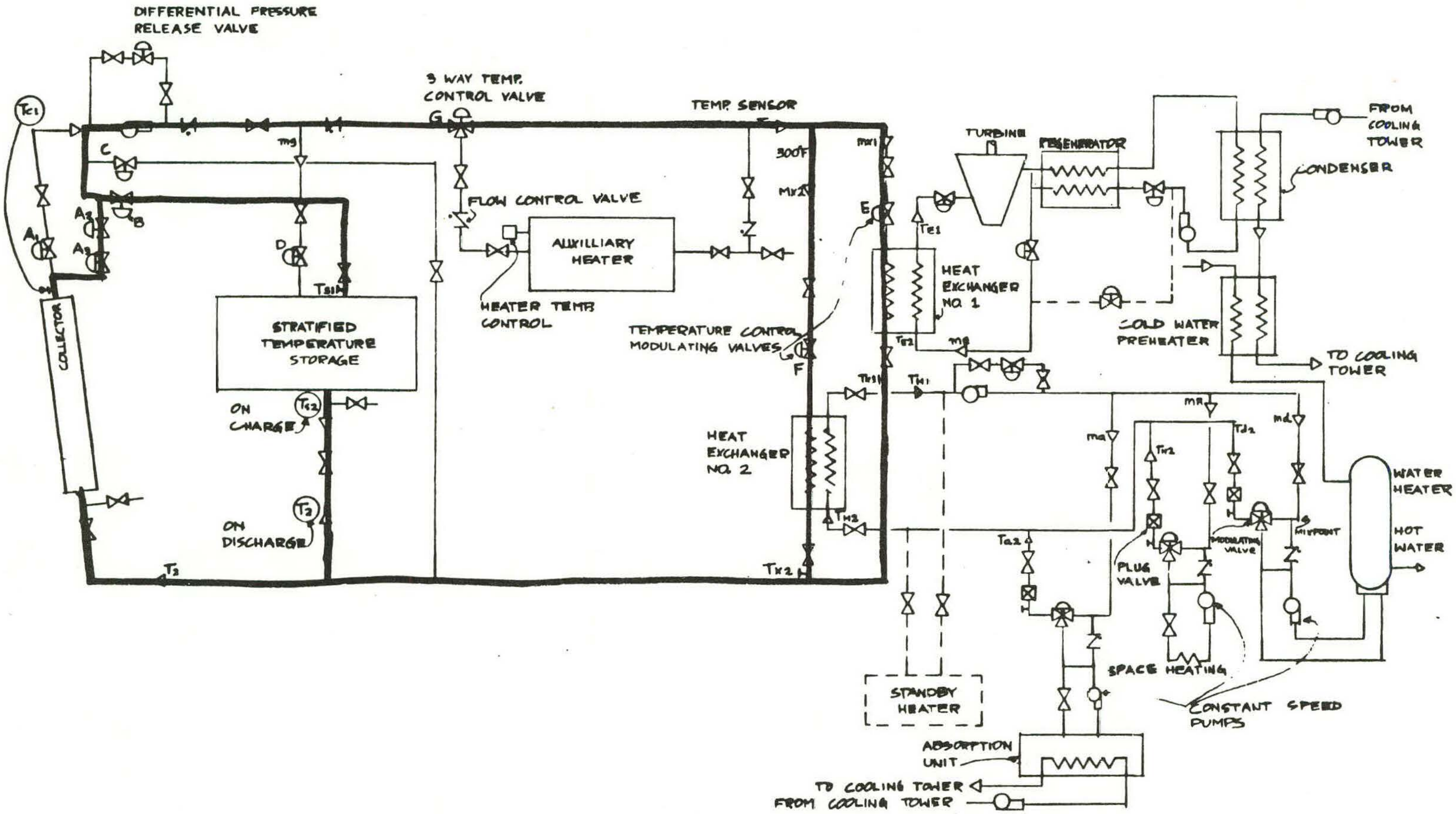

Figure 26. LOW-TEMPERATURE STES CONCEPTUAL DESIGN USING ORC — MODE 3

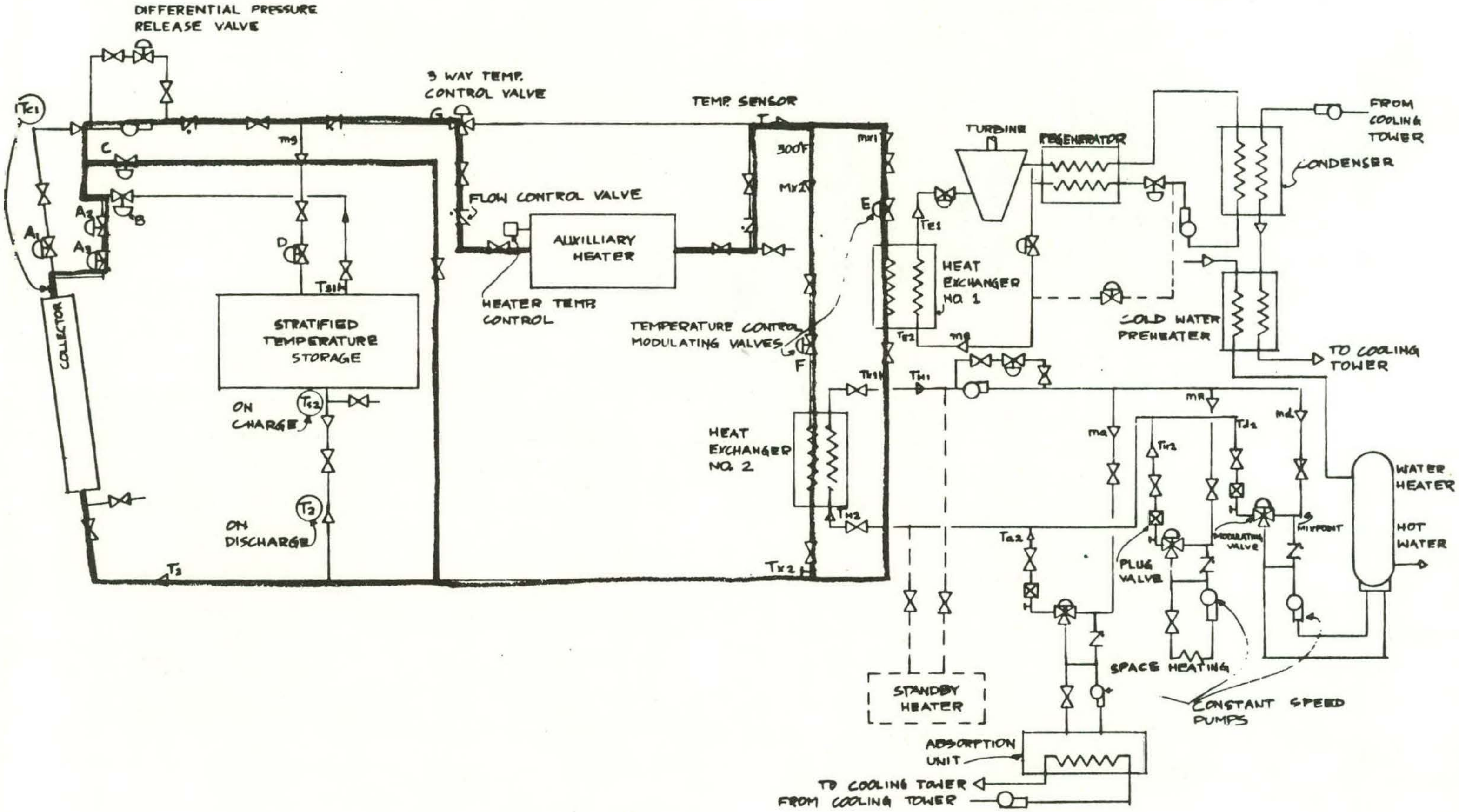

Figure 27. LOW-TEMPERATURE STES CONCEPTUAL DESIGN USING ORC — MODE 4

4/78
8987

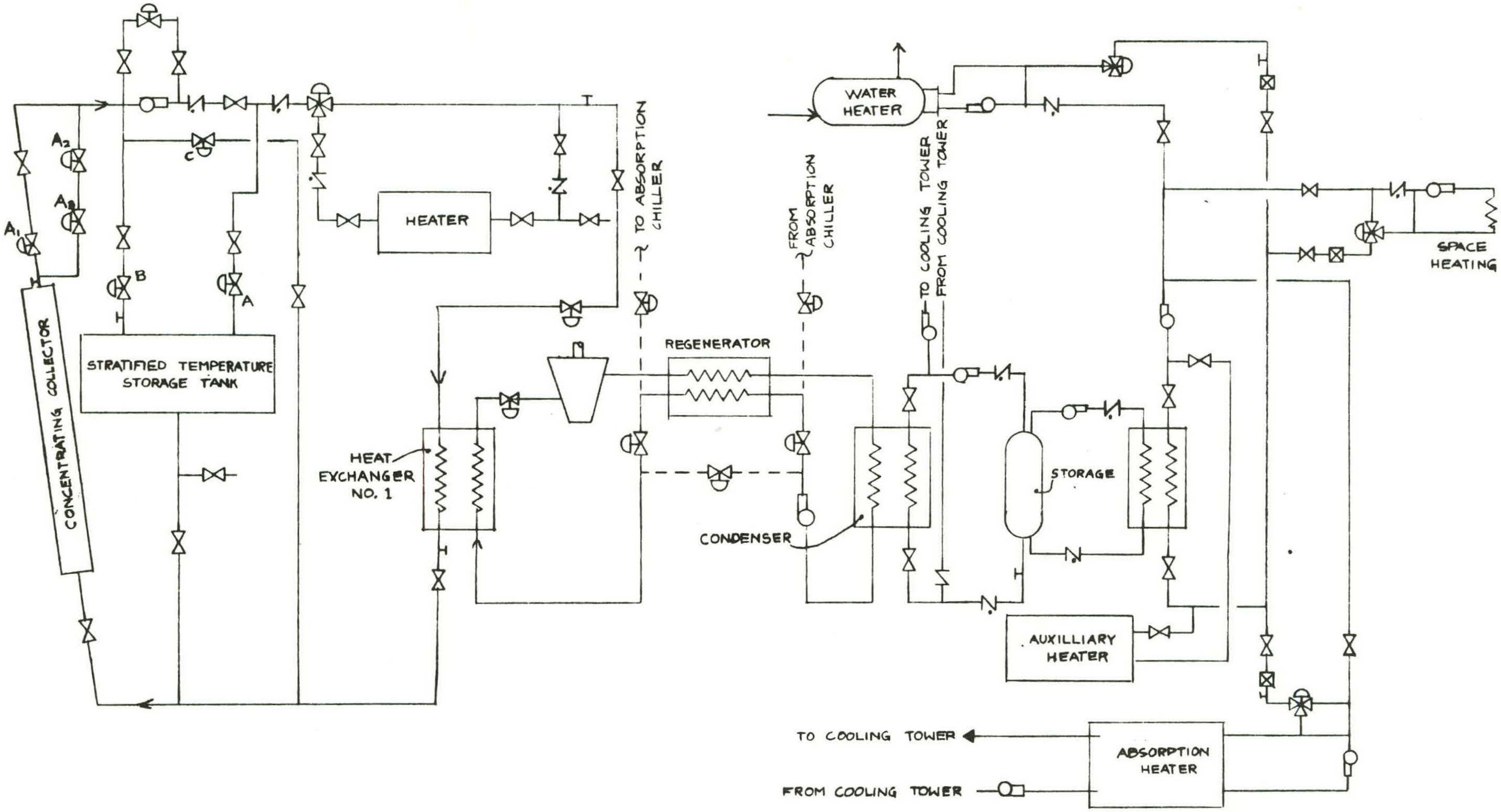

Figure 28. HIGH-TEMPERATURE STES CONCEPTUAL DESIGN USING ORC

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8987

the condenser temperature is raised to approximately 200°F. When the low-temperature storage is full, the condenser temperature is lowered to 110°F. The condenser will remain operating at T_{cond} = 200°F (if the low-temperature storage is not full) until the ambient temperature goes below 60°F after which the condenser pressure is then lowered so that the condenser operates at a temperature of 160°F. Allowing ambient temperature to drop below 60°F before reducing condenser temperature to 160°F prevents the system from excessive switching from cooling season operation (200°F condenser temperature) to heating season operation (160°F condenser temperature).

We have distinguished between two conditions: 1) self-sustaining system ("stand-alone" system), and 2) thermal tracking system ("purchased power" system). In the stand-alone system, no power is purchased; in the thermal tracking system, the analysis is carried out based upon generating electricity to track the thermal loads. The amount of purchased power and the amount of fuel consumed are then calculated.

Operation (See Appendix E for details)

The operational modes of the high-temperature (600°F) ORC STES are described in this section. The discussion refers explicitly to the option in which back-up electricity is purchased from the utility. However, the stand-alone system operates in a comparable fashion.

The thermal system supplies hot water from a low-temperature storage (LTS) tank to the absorption chiller, the space heating system, and the water heater. LTS receives heat from the condenser of the ORC system. The schedule of electric generation minimizes loss of high-temperature (600°F) from the primary system and of low-temperature heat (110°F) from the condenser to the cooling tower. High-temperature heat loss is minimized by generating electric power to meet demand whenever primary storage is full and solar energy is available, although low-temperature heat may be rejected at the cooling tower. The more low-temperature heat that is lost (in order to minimize high-temperature heat loss), the less is the effective utilization of thermal energy available at the condenser. This is an indication of oversized collector area. However, this may inevitably occur in the mild seasons if we are to design a meaningful STES generating significant electric power compared to demand.

3.2 Photovoltaic Solar Total Energy System Design

3.2.1 System Description

The photovoltaic solar total energy system is designed to supply the bulk of electrical, space heating and cooling, and hot water requirements of the residence by cooling the photovoltaic cells and utilizing the reject heat in the cooling water to provide space heating and hot water.

Figure 29 is a block diagram of the important subsystems as they are combined to form the overall photovoltaic total energy system. The size specified for the solar cell module (32" X 96" — centerline dimensions) is based upon standard roof structure dimensions. Module dimensions may be varied to suit alternative installation approaches (e.g., rack mounting). The collector is provided with a single glass cover to ensure adequate temperature for heat transfer during winter. An appropriate number of modules is rack-mounted and tilted at local latitude (module dimensions do allow integration with appropriately sloped roof) and connected to form an array which provides electrical and thermal energy to the residence.

The output of the photovoltaic array will provide a portion of the electrical energy required by the residence plus thermal energy whenever it can be used to space heat the residence and provide hot water. The thermal output will be used directly as needed, or stored in a water thermal storage system designed to provide short-term heating reserve capacity. Because the thermal energy produced by the collector is at too low a temperature to be used for absorption cooling,* air-conditioning is accomplished with electrically driven vapor compression chillers. The electrical demand can be supplied either by the solar array or the battery storage subsystem. When array output is unavailable or battery storage is depleted, the utility backup can supply the load. The power conditioning equipment and the electrical and thermal stores match incident array energy with the demands of the residence.

* Higher temperature thermal energy results in degradation of photovoltaic array efficiency. Analysis of a higher operating temperature system design with absorption cooling was not undertaken, nor was an all electric system with heat pump heating.

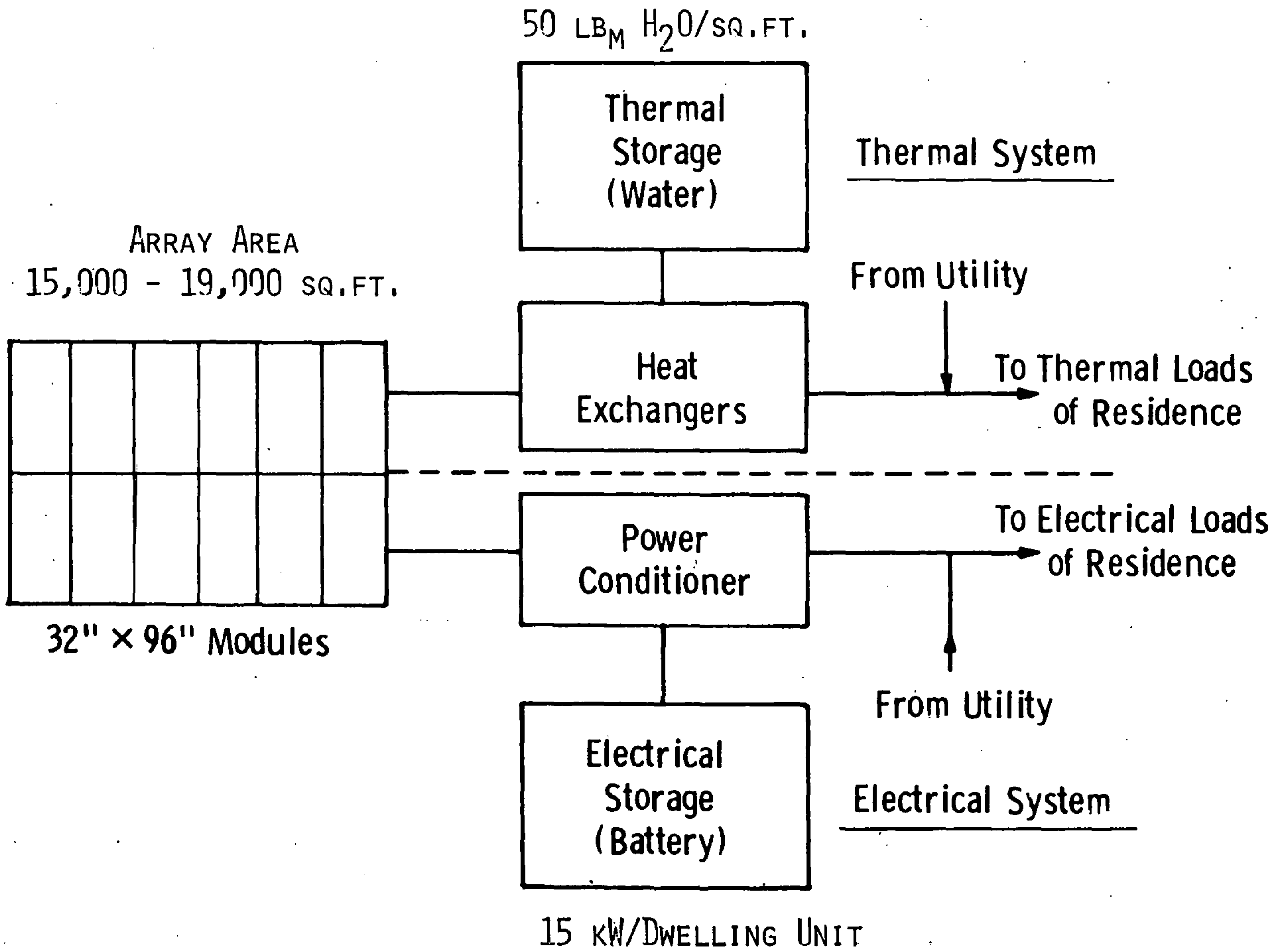


Figure 29. RESIDENTIAL TOTAL ENERGY SYSTEM BLOCK DIAGRAM

3.2.2 Mode Description of Photovoltaic Solar Total Energy Systems

This system illustrated in Figure 30, consists of a water-cooled silicon photovoltaic array coupled with a direct solar heating system employing heat recovery from the photovoltaic arrays.

For water to circulate through the solar system, Pump No. 1 will be in operation. The fluid path will be determined by a control valve and will either pass through a plate fin coil or go directly to the rooftop array structure. The fluid pathway through the plate fin coil is provided to reject excess heat collected. This circuit is necessary because the photovoltaic array's efficiency begins to drop below its design value of 13% at array temperatures exceeding 130°F.*

From the rooftop array, the fluid passes through the heat exchanger coils (fan coils) of the heating/cooling system. If the residence is in the heating mode, the fan would be in operation and heat would be transferred from the water to satisfy the residential heating load. Space cooling is accomplished with an electrically driven vapor compression chiller.

The domestic hot water circuit is hydronically separated from the collector fluid circuit. Heat is transferred from the main storage tank through a heat exchanger nested in the main storage tank and then back into the domestic hot water tank. Backup heaters are provided to supplement the heating and domestic hot water systems. Although not explicitly shown in Figure 42, the backup heater for the space heating system is actually in series with the solar-heated fluid to supplement its energy content if insufficient stored heat is available. Of course, when no stored heat is available, the total flow for the fan coil units is directed to the backup heater by the appropriate control valves.

The following descriptions illustrate more specifically the actual mode conditions which would occur in a direct solar heating system.

Mode 1: Collector Thermal Circuit Operation—Domestic Hot Water Circuit Operation

This mode, shown in Figure 31, illustrates the operation of the collector cooling circuit in conjunction with the domestic hot water circuit. Pump No. 1 is activated by a differential thermostat which senses the temperatue differ-

* Cell efficiency may be expressed as $\eta = \eta_o (1 - \beta [T - T_c])$, with insolation at 1000 w/μ^2. η_o is cell efficiency at T_c. In this case, based on Westinghouse[6] data, $\eta_o = 0.16$, $T_c = 25°C$, and $\beta = 5.77 \times 10^{-3}/°C$.

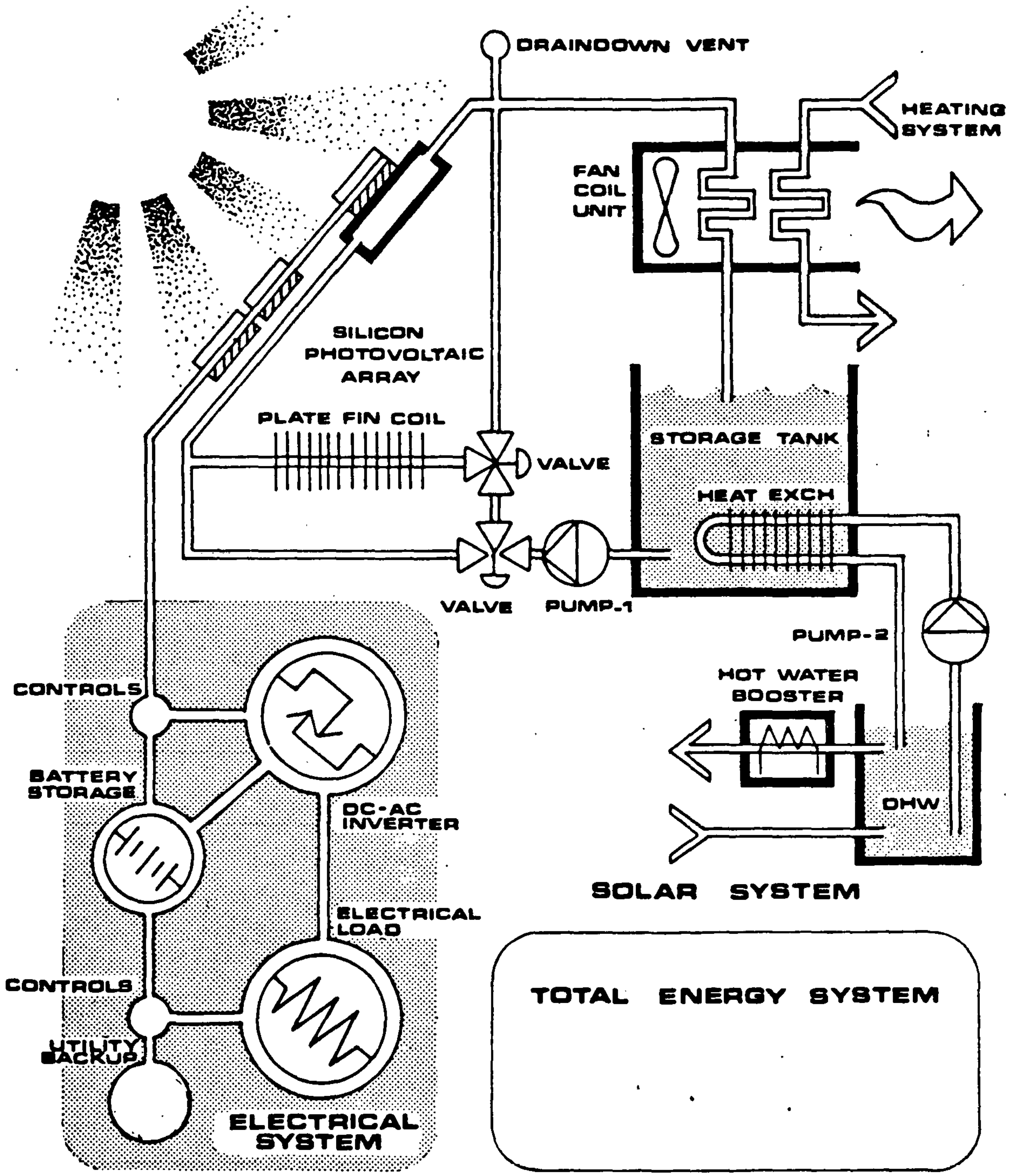


Figure 30. GENERAL SCHEMATIC OF TOTAL ENERGY SYSTEM[6]

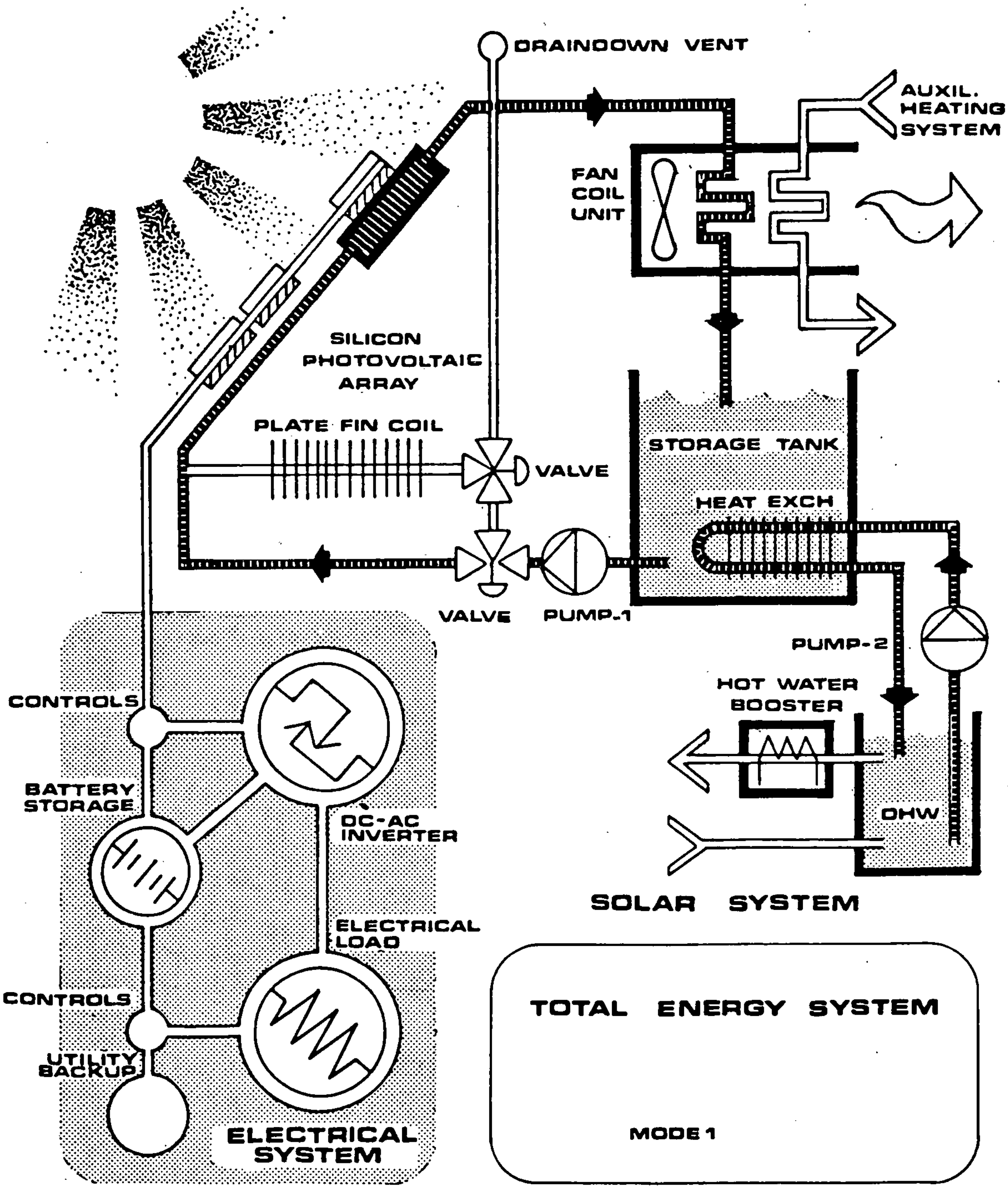


Figure 31. TOTAL ENERGY SYSTEM — MODE 1[6]

ence between the photovoltaic module substrate and the water in the storage tank. If the array requires cooling, water is circulated through the module fluid passages until the thermostat registers an insufficient temperature difference to collect solar energy, or no thermal cooling of the array is required. Pump No. 1 then shuts down thus allowing the fluid in the array, supply, and return pipes to drain down providing freeze protection for the system. To operate the domestic hot water circuit, a differential thermostat would sense a temperature difference sufficient to transfer heat from the main storage tank to the domestic hot water storage tank. Pump No. 2 would then begin operation and continue until the domestic hot water tank reaches the desired temperature. The hot water circuit can also operate when the collector cooling circuit is not functioning.

Mode 2: Nighttime Space Heating

In this mode, illustrated in Figure 32, the space heating thermostat senses a nighttime heating requirement. If the storage tank temperature is sufficiently warm to effect a heat boost to the auxiliary heating system or to provide the entire space heating requirement, Pump No. 1 turns on and the control valves are set to direct the flow of heated water to the fan coil units.

Mode 3: Daytime Space Heating

In this mode, illustrated in Figure 33, the space heating thermostat senses a daytime heating requirement. Assuming that the domestic hot water load has been satisfied, Pump No. 1 begins operation, with the valves positioned to route the fluid from the storage tank through the collector and the fan coil unit and then back to the storage tank. The fan coil unit begins operation to extract heat from the solar water coil. The collector circuit could already have been operating to keep the photovoltaic array cool and charging thermal storage with solar heated fluid.

Mode 4: Photovoltaic Array Protection

This mode, illustrated in Figure 34, is used to make sure that the photovoltaic array temperature does not exceed 130°F. At array temperatures above 130°F, cell efficiency is reduced. If this condition occurs during the daytime when the system is collecting heat, the differential thermostat signals the control valve to route the fluid through the plate fin coil located outside before

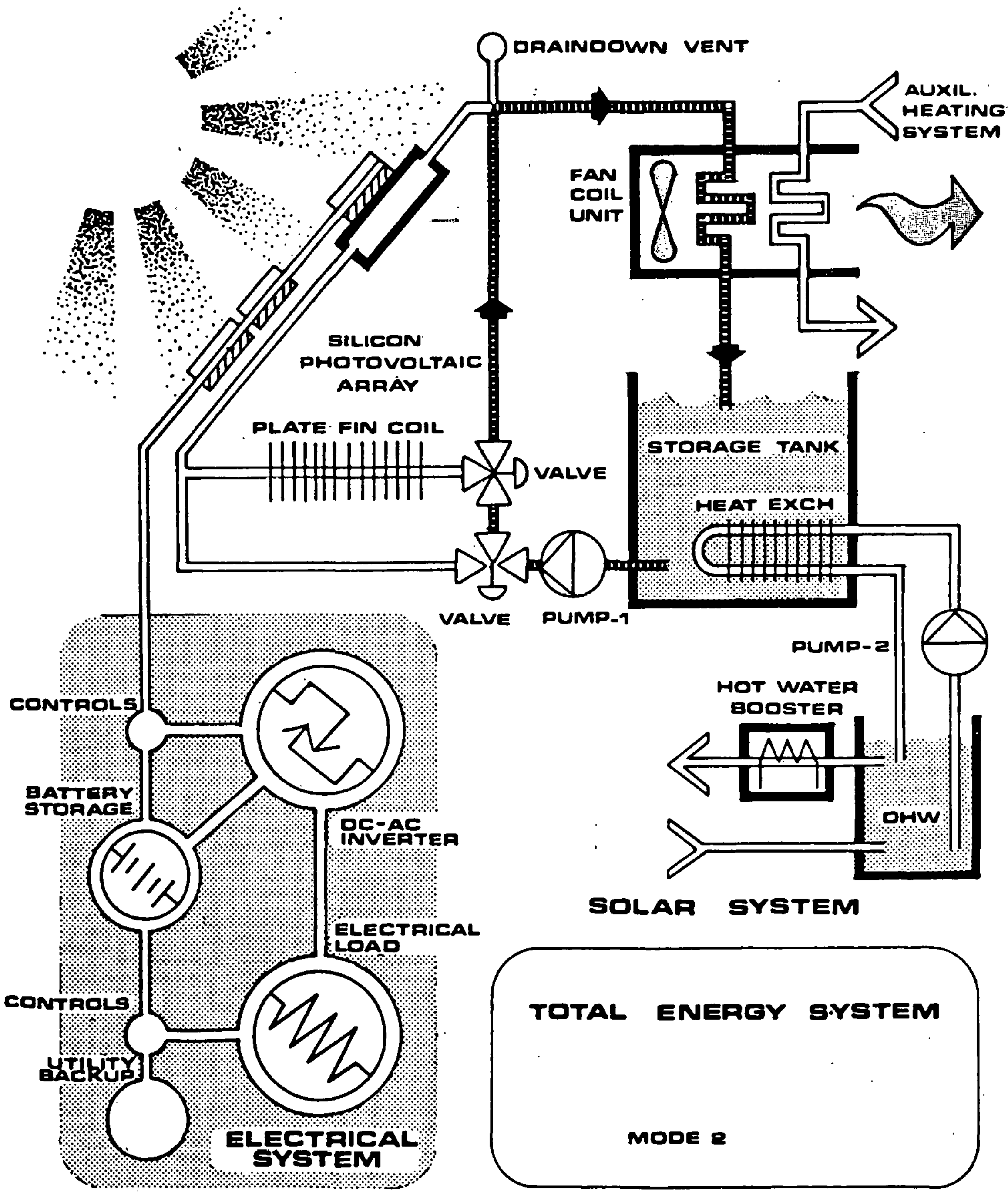


Figure 32. TOTAL ENERGY SYSTEM — MODE 2[6]

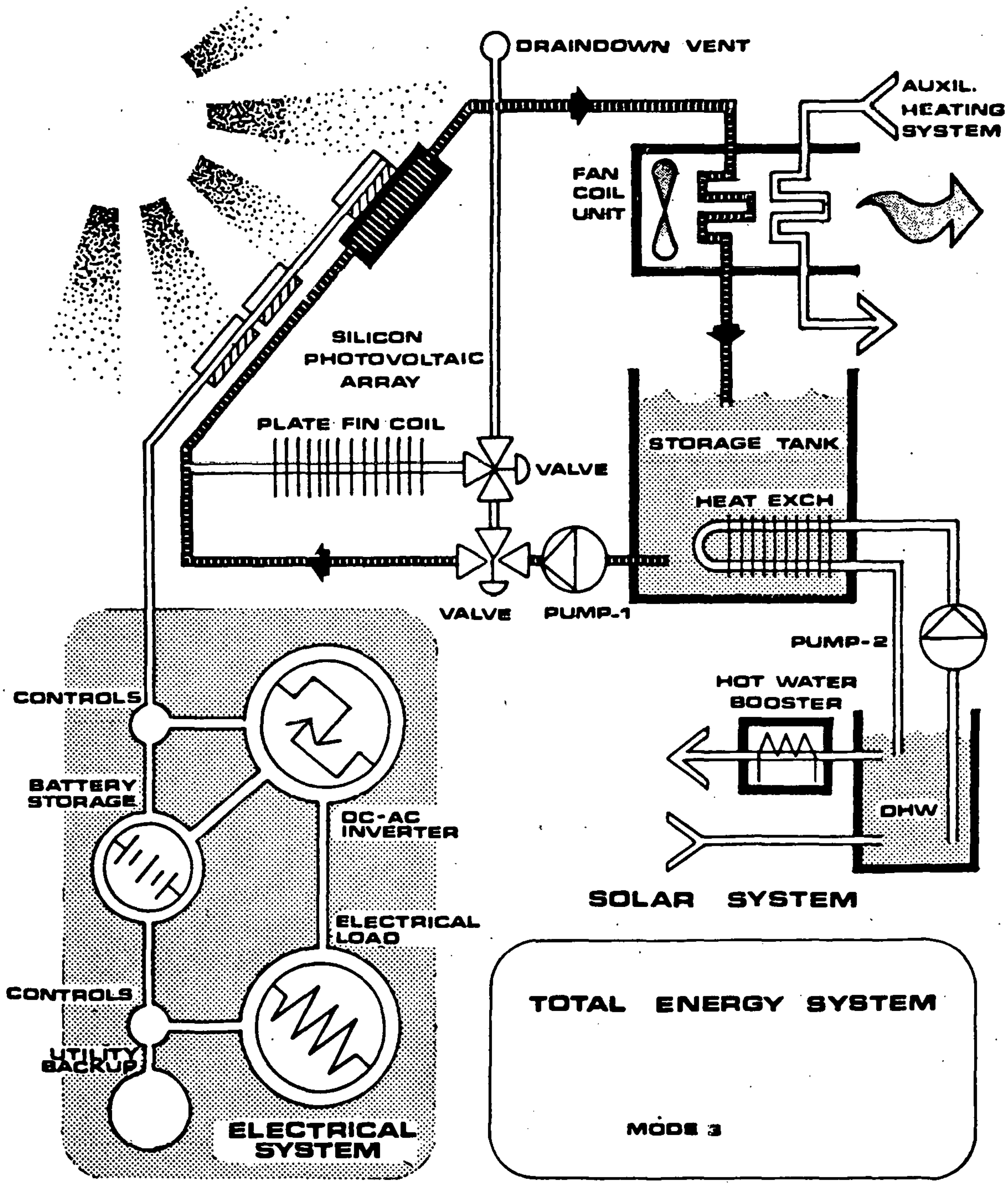


Figure 33. TOTAL ENERGY SYSTEM — MODE 3[6]

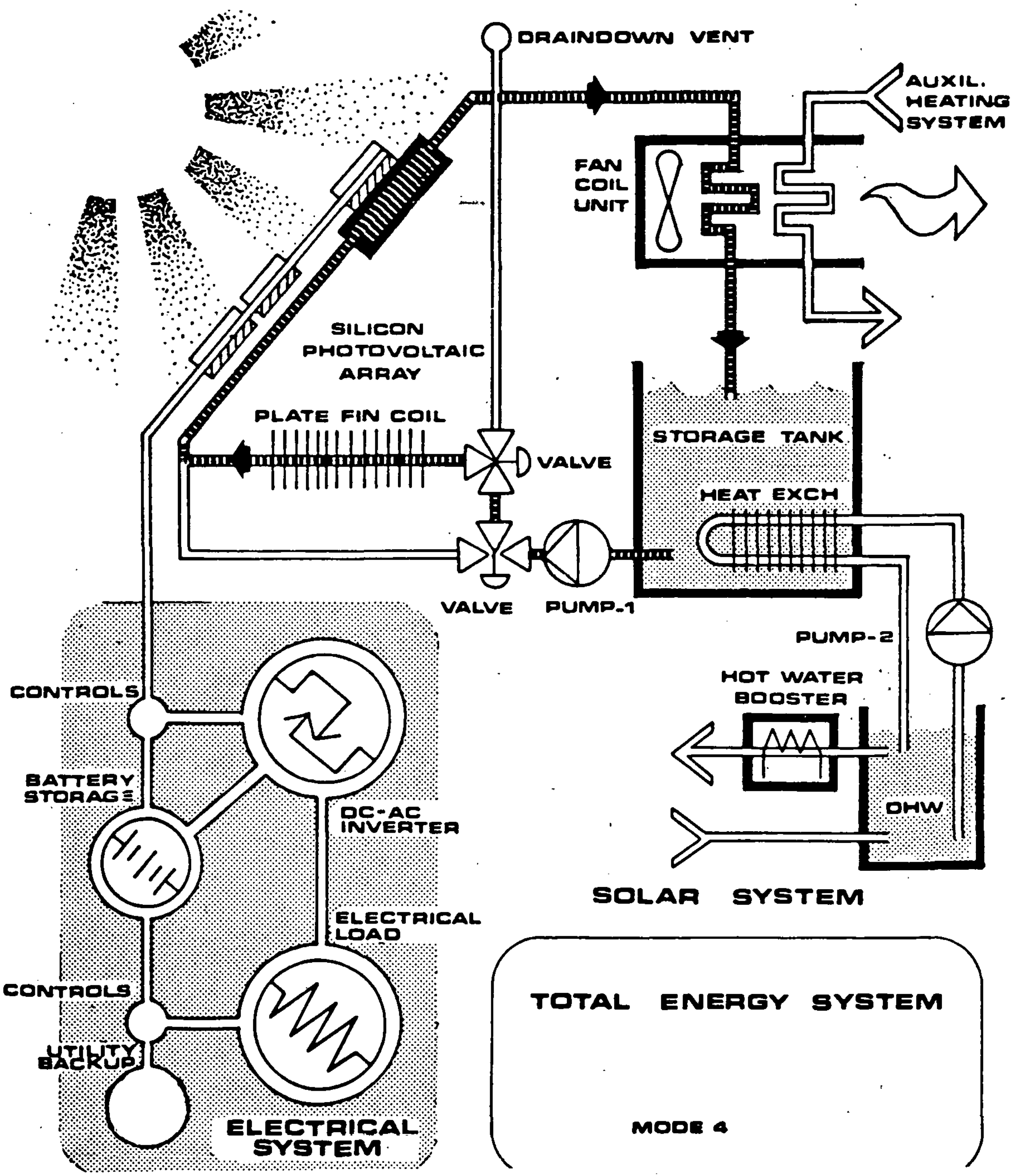


Figure 34. TOTAL ENERGY SYSTEM — MODE 4[6]

it enters the array. The rejection of excess heat assures that the entering water temperature will always be below 110°F, thereby allowing for an approximately 20°F temperature rise across the collector plate without adversely affecting the photovoltaic array's performance.

3.2.3 Component Description of Photovoltaic Total Energy Systems

A residential photovoltaic solar total energy system consists of components to collect electrical and thermal energy and to store this energy in batteries and hot water tanks; power conditioning and control equipment to provide utility quality power and interface with the backup electric utility; and fan coil units, chillers, and back-up heaters to meet the space conditioning requirements of the residence. In the following sections we will elaborate on the descriptions of collectors, storage devices, and power conditioning equipment essential to, and also unique to, residential photovoltaic solar total energy systems.

Collector

The flat plate collector module consists of the single cover glazing, desiccant spacer, photovoltaic cells, thermal absorber plate, and enclosure. Figure 35 shows the general concept of the combined thermal-photovoltaic collectors.

The glazing specified is a single piece of 3/16" clear ("water-white") glass. Double glazing has been avoided in this design because the transmission losses through both pieces of glass would decrease the electrical productivity of the module by about 15%. Although double glazing, acting as an insulating space, would increase the thermal production of the module,the emphasis is on electrical rather than thermal output.

The spacer between the glass and the absorber plate is a metal channel with an encased desiccant to absorb moisture which might leak into the sealed air space and condense on the cover glass or the photovoltaic cells, thus causing reduced electrical production or damage to the module.

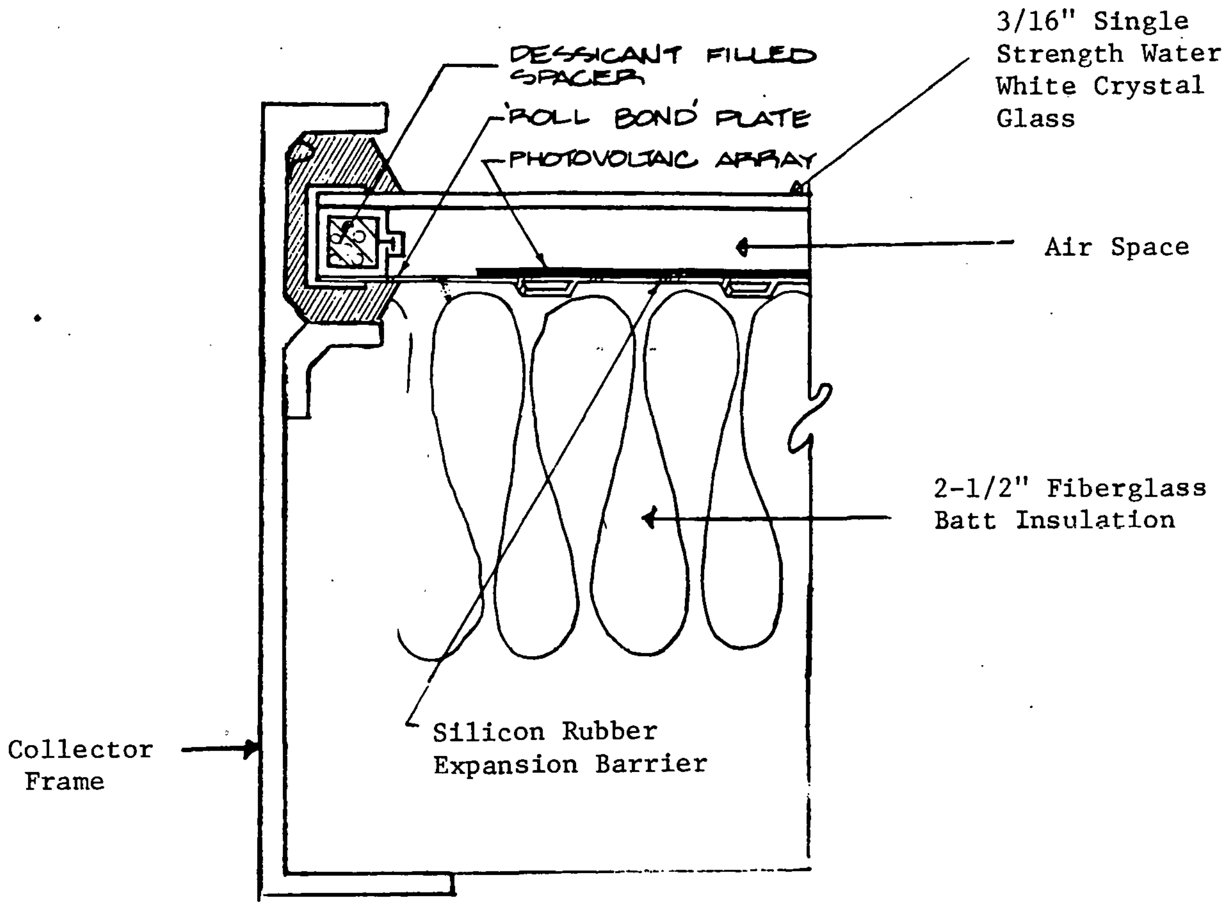


Figure 35. COMBINED PHOTOVOLTAIC-THERMAL COLLECTOR[6]

The absorber is a "Roll-bond"* type copper panel which has a flat top surface to receive the photovoltaic cells. The cells are in turn bonded to the absorber panel with a thin layer of silicon sealant which will accommodate thermal expansion. The photovoltaic array is kept within its optimum thermal operating range by circulating water through channels in the absorber panel.

Battery Storage for the Residential Power System

Because the cost of batteries in a photovoltaic STES is substantial (10% to 20% of overall system capital cost, depending upon collector area and time frame), the sizing of battery storage is important in the development of the most economic system configurations. As can be seen by examination of the output reports from system simulations in Appendix C, the battery capacity of

* Roll-bond is an Olin-Brass Corporation trademark.

15 kWhr per dwelling unit was sufficient to avoid the wasting of electrical power at any time. As a result, it is conceivable that a smaller battery storage capacity might be appropriate in a residential photovoltaic STE system. The impact of this reduction in capacity would be a lowering of system capital cost, perhaps by as much as 10%. Although the evaluation of the potential to reduce battery capacity requirements is beyond the scope of this study, such an effort would entail an examination of the utilization of battery capacity during the yearlong performance of the system, investigating the maximum capacity of the batteries. Subsequently, the size of the battery storage system could be adjusted downward, and performance results could be coupled with system economics to determine the point at which a balance is struck between battery capacity and lost electricity due to insufficient battery capacity, thus achieving the best system economics.

Further discussion of battery storage as a component of solar total energy systems can be found on pp. 67-69 of this volume.

Power Conditioners

Photovoltaic STE systems that incorporate battery storage require a power conditioner for connection to an a.c. system. This is discussed on pp. 69-70 of this volume.

Thermal Storage

Some type of thermal storage should be provided for photovoltaic STE systems. This is discussed on pp. 65-67 of this volume.

Collector Areas for Photovoltaic STE Systems (See Section 2.1.8 of this volume.)

Section 4.
DESIGN PERFORMANCE SIMULATION AND EVALUATION

Using the Energy Requirements tapes (Volume II) and the algorithms developed as part of the conceptual design effort, the performances of the 300°F ORC systems, the 600°F ORC system, and the pholovoltaic system were evaluated by an hourly STES simulation program. The flow diagram for this program is shown in Figure 36.

Hourly performances for the two designs were determined for the different building types (both generic and ASHRAE 90-75 conservative structures) in different regions of the country. Determinations were based on two different scenarios: 1) using purchased power to supplement solar energy, and 2) stand-alone (i.e., no purchased power).

The original intent was to utilize the entire E-Cube package for the evaluation adding whatever subroutines were needed to adapt the program to STES evaluation. Hcwever, overall program considerations suggested that a different program be written and used instead of the E-Cube equipment package; this program was written and used in conjunction with weather tapes* and the load tapes (See Vol. II) to provide the hourly simulation performance. Overall, E-Cube data management format is used.

Space does not permit inclusion of the entire computer output here; however, a sample of the simulation program output is illustrated in Table 49. The example shown is for illustration only and not intended to represent an optimized system.

Table 49, Part 1

- "Polar Mount Parabolic Trough" — describes the type of parabolic trough collector and its orientation. In this case, a polar mount orientation is employed. The other collector orientation method used in some sites was a North-South horizontal trough.

- "Building 7" — is the code for the low-rise, energy conservative dwelling type. The following list summarizes codes for the other dwelling types:

Building No.	Dwelling Type
1	Single-family detached, generic loads, 36 units
2	Townhouse apartment, generic loads, 36 units
3	Low-rise apartment, generic loads, 48 units
5	Single-family detached, conservative loads, 36 units.

* See Appendix B.

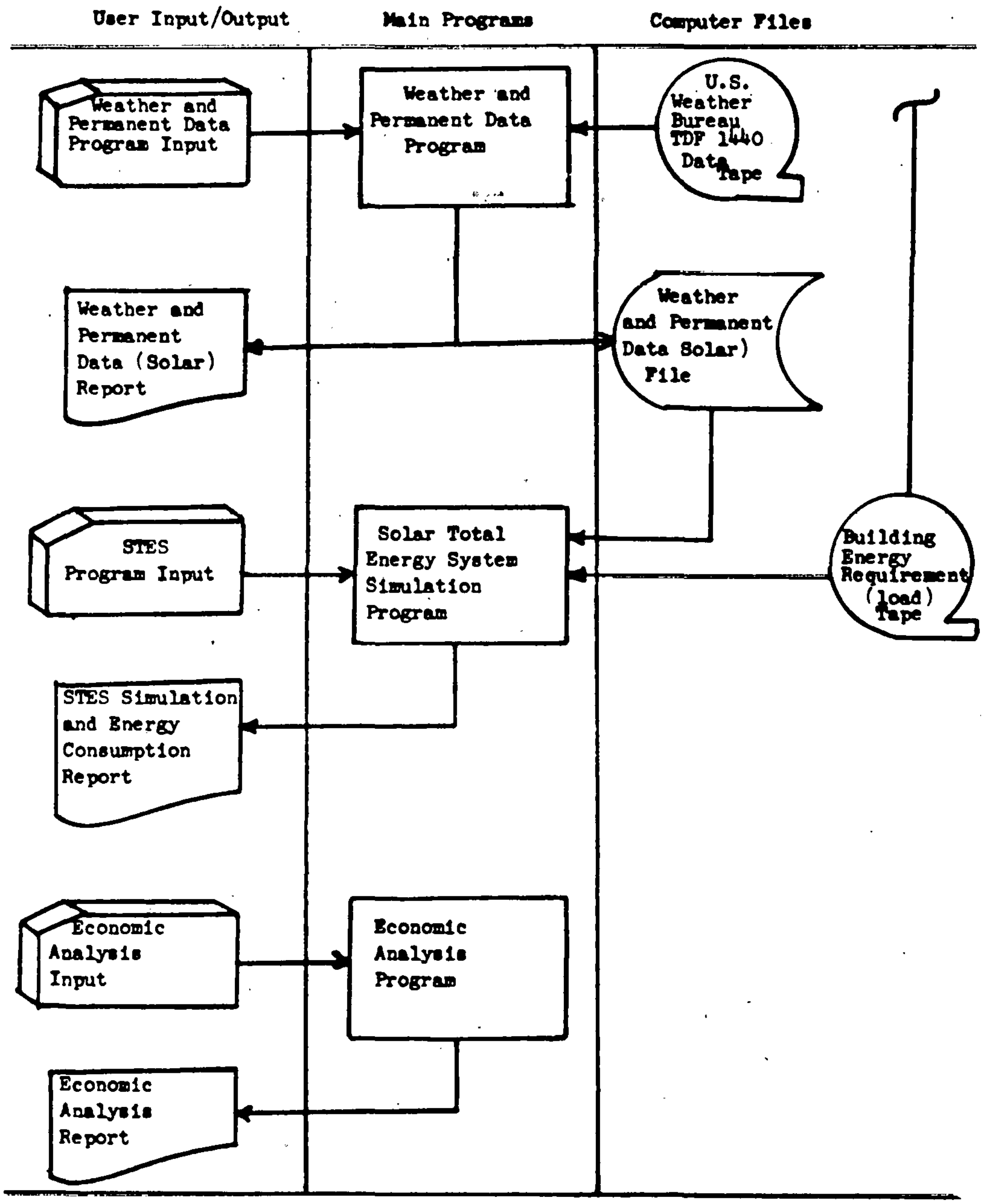


Figure 36. SOLAR TOTAL ENERGY SYSTEM ANALYSIS PROCEDURE

Table 49, Part 1. SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 2787. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.123739+09	.926572+02	.293911+05	.811140+04	.581252+08	.926572+02	.375025+05	.135652+09
FEB	.884785+08	.927756+02	.279710+05	.607813+04	.466418+08	.929290+02	.340491+05	.102440+09
MAR	.720189+08	.882212+02	.293266+05	.650376+04	.630612+08	.882212+02	.358304+05	.108381+09
APR	.156411+09	.892966+02	.264812+05	.102004+05	.735653+08	.892966+02	.366816+05	.171812+09
MAY	.171503+09	.887921+02	.269271+05	.105592+05	.698935+08	.887921+02	.374864+05	.177801+09
JUN	.228866+09	.829166+02	.239660+05	.133482+05	.817267+08	.853149+02	.373142+05	.225282+09
JUL	.337783+09	.830578+02	.229135+05	.166619+05	.698395+08	.851936+02	.395754+05	.282433+09
AUG	.416834+09	.838812+02	.212542+05	.195806+05	.705758+08	.879526+02	.408348+05	.333235+09
SEP	.258095+09	.863841+02	.238774+05	.142572+05	.813132+08	.882563+02	.381346+05	.244308+09
OCT	.239117+09	.876495+02	.271989+05	.125414+05	.614509+08	.906759+02	.397404+05	.211893+09
NOV	.112952+09	.924147+02	.294279+05	.709233+04	.481202+08	.924147+02	.365202+05	.118929+09
DEC	.134502+09	.923786+02	.297078+05	.778639+04	.461312+08	.923786+02	.374942+05	.130607+09
TOTAL	.234089+10	.927756+02	.318438+06	.132717+06	.771143+09	.929290+02	.451154+06	.224274+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

Table 49, Part 2. SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 2787. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.8775+07	.8111+04	.5294+03	.1150+09	.4306+04	.0000	.1361+09	.0000	21.63	57.15	100.00	*100.00*	.5979+03
FEB	.1533+08	.6078+04	.5756+03	.7315+08	.2735+04	.0000	.1020+09	.0000	17.85	54.47	100.00	*100.00*	.5960+03
MAR	.1926+08	.6504+04	.7218+03	.5336+08	.1998+04	.0000	.1091+09	.0000	18.15	41.82	100.00	*100.00*	.5956+03
APR	.1499+08	.1020+05	.5651+03	.1414+09	.5268+04	.0000	.1717+09	.0000	27.81	57.18	100.00	*100.00*	.5964+03
MAY	.2233+08	.1056+05	.8392+03	.1492+09	.5569+04	.0000	.1775+09	.0000	28.17	60.69	100.00	*100.00*	.5949+03
JUN	.5195+06	.1335+05	.1977+02	.2283+09	.8483+04	.1986+06	.2256+09	.0000	55.77	63.70	99.93	*100.07*	.5999+03
JUL	.0000	.1666+05	.0000	.3377+09	.1254+05	.5431+06	.2819+09	.0000	42.10	75.23	99.85	*100.15*	.6000+03
AUG	.0000	.1958+05	.0000	.4166+09	.1541+05	.2451+07	.3311+09	.0000	47.95	78.70	99.41	*100.59*	.6000+03
SEP	.5157+07	.1426+05	.1931+03	.2528+09	.9253+04	.4175+07	.2410+09	.0000	37.39	66.26	98.63	*101.39*	.5988+03
OCT	.9803+07	.1254+05	.3686+03	.2293+09	.8536+04	.0000	.2117+09	.0000	31.56	71.00	100.00	*100.00*	.5978+03
NOV	.5281+07	.7092+04	.1989+03	.1077+09	.4024+04	.0000	.1192+09	.0000	19.42	59.54	100.00	*100.00*	.5987+03
DEC	.2139+07	.7786+04	.8063+02	.1324+09	.4956+04	.0000	.1307+09	.0000	20.77	64.68	100.00	*100.00*	.5995+03
TOTAL	.1036+09	.1327+06	.5892+04	.2237+10	.8307+05	.7368+07	.2238+10	.0000	29.42	65.53	99.74	*100.26* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1816+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

Table 49, Part 3. SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 2787. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.59550+05	.34102+04	.55610+05	.00000	.804650+08	.103056+05	.4848+02	.5191755+02
FEB	.49649+05	.29068+04	.48295+05	.00000	.665293+08	.119912+05	.4808+02	.4942842+02
MAR	.62320+05	.43343+04	.62159+05	.00000	.876971+08	.116935+05	.5049+02	.5062259+02
APR	.70711+05	.65250+04	.69268+05	.00000	.996461+08	.153337+05	.5056+02	.5161670+02
MAY	.73363+05	.85733+04	.69281+05	.00000	.971829+08	.170956+05	.4753+02	.5033134+02
JUN	.83098+05	.11044+05	.76276+05	.00000	.110948+09	.166679+05	.4791+02	.5219102+02
JUL	.73229+05	.99786+04	.67903+05	.00000	.959945+08	.166420+05	.4704+02	.5072501+02
AUG	.70366+05	.87148+04	.67688+05	.00000	.964004+08	.172327+05	.4916+02	.5110092+02
SEP	.73712+05	.73024+04	.73285+05	.00000	.110406+09	.172936+05	.5374+02	.5405523+02
OCT	.59866+05	.45326+04	.58372+05	.00000	.854987+08	.150764+05	.5124+02	.5255556+02
NOV	.51290+05	.32476+04	.48226+05	.00000	.681660+08	.134947+05	.4769+02	.5071621+02
DEC	.51219+05	.30415+04	.46871+05	.00000	.657897+08	.109150+05	.4609+02	.5036410+02
TOTAL	.77837+06	.73610+05	.74323+06	.00000	.106471+10	.172936+05 (ANNUAL PEAK)	.4908+02	.5140140+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

Building No.	Dwelling Type
6	Townhouse apartment, conservative loads, 36 units
7	Low-rise apartment, conservative loads, 48 units

- "Los Angeles" — is the site where, in this case, system performance is being evaluated.

- "Solar Collector Aperture Area" — is the total collector area for parabolic trough collectors located on the roof of the low-rise apartments. In this case, the aperture area is 2787 sq ft.

- "STES Chart 4" — refers to the solar total energy system conceptual design using a high-temperature (600°F) Organic Rankine Cycle (ORC) heat engine with an electric utility backup for any shortfall in electrical energy production and fossil fuel backup for any deficiency in thermal energy required.

- "Purchased Energy" — refers to the monthly determination and annual summary of energy purchased, both fossil fuel and electricity, to supplement the system which cannot wholly provide for system energy needs.

- "Fuel Consumption" — is a monthly tabulation of total fossil fuel burned by the system. Fossil fuel is burned in the primary boiler to supplement the energy output from the collector. Fossil fuel is also burned in the primary boiler when no solar or high-temperature thermal energy is available and a thermal load exists. Thus, the thermal load is met and the best use of the fuel value is made by producing work (electricity) and thermal energy. Fossil fuel is burned in the secondary boiler when the thermal load is so great that providing heat at the ORC condenser would cause the ORC to produce more electricity than required. Because the operating philosophy of the system is such that electricity cannot be wasted, fuel must be burned in the secondary boiler to meet thermal loads. In this case peak fuel consumption occurs in August and is attributable to the large air conditioning load.

- "Electric Demand" — is the monthly peak electrical demand by the system in kW. The figure in the "total" summary is actually the peak electric demand seen by the system. In this case, the peak demand of 93 kW occurred in February and is somewhat smaller than the installed capacity of the ORC (100 kW).

- "Electric Consumption" — is the monthly and annual total amount of utility electricity purchased by the system.

- "System Energy Displacement" — is the quantity of energy produced by the system in comparison to a similar system operated exclusively on fossil fuel and utility electricity. This is not the same as the displacement of energy compared with a conventional system which might use different types of space conditioning machinery, vapor compression chillers instead of absorption chillers, for instance, thus producing a different totality and mix of energy use. Displacement compared to conventional systems is treated in the discussion of system economic analysis (Volume IV).

- "Electric Displacement" — is the electric energy produced by the solar energy and primary fuel inputs to the solar total energy system.

- "Thermal Displacement" — is the portion of thermal energy produced at the ORC condenser relative to the thermal requirement that is attributable to the solar energy input to the system. Thus, heat produced at the condenser by fossil fuel burned in the primary boiler and heat produced by the secondary boiler are not counted in the determination of thermal displacement. In this case, only 34% of the thermal requirement was displaced by the solar energy input, although nearly 100% of system thermal needs were met by condenser heat.

- "Building Electric/Thermal Loads" — is a monthly and annual summary of the total electric loads for cooking, lights, appliances, fan coils, and pumps, and <u>input</u> thermal requirements to the heating and cooling machinery (and domestic hot water) after the efficiencies of the space conditioning machinery have been accounted for.

- "Electric Consumption" — is the monthly and annual summary of all electric loads required by the living spaces and space conditioning machinery.

- "Thermal Requirements" — is the monthly and annual summary of input requirements to the space conditioning apparatus after machinery performance is accounted for. The heating and air conditioning loads are computed by the hour relative to structure design, regional characteristics, and hourly temperatures from the weather tapes.

<u>Table 49, Part 2</u>

- "Fuel to Boost Collector Temperature" — is the quantity of fuel used to boost the collector outlet temperature to 600°F. The philosophy of collector operation is to allow the collector outlet temperature to float through a range of temperatures (550° to 600°F) under conditions where collected solar energy is less than the load but such that full flow of the heat transfer fluid through the collector field does not result in a collector outlet temperature less than the minimum float temperature.

- "Electricity Produced by Solar Plus Fuel" — tabulates the total monthly and annual electrical energy outputs by the system. The fuel component comes in two aspects of system operation. The first is the fuel consumed to boost collector outlet temperature, the second is fuel consumed to track the thermal loads while at the same time producing electricity to obtain the maximum useful extraction of energy from fuel consumed.

- "Electricity Produced by Fuel in Column 1" — refers to the amount of electricity generated by the fuel used to boost collector outlet temperature to 600°F.

- "Fuel to Run System When No Solar or Storage is Available" — is the amount of fuel burned in the primary boiler to produce sufficient heat at the heat engine condenser to track thermal loads. By operating the heat engine to simultaneously generate electricity, the maximum recovery of useful energy from the fuel is obtained.

- "Electricity Produced by Fuel in Column 4" — is the quantity of electricity produced by the use of fossil fuel to track thermal loads and also generate electricity when solar or stored thermal is unavailable. The amount of electricity attributable to solar energy collected is the difference between the sum of Columns 3 and 5 and Column 2.

- "Fuel to Meet Thermal Requirements" — under circumstances when complete thermal tracking would produce more electricity than demanded, the secondary boiler is fired to produce thermal energy for satisfaction of system thermal requirements so that electricity is not wasted.

Columns 7, 8, 9, 11, and 12 are highlighted by stars because of their importance in the meaningful understanding of simulation results.

- "ORC Condenser Heat" — is the heat produced at the condenser of the heat engine when electricity is being generated. The monthly and annual totals may be compared to system thermal requirements to get a rough sense of how close the reject heat comes to satisfying the thermal loads.

- "Heat Rejection to the Cooling Tower" — under circumstances when low temperature thermal storage is full or a demand for electricity exists with little or no requirement for thermal energy (as in the spring or fall), the heat engine operates to produce electricity and the condenser heat is wasted. The system is designed to minimize the waste of thermal energy.

- "Percent Electricity by Solar Plus Fuel" — is the percentage of the electricity requirement satisfied by the solar total energy system and is summarized monthly and annually.

- "Percent of 9 by Fuel" — is the fraction of electricity produced that is attributable to fuel burned in the primary boilers to boost collector temperature or to allow thermal tracking.

- "Percent Thermal From Condenser Heat" — is the monthly and annual tabulation of how closely the ORC condenser heat succeeded in meeting the hour-by-hour thermal loads imposed on the system. Of course, a substantial amount of that condenser heat may be attributable to fuel burned in the primary boiler as suggested by Column 10.

- "Percent Utilization" — is a measure of how well the system is able to utilize the heat available at the ORC condenser in meeting thermal loads. Defined as the ratio of the thermal load to the sum of the condenser heat used to satisfy thermal loads and heat rejected at the cooling tower (sums calculated hourly); a system showing high utilization is one able to match condenser heat to the load very closely and reject little heat. Such a system has a utilization close to 100%. Utilization is considered a valuable indication of the best system size in that systems with high utilization generally show the most favorable economics; larger systems show poorer economics; smaller systems also show poor economics despite good utilization because they underutilize their capital intensive components. Utilizations are calculated monthly and annually. Utilization exceeds 100% where the sum of condenser heat and cooling tower reject heat is less than the monthly thermal load.

- "Average Collector Fluid Outlet Temperature" — is the average temperature at the collector outlet and indicates the extent to which the collector temperature floats within its allowed range (550° to 600°F). Generally, collector outlet temperature remains close to 600°F, suggesting that the collector does not necessarily spend very much time in this mode of operation. Thus, a fixed collector outlet temperature might be a more appropriate design alternative.

- "High-Temperature Heat Rejected to Tower" — is the total amount of primary heat that is wasted under circumstances when high-temperature storage is full and collected energy exceeds that required to produce electricity.

- "Purchased Electricity 8 p.m. (a.m.) — 8 a.m. (p.m.)" — is the amount of electricity purchased during these 12-hour periods and is used to indicate the impact of time of day electricity pricing on STES economics.

Table 49, Part 3

- "Direct Normal Radiation" — is the monthly and annual direct solar radiation available to a fully-tracking solar collector.

- "Diffuse Radiation" — is the monthly and annual solar radiation that is diffused by dust, water vapor, clouds, etc. and is available to non-concentrating collectors. The diffuse radiation is not available to the concentrating collectors used in this study.

- "Collector Beam Radiation" — is the beam radiation in the plane of the collector and accounts for the cosine effect in reducing solar radiation to a collector that does not track perfectly (i.e., not always normal to) the sun.

- "Energy Collected" — is the total useful output of the collector array and accounts for the total area of the array. This is the solar energy input into the system.

- "Peak Fluid Mass Flow" — is the maximum flow rate through the collector field and corresponds to the mass flow to supply energy by the ORC under a high load requirement.

- "Overall Collector Efficiency" — relates the useful collector output to the radiation incident on a perfectly tracking collector. The overall collector efficiency accounts for both the thermal losses from the collector and its imperfect tracking (cosine losses).
- "Collector Efficiency" — accounts for the fraction of incident solar energy on the collector aperture that appears as useful output.

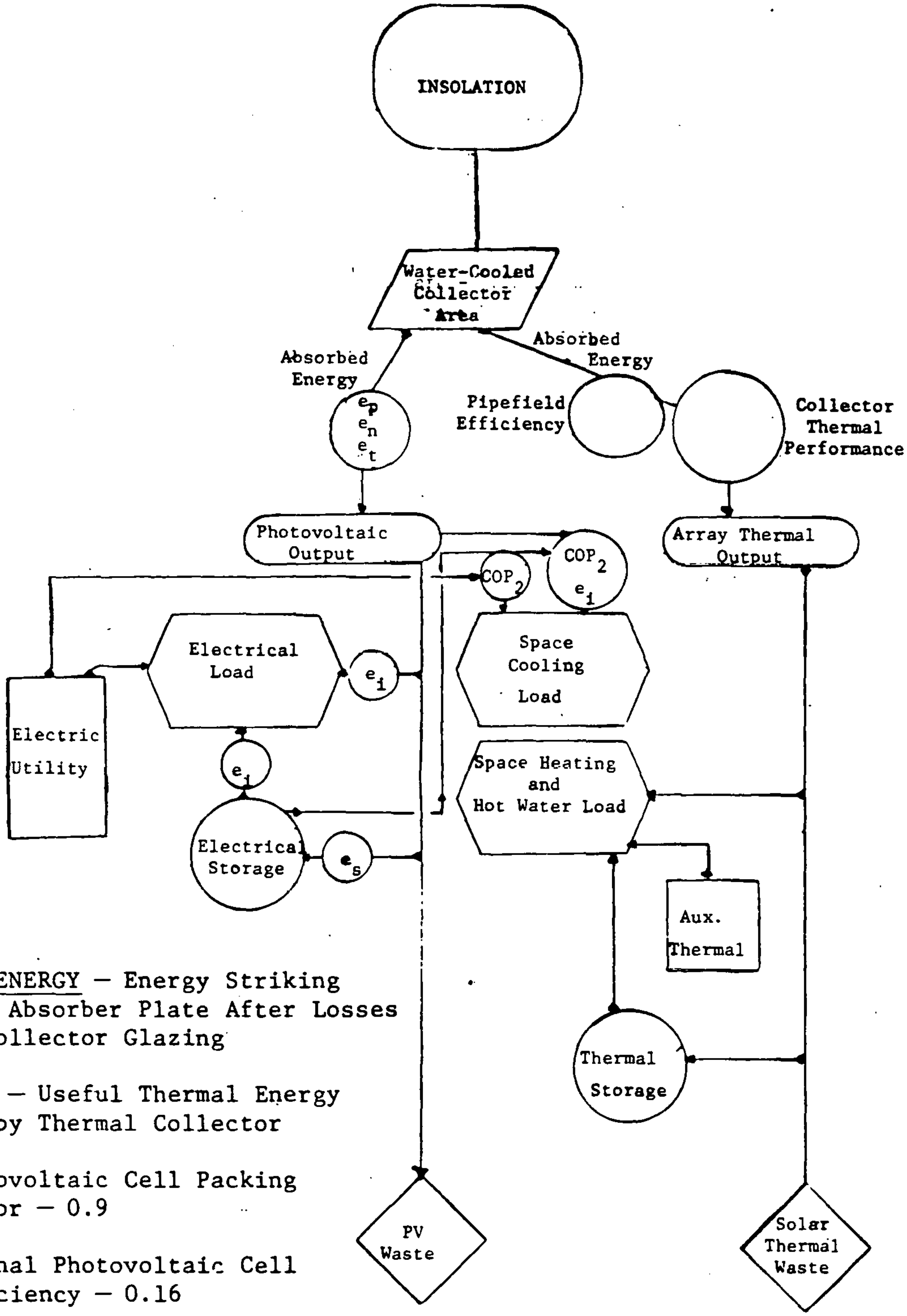
Simulation Model of Photovoltaic Systems

The energy balance program calculates the solar energy received and converted by the photovoltaic array, and determines its means of transfer to load. The available energy is utilized by the load through the subsystems needed to provide energy in the proper form at the time required by the electrical and thermal loads. The subsystems included are the inverter which converts the solar cell output to a constant voltage, 60 Hertz output; the batteries which supply the load when solar energy is not available, in addition to providing peak power; and the thermal storage and heat transfer apparatus together with all of the controls for the entire system. In order to accomplish this, it is first necessary to calculate on an hourly basis the insolation received throughout the year by the collector in its geographical and geometric location. The energy actually received by the cell is termed the absorbed energy and is less than the energy calculated as falling on the glass outer surface of the array. The computed absorbed energy suffers further losses as it is converted to electrical energy and conditioned for use by the residential loads. These include cell, module, array, inverter, and battery losses — all of which affect overall system efficiency.

Figure 37 shows a computer model developed by the IGT project team for evaluating system components and performance. This analysis considers both received solar energy and residential structure thermal and electrical energy requirements, both on an hourly basis.

The system to be evaluated is determined by specifying the area and tilt (collector arrays are tilted at local latitude) for the water-cooled collector arrays, efficiencies of the various components of the system, and the thermal characteristics of the residences.

The hourly electrical load is specified as an input to the model. Cooling loads are supplied by an electrically-driven vapor compression system



ABSORBED ENERGY — Energy Striking Collector Absorber Plate After Losses Through Collector Glazing

COLLECTOR — Useful Thermal Energy Produced by Thermal Collector

e_p — Photovoltaic Cell Packing Factor — 0.9

e_n — Nominal Photovoltaic Cell Efficiency — 0.16

e_t — Photovoltaic Cell Efficiency Reduction Factor for High-Temperature Operation — 0.83

e_i — Inverter Efficiency — 0.93

e_s — Battery Storage Efficiency — 0.80

COP_1 — Coefficient of Performance of Vapor Compression Chiller — 2.34

Figure 37. PHOTOVOLTAIC STES SIMULATION MODEL

(COP = 2.34; EER = 8.0*) and are therefore counted as electrical loads. Cooling loads are calculated hourly from previously determined structure energy requirements and equipment performance. With the exception of the cooling load, electrical loads are determined in the same way as for the thermal STES conceptual designs.

In actual operation, the strategy assumed for distribution of the electrical energy is as follows:

1. Electrical energy from available insolation is used directly to supply the load. If it exceeds the load requirement, it is stored. If the storage capability available at the time is exceeded, the remaining insolation is wasted.
2. If available electrical energy from insolation is not sufficient or not available, the load is supplied by battery storage to the degree necessary.
3. If battery storage is exhausted and insolation does not provide sufficient electrical energy for the load, the insufficiency is supplied by the backup source — a utility connection.

The space heating load is computed hourly from previously determined structure energy requirements and domestic hot water load. Space heating is supplied by the following methods:

1. Thermal energy from available insolation is used directly to supply the load. If it exceeds the load requirement, it is stored. If the storage capability available at the time is exceeded, the remaining insolation is wasted.
2. If available thermal energy from insolation is not sufficient or not available, the load is supplied by thermal storage to the extent necessary.
3. If thermal storage is exhausted and insolation does not provide sufficient thermal energy for the load, the insufficiency is supplied by the backup source — a utility connection supplying gas or onsite fuel oil tank.

The efficiencies of the various system components are taken into account at the appropriate place. These efficiencies are indicated in Figure 37 by the smaller circular blocks. Only the absorbed energy and collector thermal performance are computed hourly. The remaining efficiencies are input constants. Values for absorbed energy are taken from computer tapes supplied through the courtesy of Westinghouse.

$$* \quad EER = \frac{\text{Nameplate Rating Cooling Capacity (Btu/hr)}}{\text{Electrical Input Requirement (kW)}}$$

The overall efficiency of the photovoltaic STES is a function of many factors in addition to the efficiency of the solar cell. The factors contributing to overall system performance are defined as follows:

e_c = collection efficiency or the relationship between the cell absorbed energy and available insolation. The product $I_A e_c$ is called absorbed energy in our analysis, and is calculated by the hour for the total energy system.

e_n = nominal cell efficiency at 25°C, air mass one.

e_p = packing factor relating solar cell area to total array area.

e_t = loss related to elevated solar cell operating temperature.

e_i = inverter efficiency.

e_s = electrical storage efficiency.

The values used for the various efficiencies are as follows:

$e_n = 0.16$
$e_p = 0.9$
$e_t = 0.83$
$e_i = 0.93$
$e_s = 0.80$.

Thermal output is derived from the value determined for absorbed energy as:[6]

$$\text{Thermal output (kWh)} = (0.8)(\text{absorbed energy}) - (0.005)(55 - T_A\,°C)$$

T_A = ambient temperature.

The combustion efficiency of the backup furnace is 80%.

A sample of the simulation program output is illustrated in Tables 50 a. 51. Following are descriptions of the contents of the tables:*

- "Raleigh, North Carolina — Collector Tilt Equals North Latitude in Degrees." Raleigh is the site where, in this case, system performance is being evaluated. The collector array performance is established for a south-facing flat plate, water-cooled photovoltaic array tilted up from the horizontal at an angle equal to local latitude. In this case tilt angle is 32.9 degrees.

*Building thermal and electric loads correspond to a 48 unit, low-rise structure.

Table 50. PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 8596. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.348304+09	.958802+02	.362098+05	.692283+04	.577674+08	.958802+02	.431926+05	.336475+09
FEB	.247812+09	.942552+02	.323100+05	.674899+04	.547061+08	.942552+02	.390589+05	.252956+09
MAR	.741148+08	.114583+03	.255381+05	.109942+05	.120000+09	.115563+03	.365322+05	.179292+09
APR	.360708+08	.163920+03	.302188+05	.946800+04	.967652+08	.168636+03	.396868+05	.125622+09
MAY	.000000	.182190+03	.415152+05	.106571+05	.102843+09	.190556+03	.521723+05	.102843+09
JUN	.000000	.208015+03	.508073+05	.106353+05	.752083+08	.210417+03	.614426+05	.752083+08
JUL	.000000	.205219+03	.581203+05	.105391+05	.777152+08	.208935+03	.686595+05	.777152+08
AUG	.000000	.198523+03	.540205+05	.101037+05	.777152+08	.201711+03	.641242+05	.777152+08
SEP	.000000	.177117+03	.417372+05	.101225+05	.752083+08	.182746+03	.518597+05	.752083+08
OCT	.266463+08	.136747+03	.317748+05	.844689+04	.952649+08	.143910+03	.402217+05	.116582+09
NOV	.159216+09	.958802+02	.350050+05	.558516+04	.587122+08	.958802+02	.405901+05	.186085+09
DEC	.339222+09	.966302+02	.380457+05	.503129+04	.331163+08	.966302+02	.430770+05	.304494+09
TOTAL	.123146+10	.208015+03	.475354+06	.105251+06	.924978+09	.210417+03	.580605+06	.191015+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

Table 51. PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 8596. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.750751+04	.577676+08	.692283+04	.348384+09	.000000	.000000	.160278+02	.171685+02	.623157+03	.582462+03
FEB	.734508+04	.552698+08	.674699+04	.247812+09	.000000	.000000	.172790+02	.216268+02	.577900+03	.462389+03
MAR	.122314+05	.125750+09	.109942+05	.741148+08	.000000	.633269+07	.300944+02	.669301+02	.330013+03	.141920+03
APR	.104711+05	.107912+09	.946800+04	.360708+08	.000000	.359271+07	.238566+02	.770290+02	.417065+03	.125174+03
MAY	.116238+05	.133075+09	.106571+05	.000000	.000000	.325871+08	.204267+02	.100000+03	.486557+03	.759380+02
JUN	.114373+05	.132675+09	.106353+05	.000000	.000000	.545227+08	.173093+02	.100000+03	.577721+03	.579725+02
JUL	.113329+05	.126629+09	.105391+05	.000000	.000000	.500190+08	.153499+02	.100000+03	.651471+03	.608413+02
AUG	.108680+05	.126610+09	.101037+05	.000000	.000000	.500001+08	.157565+02	.100000+03	.634660+03	.608503+02
SEP	.109838+05	.135795+09	.101225+05	.000000	.000000	.585975+08	.195190+02	.100000+03	.511911+03	.562071+02
OCT	.933399+04	.983792+08	.844689+04	.266463+08	.000000	.621843+07	.210008+02	.817150+02	.473773+03	.114878+03
NOV	.607714+04	.538947+08	.558516+04	.159216+09	.000000	.000000	.137599+02	.315513+02	.725642+03	.316944+03
DEC	.543633+04	.331163+08	.503129+04	.339222+09	.000000	.000000	.116798+02	.108759+02	.855916+03	.919468+03
TOTAL	.114647+06	.118689+10	.105251+06	.123146+10	.000000	.261670+09	.181279+02	.484259+02	.550450+03	.160939+03

PURCHASED ELECTRICITY 8PM-8AM = .2400+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .2354+06 KWH

ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

- "Solar Collector Aperture Area" — is the total collector area of the flat plate photovoltaic arrays located on the roof of the low-rise apartments. In this case, the aperture area is 8,596 sq ft.

- "Purchased Energy" — refers to the monthly determination and annual summary of energy purchased, both fossil fuel and electricity, to supplement the system which cannot wholly provide for system energy needs.

- "Fuel Consumption" — is a monthly and annual tabulation of total fossil fuel burned by the system (at 80% efficiency). Fossil fuel is consumed when waste heat recovery from the photovoltaic array combined with stored thermal energy is insufficient to meet the building's thermal requirements.

- "Electric Demand" — is the monthly peak electrical demand by the system in kW. The figure in the "total" summary is actually the peak electric demand seen by the system. The peak demands in general exceed the 100-kW system size prescribed for the residential solar total energy systems. This is because the system is sized for 48 low-rise dwelling apartment units — in the case of the thermal systems using absorption chillers the peak load was about 100 kW; however, because electrically driven vapor compression air conditioning is used in the photovoltaic system, a significant additional electric load is imposed on the system. In this case, the peak demand of 208 kW occurred in June and is associated with summer air-conditioning loads.

- "Electric Consumption" — is the monthly total amount of utility electricity purchased by the system.

- "System Energy Displacement" — is the quantity of energy produced by the system in comparison to a similar system operated exclusively on fossil fuel and utility electricity. This is not the same as the displacement of energy compared to a conventional system which might use different types of appliances and space conditioning equipment, thus producing a different totality and mix of energy use.

- "Electric Displacement" — is the electric energy produced by the photovoltaic array that ultimately provides useful energy to the residence after storage and inverter losses are accounted for.

- "Thermal Displacement" — is the quantity of thermal energy recovered from cooling the photovoltaic array that ultimately satisfies the building's thermal needs after losses and the quantity of thermal energy wasted because of fuel storage are accounted for. Thermal energy displacement is effectively the difference between building thermal loads and the output of the auxiliary boiler.

- "Building Electric/Thermal Loads" — is a monthly and annual summary of the total electric loads for cooking, lights, appliances, fan coils, pumps, and air conditioning and thermal requirements for heating and domestic hot water.

- "Electric Consumption" — is the monthly and annual summary of all electric loads required by the living spaces and space conditioning machinery. In particular, the electric consumption data include the input requirements for a vapor compression chiller operating at a COP of 2.34.

- "Thermal Requirements" — is the monthly and annual summary of space heating and hot water loads. The heating and air-conditioning loads (air-conditioning loads are used to calculate input requirements for vapor compression chillers as tabulated under "Electric Consumption") are computed by the hour relative to structure design, regional characteristics, and hourly temperatures from the weather tapes.

Table 51

- "D.C. Electrical Output From Photovoltaic Array" — is the monthly and annual tabulation of output from the photovoltaic array after losses through the cover glazing, photovoltaic inefficiency due to elevated temperature operation, and the nominal efficiency of the cell are accounted for. Although the electrical output suffers further losses due to inversion to alternating current and/or recovery from battery storage, this column may be compared to the electric consumption from Table 1 to get a rough idea of how close array electrical output comes to meeting system electric loads.

- "Thermal Output of Photovoltaic Array after Losses." The photovoltaic array operates at elevated temperature with a coolant loop operated to recover the waste heat generated by the inefficiencies of photovoltaic conversion. The recovered thermal energy at 130°F loses energy through the pipes conveying it to thermal storage (10% of the thermal energy is lost in the single-family detached application, only 2% in the townhouse and low-rise applications). This column tabulates the monthly and annual total recovered thermal energy from the photovoltaic array. These values may be compared with the system thermal requirements to see how close the recovered thermal energy matches the thermal loads imposed by the building structure.

- "Electric Load Met By Solar" — is the total amount of electricity produced by the photovoltaic array after the effects of conversion losses, battery inefficiencies, and the mismatch of solar availability and electric loads are accounted for. The values in this column are always less than the values tabulated in Column 1.

- "Fuel to Meet Thermal Loads" — is the monthly and annual tabulation of the fuel consumed in the auxiliary boiler in order to satisfy the lack of sufficient thermal energy recovered from the photovoltaic array.

- "Electricity Wasted" — is the monthly and annual tabulation of the quantity of electricity generated by the system that must be wasted because battery storage is filled. In this case no electricity is wasted, indicating that sufficient battery storage has been provided for the system. More detailed studies are required to achieve the necessary trade-off in battery capacity and cost versus the value of energy wasted due to insufficient battery storage capacity in order to find the most economic size for this expensive system component.

- "Thermal Energy Wasted" — is the quantity of thermal energy recovered from cooling the photovoltaic array that must be rejected because thermal storage is full. Note that in Table 61 thermal energy must be rejected in spring, summer, and fall because the thermal requirements for space heating and domestic hot water are very small compared with the amount of heat recovered from the photovoltaic array.

- "Percent Electric Load Met by Solar" — is the percentage fraction of the electric load met by the combination of photovoltaic output and battery storage. The monthly and annual tabulation indicates how well the array size (in this case 8596 sq ft) succeeded in meeting system electrical loads (in this case the annual percentage was 18%, with a peak contribution of 30% in March).

- "Percent Thermal Load Met by Waste Heat" — is the percentage fraction of the thermal load met by the combination of heat recovered by cooling the photovoltaic array and thermal storage. The monthly and annual tabulation indicates how well the array size (in this case 8596 sq ft) succeeded in meeting the system thermal loads. In this case the system easily met 100% of the late spring, summer, and early fall thermal loads, which are small compared to the reject waste heat, but only provided an annual contribution of 48% because of the large winter thermal loads in relation to the availability of recovered thermal energy.

- "Electric Utilization" — is a measure of how well the electricity produced by the array is used to meet electrical loads. Utilization is the ratio of electrical load to array electrical output. High utilization is desirable as it implies effective use of the electricity produced by the array. Low utilization means costly electricity is wasted which probably compromises system economics. In this case the monthly and annual utilizations are greater than 100%, meaning that in no case was any electricity wasted; in fact, the electric load always substantially exceeded the photovoltaic generated electricity.

- "Thermal Utilization" — is a measure of how well the thermal energy recovered from the photovoltaic array is used to meet thermal loads. Utilization is the ratio of thermal load to array thermal output. High utilization is desirable as it implies effective use of the thermal energy produced by the array. Low utilization means thermal energy is wasted, probably compromising system economics. In this case, annual utilization is greater than 100%, meaning that generally the thermal load exceeded recovered thermal energy. However, particularly in late spring, summer, and early fall, the utilization of thermal energy is less than 100%, implying that substantial quantities of thermal energy must be rejected. In late fall and early spring, thermal utilization, in this case, exceeds 100%, although small amounts of thermal energy are wasted.

This results from the method of monthly summation of loads and available thermal energy that tends to overwhelm the impact of the small quantity of wasted thermal energy on reducing the value of thermal utilization.

- "Purchased Electricity 8 p.m. (a.m.) — 8 a.m. (p.m.)" — is the amount of electricity purchased during these 12-hour periods and is used to indicate the impact of time-of-day electricity pricing on STES economics.

Section 5.
HEALTH, SAFETY, AND ENVIRONMENTAL FACTORS

Although solar systems generally are regarded as being environmentally benign, the siting of solar total energy systems in the residential sector places more emphasis on the health, safety, and environmental factors than might be expected in some of the other applications. This does not suggest that non-residential applications do not require safeguards; it merely suggests that society places particular emphasis on the well-being of the family unit.

The residential sector also contains people with chronic respiratory and heart disease, who would be most susceptible to any pollutants released from solar total energy systems.

5.1 Health and Safety Hazards

Probably the greatest potential hazard associated with STE systems lies in the working fluids used in transferring thermal energy from the solar collector and in the organic Rankine cycle heat engine. At the operating temperatures envisioned for STE systems, hot oil circulation is a preferred mechanism for transferring thermal energy from the solar collector to storage or the ORC unit. The circulation of this hot oil takes place within an enclosed, insulating piping system and does not constitute a safety hazard under normal operating conditions; certainly, the practice of using hot oil transfer is an established technology that is commonplace in industrial applications. However, rupture of transfer pipes is always a possibility that poses the potential threat of releasing hot flammable fluids to the atmosphere, contaminating the air at best and posing a severe burn or fire hazard under the worst circumstances. This could occur in the event of a fire, high winds, faulty equipment or installation, or similar events. Furthermore, the storage of this hot oil in insulated tanks poses the additional hazard that fire could spread to a large volume of flammable liquid that is probably above its flash point. Onsite tank storage of fuel oil, of course, is accepted practice, but the high fluid temperature and direct connection to a system that could rupture under adverse conditions constitute a problem of a different magnitude.

The same safety hazards are connected with the use of certain working fluids in an ORC system, particularly toluene. These are sealed systems, similar to air-conditioning systems, and should not pose a problem under normal operating conditions. However, leakage or rupture could occur under the same conditons cited for the oil transfer systems and thus release a toxic material to the atmosphere. Toluene would be well above its flash point under operating conditions, and a sudden release to the atmosphere would surely result in an immediate fire hazard, as well as an air pollutant.

Another potential safety hazard associated with the use of solar collectors is the glare that could be associated with a misaligned heliostat. This should not be a problem generally because the beam becomes quite diffuse beyond the focal point; however, a heliostat field that is out of focus could cause the focal point to occur at some distance away from the receiver and pose a glare problem for nearby motor vehicles or overflying aircraft. The subject of misdirected radiation is most often mentioned as a potential safety hazard associated with central receiver/heliostat systems, either because of the glare problem or because of a potential burn/fire hazard in the event that misaligned heliostats could focus on nearby persons or combustible material. Frankly, we expect central receiver systems to be used much more in nonresidential applications but their use in residential applications is certainly possible and the problem of potential misdirected radiation cannot be ignored as being inapplicable to residential applications. If future heliostat costs are as low as are being projected, central receivers might possibly be used in some future residential applications and the misdirected radiation possibilities will have to be addressed. This could take the form of measures to ensure that no combustible material is accessible to misdirected radiation or regulations that prevent motor vehicles/aircraft from traveling too close to the heliostat field.

Another potential safety problem is posed for workmen or maintenance personnel working in the vicinity of solar collectors, although this is not unique to solar total energy systems. Intense glare or burns could incapacitate workmen who might be working around collectors when the sun is shining brightly, unless special provisions are made to prevent it. The most obvious way of preventing such an occurrence is to schedule work in the immediate vicinity of concentrating collectors only when the sun is not shining brightly, such as early in the morning or late in the day. However, emergency repairs may require workmen to be present when solar radiation is quite intense, and special instructions or preventative measures (such as covering the collectors or wearing protective devices) may be required.

Worker exposure to sunlight (especially concentrated sunlight) should be minimized to prevent thermal injury to the retina of the eye and possible cataract formation from the infrared portion of the solar spectrum.

Since STE systems may have relatively high maintenance requirements, work-related accidents such as falls may occur more frequently than in the systems they were designed to replace. One must be on guard to ensure that complacency about safety matters does not develop due to the routine nature of some maintenance work. The best maintenance practices must be conscientiously followed.

All of the health and safety hazards discussed above can be either eliminated or minimized by appropriate regulatory action or preventative measures, but some recognition of their importance is imperative. The important thing is to recognize the potential dangers and take appropriate steps to eliminate or reduce them. After all, we have learned to live with high voltages in our television sets and we carry roughly 20 gallons of volatile, highly combustible gasoline in our automobiles, so we have learned to accept certain risks in exchange for the benefits that we want. Nonetheless, provisions must be made to eliminate as many health and safety hazards of STES as possible so as to avoid any adverse impact on public acceptance, if solar total energy systems are to compete in the marketplace with conventional energy systems.

5.2 Environmental Factors

Environmentalists are generally strong proponents of solar energy because solar energy systems do not release unwanted pollutants to the air or water. Consequently, the potential for supplying energy without concomitant pollution of the environment is one of the strongest points in favor of solar total energy systems. In fact, this point alone may ultimately be sufficient justification for implementing solar total energy systems in certain regions if the economic comparison with conventional systems is not too unfavorable.

Use of solar collectors in the residential sector tends to increase the absorbtion of solar energy in that area. The altered solar energy budget that results could cause climatological changes. Space requirements for the STE systems could lessen the amount of land available for parks and open areas, and thereby effect the ecology and appearance of the residential community.

STE systems are not completely pollution-free because they do require backup systems that release gaseous combustion products to the atmosphere, but the extent of pollution is reduced by an amount equal to the solar energy utilized. This is less important where natural gas is the backup fuel, but becomes increasingly more important where coal combustion becomes the source of electricity for electrical backup. Since coal-based electric plants will become more prevalent in the future, the environmental advantages of solar total energy systems in reducing at least part of the pollution due to coal-derived electricity may also become more significant.

As described in the previous section, however, the accidental rupture of transfer lines carrying hot oil from the collector or toluene from ORC units could have an adverse environmental effect, not only because this could release hydrocarbon pollutants into the atmosphere, but also because spills of these materials could contaminate water supplies or sewer systems and damage nearby plant and animal life. Furthermore, fires from an accidental release of the hot working fluids would release polluting combustion products into the atmosphere.

In colder climates, additives to prevent freezing of water used for the low-temperature side of a solar total energy system could represent a possible source of water pollution in the event of line rupture or leakage. The same is true with inorganic salts such as chromates or phosphates added to the water to inhibit corrosion; many of these salts are toxic and could create health hazards if they find their way into water supplies or sewer treatment plants by virtue of leakage or pipe rupture. Needless to say, these materials could also be detrimental to plant or animal life if released to the ecosystem.

Finally, some people may object to the aesthetics of STE systems in a residential community because they "look different." Many people have very strong feelings about living near a building that "looks funny" to them, and they may very well feel that a solar collector on the roof of an adjacent building impacts unfavorably on the aesthetics of a neighborhood. In fact, we have heard of a few instances where neighbors have objected to the presence of a solar collector in the neighborhood; however, this may represent only the opinion of a few individuals and not necessarily a deterrent to STE systems. On the other hand, homeowners are very sensitive to anything that could have an adverse effect on property values and could easily raise the issue of "visual pollution" if they feel that it might decrease the desirability of the neighborhood and lower property values. Of course, solar collectors on a residential roof could take on the aspects of a status symbol, as became the situation with antennas in the early days of television; this is in contrast to the objections of some neighbors in living next door to someone with the larger antennas used by ham radio operators or someone who parks a boat or motor home in his driveway. These points are usually resolved by local zoning ordinances, but the rationale often used is that of "visual pollution" — a polite way of saying, "We don't like its looks." Obviously, this is a matter of local preference.

A more complete discussion of the environmental aspects of solar total energy systems may be found in a March 1977 report by the Environmental and Resource Assessments Branch of the ERDA (now DOE) Division of Solar Energy entitled "Solar Program Assessment: Environmental Factors. Solar Total Energy Systems."

Section 6.
DEVELOPMENT REQUIREMENTS AND SUBSEQUENT PHASES

Although residential applications of solar total energy systems have been shown to be technically feasible, the prospects for their successful commercialization depend strongly on the prospects for substantial reductions in the capital costs of the systems. The approximate breakdown in capital costs for a hypothetical 600°F ORC solar total energy system is shown in Table 56.

Table 56. STES COST BREAKDOWN

Collector System (parabolic trough)	40%
ORC System (100 kW)	20%
Storage	5%
Conventional Components	35%
TOTAL	100%

This indicates where major R&D effort might pay off most effectively. All of these cost centers would contribute, of course, but major reductions in collector costs and cost of conventional components (piping, absorption chiller, fan coil units) would have the greatest impact on total system costs.

6.1. Constraints to Commercialization

The issue of existing significant constraints to the widespread commercialization of solar components and appropriate incentives necessary and sufficient to overcome them is a present-day concern not only affecting solar components for STES residential applications but one which strongly influences the entire solar community composed of private, industrial, and governmental interests.

For solar energy to become viable and both successfully and significantly penetrate the applications marketplace, economic, technological, and institutional constraints to the utilizations of solar energy components and systems must be systematically identified and documented, and cost-effective incentive programs must be developed, approved, and implemented.

The term "constraint," or "barrier," refers to any factor, relationship, or characteristic having the potential to retard or limit introduction or utilization of solar components and systems. While some constraints are obvious, such as sun access rights, others, such as domestic fuels price regulation, are simultaneously more complex and more significant.

Solar energy technology is perceived as experimental and unproven in the market place. No standards of quality, performance, or safety exist to protect the consumer and avoid damaging the new market through sale of poor quality components and systems. Warranties on the quality and performance of equipment are generally not provided by the industry or mandated by state regulatory agencies. Financing for solar installations may be expensive or not available because of such risk. Finally, the insurance industry is unable to assess the risk associated with solar components and system installations and until actuarial risks are defined, insurance premiums will be high. All these aspects directly impact the commercialization potential of all solar components.

Specific barriers affecting all solar systems, and therefore all solar components, are listed below:

Discipline	Barrier
• Economic	Cost competitive energy High initial cost
• Institutional/Technological	Utility Interface Material & Equipment standards
• Legal/Social	Zoning & Building Codes Land Use Public Acceptance

Clearly, the number one barrier to commercial introduction of solar systems is cost. Both the cost competitiveness and the initial large capital expenditure required for solar systems are important. Cost reductions must be achieved in both the manufacturing process and in the procedures required for field installation, operation, and maintenance.

Present day solar collectors are quite obviously based upon state-of-the-art technology. Much of the development effort presently being invested is aimed at reducing component costs as well as improving performance. To a lesser extent, effort is also being devoted to improving the long-term reliability of the components. The high capital investments required to acquire and install a solar system make it imperative that such systems be long-lived and have manageable operating and maintenance costs.

To this end, there are two essential criteria that must be met to make solar systems attractive:

- System components must be demonstrated to work reliably, to have reasonable O & M costs, and to have operating life-times of 15 to 25 years.
- A reasonable rate-of-return on the solar investment for a given application must be possible to stimulate demand in the solar component market place.

Interfacing with electric utilities is probably the second most serious barrier, especially for STES applications. Problems develop when local utilities realize that installation of solar systems tends to increase peakload generating requirements while decreasing base-load generating requirements. As a result, utilities have begun to request rate structures effectively penalizing owners of solar installations employing electric-based backup systems. (This subject is disucssed in some detail in a recent report by the Office of Technology Assessment, "Application of Solar Technology to Todays Energy Needs," June 1977. The report describes in detail numerous factors which influence the future of solar energy.)

A technological concern may involve system operating problems and possible damage which could result from use of materials and equipment that was unanticipated when governing specifications and standards were originally prepared. Risks involved could be fluid leakage, explosion from excessive temperatures, failures induced by high pressures, corrosion, human contact with hot surfaces or broken glass, contamination of potable water with toxic coolants, and structural damage caused by high winds or heavy snowfalls.

Standards typically are either specification standards, which identify materials and equipment that may be in system construction, or performance standards, which set criteria that materials must meet or exceed. If a solar system design employs components in such a way that applicable building codes are satisfied, then those solar components may be said to be developed. However, if a given design employs components in an unusual or innovative manner, or requires use of non-standard assembly techniques, further testing of materials and/or techniques may be required to satisfy applicable codes and standards.

The third most serious barrier relates to legal and regulatory problems such as zoning ordinances and building codes. Even if technological, economic, and utility interface solutions are found and adopted, legal barriers could significantly constrain solar energy commercialization at all levels. There exists some latitude within the varying building codes for approval or rejection of materials, equipment, and methods not specifically provided for or referenced. The principal concerns are that if alternative materials, equipment or techniques are to be employed in a system, that the resultant system and the structure on/in which it is installed will be at least equal in strength, fire resistance, safety, quality, and effectiveness compared to similar systems satisfying applicable codes.

6.2. Development Planning

Manufacturers of solar equipment have sensed public awareness and interest and have started to produce solar collectors and associated components, but the resultant present-day, first-effort prices are very high. Of the many new collector concepts, designs, and design variations reported by manufacturers or displayed in the literature, a great number have only reached the prototype stage. Of those collectors built and installed, most have not been in operation long enough to validate performance predictions. In many instances, only estimated performance data is available.

Convincing demonstration programs, increased production, support services, lowered prices and government incentives are required before a substantial and stable market can be developed. Presently, the Federal government is funding development and demonstration programs to alleviate some barriers. State government are most active in providing economic incentives in the form of tax credits for solar system installations.

Industry planning for future commercial efforts has been closely tied to government support of the development process. Without supporting funds the creation of a widespread solar industry would probably be delayed for years or possibly lie dormant until a major change in fossil fuel costs occurred. The posture of aggressive government support of solar technology development depends upon the national value assigned to increasing the use of solar resources to achieve energy displacement and, ultimately, independence. Since private industry planning is closely tied to government planning it is appropriate to briefly review present DOE program plans.

The objectives of these Solar Total Energy activities are to:

- Develop within an appropriate industrial sector those solar total energy technologies which are economically competitive with other energy sources.
- Demonstrate the technical, economic, and institutional feasibiltiy of the solar total energy concept.

These objectives can be accomplished by establishing programs to provide comparative analyses, component research and experiments, system experiments and system demonstrations.

The development process has three essential activities to perform. First, products must be created possessing actual and perceived value. Research, development, and demonstration define the create function by activity but do not by themselves guarantee the achievement of the objective. Second, manufacturing of the products must occur in quantities sufficient to yield reasonable production costs and returns on investment. Third, marketing to sell and service the products must begin. The two most critical activities are the creation and marketing functions. The creation function must insure that anticipated operating and maintenance costs will be reasonable. Additionally, satisfactory control and integration with utility systems must be provided. Finally, reliability and maintenance standards must be developed compatible with both application and operating environment requirements.

Successful marketing will be enhanced if direct utility and/or user interfaces are not only provided but promoted. In addition, standards for warranties, insurance, and truth-in-advertising must be established and administered. The development of a solar total energy system thus follows the program shown in Figure 38. Specific component development occurs early and initial large scale experiments are often started before all the data and testing is completed.

Each step of the process commences when a minimum sufficient amount of information is available from the previous step to allow selection of alternative choices from the varying approaches being evaluated. The objective should be to retain as many best options as possible within

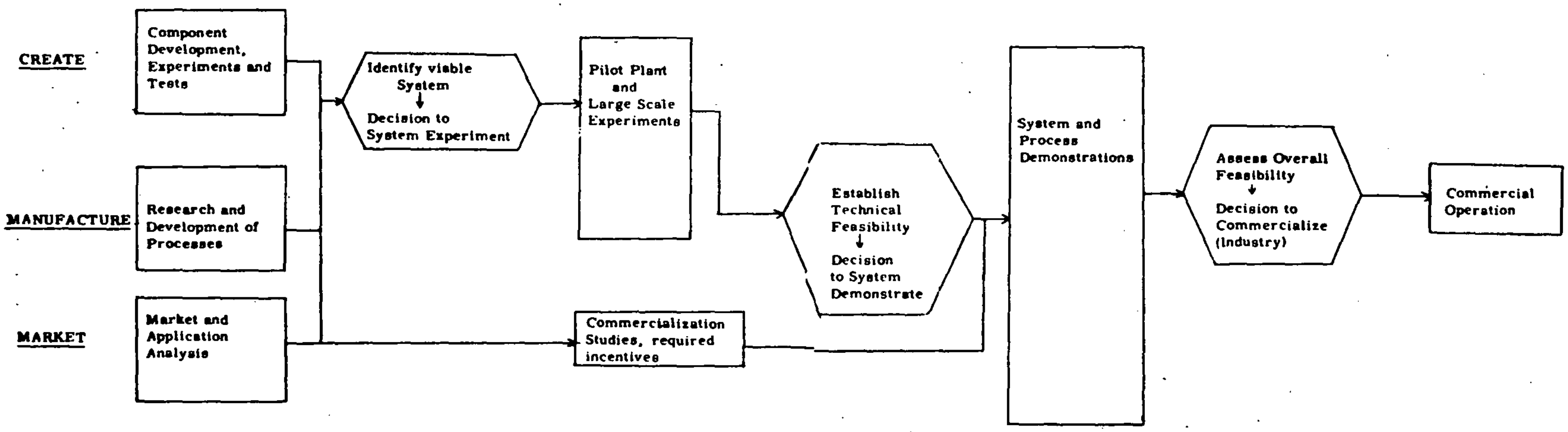


Figure 38. SOLAR TOTAL ENERGY DEVELOPMENT PROGRAM

programmatic constraints rather than to unknowingly pre-select a false optimum system. It is recommended that several collectors be evaluated in subsystem size to permit alternative choices for design and construction in larger scale experimental and demonstration projects.

The decision to commercially introduce solar total energy systems naturally depends upon removing the constraints or barriers discussed earlier. The large demonstration program can successfully prove technical credibility but this must be aided by other incentives.

The term "incentive" refers to action (taken typically by a government segment) to encourage, support, or otherwise accelerate the commercialization of solar components and systems.

Federal, state, regional, and local governing commissions nationwide are continually becoming more aware of and involved in issues pertaining to solar-related incentive policies and programs. Legislative conflicts often arise when it is realized that specific barriers often constrain several different types of solar technologies, while, similarly, specific incentives often impact across different technologies not always solar related.

Most prominent among all incentives addresses the high first cost of solar components and systems. Low-interest loans, loan guarantees and insurance, property and sales tax waivers, investment tax credits, and accelerated depreciation plans have all been suggested. Primary interest centers on low-interest loans and tax credits as the incentives most likely to successfully spur solar market penetrations. Reconciliation of utility interface problems is likely the second most important incentive, followed by legal and regulatory solutions.

6.2.1. Collectors

As an example of the type of program necessary to develop solar components, we can assume that a specific collector (say a CPC) seems especially attractive for residential STES applications. The CPC (compound-parabolic-concentrator) is described in Appendix A. Briefly, it is used to achieve concentration ratios of 1.5 to 4.0 without tracking and higher (up to 10 to 12) concentrations if seasonal tilt adjustments are made. The best concentration ratio (most cost-effective) is unknown and will certainly be influenced by the specific application.

Since the CPC concept has been available for several years now, a part of the create function has been accomplished. Federal funds have been used to analyze the concept and engineering models and prototypes have been built and tested. Further efforts to develop the collector must be directed toward the investigation of low-cost manufacturing processes applied to a reliable design. The need to trim costs, improve performance and make the collector easily installed and maintained can be accomplished by value engineering processes and continued efforts to apply new, improved materials to the design. Figure 39 shows how a program may proceed to further develop the CPC concept.

The first two tasks shown in Figure 39 are necessary to establish the ground rules for the design task and ensure that the designers create a collector compatible with the energy marketplace. The component design phase must evaluate the merit of using improved materials such as high reflectance films, high transmittance glass or selective absorber coatings. A prototype design is required to establish a basis for the value engineering and production studies. Compromises in design may be cost-effective and mass production cost estimates provided at this stage must be compared to established goals.

A return to design tasks may be required if goals are not met but still seem possible. Finally, a production design can be used in demonstration programs which will show technical and economic feasibility of a solar system.

Two other specific collectors should be carefully studied as potential collectors for residential applications — central receivers and parabolic dish collectors. Both collectors were seriously considered during the course of this project, but were eliminated as being currently non-applicable to residential applications for the reasons listed. Nevertheless they each have a potentially important contribution to make to a more economic system. The central receiver is somewhat more efficient than a parabolic trough, and apparently has the potential of achieving very high production costs at high production rates; this is presumably due to the fact that heliostats are essentially flat mirrors and should adapt to mass production techniques quite readily. Of course, the full economic potential of central receivers and heliostats may never be realized in the residential sector because maximum savings are realized with a large system involving a large area of land covered with heliostats. This is inconceivable in a residential application. Nevertheless, the task of

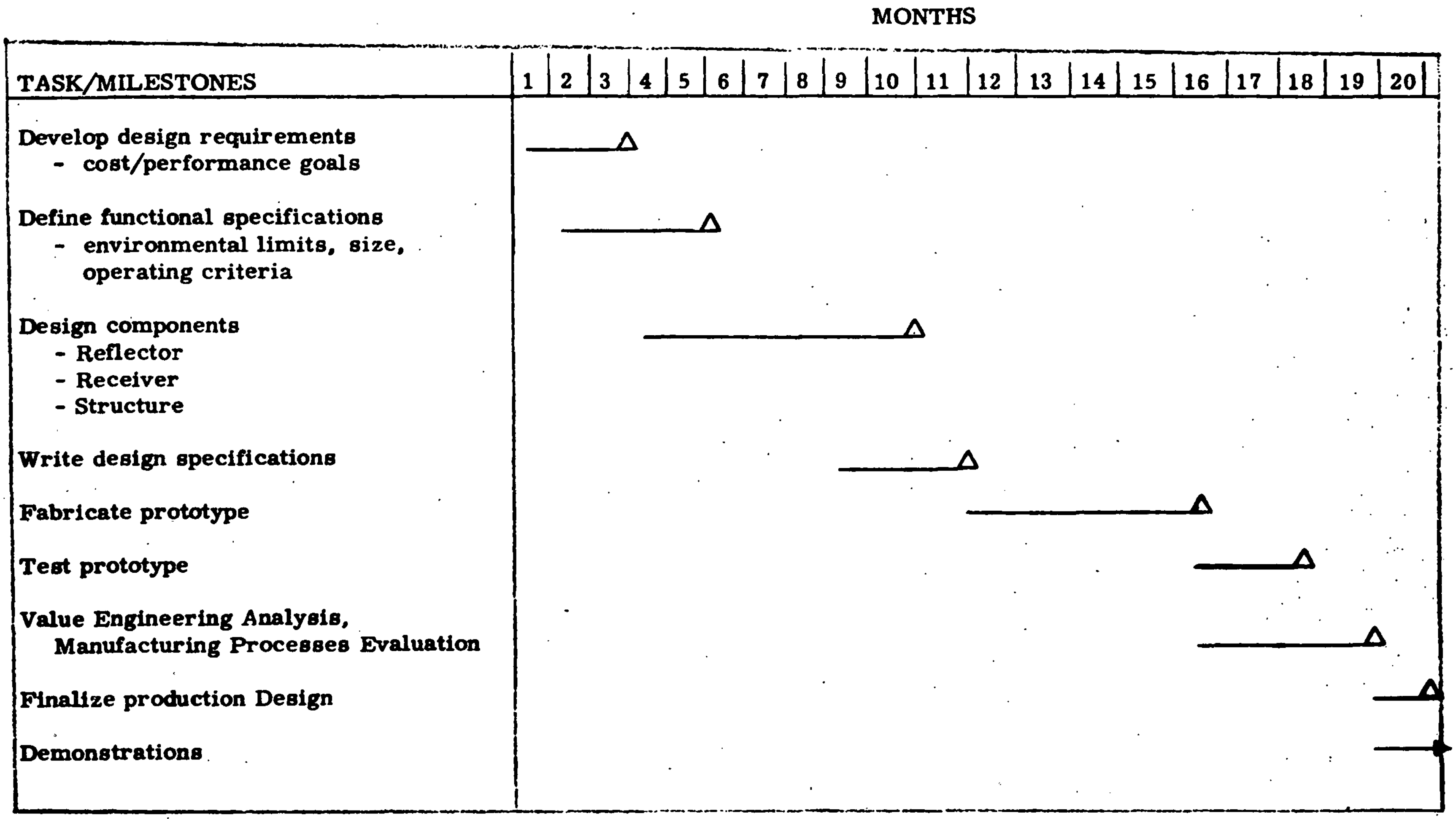


Figure 39. COLLECTOR DEVELOPMENT SCHEDULE

designing a roof-mounted small central receiver specifically for the residential sector and defining the wind loading factor for the roof might be considered as a long range future goal, especially if other types of applications would seem to ensure a large future production level for heliostats.

In a similar manner, the parabolic dish is much better suited to nonresidential applications, where it can better take advantage of higher output temperatures. Nevertheless, the high (>70%) efficiency of the dish collector could be a way of reducing overall collector costs if the manufacturing costs could be reduced sufficiently. Perhaps some kind of breakthrough in dish design and manufacturing costs could bring the parabolic dish into contention as a residential collector, although it doesn't seem likely that the same cost reductions could be achieved for a 2-axis tracker as for a single-axis tracker.

6.2.2. Energy Conversion

The proposed R&D required to achieve DOE goals for photoelectric arrays have been well described elsewhere and need not be repeated here. Suffice it to say that such drastic reductions in manufacturing costs of photovoltaic-grade silicon, if achieved, could give photovoltaic systems a decided advantage over ORC systems in certain residential applications. Although cost reductions of 50% in ORC systems could conceivably take place with a sufficiently high production rate, the production of a complicated mechanical system such as ORC units is much less susceptible to major cuts in production costs than the mass production of photovoltaic-grade silicon or gallium arsenide.

Some (say, 5 to 15%) improvement in ORC costs and efficiency can probably be achieved by improvements in heat exchange surfaces — both geometry and material.

A longer range possibility that should be watched carefully is the Stirling engine field. At the present time, no Stirling engine of the size needed for 50-100 kWe systems is scheduled to be developed in time for a 1980-1985 residential demonstration unit. Nevertheless, a great deal of research is being planned for the Stirling engine and efficiencies of 30% are projected. This could offer the possibility of much lower capital costs.

6.2.3. Storage

Generally speaking, the relative cost contribution of storage to total STES capital costs is small compared with the other components. However, some interesting new concepts offer distinct possibilities and should be watched carefully for breakthroughs. One of the more interesting ones involves a system of complex metal hydrides used as a "chemical heat pump", currently being developed at Argonne National Laboratory called HYCSOS (Hydride Conservation of Solar Energy System), it offers the possibility of reducing collector area requirements by 50%. Although the system is only at a laboratory scale development level, a demonstration unit is being built to verify and scale up the results that have been achieved in the laboratory unit.

A hydride-based total energy system consists of two systems, essentially operating in parallel. The first is the power generation component, the second is the heat pump, which provides both heating and cooling. The power generation component consists of at least two hydride beds of $LaNi_5H_x$. In operation, the two hydride beds are maintained at 140°C and around 30°C, respectively. The high-temperature hydride bed evolves hydrogen at around 50 atmospheres. This high-pressure gas is allowed to do work in an expansion engine and the exiting low pressure hydrogen is fed to the second bed where heat is evolved and rejected to ambient as hydrogen is absorbed. By using three vessels, which are alternately absorbing and desorbing hydrogen, a practically constant flow of hydrogen should be maintained through the expansion engine and steady power generation should be achieved.

Heat pumping operation is accomplished with a second set of hydride beds. Heat pumping exploits the different pressure-temperature relationships of two different hydride materials such as $CaNi_5H_x$ and $LaNi_5H_x$. In operation, heat transfer fluid from the solar collector at around 117°C is circulated through the first hydride bed containing $CaNi_5H_x$, decomposing the hydride. The hydrogen is evolved in the first hydride bed and absorbed exothermally by the second hydride bed of $LaNi_5H_x$, evolving heat at 40°C for space heating. Operation is then reversed by thermal coupling of the $CaNi_5H_x$ bed to the space to be heated and allowing the $LaNi_5H_x$ bed to absorb heat at low temperature (~8°C) from the ambient. Under these conditions, the hydrogen pressure in the $LaNi_5H_x$ bed is greater than that of the $CaNi_5H_x$ bed operating at 40°C, thus hydrogen is transferred to the calcium-nickel hydride bed, evolving heat at 40°C.

A continuous flow of hydrogen can be maintained by a four-unit system (two calcium-nickel hydride beds and two lanthanum-nickel hydride beds) by periodic switching of the flows of heat transfer fluid and hydrogen. Efficient operation is achieved by regenerative heat exchange as hydride beds are heated and cooled. Cooling is simply the reversal of heat pump operation. Ideal COP's of 2.0 and 1.0 are achievable in the heat pump and cooling modes, respectively. TRW has estimated that a practical device can achieve a COP of 0.46 in the cooling mode. A comparable figure for the heating mode is not currently available.

Although a hydride-based total energy system has not previously been investigated, work at Argonne on this hydride system is built upon an increasingly strong base of engineering knowledge derived from parallel development efforts in other organizations. As an example, a small (1.0 lb hydrogen per hour discharge rate) fixed-bed iron titanium hydride hydrogen storage system coupled with an electrolyzer and fuel cell for hydrogen production, storage, and reconversion to electricity is being demonstrated at Public Service Electric and Gas Company in conjunction with Brookhaven National Laboratory.

An appealing feature of hydride cooling machines in comparison with absorption cooling machines is that they scale fairly linearly in cost as size is reduced. This is due to the reduction in hydride material required and the use of smaller heat exchangers. In residential-sized units, they may be at a lower cost per ton than conventional absorption cooling machines, although they may not be as attractive in cost for a central chiller application. The heat pumping feature would be desirable as compared with the space heating method utilized by our 300°F organic Rankine-cycle system because it effectively reduces the thermal input required for heating; in fact, condenser reject heat could be used to boost heating COP. Heat pumping thus provides additional thermal energy for power generation. Of course, the power conversion system is subject to the same thermodynamic limitations as the Rankine-cycle systems. For the power conversion system, anticipated costs will be an important factor in its evaluation as a component of a total energy system.

6.2.4. Conventional Components

It doesn't seem likely that significant breakthroughs can be made in such mundane components as piping, controls, chillers, fan coil units, etc. but some elimination or reduction of these components are needed for STES to be economically competitive in the residential sector. This may come about as the result of improved piping layouts or breakthroughs in some component such as absorption chillers. Perhaps someone can design apartments that require only 2 fan coil units per apartment. This could cut roughly $40,000 from the total STES cost and would have as much of an economic impact as reducing the cost of the ORC unit by a factor of 2/3. Improvements in absorption chillers could also offer the opportunity of significant reduction in capital costs. In short, the capital costs of the conventional components must be reduced as much as the cost of the solar components if STE systems are ever to achieve market penetration in the residential sector. Somehow capital costs must be cut at least by half and no opportunity to reduce costs can be overlooked.

For example, marketing statistics indicate that market penetration probably will not take place until a capital cost differential of about $3500/apartment can be achieved over the cost of conventional systems, or a total cost differential of less than $200,000 for a 48-unit low-rise apartment building. Since this cost differential is currently being projected at about $500,000 (or a total capital cost of about $650,000), the cost must obviously be reduced by a factor of about 50%. This would mean that the total STES capital cost must be reduced to less than $350,000 in order to provide a cost differential of less than $200,000 over conventional systems. If cost reductions of this magnitude could be achieved, then the following targets might be established for a potentially economic STE system for the residential sector:

Solar Collector, installed (including O&M)		$120,000
ORC System, installed (including batteries)		$ 70,000
Storage, thermal		$ 25,000
Remainder of System		$110,000
	Total	$325,000

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8. Barber, R.E., "Solar Powered Organic Rankine Cycle Engines — Characteristics and Costs." Paper No. 769200 presented at the Eleventh Intersociety Energy Conversion Engineering Conference, State Line, Nevada, September 12-17, 1976.

APPENDIX A. COLLECTOR PERFORMANCE CHARACTERISTICS

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This section identifies a number of representative types of solar collectors which are of possible interest for solar total energy residential applications. Collector types are characterized by their current availability, efficiency, and cost. Future collector characteristics are also projected.

It is not our intent to compile a complete data bank of collector and collector system design data. In fact, because of the rapid growth of solar technology, new collector innovations and on-going test programs soon make any list of collector data incomplete. We have compiled cost and performance data for a variety of collector designs in various stages of development so that we will have a basis for projecting future costs and performance estimates.

Naturally, the level of detail available is coupled to the development stage of the collector or collector system. As one would expect, there is an abundance of specific data available on flat plate systems since a number of federally funded and private installations are already operational. Data on concentrating systems is limited because of the limited demand or market which currently exists for these collectors.

In reviewing the available information we have attempted to obtain a wide data base for selected collector types. The selection of particular collectors does not imply any judgment about their quality compared to other alternatives, rather, it is meant other to be a representative selection. For the data obtained, we have filtered out what we believe to be the generic characteristics of several collector types.

The data base which we worked from is best described by referring to the Bibliography. The Bibliography lists those information sources which were found most helpful in the process of compiling this report. Throughout the text, the reference numbers refer to the Bibliography number. In addition to the reports listed, we have relied on collector manufacturers' data sheets describing their product and responses to a brief questionnaire which we sent to collector manufacturers. (All manufacturers are referenced by "Vendor A," "Vendor B," etc.)

Within the large body of available data on collector cost and performance characteristics there exists considerable differences in reported efficiency and cost values. This can be explained by the continuously varying state of collector development and by the specific nature of solar system designs. Even in the area of flat plate systems (which have been widespread in commercial demonstration programs), analysis of the data shows wide variation in cost components, such as support structure for installation, control, and direct/indirect labor charges. In recommending generic collector characteristics for use in the application analysis study we have used some subjective judgment as to the level of performance that can be justified for comparative collector evaluations.

Collector Types Investigated

Flat Plate

Solar flat plate collectors are composed of four basic pieces (Figure A-1): the frame or cabinet; insulation; absorber plate, including some methods of fluid flow for heat transfer (i.e., piping); and one or more glass covers (which may be etched or plain). A typical collector size is 3 ft x 8 ft, with an aperture area of 15 to 16 ft^2. Weights range from about 70 to 150 pounds per unit, depending on the manufacturer.

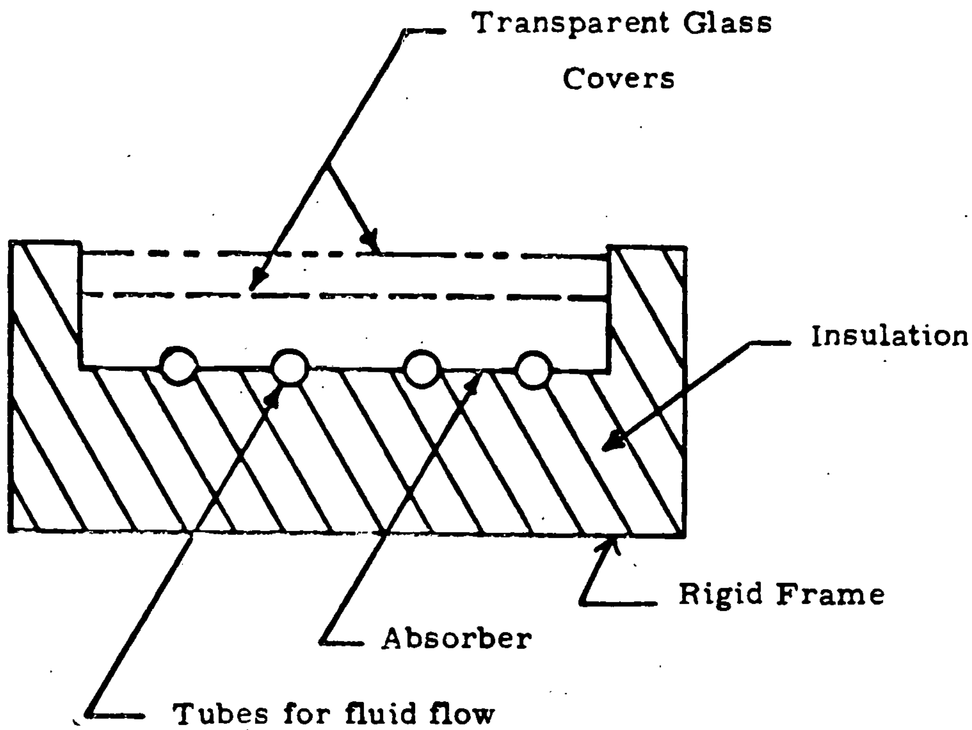


Figure A-1. TYPICAL CROSS-SECTION OF A FLAT PLATE MODULAR COLLECTOR

Samples of flat plates manufactured by several companies were compared in terms of production quantity and special features, shown in Figure A-2.

Manufacturer Vendors	Prod. Quantity	Collector Characteristics			
		Number of Glass covers	Etched Glass	Absorber Coating Type	Selective
A	>100,000 sq. ft.	2	Yes	Black chrome on bright Ni.	Yes
B	>500,000 sq. ft.	1	No	TABOR	Yes
C	20,000 sq. ft.	2	No	flat black	No
D	50,000 units	1	No	Ethone	Yes
E		2	No	3M Nextel	Yes
F	75,000 sq. ft.	2	No	PPG Duraction enamel	No
G	22,300 sq. ft.	1	No	Sherwin Williams combo-black paint	No

Figure A-2. SAMPLE COLLECTOR DATA

Some of the collectors with non-selective absorber coatings are offered with selective surfaces at additional cost. The method of heat transfer can vary widely in flat plate collectors, from the simple trickle-down water to the more advanced absorber designs with copper tubing bonded to coated steel plate (which is less expensive than an all copper system). Most systems used treated water (exceptions are those using copper tubing), which inhibits corrosion. The systems are frequently sold with a limited warranty. (Glass breakage is excluded.)

Efficiency of the flat plate collector can be increased by adding one or more flat mirrors mounted so that they reflect light onto the collector most of the time. The collector rows, when using this method, are run east-west with the mirrors between the rows. In this manner, additional concentration can be obtained.

Evacuated Tube

Evacuated tube solar collectors are non-tracking, modular units which may be mounted on the roof or ground. They are made of four basic components:

1. Tubular glass outer shell
2. Coated solar absorber (may or may not be cylindrical)
3. Pipe for delivery of heat transfer fluid
4. Mounting surface of reflective nature (may be flat or curved).

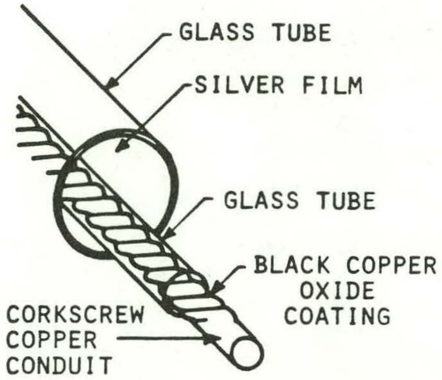
The heat transfer fluid is circulated through a glass or metal tube which is enclosed in a larger glass tube. The area between the glass shell and absorber is evacuated to about 10^{-4} torr and sealed permanently. The tubes are arranged in arrays, spaced to allow for optimal use of both direct and diffuse sunlight. The modular arrays, which eliminate the insulation in back of the absorber with the tubular concept, can be lighter than the conventional double-glazed flat-plate type.

Manufacturers boost collector performance differently (Figure A-3). For example, Figure A-3a presents a concept in which the manufacturer silvers the bottom half of the glass tube. Figure A-3b shows a tube spacing with white reflector placed behind them. Figure A-3c shows a similar tube spacing, but with a reflective V-trough placed behind them. Figure A-3a also indicates a second inner-glass tube to cut heat losses. Concepts in Figures A-3b and A-3c also apply a selective surface to the absorber.

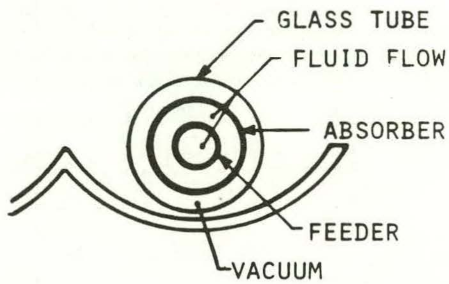
The production quantities of these collectors range from 450 ft^2 representing 3 systems for the concept in Figure A-3c to 20,000 ft^2 of collector produced up to January 1977. Six thousand complete systems using the concept shown in Figure A-3 have been produced.

Compound Parabolic Concentrator (CPC)

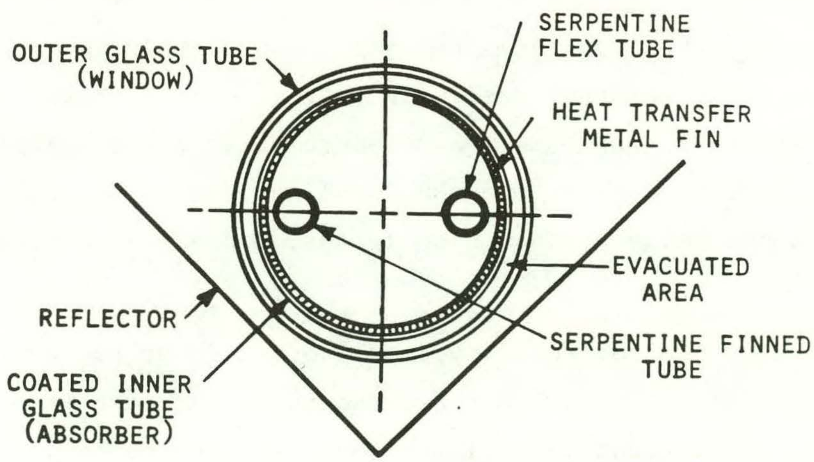
Compound parabolic concentrators are non-tracking modular units consisting of glass cover(s), reflective trough with the receiver at the bottom (typically a flat fin or a tube type), insulation and support box. Each of the trough walls is a section of parabola, but the two walls are sections of two different parabolas. Because of this, the trough will accept off-axis sunlight and focus it on the receiver in a wide band rather than a fine line. The trough panels are backed with foam to decrease heat loss. Figure A-4 shows a typical CPC unit.



a. GLASS SILVERING



b. WHITE REFLECTOR



c. V-TROUGH REFLECTOR

Figure A-3. VARIOUS EVACUATED TUBE COLLECTORS

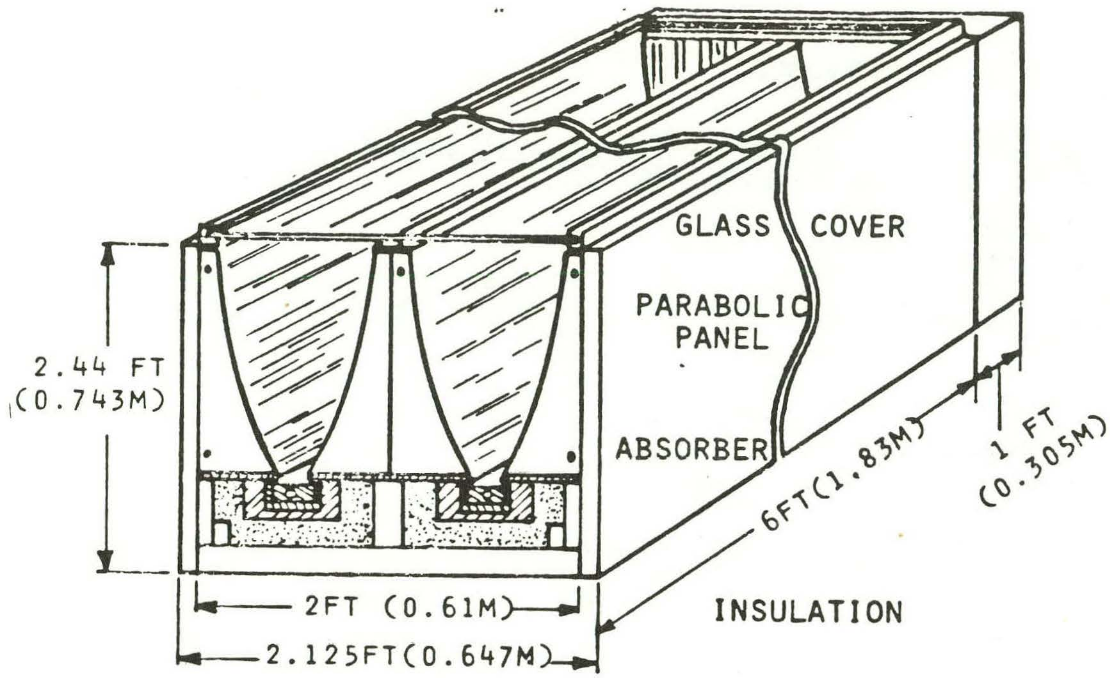


Figure A-4. TYPICAL CPC UNIT

Three companies hold University of Chicago licenses to manufacture the CPC collector. Vendor P is planning to produce a collector, operating at 400°F, with a metal receiver pipe which has selective surface coating and is surrounded by an evacuated glass tube. The reflectors will be polished aluminum in 3 ft x 8 ft modules, which will require seasonal adjustment.

Another company, Vendor K, has designed a solid plastic CPC about 1 cm wide, which uses total internal reflectance to give five times the concentration of normal sunlight, which is focused onto solar cells. Thirdly, Vendor L has built prototypes for the Argonne National Laboratory but has not decided on whether to commercially produce a collector, nor has it defined a production design.

In general, the CPC collector typically operates at concentration ratios of 3 to 10 times, and may or may not use vacuum to increase the efficiency, which is expected to be used with higher concentration ratios, in the periodical adjustment of the tilt angle of the collector.

Currently, however, CPC's are not available on the market, although work on them is ongoing. In the near future, the first CPC modules should be available.

One Axis Trackers

One axis tracking collectors concentrate the incoming solar energy onto a linear receiver. Although there are many designs, these collectors typically produce temperatures in the 350° to 600°F range, although they may be considered for use at lower temperatures.

Single-axis parabolic troughs reflect the solar energy from a parabolic surface to a receiver mounted at the parabola's focal distance. Two examples are discussed below.

Figure A-5 shows a full-parabolic trough. It is formed by clamping polished aluminum reflective sheets to parabolic ribs. (In this manner, the units collapse for shipping and are easily replaceable.) The receiver has a stainless steel absorber pipe, which is selectively coated with black chrome and is surrounded by an unevacuated glass tube. The troughs are 10 feet long and 6 feet wide. Eight troughs are attached together to form a row which is driven by a tracker unit. Receiver pipes are attached directly to each other eliminating interconnection losses.

Figure A-6 shows a half parabolic trough. This results in lowering wind resistance and weight. The panel is preshaped aluminum honeycomb with strengthening ribs. The concave surface is covered with an aluminized acrylic reflective surface. The receiver is mounted at the focal line and rotates with the panel. The stainless steel absorber is coated with black chrome and sets into an insulated receiver housing which has an etched glass window. Heat losses from the receiver are kept to a minimum in this manner. Typical trough lengths are 16 to 20 feet and are connected to form rows 80 to 120 feet long. Each row is then driven by its own motor, making the system adaptable to any size required.

Another type of tracking concentrating collector being developed is the tracking receiver, fixed reflector concept. Known as the Russell-type collector after its originator, it is available from General Atomic Co., or Scientific Atlanta. This design allows the benefits of concentration while the large reflector remains fixed. The reflector consists of rigidly fixed reflective strips, which maintain sharp focus. The troughs are east-west oriented and the reflective surface is obtained by bonding glass mirrors to a concrete form.

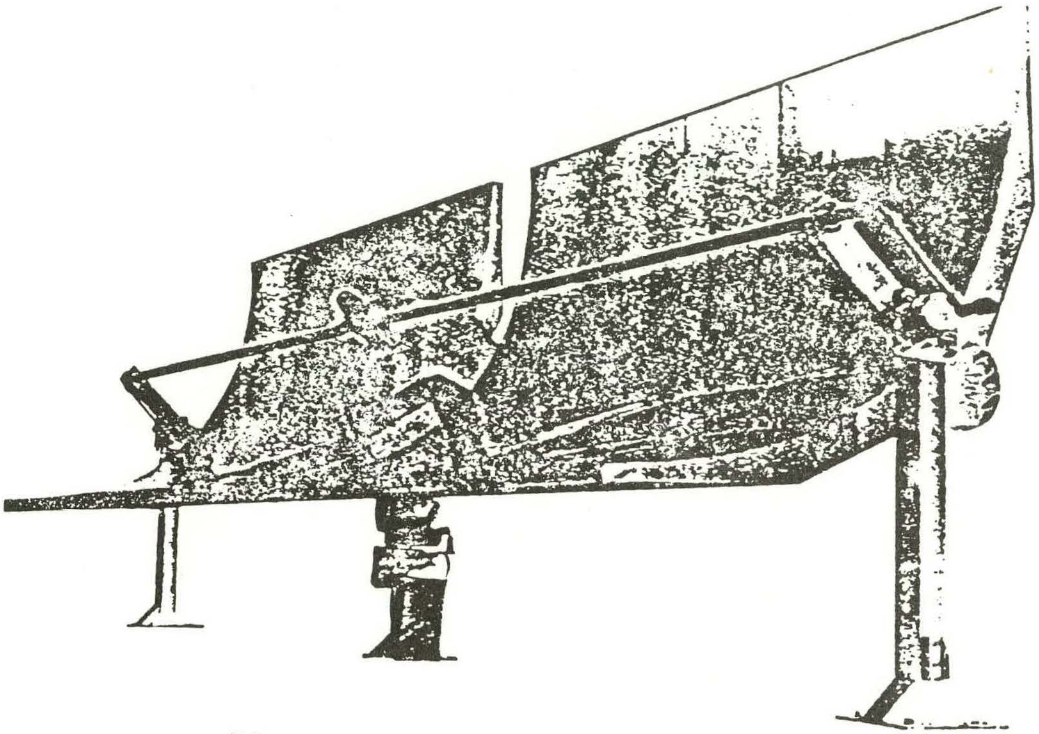


Figure A-5. FULL PARABOLIC TROUGH

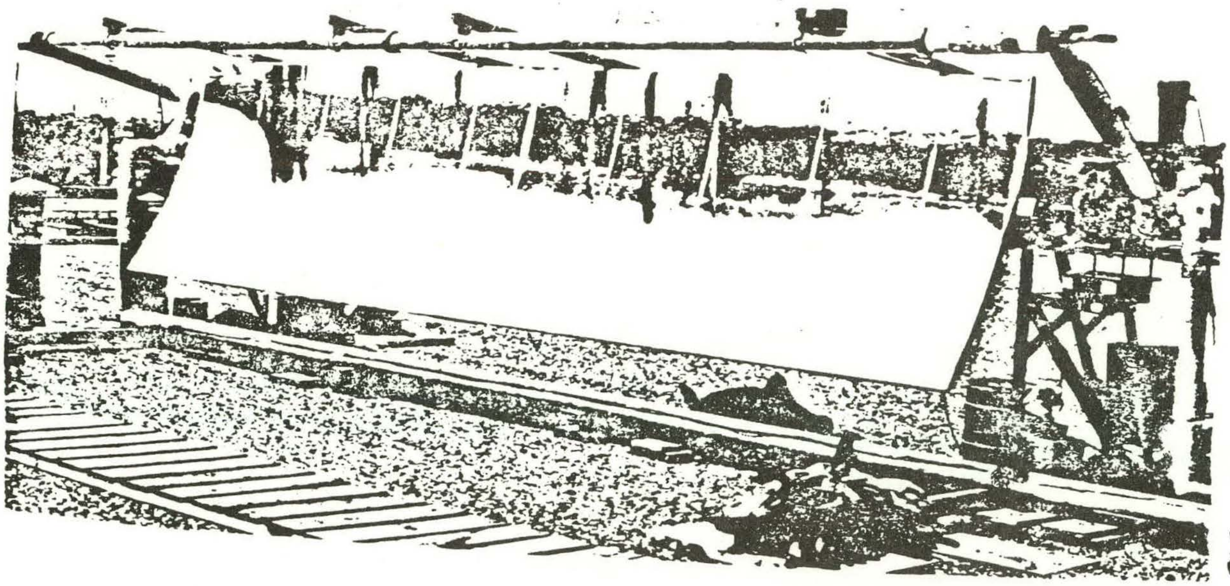


Figure A-6. HALF PARABOLIC TROUGH

The receiver follows the focal line in the circular arc described as the sun changes position. For large plants, it is anticipated that troughs as wide as 15 feet may be built. An offshoot of this design is being developed. It uses low iron silver backed glass mirrors fixed to steel sheet metal ribs, with an evacuated tubular receiver.

The third type of tracking concentrating collector considered is the linear segmented reflector (linear heliostats, fixed receiver) concept. The heliostats are long, narrow mirrors which track the sun while being driven by a single tracker (Figure A-7). The collector consists of 10 reflectors, each one foot wide and either 10 or 20 feet long in row lengths from 50 feet (minimum) to 200 feet. Each reflector concentrates the sun by four times giving an overall concentration ratio of 40 times. The mirrors are stored inverted to prevent frost accummulation and to protect the optical surface when not in use. The units are also able to withstand high winds.

Two-Axis Trackers

Two-axis tracking solar collectors are less available than the previously discussed collector types although work on the designs is currently proceeding.

A two-axis tracking circular paraboloid-of-revolution dish-shaped concentrator is currently being studied.[1] This dish collects the solar insolation and reflects it toward a high-temperature, cavity-type thermal receiver/heat exchanger which is positioned with the center of the aperture at the focal point of the dish. (See Figure A-8.)

The solar collector is a 48-foot diameter dish-shaped structure with reflective film attached to aluminum structural panels, which are attached to an all-aluminum backup structure. The lightweight concentrator employs an elevation over azimuth controlled motion support for the reflector. The high energy concentration ratios available and point focusing characteristics of the parabolic reflector allow high net thermal efficiencies to be achieved. The thermal receiver design is a high temperature cavity type which minimizes reradiation and convection thermal losses. The cavity receiver includes the heat exchanger. The working fluid used is air, which is heated to 1500°F.

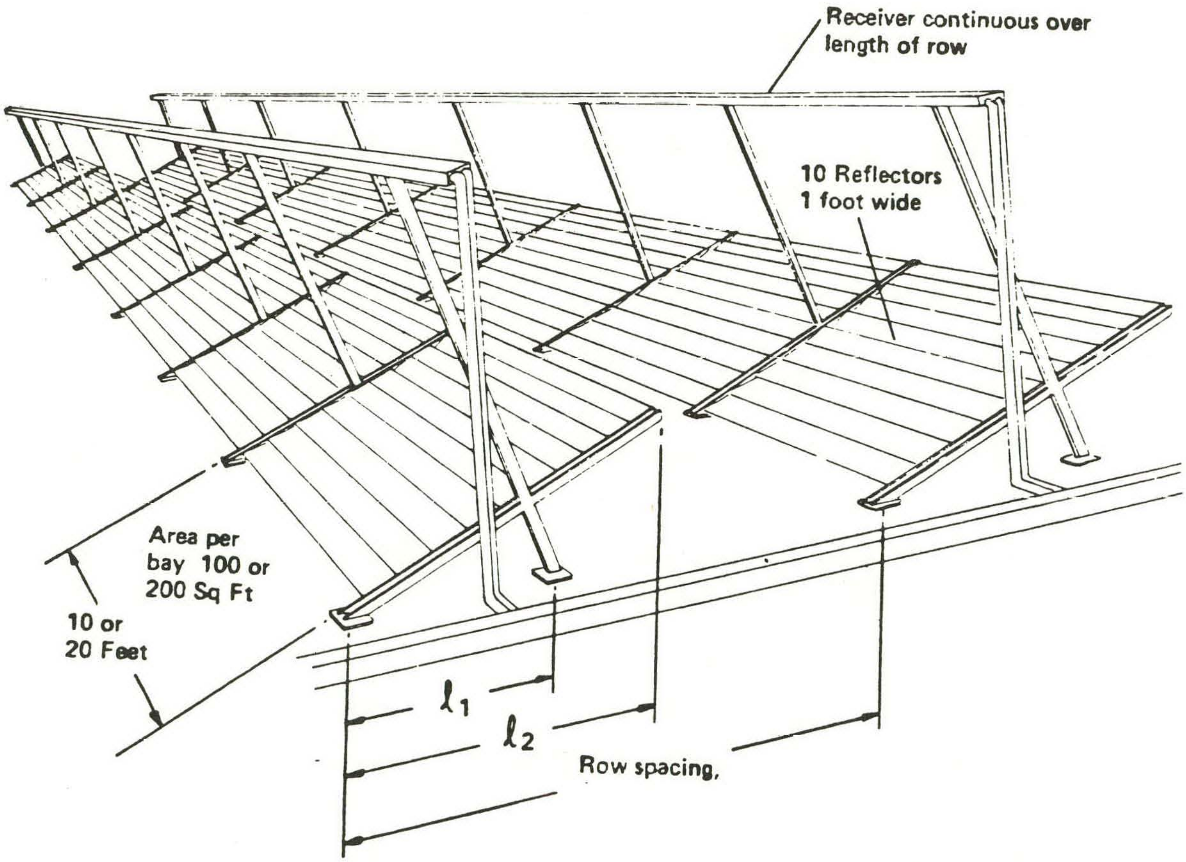


Figure A-7. SLATS COLLECTOR ARRAY CONFIGURATION

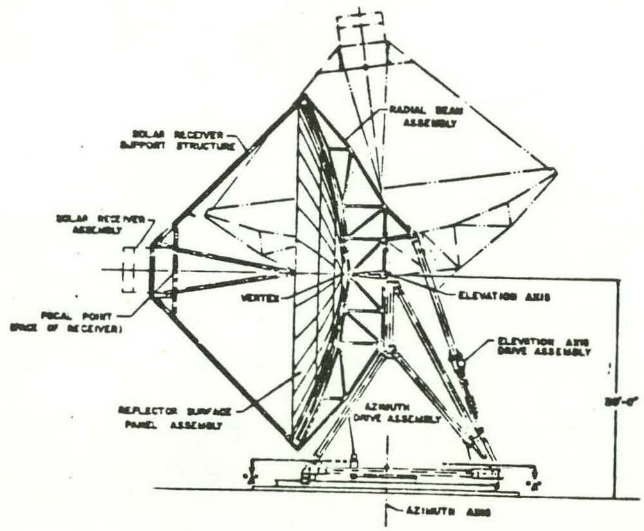


Figure A-8. PARABOLIC DISH SOLAR CONCENTRATOR

Two-axis tracking parabolic trough collectors are also being considered. The design and performance of their collectors is unchanged from single-axis troughs except that no cosine losses occur and the tracking drive system cost is increased. In addition to this, there are other two-axis tracking collectors (or point focusing collectors) which are being designed. One such is a Fresnel lens, another is a fixed mirror/tracking receiver. We have not closely examined two-axis trackers because of the very early stage of development and also because we believe that very high temperature collectors are not well suited to residential applications. (See Section 2.1.2.)

Collector Efficiency

The steady-state efficiency of solar collector devices is generally defined as the absorbed thermal power divided by the total possible power which can strike the collector aperture. The total possible power (the denominator of the collector efficiency) is defined as that power which actually strikes the aperture. The cosine effect is, therefore, not in the efficiency calculation. The cosine effect accounts for the power lost due to the angular difference between the collector normal and the incoming direct solar rays and must be applied to the assumed solar insolation available.

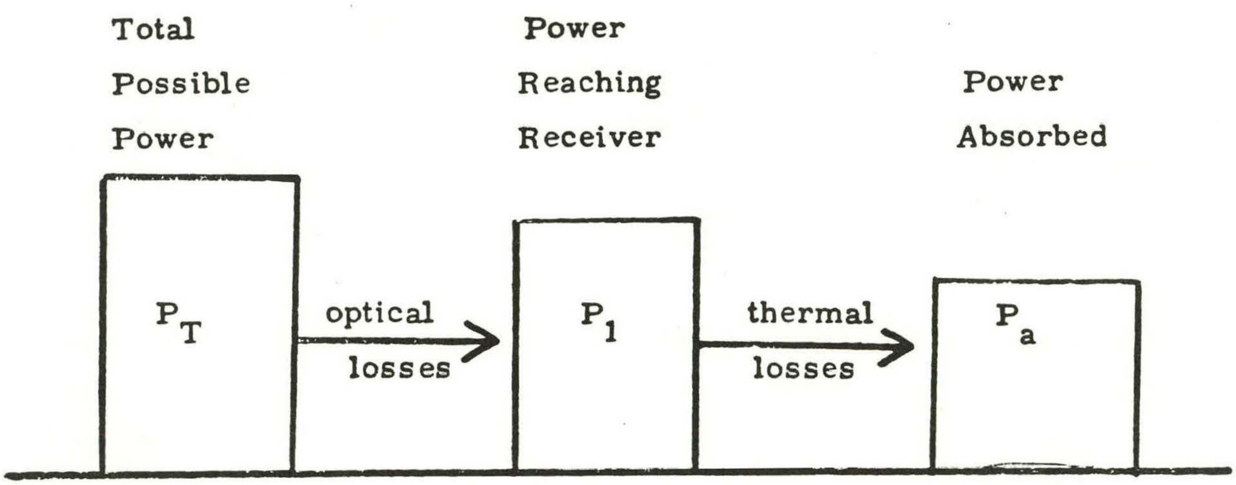
The collector efficiency modeling must account for all losses between the incoming available power and the final collected, or absorbed, power. Power losses can be broken down into two categories: optical losses and thermal losses. Optical losses can include losses due to the following:

- Transmission (i.e., flat plate cover)
- Reflectance
- Atmospheric attenuation
- Shading and blocking
- Absorptance of receiver
- Spillage at receiver.

Thermal losses are thought of as losses which occur after the solar power has gotten into the receiver (absorber) surface and account for losses due to the following:

- Reradiation
- Conduction
- Convection.

The general form of the collector efficiency equation can then be derived by reference to the following diagram:



The collector efficiency (η) is —

$$\eta = \frac{Pa}{P_T}$$

We can define an optical efficiency (η opt) as —

$$\eta\ opt = \frac{P_1}{P_T}$$

and the thermal losses are —

$$\text{Thermal loss} = P_1 - Pa$$

such that the collector efficiency may be rewritten as —

$$\eta = \eta\ \text{opt} - \frac{\text{Thermal loss}}{P_T}$$

This is the general format of the collector efficiency that is used for the analysis of all collector types.

The conduction, convection, and reradiation losses can be expressed as a function of the average collector receiver temperature and the ambient temperature —

$$q_{rerad} = B\ (T_c^{\ 4} - T_{amb}^{\ 4})$$

$$q_{cond\ \&\ conv} = A\ (T_c - T_{amb})$$

The general form of the collector efficiency is, then —

$$\eta = \eta_{\ opt} - \frac{A\ (T_c - T_{amb}) + B\ (T_c^{\ 4} - T_{amb}^{\ 4})}{I}$$

where —

η = collector efficiency

η_{opt} = optical efficiency constants

A = conduction and convection loss constant, Btu/hr ft^2-°F

B = reradiation loss constant, Btu/hr ft^2-°R^4

T_c = average receiver temperature, °R

T_{amb} = ambient temperature, °R

I = available solar insolation on collector aperture, Btu/hr-ft^2.

The constants η_{opt}, A, and B vary from one collector design to another. The value of these constants is available from both experimental and analytical investigations. We have tried to gather data from a number of sources; with these data, we will characterize the performance of available types of collectors of interest to solar total energy residential applications.

Our first step in the efficiency characterization was to look at the range of performance available for the identified collectors types. Figures A-9 through A-14 show collector efficiencies reported from analytical predictions and actual test data. For comparison, the efficiency curves for the generic

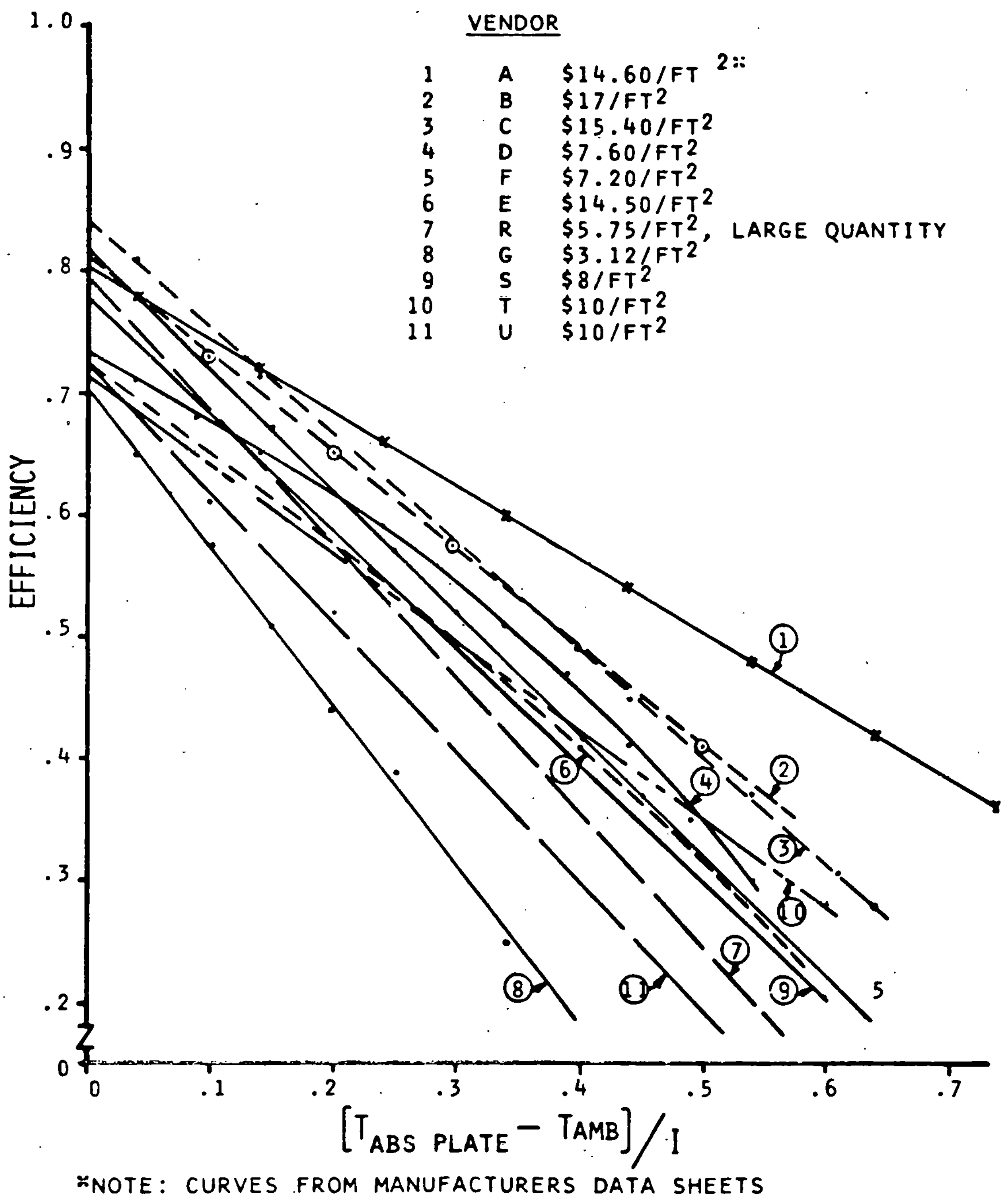


Figure A-9. FLAT PLATE COLLECTOR PERFORMANCE

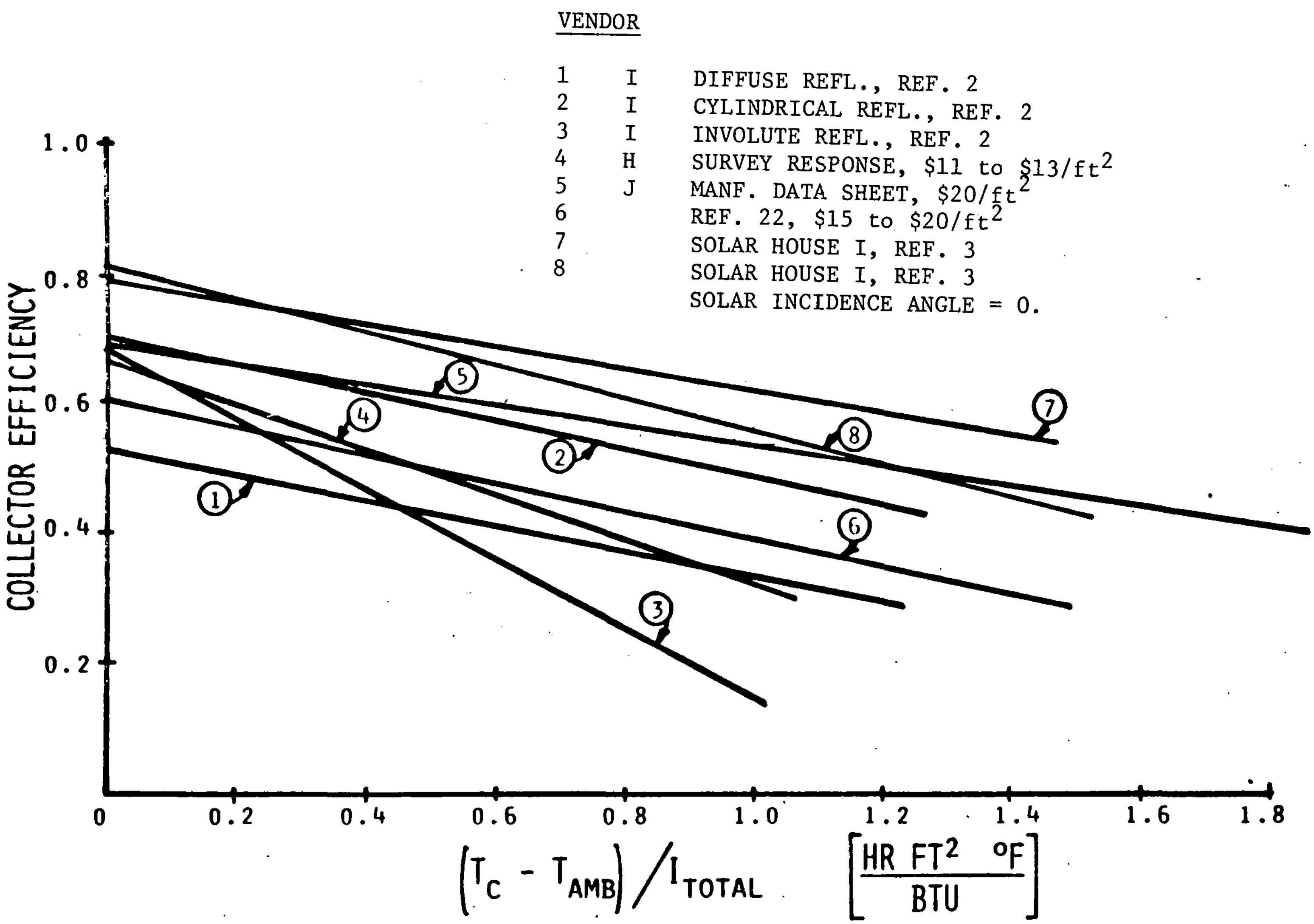


Figure A-10. PERFORMANCE FOR EVACUATED TUBE COLLECTORS

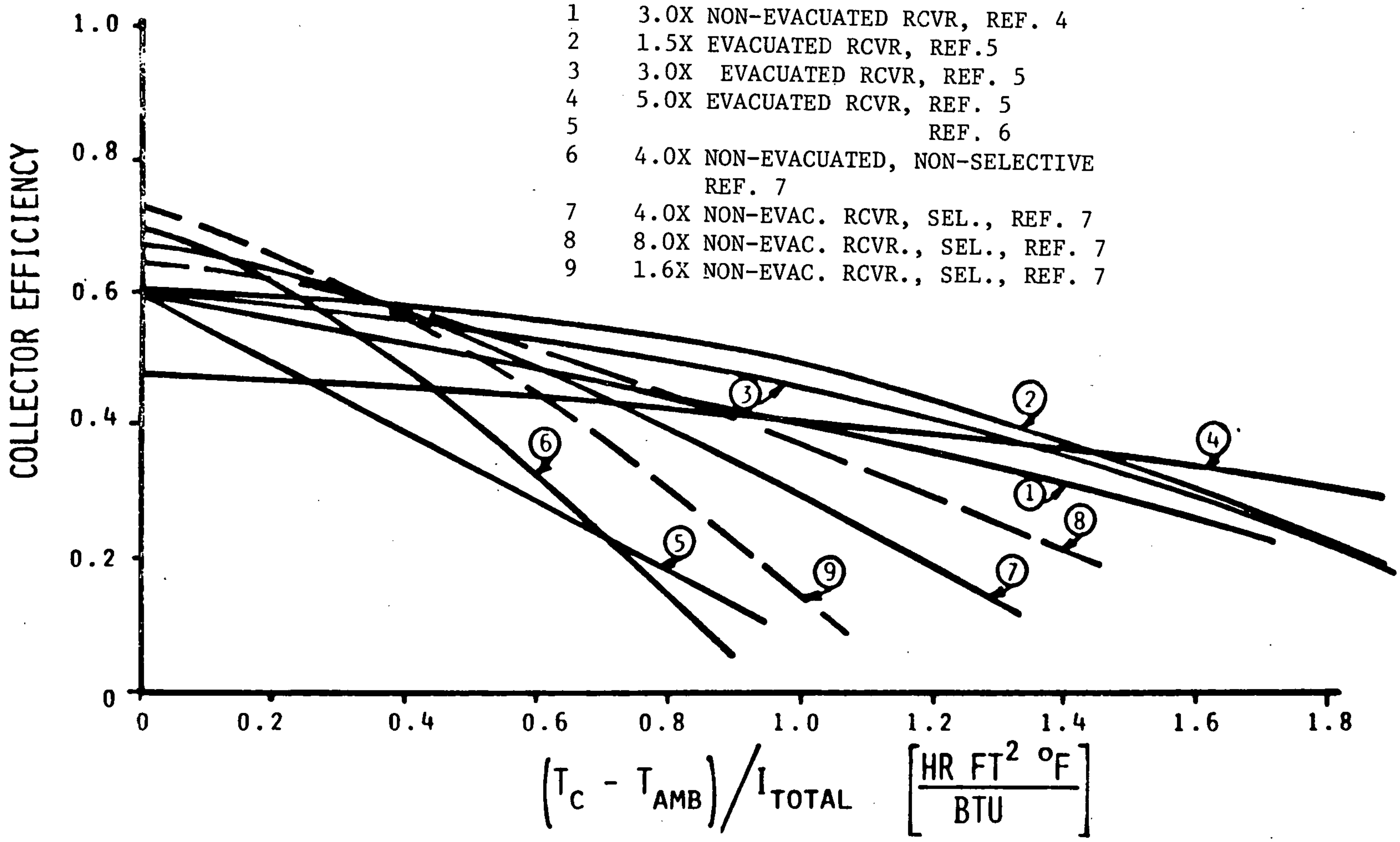


Figure A-11. PERFORMANCE FOR COMPOUND PARABOLIC COLLECTORS

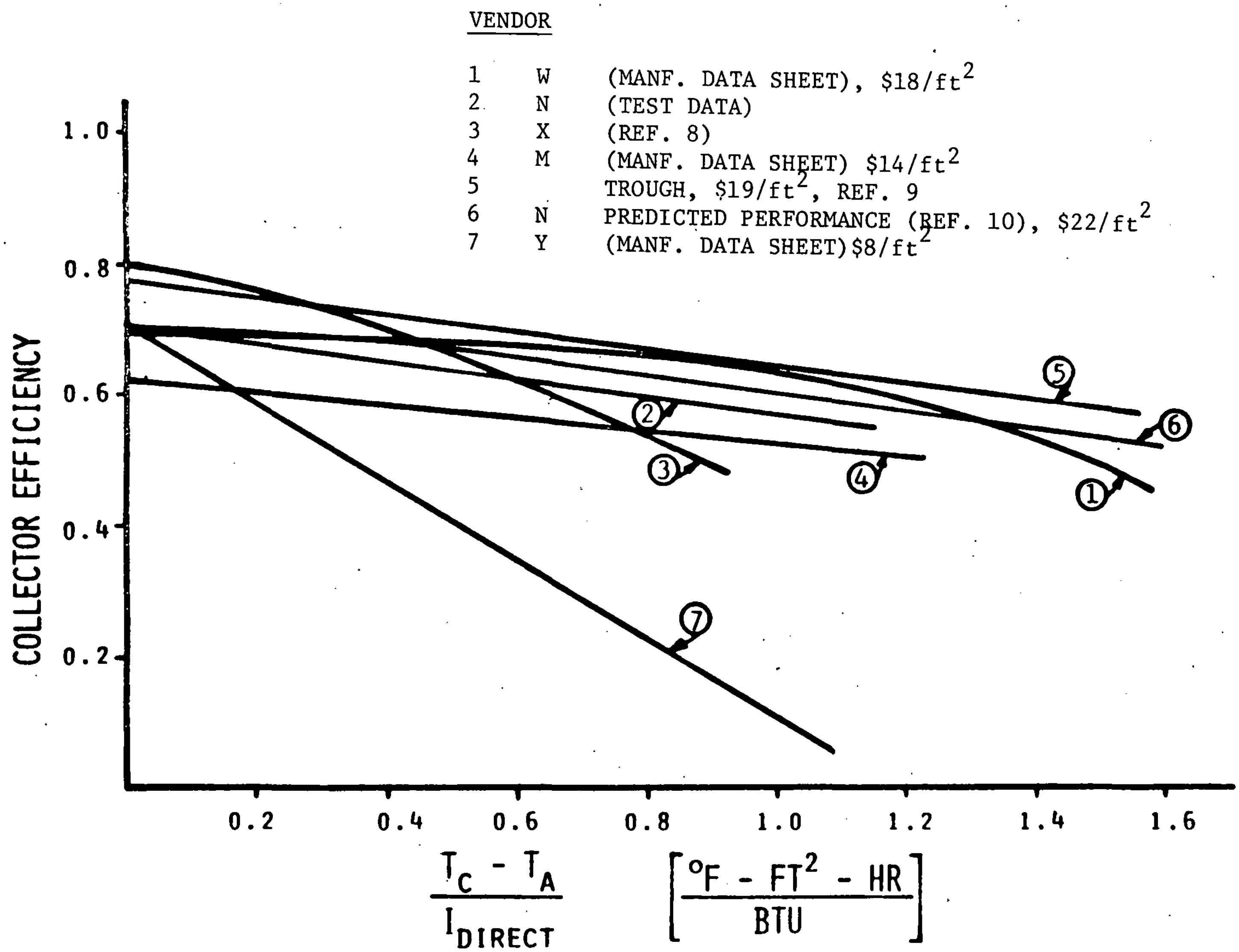


Figure A-12. PERFORMANCE FOR ONE-AXIS TRACKING TROUGH CONCENTRATORS

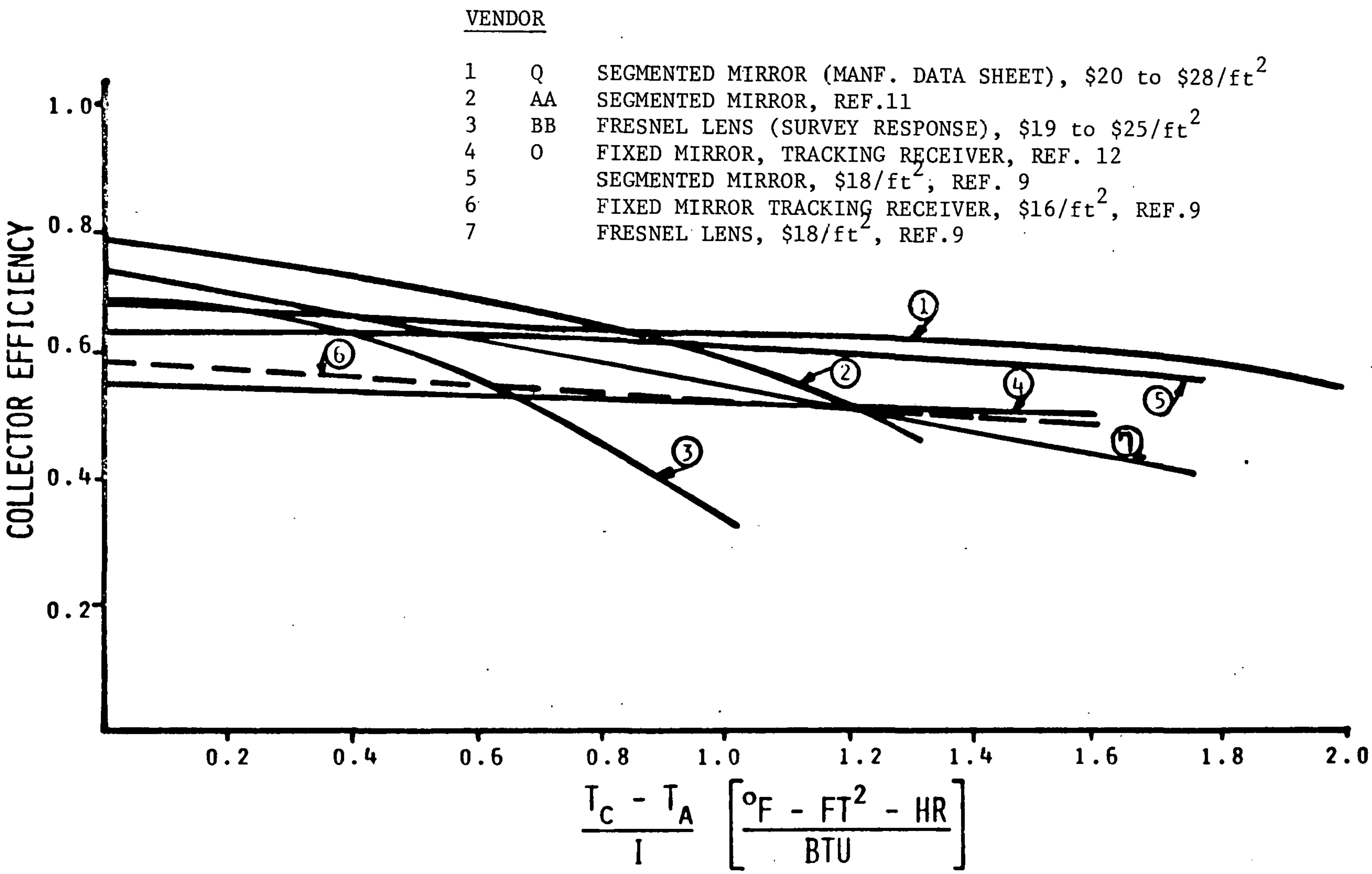


Figure A-13. PERFORMANCE FOR ONE-AXIS TRACKING COLLECTORS

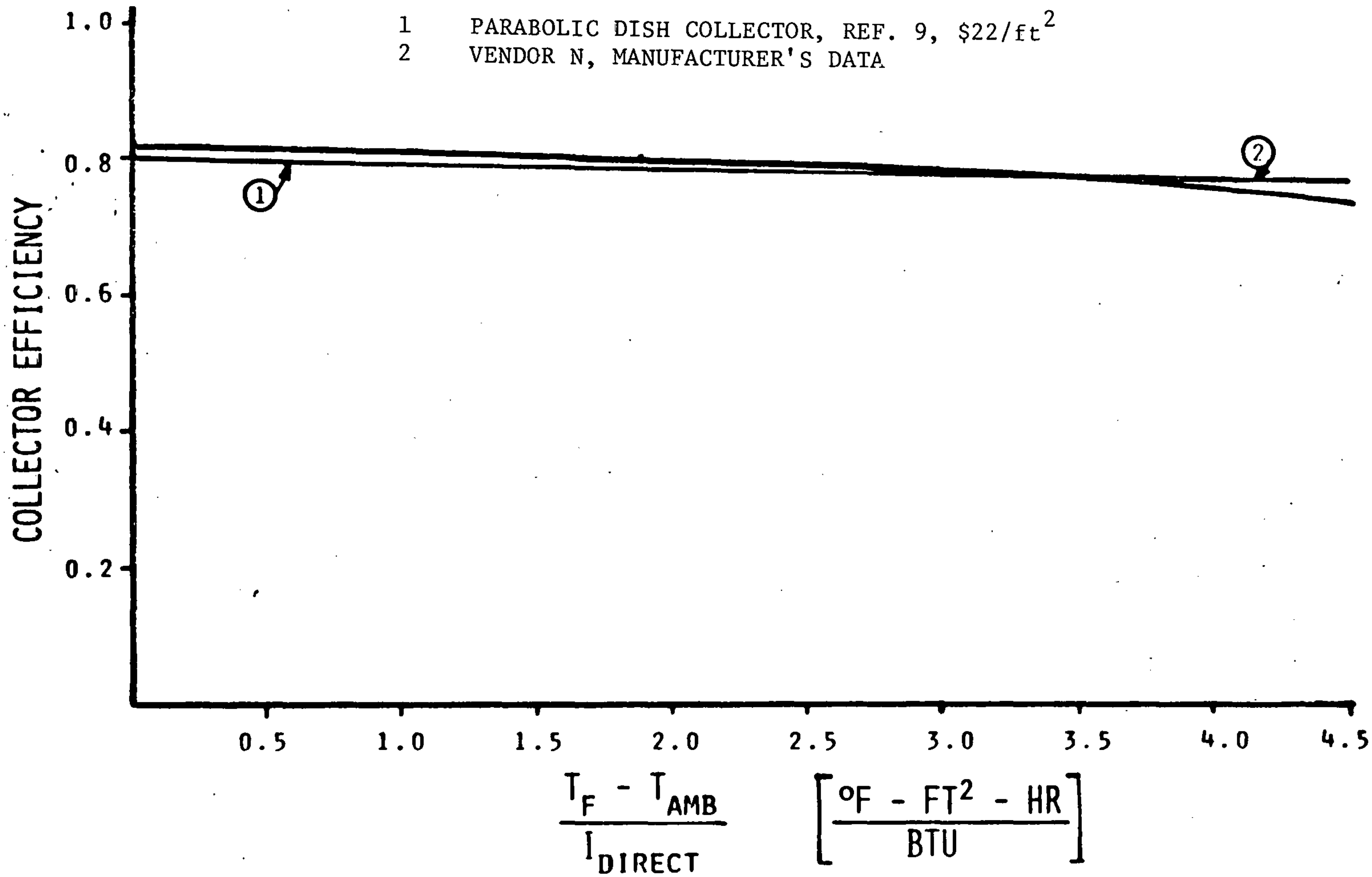


Figure A-14. TWO-AXIS TRACKING PARABOLIC DISH COLLECTORS

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collectors are also presented in the figures. Each curve is identified as to source, and the reported current cost (when available) is also shown. Where a range of cost per square foot is shown, the first cost is for small- and the second for large-quantity purchases. When making generic cost estimates, we assumed large-quantity prices.

Note that a number of curves do not have any cost associated with the performance. In fact, Figure A-11 shows no cost values at all for CPC type collectors. Where performance alone is given, it is usually the case that the particular collector is in the very early stage of development such that no reliable design information is associated with the performance and it is, therefore, very difficult to estimate cost. In just a few cases, the design is complete, but we were simply unable to define cost. For the CPC collector, it seems clear that cost estimates must be considered very preliminary.

Our next step in the characterization process was to interpret the data in Figures A-9 through A-14. Our interpretation can quite obviously be the subject of much debate because some collectors seem to offer higher performance than others which cost less. We believe this to be true because of the relatively youthful age of the solar industry. Certainly, some cost discrepanccy can be due to differences in manufacturing techniques. Note that collector lifetimes, maintenance, and installation costs are not a part of costs shown in these figures: These can overwhelm the actual collector costs. Cost estimates for these items, as well as the factory f.o.b. collectors costs, will be further addressed in the next subsection. We mention the seeming discrepancies here only to point out that our interpretation of collector performance characteristics will tend to neglect the extremes of reported data. In arriving at generic performance (both cost and efficiency), our recommended values reflect what we saw as the normal or mean values. It can be argued that superior collector designs are being bypassed by our methods. We tend to believe that this cannot be true because most collector cost and performance estimates for large-scale production are highly speculative. Also, we point out that it is not our purpose to show that one manufacturer's design is superior; rather, we wish to describe variations possible and typical expected performance.

To this end, Table A-1 shows our recommended collector constants; η_{opt}, A, and B for several types of collectors. Current factory cost estimates recommended are also shown. Figures A-15 and A-16 show the efficiency curves

Table A-1. GENERIC COLLECTOR EFFICIENCY CHARACTERISTICS

$$\text{Collector Efficiency} = \eta_{opt} - \frac{A\,(T_c - T_A) + B\,(T_c^4 - T_a^4)}{I}$$

Collector	η opt (clean)[a]	A[b]	B[c]	I[d]	Comments
Flat Plate (FP1)	0.805	0.6	0	total insolation	average $15/ft² (Vendor A) - Lennox
(FP2)	0.775	0.75	0	total	$9.00/ft²
(FP3)	0.750	1.22	0	total	$5.00/ft² Flat plates are not candidates for STES
Evac. Tube (ET1)	0.700	0.157	0	total	$20/ft² (Vendor J and I) - G. E., Owens, Ill.
(ET2)	0.670	0.35	0	total	$12/ft² (Vendor H) - KTA estimate Collectors tilted at local latitude.
CPC (CPC1)	0.60	0.13	0	total	$25/ft² (OTA estimates) CR = 1.5X
(CPC1A)	0.74	0.12	0	total	$32.5/ft² Advanced CPC — better mirrors, selective surface, cover glazing, cost 50% above current CPC. CR = 1.5X. 1.5 CPC's tilted at local altitude.
(CPC2)	0.48	0.12	0	total	$25/ft² CR = 5X. Tilt angle adjusted monthly.
(CPC2A)	0.67	0.084	0	total	$32.5/ft² Advanced CPC. CR = 1.5X.
One Axis Tracking (T1)	0.68	0.071	0	direct	Segmented mirror $20/ft² (Vendor Q) - SLATS
(T2)	0.59	0.060	0	direct	Fixed mirror tracking receiver, (Vendor O) - General Atomic
(T3)	0.69	0.190	0	direct	Fresnel lens ($19/ft²), (Vendor BB and CC) Northrup, MDAC
One Axis Tracking Parabolic Trough Concentrators (PT1)	0.750	0.0663	0.455×10^{-11}	direct	$25/ft² also used - worst case incidence angle-ref. report 1
(PT2)	0.620	0.080	0.50×10^{-10}	direct	$14/ft² (Vendor M)-Acurex (Vendor N Honeywell)
(PT3)	0.700	0.55		direct	$8.00/ft² (Vendor Y) - ZZ Corp.
Two Axis Tracking	0.8	0.0075	0.734×10^{-12}	direct	$40/ft² (Vendor N) - Honeywell
	0.82	0.013	---	direct	$22/ft² noon time efficiency only (Vendor DD) - Raytheon

[a] Performance of collectors determined with an optical efficiency of $0.90\,\eta_{opt}$ (clean)
[b] Btu/sq ft °F hr
[c] Btu/sq ft °R⁴ hr
[d] Btu/sq ft hr

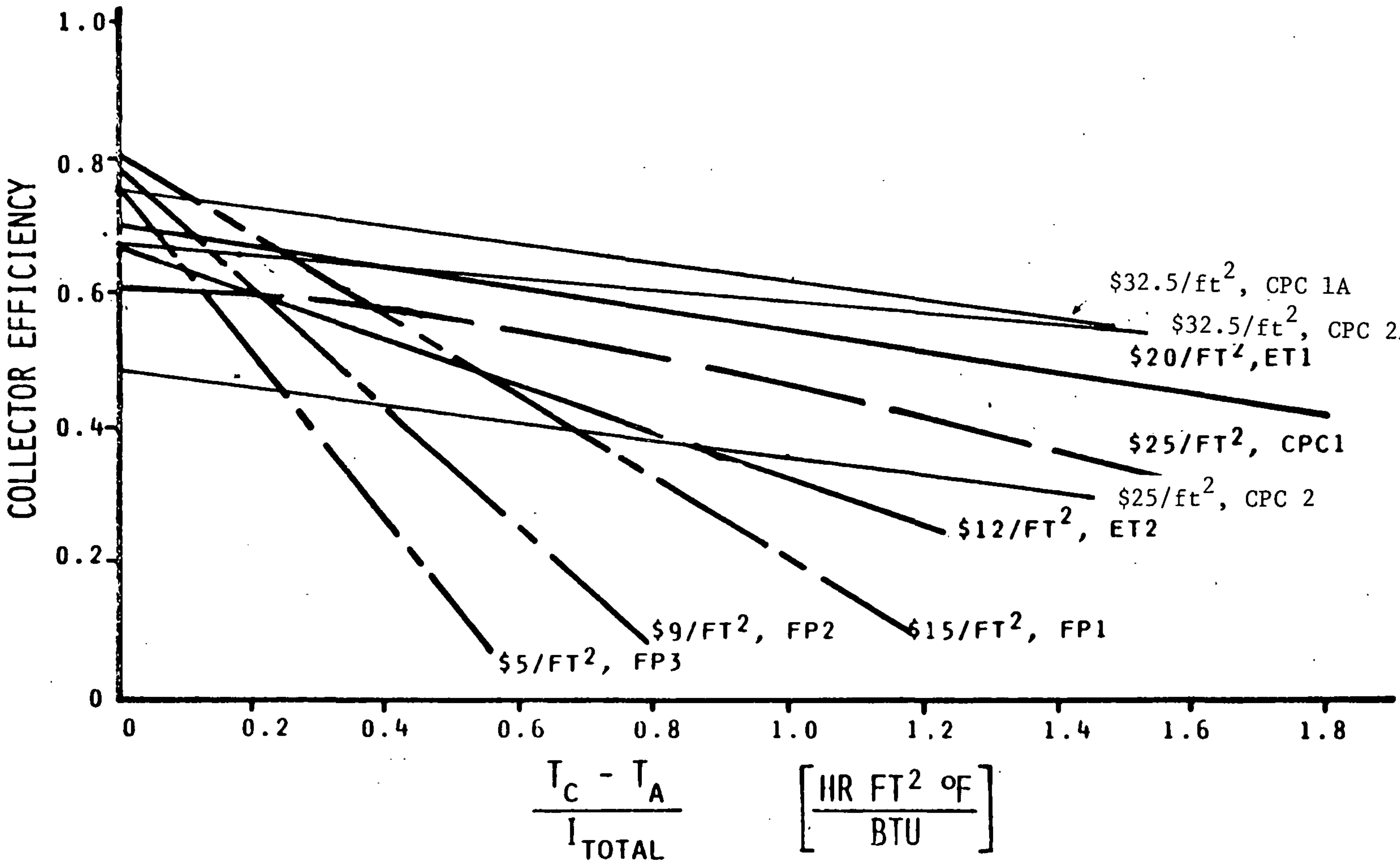

Figure A-15. GENERIC EFFICIENCY CHARACTERISTICS OF NON-TRACKING COLLECTORS

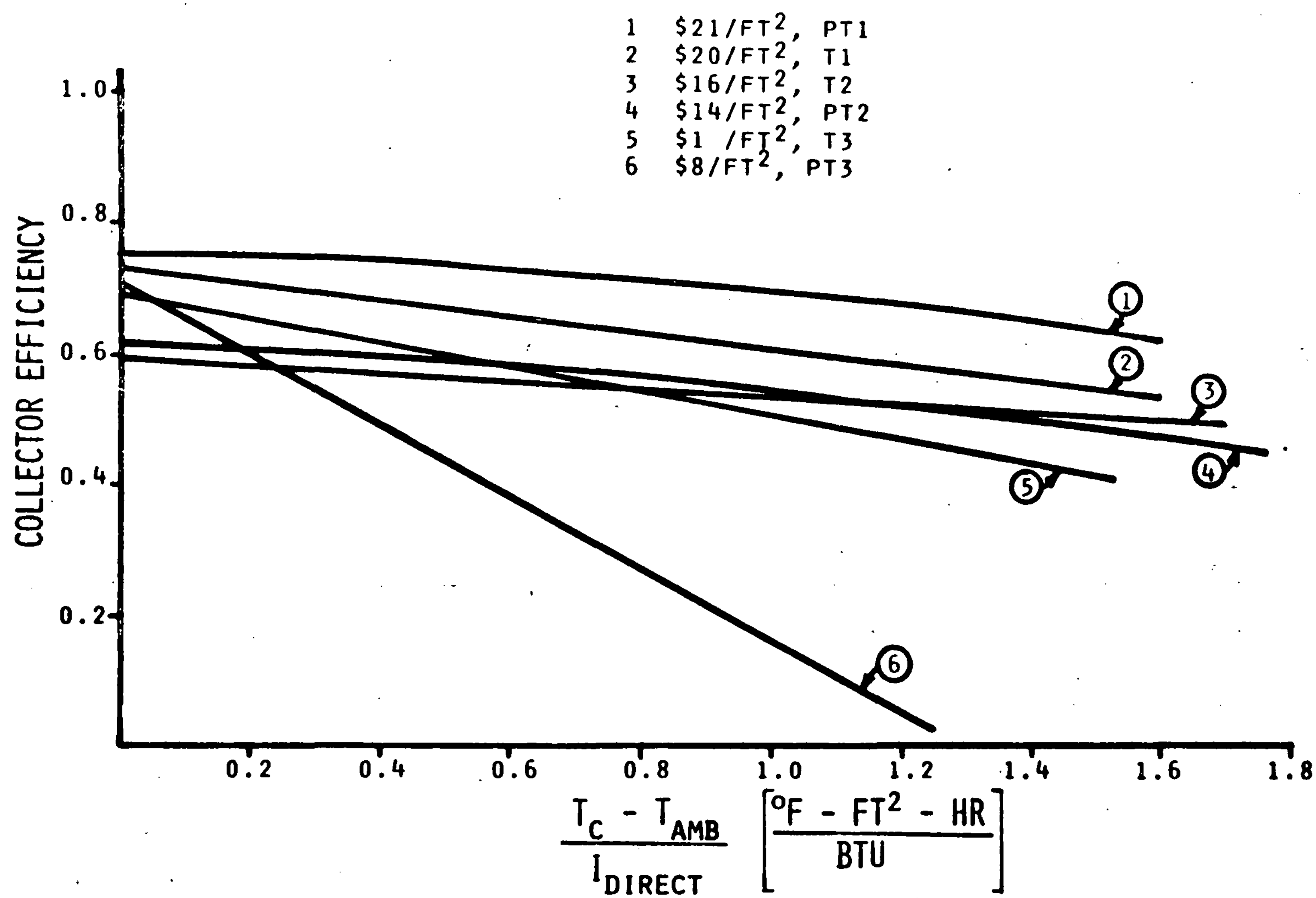

Figure A-16. GENERIC EFFICIENCY CHARACTERISTICS OF TRACKING COLLECTORS associated with the constants of Table A-1. Several flat-plate collectors are shown for comparison in Figure A-15. Flat-plate collectors are not considered appropriate for STES because of poor performance at elevated temperatures. All efficiency values reported thus far are for clean or "test condition" collectors. For the purposes of collector screening and system performance evaluation, collector optical efficiency was reduced by 10%.

The generic collector characteristics are recommended based on a number of assumed conditions. For example, all flat-plate types are considered to be 1.0X concentration (no mirrors to boost performance). Thus, the different curves come from differences in absorber selection, cover glass, etc., which can boost performance at increased cost. In all cases, we have tried to cover the range of performance which can be attained with current collectors.

Our greatest problem in this regard was in dealing with the CPC collector alternatives. Because CPC's are among the least developed of the collectors that we investigated, and because of the large variety of design options available, it is difficult to identify a consistent cost and reasonable range of performance. In general, for CPC collectors using evacuated tube receivers, higher concentrations seem to decrease performance (optical losses outweigh receiver gains) while non-evacuated tube CPC's seem to increase efficiency with increasing concentration. (Increased receiver efficiency outweighs degraded optical performance.) Because the uncertainty in designs creates uncertainty in costs, we feel that we cannot reliably predict whether a 5.0X CPC is more cost effective than a 3.0X or 1.5X CPC. We hasten to add that many solar energy investigators believe that CPC's will prove to be one of the better collector alternatives. Unfortunately, little data is currently available to aid in supporting this belief. In an attempt to throw some light on this issue, we have selected four generic CPC types: Two have concentration ratios of 1.5X and two of 5X. At each concentration ratio, collector performance characteristics represent current state-of-the-art CPC's with evacuated tube and selective absorbers, also, the other set represents advanced technology CPC's with improved glazing, better mirrored surfaces, and better selective absorbers. In the evaluation of collector costs, an effort was made to indicate a cost differential for the manufacture of the advanced CPC's. Generic CPC performance characteristics were derived from Reference 5.

For the other collector types, Table A-1 identifies the most common current solar collector designer associated with each set of generic efficiency values. The values are typical of a range of performance which can currently be obtained. Collector performance characteristics are combined with collector installed costs to establish the most appropriate collector types for residential STES applications.

Effect of Environment

The majority of the available reported efficiency values for solar collectors concern themselves only with the "test conditions" efficiency; that is, any glass or reflecting surfaces are normally new and clean. When solar collectors are exposed to the environment, these surfaces can be degraded due to dust, dirt, and continuous exposure to sunlight. For example, the accumulation of dust on a glass cover can reduce the solar transmission. Reductions in transmittance or reflectance values directly impact the collector optical efficiency. Reductions in these values can be permanent (degraded performance even after washing) or temporary (due to light scattering by dust). Both permanent and temporary degradation effects have been investigated. Our primary source of data is the University of Minnesota and Honeywell tests, which were reported in "Research Applied to Solar Thermal Power Systems" as sponsored by the National Science Foundation.

A description of various reflective materials which have been tested for degradation effects is shown in Table A-2. Both first- and second-surface mirrors were tested, and the original reflectivity is shown in the table. Samples of each of these materials were exposed to the environment for periods exceeding 2 years; samples were tested in Arizona, Minnesota, and Florida. Permanent degradation of the materials was measured for several time intervals and the results are shown in Table A-3. This table shows that degradation rates varied for different materials, with some materials showing no loss in reflectivity for the entire test period. Those that did not degrade in 58 weeks also did not degrade in over 2 years of exposure. Note that all samples which did not degrade are second surface mirrors. An acrylic or Teflon® protective layer on the reflective surface is believed to be acceptable. The data indicate that no reduction in optical efficiency is likely since materials can be used to prevent permanent degradation of reflectivity.

Table A-2. DESCRIPTION OF REFLECTOR SAMPLES

Code	Manufacturer	Mirror (1st or 2nd Surface)	Original Average Reflectivity	Material
GD/1	GENERAL DYNAMICS	1st	0.85	Aluminized fiberglass with protective coating
GD/3	GENERAL DYNAMICS	1st	0.83	Aluminized fiberglass with protective coating
GD/4	GENERAL DYNAMICS	1st	0.92	Aluminized fiberglass without protective coating
3M/1	3M COMPANY	2nd	0.86	Aluminized acrylic
H/1	HONEYWELL	2nd	0.76	Aluminized glass
S/3	G.T. SHELDAHL	2nd	0.77	Aluminized Teflon
S/1	G.T. SHELDAHL	2nd	0.79	Aluminized Teflon
S/2	G.T. SHELDAHL	2nd	0.86	Silvered Teflon
R/1	RAM PRODUCTS	2nd	0.80	Aluminized acrylic plexiglass
AK/1	ALCAO	1st	0.82	Anodized aluminum reflector sheeting (Alzak)

Table A-3. DEGRADATION OF SAMPLES AS A FUNCTION OF TIME

Sample Type	Location	Original Reflectivity	Degradation After Approximately 15 Weeks	Degradation After Approximately 45 Weeks	Degradation After 58 Weeks (or greater)
GD/1	Arizona	0.88	3%	14%	22%
	Floria	0.85	Failed		
	Minnesota	0.85	Failed		
GD/3	Arizona	0.83	11%	Failed	
	Florida	0.83	Failed		
	Minnesota	0.81	4%	Failed	
GD/4	Arizona	0.92	5%	11%	17%
	Florida	0.93	34%	Failed	
	Minnesota	0.92	Failed		
3M/1	Arizona	0.86	0	0	0
	Florida	0.87	1%	31%	Failed
	Minnesota	0.85	1%	1%	1%
S/1	Arizona	0.78	0	0	0
	Florida	0.79	0	0	0
	Minnesota	0.79	0	0	0
S/2	Arizona	0.86	0	0	0
	Florida	0.86	0	0	0
	Minnesota	0.87	0	0	0
S/3	Arizona	0.78	0	0	0
	Florida	0.77	0	4%	3%
	Minnesota	0.77	0	0	0
H/1	Arizona	0.76	0	0	0
	Florida	0.76	0	0	0
	Minnesota	0.76	0	0	0
R/1	Arizona	0.80	3%	3%	10%
	Florida	0.80	0	5%	8%
	Minnesota	0.80	0	1%	4%

A reduction in reflectivity due to the effects of dirt can be expected. For the same samples discussed above, the reflectivity when clean and when dirty was measured. Measurements were made at time intervals between washings of 9 to 45 weeks. The time periods are all long enough so that no trend in reflectivity reduction versus time was noticed, although the percentage reduction varied from one measurement to the next. For the samples which did not fail, Table A-4 shows the range of measured reflectivity reduction. (Note that some materials seem to be more susceptible to degradation than others.)

Some operating experience with mirror surfaces was gained as a result of the recently completed central receiver design study. The Honeywell heliostat used second surface silvered glass mirrors. Prototype heliostats were tested in the Florida environment. Data from the tests indicate that reflectivity reduction can be maintained below 10% by weekly cleaning. An average reflectivity reduction from 4% to 6% is estimated for a 2-week period.

For collectors which have glass covers either over the collector or the receiver, the glass transmittance value can be degraded. Test data for several types of etched anti-reflection glass are shown in Table A-5. The data indicate that no permanent degradation should be expected. Dirt accummulation on the glass can, however, reduce transmittance by as much as 4%. An average reduction in transmittance of approximately 2% was noted for tests conducted at 1-month intervals.

A reduction in optical efficiency of 10% was used to represent the effects of environment on collector performance in the collector screeming study and system performance estimation.

Future Collector Efficiency Improvement

Improvements in reported state-of-the-art collector efficiency values can be made by using a number of possible advanced design techniques and materials. Performance improvements can be gained by use of high transmittance, anti-reflection coating glass covers or tubes, or by using improved selective coatings or future highly reflective materials. Design changes that would allow higher concentration ratio collectors, with attendant lower heat losses, may be a source of future increased performance. In short, there are a great number of methods that can theoretically offer significant efficiency gains.

Table A-4. REDUCTION IN REFLECTIVITY DUE TO DIRT TESTED IN ARIZONA ENVIRONMENT

SAMPLE TYPE	3M/1	S/1	S/2	S/3	H/1	R/1
PERCENT REDUCTION IN REFLECTIVITY	3-8%	1-10%	4-18%	5-22%	1-9%	4-13%

* Times from last cleaning varies from 9 - 45 weeks

Table A-5. SOLAR TRANSMITTANCE OF ETCHED GLASS AFTER 6-MONTH OUTDOOR EXPOSURE

LOF Single Strength A Glass	Solar Transmittance (%)
Unetched	86
As Etched	90
Etched, Exposed, Uncleaned	86
Etched, Exposed, Cleaned	90
Fourco Glass	**Solar Transmittance (%)**
Unetched	89
As Etched	95.6
Etched, Exposed, Uncleaned	94.1*
Etched, Exposed, Cleaned	95.4

Whether or not these efficiency gains are cost effective is a question which only continued research and development can answer.

We expect that it is optimistic to believe that substantial efficiency improvements can be made over the high efficiency curves which we have already presented as the upper range of current day collectors. That is, we believe that significant improvements will probably not be cost effective within the next 10 to 15 years. In fact, it is more practical to consider design improvements which can reduce weight, and thereby cost, or can ensure long collector lifetime with minimal operating and maintenance costs. With this in mind, we have concentrated on projecting future cost reductions in the collectors and have used the same generic efficiency values as reported for current collectors.

We do not wish to misguide readers to interpret this as meaning that improvements are not possible; some improvements can be made. Efficiency improvements possible are treated only briefly by examining known sources of increased performance. For example, current parabolic trough collectors typically use reflective films with reflectance values of 0.77 to 0.87; advances in materials may boost reflectance to as high as 0.90 to 0.95. This may be represented as a 3% to 23% increase in optical efficiency. The cost of this improvement is forecast as being an increase of 5% to 10% of the collector cost. In some cases, it may prove economic to use higher performance materials.

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APPENDIX B. WEATHER AND INSOLATION DATA FOR STES PERFORMANCE EVALUATION

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Introduction

Performance simulations for solar energy systems require a mathematical model of the energy incident on the collectors and of ambient weather conditions which affect the system components. It is possible to model the behavior of a solar system using hourly weather and insolation data* recorded for the location in question as input to the equipment simulation program. This approach gives the best estimate of performance of a specified solar energy system.

Hourly weather data, such as dry bulb and wet bulb temperatures, are readily available from the U.S. Weather Bureau in the form of 10-year data on the TDF 1440 Airways Surface Observation tapes. However, hourly insolation data are not readily available in this form and much of the data in existence were measured with instruments that were out of calibration and thus not reliable. The insolation data, therefore, are calculated using accepted ASHRAE* algorithms andare placed on the weather tape along with recorded data and other calculated hourly values.

The data extracted for use from the TDF 1440 weather tapes include dry bulb, wet bulb, and dew point temperatures, relative humidity, barometric pressure, wind speed and direction, total cloud amount, and the amount of cirros, cirrostratus, and cirrocumulus clouds in the first, second, third, and fourth layers. The weather processing program then calculates the following data and places them on the output weather tape as permanent data:

1. Psychrometric Data: The algorithms calculate humidity ratio, enthalpy, and density.

2. Solar Radiation Data: The algorithms calculate sunrise and sunset times, declination angle, equation of time, apparent solar constant, atmospheric extinction coefficient, sky diffuse factor, sun index, hour angle, solar time, direction cosines of sun ray, solar altitude and azimuth, cloud cover, cloud cover modifier, solar radiation intensities for direct normal, sky diffuse, ground diffuse, direct horizontal, and total horizontal. Other data are calculated and printed but not written on tape for use with the system simulation program.

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* See References 1, 2, and 3 in this section.

3. Film Coefficient Data: The algorithms calculate outside film coefficient as a function of wind speed for six different surface types. The smooth surface coefficient may be used in the collector heat loss calculation.

The methodology described below uses reliable recorded data where available and accepted calculation procedures to derive data which are not available in accurate records.

Solar Radiation Model

1. Scope — The weather and permanent data preparation program produces basic solar data, which may be used by the collector simulation programs to calculate final insolation values.

   The collector models in the system simulation program use a sub-routine called Solar Radiation Processor to determine the angle-of-incidence and insolation for a specific collector system. This discussion is limited to the hourly data produced by the weather and permanent data preparation program. The reader is referred to the discussion on the Solar Radiation Processor for the insolation models relating to the specific collector types.

2. Extraterrestrial Radiation — At the average distance of the Earth from the Sun (92,955,888 miles), the mean intensity or strength of the solar beam has been measured at 1.94 gram calories/minute-cm^2 on a plane surface presented perpendicular to the beam outside the atmosphere. This is equivalent to 429.2 Btu/hr-ft^2 of the same surface. This is called the solar constant, I_{sc}, and is modified only by a small amount because of the seasonal variations in the Earth-Sun distance.

   The value of I_o varies from 139.9 mW/cm^2 in January to 130.9 mW/cm^2 in July. Table B-1 lists, as a function of date, the extraterrestrial radiation variations, and five variables related to solar radiation. These variables are declination angle, δ; the equation of time, ET; the apparent solar constant, A; the atmospheric extinction coefficient, B; and sky diffuse factor, C. Table B-1 values could be stored in computer memory, but this would necessitate an interpolation procedure for each day of the year. In order to avoid such a problem and to save computer core space, δ, ET, A, B, and C are expressed in Fourier Series form and the values are calculated as a function of the day of the year, d, from the following truncated Fourier Series. (See Table B-2.)

$$\left.\begin{matrix}\delta \\ ET \\ A \\ B \\ C\end{matrix}\right\} = A_0 + A_1 * Cos(w*d) + A_2 * Cos(2*w*d) + A_3 * Cos(3*w*d) + B_1 * sin(w*d) + B_2 * sin(2*w*d) + B_3 * sin(3*w*d)$$

where: $w = \frac{2*\pi}{366}$

DATE	I_o BTUH/SF	δ DEGREES	ET HOURS	A BTUH/SF	B AIR MASS^{-1}	C DIMENSIONLESS
Jan. 21	440.1	-20.0	-.190	390.	0.142	0.058
Feb. 21	436.5	-10.8	-.230	385.	0.144	0.060
Mar. 21	430.0	0.0	-.123	376.	0.156	0.071
Apr. 21	422.8	11.6	.020	360.	0.180	0.097
May 21	416.5	20.0	.060	350.	0.196	0.121
Jun. 21	413.1	23.45	-.025	345.	0.205	0.134
Jul. 21	413.5	20.6	-.103	344.	0.207	0.136
Aug. 21	417.6	12.3	-.051	351.	0.201	0.122
Sep. 21	424.0	0.0	.113	365.	0.177	0.092
Oct. 21	431.1	-10.5	.255	378.	0.160	0.073
Nov. 21	437.6	-19.8	.235	387.	0.149	0.063
Dec. 21	441.0	-23.45	.033	391.	0.142	0.057

A - apparent solar constant
B - atmospheric extinction coefficient
C - sky diffuse factor
δ - solar declination
ET - equation of time

Table B-1. SOLAR RADIATION INTENSITY AND RELATED DATA

	A_0	A_1	A_2	A_3	B_1	B_2	B_3
δ	.302	-22.92	- .229	- .243	3.851	.002	-.055
ET	0.0	.007	-0.05	-0.0015	-0.122	-0.156	-.005
A	368.44	24.52	-1.14	-1.09	0.58	-0.18	.28
B	.1717	- .0344	.0032	.0024	- .0043	0.0	-.0008
C	.0905	- .0410	.0073	.0015	- .0034	.0004	-.0006

Table B-2. FOURIER COEFFICIENTS

The program calculates the following on a daily basis:

1 - sunrise time
2 - sunset time
3 - declination angle
4 - equation of time
5 - apparent solar constant
6 - atmospheric extinction coefficient
7 - sky diffuse factor.

All other data values discussed here are determined hourly for a full 8760-hour year.

The hour angle, h, is calculated in degrees as —

$$H = 15 * (t-12 + TZN + ET) - \ell$$

where —

t = time, hours (after midnight), (0-24)
TZN = time zone number shown in Figure B-1 and Table B-3
ℓ = longitude, degrees, + west
− east.

The direction cosines of the solar beam are then computed.

1. Direction cosine of sun ray in the zenith direction
   L = latitude; δ = declination
   $\text{CosZ} = \text{Sin L} * \sin\delta + \text{CosL} * \cos\delta * \cos h$
   The zenith angle is the angle between the vertical and the beam.

2. Direction cosine of sun ray in west direction.
   $\text{CosW} = \cos\delta * \sin h$

3. Direction cosine of sun ray in south direction.
   CosS = ± (1-cos z**2-cosW**2)**0.5

   if cosh > tan δ/ tan L, cosS is positive; otherwise it is negative.

In addition to the direction cosines discussed above, the program also computes the solar altitude and solar azimuth as:

SALT = arcsin (cos Z); SALT = Solar Altitude (position of the sun above the horizontal)

If cos s>o, SAZM - arcsin $\frac{(\cos W)}{(\cos \text{SALT})}$; SAZM = Solar Azimuth (position of the sun measured from the South)

If cos s < o, SAZM = 180 - arcsin $\frac{(\cos W)}{(\cos \text{SALT})}$

Incidence angle algorithms are discussed in the Solar Radiation Processor subroutine section.

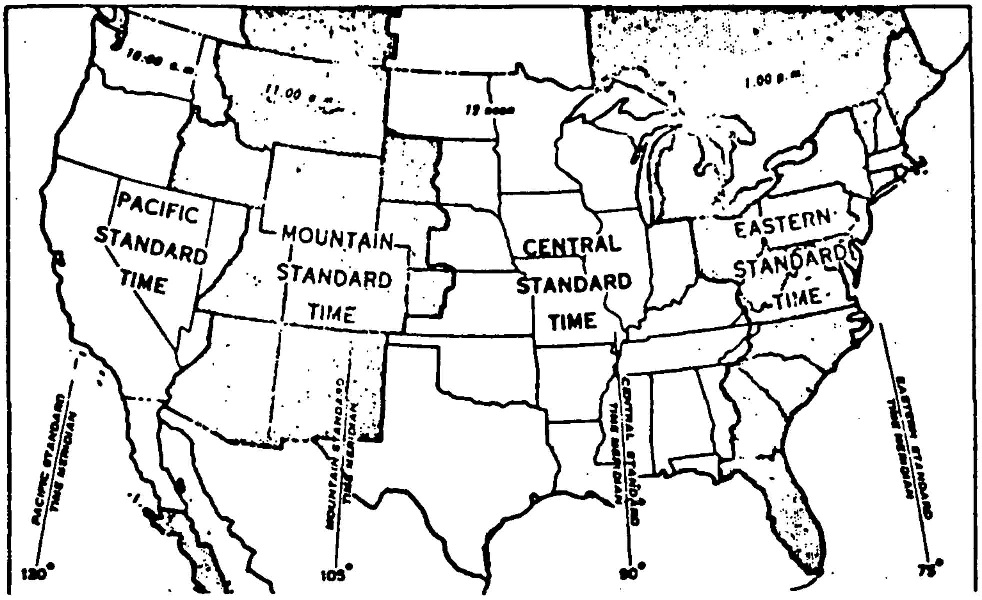

Figure 1. TIME ZONES IN THE UNITED STATES

Table B-3. TIME ZONE NUMBERS IN UNITED STATES FOR STANDARD TIME

TIME ZONE	TZN
Atlantic	4
Eastern	5
Central	6
Mountain	7
Pacific	8

3. Direct Normal Radiation — The Threlkeld and Jordan study* took into account the wide variation of water vapor which is in the atmosphere above the United States at any given time. These differences cause a variation in the amount of attenuation of the direct solar beam. The intensity of the direct normal irradiation at the earth's surface on a cloudless day can be well represented by:

$$I_{DN} = A * CN * \mathrm{Exp}\,\frac{(-B)}{(\cos Z)}$$

The factor CN is the clearness number for the local atmospheric conditions shown in Figure B-2. The term A (apparent solar constant) includes the effect of upper atmosphere absorption and of variable Earth-Sun distance. Clearness number is input as a seasonal variable (summer and winter factors).

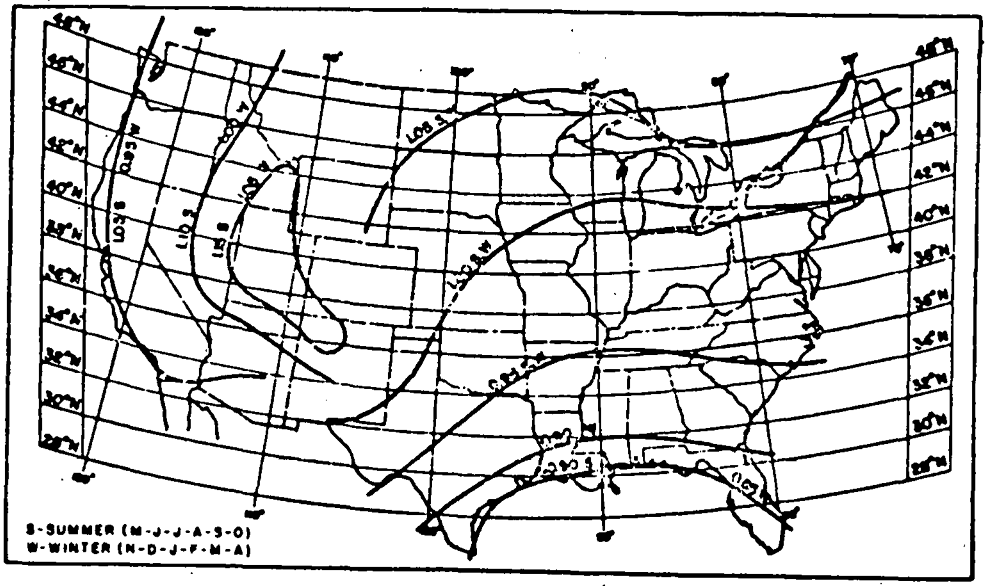

Figure B-2. CLEARNESS NUMBERS OF NON-INDUSTRIAL ATMOSPHERE IN UNITED STATES

4. Diffuse Radiation — A portion of the radiation is scattered by particulates in the atmosphere and reaches a surface at ground level as sky diffuse radiation. The same surface may receive diffuse radiation as a function of ground reflectivity.

Sky Diffuse Radiation

$I_{DS} = C * I_{DN}$ (for horizontal surface)

$I_{DS} = C * I_{DN} * (\frac{1+\alpha}{2})$ (for tilted surface)

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* See References 4 and 5.

Ground Diffuse Radiation

BS = C * I_{DN}/CN**^{2} (brightness of sky)

BG = ρ_g * (BS + I_{DN} * CosZ) (brightness of ground)

I_{DG} = BG * ([1 -α]/2)

where —

ρ_g = ground reflectivity

α = Cos(CTA); direction cosine of normal to surface

CTA = surface tilt angle; degrees from horizontal.

5. Cloud Cover Effect — The available insolation is reduced by the intermittent (but sometimes long range) effects of cloud layers. The CLOUD subroutine calculates the degree of this reduction and produces an hourly factor CCF to be used in computing the reduced insolation amount (insolation is multiplied by CCF).

This factor varies by season and is calculated as follows:

A. Cloud cover:

cc = TCA - 0.5 (CAj) cirrus + (CAj) cirrostratus
+ (CAj) cirrocumulus

B. Cloud Cover Factor:

CCF = P (IS) + Q(IS) * CC + R(IS) * CC **2

where —

TCA = Total cloud amount
CAj = Cloud amount at j-th layer, where j = 1, 2, 3 and 4
IS = Season index; 1 = spring, 2 = summer, 3 = fall, 4 = winter
P,Q, and R are found in Table B-4 for the appropriate season.

Table B-4. CLOUD FACTORS

Season	P	Q	R
Spring	1.06	0.012	-0.0084
Summer	0.96	0.033	-0.0106
Autumn	0.95	0.030	-0.0108
Winter	1.14	0.003	-0.0082

The cloud cover factor is used to modify the direct beam and horizontal solar radiation values (IDN*CCF).

6. Film Heat Transfer Coefficient — The heat losses from a collector of given design will vary as a function of wind motion at the outside surface.

The outside surface heat transfer coefficient in Btu/hr-ft^2-°F is calculated for a smooth surface as:

FO = - 0.001661 * V **2 + 0.302 * V + 1.45

where —

V = wind velocity, mph.

These hourly values are placed on the processes weather tape for later use. All evaluations of loads, atmospheric conditions, and system simulations are performed on an hourly basis, 8760-hours/year.

Figure B-3 presents a sample data printout of the weather and permanent data for a 24-hour period. Three hundred and sixty five such reports are available with each run of the weather processing program.

Solar Radiation Processor

1. Scope — Each collector subroutine calculates the insolation and incidence angle of the solar radiation available to it each hour (8760-hours/year). Using the basic hourly data from the Weather and Permanent Data Preparation program and the specified collector type and operation (aperture orientation), the collector subroutine calculates the time-varying incidence angle and available insolation.

2. Angle of Incidence — One key to the performance of a solar collector is the angle of incidence of the solar beam with respect to the collector surface or aperture. This relation must be accurately calculated on an hour-by-hour basis, particularly with concentrating collectors which accept little or no diffuse radiation. Flat plate collector arrays accept both diffuse and direct radiation. In this case, the angle of incidence affects the direct component but has only secondary influence over diffuse components, such as:

   a. The diffuse enhancement factor of an evacuated tube collector is affected by the "effective" angle of incidence when a cylindrical or involute reflector is employed.

   b. The ground diffuse radiation is a function of the sun's zenith angle and the collector tilt angle.

Variation of the incidence angle depends upon the tracking pattern or fixed orientation of the collector.

For flat plate collector arrays the incidence angle is given by:

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***************************************************************************************************
* YEAR = 1959   DAY OF THE YEAR = 100   MONTH OF THE YEAR = 4   DAY OF THE MONTH = 10   DAY OF THE WEEK = 6 *
* LEAP YEAR INDEX = 0   DAY LIGHT SAVING TIME INDEX = 0   HOLIDAY INDEX = 0   SEASON INDEX = 1          *
* SUN RISE TIME = 5.54   SUN SET TIME = 18.46   DECLINATION ANGLE = .134   EQUATION OF TIME = -.020     *
* APPARENT SOLAR CONSTANT = 365.8   ATMOSPHERIC EXTINCTION COEFFICIENT = .171   SKY DIFFUSE FACTOR = .087 *
***************************************************************************************************
```

H O U R O F T H E D A Y

	1	2	3	4	5	6	7	8	9	10	11	12
HR OF YR	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388
DRY-BULB	60	60	60	59	60	59	60	60	61	64	68	68
WET-BULB	58	58	58	57	58	58	58	57	58	59	61	61
DEW POINT	56	57	57	56	57	56	57	56	56	55	56	56
REL HUM	87	90	89	89	89	90	89	88	85	73	65	65
PRESSURE	2989	2989	2988	2988	2987	2987	2988	2990	2991	2991	2991	2990
WIND SPD	4	6	5	5	4	5	5	0	0	3	9	0
WIND DIR	67	67	67	113	45	45	135	360	360	270	270	247
HUM RAT	.0099	.0099	.0099	.0096	.0099	.0102	.0099	.0093	.0097	.0096	.0100	.0100
ENTHALPY	25.2	25.2	25.2	24.5	25.2	25.2	25.2	24.5	25.2	25.8	27.2	27.2
DENSITY	.0750	.0750	.0750	.0752	.0750	.0751	.0750	.0751	.0750	.0746	.0739	.0739
SUN INDEX	0	0	0	0	0	1	1	1	1	1	1	1
HR ANGLE	0	0	0	0	0	88	73	58	43	28	13	-1
SOL TIME	.0	.0	.0	.0	.0	6.1	7.1	8.1	9.1	10.1	11.1	12.1
COSZ	.00	.00	.00	.00	.00	.10	.31	.51	.68	.80	.88	.90
COSW	.00	.00	.00	.00	.00	-.99	-.95	-.84	-.68	-.47	-.22	.02
COSB	.00	.00	.00	.00	.00	-.09	.05	.18	.29	.38	.43	.44
SOL ALT	0	0	0	0	0	5	18	30	42	53	61	63
SOL AZM	0	0	0	0	0	95	86	77	66	50	27	-2
TO CL AMO	10	10	10	10	10	10	10	10	8	3	2	1
CL CO	.00	.00	.00	.00	.00	10.00	10.00	10.00	8.00	3.00	2.00	1.00
CL CO FA	.00	.00	.00	.00	.00	.30	.34	.34	.62	1.00	1.00	1.00
DIR NOR	0	0	0	0	0	66	201	248	269	280	285	287
DIR NOR C	0	0	0	0	0	22	69	84	166	280	285	287
SKY DIF	0	0	0	0	0	6	19	24	26	27	27	27
GR DIF	0	0	0	0	0	2	16	30	41	50	55	56
DIR HOR	0	0	0	0	0	6	63	126	181	224	249	257
TOT HOR	0	0	0	0	0	12	82	150	207	251	276	284
DIR HOR C	0	0	0	0	0	-0	-0	-0	40	177	226	263
DIF HOR C	0	0	0	0	0	4	27	50	88	74	50	21
TOT HOR C	0	0	0	0	0	4	27	50	128	251	276	264
O F C 1	4.2	5.2	4.7	4.7	4.2	4.7	4.7	2.0	2.0	3.6	6.9	2.0
O F C 2	3.7	4.5	4.1	4.1	3.7	4.1	4.1	2.2	2.2	3.3	5.5	2.2
O F C 3	3.4	4.2	3.8	3.6	3.4	3.8	3.8	1.9	1.9	3.0	5.3	1.9
O F C 4	2.9	3.5	3.2	3.2	2.9	3.2	3.2	1.4	1.4	2.5	4.5	1.4
O F C 5	2.9	3.5	3.2	3.2	2.9	3.2	3.2	1.8	1.8	2.6	4.3	1.8
O F C 6	2.6	3.2	2.9	2.7	2.6	2.9	2.9	1.4	1.4	2.3	4.0	1.4

	13	14	15	16	17	18	19	20	21	22	23	24
HR OF YR	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400
DRY-BULB	70	70	71	70	69	68	66	65	65	64	62	62
WET-BULB	62	62	63	63	62	62	61	60	59	60	60	59
DEW POINT	56	57	58	58	58	59	58	56	56	57	58	58
REL HUM	62	62	63	66	69	73	73	72	72	79	87	88
PRESSURE	2988	2986	2985	2983	2982	2982	2981	2981	2982	2983	2982	2982
WIND SPD	1	3	6	7	5	4	1	7	6	7	7	4
WIND DIR	270	247	270	270	270	270	247	247	247	247	293	225
HUM RAT	.0102	.0102	.0106	.0108	.0104	.0106	.0105	.0100	.0094	.0103	.0107	.0101
ENTHALPY	27.9	27.9	28.6	28.6	27.9	27.9	27.2	26.5	25.9	26.5	26.6	25.9
DENSITY	.0736	.0735	.0733	.0734	.0735	.0736	.0739	.0741	.0742	.0743	.0745	.0746
SUN INDEX	1	1	1	1	1	1	0	0	0	0	0	0
HR ANGLE	-16	-31	-46	-61	-76	-91	0	0	0	0	0	0
SOL TIME	13.1	14.1	15.1	16.1	17.1	18.1	.0	.0	.0	.0	.0	.0
COSZ	.86	.78	.65	.47	.27	.06	.00	.00	.00	.00	.00	.00
COSW	.27	.51	.71	.87	.96	.99	.00	.00	.00	.00	.00	.00
COSB	.42	.36	.27	.16	.02	-.12	.00	.00	.00	.00	.00	.00
SOL ALT	59	51	40	28	15	3	0	0	0	0	0	0
SOL AZM	-32	-54	-68	-79	-88	-97	0	0	0	0	0	0
TO CL AMO	0	0	0	0	0	0	0	0	0	0	0	0
CL CO	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
CL CO FA	1.00	1.00	1.00	1.00	1.00	1.00	.00	.00	.00	.00	.00	.00
DIR NOR	285	278	266	241	185	20	0	0	0	0	0	0
DIR NOR C	285	278	266	241	185	20	0	0	0	0	0	0
SKY DIF	27	26	25	23	17	1	0	0	0	0	0	0
GR DIF	54	48	39	27	13	0	0	0	0	0	0	0
DIR HOR	246	216	171	113	50	1	0	0	0	0	0	0
TOT HOR	273	242	196	136	67	2	0	0	0	0	0	0
DIR HOR C	246	216	171	113	50	1	0	0	0	0	0	0
DIF HOR C	27	26	25	23	17	1	0	0	0	0	0	0
TOT HOR C	273	242	196	136	67	2	0	0	0	0	0	0
O F C 1	2.6	3.6	5.2	5.8	4.7	4.2	2.6	5.0	5.2	5.6	5.6	4.2
O F C 2	2.6	3.3	4.5	4.8	4.1	3.7	2.6	4.8	4.5	4.8	4.8	3.7
O F C 3	2.3	3.0	4.2	4.6	3.8	3.4	2.3	4.6	4.2	4.6	4.6	3.4
O F C 4	1.8	2.5	3.5	3.9	3.2	2.9	1.8	3.9	3.5	3.9	3.9	2.9
O F C 5	2.1	2.6	3.5	3.8	3.2	2.9	2.1	3.8	3.5	3.8	3.8	2.9
O F C 6	1.8	2.3	3.2	3.5	2.9	2.6	1.8	3.5	3.2	3.5	3.5	2.6

Figure B-3. DATA PRINTOUT OF WEATHER AND PERMANENT DATA
(24-hour period)

COSTHT = COSCTA * COSZ + SINCFA * SINCTA * COSW + COSCFA * SINCTA * COSS

where —

CTA = collector tilt angle, degrees from horizontal
CFA = collector facing AZIMUTH, south = 0.0.

For evacuated tube collector arrays with cylindrical, involute, or diffuse reflectors, the "effective" incidence angle is calculated as:

$$\frac{\text{COS(LAT-CTA)*COSDEL * COSHRAD + SIN(LAT-CTA)*SINDEL}}{\{1-[\text{SIN(CTA-LAT)COSDEL * COSHRAD + COS(CTA-LAT)SINDEL}]\}\text{**2 **0.5}}$$

where —

THE = effective incidence angle when tube axes are in a north-south orientation
LAT = latitude angle
CTA = collector array tilt angle
DEL = declination angle
HRAD = hour angle.

The incidence angle for a parabolic trough with its axis aligned in the east-west horizontal plane and tracking altitude only is given by:

COSTHT = [1-COSDEL **2 * SINHRAD **2] **0.5

The SLATS[tm] collector system manufactured by Sheldahl represents a special case of the east-west oriented altitude tracking system and is discussed in detail in its subroutine documentation.

The incidence angle of the solar beam striking the aperture of a Compound Parabolic Concentrator (CPC) array of a given tilt angle is given by:

COSTHT = COSCTA * COSZ + SINCFA * SINCTA * COSW
+ COSCFA * SINCTA * COSS

The expression above is identical to a flat plate collector equation with an important exception. The CPC is subject to a limitation by its angular acceptance angle, which is given by the ratio of the absorbing surface width to its aperture width (or as a program input value in degrees):

$$\text{THMAX} = \arcsin \frac{\text{ABW}}{\text{APW}}$$

where —

ABW = absorbing surface width
APW = aperture width
THMAX = angular acceptance half angle of CPC.

The subroutine must decide for each hour whether or not to accept the direct component of solar radiation based on the angular acceptance half-angle cutoff. This is accomplished as follows:

a. Calculate Altitude of Acceptance

$$ALTA = \frac{\pi}{2} - CTA - SALTD$$

where —

ALTA = Altitude of Acceptance
CTA = Collector Array Tilt Angle
SALTD = Solar Altitude for a given hour from the weather tape.

b. Test for Acceptance of Direct Radiation

1. If ALTA < THMAX, both direct and diffuse radiation is accepted.

2. If ALTA > THMAX, only diffuse radiation is accepted.

The remaining collector categories are identified in Table B-5.

Table B-5. MISCELLANEOUS INCIDENCE ANGLE RELATIONSHIPS

COLLECTOR TYPE	INCIDENCE ANGLE RELATION
Single axis in North-South plane with fixed tilt above horizontal, tracking solar azimuth	SINTHT = COSDEL*SIN(LAT-CTA) * COSHRAD - SINDEL * COS(LAT-CTA)
Single Axis, North-South Plane, with axis adjusted to parallel earth's axis (polar axis)	COSTHT = COSDEL
E-W tracks altitude but not azimuth	COSTHT =(1-COSDEL**2*SIN HRAD **2)**0.5
Fixed surface to be normal to solar beam at noon on the equinoxes	COSTHT = COSDEL * COSHRAD
Two-axis tracking to allow surface normal coincide with solar beam at all times	COSTHT = 1.0

3. <u>Insolation on Collector Surface (Aperture)</u>

The insolation reaching a collector surface (aperture) is defined as:

TI = DNC * COSTHT + DIFS + DIFG

where —

TI = Total insolation on aperture
COSTHT = Incidence angle of direct radiation
DNC = Direct normal radiation modified by cloud cover
DIFS = Sky diffuse radiation
DIFG = Ground diffuse radiation.

The basic data needed to determine the above quantities are available on the weather and permanent data tape.

The calculation of COSTHT was discussed in the preceding section.

The value DNC is available directly from the weather tape.

Sky Diffuse Radiation is given by:*

$$DIFS = (DNC*C) * \frac{(1+COSCTA)}{2}$$

where —

DNC*C = Sky Diffuse Radiation on Horizontal Surface.

Ground Diffuse Radiation is given by:*

$$DIFG = [(DNC*COSZ) + (DNC*C)] * [\frac{(1-COSCTA)}{2} * \rho_g]$$

where —

-DNC*COSZ = Direct Radiation on Horizontal Surface
-DNC*C = Sky Diffuse Radiation on Horizontal Surface
ρ_g = Ground Reflectivity.

When a tracking collector is employed which does not accept diffuse radiation, the total insolation becomes:

$$TI = DNC * COSTHT$$

The compound parabolic concentrator accepts no ground diffuse radiation, accepts the same amount of direct radiation as a flat plate collector, and accepts sky diffuse radiation in proportion to the reciprocal of its concentration rate (CR).

$$TI = DNC * COSTHT + \frac{DIFS}{CR} \quad \text{within angular acceptance}$$

$$TI = \frac{DIFS}{CR} \quad \text{outside angular acceptance}$$

* See Reference 6.

The evacuated tube collector absorbs more than the radiation incident on the tube cross-section when a plate, cylindrical, or involute reflector is placed behind the tubes. The enhancement resulting from this design results in:

TIEF = DNC * COSTHE * ENHB + DIFS * ENHD
+ DIFG * ENHD

where —

TIEFF = Total "effective" insolation
COSTHE = "Effective" incidence angle
ENHB = Direct beam radiation enhancement factor
ENHD = Diffuse radiation enhancement factor.

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6. Duffie, J.H. and Beckman, W.A., Solar Energy Thermal Processes, 185. New York: John Wiley and Sons, 1974.

APPENDIX C. SELECTED HIGH-TEMPERATURE, PURCHASED POWER, ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM OUTPUT REPORTS

(Building 7 is a low-rise apartment with ASHRAE 90-75 conservation measures.)

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 2530. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.597449+09	.996302+02	.208877+05	.240531+05	.344994+08	.996302+02	.449407+05	.410884+09
FEB	.490255+09	.998552+02	.207053+05	.200860+05	.365705+08	.998552+02	.407921+05	.347045+09
MAR	.362390+09	.829504+02	.206758+05	.167912+05	.564353+08	.829504+02	.374671+05	.284602+09
APR	.172825+09	.779504+02	.254675+05	.991341+04	.576974+08	.779504+02	.353809+05	.166262+09
MAY	.211937+09	.918772+02	.264207+05	.114510+05	.597512+08	.947652+02	.378717+05	.192948+09
JUN	.290906+09	.864870+02	.246139+05	.140443+05	.544373+08	.931515+02	.386583+05	.237643+09
JUL	.445685+09	.888876+02	.231030+05	.192883+05	.460164+08	.913751+02	.423913+05	.320398+09
AUG	.325802+09	.904713+02	.257349+05	.148812+05	.461248+08	.904713+02	.406161+05	.250752+09
SEP	.172452+09	.875967+02	.269910+05	.924219+04	.472321+08	.875967+02	.362332+05	.155201+09
OCT	.172725+09	.884955+02	.277742+05	.847174+04	.337753+08	.884955+02	.362459+05	.142344+09
NOV	.330503+09	.940052+02	.276706+05	.138245+05	.249762+08	.943802+02	.414951+05	.233203+09
DEC	.541233+09	.100755+03	.232111+05	.216152+05	.260010+08	.100755+03	.448263+05	.367379+09
TOTAL	.411414+10	.100755+03	.293252+06	.183657+06	.523746+09	.100755+03	.476909+06	.311459+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 2530. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.0000	.2405+05	.0000	.5974+09	.2200+05	.7991+07	.4051+09	.0000	53.52	91.47	98.44	*101.56*	.6000+03
FEB	.0000	.2009+05	.0000	.4903+09	.1792+05	.1018+08	.3383+09	.0000	49.24	89.21	97.65	*102.40*	.6000+03
MAR	.1150+07	.1679+05	.4312+02	.3612+09	.1338+05	.4073+07	.2817+09	.0000	44.82	79.94	98.86	*101.16*	.5997+03
APR	.0000	.9913+04	.0000	.1728+09	.6473+04	.0000	.1664+09	.0000	28.02	65.30	100.00	*100.00*	.6000+03
MAY	.0000	.1145+05	.0000	.2119+09	.7902+04	.2202+06	.1927+09	.0000	30.24	69.00	99.91	*100.09*	.6000+03
JUN	.0000	.1404+05	.0000	.2909+09	.1083+05	.5203+05	.2372+09	.0000	36.33	77.09	99.98	*100.02*	.6000+03
JUL	.0000	.1929+05	.0000	.4452+09	.1656+05	.1074+07	.3255+09	.0000	45.50	85.86	99.74	*100.26*	.6000+03
AUG	.0000	.1488+05	.0000	.3258+09	.1214+05	.1316+06	.2509+09	.0000	36.64	81.60	99.96	*100.04*	.6000+03
SEP	.0000	.9242+04	.0000	.1725+09	.6427+04	.1992+06	.1556+09	.0000	25.51	69.54	99.90	*100.10*	.6000+03
OCT	.0000	.8472+04	.0000	.1727+09	.6462+04	.0000	.1423+09	.0000	23.37	76.27	100.00	*100.00*	.6000+03
NOV	.0000	.1382+05	.0000	.3305+09	.1234+05	.1577+06	.2325+09	.0000	33.32	89.28	99.95	*100.05*	.6000+03
DEC	.0000	.2162+05	.0000	.5412+09	.2007+05	.3355+07	.3640+09	.0000	48.22	92.87	99.27	*100.74*	.6000+03
TOTAL	.1150+07	.1837+06	.4312+02	.4112+10	.1525+06	.2744+08	.3092+10	.0000	38.51	83.06	99.30	*100.71* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1534+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1398+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 2530. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.45826+05	.26215+04	.42468+05	.00000	.503359+08	.131224+05	.4342+02	.4684819+02
FEB	.45749+05	.26665+04	.44169+05	.00000	.534848+08	.135828+05	.4621+02	.4786226+02
MAR	.63293+05	.44237+04	.62653+05	.00000	.794504+08	.101162+05	.4962+02	.5012291+02
APR	.65599+05	.60419+04	.64407+05	.00000	.807004+08	.112554+05	.4862+02	.4952499+02
MAY	.72086+05	.84726+04	.67986+05	.00000	.832260+08	.158781+05	.4563+02	.4838604+02
JUN	.68451+05	.91002+04	.62646+05	.00000	.755216+08	.182882+05	.4361+02	.4764959+02
JUL	.61425+05	.83767+04	.56804+05	.00000	.657703+08	.179416+05	.4232+02	.4576461+02
AUG	.57560+05	.71228+04	.55429+05	.00000	.660569+08	.176414+05	.4536+02	.4710457+02
SEP	.54087+05	.53985+04	.53518+05	.00000	.667644+08	.142288+05	.4879+02	.4930908+02
OCT	.42217+05	.32039+04	.40291+05	.00000	.497584+08	.111691+05	.4659+02	.4881326+02
NOV	.36531+05	.23038+04	.32974+05	.00000	.396568+08	.121887+05	.4312+02	.4777602+02
DEC	.37513+05	.22249+04	.33334+05	.00000	.397705+08	.132348+05	.4190+02	.4715806+02
TOTAL	.65034+06	.61956+05	.61667+06	.00000	.750689+09	.182882+05 (ANNUAL PEAK)	.4562+02	.4811561+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 5059. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.532795+09	.996302+02	.209289+05	.240118+05	.744381+08	.996302+02	.449407+05	.410884+09
FEB	.421778+09	.989552+02	.206647+05	.201274+05	.800867+08	.998552+02	.407921+05	.347045+09
MAR	.261263+09	.829504+02	.206780+05	.167891+05	.119769+09	.829504+02	.374671+05	.284602+09
APR	.914994+08	.779504+02	.245423+05	.108386+05	.113514+09	.779504+02	.353809+05	.160262+09
MAY	.123925+09	.947652+02	.256060+05	.122657+05	.119889+09	.947652+02	.378717+05	.192948+09
JUN	.196728+09	.894816+02	.245672+05	.140910+05	.114043+09	.931515+02	.386583+05	.237643+09
JUL	.361916+09	.883233+02	.230445+05	.193468+05	.988973+08	.913751+02	.423913+05	.320398+09
AUG	.243793+09	.904713+02	.255667+05	.150494+05	.991389+08	.904713+02	.406161+05	.250792+09
SEP	.116450+09	.875967+02	.257896+05	.104435+05	.904423+08	.875967+02	.362332+05	.155201+09
OCT	.112672+09	.884955+02	.275748+05	.867112+04	.730442+08	.884955+02	.362459+05	.142344+09
NOV	.278162+09	.943802+02	.276744+05	.138207+05	.578238+08	.943802+02	.414951+05	.233203+09
DEC	.492667+09	.100755+03	.231423+05	.216840+05	.575235+08	.100755+03	.448263+05	.367379+09
TOTAL	.323362+10	.100755+03	.289776+06	.187133+06	.111263+10	.100755+03	.476909+06	.311459+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

I N S T I T U T E   O F   G A S   T E C H N O L O G Y

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS, - LATITUDE=42,4N

SOLAR COLLECTOR APERTURE AREA = 5059, SQ,FT,

STES CHART NO, 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP, (BTU)	(2) ELECT, PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT, PRODUCED BY FUEL IN COL,1 (KWH)	(4) FUEL TO RUN SYST, WHEN NO SOLAR OR STORAGE AVL,(BTU)	(5) ELECT, PRODUCED BY FUEL IN COL,4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS, (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT, BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND, HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP, (DEG,F)
JAN	,8035+08	,2001+05	,1502+04	,4924+09	,1809+05	,8001+07	,4044+09	,0000	53,43	81,60	98,44	*101,58*	,5923+03
FEB	,5368+08	,2013+05	,1999+04	,3679+09	,1337+05	,1029+08	,3389+09	,0000	49,34	76,36	97,63	*102,43*	,5895+03
MAR	,5013+08	,1679+05	,1872+04	,2111+09	,7773+04	,3931+07	,2818+09	,0000	44,81	57,45	98,90	*101,12*	,5891+03
APR	,5052+08	,1084+05	,1899+04	,4098+08	,1540+04	,0000	,1799+09	,1401+08	30,63	31,73	100,00	* 92,23*	,5878+03
MAY	,6139+08	,1227+05	,2308+04	,6254+08	,2337+04	,0000	,2040+09	,1108+08	32,39	37,87	100,00	* 94,57*	,5864+03
JUN	,6956+08	,1409+05	,2601+04	,1272+09	,4723+04	,2291+06	,2374+09	,0000	36,45	51,97	99,92	*100,08*	,5853+03
JUL	,6308+08	,1935+05	,2357+04	,2988+09	,1112+05	,2420+06	,3262+09	,0000	45,64	69,68	99,94	*100,06*	,5878+03
AUG	,6434+08	,1505+05	,2405+04	,1794+09	,6692+04	,1316+06	,2531+09	,2195+07	37,05	60,45	99,96	* 99,17*	,5873+03
SEP	,4944+08	,1044+05	,1861+04	,6701+08	,2496+04	,1606+05	,1735+09	,1402+08	28,82	41,72	99,99	* 91,72*	,5888+03
OCT	,3937+08	,8671+04	,1478+04	,7330+08	,2743+04	,0000	,1444+09	,5804+07	23,92	48,68	100,00	* 96,08*	,5911+03
NOV	,3831+08	,1382+05	,1427+04	,2399+09	,8964+04	,2002+06	,2325+09	,0000	33,31	75,19	99,93	*100,07*	,5920+03
DEC	,2593+08	,2168+05	,9653+03	,4667+09	,1730+05	,3500+07	,3652+09	,0000	48,37	84,22	99,24	*100,77*	,5950+03
TOTAL	,6061+09	,1871+06	,2267+05	,2627+10	,9715+05	,2654+08	,3141+10	,4711+08	39,24	64,03	99,32	* 99,18* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = ,0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = ,1647+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = ,1251+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P,U,=(TH,LD,/(COND,HT,TO TH,LD,+TOT,TOWER HT,))*100,

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED,

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 5059. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.45826+05	.26215+04	.42479+05	.00000	.101753+09	.136973+05	.4389+02	.4734911+02
FEB	.45749+05	.26665+04	.44102+05	.00000	.108334+09	.135828+05	.4681+02	.4849000+02
MAR	.63293+05	.44237+04	.62713+05	.00000	.160213+09	.101545+05	.5004+02	.5049848+02
APR	.65599+05	.60419+04	.64416+05	.00000	.162973+09	.111472+05	.4911+02	.5001040+02
MAY	.72086+05	.84726+04	.68024+05	.00000	.168203+09	.158781+05	.4612+02	.4887709+02
JUN	.68451+05	.91002+04	.62786+05	.00000	.152725+09	.182882+05	.4410+02	.4808189+02
JUL	.61425+05	.83767+04	.56847+05	.00000	.133286+09	.179416+05	.4289+02	.4634580+02
AUG	.57560+05	.71228+04	.55442+05	.00000	.133737+09	.176414+05	.4593+02	.4768102+02
SEP	.54087+05	.53985+04	.53711+05	.00000	.135166+09	.142288+05	.4941+02	.4975148+02
OCT	.42217+05	.32039+04	.40820+05	.00000	.101326+09	.110841+05	.4744+02	.4906592+02
NOV	.36531+05	.23038+04	.32857+05	.00000	.805945+08	.121164+05	.4361+02	.4848580+02
DEC	.37513+05	.22249+04	.33310+05	.00000	.801770+08	.134045+05	.4225+02	.4757898+02
TOTAL	.65034+06	.61956+05	.61756+06	.00000	.151849+10	.182882+05 (ANNUAL PEAK)	.4615+02	.4860365+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 7589. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.468846+09	.996302+02	.209406+05	.240002+05	.114284+09	.996302+02	.449407+05	.410884+09
FEB	.356430+09	.998552+02	.206370+05	.201551+05	.121317+09	.998552+02	.407921+05	.347045+09
MAR	.172730+09	.829504+02	.203068+05	.171603+05	.177612+09	.829504+02	.374671+05	.284602+09
APR	.340243+08	.779504+02	.227636+05	.126173+05	.149307+09	.779504+02	.353809+05	.166262+09
MAY	.715517+08	.947652+02	.234584+05	.144133+05	.156839+09	.947652+02	.378717+05	.192948+09
JUN	.111367+09	.931515+02	.240880+05	.145703+05	.169881+09	.931515+02	.386583+05	.237643+09
JUL	.278099+09	.884362+02	.230826+05	.193087+05	.151305+09	.913751+02	.423913+05	.326398+09
AUG	.183163+09	.899008+02	.247210+05	.158951+05	.142782+09	.904713+02	.406161+05	.250752+09
SEP	.623905+08	.875967+02	.245463+05	.116868+05	.124175+09	.875967+02	.362332+05	.155201+09
OCT	.641809+08	.884955+02	.270256+05	.922038+04	.105218+09	.884955+02	.362459+05	.142344+09
NOV	.220603+09	.943802+02	.277087+05	.137864+05	.899133+08	.943802+02	.414951+05	.233203+09
DEC	.444079+09	.100755+03	.231123+05	.217140+05	.883052+08	.100755+03	.448263+05	.367379+09
TOTAL	.247345+10	.100755+03	.282388+06	.194521+06	.163868+10	.100755+03	.476909+06	.311459+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

INSTITUTE OF GAS TECHNOLOGY

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 7589. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.3740+08	.2400+05	.1393+04	.4314+09	.1583+05	.7850+07	.4041+09	.0000	53.40	71.75	98.47	*101.55*	.5932+03
FEB	.3255+08	.2016+05	.1213+04	.3237+09	.1173+05	.1022+08	.3393+09	.0000	49.41	64.20	97.64	*102.41*	.5934+03
MAR	.1864+08	.1716+05	.6972+03	.1541+09	.5635+04	.3913+07	.2880+09	.2178+07	45.80	36.90	98.90	*100.34*	.5958+03
APR	.2093+08	.1262+05	.7924+03	.1310+08	.4938+03	.0000	.2060+09	.4227+08	35.66	10.20	100.00	* 79.73*	.5945+03
MAY	.3491+08	.1441+05	.1324+04	.3665+08	.1374+04	.0000	.2351+09	.4316+08	38.06	18.71	100.00	* 81.72*	.5923+03
JUN	.5421+08	.1457+05	.2029+04	.5716+08	.2126+04	.0000	.2443+09	.7160+07	37.69	28.51	100.00	* 97.08*	.5895+03
JUL	.6265+08	.1931+05	.2338+04	.2150+09	.8009+04	.4886+06	.3254+09	.0000	45.55	53.59	99.88	*100.12*	.5883+03
AUG	.4554+08	.1590+05	.1708+04	.1376+09	.5133+04	.1316+06	.2661+09	.1509+08	39.13	43.03	99.96	* 94.36*	.5912+03
SEP	.2749+08	.1169+05	.1037+04	.3490+08	.1300+04	.0000	.1919+09	.3081+08	32.25	19.99	100.00	* 83.44*	.5939+03
OCT	.1657+08	.9220+04	.6226+03	.4761+08	.1782+04	.0000	.1522+09	.1518+08	25.44	26.08	100.00	* 90.36*	.5960+03
NOV	.3254+08	.1379+05	.1213+04	.1941+09	.7254+04	.2002+06	.2319+09	.0000	33.22	61.42	99.93	*100.07*	.5933+03
DEC	.4060+08	.2171+05	.1512+04	.4035+09	.1494+05	.5500+07	.3656+09	.0000	48.44	75.78	99.24	*100.77*	.5927+03
TOTAL	.4240+09	.1945+06	.1580+05	.2049+10	.7560+05	.2631+08	.3250+10	.1558+09	40.79	47.03	99.32	* 95.85* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1714+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1110+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 7589. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.45826+05	.26215+04	.42556+05	.00000	.152403+09	.136973+05	.4382+02	.4718948+02
FEB	.45749+05	.26665+04	.44152+05	.00000	.161552+09	.135828+05	.4653+02	.4821427+02
MAR	.63293+05	.44237+04	.62837+05	.00000	.238941+09	.101545+05	.4975+02	.5010587+02
APR	.65599+05	.60419+04	.64428+05	.00000	.243551+09	.997410+04	.4892+02	.4981189+02
MAY	.72086+05	.84726+04	.67969+05	.00000	.251704+09	.146938+05	.4601+02	.4879717+02
JUN	.68451+05	.91002+04	.62912+05	.00000	.228411+09	.177796+05	.4397+02	.4784084+02
JUL	.61425+05	.83767+04	.56766+05	.00000	.199499+09	.179416+05	.4280+02	.4630962+02
AUG	.57560+05	.71228+04	.55567+05	.00000	.199933+09	.176414+05	.4577+02	.4741130+02
SEP	.54087+05	.53985+04	.53693+05	.00000	.201986+09	.142055+05	.4921+02	.4957024+02
OCT	.42217+05	.32039+04	.40828+05	.00000	.150921+09	.111891+05	.4711+02	.4870846+02
NOV	.36531+05	.23038+04	.33158+05	.00000	.120792+09	.123002+05	.4357+02	.4800186+02
DEC	.37513+05	.22249+04	.33366+05	.00000	.120778+09	.140244+05	.4242+02	.4769809+02
TOTAL	.65034+06	.61956+05	.61823+06	.00000	.227045+10	.179416+05 (ANNUAL PEAK)	.4600+02	.4839272+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 10118. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.407302+09	.996302+02	.208779+05	.240629+05	.153554+09	.996302+02	.449407+05	.410884+09
FEB	.288174+09	.998552+02	.206998+05	.200923+05	.163589+09	.998552+02	.407921+05	.347045+09
MAR	.130774+09	.803043+02	.179910+05	.194761+05	.212703+09	.829504+02	.374671+05	.284602+09
APR	.129697+08	.779504+02	.195513+05	.158296+05	.161070+09	.779504+02	.353809+05	.166262+09
MAY	.425437+08	.918772+02	.203321+05	.175396+05	.175329+09	.947652+02	.378717+05	.192948+09
JUN	.620869+08	.931515+02	.223016+05	.163567+05	.203961+09	.931515+02	.386583+05	.237643+09
JUL	.199495+09	.913751+02	.230286+05	.193627+05	.200999+09	.913751+02	.423913+05	.326398+09
AUG	.139240+09	.898521+02	.231704+05	.174457+05	.175954+09	.904713+02	.406161+05	.250752+09
SEP	.367070+08	.875967+02	.222287+05	.140044+05	.139982+09	.875967+02	.362332+05	.155201+09
OCT	.396066+08	.884955+02	.254068+05	.108392+05	.122838+09	.884955+02	.362459+05	.142344+09
NOV	.178478+09	.943802+02	.276573+05	.138377+05	.120706+09	.943802+02	.414951+05	.233203+09
DEC	.391824+09	.100755+03	.231632+05	.216631+05	.120375+09	.100755+03	.448263+05	.367379+09
TOTAL	.192919+10	.100755+03	.266406+06	.210503+06	.204788+10	.100755+03	.476909+06	.311459+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 10118. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.2815+08	.2406+05	.1049+04	.3791+09	.1388+05	.7777+07	.4051+09	.0000	53.54	62.05	98.49	*101.54*	.5947+03
FEB	.1771+08	.2009+05	.6598+03	.2703+09	.9734+04	.1020+08	.3384+09	.0000	49.26	51.73	97.65	*102.41*	.5964+03
MAR	.1688+08	.1948+05	.6311+03	.1138+09	.4139+04	.3637+07	.3238+09	.3627+08	51.98	24.49	98.98	* 89.51*	.5961+03
APR	.1088+08	.1583+05	.4150+03	.2088+07	.7930+02	.0000	.2543+09	.9130+08	44.74	3.12	100.00	* 64.55*	.5969+03
MAY	.1404+08	.1754+05	.5315+03	.2850+08	.1070+04	.0000	.2823+09	.8884+08	46.31	9.13	100.00	* 68.47*	.5968+03
JUN	.3614+08	.1636+05	.1351+04	.2595+08	.9570+03	.2291+06	.2713+09	.3582+08	42.31	14.11	99.92	* 86.96*	.5934+03
JUL	.3509+08	.1936+05	.1308+04	.1644+09	.6131+04	.8855+04	.3262+09	.8925+06	45.68	38.42	100.00	* 99.73*	.5938+03
AUG	.2622+08	.1745+05	.9810+03	.1130+09	.4223+04	.0000	.2896+09	.3893+08	42.95	29.83	100.00	* 86.56*	.5953+03
SEP	.1562+08	.1400+05	.5876+03	.2108+08	.7857+03	.0000	.2266+09	.6522+08	38.65	9.81	100.00	* 70.41*	.5966+03
OCT	.1331+08	.1084+05	.5017+03	.2630+08	.9837+03	.0000	.1759+09	.3896+08	29.90	13.70	100.00	* 78.51*	.5967+03
NOV	.2059+08	.1384+05	.7678+03	.1579+09	.5903+04	.2002+06	.2329+09	.0000	33.35	48.20	99.93	*100.07*	.5958+03
DEC	.2981+08	.2166+05	.1110+04	.3620+09	.1340+05	.3500+07	.3647+09	.0000	48.33	66.98	99.24	*100.77*	.5946+03
TOTAL	.2644+09	.2105+06	.9894+04	.1664+10	.6129+05	.2555+08	.3491+10	.3962+09	44.14	33.81	99.34	* 89.23* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1751+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .9131+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 10118. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.45826+05	.26215+04	.42565+05	.00000	.202390+09	.136973+05	.4365+02	.4699448+02
FEB	.45749+05	.26665+04	.44144+05	.00000	.214603+09	.135828+05	.4636+02	.4804787+02
MAR	.63293+05	.44237+04	.62882+05	.00000	.319210+09	.101545+05	.4985+02	.5017122+02
APR	.65599+05	.60419+04	.64356+05	.00000	.324715+09	.111472+05	.4892+02	.4986725+02
MAY	.72086+05	.84726+04	.68029+05	.00000	.334997+09	.150175+05	.4593+02	.4866904+02
JUN	.68451+05	.91002+04	.62804+05	.00000	.303734+09	.174750+05	.4385+02	.4779788+02
JUL	.61425+05	.83767+04	.56809+05	.00000	.264113+09	.174336+05	.4250+02	.4594952+02
AUG	.57560+05	.71228+04	.55366+05	.00000	.265248+09	.169439+05	.4554+02	.4734932+02
SEP	.54087+05	.53985+04	.53562+05	.00000	.268714+09	.142288+05	.4910+02	.4958402+02
OCT	.42217+05	.32039+04	.40963+05	.00000	.201803+09	.111891+05	.4724+02	.4869035+02
NOV	.36531+05	.23038+04	.33286+05	.00000	.160593+09	.123002+05	.4345+02	.4768453+02
DEC	.37513+05	.22249+04	.33286+05	.00000	.160181+09	.140244+05	.4220+02	.4756135+02
TOTAL	.65034+06	.61956+05	.61804+06	.00000	.302027+10	.174750+05 (ANNUAL PEAK)	.4590+02	.4829629+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 12647. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.344846+09	.996302+02	.209172+05	.240235+05	.192399+09	.996302+02	.449407+05	.410884+09
FEB	.227580+09	.998552+02	.204931+05	.202990+05	.203157+09	.998552+02	.407921+05	.347045+09
MAR	.103033+09	.798503+02	.157023+05	.217648+05	.233384+09	.829504+02	.374671+05	.284602+09
APR	.792657+07	.779504+02	.161876+05	.191933+05	.163615+09	.779504+02	.353809+05	.166262+09
MAY	.312450+08	.918772+02	.168398+05	.210319+05	.182112+09	.947652+02	.378717+05	.192948+09
JUN	.349419+08	.931515+02	.194879+05	.191704+05	.221412+09	.931515+02	.386583+05	.237643+09
JUL	.135444+09	.913751+02	.222219+05	.201694+05	.244565+09	.913751+02	.423913+05	.326398+09
AUG	.103891+09	.873345+02	.212019+05	.194142+05	.200525+09	.904713+02	.406161+05	.250752+09
SEP	.261680+08	.875967+02	.192890+05	.169441+05	.146240+09	.875967+02	.362332+05	.155201+09
OCT	.242177+08	.884955+02	.235248+05	.127211+05	.132166+09	.884955+02	.362459+05	.142344+09
NOV	.134783+09	.943802+02	.274337+05	.140614+05	.149527+09	.943802+02	.414951+05	.233203+09
DEC	.342149+09	.100755+03	.232277+05	.215987+05	.150877+09	.100755+03	.448263+05	.367379+09
TOTAL	.151622+10	.100755+03	.246524+06	.230385+06	.234507+10	.100755+03	.476909+06	.311459+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 12647. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.1906+08	.2402+05	.7105+03	.3258+09	.1189+05	.7857+07	.4046+09	.0000	53.46	52.45	98.47	*101.55*	.5963+03
FEB	.9790+07	.2030+05	.3646+03	.2176+09	.7776+04	.9831+07	.3419+09	.2777+07	49.76	40.10	97.73	*101.49*	.5980+03
MAR	.1396+08	.2176+05	.5254+03	.8894+08	.3208+04	.3622+07	.3587+09	.8395+08	58.09	17.15	98.98	* 77.92*	.5966+03
APR	.7927+07	.1919+05	.3056+03	.0000	.0000	.0000	.3053+09	.1527+09	54.25	1.59	100.00	* 52.12*	.5975+03
MAY	.7652+07	.2103+05	.2948+03	.2359+08	.8863+03	.0000	.3346+09	.1442+09	55.53	5.62	100.00	* 57.23*	.5980+03
JUN	.2176+08	.1917+05	.8189+03	.1318+08	.4904+03	.0000	.3125+09	.7936+08	49.59	6.83	100.00	* 74.97*	.5958+03
JUL	.2552+08	.2017+05	.9545+03	.1099+09	.4102+04	.0000	.3384+09	.1420+08	47.58	25.07	100.00	* 95.83*	.5955+03
AUG	.1814+08	.1941+05	.6833+03	.8575+08	.3205+04	.0000	.3189+09	.6865+08	47.80	20.03	100.00	* 78.51*	.5966+03
SEP	.1284+08	.1694+05	.4826+03	.1333+08	.4957+03	.0000	.2701+09	.1098+09	46.76	5.77	100.00	* 58.56*	.5973+03
OCT	.7779+07	.1272+05	.2944+03	.1644+08	.6153+03	.0000	.2039+09	.6878+08	35.10	7.15	100.00	* 67.42*	.5981+03
NOV	.1283+08	.1406+05	.4789+03	.1220+09	.4561+04	.1787+06	.2365+09	.2851+07	33.89	35.84	99.94	* 98.85*	.5974+03
DEC	.2103+08	.2160+05	.7839+03	.3211+09	.1188+05	.3392+07	.3637+09	.0000	48.18	58.63	99.26	*100.74*	.5959+03
TOTAL	.1783+09	.2304+06	.6698+04	.1338+10	.4911+05	.2488+08	.3789+10	.7269+09	48.31	24.22	99.36	* 81.50* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .3268+08 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1700+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .7651+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM. ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - BOSTON,MASS. - LATITUDE=42.4N

SOLAR COLLECTOR APERTURE AREA = 12647. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.45826+05	.26215+04	.42478+05	.00000	.252354+09	.136973+05	.4354+02	.4697403+02
FEB	.45749+05	.26665+04	.44129+05	.00000	.267850+09	.135828+05	.4629+02	.4799270+02
MAR	.63293+05	.44237+04	.62843+05	.00000	.399355+09	.101545+05	.4989+02	.5024734+02
APR	.65599+05	.60419+04	.64321+05	.00000	.406409+09	.997410+04	.4899+02	.4996020+02
MAY	.72086+05	.84726+04	.68032+05	.00000	.419431+09	.158781+05	.4601+02	.4874866+02
JUN	.68451+05	.91002+04	.62769+05	.00000	.380171+09	.177796+05	.4391+02	.4789040+02
JUL	.61425+05	.83767+04	.56931+05	.00000	.330503+09	.173366+05	.4254+02	.4590312+02
AUG	.57560+05	.71228+04	.55342+05	.00000	.331583+09	.176414+05	.4555+02	.4737511+02
SEP	.54087+05	.53985+04	.53562+05	.00000	.336422+09	.142288+05	.4918+02	.4966427+02
OCT	.42217+05	.32039+04	.40737+05	.00000	.251454+09	.111891+05	.4710+02	.4880089+02
NOV	.36531+05	.23038+04	.33299+05	.00000	.200179+09	.123002+05	.4333+02	.4753320+02
DEC	.37513+05	.22249+04	.33457+05	.00000	.199948+09	.140244+05	.4215+02	.4725444+02
TOTAL	.65034+06	.61956+05	.61789+06	.00000	.377562+10	.177796+05 (ANNUAL PEAK)	.4591+02	.4831567+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALEIGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 4095. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.345987+09	.958802+02	.281500+05	.150420+05	.365373+08	.958802+02	.431920+05	.254527+09
FEB	.227240+09	.942552+02	.276250+05	.114339+05	.504809+08	.942552+02	.390589+05	.192963+09
MAR	.108141+09	.835713+02	.277830+05	.855234+04	.750874+08	.871969+02	.363353+05	.142548+09
APR	.154626+09	.880086+02	.265563+05	.978834+04	.667767+08	.931712+02	.363447+05	.162939+09
MAY	.272940+09	.946897+02	.252699+05	.150056+05	.822027+08	.946897+02	.402755+05	.253998+09
JUN	.376299+09	.956454+02	.231307+05	.186063+05	.794483+08	.956454+02	.417370+05	.316963+09
JUL	.506991+09	.933918+02	.214015+05	.222687+05	.607280+08	.933918+02	.436702+05	.379902+09
AUG	.417255+09	.898620+02	.238738+05	.194845+05	.699602+08	.912739+02	.433584+05	.333170+09
SEP	.257667+09	.893905+02	.253329+05	.140337+05	.759188+08	.902265+02	.393665+05	.238349+09
OCT	.140353+09	.895892+02	.287754+05	.887682+04	.569530+08	.900521+02	.376522+05	.148285+09
NOV	.148682+09	.958802+02	.319606+05	.862951+04	.522616+08	.958802+02	.405901+05	.140307+09
DEC	.329282+09	.966302+02	.292711+05	.138059+05	.254724+08	.966302+02	.430770+05	.232322+09
TOTAL	.329144+10	.966302+02	.319126+06	.105523+06	.732479+09	.966302+02	.484048+06	.280221+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALEIGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 4095. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** * PCT * * UTIL*	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.0000	.1504+05	.0000	.3460+09	.1287+05	.1522+07	.2530+09	.0000	34.83	85.58	99.52	*100.48*	.6000+03
FEB	.0000	.1143+05	.0000	.2272+09	.8416+04	.2131+07	.1924+09	.0000	29.27	73.61	99.12	*100.89*	.6000+03
MAR	.3950+08	.8552+04	.1476+04	.6864+08	.2570+04	.7032+05	.1437+09	.0000	23.54	47.30	99.96	*100.04*	.5913+03
APR	.2362+08	.9788+04	.8876+03	.1310+09	.4889+04	.0000	.1642+09	.2573+07	26.93	59.02	100.00	* 98.45*	.5943+03
MAY	.1153+08	.1501+05	.4325+03	.2614+09	.9710+04	.4266+06	.2534+09	.0000	37.26	67.59	99.87	*100.13*	.5974+03
JUN	.5855+06	.1861+05	.2192+02	.3755+09	.1390+05	.2028+07	.3147+09	.0000	44.58	74.81	99.49	*100.51*	.5999+03
JUL	.0000	.2227+05	.0000	.5070+09	.1867+05	.4914+07	.3766+09	.0000	50.99	83.85	98.97	*101.05*	.6000+03
AUG	.0000	.1948+05	.0000	.4172+09	.1535+05	.4752+07	.3294+09	.0000	44.94	78.76	98.86	*101.15*	.6000+03
SEP	.6717+07	.1403+05	.2519+03	.2505+09	.9297+04	.1006+07	.2372+09	.0000	35.65	68.04	99.66	*100.34*	.5984+03
OCT	.9665+07	.8877+04	.3619+03	.1367+09	.5105+04	.4975+05	.1493+09	.0000	23.58	61.58	99.97	*100.03*	.5977+03
NOV	.0000	.8630+04	.0000	.1487+09	.5541+04	.3474+06	.1453+09	.0000	21.26	64.21	99.81	*100.19*	.6000+03
DEC	.0000	.1361+05	.0000	.3293+09	.1229+05	.5861+06	.2321+09	.0000	32.05	89.01	99.80	*100.20*	.6000+03
TOTAL	.9162+08	.1655+06	.3432+04	.3199+10	.1186+06	.1783+08	.2791+10	.2573+07	34.15	73.73	99.49	*100.42*	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1802+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1390+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :
P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 4095. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.51132+05	.29253+04	.33261+05	.00000	.534608+08	.128067+05	.2553+02	.3925014+02
FEB	.52732+05	.30741+04	.38959+05	.00000	.706263+08	.120276+05	.3271+02	.4426965+02
MAR	.66257+05	.46413+04	.53292+05	.00000	.104071+09	.113728+05	.3836+02	.4768835+02
APR	.59334+05	.54834+04	.49787+05	.00000	.927730+08	.151106+05	.3818+02	.4550466+02
MAY	.68729+05	.80156+04	.57563+05	.00000	.110824+09	.185498+05	.3938+02	.4699850+02
JUN	.67216+05	.89646+04	.56304+05	.00000	.107887+09	.187119+05	.3920+02	.4679260+02
JUL	.57083+05	.78695+04	.48372+05	.00000	.845980+08	.181148+05	.3581+02	.4270858+02
AUG	.61407+05	.76082+04	.51531+05	.00000	.962197+08	.179219+05	.3826+02	.4559746+02
SEP	.63208+05	.62749+04	.52386+05	.00000	.103404+09	.177175+05	.3995+02	.4820190+02
OCT	.58147+05	.43662+04	.44345+05	.00000	.804309+08	.140117+05	.3378+02	.4429229+02
NOV	.57384+05	.36397+04	.39023+05	.00000	.723395+08	.115695+05	.3078+02	.4526926+02
DEC	.42998+05	.25548+04	.27343+05	.00000	.402793+08	.123841+05	.2288+02	.3597315+02
TOTAL	.70623+06	.65417+05	.55218+06	.00000	.101690+10	.187119+05 (ANNUAL PEAK)	.3516+02	.4497233+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 8169. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.277763+09	.958802+02	.280264+05	.151662+05	.807965+08	.958802+02	.431926+05	.254527+09
FEB	.144388+09	.942552+02	.273385+05	.117204+05	.104301+09	.942552+02	.390589+05	.192963+09
MAR	.445720+08	.871969+02	.250059+05	.113295+05	.121369+09	.871969+02	.363353+05	.142548+09
APR	.694305+08	.931712+02	.251874+05	.111573+05	.124915+09	.931712+02	.363447+05	.162939+09
MAY	.133704+09	.946897+02	.252283+05	.150472+05	.169849+09	.946897+02	.402755+05	.253998+09
JUN	.241816+09	.956454+02	.228168+05	.189203+05	.166223+09	.956454+02	.417370+05	.316963+09
JUL	.404312+09	.933918+02	.211559+05	.225143+05	.127738+09	.933918+02	.436702+05	.379902+09
AUG	.302368+09	.912739+02	.234263+05	.199321+05	.146004+09	.912739+02	.433584+05	.333170+09
SEP	.145102+09	.902265+02	.244504+05	.149161+05	.151970+09	.902265+02	.393665+05	.238349+09
OCT	.102564+09	.895892+02	.263431+05	.113091+05	.978856+08	.900521+02	.376522+05	.148285+09
NOV	.947800+08	.958802+02	.302958+05	.102944+05	.955764+08	.958802+02	.405901+05	.146307+09
DEC	.268270+09	.966302+02	.295465+05	.135305+05	.662426+08	.966302+02	.430770+05	.232322+09
TOTAL	.222912+10	.966302+02	.308817+06	.175832+06	.147817+10	.966302+02	.484648+06	.280221+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 8189. SQ.FT.

SIES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** UHC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** * PCT * * UTIL*	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.5571+08	.1517+05	.2076+04	.2221+09	.8253+04	.1522+07	.2550+09	.1930+07	35.11	68.10	99.52	* 99.72*	.5893+03
FEB	.5354+06	.1172+05	.2000+04	.9085+08	.3341+04	.1667+07	.1969+09	.4682+07	30.01	45.57	99.30	* 98.30*	.5883+03
MAR	.2805+08	.1133+05	.1061+04	.1652+08	.6205+03	.0000	.1848+09	.3688+08	31.18	14.84	100.00	* 79.45*	.5933+03
APR	.3787+08	.1116+05	.1425+04	.3156+08	.1179+04	.0000	.1838+09	.2144+08	30.70	23.34	100.00	* 88.37*	.5916+03
MAY	.7249+08	.1505+05	.2704+04	.6127+08	.2281+04	.0000	.2533+09	.4139+07	37.36	33.13	100.00	* 98.40*	.5871+03
JUN	.9734+08	.1892+05	.3627+04	.1442+09	.5358+04	.4972+06	.3194+09	.5264+07	45.33	47.49	99.87	* 99.10*	.5838+03
JUL	.6534+08	.2251+05	.2435+04	.3386+09	.1243+05	.4656+07	.3803+09	.3600+07	51.56	66.04	99.02	*100.03*	.5893+03
AUG	.8182+08	.1993+05	.3054+04	.2203+09	.8066+04	.3639+07	.3363+09	.5989+07	45.97	55.79	99.13	* 99.08*	.5864+03
SEP	.7186+08	.1492+05	.2682+04	.7324+08	.2724+04	.0000	.2502+09	.1217+08	37.89	36.24	100.00	* 95.14*	.5870+03
OCT	.3327+08	.1131+05	.1255+04	.6925+08	.2587+04	.4975+05	.1853+09	.3100+08	30.04	33.97	99.97	* 82.73*	.5928+03
NOV	.6924+08	.1029+05	.2614+04	.2554+08	.9541+03	.3205+05	.1697+09	.2446+08	25.36	34.66	99.98	* 85.69*	.5843+03
DEC	.2790+08	.1353+05	.1039+04	.2404+09	.8977+04	.4716+06	.2275+09	.0000	31.41	74.03	99.84	*100.16*	.5947+03
TOTAL	.6944+09	.1758+06	.2597+05	.1534+10	.5678+05	.1255+08	.2943+10	.1495+09	36.28	47.06	99.64	* 95.26*	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .2001+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1087+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 8189. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.51132+05	.29253+04	.33224+05	.00000	.109366+09	.128067+05	.2612+02	.4019800+02
FEB	.52732+05	.30741+04	.38959+05	.00000	.143200+09	.123282+05	.3316+02	.4488537+02
MAR	.66257+05	.46413+04	.53429+05	.00000	.208266+09	.114292+05	.3838+02	.4760083+02
APR	.59334+05	.54834+04	.49834+05	.00000	.186277+09	.167421+05	.3834+02	.4564625+02
MAY	.68729+05	.80156+04	.57694+05	.00000	.223823+09	.185498+05	.3977+02	.4737425+02
JUN	.67216+05	.89646+04	.56404+05	.00000	.219418+09	.185967+05	.3986+02	.4750454+02
JUL	.57683+05	.78695+04	.48377+05	.00000	.171676+09	.181148+05	.3634+02	.4333548+02
AUG	.61407+05	.76082+04	.51486+05	.00000	.195479+09	.177504+05	.3887+02	.4636429+02
SEP	.63208+05	.62749+04	.52475+05	.00000	.209583+09	.172180+05	.4049+02	.4877187+02
OCT	.58147+05	.43662+04	.44377+05	.00000	.162651+09	.143656+05	.3416+02	.4475812+02
NOV	.57384+05	.36397+04	.39207+05	.00000	.148545+09	.116747+05	.3161+02	.4626619+02
DEC	.42998+05	.25548+04	.27332+05	.00000	.820724+08	.123841+05	.2331+02	.3666822+02
TOTAL	.70623+06	.65417+05	.55279+06	.00000	.200034+10	.185967+05 (ANNUAL PEAK)	.3563+02	.4551421+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 12283. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.215391+09	.958802+02	.278645+05	.153281+05	.121142+09	.958802+02	.431920+05	.254527+09
FEB	.802847+08	.942552+02	.264433+05	.126156+05	.146812+09	.942552+02	.390589+05	.192963+09
MAR	.246947+08	.871969+02	.206031+05	.157323+05	.134101+09	.871969+02	.363353+05	.142548+09
APR	.262527+08	.921584+02	.221897+05	.141550+05	.151557+09	.931712+02	.363447+05	.162939+09
MAY	.398140+08	.946897+02	.234536+05	.168219+05	.231559+09	.946897+02	.402755+05	.253998+09
JUN	.122608+09	.956454+02	.222229+05	.195141+05	.242847+09	.956454+02	.417370+05	.316963+09
JUL	.308431+09	.922182+02	.207327+05	.229375+05	.190750+09	.933918+02	.436702+05	.379902+09
AUG	.197849+09	.906763+02	.228409+05	.205174+05	.213909+09	.912739+02	.433584+05	.333170+09
SEP	.705334+08	.898201+02	.222753+05	.170913+05	.201701+09	.902265+02	.393665+05	.238349+09
OCT	.677763+08	.900521+02	.236621+05	.139900+05	.121389+09	.900521+02	.376522+05	.148285+09
NOV	.361048+08	.958802+02	.290275+05	.115626+05	.129094+09	.958802+02	.405901+05	.146307+09
DEC	.224234+09	.966302+02	.292816+05	.137954+05	.911288+08	.966302+02	.430770+05	.232322+09
TOTAL	.141397+10	.966302+02	.290593+06	.194055+06	.203937+10	.966302+02	.484648+06	.280221+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALEIGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 12283. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** UNC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** * PCT * * UTIL*	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.3687+08	.1533+05	.1376+04	.1785+09	.6620+04	.1588+07	.2575+09	.4487+07	35.49	52.17	99.50	* 98.75*	.5927+03
FEB	.1935+08	.1262+05	.7251+03	.6094+08	.2225+04	.1687+07	.2105+09	.1842+08	32.30	23.38	99.30	* 91.87*	.5958+03
MAR	.1076+08	.1573+05	.4071+03	.1394+08	.5252+03	.0000	.2511+09	.1015+09	43.30	5.93	100.00	* 58.41*	.5972+03
APR	.1342+08	.1416+05	.5098+03	.1283+08	.4789+03	.0000	.2283+09	.6629+08	38.95	6.99	100.00	* 71.08*	.5967+03
MAY	.3365+08	.1682+05	.1256+04	.6165+07	.2302+03	.0000	.2800+09	.3049+08	41.77	8.83	100.00	* 89.28*	.5942+03
JUN	.5759+08	.1951+05	.2143+04	.6484+08	.2412+04	.2145+06	.3289+09	.1012+08	46.75	23.34	99.95	* 96.90*	.5914+03
JUL	.5017+08	.2294+05	.1869+04	.2572+09	.9442+04	.4483+07	.3864+09	.1359+08	52.52	49.31	99.06	* 97.44*	.5925+03
AUG	.4771+08	.2052+05	.1778+04	.1499+09	.5479+04	.2731+07	.3454+09	.1423+08	47.32	35.37	99.34	* 96.51*	.5927+03
SEP	.3718+08	.1709+05	.1388+04	.3335+08	.1240+04	.0000	.2833+09	.4505+08	43.42	15.38	100.00	* 84.10*	.5935+03
OCT	.1081+08	.1399+05	.4078+03	.5097+08	.2127+04	.4975+05	.2253+09	.7043+08	37.16	18.12	99.97	* 67.81*	.5974+03
NOV	.2317+08	.1156+05	.8740+03	.1293+08	.4846+03	.3205+05	.1887+09	.4440+08	28.49	11.75	99.98	* 76.73*	.5947+03
DEC	.3979+08	.1380+05	.1484+04	.1844+09	.6891+04	.4716+06	.2318+09	.2955+07	32.02	60.71	99.84	* 98.90*	.5925+03
TOTAL	.3805+09	.1941+06	.1422+05	.1032+10	.3815+05	.1126+08	.3217+10	.4220+09	40.04	26.99	99.68	* 87.10*	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .2037+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .8689+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM. ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC THROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 12283. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.51132+05	.29253+04	.33303+05	.00000	.162672+09	.128067+05	.2590+02	.3976773+02
FEB	.52732+05	.30741+04	.38959+05	.00000	.212126+09	.123282+05	.3275+02	.4432853+02
MAR	.66257+05	.46413+04	.53256+05	.00000	.311436+09	.114292+05	.3827+02	.4760993+02
APR	.59334+05	.54834+04	.49832+05	.00000	.279002+09	.152590+05	.3828+02	.4558219+02
MAY	.68729+05	.80156+04	.57718+05	.00000	.333674+09	.184654+05	.3953+02	.4706607+02
JUN	.67216+05	.89646+04	.56341+05	.00000	.326121+09	.185812+05	.3950+02	.4712511+02
JUL	.57683+05	.78695+04	.48381+05	.00000	.256540+09	.183351+05	.3621+02	.4316942+02
AUG	.61407+05	.76082+04	.51533+05	.00000	.291070+09	.179219+05	.3859+02	.4598426+02
SEP	.63208+05	.62749+04	.52400+05	.00000	.312012+09	.174581+05	.4019+02	.4847726+02
OCT	.58147+05	.43662+04	.44327+05	.00000	.242922+09	.143656+05	.3401+02	.4461647+02
NOV	.57384+05	.36397+04	.39127+05	.00000	.219570+09	.116747+05	.3115+02	.4568689+02
DEC	.42998+05	.25548+04	.27343+05	.00000	.123760+09	.123841+05	.2344+02	.3685505+02
TOTAL	.70623+06	.65417+05	.55251+06	.00000	.307069+10	.185812+05 (ANNUAL PEAK)	.3540+02	.4524998+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 16376. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.51132+05	.29253+04	.33129+05	.00000	.214648+09	.128067+05	.2563+02	.3955968+02
FEB	.52732+05	.30741+04	.36906+05	.00000	.283492+09	.123282+05	.3283+02	.4442211+02
MAR	.60257+05	.46413+04	.53247+05	.00000	.415535+09	.114292+05	.3829+02	.4704916+02
APR	.59334+05	.54834+04	.49776+05	.00000	.371768+09	.167421+05	.3828+02	.4560238+02
MAY	.66724+05	.80156+04	.57684+05	.00000	.445993+09	.184691+05	.3962+02	.4720754+02
JUN	.67216+05	.89646+04	.56319+05	.00000	.435095+09	.187119+05	.3952+02	.4717046+02
JUL	.57663+05	.78695+04	.48262+05	.00000	.342239+09	.183351+05	.3623+02	.4329726+02
AUG	.61407+05	.76082+04	.51543+05	.00000	.386545+09	.179219+05	.3863+02	.4602087+02
SEP	.63208+05	.62749+04	.52371+05	.00000	.410239+09	.176345+05	.4021+02	.4852773+02
OCT	.50147+05	.43662+04	.44316+05	.00000	.324927+09	.142214+05	.3412+02	.4476768+02
NOV	.57384+05	.36397+04	.39024+05	.00000	.291594+09	.110747+05	.3103+02	.4562368+02
DEC	.42998+05	.25548+04	.27360+05	.00000	.163048+09	.123841+05	.2315+02	.3635937+02
TOTAL	.70023+06	.65417+05	.55201+06	.00000	.409309+10	.187119+05 (ANNUAL PEAK)	.3539+02	.4527330+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 20472. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.125211+09	.958802+02	.262065+05	.169861+05	.184290+09	.958802+02	.431926+05	.254527+09
FEB	.327350+08	.942552+02	.214491+05	.176098+05	.179236+09	.942552+02	.390589+05	.192963+09
MAR	.170036+08	.871969+02	.143404+05	.219949+05	.138390+09	.871969+02	.363353+05	.142548+09
APR	.128103+08	.879886+02	.159407+05	.204039+05	.159028+09	.931712+02	.363447+05	.162939+09
MAY	.159065+08	.946333+02	.150421+05	.252333+05	.247976+09	.946897+02	.402755+05	.253998+09
JUN	.385524+08	.947329+02	.150892+05	.266478+05	.299732+09	.956454+02	.417370+05	.316963+09
JUL	.158646+09	.887037+02	.182285+05	.254417+05	.291576+09	.933918+02	.436702+05	.379902+09
AUG	.940497+08	.878207+02	.174181+05	.259402+05	.287637+09	.912739+02	.433584+05	.333170+09
SEP	.319447+08	.893905+02	.147318+05	.246348+05	.226811+09	.902265+02	.393665+05	.238349+09
OCT	.382938+08	.900521+02	.178823+05	.197699+05	.137508+09	.900521+02	.376522+05	.148285+09
NOV	.808290+07	.935052+02	.229835+05	.176066+05	.143800+09	.958802+02	.405901+05	.146307+09
DEC	.151785+09	.966302+02	.281850+05	.148919+05	.143712+09	.966302+02	.430770+05	.232322+09
TOTAL	.725021+09	.966302+02	.227495+06	.257154+06	.250445+10	.966302+02	.484648+06	.280221+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC TROUGH COLLECTOR - RALEIGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 20472. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.9584+07	.1699+05	.3593+03	.1156+09	.4278+04	.1291+07	.2832+09	.2989+08	39.33	27.30	99.59	* 89.82*	.5977+03
FEB	.6563+07	.1761+05	.2446+03	.2617+08	.9511+03	.8380+06	.2883+09	.9940+08	45.09	6.79	99.65	* 66.15*	.5986+03
MAR	.1334+08	.2199+05	.5036+03	.3664+07	.1381+03	.0000	.3452+09	.2758+09	60.53	2.92	100.00	* 34.07*	.5963+03
APR	.1204+08	.2040+05	.4606+03	.7660+06	.2913+02	.0000	.3221+09	.2114+09	56.14	2.40	100.00	* 43.52*	.5967+03
MAY	.1591+08	.2523+05	.5983+03	.0000	.0000	.0000	.4071+09	.1950+09	62.65	2.37	100.00	* 56.57*	.5970+03
JUN	.3028+08	.2665+05	.1139+04	.8230+07	.3074+03	.4053+05	.4378+09	.1261+09	63.85	5.43	99.99	* 71.54*	.5945+03
JUL	.3878+08	.2544+05	.1445+04	.1191+09	.4365+04	.2539+07	.4248+09	.5833+08	58.26	22.84	99.47	* 87.09*	.5940+03
AUG	.2934+08	.2594+05	.1103+04	.6341+08	.2329+04	.2089+07	.4280+09	.1011+09	59.83	13.23	99.50	* 77.02*	.5949+03
SEP	.1694+08	.2463+05	.6345+03	.1500+08	.5580+03	.0000	.3976+09	.1850+09	62.58	4.84	100.00	* 56.30*	.5969+03
OCT	.1195+08	.1977+05	.4523+03	.2634+08	.9844+03	.0000	.3129+09	.1835+09	52.51	7.27	100.00	* 44.70*	.5971+03
NOV	.6994+07	.1761+05	.2609+03	.1088+07	.4087+02	.0000	.2812+09	.1383+09	43.38	1.71	100.00	* 51.40*	.5983+03
DEC	.1522+08	.1489+05	.5682+03	.1366+09	.5097+04	.4716+06	.2490+09	.1744+08	34.57	38.04	99.84	* 93.16*	.5968+03
TOTAL	.2070+09	.2572+06	.7769+04	.5160+09	.1908+05	.7209+07	.4177+10	.1621+10	53.06	10.44	99.79	* 63.43* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .2454+09 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1721+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .5536+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

NORTH/SOUTH PARABOLIC THROUGH COLLECTOR - RALIEGH, NORTH CAROLINA - 32.9N

SOLAR COLLECTOR APERTURE AREA = 20472. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.51132+05	.29253+04	.33267+05	.00000	.268627+09	.128067+05	.2566+02	.3944317+02
FEB	.52732+05	.30741+04	.38966+05	.00000	.354214+09	.121608+05	.3281+02	.4440422+02
MAR	.66257+05	.46413+04	.53246+05	.00000	.521224+09	.113728+05	.3843+02	.4781662+02
APR	.59334+05	.54834+04	.49688+05	.00000	.466368+09	.151106+05	.3839+02	.4584753+02
MAY	.68729+05	.80156+04	.57644+05	.00000	.557673+09	.184654+05	.3964+02	.4725715+02
JUN	.67216+05	.89646+04	.56270+05	.00000	.545171+09	.187746+05	.3962+02	.4732555+02
JUL	.57683+05	.78695+04	.48259+05	.00000	.427577+09	.183351+05	.3621+02	.4327893+02
AUG	.61407+05	.76082+04	.51419+05	.00000	.485926+09	.179219+05	.3865+02	.4616192+02
SEP	.63208+05	.62749+04	.52332+05	.00000	.520265+09	.176345+05	.4021+02	.4856163+02
OCT	.58147+05	.43662+04	.44211+05	.00000	.405847+09	.143656+05	.3409+02	.4484076+02
NOV	.57384+05	.36397+04	.39020+05	.00000	.364697+09	.112586+05	.3104+02	.4565426+02
DEC	.42998+05	.25548+04	.27369+05	.00000	.203217+09	.123841+05	.2309+02	.3626910+02
TOTAL	.70623+06	.65417+05	.55169+06	.00000	.512075+10	.187746+05 (ANNUAL PEAK)	.3542+02	.4534004+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 2787. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.123739+09	.926572+02	.293911+05	.811140+04	.581252+08	.926572+02	.375025+05	.135652+09
FEB	.884785+08	.927756+02	.279710+05	.607813+04	.466418+08	.929290+02	.340491+05	.102440+09
MAR	.726189+08	.882212+02	.293266+05	.650376+04	.630612+08	.882212+02	.358304+05	.108381+09
APR	.156411+09	.892966+02	.264812+05	.102004+05	.735653+08	.892966+02	.366816+05	.171812+09
MAY	.171503+09	.887921+02	.269271+05	.105592+05	.698935+08	.887921+02	.374864+05	.177801+09
JUN	.228866+09	.829166+02	.239660+05	.133482+05	.817267+08	.853149+02	.373142+05	.225282+09
JUL	.337783+09	.830578+02	.229135+05	.166619+05	.698395+08	.851936+02	.395754+05	.282433+09
AUG	.416834+09	.838812+02	.212542+05	.195806+05	.705758+08	.879526+02	.408348+05	.333235+09
SEP	.258095+09	.863841+02	.238774+05	.142572+05	.813132+08	.882363+02	.381346+05	.244308+09
OCT	.239117+09	.876495+02	.271989+05	.125414+05	.614509+08	.906759+02	.397404+05	.211893+09
NOV	.112952+09	.924147+02	.294279+05	.709233+04	.481202+08	.924147+02	.365202+05	.118929+09
DEC	.134502+09	.923786+02	.297078+05	.778639+04	.461312+08	.923786+02	.374942+05	.130607+09
TOTAL	.234089+10	.927756+02	.318438+06	.132717+06	.771143+09	.929290+02	.451154+06	.224274+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 2787. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.8775+07	.8111+04	.3294+03	.1150+09	.4306+04	.0000	.1361+09	.0000	21.63	57.15	100.00	*100.00*	.5979+03
FEB	.1533+08	.6078+04	.5756+03	.7315+08	.2735+04	.0000	.1020+09	.0000	17.85	54.47	100.00	*100.00*	.5960+03
MAR	.1926+08	.6504+04	.7218+03	.5336+08	.1998+04	.0000	.1091+09	.0000	18.15	41.82	100.00	*100.00*	.5956+03
APR	.1499+08	.1020+05	.5651+03	.1414+09	.5268+04	.0000	.1717+09	.0000	27.81	57.18	100.00	*100.00*	.5964+03
MAY	.2233+08	.1056+05	.8392+03	.1492+09	.5569+04	.0000	.1775+09	.0000	28.17	60.69	100.00	*100.00*	.5949+03
JUN	.5195+06	.1335+05	.1977+02	.2283+09	.8483+04	.1986+06	.2256+09	.0000	35.77	63.70	99.93	*100.07*	.5999+03
JUL	.0000	.1666+05	.0000	.3377+09	.1254+05	.5431+06	.2819+09	.0000	42.10	75.23	99.85	*100.15*	.6000+03
AUG	.0000	.1958+05	.0000	.4166+09	.1541+05	.2451+07	.3311+09	.0000	47.95	78.70	99.41	*100.59*	.6000+03
SEP	.5157+07	.1426+05	.1931+03	.2528+09	.9253+04	.4175+07	.2410+09	.0000	37.39	66.26	98.63	*101.39*	.5988+03
OCT	.9803+07	.1254+05	.3686+03	.2293+09	.8536+04	.0000	.2117+09	.0000	31.56	71.00	100.00	*100.00*	.5978+03
NOV	.5281+07	.7092+04	.1989+03	.1077+09	.4024+04	.0000	.1192+09	.0000	19.42	59.54	100.00	*100.00*	.5987+03
DEC	.2139+07	.7786+04	.8063+02	.1324+09	.4956+04	.0000	.1307+09	.0000	20.77	64.68	100.00	*100.00*	.5995+03
TOTAL	.1036+09	.1327+06	.3892+04	.2237+10	.8307+05	.7368+07	.2238+10	.0000	29.42	65.53	99.74	*100.26* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1816+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1369+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM. ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 2787. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.59550+05	.34102+04	.55610+05	.00000	.804650+08	.103056+05	.4848+02	.5191755+02
FEB	.49649+05	.29068+04	.48295+05	.00000	.665293+08	.119912+05	.4808+02	.4942842+02
MAR	.62320+05	.43343+04	.62159+05	.00000	.876971+08	.116935+05	.5049+02	.5062259+02
APR	.70711+05	.65250+04	.69268+05	.00000	.996461+08	.153337+05	.5056+02	.5161670+02
MAY	.73363+05	.85733+04	.69281+05	.00000	.971829+08	.170956+05	.4753+02	.5033134+02
JUN	.83098+05	.11044+05	.76276+05	.00000	.110948+09	.166679+05	.4791+02	.5219102+02
JUL	.73229+05	.99786+04	.67903+05	.00000	.959945+08	.166420+05	.4704+02	.5072501+02
AUG	.70366+05	.87148+04	.67688+05	.00000	.964004+08	.172327+05	.4916+02	.5110092+02
SEP	.73712+05	.73024+04	.73285+05	.00000	.110406+09	.172936+05	.5374+02	.5405523+02
OCT	.59866+05	.45326+04	.58372+05	.00000	.854987+08	.150764+05	.5124+02	.5255556+02
NOV	.51290+05	.32476+04	.48226+05	.00000	.681660+08	.134947+05	.4769+02	.5071621+02
DEC	.51219+05	.30415+04	.46871+05	.00000	.657897+08	.109150+05	.4609+02	.5036410+02
TOTAL	.77837+06	.73610+05	.74323+06	.00000	.106471+10	.172936+05 (ANNUAL PEAK)	.4908+02	.5140140+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 5573. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.599475+08	.926572+02	.278093+05	.969314+04	.103985+09	.926572+02	.375025+05	.135652+09
FEB	.352720+08	.929290+02	.266544+05	.739469+04	.839871+08	.929290+02	.340491+05	.102440+09
MAR	.289091+08	.882212+02	.264224+05	.940796+04	.956783+08	.882212+02	.358304+05	.108381+09
APR	.804130+08	.892966+02	.243648+05	.123168+05	.129709+09	.892966+02	.366816+05	.171812+09
MAY	.803365+08	.887921+02	.255559+05	.119304+05	.132625+09	.887921+02	.374864+05	.177801+09
JUN	.122837+09	.838183+02	.223805+05	.149336+05	.155804+09	.853149+02	.373142+05	.225282+09
JUL	.214933+09	.840127+02	.228556+05	.167198+05	.147398+09	.851936+02	.395754+05	.282433+09
AUG	.293682+09	.867698+02	.212326+05	.196022+05	.147968+09	.879526+02	.408348+05	.333235+09
SEP	.156053+09	.864242+02	.222432+05	.158915+05	.155024+09	.882363+02	.381346+05	.244308+09
OCT	.137066+09	.906759+02	.268677+05	.128727+05	.127734+09	.906759+02	.397404+05	.211893+09
NOV	.593946+08	.924147+02	.280496+05	.847062+04	.874955+08	.924147+02	.365202+05	.118929+09
DEC	.735786+08	.923786+02	.287490+05	.874520+04	.893295+08	.923786+02	.374942+05	.130607+09
TOTAL	.134241+10	.929290+02	.303181+06	.147974+06	.148217+10	.929290+02	.451154+06	.224274+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 5573. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.4935+08	.9693+04	.1864+04	.1060+08	.3986+03	.0000	.1594+09	.1905+08	25.85	23.34	100.00	* 87.69*	.5885+03
FEB	.2865+08	.7395+04	.1083+04	.6618+07	.2487+03	.0000	.1209+09	.1708+08	21.72	18.01	100.00	* 85.71*	.5928+03
MAR	.2891+08	.9408+04	.1103+04	.0000	.0000	.0000	.1498+09	.4219+08	26.26	11.72	100.00	* 71.98*	.5928+03
APR	.5317+08	.1232+05	.2005+04	.2725+08	.1013+04	.0000	.2013+09	.3285+08	33.58	24.51	100.00	* 83.95*	.5883+03
MAY	.4767+08	.1193+05	.1794+04	.3267+08	.1224+04	.0000	.1976+09	.1791+08	31.83	25.30	100.00	* 90.85*	.5902+03
JUN	.8334+08	.1493+05	.3137+04	.3950+08	.1464+04	.1392+06	.2485+09	.2663+08	40.02	30.81	99.95	* 89.47*	.5827+03
JUL	.1023+09	.1672+05	.3811+04	.1125+09	.4181+04	.6399+05	.2826+09	.0000	42.25	47.80	99.98	*100.02*	.5820+03
AUG	.9359+08	.1960+05	.3486+04	.2000+09	.7379+04	.1579+07	.3313+09	.0000	48.00	55.43	99.62	*100.38*	.5837+03
SEP	.8513+08	.1589+05	.3184+04	.7013+08	.2528+04	.2879+07	.2658+09	.1918+08	41.67	35.94	99.06	* 93.54*	.5839+03
OCT	.6699+08	.1287+05	.2504+04	.7007+08	.2606+04	.1053+06	.2165+09	.5592+07	32.39	39.69	99.96	* 97.47*	.5877+03
NOV	.4362+08	.8471+04	.1651+04	.1577+08	.5882+03	.0000	.1392+09	.1937+08	23.19	26.43	100.00	* 85.99*	.5895+03
DEC	.5383+08	.8745+04	.2023+04	.1975+08	.7413+03	.0000	.1448+09	.1395+08	23.32	31.60	100.00	* 90.35*	.5881+03
TOTAL	.7366+09	.1480+06	.2764+05	.6049+09	.2237+05	.4767+07	.2458+10	.2138+09	32.80	33.80	99.83	* 91.44* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1983+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1048+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

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INSTITUTE OF GAS TECHNOLOGY

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 5573. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.59550+05	.34102+04	.55585+05	.00000	.162330+09	.103056+05	.4891+02	.5240273+02
FEB	.49649+05	.29068+04	.48222+05	.00000	.133600+09	.123446+05	.4828+02	.4971313+02
MAR	.62320+05	.43343+04	.62159+05	.00000	.176623+09	.909142+04	.5085+02	.5098642+02
APR	.70711+05	.65250+04	.69431+05	.00000	.200966+09	.125152+05	.5100+02	.5193714+02
MAY	.73363+05	.85733+04	.69285+05	.00000	.195137+09	.170956+05	.4773+02	.5053725+02
JUN	.83098+05	.11044+05	.76301+05	.00000	.224863+09	.166679+05	.4856+02	.5288056+02
JUL	.73229+05	.99786+04	.68083+05	.00000	.195006+09	.166420+05	.4778+02	.5139519+02
AUG	.70366+05	.87148+04	.67977+05	.00000	.195679+09	.172327+05	.4990+02	.5165269+02
SEP	.73712+05	.73024+04	.73323+05	.00000	.223256+09	.172936+05	.5435+02	.5463534+02
OCT	.59866+05	.45326+04	.58511+05	.00000	.172463+09	.150764+05	.5169+02	.5288905+02
NOV	.51290+05	.32476+04	.48570+05	.00000	.138052+09	.131108+05	.4830+02	.5100175+02
DEC	.51219+05	.30415+04	.47098+05	.00000	.133360+09	.106387+05	.4672+02	.5080834+02
TOTAL	.77837+06	.73610+05	.74454+06	.00000	.215131+10	.172936+05 (ANNUAL PEAK)	.4959+02	.5184753+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 8360. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.218988+08	.926572+02	.252207+05	.122818+05	.126436+09	.926572+02	.375025+05	.135652+09
FEB	.149025+08	.929290+02	.240225+05	.100260+05	.966698+08	.929290+02	.340491+05	.102440+09
MAR	.190566+08	.849229+02	.221907+05	.136397+05	.102521+09	.882212+02	.358304+05	.108381+09
APR	.446744+08	.892966+02	.207359+05	.159457+05	.153656+09	.892966+02	.366816+05	.171812+09
MAY	.412127+08	.886176+02	.221784+05	.153080+05	.159746+09	.887921+02	.374864+05	.177801+09
JUN	.674724+08	.831933+02	.188644+05	.184497+05	.194440+09	.853149+02	.373142+05	.225282+09
JUL	.969930+08	.840703+02	.228291+05	.167463+05	.221634+09	.851936+02	.395754+05	.282433+09
AUG	.174305+09	.879526+02	.212084+05	.196204+05	.223332+09	.879526+02	.408348+05	.333235+09
SEP	.766300+08	.882363+02	.199849+05	.181498+05	.205252+09	.882363+02	.381346+05	.244308+09
OCT	.697097+08	.906759+02	.252282+05	.145121+05	.173833+09	.906759+02	.397404+05	.211893+09
NOV	.188489+08	.924147+02	.262656+05	.102546+05	.110644+09	.924147+02	.365202+05	.118929+09
DEC	.324712+08	.923786+02	.270374+05	.104507+05	.115281+09	.923786+02	.374942+05	.130607+09
TOTAL	.678173+09	.929290+02	.275763+06	.175392+06	.191702+10	.929290+02	.451154+06	.224274+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 8360. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.1989+08	.1228+05	.7593+03	.2006+07	.7509+02	.0000	.1974+09	.5665+08	32.75	6.79	100.00	* 70.54*	.5949+03
FEB	.1378+08	.1003+05	.5226+03	.1127+07	.4226+02	.0000	.1587+09	.5490+08	29.45	5.63	100.00	* 65.11*	.5963+03
MAR	.1906+08	.1364+05	.7376+03	.0000	.0000	.0000	.2116+09	.1036+09	38.07	5.41	100.00	* 51.12*	.5945+03
APR	.3420+08	.1595+05	.1295+04	.1047+08	.3899+03	.0000	.2560+09	.8625+08	43.47	10.57	100.00	* 66.58*	.5923+03
MAY	.2655+08	.1531+05	.1004+04	.1466+08	.5507+03	.0000	.2475+09	.6756+08	40.84	10.15	100.00	* 72.47*	.5946+03
JUN	.4417+08	.1845+05	.1660+04	.2331+08	.8662+03	.0000	.2999+09	.8046+08	49.44	13.69	100.00	* 73.68*	.5920+03
JUL	.6655+08	.1675+05	.2475+04	.3045+08	.1130+04	.0000	.2830+09	.0000	42.31	21.53	100.00	*100.00*	.5896+03
AUG	.4580+08	.1963+05	.1704+04	.1283+09	.4722+04	.1465+07	.3316+09	.0000	48.06	32.74	99.65	*100.35*	.5927+03
SEP	.2189+08	.1815+05	.8212+03	.5374+08	.1903+04	.3506+07	.3003+09	.5277+08	47.59	15.01	98.85	* 83.02*	.5963+03
OCT	.2874+08	.1451+05	.1081+04	.4097+08	.1520+04	.0000	.2410+09	.3188+08	36.52	17.96	100.00	* 86.92*	.5944+03
NOV	.1885+08	.1025+05	.7144+03	.0000	.0000	.0000	.1657+09	.4423+08	28.08	6.97	100.00	* 72.89*	.5954+03
DEC	.2175+08	.1046+05	.8245+03	.1073+08	.4026+03	.0000	.1698+09	.3978+08	27.89	11.73	100.00	* 76.65*	.5947+03
TOTAL	.3612+09	.1754+06	.1360+05	.3158+09	.1161+05	.4971+07	.2863+10	.6181+09	38.88	14.37	99.82	* 78.50* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .2015+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .7423+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 8360. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.59550+05	.34102+04	.55515+05	.00000	.242520+09	.103021+05	.4871+02	.5225520+02
FEB	.49649+05	.29068+04	.48155+05	.00000	.200212+09	.118005+05	.4824+02	.4973268+02
MAR	.62320+05	.43343+04	.62159+05	.00000	.265559+09	.909142+04	.5097+02	.5110357+02
APR	.70711+05	.65250+04	.69251+05	.00000	.300933+09	.121204+05	.5091+02	.5198024+02
MAY	.73363+05	.85733+04	.69322+05	.00000	.292771+09	.163930+05	.4774+02	.5051880+02
JUN	.83098+05	.11044+05	.76335+05	.00000	.336461+09	.166679+05	.4843+02	.5272330+02
JUL	.73229+05	.99786+04	.68077+05	.00000	.290168+09	.166420+05	.4740+02	.5098874+02
AUG	.70366+05	.87148+04	.67857+05	.00000	.290872+09	.169790+05	.4945+02	.5127463+02
SEP	.73712+05	.73024+04	.73400+05	.00000	.332447+09	.171657+05	.5395+02	.5417793+02
OCT	.59866+05	.45326+04	.58763+05	.00000	.256072+09	.142038+05	.5156+02	.5253328+02
NOV	.51290+05	.32476+04	.48510+05	.00000	.205808+09	.121020+05	.4800+02	.5074913+02
DEC	.51219+05	.30415+04	.47020+05	.00000	.198825+09	.106387+05	.4643+02	.5058091+02
TOTAL	.77837+06	.73610+05	.74435+06	.00000	.321464+10	.171657+05 (ANNUAL PEAK)	.4940+02	.5165899+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 11146. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.152921+08	.916833+02	.214006+05	.161018+05	.130759+09	.926572+02	.375025+05	.135652+09
FEB	.145523+08	.929290+02	.204908+05	.135583+05	.981835+08	.929290+02	.340491+05	.102440+09
MAR	.142702+08	.812092+02	.178883+05	.179420+05	.104988+09	.882212+02	.358304+05	.108381+09
APR	.285836+08	.892966+02	.165369+05	.201447+05	.165109+09	.892966+02	.366816+05	.171812+09
MAY	.212911+08	.886176+02	.179028+05	.195836+05	.170504+09	.887921+02	.374864+05	.177801+09
JUN	.457854+08	.831847+02	.141259+05	.231883+05	.208551+09	.853149+02	.373142+05	.225282+09
JUL	.332866+08	.825258+02	.205596+05	.190158+05	.264013+09	.851936+02	.395754+05	.282433+09
AUG	.971516+08	.857797+02	.194326+05	.214022+05	.276863+09	.879526+02	.408348+05	.333235+09
SEP	.383109+08	.802718+02	.158014+05	.223333+05	.228185+09	.882363+02	.381346+05	.244308+09
OCT	.334578+08	.879769+02	.223322+05	.174082+05	.196643+09	.906759+02	.397404+05	.211893+09
NOV	.117102+08	.924147+02	.229500+05	.135703+05	.114990+09	.924147+02	.365202+05	.118929+09
DEC	.148188+08	.923786+02	.243489+05	.131453+05	.125066+09	.923786+02	.374942+05	.130607+09
TOTAL	.360310+09	.929290+02	.233767+06	.217387+06	.210204+10	.929290+02	.451154+06	.224274+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 11146. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.1340+08	.1610+05	.5102+03	.1888+07	.7058+02	.0000	.2548+09	.1139+09	42.94	3.61	100.00	* 54.37*	.5967+03
FEB	.1455+08	.1356+05	.5633+03	.0000	.0000	.0000	.2113+09	.1077+09	39.82	4.15	100.00	* 48.75*	.5956+03
MAR	.1427+08	.1794+05	.5617+03	.0000	.0000	.0000	.2753+09	.1677+09	50.07	3.13	100.00	* 39.26*	.5955+03
APR	.1576+08	.2014+05	.6061+03	.4821+07	.1797+03	.0000	.3172+09	.1479+09	54.92	3.90	100.00	* 53.75*	.5959+03
MAY	.1816+08	.1958+05	.6866+03	.3130+07	.1171+03	.0000	.3111+09	.1301+09	52.24	4.10	100.00	* 57.74*	.5965+03
JUN	.2928+08	.2319+05	.1103+04	.1651+08	.6087+03	.1392+06	.3705+09	.1484+09	62.14	7.38	99.95	* 60.30*	.5955+03
JUL	.3329+08	.1902+05	.1240+04	.0000	.0000	.0000	.3171+09	.3164+08	48.05	6.52	100.00	* 89.93*	.5953+03
AUG	.3985+08	.2140+05	.1486+04	.5710+08	.2106+04	.6657+06	.3587+09	.2643+08	52.41	16.78	99.84	* 92.79*	.5941+03
SEP	.1595+08	.2233+05	.5967+03	.2235+08	.7768+03	.1461+07	.3631+09	.1188+09	58.56	6.15	99.52	* 67.50*	.5976+03
OCT	.1182+08	.1741+05	.4468+03	.2164+08	.8060+03	.0000	.2844+09	.7584+08	43.80	7.20	100.00	* 73.64*	.5976+03
NOV	.1171+08	.1357+05	.4495+03	.0000	.0000	.0000	.2142+09	.9299+08	37.16	3.31	100.00	* 56.12*	.5968+03
DEC	.8996+07	.1315+05	.3460+03	.5623+07	.2118+03	.0000	.2095+09	.7867+08	35.06	4.24	100.00	* 62.41*	.5976+03
TOTAL	.2270+09	.2174+06	.8596+04	.1331+09	.4877+04	.2266+07	.3487+10	.1240+10	48.18	6.20	99.92	* 64.43* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .3487+06 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1866+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .4718+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM. ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 11146. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.59550+05	.34102+04	.55525+05	.00000	.323378+09	.100890+05	.4872+02	.5225219+02
FEB	.49649+05	.29068+04	.48122+05	.00000	.268112+09	.118005+05	.4845+02	.4998616+02
MAR	.62320+05	.43343+04	.62159+05	.00000	.354911+09	.900411+04	.5109+02	.5122668+02
APR	.70711+05	.65250+04	.69111+05	.00000	.401328+09	.125152+05	.5092+02	.5209982+02
MAY	.73363+05	.85733+04	.69315+05	.00000	.390694+09	.170956+05	.4778+02	.5056986+02
JUN	.83098+05	.11044+05	.76352+05	.00000	.448214+09	.166679+05	.4839+02	.5266791+02
JUL	.73229+05	.99786+04	.68129+05	.00000	.385253+09	.166420+05	.4720+02	.5073318+02
AUG	.70366+05	.87148+04	.67732+05	.00000	.387748+09	.172327+05	.4944+02	.5136104+02
SEP	.73712+05	.73024+04	.73380+05	.00000	.443747+09	.172936+05	.5401+02	.5425498+02
OCT	.59866+05	.45326+04	.58696+05	.00000	.344109+09	.150764+05	.5157+02	.5259764+02
NOV	.51290+05	.32476+04	.48316+05	.00000	.274433+09	.134947+05	.4800+02	.5095966+02
DEC	.51219+05	.30415+04	.47094+05	.00000	.265088+09	.106387+05	.4643+02	.5050153+02
TOTAL	.77837+06	.73610+05	.74392+06	.00000	.428697+10	.172936+05 (ANNUAL PEAK)	.4941+02	.5170153+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 13932. SQ.FT.

STES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.904055+07	.916833+02	.175511+05	.199514+05	.133311+09	.926572+02	.375025+05	.135652+09
FEB	.171155+08	.929290+02	.178162+05	.162329+05	.982644+08	.929290+02	.340491+05	.102440+09
MAR	.159610+08	.765254+02	.145509+05	.212795+05	.105227+09	.882212+02	.358304+05	.108381+09
APR	.700535+07	.888394+02	.135686+05	.231130+05	.169814+09	.892966+02	.366816+05	.171812+09
MAY	.127871+08	.884485+02	.147265+05	.227599+05	.173985+09	.887921+02	.374864+05	.177801+09
JUN	.270600+08	.831847+02	.100480+05	.272661+05	.216853+09	.853149+02	.373142+05	.225282+09
JUL	.190469+08	.795779+02	.163271+05	.232484+05	.273814+09	.851936+02	.395754+05	.282433+09
AUG	.545902+08	.857797+02	.162606+05	.245742+05	.305524+09	.879526+02	.408348+05	.333235+09
SEP	.250731+08	.823404+02	.116501+05	.264846+05	.234826+09	.882363+02	.381346+05	.244308+09
OCT	.178001+08	.879769+02	.189944+05	.207460+05	.205077+09	.906759+02	.397404+05	.211893+09
NOV	.846118+07	.921747+02	.195785+05	.169417+05	.116646+09	.924147+02	.365202+05	.118929+09
DEC	.757281+07	.923786+02	.213905+05	.161037+05	.128222+09	.923786+02	.374942+05	.130607+09
TOTAL	.222113+09	.929290+02	.192460+06	.258694+06	.216910+10	.929290+02	.451154+06	.224274+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 13932. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.7806+07	.1995+05	.2982+03	.1235+07	.4610+02	.0000	.3120+09	.1714+09	53.20	1.73	100.00	* 44.17*	.5979+03
FEB	.1712+08	.1623+05	.6610+03	.0000	.0000	.0000	.2506+09	.1666+09	47.67	4.08	100.00	* 38.08*	.5943+03
MAR	.1596+08	.2128+05	.6192+03	.0000	.0000	.0000	.3251+09	.2427+09	59.39	2.91	100.00	* 30.87*	.5951+03
APR	.6041+07	.2311+05	.2324+03	.9647+06	.3640+02	.0000	.3612+09	.2231+09	63.01	1.16	100.00	* 43.51*	.5983+03
MAY	.1279+08	.2276+05	.4884+03	.0000	.0000	.0000	.3555+09	.2058+09	60.72	2.15	100.00	* 46.35*	.5969+03
JUN	.1749+08	.2727+05	.6565+03	.9568+07	.3508+03	.1392+06	.4307+09	.2235+09	73.07	3.69	99.95	* 50.22*	.5973+03
JUL	.1905+08	.2325+05	.7094+03	.0000	.0000	.0000	.3802+09	.9830+08	58.74	3.05	100.00	* 74.18*	.5974+03
AUG	.2364+08	.2457+05	.8848+03	.3095+08	.1133+04	.4783+06	.4072+09	.7387+08	60.18	8.21	99.89	* 81.93*	.5963+03
SEP	.1509+08	.2648+05	.5659+03	.1038+08	.3403+03	.1451+07	.4258+09	.2018+09	69.45	3.42	99.52	* 54.90*	.5978+03
OCT	.5341+07	.2075+05	.2033+03	.1246+08	.4640+03	.0000	.3357+09	.1320+09	52.20	3.22	100.00	* 61.61*	.5987+03
NOV	.8461+07	.1694+05	.3252+03	.0000	.0000	.0000	.2651+09	.1453+09	46.39	1.92	100.00	* 45.01*	.5976+03
DEC	.6752+07	.1610+05	.2630+03	.8205+06	.3114+02	.0000	.2542+09	.1234+09	42.95	1.83	100.00	* 51.42*	.5980+03
TOTAL	.1555+09	.2587+06	.5908+04	.6638+08	.2402+04	.2069+07	.4103+10	.2008+10	57.34	3.21	99.93	* 52.78* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .1523+09 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1572+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .3528+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM. ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - BUILDING 7 - LOS ANGELES - LATITUDE=34.0N

SOLAR COLLECTOR APERTURE AREA = 13932. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.59550+05	.34102+04	.55515+05	.00000	.404715+09	.100890+05	.4878+02	.5232065+02
FEB	.49649+05	.29068+04	.48161+05	.00000	.336797+09	.100170+05	.4869+02	.5019462+02
MAR	.62320+05	.43343+04	.62159+05	.00000	.444295+09	.932604+04	.5117+02	.5130430+02
APR	.70711+05	.65250+04	.69074+05	.00000	.501223+09	.132006+05	.5088+02	.5208361+02
MAY	.73363+05	.85733+04	.69275+05	.00000	.489263+09	.169842+05	.4787+02	.5069356+02
JUN	.83098+05	.11044+05	.76319+05	.00000	.559654+09	.166679+05	.4834+02	.5263498+02
JUL	.73229+05	.99786+04	.68040+05	.00000	.479700+09	.166420+05	.4702+02	.5060480+02
AUG	.70366+05	.87148+04	.67779+05	.00000	.485324+09	.172327+05	.4951+02	.5139535+02
SEP	.73712+05	.73024+04	.73453+05	.00000	.555334+09	.172936+05	.5408+02	.5426619+02
OCT	.59866+05	.45326+04	.58721+05	.00000	.430251+09	.140510+05	.5159+02	.5259116+02
NOV	.51290+05	.32476+04	.48354+05	.00000	.343449+09	.131108+05	.4806+02	.5098168+02
DEC	.51219+05	.30415+04	.46888+05	.00000	.330930+09	.107329+05	.4638+02	.5065899+02
TOTAL	.77837+06	.73610+05	.74373+06	.00000	.536088+10	.172936+05 (ANNUAL PEAK)	.4944+02	.5173757+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 2724. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.414601+09	.982802+02	.249814+05	.190802+05	.627471+08	.982802+02	.440616+05	.324249+09
FEB	.281308+09	.976052+02	.251319+05	.139796+05	.588346+08	.976052+02	.391115+05	.235611+09
MAR	.183536+09	.778254+02	.246546+05	.120404+05	.861039+08	.778254+02	.366950+05	.200967+09
APR	.141435+09	.914084+02	.262307+05	.963035+04	.733315+08	.914084+02	.358611+05	.162597+09
MAY	.287511+09	.953174+02	.243601+05	.152691+05	.771845+08	.953174+02	.396291+05	.258244+09
JUN	.403678+09	.956444+02	.214426+05	.199292+05	.830465+08	.956444+02	.413718+05	.336691+09
JUL	.461192+09	.939983+02	.220912+05	.218323+05	.791757+08	.952819+02	.439235+05	.368934+09
AUG	.445631+09	.932872+02	.220512+05	.207900+05	.713989+08	.932872+02	.428413+05	.351703+09
SEP	.229726+09	.928479+02	.252553+05	.131892+05	.784914+08	.930274+02	.384445+05	.223022+09
OCT	.126384+09	.891667+02	.284103+05	.850541+04	.635695+08	.901188+02	.369157+05	.142845+09
NOV	.257724+09	.941302+02	.283565+05	.130361+05	.577500+08	.941302+02	.413926+05	.219896+09
DEC	.443608+09	.955052+02	.249018+05	.185401+05	.382716+08	.955052+02	.434419+05	.319025+09
TOTAL	.367631+10	.982802+02	.297864+06	.185816+06	.830190+09	.982802+02	.483680+06	.314371+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 2724. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.0000	.1908+05	.0000	.4146+09	.1535+05	.3803+07	.3210+09	.0000	43.30	80.46	99.05	*100.96*	.6000+03
FEB	.1830+07	.1398+05	.6838+02	.2795+09	.1040+05	.1454+07	.2350+09	.0000	35.74	74.91	99.51	*100.50*	.5996+03
MAR	.3598+08	.1204+05	.1345+04	.1476+09	.5530+04	.3048+06	.2019+09	.0000	32.81	57.10	99.88	*100.12*	.5920+03
APR	.1044+08	.9630+04	.3912+03	.1310+09	.4895+04	.2745+05	.1619+09	.0000	26.85	54.89	99.99	*100.01*	.5975+03
MAY	.6186+07	.1527+05	.2331+03	.2813+09	.1047+05	.0000	.2575+09	.0000	38.53	70.11	100.00	*100.00*	.5986+03
JUN	.2499+07	.1993+05	.9492+02	.4012+09	.1492+05	.0000	.3369+09	.0000	46.17	75.33	100.00	*100.00*	.5993+03
JUL	.0000	.2183+05	.0000	.4612+09	.1715+05	.0000	.3692+09	.0000	49.71	78.54	100.00	*100.00*	.6000+03
AUG	.0000	.2079+05	.0000	.4456+09	.1657+05	.0000	.3516+09	.0000	48.53	79.70	100.00	*100.00*	.6000+03
SEP	.2324+07	.1319+05	.6807+02	.2274+09	.8459+04	.2469+05	.2227+09	.0000	34.31	64.80	99.99	*100.01*	.5994+03
OCT	.8100+07	.8505+04	.3039+03	.1183+09	.4416+04	.0000	.1431+09	.0000	23.04	55.50	100.00	*100.00*	.5981+03
NOV	.0000	.1304+05	.0000	.2577+09	.9597+04	.1213+07	.2191+09	.0000	31.49	73.62	99.56	*100.44*	.6000+03
DEC	.0000	.1854+05	.0000	.4436+09	.1627+05	.8592+07	.3116+09	.0000	42.68	87.74	97.85	*102.20*	.6000+03
TOTAL	.6736+08	.1858+06	.2525+04	.3609+10	.1340+06	.1548+08	.3131+10	.0000	38.42	73.49	99.61	*100.40* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1637+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1342+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

4/78

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.IN LATITUDE

SOLAR COLLECTOR APERTURE AREA = 2724. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.65389+05	.37419+04	.61109+05	.00000	.865638+08	.123841+05	.4860+02	.5200241+02
FEB	.59582+05	.34920+04	.57830+05	.00000	.818219+08	.120276+05	.5041+02	.5194106+02
MAR	.80481+05	.55849+04	.80202+05	.00000	.118153+09	.102452+05	.5389+02	.5408158+02
APR	.72155+05	.66491+04	.70898+05	.00000	.993261+08	.148991+05	.5053+02	.5143098+02
MAY	.79647+05	.92847+04	.75295+05	.00000	.105166+09	.157252+05	.4847+02	.5127463+02
JUN	.85480+05	.11364+05	.78508+05	.00000	.112608+09	.184879+05	.4836+02	.5265613+02
JUL	.82331+05	.11219+05	.76502+05	.00000	.108084+09	.187037+05	.4819+02	.5186568+02
AUG	.72603+05	.89775+04	.70149+05	.00000	.975368+08	.183004+05	.4932+02	.5104310+02
SEP	.73200+05	.73173+04	.72604+05	.00000	.106839+09	.158509+05	.5354+02	.5402114+02
OCT	.62976+05	.47840+04	.61731+05	.00000	.874647+08	.114936+05	.5099+02	.5201435+02
NOV	.60184+05	.38048+04	.56795+05	.00000	.805763+08	.121164+05	.4915+02	.5208216+02
DEC	.47063+05	.27956+04	.42297+05	.00000	.562274+08	.116571+05	.4386+02	.4880132+02
TOTAL	.84115+06	.79014+05	.80391+06	.00000	.114036+10	.187037+05 (ANNUAL PEAK)	.4977+02	.5207447+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 5448. SQ.FT.

SIES CHART NO. 4

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.305447+09	.982802+02	.248890+05	.191726+05	.132095+09	.982802+02	.440616+05	.324249+09
FEB	.188104+09	.976052+02	.247343+05	.143773+05	.120606+09	.976052+02	.391115+05	.235611+09
MAR	.677475+08	.778254+02	.232961+05	.133989+05	.162771+09	.778254+02	.366950+05	.200967+09
APR	.647911+08	.914084+02	.241551+05	.117059+05	.128705+09	.914084+02	.358611+05	.162597+09
MAY	.155939+09	.927081+02	.242193+05	.154098+05	.160721+09	.953174+02	.396291+05	.258244+09
JUN	.261057+09	.949600+02	.212746+05	.200972+05	.173705+09	.956444+02	.413718+05	.336691+09
JUL	.324150+09	.952819+02	.219200+05	.220035+05	.166604+09	.952819+02	.439235+05	.368934+09
AUG	.317271+09	.932872+02	.221590+05	.206822+05	.150874+09	.932872+02	.428413+05	.351703+09
SEP	.127148+09	.928107+02	.237592+05	.146853+05	.150682+09	.930274+02	.384445+05	.223022+09
OCT	.653368+08	.901188+02	.262873+05	.106283+05	.109747+09	.901188+02	.369157+05	.142845+09
NOV	.158752+09	.941302+02	.281947+05	.131980+05	.121098+09	.941302+02	.413926+05	.219896+09
DEC	.371126+09	.955052+02	.249225+05	.185194+05	.836148+08	.955052+02	.434419+05	.319025+09
TOTAL	.240685+10	.982802+02	.289808+06	.193872+06	.168820+10	.982802+02	.483680+06	.314371+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 5448. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.8759+08	.1917+05	.3261+04	.2179+09	.8025+04	.3899+07	.3225+09	.0000	43.51	58.87	99.04	*100.97*	.5841+03
FEB	.6732+08	.1438+05	.2511+04	.1208+09	.4476+04	.1242+07	.2419+09	.2740+07	36.76	48.59	99.58	* 99.26*	.5859+03
MAR	.4529+08	.1340+05	.1701+04	.2246+08	.8389+03	.1669+06	.2216+09	.2067+08	36.51	16.95	99.93	* 90.73*	.5897+03
APR	.4506+08	.1171+05	.1704+04	.1974+08	.7360+03	.0000	.1918+09	.3137+08	32.64	20.84	100.00	* 83.83*	.5889+03
MAY	.7536+08	.1541+05	.2821+04	.8058+08	.2998+04	.0000	.2582+09	.3250+07	38.89	37.76	100.00	* 98.76*	.5849+03
JUN	.1335+09	.2010+05	.4987+04	.1276+09	.4742+04	.0000	.3386+09	.1841+07	48.58	48.41	100.00	* 99.46*	.5745+03
JUL	.1386+09	.2200+05	.5169+04	.1855+09	.6898+04	.0000	.3715+09	.0000	50.09	54.84	100.00	*100.00*	.5764+03
AUG	.1050+09	.2068+05	.3917+04	.2122+09	.7893+04	.0000	.3492+09	.0000	48.28	57.10	100.00	*100.00*	.5815+03
SEP	.9129+08	.1469+05	.3428+04	.3586+08	.1335+04	.0000	.2438+09	.2132+08	38.20	32.44	100.00	* 91.27*	.5816+03
OCT	.4621+08	.1063+05	.1750+04	.1913+08	.7129+03	.0000	.1731+09	.2968+08	28.79	23.17	100.00	* 82.80*	.5887+03
NOV	.8207+08	.1320+05	.3060+04	.7668+08	.2843+04	.1024+07	.2219+09	.1872+07	31.88	44.72	99.63	* 99.52*	.5833+03
DEC	.5407+08	.1852+05	.2013+04	.3171+09	.1154+05	.8648+07	.3114+09	.0000	42.63	73.21	97.83	*102.22*	.5898+03
TOTAL	.9714+09	.1939+06	.3632+05	.1436+10	.5304+05	.1498+08	.3245+10	.1127+09	40.08	46.09	99.62	* 96.89* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1866+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1032+06 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 5448. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.65369+05	.37419+04	.61066+05	.00000	.175302+09	.131298+05	.4921+02	.5269282+02
FEB	.59562+05	.34920+04	.57967+05	.00000	.165362+09	.120276+05	.5095+02	.5236863+02
MAR	.80481+05	.55849+04	.80276+05	.00000	.236724+09	.102452+05	.5399+02	.5412751+02
APR	.72155+05	.66491+04	.70885+05	.00000	.200021+09	.143049+05	.5088+02	.5179502+02
MAY	.79647+05	.92847+04	.75379+05	.00000	.212025+09	.157252+05	.4886+02	.5163010+02
JUN	.85480+05	.11364+05	.78584+05	.00000	.226622+09	.187744+05	.4909+02	.5340084+02
JUL	.82331+05	.11219+05	.76518+05	.00000	.219620+09	.185277+05	.4896+02	.5268325+02
AUG	.72603+05	.89775+04	.70177+05	.00000	.197829+09	.183004+05	.5001+02	.5174362+02
SEP	.73260+05	.73173+04	.72823+05	.00000	.216519+09	.180750+05	.5425+02	.5457463+02
OCT	.62976+05	.47840+04	.61868+05	.00000	.176944+09	.107655+05	.5157+02	.5249704+02
NOV	.60184+05	.38048+04	.56851+05	.00000	.163426+09	.121164+05	.4984+02	.5276551+02
DEC	.47063+05	.27956+04	.42383+05	.00000	.113896+09	.121386+05	.4442+02	.4932671+02
TOTAL	.84115+06	.79014+05	.80477+06	.00000	.230629+10	.187744+05 (ANNUAL PEAK)	.5033+02	.5260255+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 8172. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.201113+09	.982802+02	.248281+05	.192335+05	.197647+09	.982802+02	.440616+05	.324249+09
FEB	.100119+09	.976052+02	.239521+05	.151594+05	.173841+09	.976052+02	.391115+05	.235611+09
MAR	.262930+08	.778254+02	.188890+05	.178060+05	.189690+09	.778254+02	.366950+05	.200967+09
APR	.333431+08	.914084+02	.203884+05	.154727+05	.149306+09	.914084+02	.358611+05	.162597+09
MAY	.603605+08	.953174+02	.226516+05	.169775+05	.223839+09	.953174+02	.396291+05	.258244+09
JUN	.150943+09	.949600+02	.201332+05	.212386+05	.247444+09	.956444+02	.413718+05	.336691+09
JUL	.195182+09	.952819+02	.216557+05	.222677+05	.248509+09	.952819+02	.439235+05	.368934+09
AUG	.204340+09	.932872+02	.218268+05	.210144+05	.224450+09	.932872+02	.428413+05	.351703+09
SEP	.440641+08	.928107+02	.217831+05	.166614+05	.200958+09	.930274+02	.384445+05	.223022+09
OCT	.280523+08	.901188+02	.233257+05	.135899+05	.131692+09	.901188+02	.369157+05	.142845+09
NOV	.740138+08	.941302+02	.275479+05	.138447+05	.175749+09	.941302+02	.413926+05	.219896+09
DEC	.303602+09	.955052+02	.248175+05	.186244+05	.127033+09	.955052+02	.434419+05	.319025+09
TOTAL	.142742+10	.982802+02	.271796+06	.211883+06	.235092+10	.982802+02	.483680+06	.314371+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 8172. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.4235+08	.1923+05	.1578+04	.1588+09	.5825+04	.3652+07	.3237+09	.0000	43.65	38.49	99.10	*100.91*	.5922+03
FEB	.1996+08	.1516+05	.7478+03	.8616+08	.3186+04	.1066+07	.2539+09	.1557+08	38.76	25.95	99.64	* 94.12*	.5955+03
MAR	.1740+08	.1781+05	.6623+03	.8891+07	.3336+03	.4828+05	.2875+09	.8539+08	48.52	5.59	99.98	* 70.19*	.5955+03
APR	.1927+08	.1547+05	.7400+03	.1408+08	.5247+03	.0000	.2472+09	.8688+08	43.15	8.17	100.00	* 65.18*	.5950+03
MAY	.4228+08	.1698+05	.1589+04	.1808+08	.6727+03	.0000	.2812+09	.2456+08	42.84	13.32	100.00	* 91.32*	.5912+03
JUN	.8685+08	.2124+05	.3247+04	.6409+08	.2383+04	.0000	.3556+09	.2209+08	51.34	26.51	100.00	* 93.84*	.5848+03
JUL	.1104+09	.2227+05	.4115+04	.8481+08	.3154+04	.0000	.3756+09	.1114+07	50.70	32.64	100.00	* 99.70*	.5815+03
AUG	.6838+08	.2101+05	.2549+04	.1360+09	.5054+04	.0000	.3540+09	.7559+07	49.05	36.18	100.00	* 97.90*	.5889+03
SEP	.3400+08	.1666+05	.1274+04	.1006+08	.3746+03	.0000	.2737+09	.5054+08	43.34	9.89	100.00	* 81.53*	.5934+03
OCT	.1712+08	.1359+05	.6524+03	.1093+08	.4086+03	.0000	.2168+09	.7402+08	36.81	7.81	100.00	* 65.87*	.5955+03
NOV	.2937+08	.1384+05	.1099+04	.4464+08	.1656+04	.6065+06	.2321+09	.1033+08	33.45	19.90	99.78	* 95.71*	.5940+03
DEC	.3162+08	.1862+05	.1179+04	.2720+09	.9868+04	.8506+07	.3132+09	.0000	42.87	59.31	97.87	*102.18*	.5939+03
TOTAL	.5190+09	.2119+06	.1943+05	.9084+09	.3344+05	.1388+08	.3514+10	.3780+09	43.81	24.95	99.65	* 89.55* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .0000 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1943+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .7747+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 8172. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.65389+05	.37419+04	.61142+05	.00000	.260827+09	.131298+05	.4881+02	.5220177+02
FEB	.59582+05	.34920+04	.58029+05	.00000	.246197+09	.120276+05	.5056+02	.5191666+02
MAR	.80481+05	.55849+04	.80150+05	.00000	.354669+09	.102452+05	.5393+02	.5414081+02
APR	.72155+05	.66491+04	.70628+05	.00000	.299455+09	.143049+05	.5079+02	.5188306+02
MAY	.79647+05	.92847+04	.75331+05	.00000	.310610+09	.155650+05	.4864+02	.5143033+02
JUN	.85480+05	.11364+05	.78585+05	.00000	.340649+09	.187744+05	.4877+02	.5304404+02
JUL	.82331+05	.11219+05	.76530+05	.00000	.327893+09	.182103+05	.4873+02	.5242932+02
AUG	.72603+05	.89775+04	.70282+05	.00000	.295076+09	.183004+05	.4973+02	.5137610+02
SEP	.73260+05	.73173+04	.72879+05	.00000	.322352+09	.180750+05	.5384+02	.5412541+02
OCT	.62976+05	.47840+04	.61744+05	.00000	.264022+09	.114319+05	.5130+02	.5232590+02
NOV	.60184+05	.38048+04	.56938+05	.00000	.242848+09	.121164+05	.4938+02	.5219241+02
DEC	.47063+05	.27956+04	.42505+05	.00000	.169908+09	.121608+05	.4418+02	.4891501+02
TOTAL	.84115+06	.79014+05	.80474+06	.00000	.344047+10	.187744+05 (ANNUAL PEAK)	.5005+02	.5231621+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 10896. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.111110+09	.982802+02	.241285+05	.199332+05	.256440+09	.982802+02	.440616+05	.324249+09
FEB	.733862+08	.965343+02	.211875+05	.179240+05	.199323+09	.976052+02	.391115+05	.235611+09
MAR	.972646+07	.770254+02	.137365+05	.229585+05	.197724+09	.778254+02	.366950+05	.200967+09
APR	.203146+08	.914084+02	.158287+05	.200324+05	.156389+09	.914084+02	.358611+05	.162597+09
MAY	.265284+08	.953174+02	.186828+05	.209463+05	.245883+09	.953174+02	.396291+05	.258244+09
JUN	.621740+08	.956444+02	.181000+05	.232718+05	.303135+09	.956444+02	.413718+05	.336691+09
JUL	.946258+08	.952819+02	.204071+05	.235164+05	.313500+09	.952819+02	.439235+05	.368934+09
AUG	.105479+09	.932142+02	.209018+05	.219394+05	.288747+09	.932872+02	.428413+05	.351703+09
SEP	.199144+08	.882798+02	.173949+05	.210496+05	.215116+09	.930274+02	.384445+05	.223022+09
OCT	.151719+08	.901188+02	.143275+05	.175861+05	.138174+09	.901188+02	.369157+05	.142845+09
NOV	.339608+08	.941302+02	.251674+05	.162253+05	.202486+09	.941302+02	.413926+05	.219896+09
DEC	.233645+09	.955052+02	.248229+05	.186190+05	.170734+09	.955052+02	.434419+05	.319025+09
TOTAL	.806040+09	.982802+02	.239683+06	.243997+06	.275221+10	.982802+02	.483680+06	.314371+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE, NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 10896. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.2457+08	.1993+05	.9162+03	.8653+08	.3130+04	.3121+07	.3353+09	.8985+07	45.24	20.30	99.23	* 98.04*	.5950+03
FEB	.1103+08	.1792+05	.4147+03	.6236+08	.2300+04	.8813+06	.2971+09	.6031+08	45.83	15.15	99.70	* 79.81*	.5975+03
MAR	.8056+07	.2296+05	.3072+03	.1670+07	.6334+02	.0000	.3658+09	.1660+09	62.57	1.61	100.00	* 54.76*	.5978+03
APR	.8983+07	.2003+05	.3430+03	.1133+08	.4218+03	.0000	.3158+09	.1546+09	55.86	3.82	100.00	* 51.26*	.5975+03
MAY	.2454+08	.2095+05	.9289+03	.1984+07	.7370+02	.0000	.3407+09	.8421+08	52.86	4.79	100.00	* 75.41*	.5941+03
JUN	.2783+08	.2327+05	.1043+04	.3434+08	.1277+04	.0000	.3867+09	.5385+08	56.25	9.97	100.00	* 86.21*	.5954+03
JUL	.4551+08	.2352+05	.1705+04	.4912+08	.1828+04	.0000	.3950+09	.1980+08	53.54	15.03	100.00	* 94.91*	.5918+03
AUG	.4001+08	.2194+05	.1492+04	.6547+08	.2435+04	.0000	.3685+09	.1902+08	51.21	17.90	100.00	* 94.87*	.5936+03
SEP	.1991+08	.2105+05	.7462+03	.0000	.0000	.0000	.3405+09	.1207+09	54.75	3.54	100.00	* 64.89*	.5967+03
OCT	.1003+08	.1759+05	.3838+03	.5140+07	.1913+03	.0000	.2759+09	.1334+09	47.64	3.27	100.00	* 51.71*	.5971+03
NOV	.1644+08	.1623+05	.6197+03	.1753+08	.6430+03	.4029+06	.2689+09	.4448+08	39.20	7.78	99.85	* 83.28*	.5964+03
DEC	.1884+08	.1862+05	.7027+03	.2148+09	.7752+04	.7859+07	.3131+09	.2573+07	42.86	45.41	98.03	*101.18*	.5961+03
TOTAL	.2558+09	.2440+06	.9602+04	.5503+09	.2012+05	.1226+08	.4003+10	.8679+09	50.45	12.18	99.69	* 78.56* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .1727+07 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1920+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .4765+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 10896. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.65389+05	.37419+04	.61040+05	.00000	.347169+09	.131298+05	.4873+02	.5220131+02
FEB	.59582+05	.34920+04	.58027+05	.00000	.328367+09	.120276+05	.5058+02	.5193492+02
MAR	.80481+05	.55849+04	.80150+05	.00000	.472905+09	.109748+05	.5393+02	.5415025+02
APR	.72155+05	.66491+04	.70675+05	.00000	.399379+09	.143049+05	.5080+02	.5186248+02
MAY	.79647+05	.92847+04	.75341+05	.00000	.422838+09	.157252+05	.4872+02	.5150817+02
JUN	.85480+05	.11364+05	.78596+05	.00000	.451339+09	.184879+05	.4846+02	.5270327+02
JUL	.82331+05	.11219+05	.76504+05	.00000	.433902+09	.184626+05	.4837+02	.5205230+02
AUG	.72603+05	.89775+04	.70269+05	.00000	.391684+09	.183147+05	.4951+02	.5115676+02
SEP	.73260+05	.73173+04	.72637+05	.00000	.429436+09	.158755+05	.5380+02	.5425929+02
OCT	.62976+05	.47840+04	.61714+05	.00000	.352112+09	.114746+05	.5131+02	.5236345+02
NOV	.60184+05	.38048+04	.56940+05	.00000	.323493+09	.118727+05	.4933+02	.5214125+02
DEC	.47063+05	.27956+04	.42439+05	.00000	.225908+09	.121608+05	.4405+02	.4885372+02
TOTAL	.84115+06	.79014+05	.80432+06	.00000	.457851+10	.184879+05 (ANNUAL PEAK)	.4996+02	.5224267+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

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SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.IN LATITUDE

SOLAR COLLECTOR APERTURE AREA = 13620. SQ.FT.

STES CHART NO. 4

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.571455+08	.982802+02	.219959+05	.220657+05	.202483+09	.982802+02	.440616+05	.324249+09
FEB	.589559+08	.976052+02	.181188+05	.209927+05	.210642+09	.976052+02	.391115+05	.235611+09
MAR	.631082+07	.770254+02	.111184+05	.255766+05	.199066+09	.778254+02	.366950+05	.200967+09
APR	.156970+08	.914084+02	.128744+05	.229867+05	.158396+09	.914084+02	.358611+05	.162597+09
MAY	.194522+08	.898164+02	.141617+05	.254674+05	.250771+09	.953174+02	.396291+05	.258244+09
JUN	.265994+08	.880298+02	.138750+05	.274967+05	.324545+09	.956444+02	.413718+05	.336691+09
JUL	.339520+08	.934605+02	.174078+05	.265157+05	.351207+09	.952819+02	.439235+05	.368934+09
AUG	.506851+08	.919038+02	.182039+05	.246373+05	.324738+09	.932872+02	.428413+05	.351703+09
SEP	.160083+08	.859747+02	.123535+05	.260910+05	.217653+09	.930274+02	.384445+05	.223022+09
OCT	.555313+07	.901188+02	.163958+05	.205199+05	.141371+09	.901188+02	.369157+05	.142845+09
NOV	.150813+08	.941302+02	.219111+05	.194816+05	.213442+09	.941302+02	.413926+05	.219896+09
DEC	.194945+09	.955052+02	.234836+05	.199583+05	.202858+09	.955052+02	.434419+05	.319025+09
TOTAL	.500985+09	.982802+02	.201898+06	.281782+06	.293094+10	.982802+02	.483680+06	.314371+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - SECONDARY BOILER OUTPUT - FRACTION OF WASTE HEAT USED WHICH IS DERIVED FROM THE PRIMARY BOILER)

8987

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.IN LATITUDE

SOLAR COLLECTOR APERTURE AREA = 13620. SQ.FT.

STES CHART NO. 4

MONTH	(1) FUEL TO BOOST COLLECTOR TEMP. (BTU)	(2) ELECT. PRODUCED BY SOLAR PLUS FUEL (KWH)	(3) ELECT. PRODUCED BY FUEL IN COL.1 (KWH)	(4) FUEL TO RUN SYST. WHEN NO SOLAR OR STORAGE AVL.(BTU)	(5) ELECT. PRODUCED BY FUEL IN COL.4 (KWH)	(6) FUEL TO MEET THERMAL REQMTS. (BTU)	***(7)*** ORC CONDENSER HEAT (BTU)	***(8)*** HEAT REJECTION TO COOLING TOWER (BTU)	**(9)** PERCENT ELECT. BY SOLAR + FUEL	(10) PERCENT OF 9 MET BY FUEL	*(11)** PERCENT THERMAL FROM COND. HEAT	*(12)** ******* * PCT * * UTIL* ******* ******* ******* *******	(13) AVERAGE COLLECTOR FLUID OUTLET TEMP. (DEG.F)
JAN	.1378+08	.2207+05	.5138+03	.4335+08	.1555+04	.1883+07	.3692+09	.4158+08	50.08	9.38	99.54	* 89.00*	.5972+03
FEB	.9493+07	.2099+05	.3577+03	.4946+08	.1829+04	.6004+06	.3452+09	.1164+09	53.67	10.41	99.80	* 67.02*	.5977+03
MAR	.6311+07	.2558+05	.2419+03	.0000	.0000	.0000	.4055+09	.2710+09	69.70	.95	100.00	* 42.58*	.5981+03
APR	.8261+07	.2299+05	.3174+03	.7436+07	.2773+03	.0000	.3604+09	.2358+09	64.10	2.59	100.00	* 40.82*	.5975+03
MAY	.1945+08	.2547+05	.7369+03	.0000	.0000	.0000	.4082+09	.1649+09	64.26	2.89	100.00	* 61.04*	.5957+03
JUN	.1487+08	.2750+05	.5567+03	.1173+08	.4352+03	.0000	.4517+09	.1138+09	66.46	3.61	100.00	* 74.74*	.5976+03
JUL	.2577+08	.2652+05	.9650+03	.8180+07	.3047+03	.0000	.4405+09	.6924+08	60.37	4.79	100.00	* 84.20*	.5952+03
AUG	.2703+08	.2464+05	.1010+04	.2365+08	.8789+03	.0000	.4099+09	.5975+08	57.51	7.67	100.00	* 85.48*	.5952+03
SEP	.1661+08	.2609+05	.6281+03	.0000	.0000	.0000	.4172+09	.2045+09	67.87	2.41	100.00	* 52.16*	.5971+03
OCT	.4047+07	.2052+05	.1556+03	.1506+07	.5608+02	.0000	.3206+09	.1993+09	55.59	1.03	100.00	* 41.75*	.5988+03
NOV	.1147+08	.1948+05	.4328+03	.3610+07	.1338+03	.7418+05	.3196+09	.9582+08	47.07	2.91	99.97	* 69.66*	.5974+03
DEC	.1667+08	.1996+05	.6251+03	.1783+09	.6411+04	.7131+07	.3342+09	.2161+08	45.94	35.26	98.21	* 95.25*	.5965+03
TOTAL	.1738+09	.2818+06	.6541+04	.3272+09	.1188+05	.9669+07	.4582+10	.1594+10	58.26	6.54	99.75	* 66.47* ********	

HIGH TEMPERATURE HEAT REJECTED TO TOWER = .1523+09 BTU/YR

PURCHASED ELECTRICITY 8PM-8AM = .1741+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .2781+05 KWH

ITEM (12) IS PERCENT THERMAL UTILIZATION CALCULATED AS :

P.U.=(TH.LD./(COND.HT.TO TH.LD.+TOT.TOWER HT.))*100.

NOTE : UTILIZATION IS BASED ONLY ON THERMAL ENERGY PRODUCED BY THE SYSTEM, ELECTRICITY IS 100 PERCENT UTILIZED.

SOLAR TOTAL ENERGY SYSTEM SIMULATION PROGRAM

POLAR MOUNT PARABOLIC TROUGH - ALBUQUERQUE,NEW MEXICO - 35.1N LATITUDE

SOLAR COLLECTOR APERTURE AREA = 13620. SQ.FT.

COLLECTOR NO. 1

MONTH	DIRECT NORMAL RAD (BTU/SQFT)	DIFFUSE RADIATION (BTU/SQFT)	COLLECTOR BEAM RADIATION (BTU/SQFT)	COLLECTOR DIFFUSE RADIATION (BTU/SQFT)	ENERGY COLLECTED (BTU)	PEAK HOUR FLUID MASS FLOW (LBS/HR)	COLLECTOR OVERALL EFFICIENCY (PCT)	COLLECTOR EFFICIENCY (PCT)
JAN	.65389+05	.37419+04	.61040+05	.00000	.433570+09	.131298+05	.4868+02	.5215124+02
FEB	.59582+05	.34920+04	.58059+05	.00000	.410951+09	.120276+05	.5064+02	.5196899+02
MAR	.80481+05	.55849+04	.80137+05	.00000	.591238+09	.109748+05	.5394+02	.5416886+02
APR	.72155+05	.66491+04	.70628+05	.00000	.499479+09	.148991+05	.5082+02	.5192333+02
MAY	.79647+05	.92847+04	.75341+05	.00000	.529926+09	.155650+05	.4885+02	.5164251+02
JUN	.85480+05	.11364+05	.78475+05	.00000	.564467+09	.187744+05	.4848+02	.5281170+02
JUL	.82331+05	.11219+05	.76576+05	.00000	.542696+09	.187037+05	.4840+02	.5203393+02
AUG	.72603+05	.89775+04	.70323+05	.00000	.490278+09	.183147+05	.4958+02	.5118784+02
SEP	.73260+05	.73173+04	.72677+05	.00000	.538079+09	.158755+05	.5393+02	.5435928+02
OCT	.62976+05	.47840+04	.61737+05	.00000	.440183+09	.112844+05	.5132+02	.5234944+02
NOV	.60184+05	.38048+04	.57033+05	.00000	.404534+09	.121164+05	.4935+02	.5207804+02
DEC	.47063+05	.27956+04	.42455+05	.00000	.282754+09	.121608+05	.4411+02	.4889869+02
TOTAL	.84115+06	.79014+05	.80447+06	.00000	.572809+10	.187744+05 (ANNUAL PEAK)	.5000+02	.5227831+02

**** OVERALL COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(DIRECT NORMAL RADIATION * COLLECTOR AREA))* 100.
**** (ACCOUNTS FOR COSINE LOSSES) ****

****** COLLECTOR EFFICIENCY = (COLLECTOR OUTPUT/(COLLECTOR BEAM RADIATION * COLLECTOR AREA))* 100.

APPENDIX D. SELECTED PHOTOVOLTAIC SOLAR TOTAL ENERGY SYSTEM OUTPUT REPORTS

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO,ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 3887. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.615055+09	.102630+03	.448114+05	.180491+04	.648097+07	.102630+03	.466163+05	.498525+09
FEB	.472926+09	.100305+03	.377671+05	.281878+04	.175398+08	.100305+03	.405859+05	.395881+09
MAR	.337396+09	.820059+02	.328919+05	.449379+04	.373054+08	.820504+02	.373857+05	.307222+09
APR	.161857+09	.107884+03	.320511+05	.390843+04	.369205+08	.107884+03	.359595+05	.166406+09
MAY	.104127+09	.162697+03	.360052+05	.363949+04	.348799+08	.162831+03	.396447+05	.118182+09
JUN	.474673+08	.187255+03	.470099+05	.418325+04	.459123+08	.189860+03	.511931+05	.838861+08
JUL	.219439+08	.190355+03	.527483+05	.509566+04	.691272+08	.192458+03	.578439+05	.866823+08
AUG	.332171+08	.172338+03	.470576+05	.477478+04	.601086+08	.178770+03	.518324+05	.866823+08
SEP	.451064+08	.173565+03	.381078+05	.396622+04	.506768+08	.173565+03	.420740+05	.867619+08
OCT	.140821+09	.113425+03	.330757+05	.365455+04	.382450+08	.113428+03	.367302+05	.150902+09
NOV	.330457+09	.951302+02	.393727+05	.210967+04	.152209+08	.951302+02	.414424+05	.279587+09
DEC	.546663+09	.100305+03	.422352+05	.277443+04	.140251+08	.100305+03	.450096+05	.451356+09
TOTAL	.285699+10	.190355+03	.483124+06	.432236+05	.426423+09	.192458+03	.526348+06	.271202+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO,ILLINOIS - LATITUDE 41,67N - COLLECTOR TILT 41,67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 3887. SQ,FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	,194077+04	,648095+07	,180491+04	,615055+09	,000000	,000000	,387184+01	,130002+01	,258274+04	,769216+04
FEB	,303095+04	,175399+08	,281878+04	,472926+09	,000000	,000000	,694523+01	,443059+01	,143984+04	,225704+04
MAR	,483204+04	,373055+08	,449379+04	,337396+09	,000000	,000000	,120201+02	,181428+02	,831941+03	,823530+03
APR	,420262+04	,369207+08	,390843+04	,161857+09	,000000	,000000	,108690+02	,821871+02	,920048+03	,450713+03
MAY	,391343+04	,348801+08	,363949+04	,104127+09	,000000	,000000	,918026+01	,895139+02	,108929+04	,338824+03
JUN	,449813+04	,462297+08	,418325+04	,474673+08	,000000	,000000	,817152+01	,547318+02	,122376+04	,182709+03
JUL	,547920+04	,692648+08	,509566+04	,219439+08	,000000	,000000	,880932+01	,797479+02	,113516+04	,125395+03
AUG	,513418+04	,612071+08	,477478+04	,332171+08	,000000	,000000	,921196+01	,693437+02	,108554+04	,144209+03
SEP	,426476+04	,491239+08	,396622+04	,451064+08	,000000	,000000	,942676+01	,584091+02	,106081+04	,171206+03
OCT	,392963+04	,382451+08	,365455+04	,140821+09	,000000	,000000	,994970+01	,255444+02	,100505+04	,394565+03
NOV	,226846+04	,152209+08	,210967+04	,330457+09	,000000	,000000	,508570+01	,844406+01	,196630+04	,183686+04
DEC	,298326+04	,140251+08	,277443+04	,546663+09	,000000	,000000	,616408+01	,310733+01	,162230+04	,321820+04
TOTAL	,464769+05	,426442+09	,432236+05	,285699+10	,000000	,000000	,821199+01	,157241+02	,121773+04	,635967+03

PURCHASED ELECTRICITY 8PM-8AM = ,2328+06 KWH   ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = ,2503+06 KWH   THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO,ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 7773. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.606956+09	.102630+03	.430073+05	.360900+04	.129602+08	.102630+03	.466103+05	.498525+09
FEB	.451007+09	.100305+03	.349726+05	.561351+04	.350750+08	.100305+03	.405859+05	.395881+09
MAR	.290776+09	.819613+02	.285282+05	.86[illegible]750+04	.746012+08	.820504+02	.373657+05	.307222+09
APR	.115719+09	.107884+03	.282966+05	.766290+04	.738316+08	.107884+03	.359595+05	.166406+09
MAY	.610775+08	.162563+03	.324686+05	.717608+04	.693198+08	.162831+03	.396447+05	.118182+09
JUN	.408966+07	.184651+03	.428468+05	.834631+04	.806144+08	.189860+03	.511931+05	.836861+08
JUL	.000000	.188251+03	.476627+05	.101813+05	.866823+08	.192458+03	.578439+05	.866823+08
AUG	.000000	.169015+03	.423223+05	.951010+04	.866823+08	.178770+03	.518324+05	.866823+08
SEP	.181099+08	.173565+03	.342305+05	.783753+04	.722740+08	.173565+03	.420740+05	.867619+08
OCT	.943376+08	.113425+03	.295344+05	.719579+04	.754315+08	.113425+03	.367302+05	.150902+09
NOV	.311436+09	.951302+02	.372776+05	.420479+04	.304378+08	.951302+02	.414624+05	.279587+09
DEC	.529136+09	.100305+03	.394642+05	.554544+04	.260465+08	.100305+03	.450096+05	.451356+09
TOTAL	.248262+10	.188251+03	.440609+06	.857389+05	.725921+09	.192458+03	.526348+06	.271202+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO, ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 7773. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.388104+04	.129602+08	.360900+04	.606956+09	.000000	.000000	.774194+01	.259971+01	.129167+04	.384658+04
FEB	.606113+04	.350752+08	.561331+04	.451007+09	.000000	.000000	.138307+02	.886004+01	.722375+03	.112866+04
MAR	.966284+04	.746015+08	.885756+04	.290776+09	.000000	.000000	.236924+02	.242826+02	.420945+03	.411818+03
APR	.840416+04	.738319+08	.766290+04	.115719+09	.000000	.000000	.213098+02	.443684+02	.467599+03	.225386+03
MAY	.782586+04	.697512+08	.717608+04	.610775+08	.000000	.158932+06	.181010+02	.586553+02	.551229+03	.170097+03
JUN	.899510+04	.924475+08	.834631+04	.408966+07	.000000	.477643+07	.163036+02	.960998+02	.613138+03	.982378+02
JUL	.109570+05	.138512+09	.101813+05	.000000	.000000	.514843+08	.176012+02	.100000+03	.568050+03	.627375+02
AUG	.102670+05	.122398+09	.951010+04	.000000	.000000	.366418+08	.183478+02	.100000+03	.544743+03	.702882+02
SEP	.852842+04	.982352+08	.783753+04	.181099+08	.000000	.286121+08	.186279+02	.833015+02	.535931+03	.859999+02
OCT	.785826+04	.764804+08	.719579+04	.943376+08	.000000	.514573+07	.195909+02	.499873+02	.509069+03	.187275+03
NOV	.453634+04	.304378+08	.420479+04	.311436+09	.000000	.000000	.101363+02	.108867+02	.986303+03	.918550+03
DEC	.596575+04	.280466+08	.554544+04	.529136+09	.000000	.000006	.123206+02	.621386+01	.811630+03	.160931+04
TOTAL	.929419+05	.852774+09	.857389+05	.248262+10	.000000	.126619+09	.162894+02	.267679+02	.613068+03	.318025+03

PURCHASED ELECTRICITY 8PM-8AM = .2322+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .2084+06 KWH

ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO, ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 11660. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.598855+09	.102630+03	.412575+05	.535875+04	.194411+08	.102630+03	.466163+05	.498525+09
FEB	.429082+09	.100305+03	.323521+05	.823378+04	.526148+08	.100305+03	.405859+05	.395881+09
MAR	.244145+09	.819168+02	.245537+05	.128321+05	.111907+09	.820504+02	.373857+05	.307222+09
APR	.776971+08	.107884+03	.248604+05	.110991+05	.104249+09	.107884+03	.359595+05	.166408+09
MAY	.289810+08	.162429+03	.292017+05	.104430+05	.949970+08	.162831+03	.396447+05	.118182+09
JUN	.000000	.182046+03	.388045+05	.123836+05	.838861+08	.189860+03	.511931+05	.838861+08
JUL	.000000	.186148+03	.426632+05	.151806+05	.866823+08	.192458+03	.578439+05	.866823+08
AUG	.000000	.167715+03	.377406+05	.140917+05	.866823+08	.178770+03	.518324+05	.866823+08
SEP	.103213+08	.173565+03	.305809+05	.114932+05	.765048+08	.173565+03	.420740+05	.867619+08
OCT	.735870+08	.113425+03	.263179+05	.104124+05	.920320+08	.113425+03	.367302+05	.150902+09
NOV	.292410+09	.951302+02	.353143+05	.616809+04	.456586+08	.951302+02	.414824+05	.279587+09
DEC	.511605+09	.100305+03	.368118+05	.819783+04	.420715+08	.100305+03	.450096+05	.451356+09
TOTAL	.220666+10	.186148+03	.400456+06	.125892+06	.898685+09	.192458+03	.526348+06	.271202+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO, ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 11660. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.582181+04	.194412+08	.535875+04	.598855+09	.000000	.000000	.114955+02	.389974+01	.868180+03	.256427+04
FEB	.909208+04	.526150+08	.823378+04	.429082+09	.000000	.000000	.202873+02	.132906+02	.490257+03	.752410+03
MAR	.144909+05	.111907+09	.128321+05	.244145+09	.000000	.000000	.343234+02	.364254+02	.287998+03	.274534+03
APR	.126068+05	.110753+09	.110991+05	.776971+08	.000000	.302806+07	.308655+02	.626472+02	.319566+03	.155118+03
MAY	.117393+05	.104631+09	.104430+05	.289810+08	.000000	.116951+08	.263415+02	.803821+02	.375823+03	.110769+03
JUN	.134932+05	.138677+09	.123836+05	.000000	.000000	.444244+08	.241901+02	.100000+03	.412391+03	.653774+02
JUL	.164562+05	.207777+09	.151808+05	.000000	.000000	.120888+09	.262443+02	.100000+03	.380576+03	.417605+02
AUG	.154012+05	.183605+09	.140917+05	.000000	.000000	.979512+08	.271872+02	.100000+03	.366883+03	.469483+02
SEP	.127932+05	.147359+09	.114932+05	.103213+08	.000000	.706792+08	.273165+02	.904831+02	.362701+03	.581576+02
OCT	.117879+05	.114725+09	.104124+05	.735870+08	.000000	.318274+08	.283482+02	.609888+02	.348562+03	.121833+03
NOV	.680481+04	.456587+08	.616809+04	.292410+09	.000000	.000000	.148692+02	.163308+02	.669360+03	.612341+03
DEC	.894901+04	.420717+08	.819783+04	.511605+09	.000000	.000000	.182135+02	.932118+01	.547682+03	.107283+04
TOTAL	.139419+06	.127922+10	.125892+06	.226666+10	.000000	.380493+09	.239180+02	.331383+02	.415353+03	.212007+03

PURCHASED ELECTRICITY 8PM-8AM = .2312+06 KWH   ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .1693+06 KWH   THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO, ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 15546. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.590756+09	.102630+03	.396121+05	.700419+04	.259204+08	.102630+03	.466163+05	.498525+09
FEB	.407163+09	.100305+03	.298541+05	.107318+05	.701501+08	.100305+03	.405859+05	.395881+09
MAR	.197525+09	.818722+02	.207045+05	.166812+05	.149202+09	.820504+02	.373857+05	.307222+09
APR	.612258+08	.107884+03	.215071+05	.144524+05	.117426+09	.107884+03	.359595+05	.166406+09
MAY	.112705+08	.162295+03	.260212+05	.136235+05	.109165+09	.162831+03	.396447+05	.118182+09
JUN	.000000	.179442+03	.348814+05	.163117+05	.838861+08	.189860+03	.511931+05	.838861+08
JUL	.000000	.185704+03	.378921+05	.199518+05	.866823+08	.192458+03	.578439+05	.866823+08
AUG	.000000	.166415+03	.334044+05	.184280+05	.866823+08	.178770+03	.518324+05	.866823+08
SEP	.201129+07	.173565+03	.270410+05	.150330+05	.851529+08	.173565+03	.420740+05	.867619+08
OCT	.570260+08	.113425+03	.231999+05	.135304+05	.105281+09	.113425+03	.367302+05	.150902+09
NOV	.273389+09	.951302+02	.334534+05	.802903+04	.608755+08	.951302+02	.414824+05	.279587+09
DEC	.494078+09	.100305+03	.343509+05	.106587+05	.560930+08	.100305+03	.450096+05	.451356+09
TOTAL	.209443+10	.185704+03	.361916+06	.164432+06	.103647+10	.192458+03	.526348+06	.271202+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

CHICAGO,ILLINOIS - LATITUDE 41.67N - COLLECTOR TILT 41.67 DEGREES

SOLAR COLLECTOR APERTURE AREA = 15546. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.776208+04	.259205+08	.700419+04	.590756+09	.000000	.000000	.150252+02	.519943+01	.661534+03	.192329+04
FEB	.121223+05	.701504+08	.107318+05	.407163+09	.000000	.000000	.264422+02	.177201+02	.373902+03	.564332+03
MAR	.193257+05	.149203+09	.166812+05	.197525+09	.000000	.000000	.446192+02	.485651+02	.219811+03	.205909+03
APR	.168083+05	.147664+09	.144524+05	.612258+08	.000000	.215351+08	.401908+02	.705658+02	.243679+03	.119750+03
MAY	.156517+05	.139502+09	.136235+05	.112705+08	.000000	.363992+08	.343640+02	.923707+02	.286070+03	.811886+02
JUN	.179902+05	.184895+09	.163117+05	.000000	.000000	.888579+08	.318631+02	.100000+03	.312105+03	.485609+02
JUL	.219140+05	.277023+09	.199518+05	.000000	.000000	.190335+09	.344925+02	.100000+03	.288625+03	.312914+02
AUG	.205341+05	.244797+09	.184280+05	.000000	.000000	.158403+09	.355530+02	.100000+03	.279206+03	.353682+02
SEP	.170568+05	.196470+09	.150330+05	.201129+07	.000000	.112016+09	.357300+02	.981455+02	.275919+03	.440039+02
OCT	.157165+05	.152961+09	.135304+05	.570260+08	.000000	.614905+08	.368371+02	.697679+02	.266008+03	.904841+02
NOV	.907268+04	.608757+08	.802903+04	.273389+09	.000000	.000000	.193553+02	.217734+02	.510713+03	.459275+03
DEC	.119315+05	.560932+08	.106587+05	.494078+09	.000000	.000000	.236809+02	.124277+02	.418553+03	.804653+03
TOTAL	.185884+06	.170555+10	.164432+06	.209443+10	.000000	.669035+09	.312402+02	.382189+02	.316194+03	.159012+03

PURCHASED ELECTRICITY 8PM-8AM = .2231+06 KWH ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .1388+06 KWH THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 4298. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.282054+09	.958802+02	.397016+05	.349098+04	.288837+08	.958802+02	.431926+05	.254527+09
FEB	.206648+09	.942552+02	.356435+05	.341546+04	.276448+08	.942552+02	.390589+05	.192963+09
MAR	.948509+08	.111847+03	.309327+05	.568759+04	.628746+08	.112337+03	.366203+05	.138755+09
APR	.735867+08	.145455+03	.352985+05	.486904+04	.531825+08	.145739+03	.401676+05	.112053+09
MAY	.409967+08	.176288+03	.464317+05	.540507+04	.673106+08	.180471+03	.518367+05	.100110+09
JUN	.133662+08	.193517+03	.545811+05	.531835+04	.645154+08	.194718+03	.598995+05	.752083+08
JUL	.162449+08	.191594+03	.611029+05	.526981+04	.647193+08	.193452+03	.663726+05	.777152+08
AUG	.210861+08	.186847+03	.574964+05	.505362+04	.608465+08	.188441+03	.625501+05	.777152+08
SEP	.141671+08	.168893+03	.465154+05	.510748+04	.638746+08	.172651+03	.516229+05	.752083+08
OCT	.673954+08	.130822+03	.365480+05	.434029+04	.512937+08	.134404+03	.408883+05	.105210+09
NOV	.148903+09	.958802+02	.377643+05	.282586+04	.271842+08	.958802+02	.405901+05	.146307+09
DEC	.269705+09	.966302+02	.408491+05	.252769+04	.165581+08	.966302+02	.430770+05	.232322+09
TOTAL	.124899+10	.193517+03	.522555+06	.533091+05	.588863+09	.194718+03	.575864+06	.158806+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 4298. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.375375+04	.288838+08	.349098+04	.282054+09	.000000	.000000	.808236+01	.113480+02	.123726+04	.881209+03
FEB	.367254+04	.276449+08	.341546+04	.206648+09	.000000	.000000	.874437+01	.143265+02	.114359+04	.698007+03
MAR	.611570+04	.628748+08	.568759+04	.948509+08	.000000	.000000	.155313+02	.453134+02	.643862+03	.220685+03
APR	.523554+04	.539559+08	.486904+04	.735887+08	.000000	.000000	.121218+02	.474618+02	.824957+03	.210696+03
MAY	.581190+04	.665374+08	.540507+04	.409987+08	.000000	.000000	.104271+02	.672370+02	.959039+03	.148728+03
JUN	.571865+04	.663377+08	.531835+04	.133662+08	.000000	.417313+06	.887878+01	.857823+02	.112628+04	.115825+03
JUL	.566646+04	.633144+08	.526981+04	.162449+08	.000000	.000000	.793972+01	.832776+02	.125949+04	.120080+03
AUG	.543400+04	.633051+08	.505362+04	.210861+08	.000000	.202991+07	.807933+01	.782940+02	.123773+04	.123600+03
SEP	.547192+04	.678476+08	.510748+04	.141671+08	.000000	.211062+07	.989383+01	.849303+02	.101073+04	.113977+03
OCT	.466699+04	.491696+08	.434029+04	.673954+08	.000000	.000000	.106150+02	.487537+02	.942060+03	.205113+03
NOV	.303857+04	.269474+08	.282586+04	.148903+09	.000000	.000000	.696194+01	.185803+02	.143638+04	.538204+03
DEC	.271817+04	.165581+08	.252789+04	.269705+09	.000000	.000000	.586831+01	.712723+01	.170407+04	.140307+04
TOTAL	.573235+05	.593444+09	.533091+05	.124899+10	.000000	.455784+07	.925723+01	.370819+02	.108020+04	.267602+03

PURCHASED ELECTRICITY 8PM-8AM = .2813+06 KWH ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .2813+06 KWH THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 8596. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.245949+09	.958802+02	.362698+05	.692283+04	.577674+08	.958802+02	.431926+05	.254527+09
FEB	.172926+09	.942552+02	.323100+05	.674899+04	.546220+08	.942552+02	.390589+05	.192963+09
MAR	.320933+08	.111357+03	.256262+05	.109942+05	.113081+09	.112337+03	.366203+05	.138755+09
APR	.202031+08	.145171+03	.306957+05	.947186+04	.958910+08	.145739+03	.401676+05	.112053+09
MAY	.000000	.172105+03	.411733+05	.106634+05	.100110+09	.180471+03	.518367+05	.100110+09
JUN	.000000	.192316+03	.492642+05	.106353+05	.752083+08	.194718+03	.598995+05	.752083+08
JUL	.000000	.189737+03	.558335+05	.105393+05	.777152+08	.193452+03	.663728+05	.777152+08
AUG	.000000	.185253+03	.524438+05	.101063+05	.777152+08	.188441+03	.625501+05	.777152+08
SEP	.000000	.167450+03	.414839+05	.101390+05	.752083+08	.172851+03	.516229+05	.752083+08
OCT	.177582+08	.127241+03	.324387+05	.844953+04	.910035+08	.134404+03	.408883+05	.105210+09
NOV	.108855+09	.958802+02	.350050+05	.558516+04	.592225+08	.958802+02	.405901+05	.146307+09
DEC	.248836+09	.966302+02	.380457+05	.503129+04	.332535+08	.966302+02	.430770+05	.232322+09
TOTAL	.846617+09	.192316+03	.470581+06	.105284+06	.910764+09	.194718+03	.575864+06	.158806+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 8596. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.750751+04	.577070+08	.692283+04	.245949+09	.000000	.000000	.160278+02	.226961+02	.623157+03	.440605+03
FEB	.734508+04	.552090+08	.674899+04	.172926+09	.000000	.000000	.172790+02	.283070+02	.577900+03	.353269+03
MAR	.122314+05	.125750+09	.109942+05	.320933+08	.000000	.118515+08	.300220+02	.814965+02	.330808+03	.111064+03
APR	.104711+05	.107912+09	.947186+04	.202031+08	.000000	.591913+07	.235809+02	.855761+02	.422007+03	.110061+03
MAY	.110238+05	.133075+09	.106634+05	.000000	.000000	.351687+08	.205711+02	.100000+03	.484995+03	.739918+02
JUN	.114373+05	.132075+09	.106353+05	.000000	.000000	.548977+08	.177552+02	.100000+03	.563215+03	.578054+02
JUL	.113329+05	.126629+09	.105393+05	.000000	.000000	.498867+08	.158790+02	.100000+03	.629764+03	.609044+02
AUG	.108680+05	.126610+09	.101063+05	.000000	.000000	.500001+08	.161571+02	.100000+03	.618921+03	.608503+02
SEP	.109838+05	.135795+09	.101390+05	.000000	.000000	.585975+08	.196405+02	.100000+03	.508623+03	.562071+02
OCT	.933399+04	.983792+08	.844953+04	.177562+08	.000000	.771346+07	.206649+02	.864970+02	.481581+03	.106577+03
NOV	.607714+04	.538947+08	.558516+04	.108855+09	.000000	.204034+07	.137599+02	.404784+02	.725642+03	.238818+03
DEC	.543633+04	.331163+08	.503129+04	.248836+09	.000000	.000000	.116798+02	.143136+02	.855916+03	.698638+03
TOTAL	.114647+06	.118689+10	.105284+06	.846617+09	.000000	.276095+09	.182827+02	.573519+02	.545779+03	.133801+03

PURCHASED ELECTRICITY 8PM-8AM = .2400+06 KWH   ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .2300+06 KWH   THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 12894. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.209844+09	.958802+02	.331427+05	.100500+05	.866512+08	.958802+02	.431926+05	.254527+09
FEB	.140317+09	.942552+02	.292468+05	.981218+04	.807096+08	.942552+02	.390589+05	.192963+09
MAR	.130891+08	.110867+03	.207525+05	.158678+05	.128284+09	.112337+03	.366203+05	.138755+09
APR	.000000	.144887+03	.264251+05	.137425+05	.112053+09	.145739+03	.401676+05	.112053+09
MAY	.000000	.167922+03	.361335+05	.157032+05	.100110+09	.180471+03	.518367+05	.100110+09
JUN	.000000	.191115+03	.439867+05	.159128+05	.752083+08	.194718+03	.598995+05	.752083+08
JUL	.000000	.187879+03	.505878+05	.157850+05	.777152+08	.193452+03	.663728+05	.777152+08
AUG	.000000	.183660+03	.474539+05	.150961+05	.777152+08	.188441+03	.625501+05	.777152+08
SEP	.000000	.166007+03	.366308+05	.149921+05	.752083+08	.172851+03	.516229+05	.752083+08
OCT	.720961+07	.126798+03	.286561+05	.122321+05	.994424+08	.134404+03	.408883+05	.105210+09
NOV	.776620+08	.958802+02	.324668+05	.812331+04	.840173+08	.958802+02	.405901+05	.146307+09
DEC	.225678+09	.966302+02	.356978+05	.737912+04	.517798+08	.966302+02	.430770+05	.232322+09
TOTAL	.673997+09	.191115+03	.421173+06	.154692+06	.104886+10	.194718+03	.575864+06	.158806+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 12894. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.112613+05	.866514+08	.100500+05	.209844+09	.000000	.000000	.232678+02	.340441+02	.426451+03	.293736+03
FEB	.110176+05	.829346+08	.981218+04	.140317+09	.000000	.000000	.251215+02	.418265+02	.394114+03	.239083+03
MAR	.183471+05	.188624+09	.158676+05	.130891+08	.000000	.544680+08	.433305+02	.924535+02	.226628+03	.759254+02
APR	.157066+05	.161868+09	.137425+05	.000000	.000000	.449594+08	.342128+02	.100000+03	.287826+03	.713658+02
MAY	.174357+05	.199612+09	.157032+05	.000000	.000000	.100545+09	.302937+02	.100000+03	.328068+03	.498916+02
JUN	.171560+05	.199013+09	.159128+05	.000000	.000000	.123621+09	.265658+02	.100000+03	.376284+03	.378255+02
JUL	.169994+05	.189943+09	.157850+05	.000000	.000000	.112099+09	.237823+02	.100000+03	.420412+03	.409427+02
AUG	.163020+05	.189915+09	.150961+05	.000000	.000000	.112421+09	.241345+02	.100000+03	.414160+03	.408733+02
SEP	.164757+05	.203693+09	.149921+05	.000000	.000000	.128390+09	.290416+02	.100000+03	.342988+03	.369395+02
OCT	.140010+05	.147569+09	.122321+05	.720961+07	.000000	.478282+08	.299160+02	.945179+02	.329600+03	.714400+02
NOV	.911571+04	.808421+08	.812331+04	.778620+08	.000000	.711206+07	.200130+02	.574255+02	.494673+03	.160548+03
DEC	.815450+04	.496744+08	.737912+04	.225678+09	.000000	.000000	.171301+02	.222879+02	.580839+03	.448673+03
TOTAL	.171970+06	.178033+10	.154692+06	.673997+09	.000000	.731443+09	.268625+02	.660477+02	.369525+03	.892008+02

PURCHASED ELECTRICITY 8PM-8AM = .2381+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1831+06 KWH

ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 17192. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.173740+09	.958802+02	.301594+05	.130332+05	.115535+09	.958802+02	.431926+05	.254527+09
FEB	.111147+09	.942552+02	.262952+05	.127638+05	.104045+09	.942552+02	.390589+05	.192963+09
MAR	.154263+07	.110377+03	.160072+05	.206131+05	.137521+09	.112337+03	.366203+05	.138755+09
APR	.000000	.144603+03	.222590+05	.179085+05	.112053+09	.145739+03	.401676+05	.112053+09
MAY	.000000	.163739+03	.313137+05	.205230+05	.100110+09	.180471+03	.518367+05	.100110+09
JUN	.000000	.189914+03	.389122+05	.209873+05	.752083+08	.194718+03	.598995+05	.752083+08
JUL	.000000	.186021+03	.455005+05	.208722+05	.777152+08	.193452+03	.663728+05	.777152+08
AUG	.000000	.182066+03	.426830+05	.198671+05	.777152+08	.188441+03	.625501+05	.777152+08
SEP	.000000	.164565+03	.320630+05	.195598+05	.752083+08	.172851+03	.516229+05	.752083+08
OCT	.113995+06	.126600+03	.249814+05	.159064+05	.105119+09	.134404+03	.408883+05	.105210+09
NOV	.507161+08	.958802+02	.300335+05	.105566+05	.105734+09	.958802+02	.405901+05	.146307+09
DEC	.202022+09	.966302+02	.334758+05	.960119+04	.707049+08	.966302+02	.430770+05	.232322+09
TOTAL	.539280+09	.189914+03	.373677+06	.202187+06	.115663+10	.194718+03	.575864+06	.158806+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

INSTITUTE OF GAS TECHNOLOGY

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

RALIEGH , NORTH CAROLINA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 17192. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.150150+05	.115535+09	.130332+05	.173740+09	.000000	.000000	.301747+02	.453922+02	.326229+03	.220302+03
FEB	.146902+05	.110580+09	.127638+05	.111147+09	.000000	.275198+07	.326782+02	.539199+02	.301107+03	.180681+03
MAR	.244628+05	.251499+09	.206131+05	.154263+07	.000000	.103812+09	.562886+02	.991106+02	.172956+03	.574953+02
APR	.209421+05	.215824+09	.179085+05	.000000	.000000	.101171+09	.445846+02	.100000+03	.219185+03	.525519+02
MAY	.232476+05	.266150+09	.205230+05	.000000	.000000	.165502+09	.395917+02	.100000+03	.249386+03	.376902+02
JUN	.228746+05	.265351+09	.209873+05	-.000000	.000000	.190555+09	.350375+02	.100000+03	.284821+03	.282989+02
JUL	.226659+05	.253258+09	.208722+05	.000000	.000000	.175986+09	.314470+02	.100000+03	.317515+03	.306326+02
AUG	.217360+05	.253221+09	.198671+05	.000000	.000000	.174699+09	.317619+02	.100000+03	.313727+03	.307888+02
SEP	.219677+05	.271590+09	.195598+05	.000000	.000000	.195642+09	.378898+02	.100000+03	.261716+03	.277674+02
OCT	.186680+05	.196758+09	.159069+05	.113995+06	.000000	.928540+08	.389033+02	.999133+02	.251208+03	.531437+02
NOV	.121543+05	.107789+09	.105566+05	.507161+08	.000000	.141429+08	.260079+02	.722687+02	.378456+03	.122047+03
DEC	.108727+05	.662326+08	.960119+04	.202022+09	.000000	.000000	.222884+02	.304340+02	.443886+03	.328580+03
TOTAL	.229294+06	.237378+10	.202187+06	.539280+09	.000000	.121711+10	.351102+02	.728340+02	.281187+03	.669005+02

PURCHASED ELECTRICITY 8PM-8AM = .2278+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .1459+06 KWH

ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 4303. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.219018+09	.985052+02	.395578+05	.349504+04	.286643+08	.985052+02	.430529+05	.203879+09
FEB	.154180+09	.100890+03	.348448+05	.341943+04	.306464+08	.100890+03	.382642+05	.153990+09
MAR	.777676+08	.145382+03	.351676+05	.569421+04	.662250+08	.145873+03	.408618+05	.128439+09
APR	.290875+08	.186289+03	.405463+05	.487471+04	.553260+08	.192666+03	.454210+05	.790760+08
MAY	.136851+08	.166717+03	.546376+05	.541136+04	.698443+08	.173286+03	.600490+05	.807924+08
JUN	.383251+07	.201767+03	.665500+05	.532452+04	.576791+08	.205873+03	.718745+05	.607451+08
JUL	.828865+06	.227936+03	.740521+05	.527593+04	.621069+08	.230156+03	.793280+05	.627700+08
AUG	.226901+07	.204978+03	.754349+05	.505950+04	.609547+08	.208417+03	.804944+05	.627700+08
SEP	.340449+07	.185939+03	.585765+05	.511342+04	.580215+08	.187423+03	.636699+05	.607451+08
OCT	.301058+08	.162367+03	.462137+05	.434535+04	.576945+08	.164359+03	.505591+05	.817791+08
NOV	.140336+09	.147491+03	.427319+05	.282915+04	.271238+08	.148737+03	.455611+05	.139393+09
DEC	.224268+09	.138688+03	.398811+05	.253083+04	.193453+08	.138688+03	.424120+05	.198760+09
TOTAL	.899377+09	.227936+03	.608181+06	.533719+05	.593605+09	.230156+03	.661553+06	.131311+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

INSTITUTE OF GAS TECHNOLOGY

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 4303. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.375812+04	.286646+08	.349504+04	.219018+09	.000000	.000000	.811802+01	.140596+02	.123182+04	.711258+03
FEB	.367681+04	.306466+08	.341943+04	.154180+09	.000000	.000000	.893636+01	.199017+02	.111902+04	.502471+03
MAR	.612282+04	.662252+08	.569421+04	.777676+08	.000000	.000000	.139353+02	.515615+02	.717601+03	.193943+03
APR	.524163+04	.569396+08	.487471+04	.296875+08	.000000	.000000	.107323+02	.699657+02	.931768+03	.142927+03
MAY	.581867+04	.707012+08	.541136+04	-.136851+08	.000000	.186733+07	.901157+01	.864492+02	.110968+04	.112663+03
JUN	.572530+04	.692816+08	.532452+04	.383251+07	.000000	.893892+07	.740808+01	.949527+02	.134987+04	.911842+02
JUL	.567305+04	.688423+08	.527593+04	.828865+06	.000000	.844389+07	.665078+01	.989436+02	.150358+04	.889713+02
AUG	.544032+04	.709553+08	.505950+04	.226901+07	.000000	.107659+08	.628552+01	.971082+02	.159096+04	.875201+02
SEP	.549830+04	.738543+08	.511342+04	.340449+07	.000000	.130434+08	.802863+01	.955164+02	.124554+04	.854783+02
OCT	.467242+04	.546869+08	.434535+04	.301058+08	.000000	.000000	.859460+01	.705492+02	.116352+04	.141745+03
NOV	.304210+04	.265498+08	.282915+04	.140336+09	.000000	.000000	.620957+01	.194586+02	.161041+04	.513911+03
DEC	.272133+04	.193455+08	.253083+04	.224268+09	.000000	.000000	.596725+01	.973309+01	.167581+04	.102742+04
TOTAL	.573902+05	.636689+09	.533719+05	.899377+09	.000000	.430594+08	.806766+01	.452077+02	.123949+04	.206281+03

PURCHASED ELECTRICITY 8PM-8AM = .2694+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .3388+06 KWH

ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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INSTITUTE OF GAS TECHNOLOGY

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 8607. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.183179+09	.985052+02	.361210+05	.693190+04	.573355+08	.985052+02	.430529+05	.203879+09
FEB	.118719+09	.100890+03	.315124+05	.675183+04	.590149+08	.100890+03	.382642+05	.153990+09
MAR	.184450+08	.144892+03	.298026+05	.110592+05	.113683+09	.145873+03	.408616+05	.128439+09
APR	.150223+07	.176892+03	.358632+05	.953770+04	.778743+08	.192686+03	.454210+05	.790760+08
MAY	.000000	.165566+03	.492736+05	.107753+05	.807924+08	.173286+03	.600490+05	.807924+08
JUN	.000000	.197660+03	.612242+05	.106503+05	.607451+08	.205873+03	.718745+05	.607451+08
JUL	.000000	.225714+03	.687749+05	.105531+05	.627700+08	.230156+03	.793280+05	.627700+08
AUG	.000000	.203168+03	.703743+05	.101202+05	.627700+08	.208417+03	.804944+05	.627700+08
SEP	.000000	.184454+03	.534635+05	.102264+05	.607451+08	.187423+03	.636899+05	.607451+08
OCT	.106844+08	.160374+03	.419757+05	.858337+04	.732316+08	.164359+03	.505591+05	.817791+08
NOV	.102979+09	.147491+03	.399336+05	.562745+04	.570094+08	.148737+03	.455611+05	.139393+09
DEC	.200081+09	.138688+03	.373796+05	.503234+04	.386952+08	.138688+03	.424120+05	.198760+09
TOTAL	.635588+09	.225714+03	.558708+06	.105845+06	.804636+09	.230156+03	.661553+06	.131311+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 8607. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.751711+04	.573358+08	.693190+04	.183179+09	.000000	.000000	.161009+02	.281224+02	.620358+03	.355588+03
FEB	.735448+04	.613003+08	.675183+04	.118719+09	.000000	.429801+06	.176453+02	.383240+02	.565489+03	.259047+03
MAR	.122471+05	.132466+09	.110592+05	.184450+08	.000000	.127227+08	.270649+02	.885113+02	.367257+03	.101608+03
APR	.104845+05	.113892+09	.953776+04	.150223+07	.000000	.358062+08	.209986+02	.984802+02	.473911+03	.695599+02
MAY	.116387+05	.141419+09	.107753+05	.000000	.000000	.607430+08	.179442+02	.100000+03	.556929+03	.570828+02
JUN	.114519+05	.138579+09	.106503+05	.000000	.000000	.777428+08	.148179+02	.100000+03	.674859+03	.438631+02
JUL	.113474+05	.137701+09	.105531+05	.000000	.000000	.751383+08	.133031+02	.100000+03	.751703+03	.455157+02
AUG	.108819+05	.141927+09	.101202+05	.000000	.000000	.795027+08	.125725+02	.100000+03	.795386+03	.441195+02
SEP	.109979+05	.147726+09	.102264+05	.000000	.000000	.861062+08	.160566+02	.100000+03	.622797+03	.413651+02
UCT	.934593+04	.109387+09	.858337+04	.106844+08	.000000	.364932+08	.169769+02	.895480+02	.588166+03	.745311+02
NUV	.608492+04	.531058+08	.562745+04	.102979+09	.000000	.418080+07	.123515+02	.408984+02	.808837+03	.227802+03
DEC	.544329+04	.386955+08	.503234+04	.200081+09	.000000	.000000	.118654+02	.194684+02	.842219+03	.513652+03
TUTAL	.114794+06	.127353+10	.105845+06	.635588+09	.000000	.468865+09	.159995+02	.612784+02	.624032+03	.103109+03

PURCHASED ELECTRICITY 8PM-8AM = .2687+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .2870+06 KWH

ELEC.UTIL.=(ELEC.LD./(TUTAL PVC ELEC.UUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TUTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 12911. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	PURCHASED ENERGY: FUEL CONSUMPTION (BTU)	PURCHASED ENERGY: ELECTRIC DEMAND (KW)	PURCHASED ENERGY: ELECTRIC CONSUMPTION (KWH)	SYSTEM ENERGY DISPLACEMENT: ELECTRIC * DISPLACEMENT (KWH)	SYSTEM ENERGY DISPLACEMENT: THERMAL ** DISPLACEMENT (BTU)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC DEMAND (KW)	BUILDING ELECTRIC/THERMAL LOADS: ELECTRIC CONSUMPTION (KWH)	BUILDING ELECTRIC/THERMAL LOADS: THERMAL REQUIREMENTS (BTU)
JAN	.147340+09	.985052+02	.329879+05	.100650+05	.860066+08	.985052+02	.430529+05	.203879+09
FEB	.916730+08	.100890+03	.284496+05	.981458+04	.806516+08	.100890+03	.382642+05	.153990+09
MAR	.000000	.144401+03	.248369+05	.160229+05	.128439+09	.145873+03	.408618+05	.128439+09
APR	.000000	.167361+03	.314938+05	.139272+05	.790760+08	.192686+03	.454210+05	.790760+08
MAY	.000000	.164414+03	.440306+05	.160164+05	.807924+08	.173286+03	.600490+05	.807924+08
JUN	.000000	.194792+03	.559336+05	.159409+05	.607451+08	.205873+03	.716745+05	.607451+08
JUL	.000000	.223493+03	.635041+05	.158239+05	.627700+08	.230156+03	.793280+05	.627700+08
AUG	.000000	.202928+03	.653194+05	.151750+05	.627700+08	.206417+03	.804944+05	.627700+08
SEP	.000000	.182969+03	.484442+05	.152456+05	.607451+08	.187423+03	.636899+05	.607451+08
OCT	.189247+07	.158382+03	.379581+05	.126010+05	.802652+08	.164359+03	.505591+05	.817791+08
NOV	.744374+08	.147491+03	.372870+05	.827402+04	.798429+08	.148737+03	.455611+05	.139393+09
DEC	.175798+09	.138688+03	.350369+05	.737508+04	.581216+08	.138688+03	.424120+05	.198760+09
TOTAL	.491140+09	.223493+03	.505276+06	.156278+06	.920194+09	.230156+03	.661553+06	.131311+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 12911. SU.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.112761+05	.860070+08	.100650+05	.147340+09	.000000	.000000	.233783+02	.421853+02	.423903+03	.237050+03
FEB	.110321+05	.919539+08	.981458+04	.916730+08	.000000	.753072+07	.256495+02	.523747+02	.385942+03	.174626+03
MAR	.183713+05	.198706+09	.160229+05	.000000	.000000	.610120+08	.392124+02	.100000+03	.251074+03	.677954+02
APR	.157273+05	.170845+09	.139272+05	.000000	.000000	.921145+08	.306625+02	.100000+03	.322557+03	.461918+02
MAY	.174587+05	.212137+09	.160184+05	.000000	.000000	.130955+09	.266756+02	.100000+03	.373920+03	.381551+02
JUN	.171786+05	.207877+09	.159409+05	.000000	.000000	.147592+09	.221788+02	.100000+03	.450741+03	.291571+02
JUL	.170218+05	.206559+09	.158239+05	.000000	.000000	.144152+09	.199475+02	.100000+03	.501316+03	.303350+02
AUG	.163235+05	.212899+09	.151750+05	.000000	.000000	.149667+09	.188523+02	.100000+03	.530432+03	.295476+02
SEP	.164975+05	.221597+09	.152456+05	.000000	.000000	.160498+09	.239373+02	.100000+03	.417427+03	.274562+02
UCT	.140194+05	.164086+09	.126010+05	.189247+07	.000000	.844714+08	.249233+02	.981487+02	.398436+03	.496424+02
NOV	.912773+04	.796610+08	.827402+04	.744374+08	.000000	.121543+08	.181603+02	.572791+02	.547673+03	.151518+03
DEC	.816525+04	.580455+08	.737508+04	.175798+09	.000000	.000000	.173892+02	.292422+02	.571746+03	.341971+03
TOTAL	.172197+06	.191036+10	.156278+06	.491140+09	.000000	.990146+09	.236228+02	.700786+02	.421067+03	.687364+02

PURCHASED ELECTRICITY 8PM-8AM = .2670+06 KWH

PURCHASED ELECTRICITY 8AM-8PM = .2382+06 KWH

ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 17214. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.111910+09	.985052+02	.299968+05	.130561+05	.114351+09	.985052+02	.430529+05	.203879+09
FEB	.726602+08	.100890+03	.255002+05	.127640+05	.958571+08	.100890+03	.382642+05	.153990+09
MAR	.000000	.144256+03	.200300+05	.208316+05	.128439+09	.145673+03	.408618+05	.128439+09
APR	.000000	.166824+03	.272698+05	.181512+05	.790760+08	.192686+03	.454210+05	.790760+08
MAY	.000000	.163263+03	.390196+05	.210293+05	.807924+08	.173286+03	.600490+05	.807924+08
JUN	.000000	.192773+03	.507641+05	.211103+05	.607451+08	.205673+03	.718745+05	.607451+08
JUL	.000000	.221272+03	.583177+05	.210103+05	.627700+08	.230156+03	.793280+05	.627700+08
AUG	.000000	.202687+03	.603623+05	.201321+05	.627700+08	.208417+03	.804944+05	.627700+08
SEP	.000000	.181485+03	.436945+05	.199954+05	.607451+08	.187423+03	.636899+05	.607451+08
OCT	.000000	.156390+03	.341426+05	.164165+05	.817791+08	.164359+03	.505591+05	.817791+08
NOV	.475239+08	.147491+03	.347789+05	.107821+05	.101374+09	.148737+03	.455611+05	.139393+09
DEC	.149351+09	.138688+03	.328165+05	.959548+04	.792796+08	.138688+03	.424120+05	.198760+09
TOTAL	.381450+09	.221272+03	.456686+06	.204808+06	.100795+10	.230156+03	.661553+06	.131311+10

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

DALLAS, TEXAS - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 17214. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.150342+05	.114072+09	.130561+05	.111910+09	.000000	.000000	.303256+02	.560878+02	.324495+03	.178292+03
FEB	.147090+05	.122001+09	.127640+05	.726662+08	.000000	.213765+08	.333575+02	.622490+02	.294797+03	.131353+03
MAR	.244941+05	.264931+09	.208318+05	.000000	.000000	.124561+09	.509811+02	.100000+03	.191550+03	.507664+02
APR	.209689+05	.227785+09	.181512+05	.000000	.000000	.149300+09	.399621+02	.100000+03	.245882+03	.346253+02
MAY	.232774+05	.282838+09	.210293+05	.000000	.000000	.202006+09	.350203+02	.100000+03	.283786+03	.285689+02
JUN	.229039+05	.277159+09	.211103+05	.000000	.000000	.216827+09	.293711+02	.100000+03	.339922+03	.218845+02
JUL	.226949+05	.275401+09	.210103+05	.000000	.000000	.212200+09	.264854+02	.100000+03	.377232+03	.228279+02
AUG	.217638+05	.283854+09	.201321+05	.000000	.000000	.219866+09	.250106+02	.100000+03	.394546+03	.222088+02
SEP	.219958+05	.295452+09	.199954+05	.000000	.000000	.236096+09	.313949+02	.100000+03	.317290+03	.204639+02
OCT	.186919+05	.218773+09	.164165+05	.000000	.000000	.137619+09	.324700+02	.100000+03	.304171+03	.372743+02
NOV	.121698+05	.106212+09	.107821+05	.475239+08	.000000	.192359+08	.236652+02	.727253+02	.417968+03	.115573+03
DEC	.108866+05	.773910+08	.959548+04	.149351+09	.000000	.000000	.226245+02	.398872+02	.436603+03	.250707+03
TOTAL	.229588+06	.254705+10	.204868+06	.381450+09	.000000	.153908+10	.309677+02	.767612+02	.319846+03	.515542+02

PURCHASED ELECTRICITY 8PM-8AM = .2613+06 KWH   ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .1954+06 KWH   THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA = COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 4865. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.444757+08	.149758+03	.436178+05	.395152+04	.421101+08	.156208+03	.475693+05	.776906+08
FEB	.378931+08	.138438+03	.417588+05	.386599+04	.388858+08	.146943+03	.456248+05	.692004+08
MAR	.507940+07	.173599+03	.480752+05	.643792+04	.724118+08	.174674+03	.545131+05	.764753+08
APR	.781072+07	.167287+03	.564545+05	.551138+04	.677598+08	.168817+03	.619659+05	.740083+08
MAY	.455156+07	.165644+03	.626682+05	.611811+04	.728340+08	.173131+03	.687863+05	.764753+08
JUN	.438798+07	.181917+03	.635454+05	.601994+04	.704980+08	.186418+03	.695653+05	.740083+08
JUL	.173885+07	.201672+03	.726690+05	.596500+04	.750842+08	.204486+03	.786340+05	.764753+08
AUG	.778726+07	.195261+03	.709666+05	.572028+04	.702455+08	.196085+03	.766869+05	.764753+08
SEP	.465982+07	.194309+03	.672816+05	.578126+04	.702805+08	.196056+03	.730628+05	.740083+08
OCT	.163555+08	.178254+03	.612358+05	.491288+04	.633908+08	.183771+03	.661487+05	.764753+08
NOV	.403436+08	.141443+03	.520975+05	.319866+04	.417334+08	.145036+03	.552962+05	.740083+08
DEC	.605086+08	.135319+03	.484553+05	.286138+04	.297337+08	.138342+03	.513166+05	.781406+08
TOTAL	.235591+09	.201672+03	.688811+06	.603433+05	.714944+09	.204486+03	.749154+06	.903417+09

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 4865. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.424895+04	.421101+08	.395152+04	.444757+08	.000000	.000000	.830688+01	.542023+02	.120382+04	.184494+03
FEB	.415703+04	.398739+08	.386599+04	.378931+08	.000000	.000000	.847344+01	.561931+02	.118016+04	.177958+03
MAR	.692250+04	.873663+08	.643792+04	.507940+07	.000000	.115011+08	.118098+02	.946865+02	.846750+03	.911366+02
APR	.592622+04	.736386+08	.551138+04	.781072+07	.000000	.711512+07	.889822+01	.915569+02	.112433+04	.988427+02
MAY	.657862+04	.816209+08	.611811+04	.455156+07	.000000	.107203+08	.889437+01	.952387+02	.112431+04	.915276+02
JUN	.647307+04	.796885+08	.601994+04	.438798+07	.000000	.779724+07	.865365+01	.952568+02	.115558+04	.945247+02
JUL	.641399+04	.780719+08	.596500+04	.173885+07	.000000	.440509+07	.758578+01	.981810+02	.131825+04	.962083+02
AUG	.615087+04	.791205+08	.572028+04	.778726+07	.000000	.954395+07	.745927+01	.918538+02	.134061+04	.960872+02
SEP	.621642+04	.860724+08	.578126+04	.468982+07	.000000	.128482+08	.791272+01	.949629+02	.126379+04	.890287+02
OCT	.528267+04	.690115+08	.491288+04	.163555+08	.000000	.537026+07	.742704+01	.828907+02	.134643+04	.111819+03
NOV	.343942+04	.398770+08	.319866+04	.403436+08	.000000	.135210+07	.578460+01	.563902+02	.172873+04	.171771+03
DEC	.307675+04	.289698+08	.286138+04	.605086+08	.000000	.000000	.557593+01	.380516+02	.179342+04	.262801+03
TOTAL	.648858+05	.785417+09	.603433+05	.235591+09	.000000	.704533+08	.805486+01	.791388+02	.124148+04	.115025+03

PURCHASED ELECTRICITY 8PM-8AM = .2803+06 KWH   ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .4045+06 KWH   THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 14594. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.870672+07	.130859+03	.361303+05	.114390+05	.707253+08	.150208+03	.475093+05	.770900+08
FEB	.000000	.138436+03	.344595+05	.111654+05	.692004+08	.146943+03	.456248+05	.692004+08
MAR	.000000	.171450+03	.358929+05	.186202+05	.764753+08	.174674+03	.545131+05	.764753+08
APR	.000000	.164227+03	.456153+05	.163505+05	.740083+08	.168617+03	.619654+05	.740083+08
MAY	.000000	.160289+03	.505606+05	.162258+05	.764753+08	.173131+03	.667865+05	.764753+08
JUN	.000000	.173866+03	.515124+05	.180529+05	.740083+08	.186418+03	.695653+05	.740083+08
JUL	.000000	.196044+03	.607523+05	.178816+05	.764753+08	.204486+03	.786340+05	.764753+08
AUG	.000000	.193615+03	.595504+05	.171365+05	.764753+08	.196085+03	.766869+05	.764753+08
SEP	.000000	.190816+03	.557863+05	.172765+05	.740083+08	.196056+03	.730620+05	.740083+08
OCT	.000000	.167221+03	.515783+05	.145703+05	.764753+08	.183771+03	.661487+05	.764753+08
NOV	.118936+07	.136008+03	.458501+05	.944607+04	.730568+08	.145036+03	.552962+05	.740083+08
DEC	.118791+08	.131704+03	.428418+05	.847479+04	.660374+08	.138342+03	.513166+05	.781406+08
TOTAL	.217751+08	.196044+03	.570519+06	.178634+06	.865997+09	.204486+03	.749154+06	.903417+09

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 14594. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.127460+05	.126322+09	.114390+05	.870672+07	.000000	.481936+08	.240470+02	.910345+02	.412756+03	.653307+02
FEB	.124702+05	.119614+09	.111654+05	.000000	.000000	.484902+08	.244721+02	.100000+03	.405293+03	.587986+02
MAR	.207661+05	.262081+09	.186202+05	.000000	.000000	.180660+09	.341573+02	.100000+03	.290319+03	.297162+02
APR	.177774+05	.220901+09	.163565+05	.000000	.000000	.146656+09	.263864+02	.100000+03	.378434+03	.335385+02
MAY	.197345+05	.244646+09	.182258+05	.000000	.000000	.168651+09	.264962+02	.100000+03	.377061+03	.311729+02
JUN	.194179+05	.239049+09	.180529+05	.000000	.000000	.164614+09	.259510+02	.100000+03	.385329+03	.310146+02
JUL	.192407+05	.234200+09	.178818+05	.000000	.000000	.157954+09	.227405+02	.100000+03	.439680+03	.326220+02
AUG	.184513+05	.237345+09	.171365+05	.000000	.000000	.161121+09	.223461+02	.100000+03	.447418+03	.321671+02
SEP	.186480+05	.258200+09	.172765+05	.000000	.000000	.183925+09	.236461+02	.100000+03	.422775+03	.286926+02
OCT	.158469+05	.207020+09	.145703+05	.000000	.000000	.129532+09	.220266+02	.100000+03	.453314+03	.371226+02
NOV	.103176+05	.119623+09	.944607+04	.118936+07	.000000	.479560+08	.170827+02	.987144+02	.563673+03	.611574+02
DEC	.922962+04	.869034+08	.847479+04	.118791+08	.000000	.301008+08	.165147+02	.878383+02	.604260+03	.791392+02
TOTAL	.194644+06	.235609+10	.178634+06	.217751+08	.000000	.146625+10	.238448+02	.980716+02	.416307+03	.383739+02

PURCHASED ELECTRICITY 8PM-8AM = .2822+06 KWH   ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .2883+06 KWH   THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

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I N S T I T U T E   O F   G A S   T E C H N O L O G Y

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PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 19458. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.777426+07	.131859+03	.327010+05	.148683+05	.714712+08	.156208+03	.475693+05	.776906+08
FEB	.000000	.131600+03	.310590+05	.145659+05	.692004+08	.146943+03	.456248+05	.692004+08
MAR	.000000	.149144+03	.302692+05	.242439+05	.764753+08	.174674+03	.545131+05	.764753+08
APR	.000000	.162697+03	.405890+05	.213769+05	.740083+08	.168817+03	.619659+05	.740083+08
MAY	.000000	.159156+03	.449275+05	.238589+05	.764753+08	.173131+03	.687863+05	.764753+08
JUN	.000000	.170435+03	.457332+05	.238321+05	.740083+08	.186418+03	.695653+05	.740083+08
JUL	.000000	.193230+03	.549489+05	.236851+05	.764753+08	.204486+03	.786340+05	.764753+08
AUG	.000000	.192791+03	.541103+05	.225766+05	.764753+08	.196065+03	.766869+05	.764753+08
SEP	.000000	.189070+03	.503962+05	.226667+05	.740083+08	.196056+03	.730628+05	.740083+08
OCT	.000000	.165876+03	.471046+05	.190441+05	.764753+08	.183771+03	.661487+05	.764753+08
NOV	.000000	.135704+03	.429699+05	.123262+05	.740083+08	.145036+03	.552962+05	.740083+08
DEC	.575488+06	.131143+03	.402226+05	.110941+05	.776802+08	.138342+03	.513166+05	.781406+08
TOTAL	.834975+07	.193230+03	.515023+06	.234131+06	.896737+09	.204486+03	.749154+06	.903417+09

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 19458. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

MONTH	(1) D.C. ELECT. OUTPUT FROM P.V. ARRAY (KWH)	(2) THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES (BTU)	(3) ELEC. LOAD MET BY SOLAR (KWH)	(4) FUEL TO MEET THERMAL LOAD (BTU)	(5) ELECTRICITY WASTED (KWH)	(6) THERMAL ENERGY WASTED (BTU)	(7) PERCENT ELEC. LOAD MET BY SOLAR (PCT)	(8) PERCENT THERMAL LOAD MET BY WASTE HEAT (PCT)	(9) ELECTRIC UTILIZATION (PCT)	(10) THERMAL UTILIZATION (PCT)
JAN	.169941+05	.168423+09	.148683+05	.777426+07	.000000	.821096+08	.312561+02	.919947+02	.315153+03	.505861+02
FEB	.166264+05	.159479+09	.145659+05	.000000	.000000	.867764+08	.319253+02	.100000+03	.309012+03	.443058+02
MAR	.276871+05	.349429+09	.242439+05	.000000	.000000	.272576+09	.444735+02	.100000+03	.221475+03	.219094+02
APR	.237024+05	.294524+09	.213769+05	.000000	.000000	.220186+09	.344979+02	.100000+03	.268159+03	.251563+02
MAY	.263118+05	.326450+09	.238589+05	.000000	.000000	.248052+09	.346855+02	.100000+03	.286982+03	.235052+02
JUN	.258896+05	.318721+09	.238321+05	.000000	.000000	.247058+09	.342586+02	.100000+03	.291336+03	.230508+02
JUL	.256533+05	.312256+09	.236851+05	.000000	.000000	.235406+09	.301207+02	.100000+03	.331713+03	.245206+02
AUG	.246009+05	.316449+09	.225766+05	.000000	.000000	.239067+09	.294400+02	.100000+03	.336899+03	.242361+02
SEP	.248631+05	.344254+09	.226667+05	.000000	.000000	.270630+09	.310235+02	.100000+03	.321139+03	.214617+02
OCT	.211285+05	.276017+09	.190441+05	.000000	.000000	.200682+09	.287898+02	.100000+03	.345201+03	.270526+02
NOV	.137563+05	.159492+09	.123262+05	.000000	.000000	.854133+08	.222913+02	.100000+03	.445033+03	.464230+02
DEC	.123057+05	.115867+09	.110941+05	.575488+06	.000000	.540406+08	.216189+02	.994108+02	.460145+03	.593229+02
TOTAL	.259517+06	.314134+10	.234131+06	.834975+07	.000000	.224159+10	.312527+02	.992606+02	.317916+03	.287866+02

PURCHASED ELECTRICITY 8PM-8AM = .2792+06 KWH ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .2359+06 KWH THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 19729. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	PURCHASED ENERGY			SYSTEM ENERGY DISPLACEMENT		BUILDING ELECTRIC/THERMAL LOADS		
MONTH	FUEL CONSUMPTION (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	ELECTRIC * DISPLACEMENT (KWH)	THERMAL ** DISPLACEMENT (BTU)	ELECTRIC DEMAND (KW)	ELECTRIC CONSUMPTION (KWH)	THERMAL REQUIREMENTS (BTU)
JAN	.772231+07	.131810+03	.325133+05	.150560+05	.715128+08	.156208+03	.475693+05	.776906+08
FEB	.144004+07	.131600+03	.308721+05	.147528+05	.680483+08	.146943+03	.456248+05	.692004+08
MAR	.000000	.149087+03	.299618+05	.245514+05	.764753+08	.174674+03	.545131+05	.764753+08
APR	.000000	.162611+03	.403136+05	.216522+05	.740083+08	.168817+03	.619659+05	.740083+08
MAY	.000000	.159093+03	.446200+05	.241664+05	.764753+08	.173131+03	.687663+05	.764753+08
JUN	.000000	.170254+03	.454211+05	.241442+05	.740083+08	.186418+03	.695653+05	.740083+08
JUL	.000000	.193073+03	.546343+05	.239996+05	.764753+08	.204486+03	.786340+05	.764753+08
AUG	.000000	.192746+03	.538159+05	.228710+05	.764753+08	.196085+03	.766869+05	.764753+08
SEP	.000000	.188973+03	.501028+05	.229600+05	.740083+08	.196056+03	.730626+05	.740083+08
OCT	.000000	.165839+03	.468618+05	.192869+05	.764753+08	.183771+03	.661467+05	.764753+08
NOV	.674075+07	.135687+03	.428121+05	.124841+05	.666157+08	.145036+03	.552962+05	.740083+08
DEC	.121788+08	.131111+03	.460793+05	.112373+05	.663976+08	.138342+03	.513166+05	.761406+08
TOTAL	.280819+08	.193073+03	.512000+06	.237154+06	.880452+09	.204486+03	.749154+06	.903417+09

* ELECTRIC ENERGY DISPLACED = (TOTAL BUILDING ELECTRIC CONSUMPTION - PURCHASED ELECTRICITY)

** THERMAL ENERGY DISPLACED = (TOTAL BUILDING THERMAL REQUIREMENTS - BOILER OUTPUT)

PHOTOVOLTAIC CELL SYSTEM SIMULATION PROGRAM

MIAMI, FLORIDA - COLLECTOR TILT EQUALS NORTH LATITUDE IN DEGREES

SOLAR COLLECTOR APERTURE AREA = 19729. SQ.FT.

WATER COOLED PHOTOVOLTAIC CELL SYSTEM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	D.C. ELECT. OUTPUT FROM P.V. ARRAY	THERMAL OUTPUT OF P.V. ARRAY AFTER LOSSES	ELEC. LOAD MET BY SOLAR	FUEL TO MEET THERMAL LOAD	ELECTRICITY WASTED	THERMAL ENERGY WASTED	PERCENT ELEC. LOAD MET BY SOLAR	PERCENT THERMAL LOAD MET BY WASTE HEAT	ELECTRIC UTILIZATION	THERMAL UTILIZATION
MONTH	(KWH)	(BTU)	(KWH)	(BTU)	(KWH)	(BTU)	(PCT)	(PCT)	(PCT)	(PCT)
JAN	.172308+05	.170769+09	.150560+05	.772231+07	.000000	.939301+08	.316506+02	.920482+02	.311282+03	.469592+02
FEB	.168580+05	.161700+09	.147528+05	.144004+07	.000000	.897469+08	.323349+02	.983352+02	.304943+03	.438545+02
MAR	.280728+05	.354296+09	.245514+05	.000000	.000000	.278084+09	.450375+02	.100000+03	.218648+03	.215691+02
APR	.240325+05	.298626+09	.216522+05	.000000	.000000	.224668+09	.349422+02	.100000+03	.284553+03	.247788+02
MAY	.266782+05	.330997+09	.241664+05	.000000	.000000	.254208+09	.351325+02	.100000+03	.283383+03	.231265+02
JUN	.262502+05	.323160+09	.241442+05	.000000	.000000	.248691+09	.347072+02	.100000+03	.287600+03	.229341+02
JUL	.260106+05	.316604+09	.239998+05	.000000	.000000	.240778+09	.305208+02	.100000+03	.327325+03	.241054+02
AUG	.249836+05	.320857+09	.228710+05	.000000	.000000	.242817+09	.298239+02	.100000+03	.334431+03	.239515+02
SEP	.252094+05	.349049+09	.229600+05	.000000	.000000	.275983+09	.314250+02	.100000+03	.317062+03	.211458+02
OCT	.214228+05	.279862+09	.192869+05	.000000	.000000	.203729+09	.291569+02	.100000+03	.340569+03	.272927+02
NOV	.139479+05	.161713+09	.124841+05	.674075+07	.000000	.936538+08	.225767+02	.927135+02	.438832+03	.456083+02
DEC	.124771+05	.117481+09	.112373+05	.121788+08	.000000	.547795+08	.218980+02	.875314+02	.454349+03	.634376+02
TOTAL	.263131+06	.318510+10	.237154+06	.280819+08	.000000	.230106+10	.316562+02	.975134+02	.313813+03	.283914+02

PURCHASED ELECTRICITY 8PM-8AM = .2790+06 KWH ELEC.UTIL.=(ELEC.LD./(TOTAL PVC ELEC.OUTPUT))*100.

PURCHASED ELECTRICITY 8AM-8PM = .2330+06 KWH THERM.UTIL.=(THERM.LD./(TOTAL PVC THERMAL OUTPUT))*100.

APPENDIX E. DESIGN ANALYSIS ALGORITHMS

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Energy Analysis (Low-Temperature System)

To analyze the energy performance of a conceptual design we have defined the relevant variables in Subsection 3.1.1. In this Appendix we will express fuel consumed, purchased power, charge/discharge rates, etc., in terms of variables that are design-selected or that have been predetermined. Figures E-1 and E-2 summarize the computations applicable to the low-temperature STES Conceptual Design.

We have first computed the flow rates, M_{X1} and M_{X2}, through the heat exchangers, which depend upon generator and thermal loads, respectively. The specified temperatures T_{X1} and T_{X2} are maintained by modulating valves E and F (Figure 22). Computations of other variables are carried out depending upon the operating conditons specified in Figures E-1 and E-2.

The model computes the temperatures T_{c1} and T_{c2}. The temperature T_{s2} at the cold side of the stratified storage tank may be slightly different from T_2 but will have values ranging between T_{X1} and T_{X2}.

There are two conditions which have to be distinguished. These are —

- Condition 1

  This condition exists when solar energy is supplemented entirely by fossil fuel for electrical power generation. Under this condition no power is to be purchased from the utilities in normal operations. Figure E-1 computes the fuel consumed each hour for this condition. (Refer to Section 3.1.1 for the definition of variables used in this chart.) This is the "stand-alone" system configuration.

- Condition 2

  This condition exists when solar energy is to be supplemented by purchased power whenever Mode 4 operates. The turbine system will be shut off in this mode. It will not be turned on, even if resumption of Modes 2 or 3 occurs with the generator off (E = 0), until storage level is sufficiently above zero. Figure E-2 indicates the simulation of this operational schedule. It can be seen that there is an iterative procedure to simulate the system properly. This is the "purchased power" system configuration.

Performance Analysis (Symbols are defined in Subsection 3.1.1.)

Figure E-3 shows the schematic diagram of the low-temperature ORC. The design supply temperature to the turbine is set at 250°F. This figure shows the temperature at the cycle points under design conditions. The temperatures

$$E = E$$

$$H_2 = h_a/\eta_a + h_h/\eta_h + h_d/\eta_d$$

$$m_{x1} = \frac{E/\eta_E}{C_{p_1}(300 - T_{x1})}, \quad m_{x2} = \frac{H_2}{C_{p_2}(300 - T_{x2})}$$

$$m_s = \frac{\eta_c AS - (H_2 + E/\eta_E)}{C_{p_1}(300 - T_{s2})}$$

$$M = m_{x1} + m_{x2}$$

T_{x1}, T_{x2} = Specified values

	Mode 1	Mode 2	Mode 3	Mode 4
Condition	$\eta_c AS \geq H_2 + E/\eta_E$	$H_2 + \frac{E}{\eta_E} > \eta_c AS \geq M C_{p_1}(T_{c_2} - T_2)$	$\eta_c AS < M C_{p_1}(T_{c_2} - T_2)$	
			$C_{i-1,j} > C_{min}$	$C_{i-1,j} \leq C_{min}$
Results	$T_{c_1} = 300°F$	$T_{c_1} = \frac{\eta_c AS + M C_{p_1} T_2}{M C_{p_1}}$	$T_{c_1} = 300°F$	$T_{c_1} = 300°F$
	$T_2 = \frac{m_{x1}T_{x1} + m_{x2}T_{x2} + m_s T_{s2}}{(m_{x1} + m_{x2} + m_s)}$	$T_2 = \frac{m_{x1}T_{x1} + m_{x2}T_{x2}}{M}$	$T_2 = \frac{m_{x1}T_{x1} + m_{x2}T_{x2}}{(m_{x1} + m_{x2})}$	$T_2 = \frac{m_{x1}T_{x1} + m_{x2}T_{x2}}{M}$
	$c = \eta_c AS - (H_2 + \frac{E}{\eta_E})$	$c = 0$	$c = H_2 + \frac{E}{\eta_E} - \eta_c AS$	$c = 0$
	IF $C_{i-1,j} \geq C_{max}$ Equate c to zero	$C_{i,j} = (1 - L_s) C_{i-1,j}$	$C_{i,j} = (1 - L_s) C_{i-1,j} - c$	$C_{i,j} = (1 - L_s) C_{i-1,j}$
	$C_{i,j} = (1 - L_s) C_{i-1,j} + c$	$b = \frac{H_2 + \frac{E}{\eta_E} - \eta_c AS}{\eta_b}$	$b = 0$	$b = \frac{H_2 + \frac{E}{\eta_E} - \eta_c AS}{\eta_b}$
	$b = 0$			

Figure E-1. LOW-TEMPERATURE STES CONCEPTUAL DESIGN — NO PURCHASED POWER ("Stand-Alone")

** TRY $E = E'$

$H_2 = h_a/\eta_a + h_h/\eta_h + h_d/\eta_d$

* $m_{x1} = \dfrac{E/\eta_E}{C_{p1}(300 - T_{x1})}$, $m_{x2} = \dfrac{H_2}{C_{p1}(300 - T_{x2})}$

T_{x1}, T_{x2} = Specified

$m_s = \dfrac{\eta_c AS - (H_2 + E/\eta_e)}{C_{p1}(300 - T_{s2})}$

$M = m_{x1} + m_{x2}$

Condition	$\eta_c AS \geq H_2 + E/\eta_E$	$H_2 + E/\eta_E > \eta_c AS \geq MC_{p1}(T_{c2} - T_2)$	$\eta_c AS < MC_{p1}(T_{c2} - T_2)$	
Condition	IF $C_{i,j} > C_{min}$ AND IF $E = 0$ GO TO STEP **	$T_{c1} = \dfrac{\eta_c AS + MC_{p1}T_2}{MC_p}$	$C_{i-1,j} > C_{min}$	$C_{i-1,j} \leq C_{min}$
Result	$T_{c1} = 300°F$ $T_2 = \dfrac{m_{x1}T_{x1} + m_{x2}T_{x2} + m_sT_{s2}}{(m_{x1} + m_{x2} + m_s)}$ $c = \eta_c AS - (H_2 + E/\eta_E)$ IF $C_{i-1,j} \geq C_{max}$ Equate c to zero $C_{i,j} = (1-L_s)C_{i-1,j} + c$ $b = 0$ $E_p = E' - E$	$T_2 = \dfrac{m_{x1}T_{x1} + m_{x2}T_{x2}}{M}$ $c = 0$ $C_{i,j} = (1-L_s)C_{i-1,j}$ $b = \dfrac{H_2 + E/\eta_E - \eta_c AS}{\eta_b}$ $E_p = E' - E$	$T_{c1} = 300°F$ $T_2 = \dfrac{m_{x1}T_{x1} + m_{x2}T_{x2}}{(m_{x1} + m_{x2})}$ $c = H_2 + E/\eta_E - \eta_c AS$ $C_{i,j} = (1-L_s)C_{i-1,j} - c$ $b = 0$ $E_p = E' - E$	IF $E = E'$ GO BACK TO STEP * with $E = 0$ $T_{c1} = 300°F$ $T_2 = T_{x1}$ $c = 0$ $C_{i,j} = (1-L_s)C_{i-1,j}$ $b = \dfrac{H_2 - \eta_c AS}{\eta_b}$ $E_p = E' - E$

Figure E-2. LOW-TEMPERATURE STES CONCEPTUAL DESIGN — WITH PURCHASED POWER

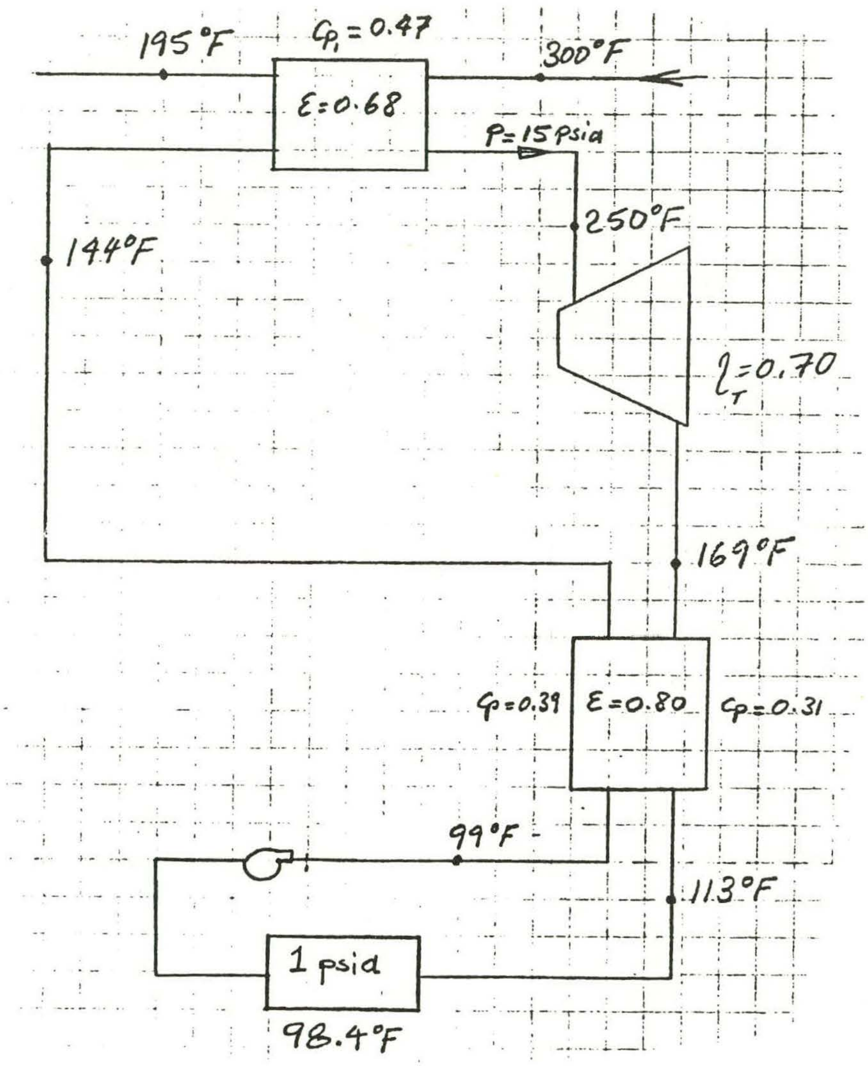

Figure E-3. LOW-TEMPERATURE ORC ANALYSIS

were selected based on the analysis of the ORC performance and the vaporizer performance with varying inlet temperature. Two disadvantages are inherent in raising the turbine supply temperature:

- The heat exchanger area required will be larger.
- The inlet temperature to the collector will be higher, lowering collector efficiency.

There is no advantage in raising the turbine supply temperature significantly beyond saturation other than a very slight improvement in efficiency. For example, at a vaporizer pressure of 15 psia, raising the turbine supply temperature from 250°F to 275°F increases the gross efficiency from 0.129 to 0.133 (a 3% improvement).

Heat exchanger studies have shown that for a shell and tube heat exchanger with two shell passes, Therminol 66 as the hot fluid, and toluene as the cold fluid, the effectiveness should not be increased above 0.70. For the conditions indicated, the effectiveness turns out to be 0.68. Therefore, we believe that the design cycle points indicated are proper in that they avoid excessive heat exchanger area without penalizing the ORC efficiency.

As the load drops from the design value, the turbine supply temperature rises and the cycle points temperatures change. Consequently, in general, the efficiency will change with the load. However, for simplicity in modeling the performance of the low-temperature ORC conceptual design, a constant heat engine efficiency of 10% has been assumed.

Energy Analysis (High Temperature System)

The computer analysis of the performance of the 600°F system was based on the relations shown in the next two figures. The "purchased power" system operation is simulated in Figure E-4, and the operation of the "stand-alone" design is simulated in Figure E-5.

If the capacity of LTS is below its maximum but not near empty (Figure E-6), or if it is near empty but the total thermal load is less than the heat rejected at the condenser ($Ht \leq 1.347\ B_E$) (Figure E-7), LTS will be charged and the thermal loads will be met without burning fossil fuel (left column in the middle of Figure E-4). If LTS is near empty and the total thermal load exceeds the heat rejected at the condenser (Figure E-8), supplementary heat will be provided by the auxiliary heater to meet the thermal loads and electric power will be generated to meet the electric demand (center column in the middle of Figure E-4). If LTS is full, energy will be discharged from storage and the thermal loads will be satisfied without supplementary heat (Figure E-9).

Each of the three thermal circuits (space heating, absorption chiller, water heating) utilize primary/secondary pumping (Figure E-10) whereby the secondary supply temperatures and the secondary and primary flow rates remain

Prespecified Values

$T_{c2}, T_{amb}, A, S, S_{min}, h_a, h_h, h_d, E', C_{min}, C_{thmin}, C_{thmax}, h_{ad}, h_{hd}, h_{dd}, E'_d, C_{p_1}, \rho_1, E_d$

Calculated Values

$\eta_b = 0.8$

$\eta_a = \eta_a(h_a / h_{ad})$

$\eta_h = 0.95$

$\eta_d = 1.4$

$H_t = h_a/\eta_a + h_h/\eta_h + h_d/\eta_d$

$E = E'$

IF $60°F < T_{amb} < 70°F$, $B(t_{ij}) = B(t_{i-1,j})$

$T_{cond}(t_{ij}) = T_{cond}(t_{i-1,j})$, $T_{s2}(t_{ij}) = T_{s2}(t_{i-1,j})$

IF $T_{amb} \leq 60°F$, $B(t_{ij}) = B_L(E)$,

$T_{cond}(t_{ij}) = 160°F$, $T_{s2}(t_{ij}) = 372°F$

IF $T_{amb} > 70°F$, $B(t_{ij}) = B_H(E)$,

$T_{cond}(t_{ij}) = 200°F$, $T_{s2}(t_{ij}) = 391°F$

$C_{max} = C_{max}(T_{s2}, 600°F)$

$$Q_L = 0.21\left(\frac{C_{max}}{C_{p_1}\rho_1(600 - T_{s2})}\right)^{2/3}\left\{(600 - T_{s2})\frac{C_{i-1,j}}{C_{max}} + (T_{s2} - 70)\right\}$$

IF $C_{thi-1,j} > C_{thmax}$, $B(t_{ij}) = B_T(E)$

$T_{cond}(t_{ij}) = 110°F$

$T_2 = T_{x_1}(E, T_{cond})$

$\eta_c = \eta_c(600, S, T_2)$

$**$ $E = E'$

$*$ $H_{E1} = 1.347E + 1.347BE$

$m_{x1} = H_{E1} / C_{p_1}(600 - T_{x1})$

$m_s = (\eta_c AS - H_{E1}) / C_{p_1}(600 - T_{s2})$

IF $m_s < 0$, $m_s = 0$

IF $S \leq S_{min}$, $\eta_c AS = 0$

$(C_{thmin} < C_{thi-1,j} \leq C_{thmax})$ or $(C_{thi-1,j} \leq C_{thmin}$ and $H_t \leq 1.347BE)$	$C_{thi-1,j} \leq C_{thmin}$ and $H_t > 1.347BE$	$C_{thi-1,j} > C_{thmax}$
$C_{th} = 1.347BE - H_t$ $C_{thi,j} = C_{thi-1,j} + C_{th}$ $b_{2th} = 0$	IF $E = 0$, GO TO $**$ $C_{th} = 0$ $C_{thi,j} = C_{thi-1,j}$ $b_{2th} = (H_t - 1.347BE)/\eta_{b2}$	$C_{th} = -H_t$ $C_{thi,j} = C_{thi-1,j} + C_{th}$ $b_{2th} = 0$

$\eta_c AS \geq H_{E1}$	$H_{E1} > \eta_c AS > m_{x1}C_{p_1}(T_{c2} - T_2)$	$\eta_c AS \leq m_{x1}C_{p_1}(T_{c2} - T_2)$: $C_{i-1,j} > C_{min}$	$\eta_c AS \leq m_{x1}C_{p_1}(T_{c2} - T_2)$: $C_{i-1,j} \leq C_{min}$
IF $C_{i-1,j} > C_{min}$ AND IF $E = 0$, GO TO $**$ $T_{c1} = 600°F$ $T_2 = \frac{m_s T_{s2} + m_{x1} T_{x1}}{m_s + m_{x1}}$ $\eta_c = \eta_c(600, S, T_2)$ $b = 0$ $c = \eta_c AS - H_{E1}$ $C_{i,j} = C_{i-1,j} + c - Q_L$ IF $C_{i-1,j} \geq C_{max}$ $C_{i,j} = C_{i-1,j} - Q_L$ Total Cons $= b + b_{2th}$ $E_p = E' - E$	$T_{c1} = \frac{\eta_c AS + m_{x1}C_{p_1}T_{x1}}{m_{x1}C_{p_1}}$ $c = 0$ $\eta_c = \eta_c(T_{c1}, S, T_2)$ $C_{i,j} = C_{i-1,j} - Q_L$ $b = (H_{E1} - \eta_c AS)/\eta_b$ Total Cons. $= b + b_{2th}$ $E_p = E' - E$	$T_{c1} = 600°F$ $c = H_{E1} - \eta_c AS$ $C_{i,j} = C_{i-1,j} - c - Q_L$ $b = 0$ Total Cons $= b + b_{2th}$ $E_p = E' - E$	IF $E = E'$ AND $C_{thi-1,j} > C_{thmin}$ GO TO $*$ With $E = 0$ $T_{c1} = 600°F$ $c = 0$ $C_{i,j} = C_{i-1,j} - Q_L$ $b = \frac{H_{E1} - \eta_c AS}{\eta_b}$ Total Cons $= b + b_{2th}$ $E_p = E' - E$

Figure E-4. HIGH-TEMPERATURE STES CONCEPTUAL DESIGN — WITH PURCHASED POWER

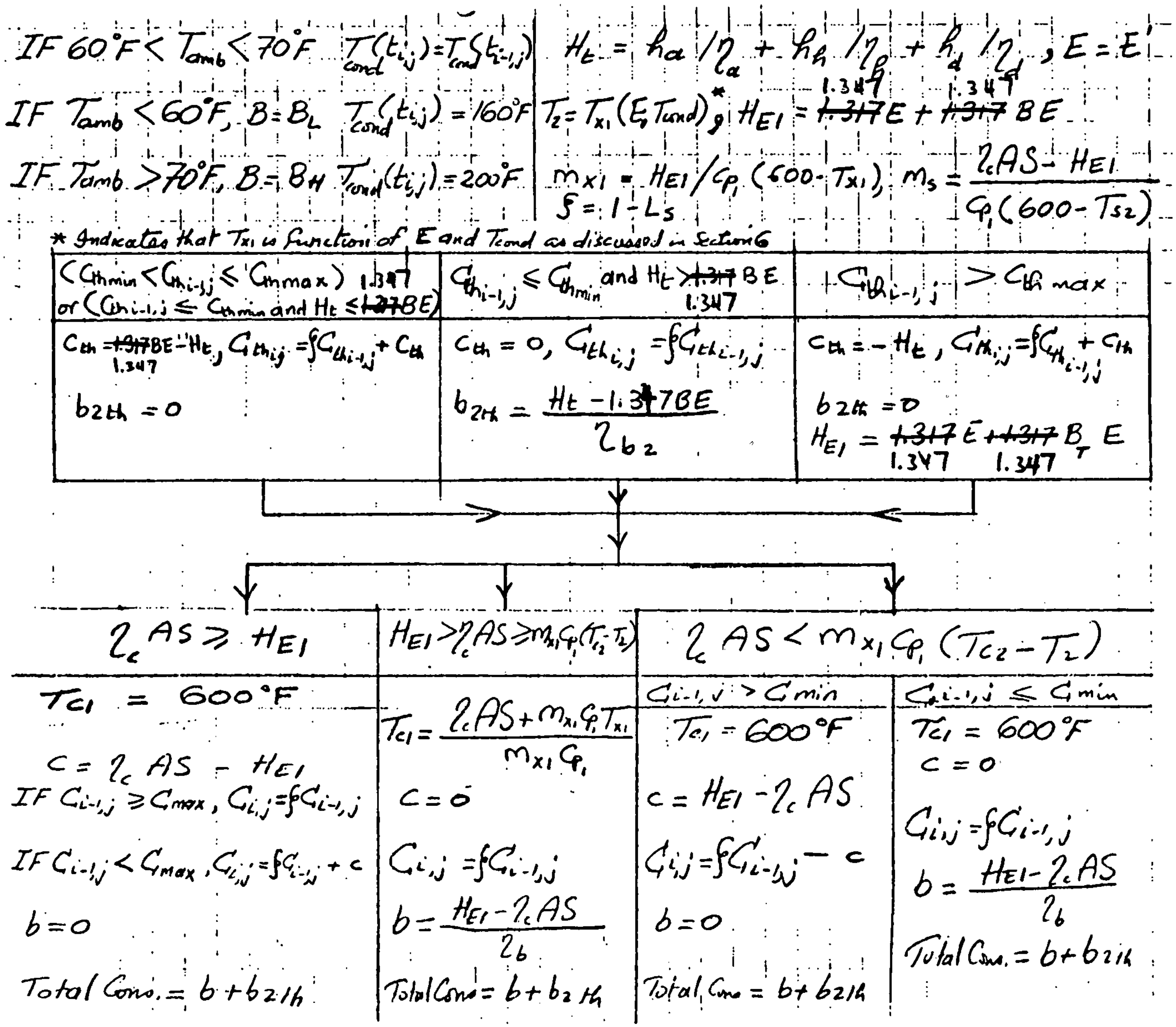

Figure E-5. HIGH-TEMPERATURE STES CONCEPTUAL DESIGN — NO PURCHASED POWER

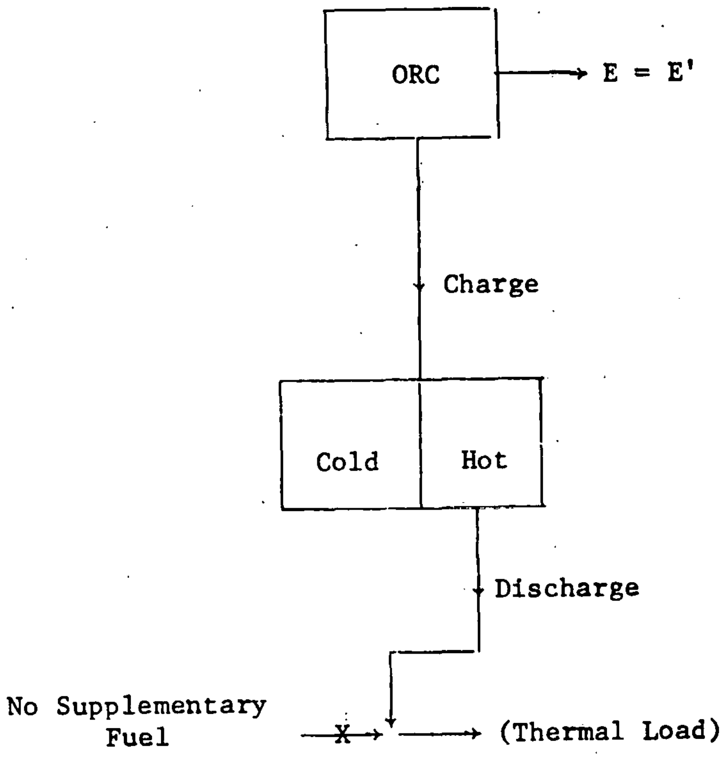

Figure E-6. LTS BELOW MAXIMUM CAPACITY

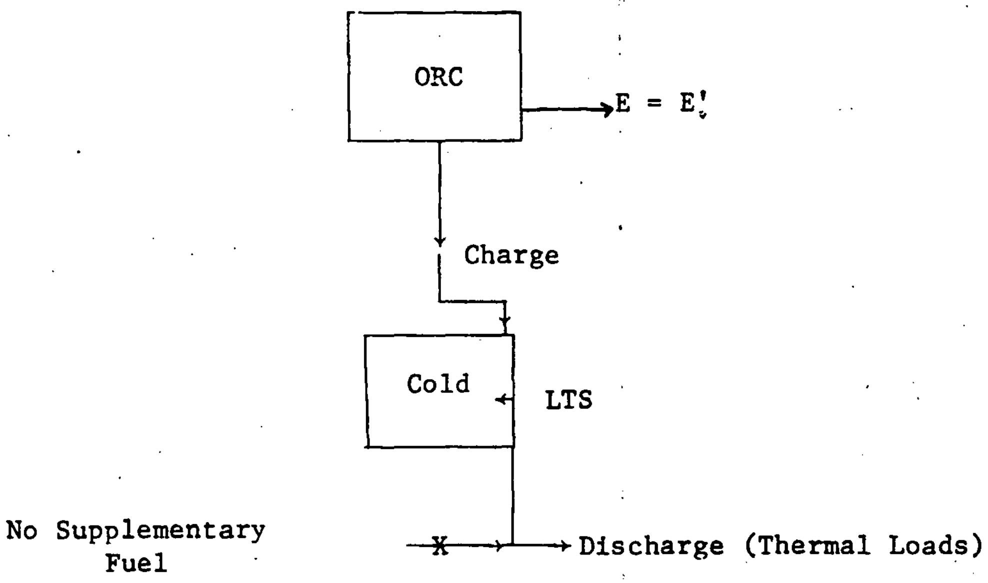

Figure E-7. LTS EMPTY, REJECTED HEAT EXCEEDS LOADS

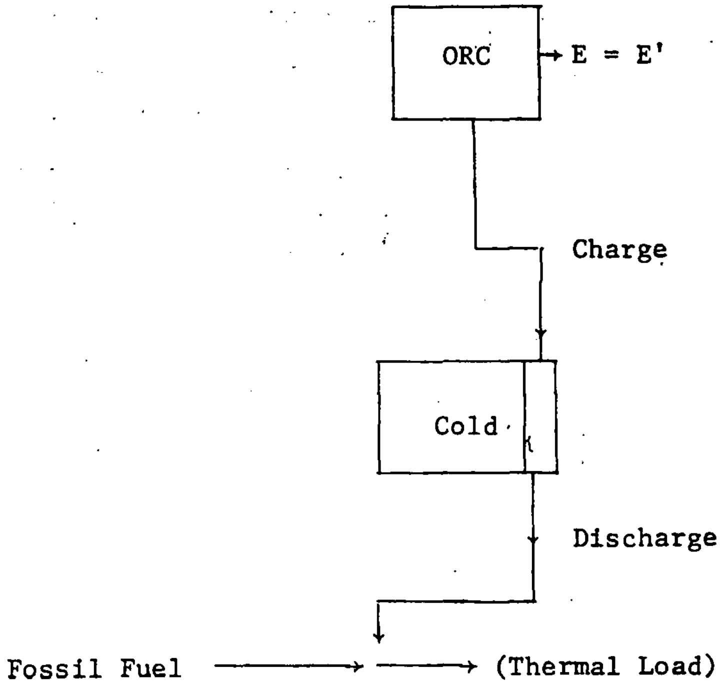

Figure E-8. LTS EMPTY, LOADS EXCEEDS REJECTED HEAT

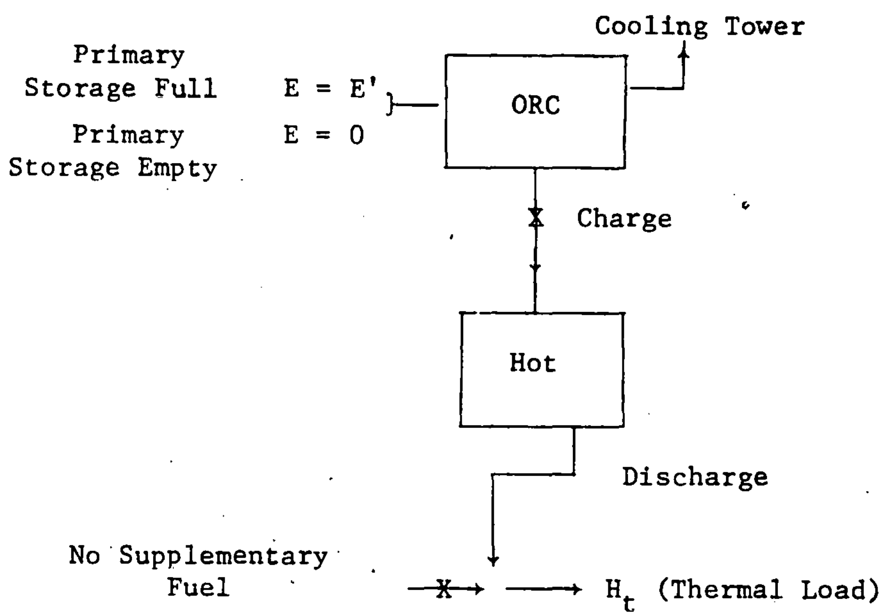

Figure E-9. FULL LTS CAPACITY

constant while the primary supply and return temperatures vary with the load. A temperature control valve maintains a constant temperature for the supply water in the secondary circuit as prescribed by the service requirements. The secondary circuit pump maintains a constant flow rate for the water entering the service equipment. The flow rate and temperature control in the secondary loop is independent of flow conditions in the primary loop. The value of M_x, as shown in Figure E-10, varies with the load in order to maintain the constant supply temperature in the secondary loop. However, the flow rate M_s of the water from the primary supply does not vary with the load. The effect of a load variation is to increase the return temperature above the design value as the load drops from its maximum value.

The control of the primary cycle operation in the high-temperature ORC design is different from that of the low-temperature ORC design in that the value of T_{X1} is no longer constant. Here, we keep the turbine supply temperature constant at 550°F. The value of T_{X1} (see Table 44) varies not only with the loads but also with the condenser pressure, as discussed in Section 4.7.

ORC Performance

Figures E-11, E-12, and E-13 give heat input, heat rejection, and toluene mass flow, respectively, as a function of the condenser pressure (temperature) and the shaft horsepower.* The regenerator effectiveness is 0.90 for these data. These curves, together with an equation based upon the turbine inlet conditions, can also be used to determine the toluene temperature at the vaporizer inlet.

Design data have been determined for an ORC with the following design point conditions.

Rating:	100 kWe
Condenser Temperature:	200°F
Working Fluid:	Toluene
Heat Source:	Therminol 66 at 600°F

Design Conditions —

Turbine Inlet:	200 psia, 550°F
Qin:	2.37×10^6 Btu/hr
Qrej:	1.91×10^6 Btu/hr
$m_{toluene}$:	11,350 lb m/hr
$T_{vaporizer}$:	370°F

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* Q = heat.
SHP = shaft horsepower.
P_{cond} = condenser pressure.

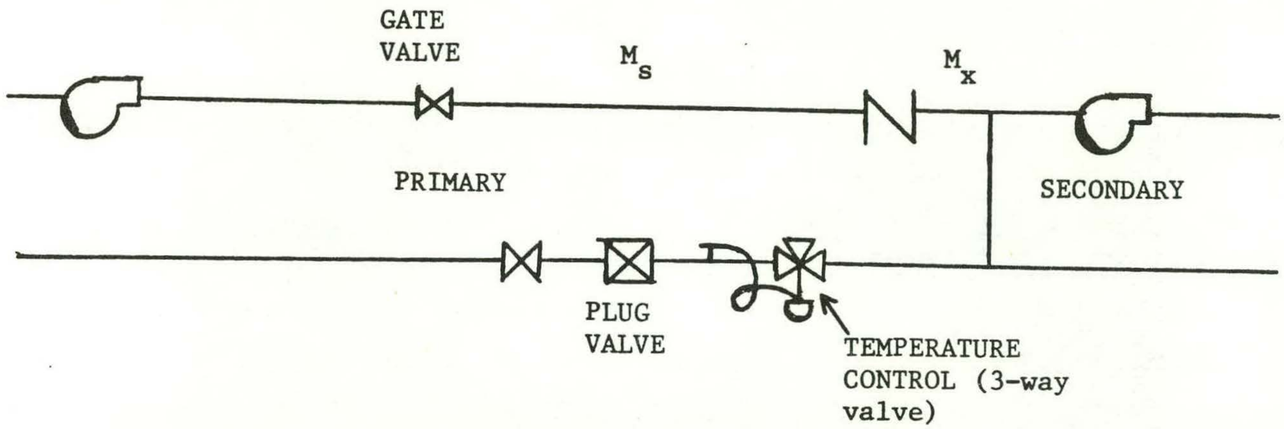

Figure E-10. PRIMARY/SECONDARY PUMPING

The following parasitics were assumed in the design case:

η Gearbox:	0.96
η Generator:	0.90
Solar Parasitics:	7% of heat engine output
PCS Parasitics:	6.36 kW

Figures E-11, E-12, and E-13 provide data for this design over a range of 40 kWe to 100 kWe. Condenser temperatures of 110°, 160°, 200°, and 220°F correspond to the dimensionless pressures of 0.153, 0.470, 1.0, and 1.407, respectively. For these turbine inlet conditions, the vaporizer inlet temperature of the toluene can be determined for off-design operation by the following equation.

$$T = 460.0 - (Q_{in}/m_{toluene} - 157)/0.575$$

Summary of ORC-Based Conceptual Design Characteristics

Table E-1 summarizes the sizes and performance characteristics of components (except collectors) used in the low- and high-temperature ORC STES conceptual designs.

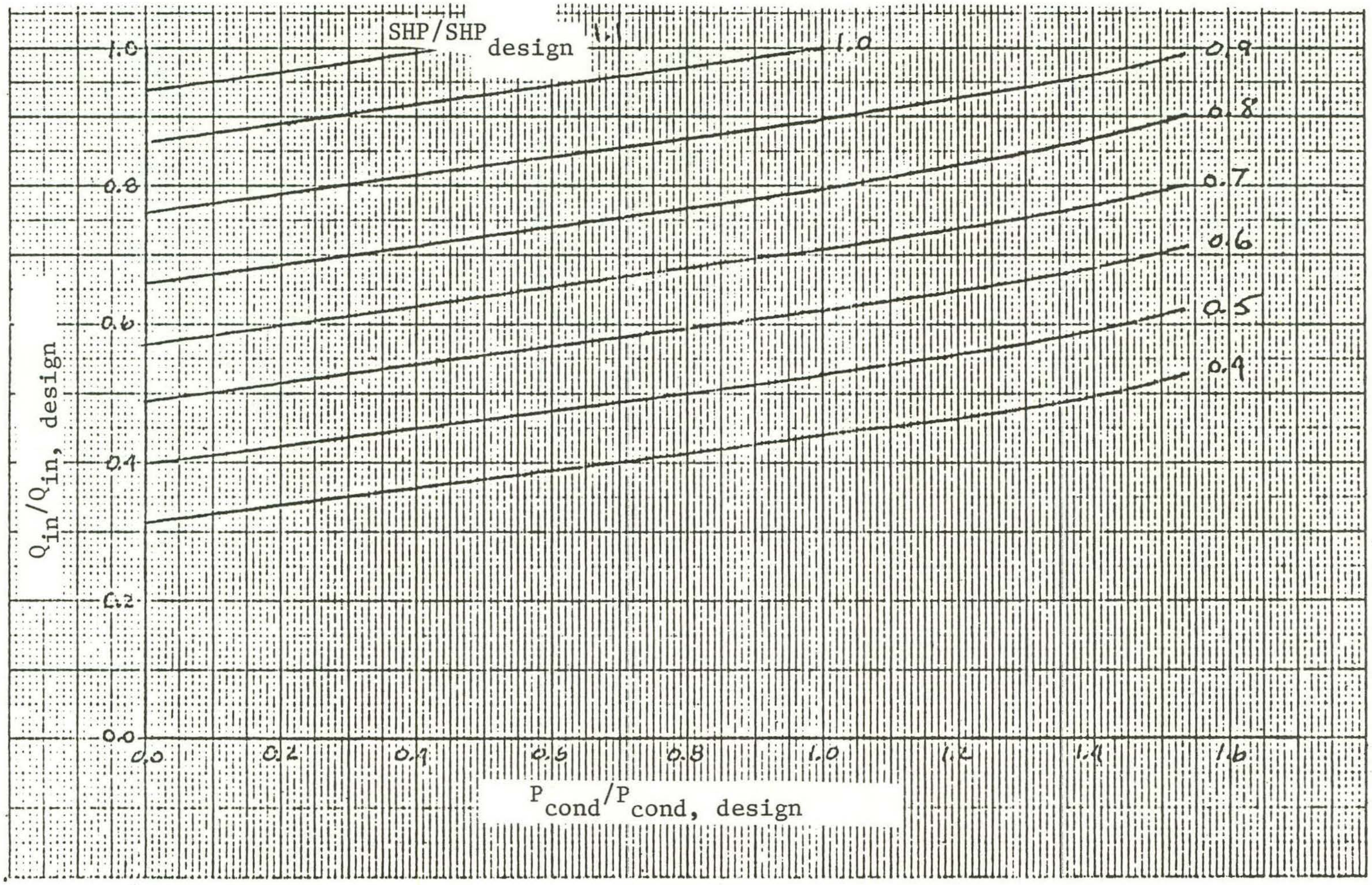

Figure E-11. HEAT INPUT

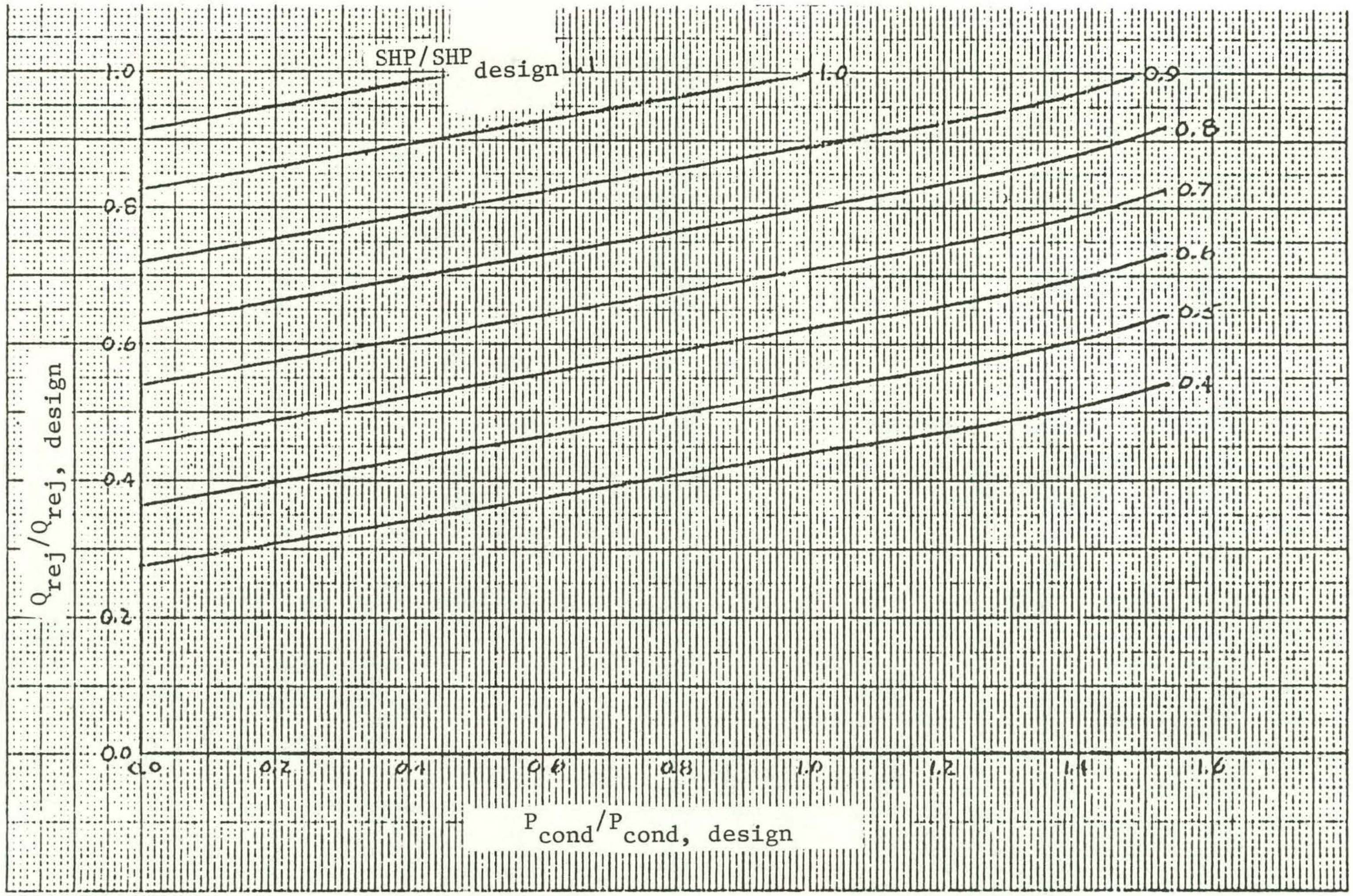

Figure E-12. HEAT REJECTION

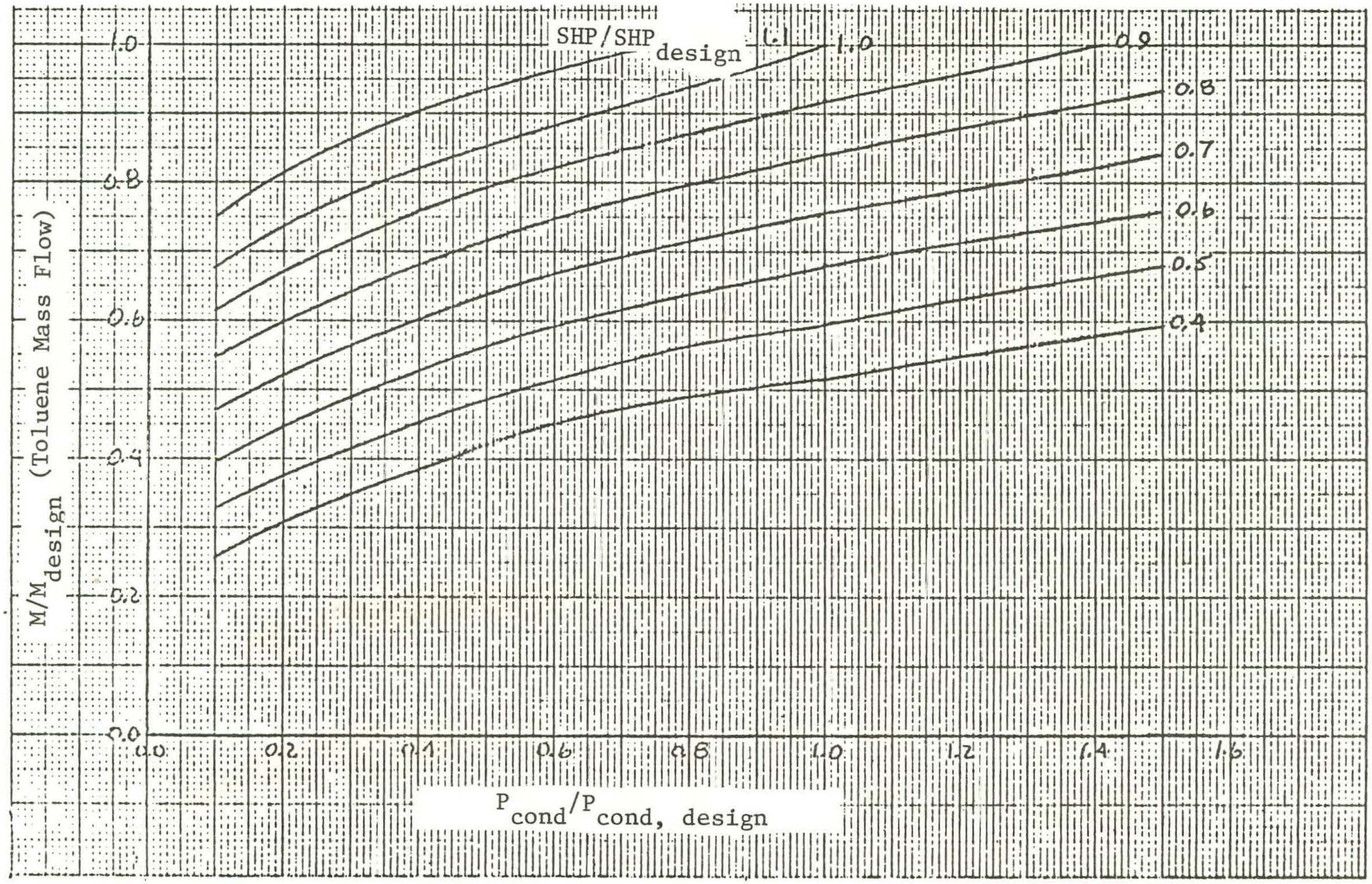

Figure E-13. TOLUENE MASS FLOW

Table E-1. SUMMARY OF ORC STES TECHNICAL CHARACTERISTICS.

Component	Size	Performance
Pipefield	Not applicable	Definition = heat delivered from collectors to storage/ collected solar energy SFD* - 0.72 @ 600°F, 0.85 @ 300°F Townhouse , Low-Rise - 0.94 @ 600°F, 0.98 @ 300°F
ORC System	100 kW net output	Overall efficiency $\frac{\text{net kW output (to site)}}{\text{thermal energy input (to heat exchanger}}$ Average = 15.8% Range = 11.3% to 18.1% High-temperature
Absorption Chiller	100 tons	COP = 0.6
Low-Temperature Storage	4×10^6 Btu	Negligible loss for high-temperature system. For low-temperature system, loss rate model comparable to that for high-temperature storage.
High-Temperature Storage	5 to 12×10^6 Btu	Loss = $Q_i = 0.21 \left(\frac{C_{max}}{C_{p1} L_1 (600 - T_{s2})} \right)^{2/3}$ $\left[(600 - T_{s2}) \frac{C'_{i-1,j}}{C_{max}} + (T_{s2} - 70) \right]$ Negligible when full.

* Single-Family Detached.

Determination of Electrical Loads — Thermal Systems

In the energy requirements effort, we calculated the base electrical loads in kilowatts on an hourly basis. We also calculated the direct process loads (cooking loads) in Btu/hr on an hourly basis. The total electrical loads in kW, on an hourly basis, are larger than the sum of the base electrical load and the kW equivalent of the direct process loads. In this section, we identify the loads that sum up to the total electrical loads. We also evaluate these loads and determine the total loads for all the structures in the various regions.

Calculations

The total electrical load in kW is composed of the following:

- Base electrical load (kW)
- Cooking load (kW; converted to kW from Btu/hr)
- Clothes dryer loads (kW)
- HVAC auxiliary loads:

1. Absorption chiller
2. Cooling tower
3. Hot water and chilled water pumps
4. Corridor supply and exhaust fans
5. Fan coil units.

- Base Electrical Load. The base electrical load has been calculated as part of Energy Requirements. It is given on an hourly basis as:

Base electrical load = $L_{base}(t_{ij})$ (kW) [From Energy Requirements tape]

- Cooking Load. The cooking load is also given in the Energy Requirements output on an hourly basis. The units are given in Btu/hr; therefore, we must convert the output from Btu/hr to kW by using a multiplication factor as follows:

Cooking electrical load = $[0.000293\ L_{cook}(t_{ij})]$(kW) [From Energy Requirements tape]

- Clothes Dryer Loads. The dryer load should be added and it is expressed as follows:

$$\text{Dryer load} = 0.2\ L_{base}\ (t_{ij})$$

Note that the dryer load is 20% of the base electrical load and, for simplicity, it has been assumed to have the same profile.

- HVAC Auxiliary Loads.

1. Absorption Chiller: The electrical consumption by the absorption chiller depends upon the number of cooling hours and on the design tons. The cooling load on an hourly basis is expressed by —

   Cooling load = $h_a\ (t_{ij})$ [From Energy Requirements tape]

   Consult Table E-2 to find what to add to take care of the chiller load parasitics.

Table E-2. ABSORPTION CHILLER LOAD (Auxiliary)

Single-Family	0.3 kW/dwelling unit	ha $(t_{ij}) > 0$
	0.0 kW/dwelling unit	ha $(t_{ij}) = 0$
Townhouse	0.3 kW/dwelling unit	ha $(t_{ij}) > 0$
	0.0 kW/dwelling unit	ha $(t_{ij}) = 0$
Low-Rise	6 kW/total	ha $(t_{ij}) > 0$
	0 kW/total	ha $(t_{ij}) = 0$
High-Rise	30 kW/total	ha $(t_{ij}) > 0$
	0 kW/total	ha $(t_{ij}) = 0$

2. <u>Cooling Tower</u>: The cooling tower load is a function of the cooling load and is expressed by —

   Cooling tower load: 0.05 kW/tons output

   Cooling tower load = 0.05 * ton output (kW)

   Since ha(t_{ij}) is given in Btu/hr, the cooling tower auxiliary electrical load is given by —

   $$\text{Cooling tower load} = \frac{0.05 \text{ ha } (t_{ij})}{12{,}000} \text{ kW}$$

3. <u>Hot Water and Chilled Water Pumps</u>: These are continuous loads and are expressed by —

Single-Family:	0.2 kW cont.
Townhouse:	0.2 kW cont.
Low-Rise:	3.1 kW cont.
High-Rise:	18.0 kW cont.

4. <u>Corridor Supply and Exhaust Fans</u>: This is only applicable to the high-rise building. This load is expressed by —

   Corridor fans: 15 kW

5. <u>Fan Coil Units</u>: The auxiliary loads due to the fan coil units are functions of the outside temperature and are given in Table E-3. Therefore, knowing the ambient temperature, one can find the auxiliary electrical load of the fan coil units using Table E-3. This load is indicated by —

   $$L_{\text{fan coil}} (t_{ij})$$

6. <u>Total Electrical Load</u>: $[E' (t_{ij})]$ (All in kW)

Table E-3. FAN COIL UNITS AUXILIARY LOADS

Temperature,* °F	Single-Family	Townhouse	Low-Rise	High-Rise
	kW			
0	0.44	0.44	8.0	59
8	0.41	0.41	7.4	55
16	0.36	0.36	6.5	49
24	0.31	0.31	5.6	42
32	0.23	0.23	4.1	31
40	0.20	0.20	3.6	27
48	0.18	0.18	3.2	24
56	0.15	0.15	2.7	20
64	0.13	0.13	2.3	18
72	0.08	0.08	1.4	11
80	0.20	0.20	3.6	27
88	0.32	0.32	5.8	43
96	0.41	0.41	7.4	55
104	0.44	0.44	7.9	59

* From weather tape.

Single-Family-Detached and Townhouse

- $ha(t_{ij})>0$

$$E'(t_{ij}) = L_{base}(t_{ij}) + 0.00293L_{cooking}(t_{ij}) + 0.2L_{base}(t_{ij}) + 0.3 + \frac{0.05ha(t_{ij})}{12{,}000} + 0.2 + L_{fan\text{-}coil}(t_{ij})$$

or, $$E'(t_{ij}) = 1.2L_{base}(t_{ij}) + 0.000293L_{cooking}(t_{ij}) + 0.5 + \frac{0.05ha(t_{ij})}{12{,}000} + L_{fan\text{-}coil}(t_{ij})$$

- $ha(t_{ij}) = 0$

$$E'(t_{ij}) = 1.2L_{base}(t_{ij}) + 0.00293L_{cooking}(t_{ij}) + 0.2 + L_{fan\text{-}coil}(t_{ij})$$

Low-Rise Apartment

- $\underline{ha(t_{ij})>0}$

$$E'(t_{ij}) = 1.2L_{base}(t_{ij}) + 0.000293L_{cooking}(t_{ij}) + 9.1 + \frac{0.05ha(t_{ij})}{12,000} + L_{fan\text{-}coil}(t_{ij})$$

- $\underline{ha(t_{ij}) = 0}$

$$E'(t_{ij}) = 1.2L_{base}(t_{ij}) + 0.000293L_{cooking}(t_{ij}) = 3.1 + L_{fan\text{-}coil}(t_{ij})$$

High-Rise Apartment

- $\underline{ha(t_{ij})>0}$

$$E'(t_{ij}) = 1.2L_{base}(t_{ij}) = 0.000293L_{cooking}(t_{ij}) + 48 + 15 + \frac{0.05ha(t_{ij})}{12,000} + L_{fan\text{-}coil}(t_{ij})$$

- $\underline{ha(t_{ij}) = 0}$

$$E'(t_{ij}) = 1.2L_{base}(t_{ij}) + 0.000293L_{cooking}(t_{ij}) + 18 + 15 + L_{fan\text{-}coil}(t_{ij})$$