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Conceptual Design Study for the Application of a Solar Total Energy System at the North Lake Campus, Dallas County Community College District

Duane E. Randall

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CONCEPTUAL DESIGN STUDY FOR THE APPLICATION OF A SOLAR TOTAL ENERGY SYSTEM AT THE NORTH LAKE CAMPUS, DALLAS COUNTY COMMUNITY COLLEGE DISTRICT

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ABSTRACT

A proposal for the design and installation of an experimental solar total energy system at the new North Lake Campus of the Dallas County Community College District was submitted to ERDA. The ERDA Division of Solar Energy authorized Sandia Laboratories, with the assistance of the DCCCD, Envirodynamics, Inc., and Stearns-Roger, Inc., to conduct a conceptual design study of a solar total energy system for the North Lake facility. This report presents the results of this conceptual design study.

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CONCEPTUAL DESIGN STUDY FOR THE APPLICATION OF A SOLAR TOTAL ENERGY SYSTEM AT THE NORTH LAKE CAMPUS, DALLAS COUNTY COMMUNITY COLLEGE DISTRICT

Introduction

The Dallas County Community College District (DCCCD), through its architect for the North Lake Campus, Envirodynamics, Incorporated, had proposed the new North Lake Campus as a site for the installation and operation of an experimental solar total energy system. This new college campus facility offered a number of features which made it an attractive candidate for an early experimental demonstration of the solar total energy concept. During 1975, Sandia Laboratories, in cooperation with Envirodynamics, Inc., prepared and submitted to the Energy Research and Development Administration (ERDA) a proposal for a program undertaking the design and installation of an experimental solar total energy facility at the North Lake Campus of the DCCCD. In October 1975, the ERDA Division of Solar Energy authorized Sandia Laboratories to proceed with a conceptual design study of a solar total energy system for the North Lake Campus facility.

The North Lake Campus represents the sixth in a series of seven campuses being constructed in the Dallas metropolitan area by the DCCCD. Construction was initiated during 1975, and initial occupancy is scheduled for the fall of 1977. The initial construction phase planned for North Lake will provide approximately 23, 250 square meters (250, 000 square feet) of building area on a 112 hectare (276 acre) site northwest of Dallas adjacent to the Dallas/Ft. Worth Regional Airport. This conceptual design study was supported jointly by the ERDA Division of Solar Energy and the Dallas County Community College District.

Project Organization

Program Support

In October 1975, the ERDA Division of Solar Energy granted Sandia Laboratories authorization to undertake a conceptual design study of a solar total energy system for the North Lake Campus facility of the DCCCD. The conceptual design phase of the program is sponsored jointly by ERDA and the DCCCD. Program support is split, with 5 percent of the funds provided by the DCCCD and 95 percent attributable to ERDA funding. The total program support level for the conceptual design phase is $98, 000.

Program Participation

The conceptual design study was conducted as a group endeavor. Two private firms, Envirodynamics, Incorporated, and Stearns-Roger, Incorporated, contracted with Sandia Laboratories for parts of the study. Envirodynamics, Inc., as the principle architect for the North Lake Campus, was brought under contract to provide load profile data, integration of the solar thermal energy system with the existing thermal distribution system and to provide general architectural support. The Envirodynamics report to Sandia is reproduced in Appendix A.

Stearns-Roger was responsible for defining the thermoelectric power conversion cycle, tie-ins between the solar electric power generation and the utility electric power supply, and data on the availability and cost of power generation system hardware. The Stearns-Roger report to Sandia is reproduced in Appendix B. Responsibility for overall system definition, performance, and cost together with collector configuration and collector field definition remained with Sandia Laboratories.

System Alternatives

At the outset of the conceptual design study, a review of possible system alternatives was conducted. The alternatives considered were limited to those systems utilizing hardware either readily available or whose operational principles are fully understood since the campus facility afforded the opportunity for the early installation and operation of a large scale solar experiment. An attempt was made to avoid those system alternatives which rely on components requiring long term development cycles.

This review resulted in the definition of three system options selected for further evaluation and comparison of performance. These three solar energy system options are described below.

Option I: Cascaded Solar Total Energy System -- Option I provides an electric power generation capability equivalent to the peak requirement defined by the lighting and miscellaneous power load plus the space cooling load. Space cooling is accomplished with two existing electrically-driven, vapor compression, water chilling machines. Solar energy collection capability is based upon the utilization of parabolic trough focusing collectors. A high temperature energy storage capability is provided based upon sensible heat storage of the heat transfer fluid utilized in the collectors. Thermoelectric power conversion is based upon the Rankine cycle. Two alternates, A and B, are considered under Option I for meeting the thermal load requirements, which consist of space heating and domestic hot water. Under Alternate A, the power cycle condenser operation is adjusted for 361 K (190°F). Waste heat recovery from the condenser is utilized for the thermal load requirements.

In Alternate B, condenser operation is adjusted for the lowest practicable temperature determined by the local ambient wet bulb temperature to maximize the thermoelectric conversion cycle efficiency. Thermal load requirements are provided through an auxiliary parabolic trough focusing collector system operating at the 361 K (190°F) temperature required by the campus thermal distribution system.

Option II: Noncascaded Solar Total Energy System -- Option II provides an electric power generation capability equivalent to the peak lighting and miscellaneous power load. Energy collection is based upon parabolic trough focusing collector performance. Thermoelectric power conversion is based upon the Rankine cycle, with condenser operation adjusted to the minimum practicable temperature allowed by the local ambient wet bulb temperature. High temperature sensible heat energy storage as in Option I is provided.

The thermal load requirements of Option II consist of space cooling, space heating, and hot water requirements. Cooling is accomplished utilizing absorption type chillers. Energy collection is based upon the performance capability of nonfocusing collectors. Provision for low temperature sensible heat storage is included in the system.

Option III: Building Heating and Cooling System -- Option III provides an energy collection capability to meet the thermal load, which consists of space cooling, space heating, and hot water only. No electric power generation capacity is provided. Space cooling is based upon the absorption type chilling equipment. Energy collection capability is based upon parabolic trough focusing collector performance. Low temperature sensible heat storage capability is included in the system.

A graphical illustration of these three options is presented in Figures 1 through 3.

Subsequently, a decision was made to also evaluate the application of the tower mounted central receiver concept to the North Lake Campus; Figure 4 illustrates the central receiver system concept.

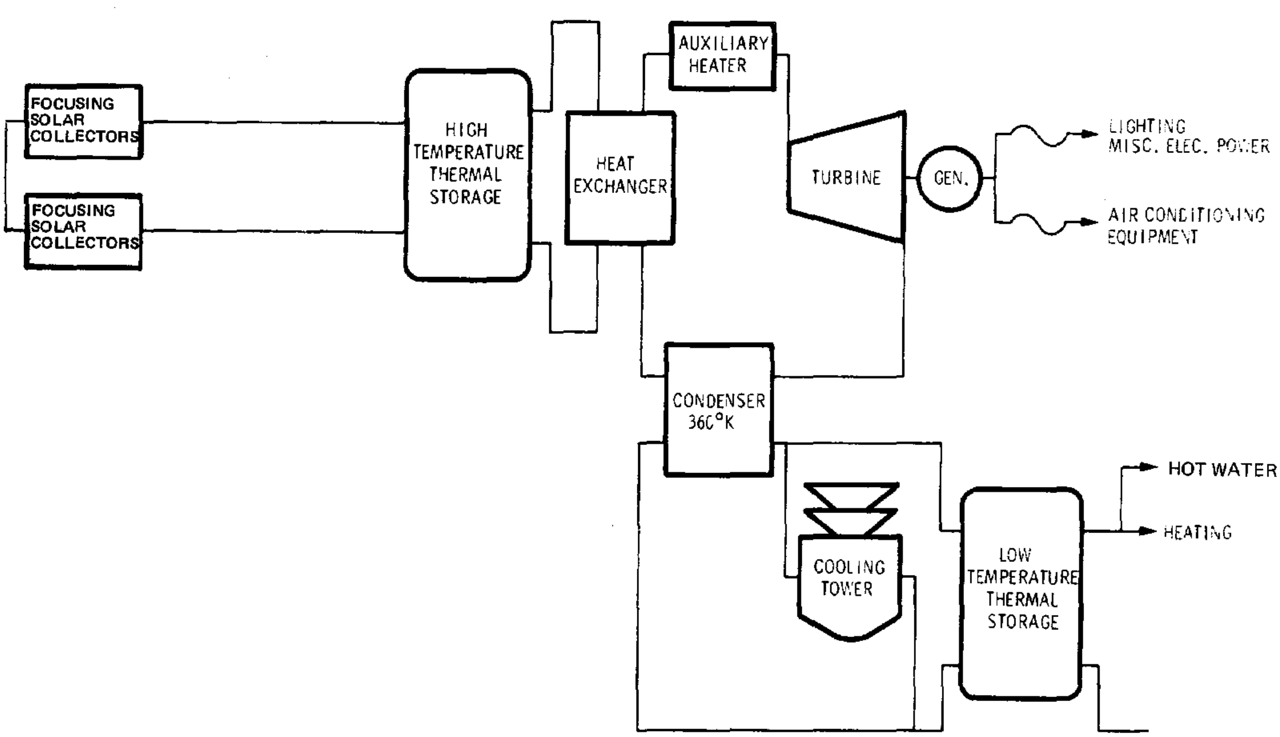


Figure 1. Option I: Cascaded Solar Total Energy System

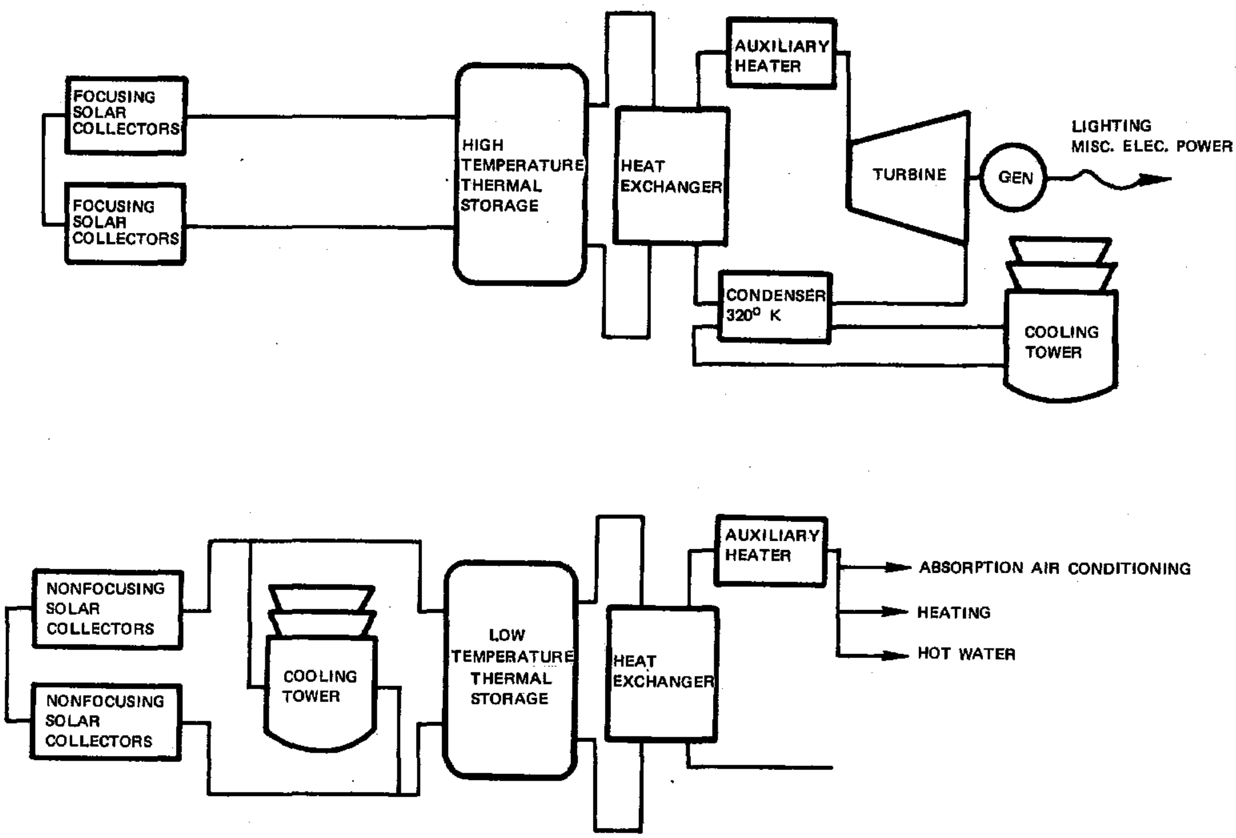


Figure 2. Option II: Noncascaded Solar Total Energy System

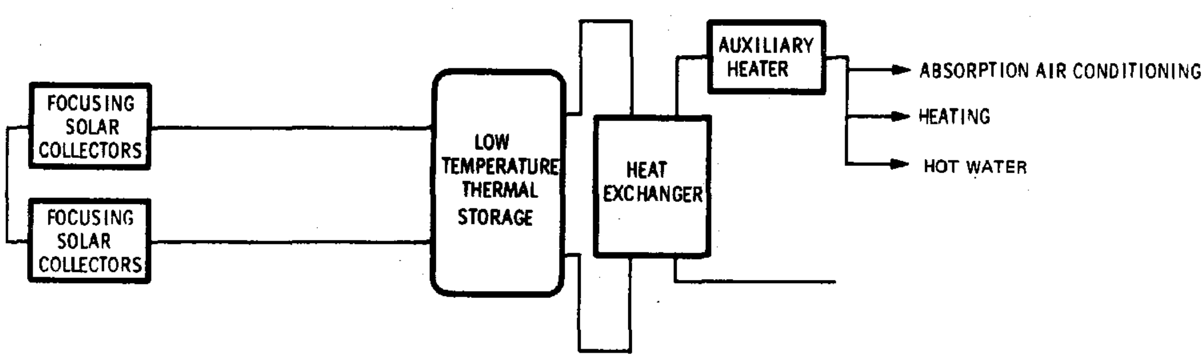


Figure 3. Option III: Building Heating and Cooling System

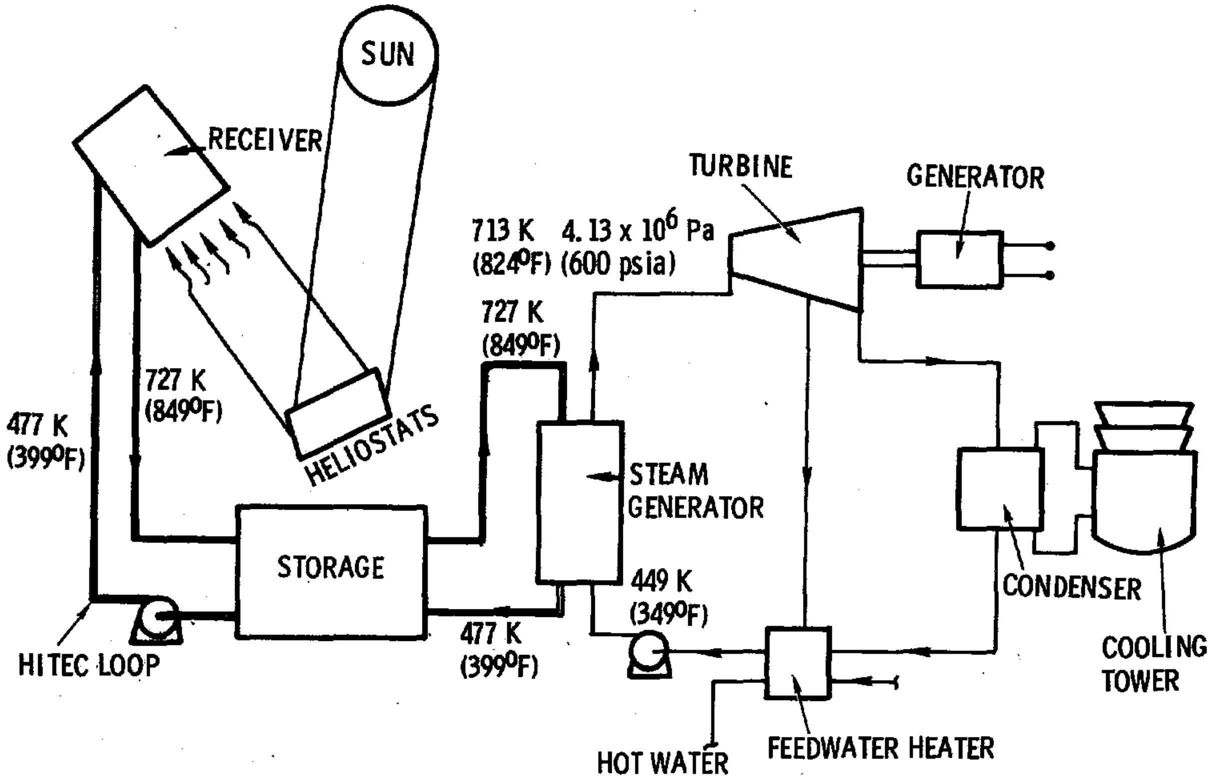


Figure 4. Central Receiver Hitec - Water/Steam Schematic

Campus Energy Requirements

An estimate of the energy requirements for the North Lake Campus was provided by Envirodynamics, Incorporated (Table I). This estimate was based upon monthly consumption data for total electric power and natural gas usage from three other comparable campuses in the DCCCD system. However, the estimate provides no information with respect to daily load profiles nor to peak loads incurred by the campus system. In order to gain some insight into the campus peak loads and load profiles, an analytical heat balance analysis for all campus buildings was carried out. This theoretical calculation, a rather sophisticated computer program known as APEC Heating-Cooling Calculation Program, provides an hourly estimate of the building's thermal energy requirements based on weather parameters such as ambient temperature and wind speed together with data characterizing the building's heat gains and losses. This analysis was carried out for twelve twenty-four hour periods; one day was selected for each month. Weather inputs used in the analysis were taken from the recorded 1962 Ft. Worth weather records for the days selected. For the months from October through February, the days were chosen on the basis of the lowest average daily temperature for the respective month. Conversely, for the months from April through August, days having the highest average daily temperature for the month were chosen. For March and September, the days were selected on the basis of most nearly approximating the monthly average temperature. This procedure was expected to provide a conservative estimate of the energy requirements for heating and cooling during each of their respective peak seasons. The results of the analysis are presented in Table II. Positive values indicate a building cooling requirement, while a building heating requirement is indicated by negative values.

This analysis suggests that the cooling system peak output is slightly in excess of 3000 kW_t. It is noteworthy that a building heating requirement exists only during nonsummer months outside of usual daylight hours. A year around requirement for building cooling exists during normal daylight hours, while during the summer months the cooling requirement exists around the clock.

In order to gain some insight into the peak load and load profiles occurring in the electric lighting load and the domestic hot water thermal load, usage schedules based upon the building occupancy schedule were estimated in conjunction with the architectural personnel for the campus project. These schedules are presented in Table III.

TABLE I

Estimated North Lake Campus Energy Requirements

	Electric Power (10^3 kWhr)		Natural Gas (10^3 ft^3)	
Month	Lights and Miscellaneous Power	Air Conditioning	Building Heat	Domestic Hot Water
January	450	100	2600	600
February	450	150	2400	600
March	450	275	1200	600
April	450	400	600	600
May	450	500	300	600
June	450	550	150	600
July	450	600	0	600
August	450	550	0	600
September	450	525	0	600
October	450	450	200	600
November	450	350	600	600
December	450	245	1300	600

TABLE II

Average Hourly Heating and Cooling Rate for North Lake Campus
(kilowatts); Cooling (+), Heating (-)

Hour Ending @	January 11	February 28	March 10	April 20	May 23	June 24	July 4	August 10	September 19	October 30	November 29	December 30
0100	-1679	-1364	- 482	- 91	254	476	470	623	235	- 427	- 630	- 988
0200	-1684	-1390	- 495	- 118	235	491	457	642	215	- 428	- 652	-1015
0300	-1689	-1392	- 540	- 109	248	458	392	584	209	- 492	- 686	-1046
0400	-1715	-1394	- 572	- 129	209	438	339	534	129	- 495	- 694	-1075
0500	-1749	-1439	- 575	- 163	186	388	325	502	81	- 539	- 721	-1080
0600	- 408	- 102	802	1195	1551	1746	1711	1868	1479	780	640	253
0700	- 61	252	1327	1921	1992	2178	2058	2182	1793	1102	982	597
0800	158	751	1803	2186	2313	2474	2398	2574	2163	1189	1534	855
0900	695	1032	2003	2342	2545	2668	2656	2864	2543	1737	1879	1345
1000	870	1134	2044	2426	2664	2780	2781	2998	2747	1974	2013	1517
1100	910	1165	2155	2479	2756	2824	2851	3102	2782	2029	2065	1589
1200	929	1184	2188	2469	2800	2865	2871	3066	2853	2078	2076	1648
1300	908	1136	2114	2401	2803	2864	2836	3114	2799	2112	2006	1636
1400	741	1000	2051	2414	2748	2866	2876	3018	2698	1988	1859	1514
1500	598	925	2084	2509	2845	2912	2905	2976	2621	1897	1753	1391
1600	580	954	2133	2551	2861	2996	2984	3040	2646	1928	1730	1351
1700	476	876	2065	2445	2858	3019	2952	3034	2624	1906	1557	1180
1800	313	651	1911	2307	2804	2993	2928	2997	2571	1822	1448	1079
1900	255	542	1709	2050	2709	2862	2835	2884	2352	1636	1354	1012
2000	157	454	1591	1958	2426	2632	2560	2632	2212	1558	1281	911
2100	- 210	55	1170	1532	2020	2110	2078	2265	1791	1118	946	534
2200	- 252	- 1	1137	1436	1898	2014	1981	2163	1660	1019	959	501
2300	-1640	-1390	- 269	26	445	538	501	769	314	- 409	- 428	- 892
2400	-1630	-1324	- 493	- 89	397	532	459	686	254	- 450	- 602	- 957

TABLE III

Estimated Usage Schedules for Electric Lighting and Hot Water

	Lighting Load	Hot Water Load
Weekday Occupancy (0700-2200)	K_e^*	K_t^*
Weekday Nonoccupancy Hours	$0.10\ K_e$	$0.05\ K_t$
Saturday Occupancy (1200-2200)	$0.25\ K_e$	$0.10\ K_t$
Saturday Nonoccupancy Hours	$0.10\ K_e$	$0.05\ K_t$
Sundays and Holidays	$0.10\ K_e$	$0.05\ K_t$

$^*K_e$ = Lighting electric power requirement during weekday occupancy in kW_e.
K_t = Hot water energy requirement during weekday occupancy in kW_t.

A one-month integration of these usage schedules equated to the monthly consumption level presented in Table I established the weekday occupancy load levels (K_e and K_t) as 1232 kW_e and 519 kW_t for the electric lighting load and the domestic hot water thermal load, respectively. The resulting load profiles for electric lighting and domestic hot water loads are illustrated in Figures 5 and 6.

The estimated North Lake campus overall electric power and thermal energy load profiles for Option I are illustrated in Figures 7 and 8. The electric load data are based on the conversion of electric power input to cooling energy by the vapor compression, water chilling equipment at an assumed COP of 4.5. The analogous load profiles for Option II are presented in Figures 9 and 10. The thermal load profile appropriate for Option II is also applicable to Option III. As illustrated in Figure 10, the data are based on the thermal output required. For thermal input to an absorption type cooling device, the data assume a COP of 1. Table IV presents a summary of the various load characteristics appropriate to sizing the North Lake Campus solar energy system for Option I. The analogous data for Option II are tabulated in Table V. For Option III, the thermal load requirements are the same as presented in Table V.

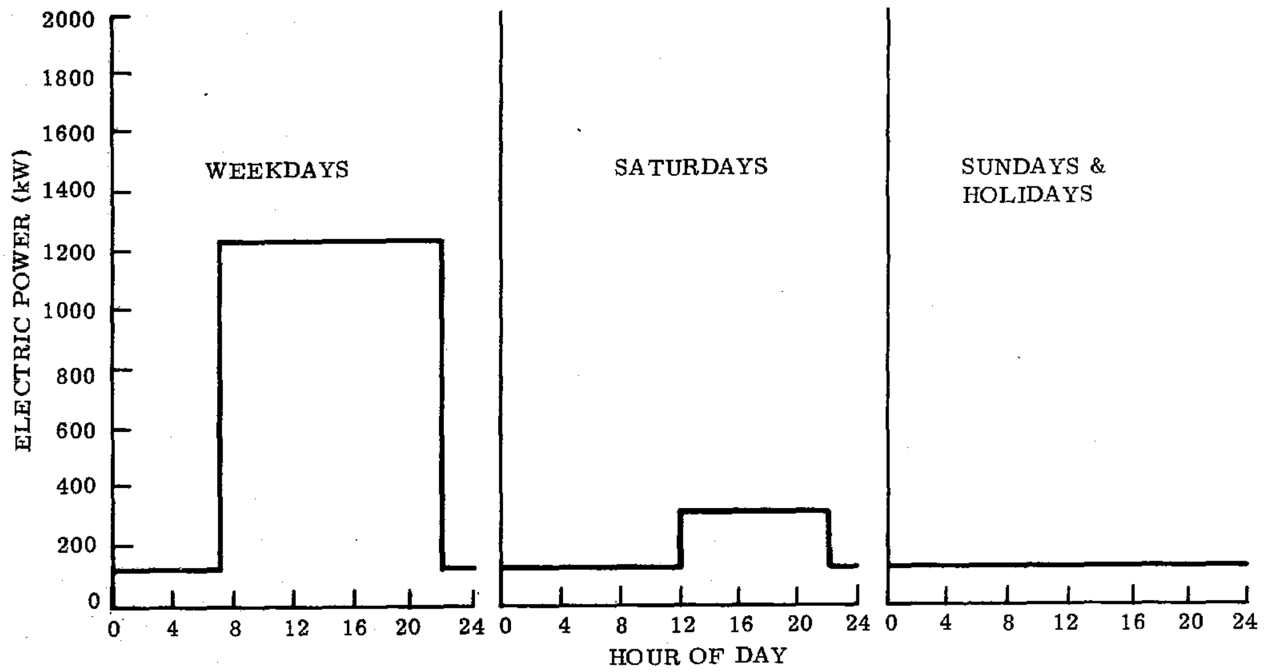


Figure 5. Estimated Load Profile, Electric Lighting

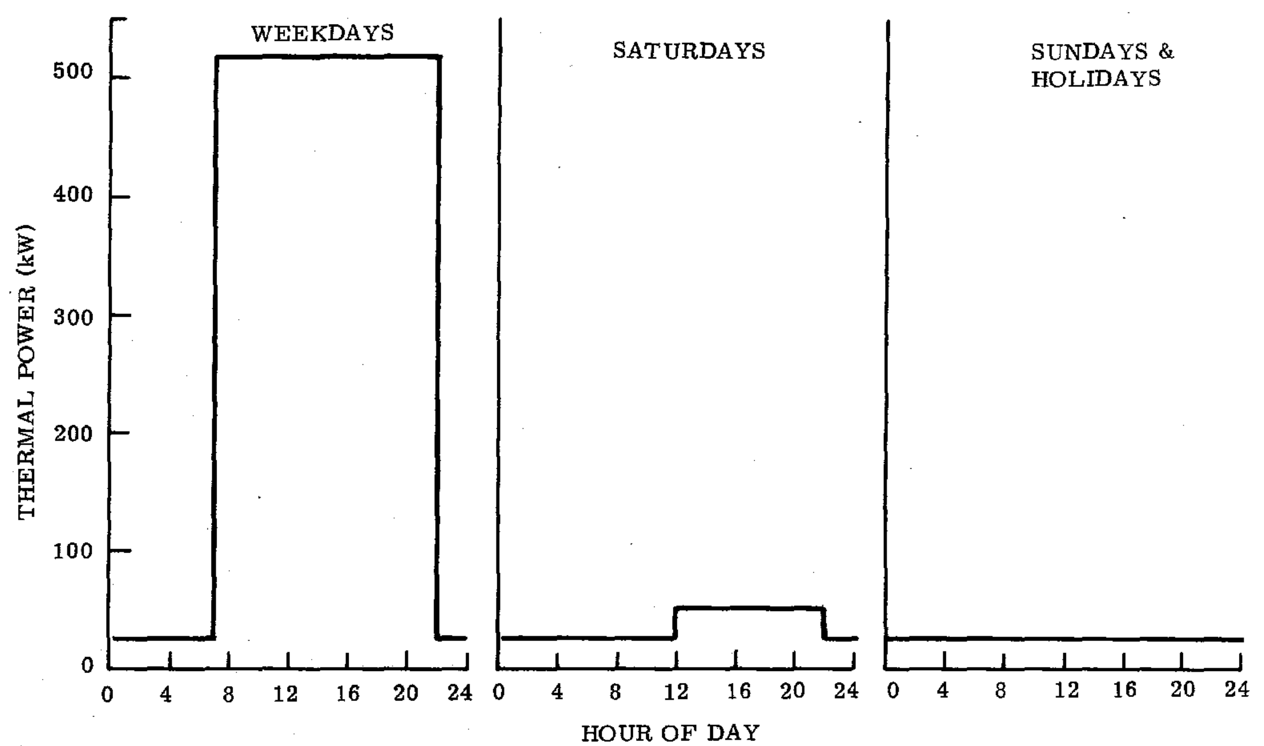


Figure 6. Estimated Load Profile, Domestic Hot Water

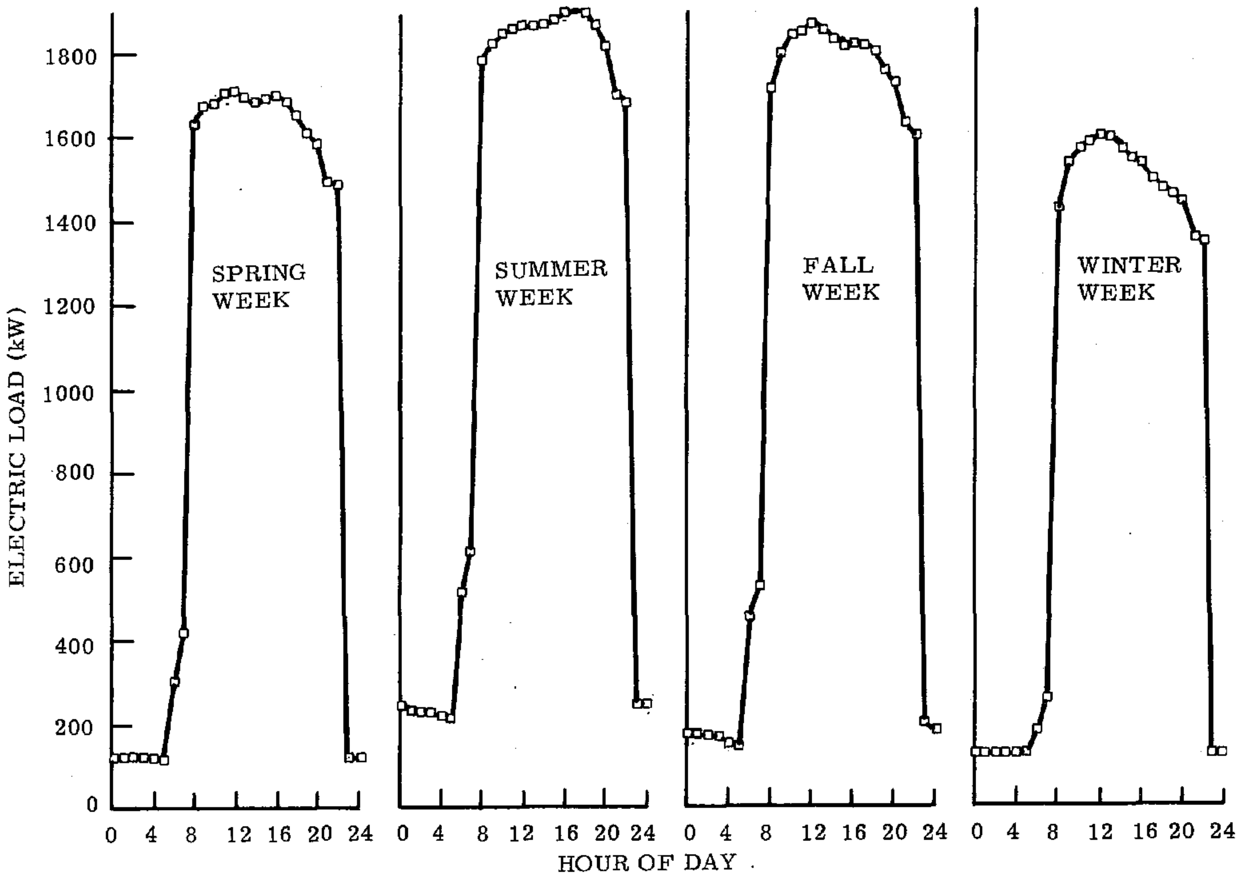


Figure 7. North Lake Campus Electric Load Profile, Option I (cooling COP = 4.5)

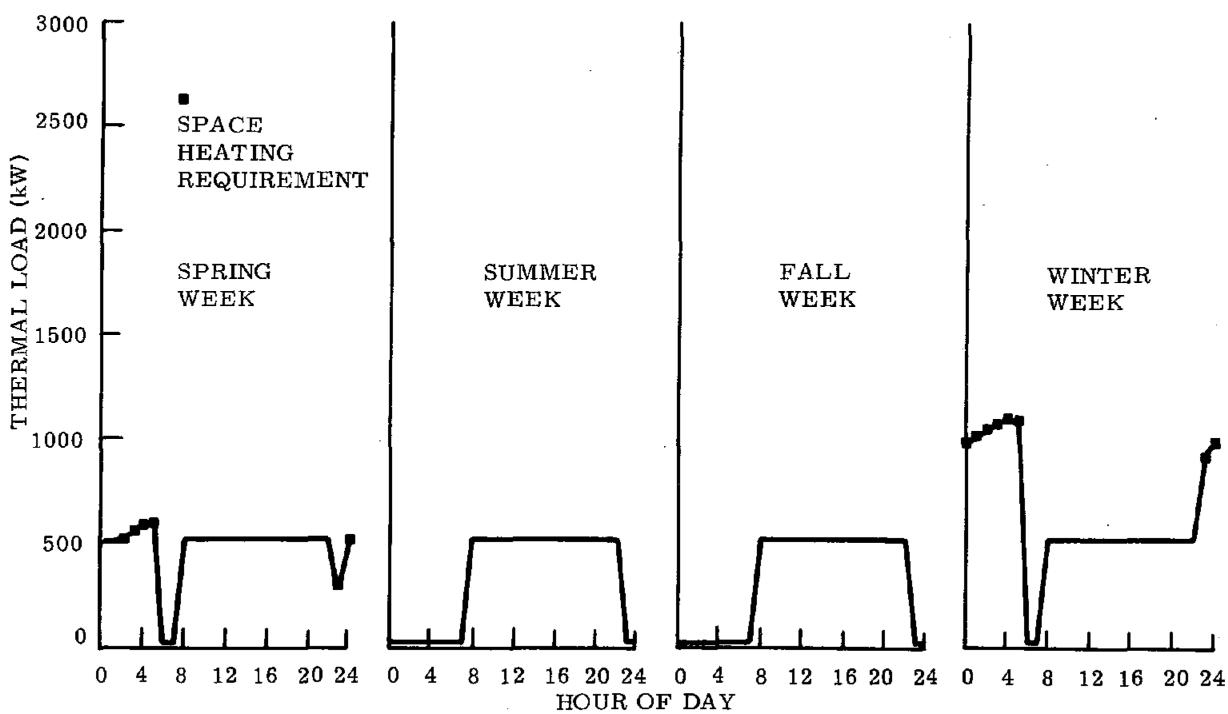


Figure 8. North Lake Campus Thermal Load Profile, Option I

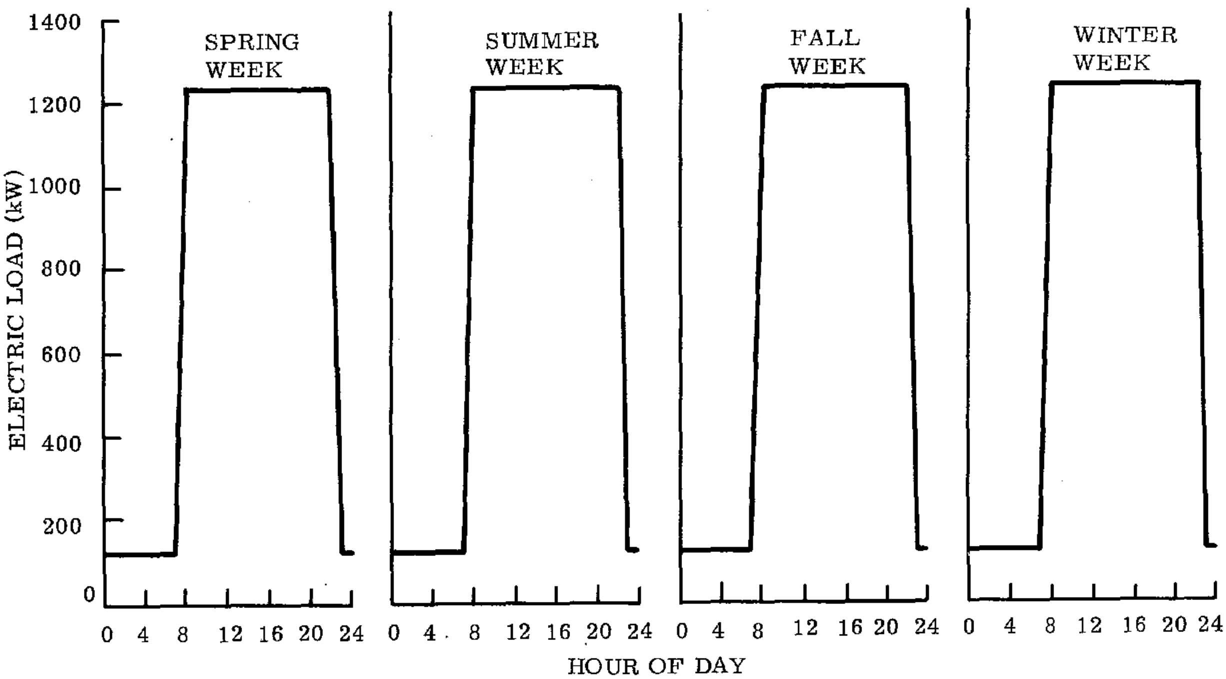


Figure 9. North Lake Campus Electric Load Profile, Option II

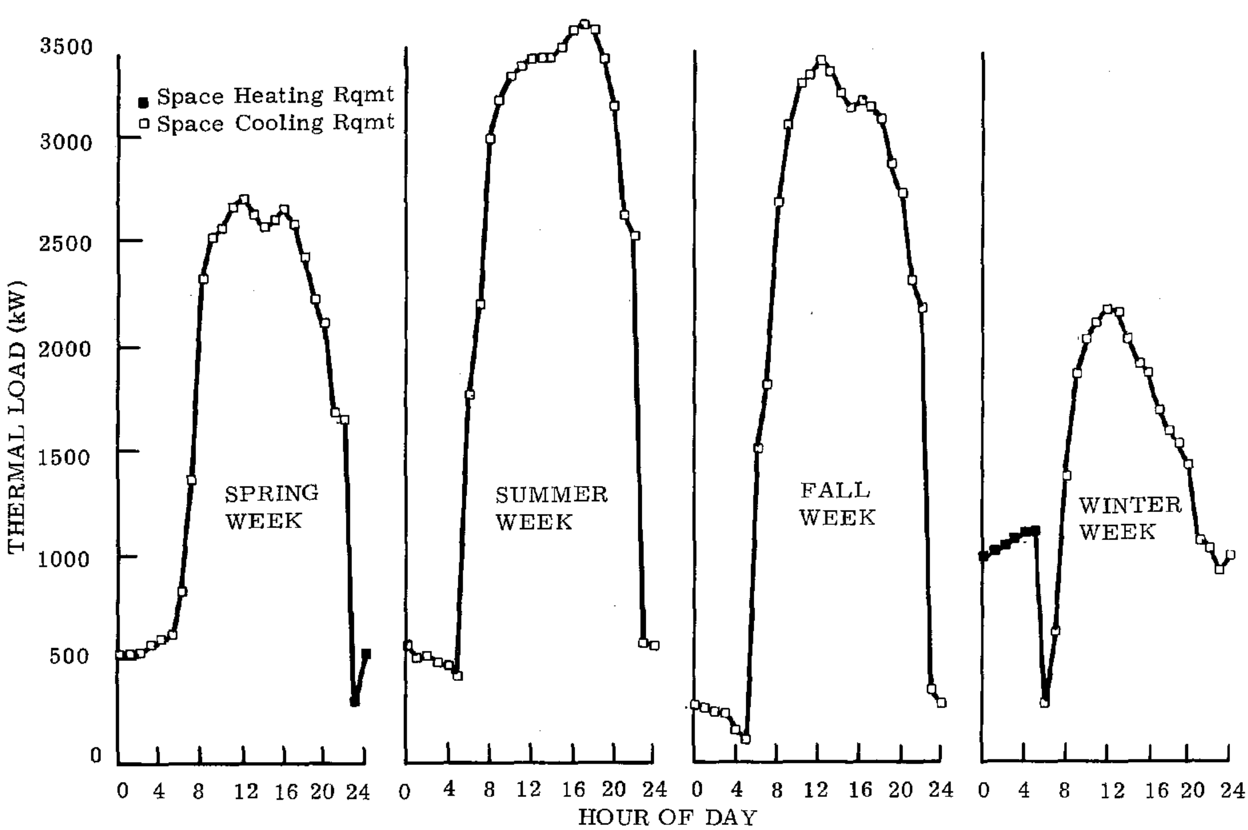


Figure 10. North Lake Campus Thermal Load Profile, Options II and III (cooling COP = 1.0)

TABLE IV

Summary of Load Characteristics, Option I
(peak loads in kW, load integrals in kW hr)

	Spring	Summer	Fall	Winter	Annual Integral
Electric Loads					
Lighting					5.4×10^6
Peak	1232	1232	1232	1232	
Daily Integral	19581	19581	19581	19581	
Space Cooling (COP = 4.5)					4.7×10^6
Peak	486@noon	671@1700	634 @ noon	366 @ noon	
Daily Integral	6730	10693	9282	4203	
Total Electric					10.1×10^6
Peak	1718 @ noon	1903 @ 1700	1866 @ noon	1598 @ noon	
Daily Integral	26311	30274	28863	23784	
Thermal Loads					
Space Heating					2.7×10^6
Peak	575 @ 0500	0	0	1080 @ 0500	
Daily Integral	3427	0	0	7054	
Hot Water					2.1×10^6
Peak	519	519	519	519	
Daily Integral	8015	8015	8015	8015	
Total Thermal					4.8×10^6
Peak	601 @ 0500	519	519	1106 @ 0500	
Daily Integral	11442	8015	8015	15069	

TABLE V

Summary of Load Characteristics, Option II

	Spring	Summer	Fall	Winter	Annual Integral
Electric Loads					
Lighting					5.4×10^6
Peak	1232	1232	1232	1232	
Daily Integral	19581	19581	19581	19581	
Total Electric					5.4×10^6
Peak	1232	1232	1232	1232	
Daily Integral	19581	19581	19581	19581	
Thermal Loads					
Space Cooling (COP = 1)					21.2×10^6
Peak	2188 @ noon	3019 @ 1700	2853 @ noon	1648 @ noon	
Daily Integral	30287	48120	41768	18912	
Space Heating					2.7×10^6
Peak	575 @ 0500	0	0	1080 @ 0500	
Daily Integral	3427	0	0	7054	
Hot Water					2.1×10^6
Peak	519	519	519	519	
Daily Integral	8015	8015	8015	8015	
Total Thermal					$26. \times 10^6$
Peak	2707 @ noon	3538 @ 1700	3372 @ noon	2167 @ noon	
Daily Integral	41729	56135	49783	33981	

Ft. Worth Insolation and Weather Data

Ft. Worth is one of some twenty-six U.S. cities for which the Weather Service has recorded total horizontal solar insolation data together with the usual weather parameters over an extended period of time. These data afford the opportunity of basing performance estimates for the North Lake Campus solar system on actual insolation data representative of the local area.

From the Ft. Worth insolation data, average daily total horizontal insolation was defined by month covering a twenty-one year time span from 1951 through 1971. From these daily averages, long term seasonal averages of the Ft. Worth total horizontal insolation were defined. From the insolation data for the 1962 calendar year, four weekly periods were selected which provide a close approximation to the long term seasonal averages. These four weekly periods are: Spring, Day Numbers 73 through 79; Summer, Day Numbers 173 through 179; Fall, Day Numbers 250 through 256; and Winter, Day Numbers 347 through 353. The direct normal solar insolation upon which focusing collector performance is based was derived for these four weekly periods utilizing a correlation relating direct normal insolation to total horizontal insolation which was developed at Sandia Laboratories.[1]

Solar Energy Collection System

General

Evaluation and comparison of the North Lake Campus solar energy system for Options, I, II, and III was based upon the performance capability of the parabolic trough collector concept and the use of Therminol 66 heat transfer fluid. These decisions were based upon the following reasoning:

1. The parabolic trough collector had attained a more advanced state of development than other linear focusing collector concepts;
2. Performance data and operational experience with this collector should be available early in the detail design phase of the campus solar system;
3. The Therminol 66 fluid offers a wide temperature capability, is readily available, and its properties are well defined; and
4. Analytical modeling tools for the performance evaluation of the parabolic trough collector configuration and heat transfer fluid were available.

The parabolic trough collector configuration offers a number of alternatives with respect to orientation and type of installation, each of which impacts collector performance and system cost. These alternatives are:

1. Trough alignment North-South on a support configuration providing two axis tracking capability, such as the Equatorial Mount or an Azimuth-Elevation Mount;

2. Trough alignment North-South with an adjustable (manually) tilt angle and a single axis tracking capability in the East-West direction;

3. Trough alignment North-South at a fixed tilt angle with a single axis tracking capability in the East-West direction; and

4. Trough alignment East-West in a horizontal orientation with a single axis tracking capability in the North-South direction.

The first alternative provides a full tracking capability and offers the maximum annual energy collection capability by allowing the collector to be pointed directly toward the sun continuously. However, this alternative would involve the greatest installed cost for the system. The second alternative offers a system exibiting only a slight reduction in the annual energy collection capability because the collector tilt angle could be adjusted to the optimum value, perhaps on a seasonal basis or somewhat oftener. This alternative offers a cost reduction roughly equivalent to the cost of providing the second axis automatic tracking capability. At the price of some further reduction in energy collection capability, the third alternative offers an additional cost saving equivalent to provision of the adjustable tilt capability. The fourth alternative is expected to offer the lowest installed cost per unit area of collector; however, this alternative also provides the lowest annual energy collection capability.

Collector Configuration Definition

To gain some insight to the comparative performance provided by the alternatives discussed above, an evaluation of tilt angle effects on the campus solar collection requirements was conducted. Both the campus energy requirements and the energy collection capability of the trough collectors vary with the season of the year. Therefore, the comparative evaluation was conducted on the basis of the total collector field area required to meet the campus load. The load requirements were based upon the electrical power generation requirements for Options I and II. A thermoelectric conversion efficiency of 20 percent was arbitrarily assumed. Two different field sizing criteria were considered: (1) a collector field sized to meet the peak load only; and (2) a collector-storage system sized to meet the 24-hour integrated campus electrical energy requirement. Figure 11 illustrates the results for Option I, while the results for Option II are presented in Figure 12.

For NS collectors possessing a variable or adjustable tilt angle capability, the minimum total collector area required is generally determined by the load-collection capability characteristics occurring during the summer season. However, the Option II case sized for daily integrated load provides one exception where the total collector area requirement is defined by the winter season load-collection capability characteristics. However, the data further illustrate the conclusion that by operating at a fixed tilt angle which balances the summer and winter collection area, the total collector area required is increased over the variable or adjustable NS collector area requirement by approximately 8 percent or less. It is considered highly unlikely that either the variable or adjustable tilt capability in NS collectors can be provided at an 8 percent cost increase over the fixed tilt NS collector. Therefore, the fixed tilt NS collector is expected to be the more cost effective system of the NS parabolic trough collector installations considered for the North Lake Campus.

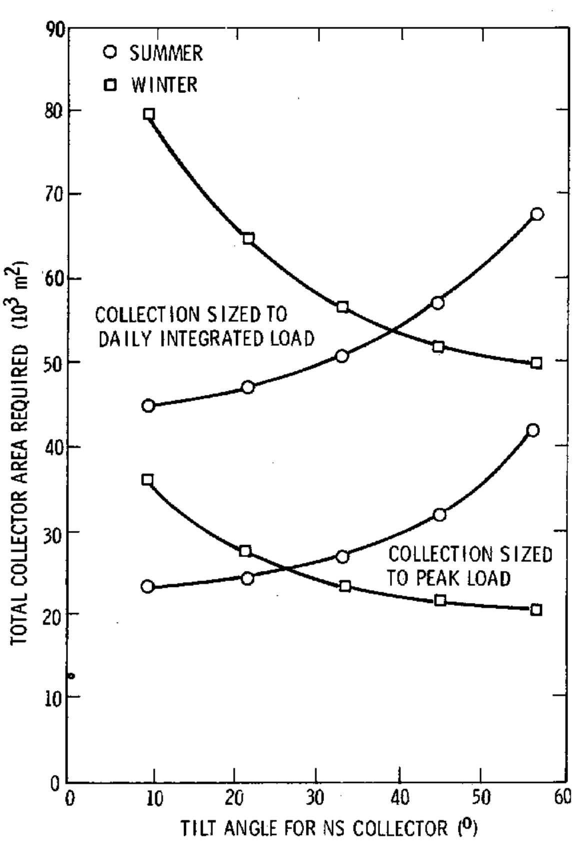


Figure 11. NS Collector Area vs. Tilt Angle, Option I Electric Load

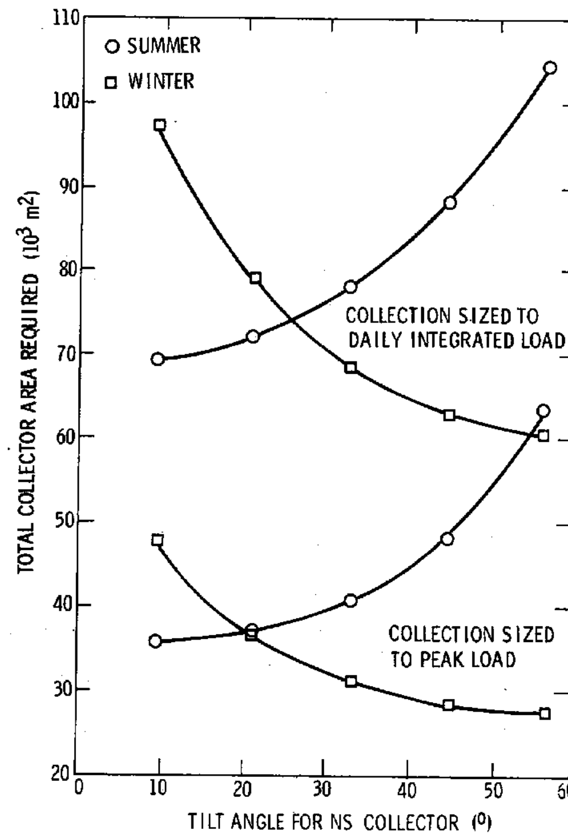


Figure 12. NS Collector Area vs. Tilt Angle, Option II Electric Load

In order to further evaluate collector performance capability and to compare the NS fixed tilt orientation with the EW orientation, a basic unit parabolic trough configuration was defined and analytically modeled using the SOLSYS computer program. Table VI presents the geometric characteristics of this unit configuration.

TABLE VI

Geometry and Performance Parameters for Unit Parabolic Trough Collector

Aperture	2.125 m	
Unit Length	3.6 m	
Focal Length	0.531 m	
Envelope Diameter	0.0508 m	
Receiver Diameter (OD)	0.0318 m	1-1/4 in. Steel Tubing
Receiver Diameter (ID)	0.0292 m	
Plug Diameter	0.0215 m	
Reflector Reflectance (visible)	0.9	
Window Reflectance (visible)	0.04	
Window Reflectance (infrared)	0.10	
Window Transmittance (visible)	0.90	
Window Emittance (infrared)	0.90	
Collector Reflectance (visible)	0.05	
Collector Reflectance (infrared)	0.75	
Collector Emittance (infrared)	0.25	

The basic operational characteristics of the parabolic trough collector are illustrated in Figure 13. These data are for a parabolic trough collector oriented NS at a fixed tilt angle of 20 degrees. However, the characteristics for a collector oriented EW in a horizontal attitude are very similar. The figure illustrates a characteristic of the parabolic trough collectors which results in the imposition of an increasingly severe penalty in collection efficiency as the collector temperature rise is increased through restriction of the fluid flow rate. This characteristic is further illustrated in Figure 14 which shows the average daily unit area energy collection versus the unit collector temperature rise. It is evident that energy collection, when integrated over the daily insolation rate cycle, commences to decrease as the temperature rise per unit collector is increased beyond a desirable level. At the other end of the scale, as the temperature rise is diminished to low values the collector fluid flow rate increases. This results in an increase in the parasitic pump work required and, conversely, a decrease in the net energy collection capability. Thus, there exists an optimum temperature rise per unit length of the parabolic trough collectors. Also indicated here is the necessity of operating a number of the unit collectors in series in order to achieve the overall fluid temperature rise desirable in the thermodynamic cycle for electric power generation.

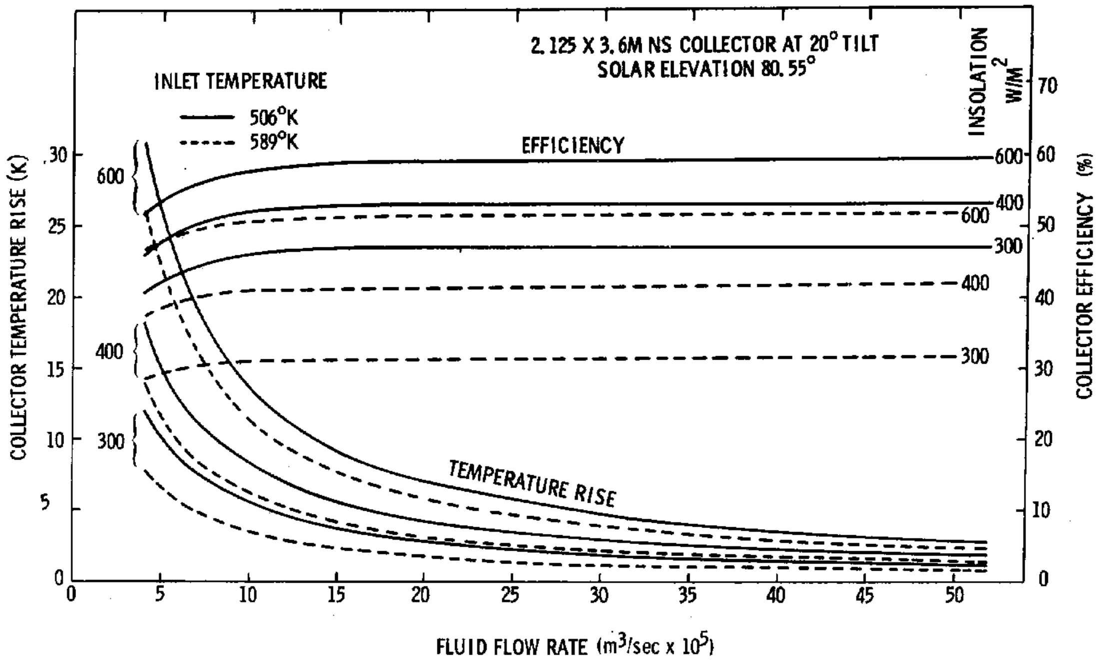


Figure 13. Collector Performance Characteristics

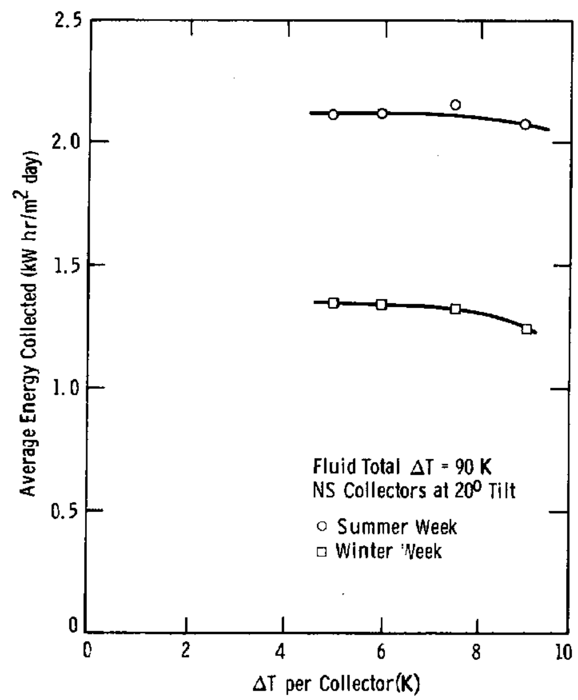


Figure 14. Average Energy Collection vs. Temperature Rise per Collector

Achieving the desired overall temperature rise with horizontal EW oriented collectors is readily accomplished by joining the required number of unit collectors end to end in series. However, there exist practical limitations to the overall length achievable by joining NS oriented collectors at selected tilt angles end to end. This restriction imposes additional piping requirements between collectors with their attendant heat losses and costs on the NS oriented collector field.

To form a basis of comparison between the fixed tilt NS oriented collector and the horizontal EW oriented collector, system requirements for total collector field area and sensible heat storage capacity were defined for three separate cases: (1) Option I, Alternate A; (2) Option I, Alternate B; and (3) the electric power supply part of Option II. The required rate of power input to the thermoelectric conversion system was defined through a thermodynamic cycle analysis for a steam Rankine cycle power plant for each of the above three cases. The power generation capacity was sized to meet the peak campus electric load for each respective case. The actual energy collection profile was based upon actual Ft. Worth insolation data, including cloud cover, etc., taken from the Ft. Worth historical records, as described earlier. The collector field area was sized to meet the required rate of power input at the field's average daily rate of energy collection. This sizing criterion is illustrated in Figure 15. Sensible heat thermal storage capacity was sized to save all energy collected by the field in excess of the power input rate required by the generation cycle and, in addition, the early morning energy collection occurring prior to start up of the generation cycle. This capacity is illustrated by the shaded area shown in Figure 15.

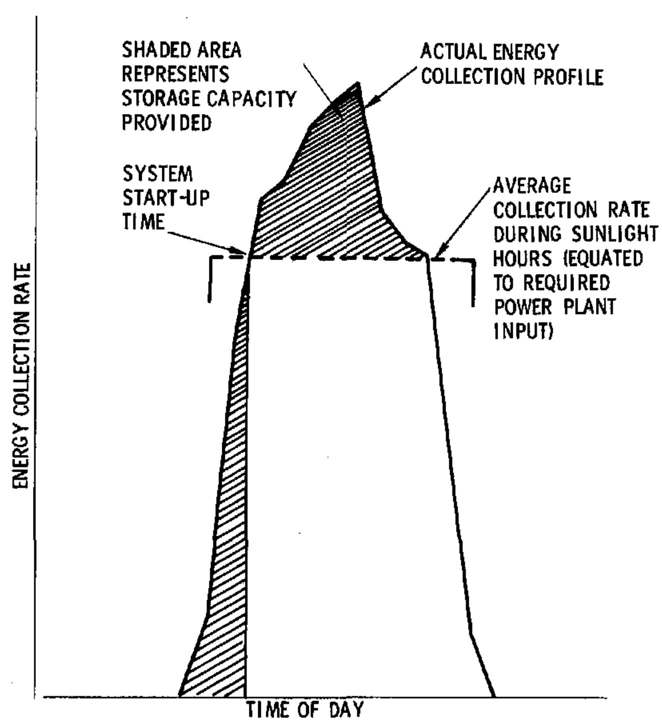


Figure 15. Energy Collection Profile and Sizing Criterion

The comparative costs estimated for the collection and storage system for the three cases considered are presented in Table VII. These cost comparisons for the three cases studied suggest that a parabolic trough energy collection and sensible heat storage system oriented in the EW direction could be installed for no more than, and perhaps significantly less than, the equivalent NS oriented system. The larger total collector area required with the EW orientation is offset by the higher unit area installed cost expected with the NS oriented collectors and by the additional piping required with the NS oriented field. Further comparisons between Options I, II, and III for the North Lake Campus application are based upon the use of horizontal EW oriented parabolic trough collectors.

TABLE VII

Cost Comparison Between Collector Orientations for North Lake Campus Electric Power Requirements

	NS Collectors			EW Collectors		
	Size	Unit Costs ($)	Item Costs ($000)	Size	Unit Costs ($)	Item Cost ($000)
Option I, Alternate A						
Collector Area	67750 m^2	200/m^2	13500	86940 m^2	100/m^2-150/m^2	8700-13040
Storage Capacity	670 m^3	1000/m^3	670	1280 m^3	1000/m^3	1280
Piping for Series	21700 m	10/m-20/m	217-434	-		
Total Cost			14400-14600			10000-14300
Option I, Alternate B						
Collector Area	51320 m^2	200/m^2	10300	65910 m^2	100/m^2-150/m^2	6600- 9900
Storage Capacity	510 m^3	100/m^3	510	970 m^3	1000/m^3	970
Piping for Series	16440 m	10/m-20/m	165-330	-		
Total Cost			11000-11150			7600-10900
Option II, Noncascaded						
Collector Area	33480 m^2	200/m^2	6700	41280 m^2	100/m^2-150/m^2	4130-6200
Storage Capacity	290 m^3	1000/m^3	290	650 m^3	1000/m^3	650
Piping for Series	13230 m	10/m-20/m	132-265	-		
Total Cost			7125-7260			4800-6850

Energy Collection Capability

The net energy collection capability for series connected optimized EW parabolic trough collectors was evaluated, utilizing the SOLSYS Computer Program, as a function of the total temperature rise and the fluid outlet temperature from the collector. The net energy collection is defined as the gross output from the collector field less the thermal input to the thermoelectric conversion system required to meet the pump work for providing fluid circulation through the collector field and piping system. The evaluation of the pump work input assumes a pump efficiency of 80 percent and a thermoelectric conversion efficiency of 20 percent. No adjustment for the collector tracking power requirement was made. The results for the average Ft. Worth sunny summer day are illustrated in Figure 16. The analogous data for the average Ft. Worth sunny winter day are presented in Figure 17.

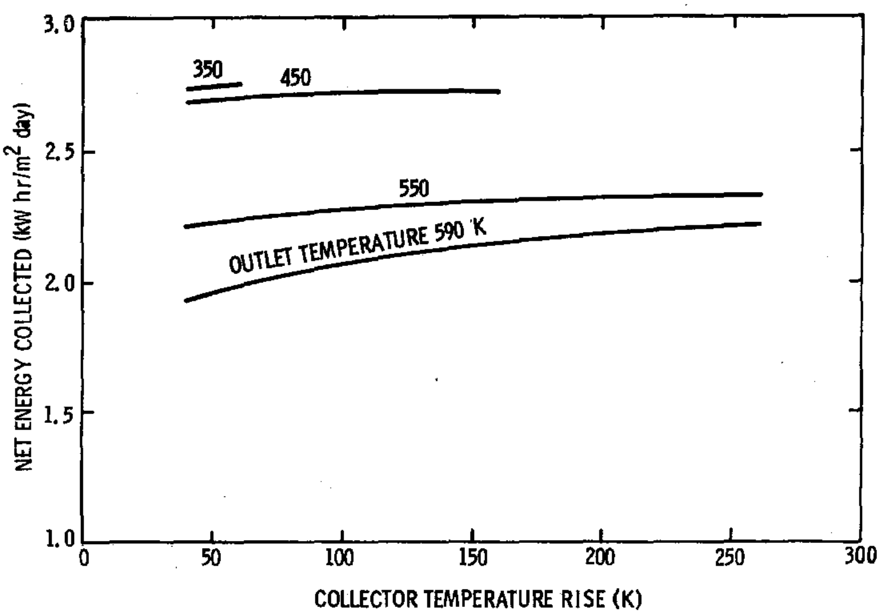


Figure 16. Estimated Performance for EW Collector Field, Average Ft. Worth Summer Day

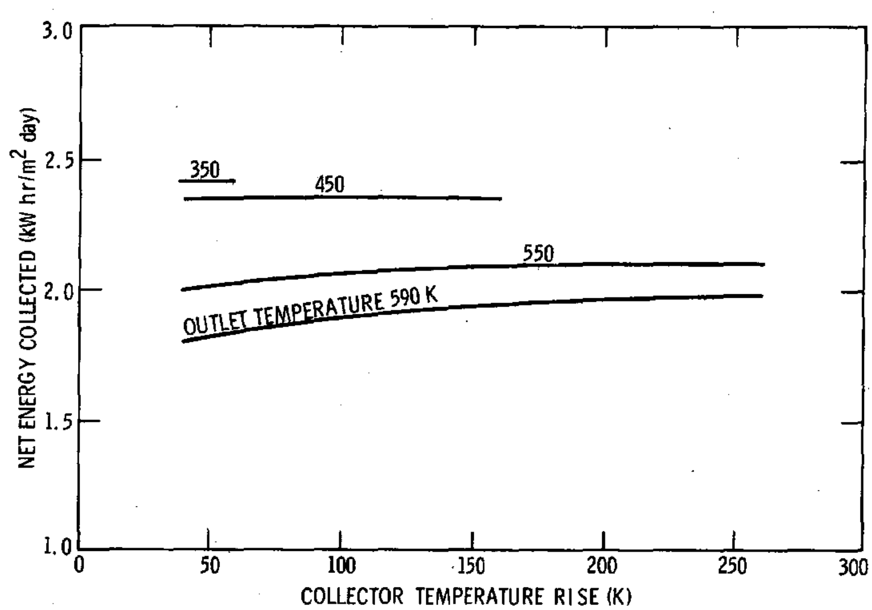


Figure 17. Estimated Performance for EW Collector Field, Average Ft. Worth Winter Day

The energy collection data presented in Figures 16 and 17 do not include the effect of shadowing between adjacent rows of collectors. The result of the shadowing effect is illustrated in Figure 18. During the summer season, collector shadowing has little effect on the energy collection capability of the field. However, energy collection capability during the winter season incurs a significant shadowing penalty as collector rows are spaced closer together. This characteristic may be used to some advantage by permitting some shadowing penalty since the campus winter load requirements decrease somewhat more than does the net energy collection capability between summer and winter seasons. Utilization of this characteristic for the North Lake Campus conditions allows a collector row spacing which results in a collector areal density of approximately one-half.

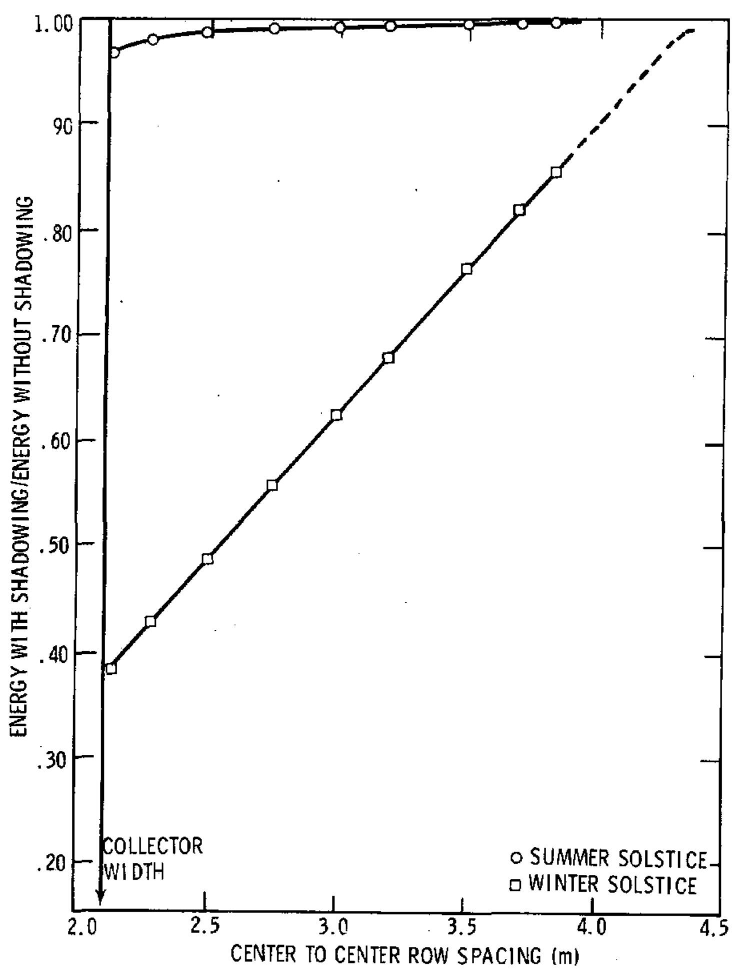


Figure 18. Effect of Shadowing on East-West Collectors at North Lake

Thermoelectric Conversion System

Evaluation of the thermoelectric conversion plant for the North Lake Campus solar energy system was conducted by Stearns-Roger, Inc. The result of their study is presented in its entirety in Appendix B. A brief review of these efforts is presented here.

A total of 52 different thermal-to-electric conversion cycles were investigated. Included in this total were 16 steam Rankine cycles, 9 Toluene Rankine cycles, and 27 Trifluoroethanol Rankine cycles. For the steam cycles both one and two feedwater heater systems were investigated, and for the trifluoroethanol cycles both subcritical and supercritical cycle operation were investigated. In addition, a range of values of the heating fluid temperature rise was investigated since this parameter affects both energy collection capability and thermoelectric conversion cycle efficiency. The peak temperature considered for these thermodynamic cycles was 561 K (550°F). This limitation results from the selection of Therminol 66 as the heat transfer fluid for the collector fluid loop. Information provided by the supplier indicates the maximum operational temperature for the Therminol 66 is approximately 617 K (650°F).

For the cascaded system (Option I, Alternate A), condensation in the working fluid cycle occurs at approximately 367 K (200°F) in order to provide the 361 K (190°F) water temperature required by the campus thermal loads (space heating and domestic hot water). For the noncascaded systems (Option I, Alternate B and Option II), condensation occurs at the lowest practical temperature determined by ambient wet bulb temperature.

Although certain of the Toluene cycles provide a slight edge in cycle efficiency and overall system cost, Stearns-Roger has recommended use of the water/steam Rankine cycle for the North Lake Campus system. This recommendation is based primarily on limitations concerning hardware availability for the Organic system and on the very limited operational experience available with the Organic fluid systems in the size range of interest.

Appendix B includes data on procurement lead times and total installation cost estimates for the thermoelectric conversion system. The pacing item governing procurement and installation scheduling is the steam turbine generator set which has a lead time of 70 to 80 weeks. Other hardware items have lead times varying from 10 to 52 weeks.

Also presented in Appendix B are suggested arrangements for the power plant control system, the tie-in between plant power generation and utility power supply, and power plant building layout.

System Cost Comparisons

General

Cost comparisons between the different options studied were based upon solar energy systems sized to meet the campus peak load only. No additional energy collection or storage capacity was provided to operate the system beyond the usual hours of sunlight. Evaluation of the desirability of extending the solar system's operating time capability through the provision of additional storage and collection capacity would be advisable in a Detail Design Phase. Electric generation capacity was sized to provide a net electric power output of 2000 kWe for Option I and 1250 kWe for Option II. Provision for the thermal load of Options II and III was based on meeting the peak thermal load of 3600 kWt which represents the space cooling and domestic hot water requirements. As was noted earlier, space heating requirements occur only at night and thus do not contribute to the peak thermal load.

Sizing of the collector field to meet the power generating capacity was based upon meeting the required cycle thermal input at the average energy collection rate existing over the daily period of sunlight. A minimal thermal storage capacity, sized to accept all energy collected by the field during the daily interval when the actual collection rate exceeds the average collection rate required for thermal input, was included for the cost comparisons. These sizing criteria are illustrated in Figure 19.

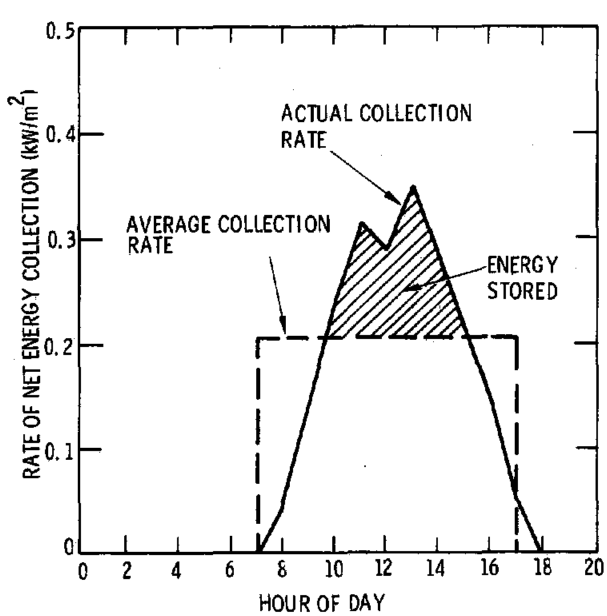


Figure 19. Rate of Energy Collection with EW Field - Average Ft. Worth Summer Day Collector Temperature 490 → 590 K

An evaluation of three different approaches to providing the separate thermal load requirements for Options II and III was conducted. Alcone[2] has presented a compilation of performance data on absorption type cooling units (Figure 20). In addition, Stearns-Roger, Inc., in Appendix B, presented performance and cost data on three Lithium Bromide Absorption chilling units. A performance/cost comparison of these three approaches is presented in Table VIII. These results indicate that the two-stage lithium bromide system operating on 125 psi steam supply offers the more cost effective system for providing the thermal load in Options II and III.

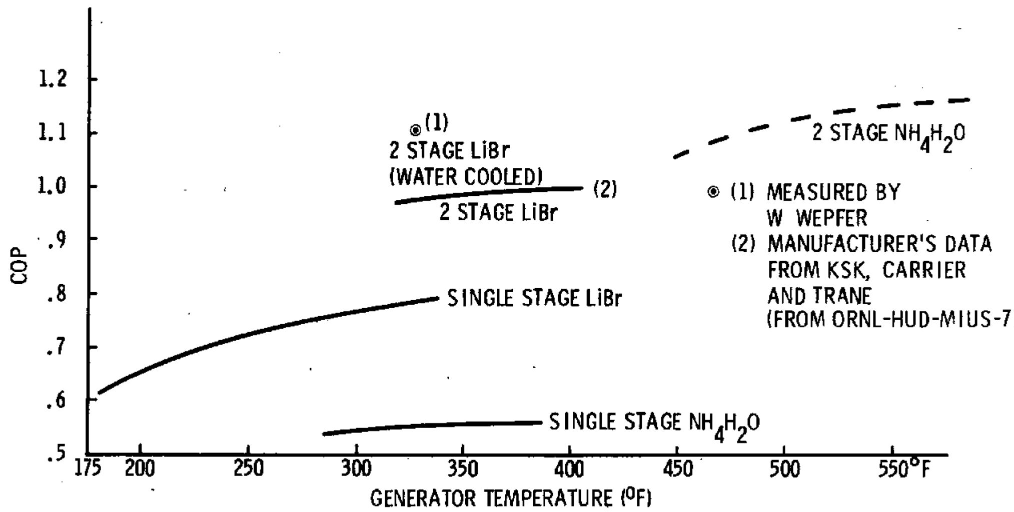


Figure 20. Absorption Refrigeration Cycle Efficiencies

TABLE VIII

Comparison of Absorption Chilling Systems

Working Fluid		Hot Water	12 psig Steam	125 psig Steam
Fluid Temperature	K	361	395	452
Cooling Load	kW	3020	3020	3020
Chiller COP		.754	.65	.98
Cooling Input	kW	4005	4646	3081
Hot Water Load	kW	519	519	519
Total Heat Added	kW	4524	5165	3600
Collector Temperature	K	450	420	480
Terminol ΔT	K	50	50	100
Net Daily Collection	kW hr/m^2 Day	2.7	2.7	2.58
Average Collection Rate	kW/m^2	0.245	0.245	0.235
Total Field Area	m^2	18500	21100	15400
Storage Volume	m^3	300	350	160
Costs				
Collectors	$\$10^6$	2.78	3.17	2.31
Storage Tankage	$\$10^6$	0.12	0.14	0.07
Piping	$\$10^6$	0.06	0.06	0.06
Therminol	$\$10^6$	0.48	0.56	0.26
Subtotal Call & Store	$\$10^6$	3.44	3.93	2.70
Chiller, etc.	$\$10^6$	0.39	0.21	0.25
Boiler/Heat Exchanger	$\$10^6$	0.06	0.06	0.06
Total Cost	$\$10^6$	3.89	4.20	3.01

Option I, Alternate A

For this option, the electric load is comprised of both the lighting and space cooling requirements. The energy system is based on the cascaded concept where the campus thermal load requirements are supplied from heat rejected from the thermoelectric conversion process. For this system, four steam, three Toluene, and nine Trifluoroethanol Rankine power generation cycles were evaluated. Pertinent parameters together with the costs are tabulated for each cycle in Tables IX-A and IX-B. These results of the cycle evaluation indicate that an inverse relationship between system cost and conversion cycle efficiency exists.

Option I, Alternate B

For Alternate B, the electric load is the same as for Alternate A. However, the system is not cascaded, allowing the thermoelectric conversion cycle to operate at its maximum efficiency. The thermal load requirements (for this Option, the daylight peak thermal load consists of the domestic hot water only) are supplied through a separate low temperature solar collection capability. A 2500 m^2 (27000 ft^2) field of parabolic trough collectors operating at 361 K (190°F) will provide this thermal requirement on the average Ft. Worth summer day. The cost of this energy collection and storage system plus a heat exchanger between the therminol and water systems is estimated to be $670, 000. For the Alternate B system, sixteen power conversion cycles analogous to those considered in Alternate A were evaluated. The results are tabulated in Tables X-A and X-B.

Option II, Noncascaded Total Energy System

For Option II, the electric load consists of lighting and miscellaneous power requirements only. Four steam, three Toluene, and nine Trifluoroethanol Rankine power generation cycles were evaluated for the electric power system of Option II.

The thermal load, which consists of the space cooling, space heating, and domestic hot water requirements, is supplied through a separate collector/storage system operating at a lower temperature. At the outset of the conceptual design study, it was intended to evaluate distributed nonfocusing and distributed focusing collector systems for the thermal loads of Options II and III, respectively, to provide a comparison of system costs for these collectors. More recent cost data suggest that, on an equivalent performance basis, the nonfocusing collectors do not offer a significant cost advantage. Therefore, the thermal load systems of Options II and III both were based upon performance and cost data of the focusing collector system and the high pressure steam absorption chiller discussed above.

TABLE IX-A

Option I

Cascaded Thermal System
Net Electric Power Generation 2000 kW

Cycle Number	A1	A2	A3	A4	A1-ORG	A2-ORG	A3-ORG
Working Fluid	Steam	Steam	Steam	Steam	TOLUENE	TOLUENE	TOLUENE
Number of Heaters	1	2	1	1	-	-	-
Throttle Pressure, Pa	3.21×10^6	3.21×10^6	2.52×10^6	1.86×10^6	1.38×10^6	1.72×10^6	1.38×10^6
Throttle Temperature, K	561.	561.	561.	561.	561.	561.	533.
Condenser Pressure, Pa	8.47×10^4	8.47×10^4	8.47×10^4	8.47×10^4	6.0×10^4	6.0×10^4	6.0×10^4
Condenser Temperature, K	368.	368.	368.	368.	367.	367.	367.
Cycle Efficiency, (net) %	15.56	15.85	14.90	14.11	16.43	17.07	15.34
Heat Added, kW	12857	12620	13420	14176	12171	11717	13039
Heating Fluid ΔT, K	81.9	78.8	97.2	111.1	95.2	85.6	112.2
Collector Field Area, m^2	63500	62500	65500	68500	59500	57750	62750
Storage Volume, m^3	615	630	540	495	500	535	450
Costs, $\$10^6$							
Collector Field	9.53	9.38	9.83	10.28	8.93	8.67	9.42
Storage Tankage	0.25	0.22	0.20	0.18	0.19	0.21	0.17
Piping	0.07	0.07	0.07	0.07	0.07	0.07	0.07
T-66 Oil	1.03	1.06	0.91	0.85	0.85	0.90	0.77
Subtotal	10.88	10.73	11.01	11.38	10.04	9.85	10.43
Power Plant	2.46	2.52	2.51	2.55	3.00	2.91	2.85
Total Cost	13.34	13.25	13.52	13.93	13.04	12.76	13.28

TABLE IX-B

Option I

Cascaded Thermal System
Net Electric Power Generation 2000 kW

Cycle Number	A1-ORG	A2-ORG	A3-ORG	A7-ORG	A8-ORG	A9-ORG	A4-ORG	A5-ORG	A6-ORG
Working Fluid	TFE	TFE	TFE	TFE	TFE	TFE	TFE	TFE	TFE
Number of Heaters	-	-	-	-	-	-	-	-	-
Throttle Pressure, Pa	2.07×10^6	2.07×10^6	2.76×10^6	2.76×10^6	2.76×10^6	2.07×10^6	5.52×10^6	5.52×10^6	6.89×10^6
Throttle Temperature, K	478	506	506	533.	478.	533.	533.	561.	533.
Condenser Pressure, Pa	21.86×10^4	21.86×10^4	21.86×10^4	21.86×10^4	21.86×10^4	21.86×10^4	21.86×10^4	21.86×10^4	21.86×10^4
Condenser Temperature, K	367.	367.	367.	367.	367.	367.	367.	367.	367.
Cycle Efficiency, (net) %	11.16	11.82	12.90	13.86	11.59	12.49	14.57	15.36	12.73
Heat Added, kW	17927	16925	15501	14431	17256	16016	13722	13018	15712
Heating Fluid ΔT, K	142.6	174.	185.3	161.2	215.8	154.1	181.8	159.7	205.6
Collector Field Area, m^2	84600	76100	71800	67500	78800	74900	64200	61500	72750
Storage Volume, m^3	350	365	325	350	310	400	295	315	295
Cost, $\$10^6$									
Collector Field	12.69	11.42	10.77	10.13	11.82	11.24	9.63	9.23	10.91
Storage Tankage	0.12	0.12	0.11	0.12	0.11	0.13	0.10	0.11	0.10
Piping	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
T-66 Oil	0.61	0.64	0.57	0.60	0.55	0.69	0.52	0.55	0.52
Subtotal	13.49	12.25	11.52	10.92	12.55	12.13	10.32	9.96	11.60
Power Plant	3.17	3.36	3.08	3.21	2.96	3.50	3.20	3.44	3.20
Total Cost	15.66	15.61	14.60	14.13	15.51	15.63	13.52	13.40	14.80

TABLE X-A

Option I

Noncascaded Thermal System
Net Electric Power Generation 2000 kW

Cycle Number	B1	B2	B3	B4	B1-ORG	B2-ORG	B3-ORG
Working Fluid	Steam	Steam	Steam	Steam	TOLUENE	TOLUENE	TOLUENE
Number of Heaters	1	2	1	1	-	-	-
Throttle Pressure, Pa	3.21×10^6	3.21×10^6	2.69×10^6	2.03×10^6	1.38×10^6	1.72×10^6	1.38×10^6
Throttle Temperature, K	561.	561.	561.	561.	561.	561.	533.
Condenser Pressure, Pa	1.02×10^4	1.02×10^4	1.02×10^4	1.02×10^4	1.18×10^4	1.18×10^4	1.18×10^4
Condenser Temperature, K	319.	319.	319.	319.	322.	322.	322.
Cycle Efficiency, (net) %	20.54	20.98	19.62	18.59	21.34	21.89	20.47
Heat Added, kW	9739	9537	10193	10759	9372	9138	9771
Heating Fluid ΔT, K	86.7	82.6	97.2	111.1	108.3	97.3	127.9
Collector Field Area, m^2	47750	47000	49750	52000	45500	44500	46750
Storage Volume, m^3	440	450	410	375	340	365	295
Costs, $\$10^6$							
Collector Field	7.17	7.05	7.47	7.80	6.83	6.68	7.02
Storage Tankage	0.19	0.20	0.17	0.15	0.14	0.15	0.12
Piping	0.07	0.07	0.07	0.07	0.07	0.07	0.07
T-66 Oil	0.75	0.77	0.70	0.64	0.59	0.63	0.52
Subtotal	8.18	8.09	8.41	8.66	7.63	7.53	7.73
Power Plant	2.18	2.23	2.22	2.25	2.67	2.59	2.51
Thermal Load Supply	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Total Cost	11.03	10.99	11.30	11.58	10.97	10.79	10.91

TABLE X-B

Option I

Noncascaded Thermal System
Net Electric Power Generation 2000 kW

Cycle Number	B1-ORG	B2-ORG	B3-ORG	B7-ORG	B8-ORG	B9-ORG	B4-ORG	B5-ORG	B6-ORG
Working Fluid	TFE	TFE	TFE	TFE	TFE	TFE	TFE	TFE	TFE
Number of Heaters	-	-	-	-	-	-	-	-	-
Throttle Pressure, Pa	2.07×10^6	2.07×10^6	2.76×10^6	2.76×10^6	2.76×10^6	2.07×10^6	5.52×10^6	5.52×10^6	6.89×10^6
Throttle Temperature, K	478.	506.	506.	533.	478.	533.	533.	561.	533.
Condenser Pressure, Pa	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4
Condenser Temperature, K	322.	322.	322.	322.	322.	322.	322.	322.	322.
Cycle Efficiency, (net) %	15.80	16.99	17.75	18.30	16.03	17.53	17.91	19.33	15.86
Heat Added, kW	12655	11770	11266	10934	12464	11409	11163	10345	12602
Heating Fluid ΔT, K	234.8	208.9	221.0	190.9	254.1	185.3	219.4	199.7	250.
Collector Field Area, m^2	57750	54250	51750	50400	56400	52900	51250	47900	57100
Storage Volume, m^3	210	220	200	220	190	240	200	200	195
Costs, $\$10^6$									
Collector Field	8.67	8.14	7.77	7.56	8.46	7.94	7.69	7.19	8.57
Storage Tankage	0.08	0.08	0.07	0.08	0.08	0.09	0.08	0.07	0.08
Piping	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
T-66 Oil	0.38	0.39	0.36	0.39	0.35	0.43	0.36	0.36	0.35
Subtotal	9.19	8.67	8.26	8.09	8.95	8.52	8.19	7.68	9.06
Power Plant	2.57	2.64	2.52	2.65	2.64	2.78	2.79	2.96	2.81
Thermal Load Supply	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Total Cost	12.43	11.98	11.45	11.41	12.26	11.97	11.65	11.31	12.54

Performance parameters and cost data for the sixteen power generation cycles are tabulated in Tables XI-A and XI-B. In addition to these sixteen noncascaded cycles, four other steam cycles utilizing the cascaded energy principle were evaluated for Option II. The first of these cycles (D1) utilizes heat rejection from the condenser at 361 K (190°F) to supply the thermal load requirements. This cycle is analogous to those evaluated for Option I, Alternate A; however, the space cooling load is supplied thermally instead of electrically. The other three cycles (E1, E2, and E3) all use an automatic extraction type turbine for providing steam to drive an absorption chilling device supplying the space cooling load. The first two of these (E1 and E2) use the cascaded principle to provide condenser heat rejection for supplying the space heating and hot water thermal loads. The fourth of these cycles (E3) relies on condensing at the minimum practicable temperature to maximize conversion cycle efficiency. This requires meeting the space heating and domestic hot water thermal loads with a separate collection/storage capability, as in Option I, Alternate B. However, in this case the space cooling load is supplied from steam extracted from the turbine. The performance/cost data representing these four cycles is presented in Table XII.

Option III, Building Heating and Cooling

This option considers the thermal load only, which consists of space cooling, space heating, and domestic hot water requirements. No electric power generating capability is provided. The same systems as defined for the separate thermal load of Option II are applicable here.

Central Receiver System

In addition to the three options based upon parabolic trough collectors, a fourth option was evaluated: a tower mounted central receiver system for the North Lake Campus application. The Solar Energy Technology Division of Sandia Laboratories conducted this evaluation of the central receiver system. The complete analysis is presented in Appendix C. A brief description of the system is given here.

A schematic of the system was illustrated earlier in Figure 4. The cascaded concept was employed to utilize heat rejected from the electric generation process to supply the space cooling, space heating, and domestic hot water thermal load. Electric generation capacity is sized to meet the peak lighting load of 1250 kW. Because of the proximity of the North Lake Campus to the Dallas Ft. Worth Regional Airport, height restrictions exist which impact the design of the central receiver system. A modular concept was developed employing six grouped heliostat fields and towers to supply the campus energy load and keep the tower height within limits. A total heliostat area of 15,300 m^2 (165,000 ft^2) is required for this system. System cost has been estimated at 12.26×10^6 dollars.

TABLE XI-A

Option II

Noncascaded Thermal System
Net Electric Power Generation 1250 kW

Cycle Number	C1	C2	C3	C4	C1-ORG	C2-ORG	C3-ORG
Working Fluid	Steam	Steam	Steam	Steam	TOLUENE	TOLUENE	TOLUENE
Number of Heaters	1	2	1	1	-	-	-
Throttle Pressure, Pa	3.21×10^6	3.21×10^6	2.69×10^6	2.03×10^6	1.38×10^6	1.72×10^6	1.38×10^6
Throttle Temperature, K	561.	561.	561.	561.	561.	561.	533.
Condenser Pressure, Pa	1.02×10^4	1.02×10^4	1.02×10^4	1.02×10^4	1.18×10^4	1.18×10^4	1.18×10^4
Condenser Temperature, K	319.	319.	319.	319.	322.	322.	322.
Cycle Efficiency, (net) %	20.50	20.95	19.56	18.57	21.50	22.04	20.61
Heat Added, kW	6099.	5970.	6389.	6729.	5817.	5671.	6061.
Heating Fluid ΔT, K	86.7	82.6	97.2	111.1	108.3	97.3	127.9
Collector Field Area, m^2	30000	29500	31200	32500	28250	27750	29000
Storage Volume, m^3	275	285	260	235	210	230	185
Costs, $\$10^6$							
Collector Field	4.50	4.43	4.68	4.88	4.24	4.17	4.35
Storage Tankage	0.13	0.14	0.12	0.11	0.10	0.11	0.08
Piping	0.07	0.07	0.07	0.07	0.06	0.07	0.06
T-66 Oil	0.48	0.49	0.45	0.41	0.37	0.40	0.33
Subtotal	5.18	5.13	5.32	5.47	4.77	4.75	4.82
Power Plant	1.75	1.78	1.76	1.78	1.94	1.89	1.85
Thermal Energy Supply	3.01	3.01	3.01	3.01	3.01	3.01	3.01
Total Cost	9.94	9.92	10.09	10.26	9.72	9.65	9.68

TABLE XI-B

Option II

Noncascaded Thermal System
Net Electric Power Generation 1250 kW

Case Number	C1-ORG	C2-ORG	C3-ORG	C7-ORG	C8-ORG	C9-ORG	C4-ORG	C5-ORG	C6-ORG
Working Fluid	TFE	TFE	TFE	TFE	TFE	TFE	TFE	TFE	TFE
Number of Heaters	-	-	-	-	-	-	-	-	-
Throttle Pressure, Pa	2.07×10^6	2.07×10^6	2.76×10^6	2.76×10^6	2.76×10^6	2.07×10^6	5.52×10^6	5.52×10^6	6.89×10^6
Throttle Temperature, K	478.	506.	506.	533.	478.	533.	533.	561.	533.
Condenser Pressure, Pa	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4	3.93×10^4
Condenser Temperature, K	322.	322.	322.	322.	322.	322.	322.	322.	322.
Cycle Efficiency, (net) %	15.93	17.11	17.89	18.44	16.16	17.65	17.93	19.37	15.91
Heat Added, kW	7851	7303	6987	6779	7728	7078	6969	6456	7863
Heating Fluid ΔT, K	234.8	208.9	221.0	190.9	254.1	185.3	219.4	199.7	250.
Collector Field Area, m^2	36000	33750	32250	31250	35000	32800	32000	29900	35600
Storage Volume, m^3	130	135	125	135	120	150	125	125	125
Costs, $\$10^6$									
Collector Field	5.40	5.07	4.84	4.69	5.25	4.92	4.80	4.49	5.34
Storage Tankage	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.06
Piping	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
T-66 Oil	0.25	0.26	0.23	0.25	0.23	0.27	0.23	0.23	0.24
Subtotal	5.77	5.45	5.19	5.06	5.60	5.31	5.14	4.83	5.70
Power Plant	1.86	1.89	1.82	1.88	1.81	1.95	2.05	2.14	2.06
Thermal Energy Supply	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01	3.01
Total Cost	10.64	10.35	10.02	9.95	10.42	10.27	10.20	9.98	10.77

TABLE XII

Option II

Net Electric Power Generation 1250 kW

Cycle Number	D1	E1	E2	E3
Working Fluid	Steam	Steam	Steam	Steam
Number of Heaters	1	1	1	1
Throttle Pressure, Pa	3.21×10^6	3.21×10^6	2.52×10^6	3.21×10^6
Throttle Temperature, K	561	561	561	561
Condenser Pressure, Pa	8.47×10^4	8.47×10^4	8.47×10^4	1.02×10^4
Condenser Temperature, K	368.	368.	368.	319.
Cycle Efficiency, (net) %	15.52	14.00	13.10	14.01
Heat Added, kW	8051	8924	9539	8921
Heating Fluid ΔT, K	81.9	85.6	97.2	85.6
Collector Field Area, m^2	39750	44000	46750	44000
Storage Volume, m^3	385	410	385	410
Costs, $\$10^6$				
Collector Field	5.97	6.60	7.02	6.60
Storage Tankage	0.18	0.19	0.15	0.19
Piping	0.07	0.07	0.07	0.07
T-66 Oil	0.66	0.70	0.66	0.70
Subtotal	6.88	7.56	7.90	7.56
Power Plant	3.11	3.96	3.99	3.82
Thermal Energy Supply	-	-	-	0.67
Total Cost	9.99	11.52	11.89	12.05

Discussion

Although higher temperature differentials provide an improvement in energy collection capability, the cost comparisons indicate that this improvement is not sufficient to overcome the loss in cycle efficiency which results. Therefore, within each Option and for each working fluid, minimum system cost results from the cycle providing maximum thermoelectric conversion efficiency. The cost comparisons further suggest that the systems utilizing Toluene as the working fluid enjoy a slight advantage in cycle efficiency and overall system cost. However, this advantage is not of sufficient significance to overcome the disadvantages in equipment availability and the lack of operational experience cited by Stearns-Roger, Inc. Therefore, a system based on the steam turbine cycle is considered the more attractive candidate for a North Lake Power Plant. Of the steam turbine cycles investigated, those utilizing the two heater extraction cycle provide the more cost effective system.

A comparison of the costs for Option I and Option II indicates that, for the North Lake Campus application, the noncascaded system offers the more cost effective approach among systems meeting both the electrical and thermal peak loads. The design temperature of 361 K (190°F) upon which the campus thermal energy distribution system is based has a significant effect upon the cycle efficiency for the cascaded system. In addition, the lower collection temperature needed to supply the thermal energy requirements, for instance 480 K (404°F) for the high pressure steam absorption chilling system, is anticipated to provide a significant improvement in the energy collection capability. These two effects in combination have a significant impact on the total collector area required, which leads to the advantage noted above for the noncascaded system. On the basis of these performance/cost analyses, the noncascaded system two-heater cycle, number C2, appears the optimum choice. However, Stearns-Roger, Inc., has cited a possible problem in availability of a dual extraction turbine for the size range of interest. It is therefore suggested that the one heater cycle of Option II, Number C1, be selected on the basis of efficiency, availability, and overall system cost. The steam cycle D1, a cascaded system providing electric generating cpacity for lighting and utilizing condenser heat rejection to supply 361 K (190°F) hot water for the thermal loads, is competitive with Cycle C1. However, this cycle has a marginal capability to supply the waste heat required by the thermal load. The cycles employing the automatic steam extraction turbine for the absorption cooling input all involve a higher cost due jointly to increased energy input to the conversion cycle and to the additional cost of this type of turbine.

To provide the thermal load requirements in conjunction with the electrical generation capability of Cycle C1, a separate thermal system based on utilization of the 125 psi steam driven lithium bromide absorption chiller is suggested. A parabolic trough collector field of 15400 m^2 (166,000 ft^2) operating at a peak temperature of 489 K (420°F) will provide the thermal input required.

Summary and Conclusions

A study was conducted to prepare a conceptual design for a solar total energy system for the North Lake Campus of the Dallas County Community College District. Various total energy system configurations were evaluated. Solar collector systems considered included the parabolic trough distributed collector concept and the tower mounted central receiver concept. Thermoelectric conversion systems evaluated included the conventional steam Rankine cycle and two organic fluid Rankine cycles based upon Toluene and Trifluoroethanol.

Comparison of the various system configurations was based upon procurement cost for the major hardware components. System configurations were sized to meet the campus peak electrical load; where the thermal load is supplied separately, the peak thermal load is the sizing criteria.

This study has resulted in the following conclusions and recommendations regarding a solar energy system for the North Lake Campus of the DCCCD.

1. A campus solar total energy system providing both electrical and thermal energy requirements should utilize the noncascaded system with separate collection/storage facilities operating at different temperature levels for the electrical and thermal parts of the system.

2. A campus solar energy system supplying space heating, cooling, and hot water loads only offers the opportunity for deploying and operating under actual load conditions a full scale collector field for approximately one-third the cost of a total energy system supplying both electrical and thermal loads.

3. The collector field for either of the above options should utilize the East-West oriented rows of focusing distributed collectors.

4. The thermoelectric conversion system for the total-energy system should be based upon the steam Rankine cycle.

References

1. E. C. Boes, Estimating the Direct Component of Solar Radiation, SAND75-0565, Sandia Laboratories, Albuquerque, NM, November 1975.

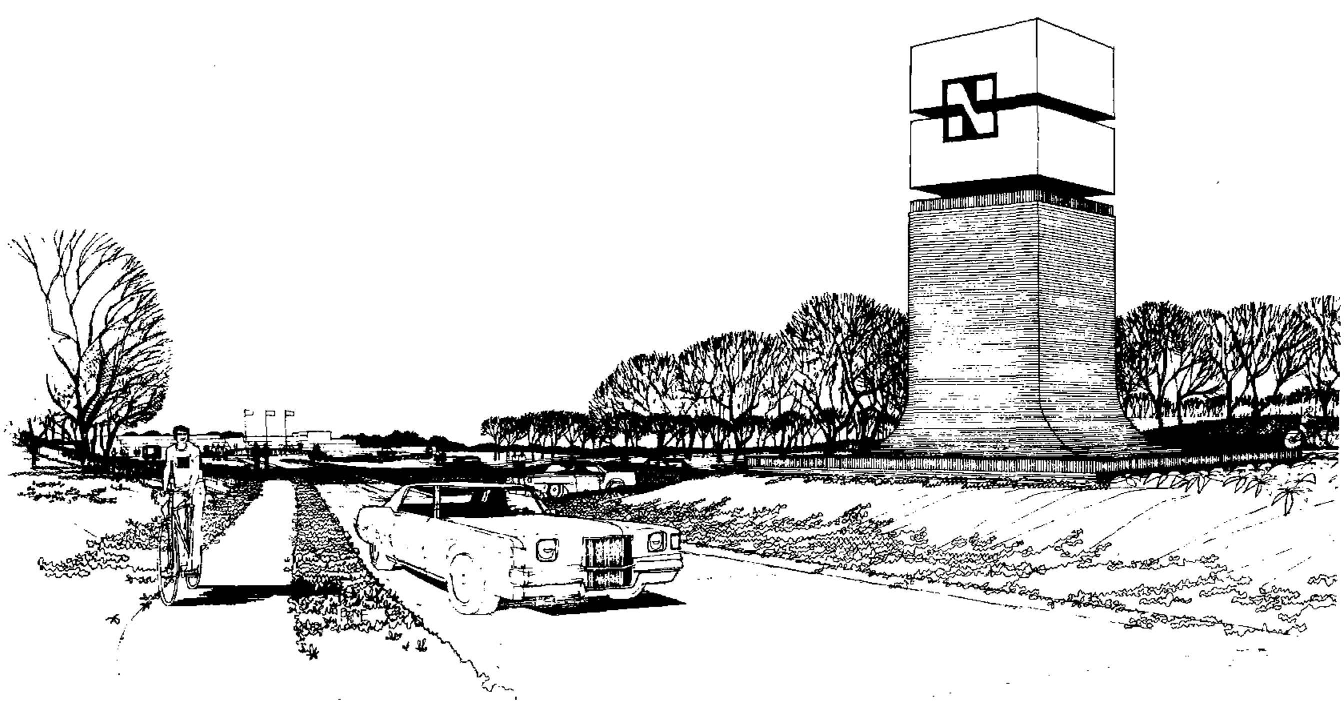
2. J. M. Alcone, Internal Memorandum dated January 20, 1976.

APPENDIX A

ENVIRODYNAMICS, INC., REPORT

A SOLAR TOTAL ENERGY SYSTEM
FOR THE NORTH LAKE COMMUNITY COLLEGE OF THE DALLAS COUNTY COMMUNITY COLLEGE DISTRICT

ENVIRODYNAMICS, INC.
ARCHITECTS, PLANNERS
ENERGY SYSTEMS



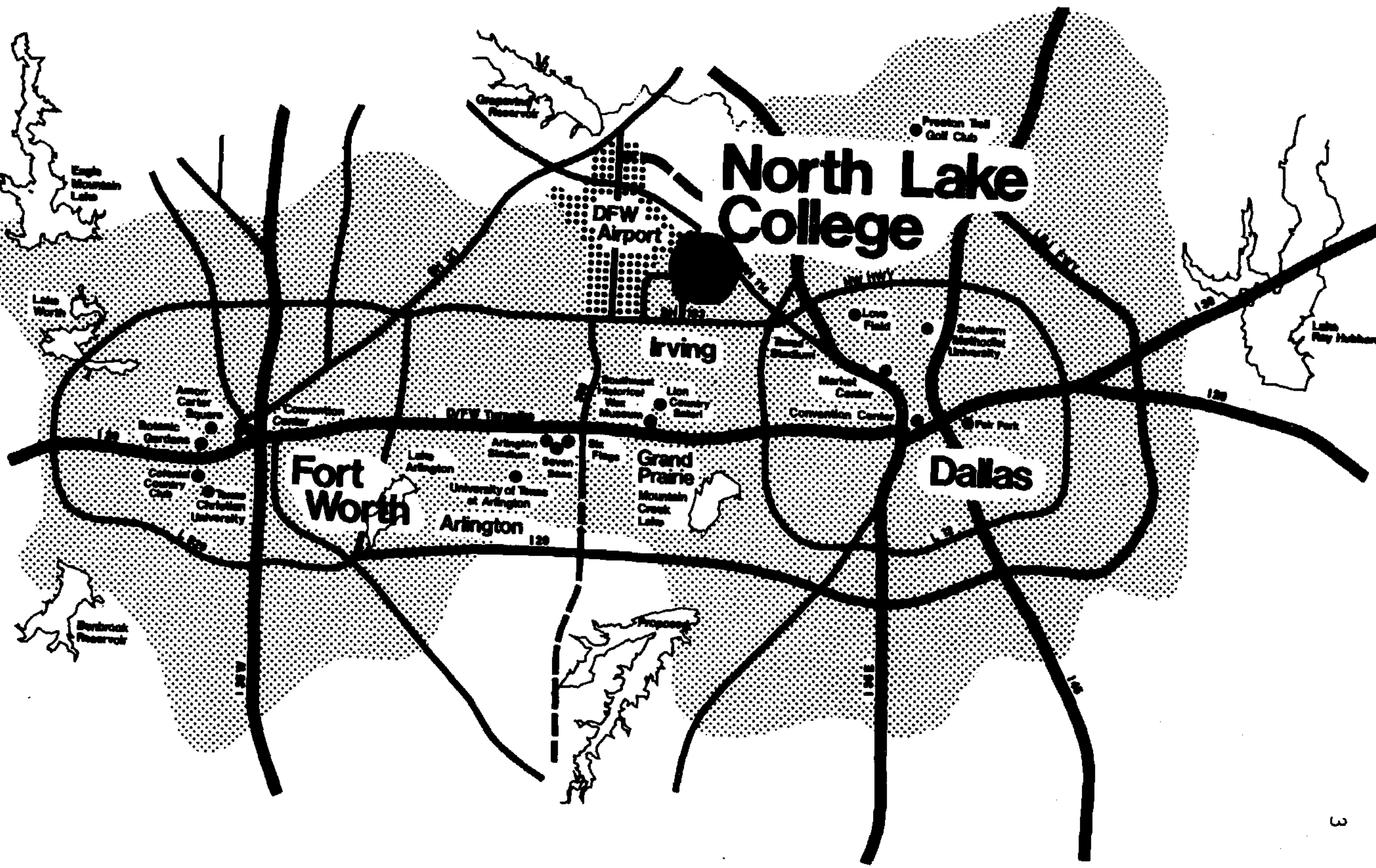
ONE NORTHPARK EAST SUITE 420 · DALLAS, TEXAS 75231 · 214 750·1945

The Northlake Community College will be the newest facility for the Dallas County Community College District; it will be the fifth in a series of seven centers which will provide a model system for community education. This system has an enrollment greater than the combined student levels of the five major local public and private universities. To handle the future impacts on this system, the college district has formulated plans and goals which will provide for the continued viability of the whole system.

One of their policies, energy conservation, forms the cornerstone of the Northlake campus, which was carefully designed to minimize its energy impact on the community. Careful siting and selection of materials were made in order that the maximum potential for energy savings could be realized. Task lighting was one of the elements where energy was saved. Compared with the national average for comparable construction, only half the energy is required to provide the proper level of illumination within this facility. Heavy construction was employed to permit the damping of temperature swings, thus reducing the rate at which heating and cooling must be added. Further, the facility was backed into a natural earth berm to further reduce and dampen the temperature swings in the building.

Studies have been conducted to identify where additional energy may be saved. They indicate that if adopted, 1.2×10^{13}

joules could be saved; this represents an energy savings of $150,000 per year (1975 dollars) at a cost of $629,000 (1976 dollars).


North Lake College
DFW Airport
Irving
Dallas
Grand Prairie
Arlington
Fort Worth
DFW Turnpike
I 20
I 30
Love Field
Southern Methodist University
Texas Stadium
Market Center
Convention Center
Fair Park
Lion Country Safari
Six Flags
Arlington Stadium
Seven Seas
University of Texas at Arlington
Lake Arlington
Mountain Creek Lake
Amon Carter Square
Botanic Gardens
Colonial Country Club
Texas Christian University
Eagle Mountain Lake
Lake Worth
Benbrook Reservoir
Grapevine Reservoir
Preston Trail Golf Club
Lake Ray Hubbard

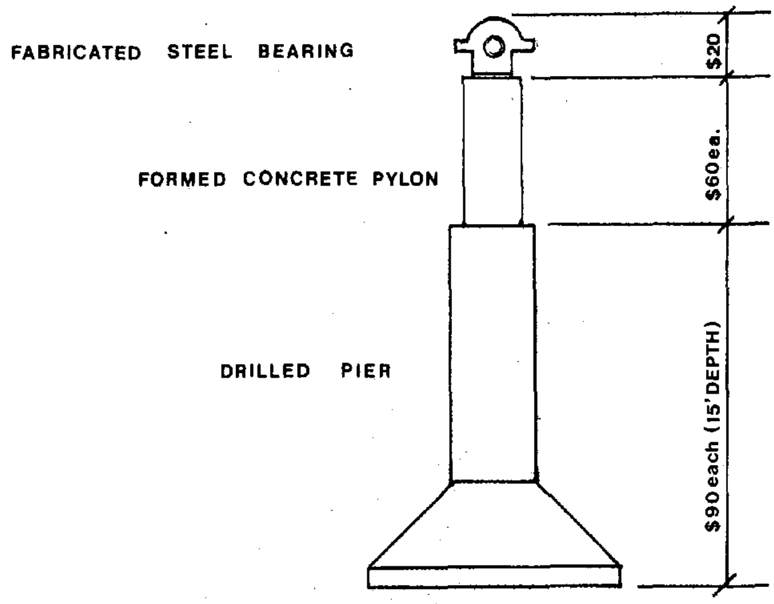
I.B.1 COLLECTOR SUPPORT STRUCTURES

Due to expansive soil conditions at the site, drilled concrete piers would be more structurally stable and therefore more desirable than surface type foundation systems.

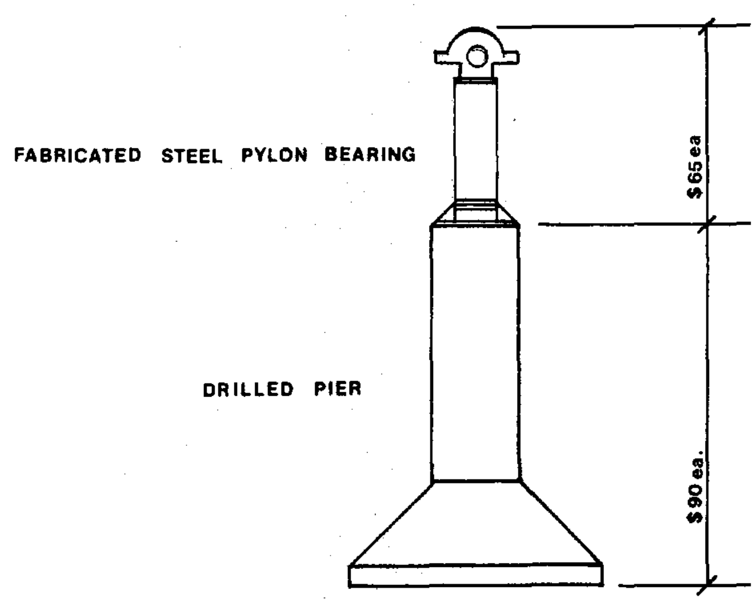
Two systems were investigated:

1. Drilled pier to grade, formed concrete pylon to 5 feet above grade, and fabricated steel mechanical bearing device to receive collector. Total cost, $170 each. (Refer to Detail 1.)
2. Drilled pier to grade, fabricated steel pylon to 5 feet above grade with fabricated steel mechanical bearing device to receive collector. Total cost, $155 each. (Refer to Detail 2.) All steel receives protective coating after fabrication.

Drilled piers are constructed by drilling a 16" hole into the earth with a mobile drilling rig and earth auger. The hole is provided a 24" Ø "Bell" or flare at the bottom to lock the pier into stable soil. Steel reinforcing is lowered into the pier's full depth and then filled with 3000# PSI concrete. In the system suggested, bolts are set into the wet concrete to receive the fabricated steel pylon.



DETAIL no.1 cost $170 each



DETAIL no.2 cost $155 each

DATE

COLLECTOR SUPPORT UNIT

EDI ENVIRODYNAMICS, INC.
ARCHITECTURE, PLANNING, ENGINEERING

I.B.3 MAINTENANCE PROCEDURE FOR COLLECTOR AND ACCESS REQUIREMENTS TO COLLECTOR FARM

Since focusing collectors are extremely dust and dirt sensitive, a rigid cleaning schedule will be required. Cleaning must be scheduled at intervals no longer than ten (10) days as routine, or, if atmospheric conditions make it necessary, more regularly.

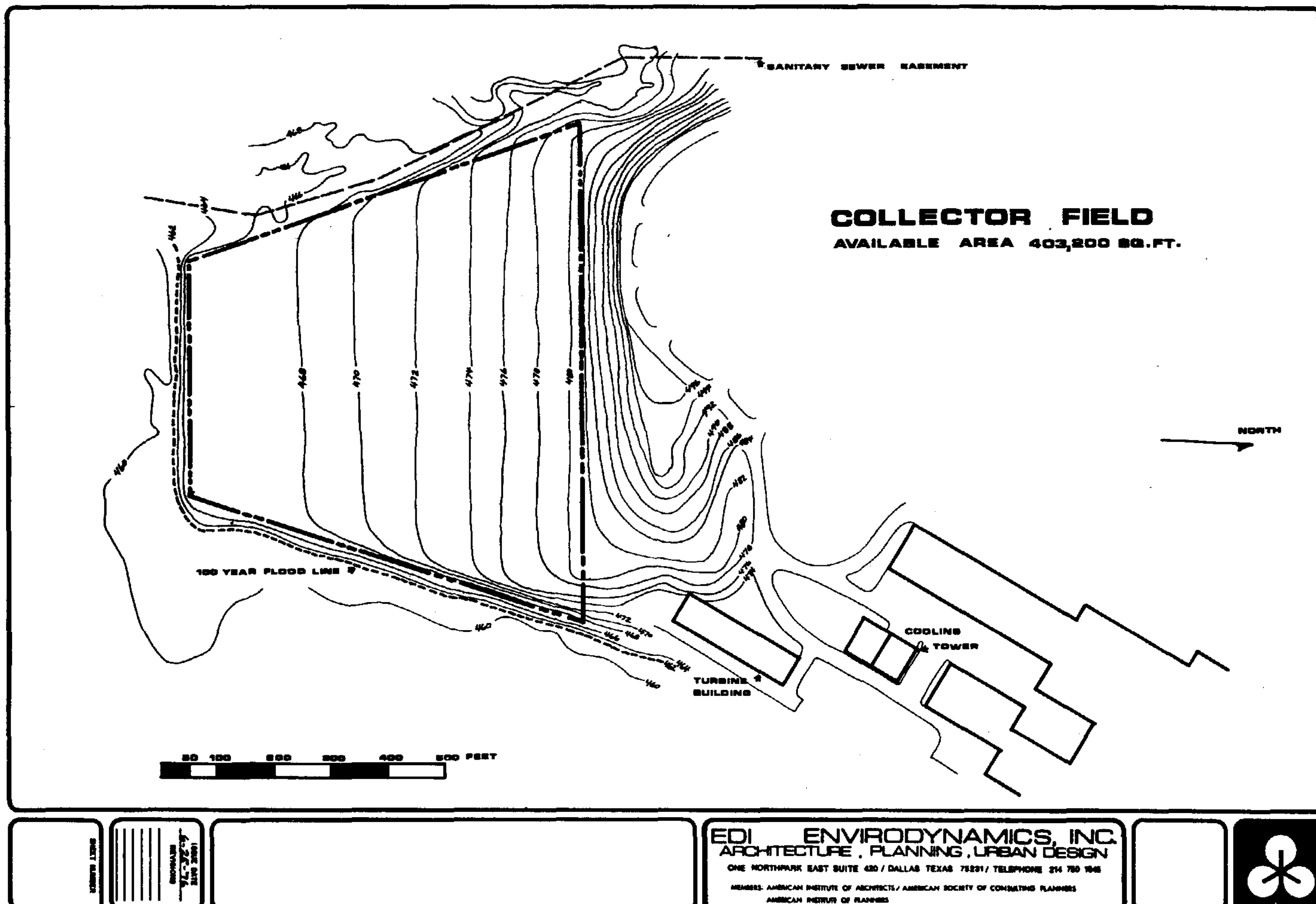
Collector placement and access will be strongly influenced by the cleaning procedures. The reflective coating has a low tolerance to scratching; thus, the cleaning procedure must offer maintenance personnel no opportunity to come in physical contact with it. Further, large dust and dirt patches can cause damage if removed by methods involving physical contact.

Safe cleaning of the reflective coating can be accomplished by a three part process in which large particles are removed by a compressed air jet; smaller particles, dust, and rain mineral deposits are removed by a high pressure water spray containing a mild detergent solution; and finally, the washed surface is sprayed with a deionized water spray containing dispersing agents to prevent spotting.

This three part washing procedure can be done quickly by unskilled people. It can also be adapted to a semi-automatic procedure wherein the equipment can is attached to a vehicle which can be driven by the collector; in this way the time for a one pass wash angle can be reduced considerably.

Within the collector farm a road network is required. To impose the minimum impact on the use of land, collectors can be grouped in rows by twos. Center to center spacing, based on simulated performance for winter solstice, is 3 meters. Separation of the row pairs can be 4.0 meters; this will impose a 16% increase on the collector area yet permit light duty vehicles to drive down the access road when the collector rows, on either side, are rotated to face the roadway. In this way access is permitted for cleaning and maintenance.

8


COLLECTOR FIELD
AVAILABLE AREA 403,200 SQ.FT.
SANITARY SEWER EASEMENT
NORTH
COOLING TOWER
TURBINE BUILDING
100 YEAR FLOOD LINE
468
470
472
474
476
478
480
50 100 200 300 400 500 FEET
EDI ENVIRODYNAMICS, INC.
ARCHITECTURE, PLANNING, URBAN DESIGN
ONE NORTHPARK EAST SUITE 420 / DALLAS TEXAS 75231 / TELEPHONE 214 750 1646
MEMBERS: AMERICAN INSTITUTE OF ARCHITECTS / AMERICAN SOCIETY OF CONSULTING PLANNERS
AMERICAN INSTITUTE OF PLANNERS
ISSUE DATE
6-28-76
REVISIONS
SHEET NUMBER

I.B.7 TANKAGE FOR HIGH TEMPERATURE ENERGY STORAGE

Thermal storage will be required to provide for continued operation of the Power Cycle during temporary periods of overcast and for power generation into the evening.

The storage fluid, Therminol 66, closely approximates the storage requirements for petroleum storage tanks. The temperature profile will range up to 343°C (650°F) and an inert blanket will be required to prevent rapid oxidation of the storage fluid. Two pressures were used in sizing the thermal storage vessels, 4.88 kgs./square meter (1 PSI) and 0.3 kgs/square meter (1 oz. SI). It was found that in large storage tanks pressures above the 4.88 kgs/square meter (1 PSI) imposed restrictions on the design and increased the price of the vessel greatly. Vessel sizes which were investigated were:

9.08×10^6 Liters	2.4×10^6 gallons
5.94×10^6 Liters	1.57×10^6 gallons
1.65×10^6 Liters	4.37×10^5 gallons
1.06×10^6 Liters	2.8×10^5 gallons
6.85×10^5 Liters	1.81×10^5 gallons
4.62×10^5 Liters	1.22×10^5 gallons

Tanks were designed within the scope of American Petroleum Institute (API) Standard 650. Maximum design pressure was determined by:

$$P = \frac{(30,800)\ (A)\ (\tan)}{D^2} + 8t$$

where:

P = internal design pressure, in inches of water

A = area of top angle (or girder) plus the participating roof and shell

θ = angle between the roof and a horizontal plane at the roof shell junction in degrees.

(NOTE: Tan θ is the slope of the roof)

D = diameter of tank in feet

+ = nominal thickness of roof, in inches

and the value of P max (Maximum Pressure) can be determined by:

$$P\ max = \frac{0.245\ W}{D^2} + 8t$$

where:

W = total weight of shell plus any framing supported by shell and roof, in pounds.

Failure pressure can be approximated by:

$$P_F = 1.6\ P - 4.8t$$

P_F = calculated failure pressure, in inches of water.

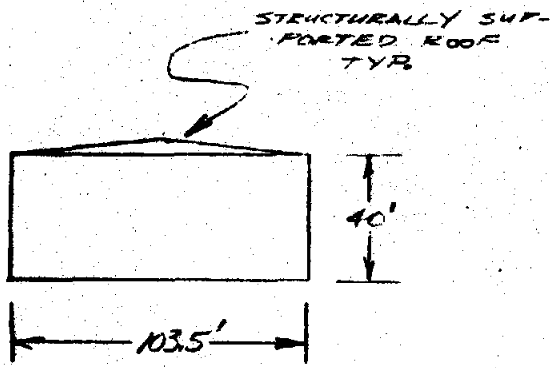
The tank is constructed of A.36 steel and is completely welded.

ALL TANK THIS SHEET DESIGNED TO CONTAIN
THE CAPACITY SHOWN AT ONE OUNCE PER SQUARE INCH.

(#2)

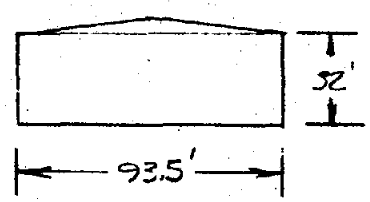
11

2.4 X 10⁶ GAL.



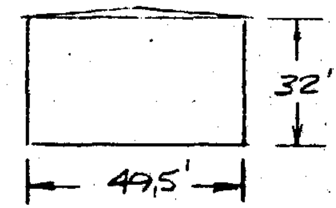
\$182,578.00/TANK

1.57 X 10⁶ GAL



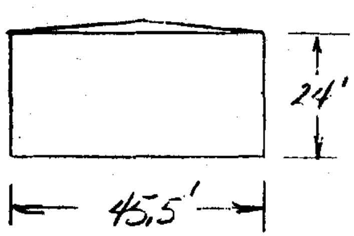
\$151,339.00/TANK

4.37 X 10⁵ GAL.



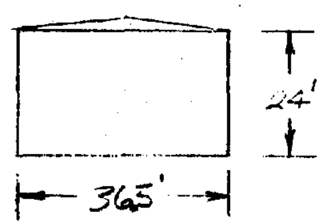
\$60,300.00/TANK

2.8 X 10⁵ GAL



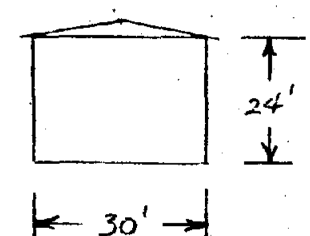
\$47,250.00/TANK

1.81 X 10⁶ GAL.

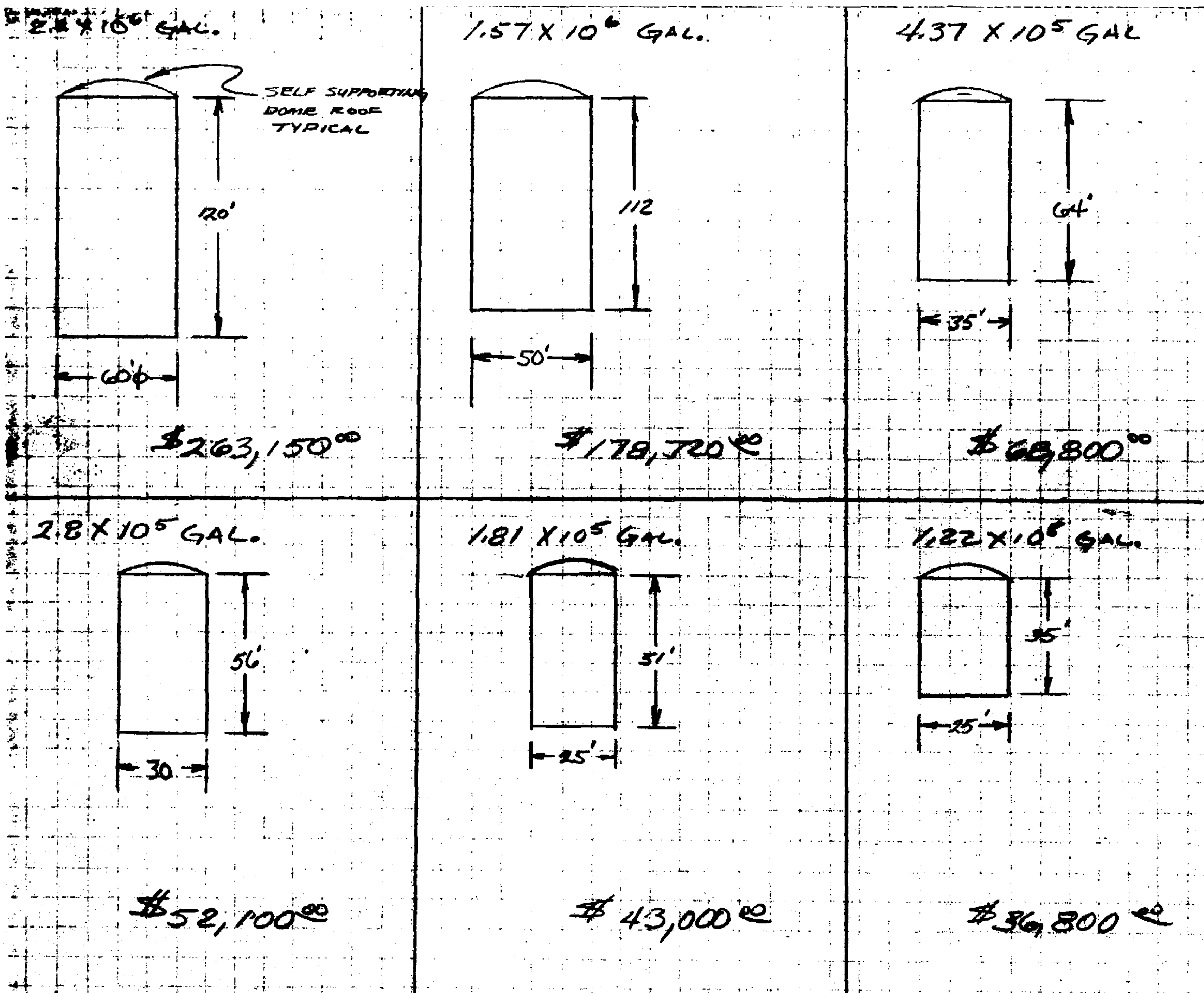


\$36,500.00/TANK

1.22 X 10⁶ GAL.



\$32,400.00/TANK



ALL TANKS THIS SHEET DESIGNED TO CONTAIN THE CAPACITY SHOWN AT 1 PSF INTERNAL PRESSURE. (1)

I.B.8 COOLING TOWER ENERGY REJECTION

A thermal rejection value of 2.108×10^{10} Joules/hour (2×10^7 BTUs/hour) is used for preliminary sizing and comparison of the two available options, cooling towers and lake cooling.

Cooling towers will employ added electrical energy to drive the cooling fans. If electricity is site generated at $8,000 per KW/plant costs, then the apparent cost of traditional cooling towers is considerably increased. If we assume .745 kilowatts per horsepower then each 10 HP used to drive the cooling tower air movement equipment costs $59,600 in electrical power generation equipment. This forces the selection of the equipment to be made on an energy efficient basis rather than on a first cost basis.

Cooling lakes, while very energy efficient, are very space intensive. Employing a cooling rate of 5.67×10^5 Joules per square meter, 3.717×10^4 square meters of lake would be required to deliver effective cooling. Factors determining the cost of lake cooling were set as follows: usable land costs of $2,000 per 4×10^7 meter^2 (1 acre), and price for excavation of earth and dam $1.00 per .764 meter^3 (1 yard^3). The detailed system design stage will indicate and evaluate the most suitable option.

For sizing purposes conditions for cooling tower selection were set as follows:

Heat Rejected (20×10^6 BTU/Hr) 2.108×10^{10} Joules/hr
Flow Rate (2944 GPM) 11,102 liter per min.

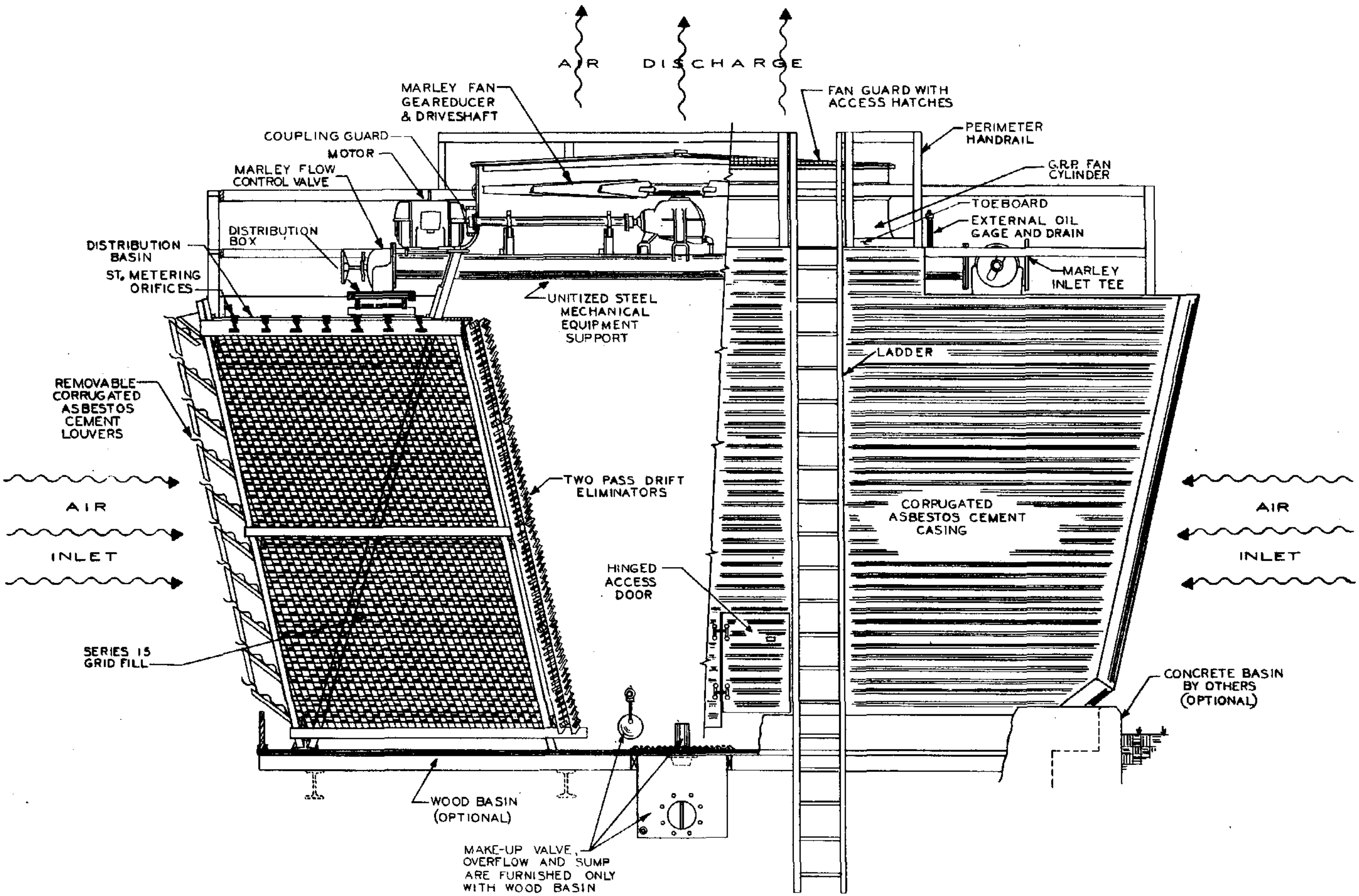
Temperature Drop (100°F to 85°F) 37.7°C to 29.4°C

Outside Wet Bulb (79 F) 26.1°C

Cooling tower information was supplied by the Marley Company, Kansas City, Missouri.

Marley Series	Model #	Cells	& HP	Total HP	Estimated Cost
15	451-302	2	40	80	$32,000
15	452-302	2	20	40	$34,200
15	453-302	2	10	20	$52,000

Using energy efficiency as the major criteria, model 451-302 consumes 60 hp more than the model 453-302. This 60 hp, if expressed in terms of its impact on the power generating cycle, means an increase in the apparent cost of the power cycle, if site generated power is to be used to operate the cooling tower. Using $8,000 per KW/plant cost, 60 HP represents $357,600 of plant cost.



LTR.	DATE	REVISIONS	BY	CHECKED	
C	12-27-72	ERR73-90	TK	RBF	
B	8-4-69	ERR 69-502	JJB	PAG	
A	5-6-68	ERR 68-360	PAG	MJR	

TYPICAL CROSS SECTION
SERIES 15 WOOD DOUBLE FLOW
THE MARLEY COMPANY
KANSAS CITY, MISSOURI

SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	1-28-65	STOTTS	MJR	RGR

Drawing No. 5-3245 Rev. C

Drawing No. 5-3245

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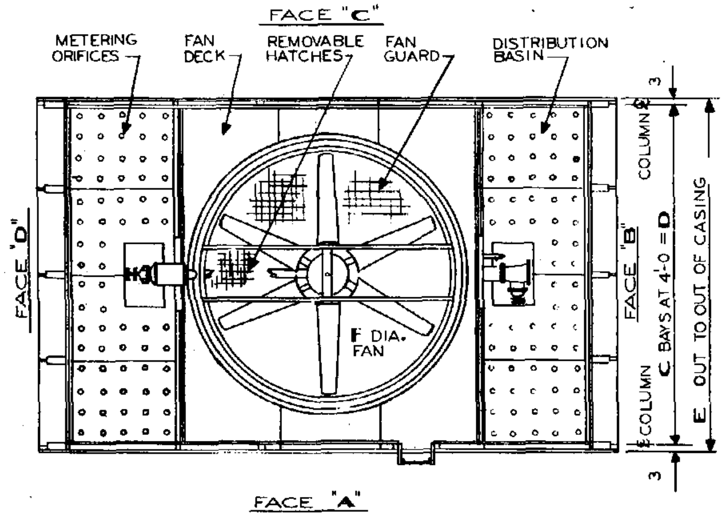
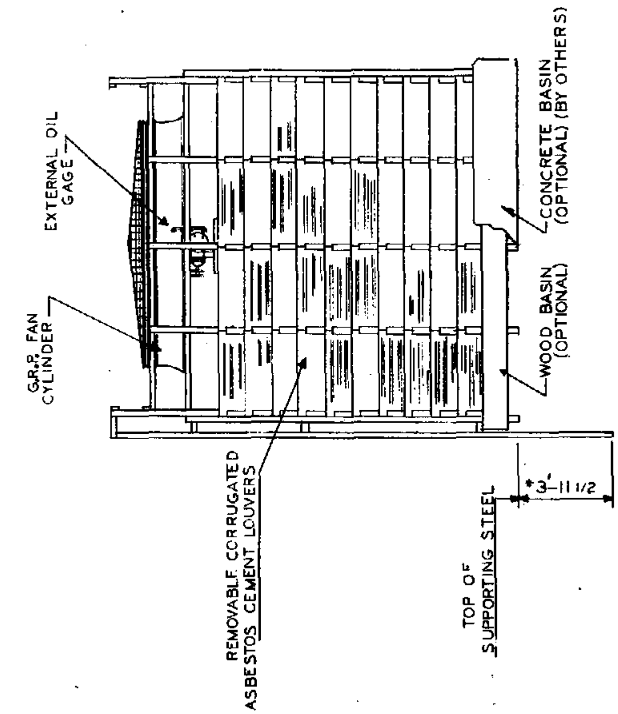


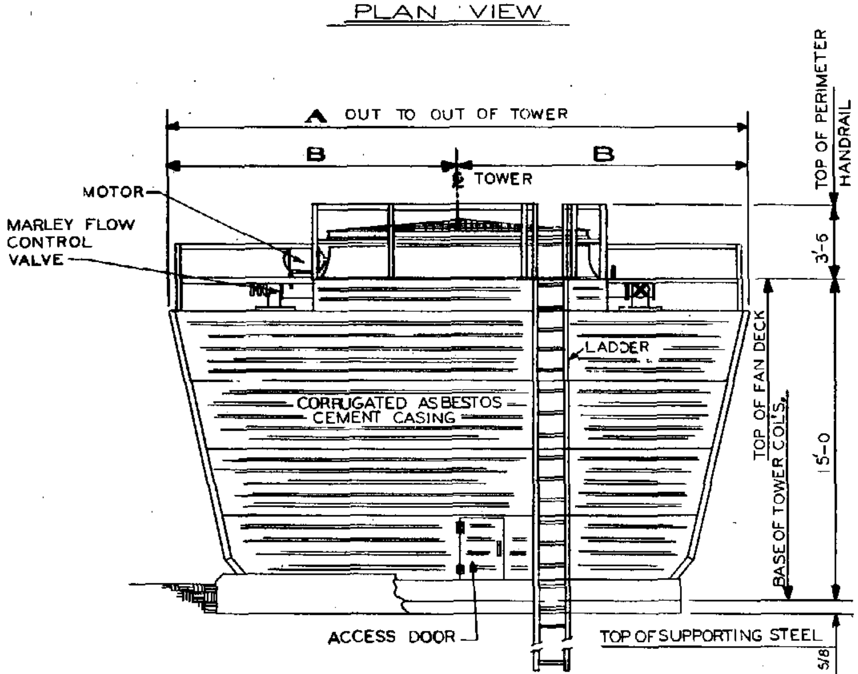
PLAN VIEW



SIDEWALL ELEVATION

FACE "B"

*SPECIAL NOTE
WHERE CONCRETE BASIN IS USED LADDER RESTS ON CONCRETE BASIN WALL



ENDWALL ELEVATION

FACE "A"

NOTE: TOWER INSTALLATIONS WITH AN ELEVATION OF 20'-0 OR MORE FROM THE TOP OF FAN DECK TO GRADE OR ROOF LEVEL REQUIRES A SAFETY CAGE ON TOWER LADDER TO BE IN COMPLIANCE WITH O.S.H.A. STANDARDS. SAFETY CAGE CAN BE PROVIDED AT EXTRA COST.

ALL TOWER INSTALLATIONS REQURE A MINIMUM OF 4'-0 FROM CENTERLINE OF TOWER ENDWALL COLUMN TO ANY VERTICAL OBSTRUCTION AT TOWER LADDER LOCATION.

TOWER DIMENSIONS

MODEL	A	B	C	D	E	F
451-201	25'-0	12'-6	3	12'-0	12'-6	120
452-201	27'-0	13'-6	4	16'-0	16'-6	144
453-201	29'-0	14'-6	5	20'-0	20'-6	168
454-201	29'-0	14'-6	6	24'-0	24'-6	168
456-201	29'-0	14'-6	3	12'-0	12'-6	120
457-201	31'-0	15'-6	4	16'-0	16'-6	144
458-201	33'-0	16'-6	5	20'-0	20'-6	168
459-201	33'-0	16'-6	6	24'-0	24'-6	168

LTR.	DATE	REVISIONS	BY	CHECKED	S.M.
C	12-20-72	ERR73-90	TK	RBF	
B	5-6-68	ERR 68-360	PAG	MJR	
A	4-25-67	ERR 67-262	JKH	MJR	

SCHEMATIC VIEWS
MODELS 451-201 THRU 459-201
SERIES 15 WOOD DF.

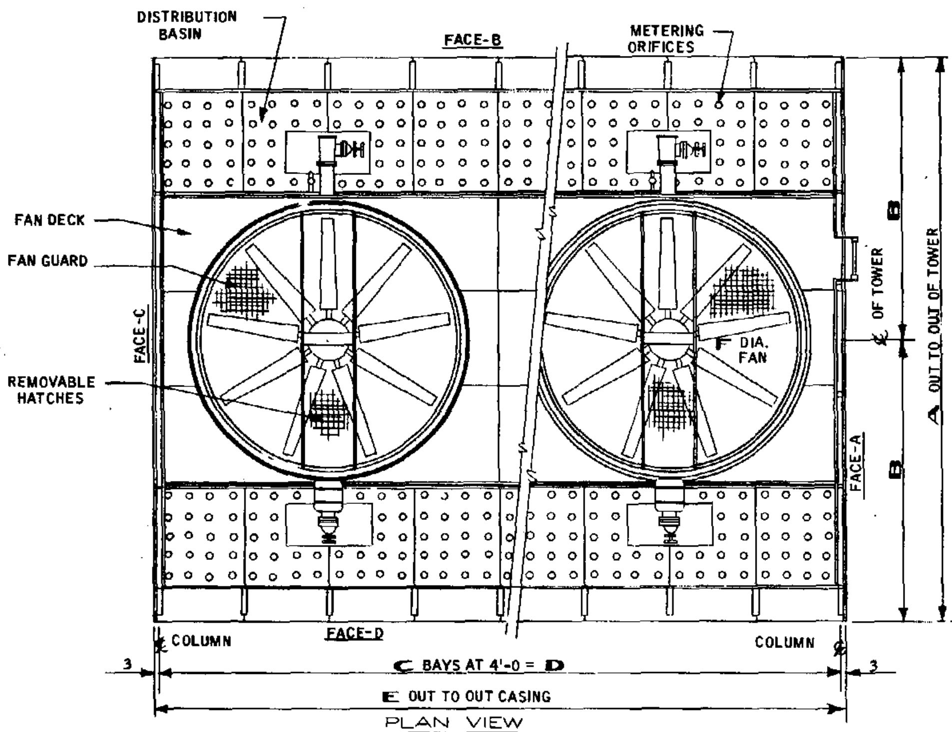
THE MARLEY COMPANY
KANSAS CITY, MISSOURI

MASTER FILE ____ FOREIGN FILE ____

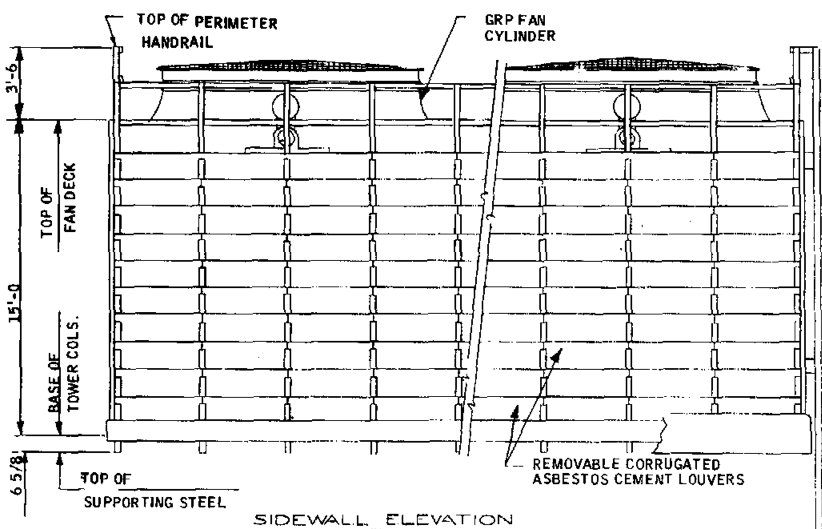
SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	1-13-65	STOTTS	MJR	RGR

Drawing No. 5-3246

.00# ____ Drawing No. 5-3246 Rev. C

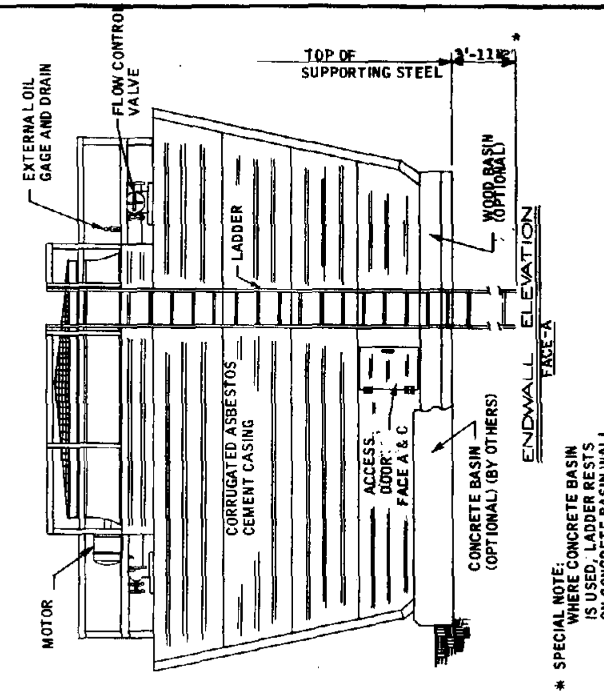


PLAN VIEW



SIDEWALL ELEVATION

FACE-D



ENDWALL ELEVATION

FACE-A

* SPECIAL NOTE: WHERE CONCRETE BASIN IS USED, LADDER RESTS ON CONCRETE BASIN WALL

NOTE: TOWER INSTALLATIONS WITH AN ELEVATION OF 20'-0 OR MORE FROM THE TOP OF FAN DECK TO GRADE OR ROOF LEVEL REQUIRE A SAFETY CAGE ON TOWER LADDER TO BE IN COMPLIANCE WITH O.S.H.A. STANDARDS. SAFETY CAGE CAN BE PROVIDED AT EXTRA COST.

ALL TOWER INSTALLATIONS REQUIRE A MINIMUM OF 4'-0 FROM CENTERLINE OF TOWER ENDWALL COLUMN TO ANY VERTICAL OBSTRUCTION AT TOWER LADDER LOCATION.

TOWER DIMENSIONS

MODEL	A	B	C	D	E	F
451 - 202	25'-0	12'-6	6	24'-0	24'-6	120
451 - 203	25'-0	12'-6	9	36'-0	36'-6	120
452 - 202	27'-0	13'-6	8	32'-0	32'-6	144
452 - 203	27'-0	13'-6	12	48'-0	48'-6	144
453 - 202	29'-0	14'-6	10	40'-0	40'-6	168
453 - 203	29'-0	14'-6	15	60'-0	60'-6	168
454 - 202	29'-0	14'-6	12	48'-0	48'-6	168
454 - 203	29'-0	14'-6	18	72'-0	72'-6	168
456 - 202	29'-0	14'-6	6	24'-0	24'-6	120
456 - 203	29'-0	14'-6	9	36'-0	36'-6	120
457 - 202	31'-0	15'-6	8	32'-0	32'-6	144
457 - 203	31'-0	15'-6	12	48'-0	48'-6	144
458 - 202	33'-0	16'-6	10	40'-0	40'-6	168
458 - 203	33'-0	16'-6	15	60'-0	60'-6	168
459 - 202	33'-0	16'-6	12	48'-0	48'-6	168
459 - 203	33 -0	16'-6	18	72'-0	72'-6	168

LTR.	DATE	REVISIONS	BY	CHECKED	E.M.
C	1-5-73	ERR 73-90	TK	RBF	
B	5-6-68	ERR 68-360	JOB	MJR	
A	7-27-67	ERR 67-262	ERR	MJR	

SCHEMATIC VIEWS
MODELS 451-202 THRU 459-203
SERIES 15 WOOD D.F.

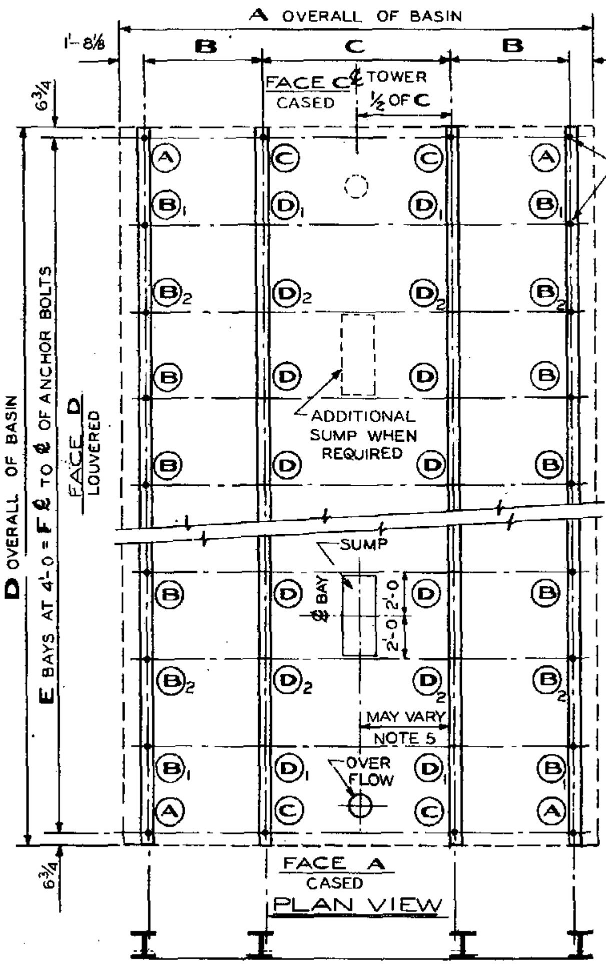
THE MARLEY COMPANY
KANSAS CITY, MISSOURI

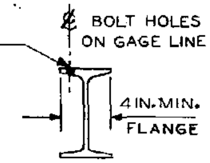
MASTER FILE ____ FOREIGN FILE ____

SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	1-15-65	STOTTS	MJR	RGR

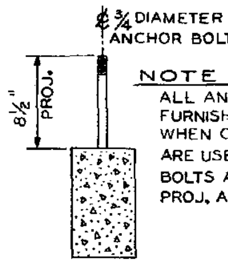
Drawing No. 5-3247

.00= ____ Drawing No. 5-3247 Rev. C





TYPICAL STEEL BEAM



OPTIONAL CONCRETE BEAM

NOTE
ALL ANCHOR BOLTS ARE FURNISHED BY PURCHASER WHEN CONCRETE BEAMS ARE USED IN LIEU OF STEEL. BOLTS ARE ¾" DIA. WITH 8½" PROJ. AND 1½ MIN. THD.

TOWER MODEL	TOWER WEIGHT*	TOWER DIMENSIONS A	B	C	D	E	F	G
451-201	37280	19'-0½	5'-6	4'-8¼	13'-1½	3	12'-0	12
452-201	48700	21'-0½	5'-6	6'-8¼	17'-1½	4	16'-0	14
453-201	61860	23'-0½	5'-6	8'-8¼	21'-1½	5	20'-0	16
454-201	72220	23'-0½	5'-6	8'-8¼	25'-1½	6	24'-0	18
456-201	45560	23'-0½	7'-6	4'-8¼	13'-1½	3	12'-0	12
457-201	59560	25'-0½	7'-6	6'-8¼	17'-1½	4	16'-0	14
458-201	75220	27'-0½	7'-6	8'-8¼	21'-1½	5	20'-0	16
459-201	88090	27'-0½	7'-6	8'-8¼	25'-1½	6	24'-0	18
451-202	71390	19'-0½	5'-6	4'-8¼	25'-1½	6	24'-0	18
452-202	93420	21'-0½	5'-6	6'-8¼	33'-1½	8	32'-0	22
453-202	119160	23'-0½	5'-6	8'-8¼	41'-1½	10	40'-0	26
454-202	139660	23'-0½	5'-6	8'-8¼	49'-1½	12	48'-0	30
456-202	87290	23'-0½	7'-6	4'-8¼	25'-1½	6	24'-0	18
457-202	114440	25'-0½	7'-6	6'-8¼	33'-1½	8	32'-0	22
458-202	145170	27'-0½	7'-6	8'-8¼	41'-1½	10	40'-0	26
459-202	170710	27'-0½	7'-6	8'-8¼	49'-1½	12	48'-0	30
451-203	105500	19'-0½	5'-6	4'-8¼	37'-1½	9	36'-0	24
452-203	138140	21'-0½	5'-6	6'-8¼	49'-1½	12	48'-0	30
453-203	176460	23'-0½	5'-6	8'-8¼	61'-1½	15	60'-0	36
454-203	207100	23'-0½	5'-6	8'-8¼	73'-1½	18	72'-0	42
456-203	129020	23'-0½	7'-6	4'-8¼	37'-1½	9	36'-0	24
457-203	169320	25'-0½	7'-6	6'-8¼	49'-1½	12	48'-0	30
458-203	215120	27'-0½	7'-6	8'-8¼	61'-1½	15	60'-0	36
459-203	253330	27'-0½	7'-6	8'-8¼	73'-1½	18	72'-0	42

* TOWER WEIGHT IS TOTAL WET OPERATING WEIGHT.

LOAD SCHEDULE	LOAD POINT	TOWER MODEL 451	452	453	454	456	457	458	459
DEAD LOAD	A	1910	1910	1915	1915	2340	2345	2350	2350
	B	3430	3300	3305	3245	4015	3920	3920	3875
	C	1725	1880	2090	2090	2095	2255	2465	2460
	D	2255	2290	2425	2375	2940	2940	3075	3010
ADDITIONAL REACTIONS AT LOAD POINTS DUE TO WIND LOAD ON FACE B OR D	C	1550	1550	1550	1550	1130	1130	1130	1130
	D	3100	3100	3100	3100	2260	2260	2260	2260
ADDITIONAL REACTIONS AT LOAD POINTS DUE TO WIND LOAD ON FACE A OR C	B_1	905	905	905	905	1180	1180	1180	1180
	B_2	520	520	520	520	680	680	680	680
	D_1	905	905	905	905	1180	1180	1180	1180
	D_2	2890	3340	3880	3880	3045	3500	4040	4040

GENERAL NOTES

1. SUPPORTING STEEL

PURCHASER TO DESIGN, CONSTRUCT AND FURNISH SUPPORTING STEEL COMPLETE WITH ⅞ DIA. HOLES FOR ANCHOR BOLTS TO SUIT THE GENERAL DIMENSIONS OF THIS DRAWING. ALL STEEL MUST BE FRAMED FLUSH AND LEVEL AT TOP. MAXIMUM BEAM DEFLECTION TO BE $\frac{1}{360}$ OF SPAN, NOT TO EXCEED ½ INCH. FLANGE WIDTH TO BE A MINIMUM OF 4 INCHES. PROVIDE CLEARANCE BELOW STEEL FOR SUMP AND PIPING.

2. TOWER DEAD LOADS

DEAD LOADS INCLUDE FIVE INCHES OF WATER IN THE COLLECTION BASIN. THIS IS THE RECOMMENDED OPERATING WATER LEVEL.

3. TOWER LIVE LOADS

WIND LOADS ARE CALCULATED ON A BASIS OF THIRTY POUNDS PER SQUARE FOOT. LIVE LOADS ARE ADDITIVE TO DEAD LOADS.

4. ANCHOR BOLTS

ALL ANCHOR BOLTS ARE ¾ DIAMETER. ANCHOR BOLTS ARE FURNISHED BY MARLEY CO. FOR STEEL BEAM CONSTRUCTION ONLY

5. SUMP AND OVERFLOW

THE SUMP MAY BE LOCATED AS SHOWN ON THE ℄ OF ANY BAY (EXCEPT END BAYS) OR ROTATED 90°. LOCATE OVERFLOW TO SUIT BETWEEN CENTER BEAMS (EXCEPT ON COLUMN LINES). SEE SUMP & OVERFLOW DRAWINGS FOR DETAILED CLEARANCE DIMENSIONS.

6. TOWER OBSTRUCTIONS

MAINTAIN TWO FEET OF CLEAR SPACE AT CASED WALLS, FACES A AND C FOR CONSTRUCTION. LOUVERED WALLS, FACES B AND D, MUST HAVE ADEQUATE AIR SUPPLY. IF OBSTRUCTIONS EXIST NEARBY, CONSULT A MARLEY SALES ENGINEER.

LTR.	DATE	REVISIONS	BY	CHECKED	B.M.
A	7-9-65	ERR 8346	JAC	DWL	

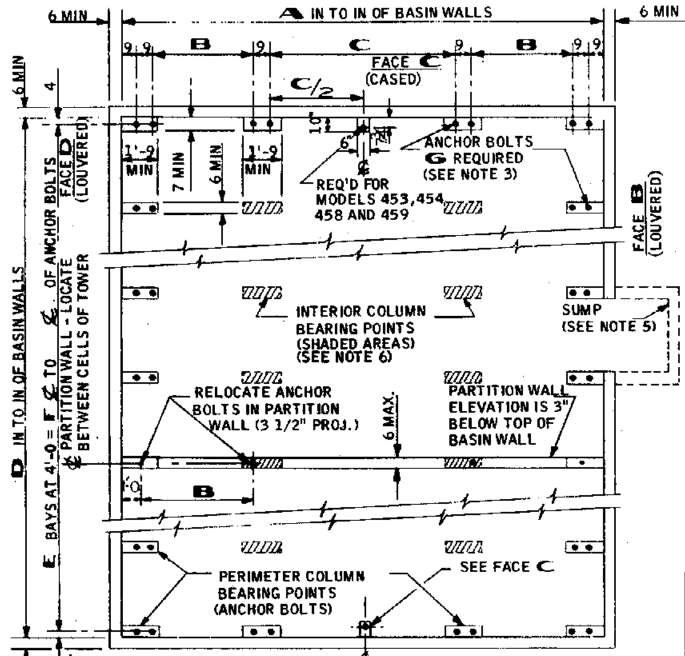
SUGGESTED SUPPORTING STEEL ARRANGEMENT - WOOD BASIN SERIES 15 DOUBLE-FLOW

THE MARLEY COMPANY
KANSAS CITY, MISSOURI

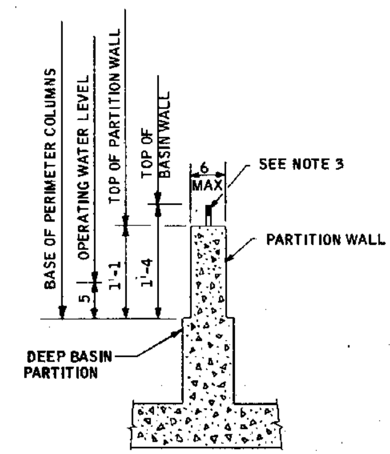
SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	1-20-65	STOTTS	MJR	RGR

Drawing No. 5 3248

.00# Drawing No. 5-3248 Rev. A



PLAN VIEW



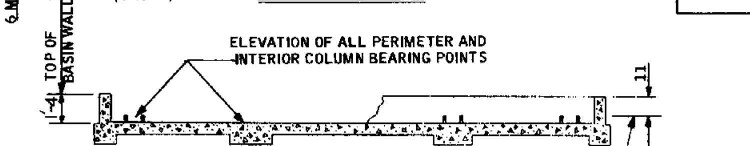
CROSS SECTION OF BASIN PARTITION

PARTITION OPTIONAL

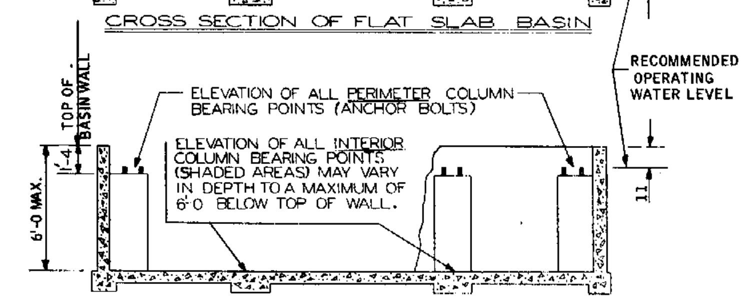
STANDARD TOWER DOES NOT REQUIRE PARTITION WALL. (SEE NOTE 8)

CAUTION

ELEVATION OF ALL PERIMETER AND INTERIOR COLUMN BEARING POINTS MUST BE TO INSTRUMENT LEVEL WITH TOLERANCE NO GREATER THAN + OR - 1/8". INSIDE FACE OF CURB FACES A AND C MUST BE TRUE TO + OR - 1/4". ANCHOR BOLTS MUST BE LOCATED ON CENTERS SHOWN WITH TOLERANCE NO GREATER THAN + OR - 1/8 INCH.



CROSS SECTION OF FLAT SLAB BASIN



CROSS SECTION OF DEEP BASIN
(SEE NOTE 7)

TOWER MODEL	TOWER WEIGHT **	BASIN DIMENSIONS A	B	C	D	E	F	G
451-201	28560	18'-8	4'-9	4'-8	12'-8	3	12'-0	24
452-201	36280	20'-8	4'-9	6'-8	16'-8	4	16'-0	28
453-201	45140	22'-8	4'-9	8'-8	20'-8	5	20'-0	34
454-201	52410	22'-8	4'-9	8'-8	24'-8	6	24'-0	38
456-201	35060	22'-8	6'-9	4'-8	12'-8	3	12'-0	24
457-201	44820	24'-8	6'-9	6'-8	16'-8	4	16'-0	28
458-201	55660	26'-8	6'-9	8'-8	20'-8	5	20'-0	34
459-201	64960	26'-8	6'-9	8'-8	24'-8	6	24'-0	38
451-202	55020	18'-8	4'-9	4'-8	24'-8	6	24'-0	36
452-202	69720	20'-8	4'-9	6'-8	32'-8	8	32'-0	44
453-202	86990	22'-8	4'-9	8'-8	40'-8	10	40'-0	54
454-202	101310	22'-8	4'-9	8'-8	48'-8	12	48'-0	62
456-202	67520	22'-8	6'-9	4'-8	24'-8	6	24'-0	36
457-202	86340	24'-8	6'-9	6'-8	32'-8	8	32'-0	44
458-202	107560	26'-8	6'-9	8'-8	40'-8	10	40'-0	54
459-202	125920	26'-8	6'-9	8'-8	48'-8	12	48'-0	62
451-203	81480	18'-8	4'-9	4'-8	36'-8	9	36'-0	48
452-203	103160	20'-8	4'-9	6'-8	48'-8	12	48'-0	60
453-203	128840	22'-8	4'-9	8'-8	60'-8	15	60'-0	74
454-203	150210	22'-8	4'-9	8'-8	72'-8	18	72'-0	86
456-203	99980	22'-8	6'-9	4'-8	36'-8	9	36'-0	48
457-203	127860	24'-8	6'-9	6'-8	48'-8	12	48'-0	60
458-203	159460	26'-8	6'-9	8'-8	60'-8	15	60'-0	74
459-203	186880	26'-8	6'-9	8'-8	72'-8	18	72'-0	86

** TOWER WEIGHT IS TOTAL WET OPERATING WEIGHT OF TOWER ONLY. EXCLUDING WATER IN CONCRETE BASIN

GENERAL NOTES

1. BASIN CONSTRUCTION
PURCHASER TO DESIGN, CONSTRUCT AND FURNISH FOUNDATION COMPLETE TO SUIT THE GENERAL DIMENSIONS OF THIS DRAWING. NO DETAILED STRUCTURAL FEATURES SUCH AS REINFORCING ARE SHOWN. BASIN DESIGNER SHOULD REFER TO SCHEMATIC VIEWS TO AVOID LOCATION OF SUMP SCREENS, PUMPS AND ADJACENT EQUIPMENT THAT WILL INTERFERE WITH SLOPING AND OVERHANGING TOWER FACES OR OTHER OBSTRUCTIONS.
2. TOWER OBSTRUCTIONS
MAINTAIN TWO FEET OF CLEAR SPACE AT CASED WALLS, FACES A AND C, FOR CONSTRUCTION. LOUVERED WALLS FACES B AND D, MUST HAVE ADEQUATE AIR SUPPLY. IF OBSTRUCTIONS EXIST NEARBY CONSULT A MARLEY SALES ENGINEER.
3. ANCHOR BOLTS
ALL ANCHOR BOLTS COMPLETE WITH NUT AND WASHER FURNISHED BY PURCHASER. BOLTS ARE 5/8" DIAMETER 1 1/2" ALL THREAD PROJECTION EXCEPT PARTITION WALL ANCHOR BOLTS MUST HAVE 3 1/2" PROJECTION.
4. LIVE LOADS
WIND LOADS ARE CALCULATED ON A BASIS OF THIRTY POUNDS PER SQUARE FOOT.
5. SUMP AND OVERFLOW
PURCHASER TO DESIGN, CONSTRUCT AND FURNISH SUMP AND OVERFLOW TO SUIT REQUIREMENTS. FOR SUGGESTED DESIGN INFORMATION SEE DWG. 0-3178.
6. INTERIOR COLUMN BEARING POINTS
INTERIOR COLUMN BEARING POINTS WILL MOVE TOWARDS BASIN CENTERLINE AT A RATE OF 2 11/16" FOR EVERY 1'-0" OF EXTENSION BELOW TOP OF PERIMETER COLUMN BEARING POINTS.
7. DEEP BASIN (ALTERNATE TO FLAT SLAB BASIN)
TOWER STRUCTURE FOR DEEP BASIN REQUIRES EXTENDED INTERIOR COLUMNS FURNISHED AT EXTRA COST.
8. BASIN PARTITION
OPTIONAL BY PURCHASER WHEN DESIRED FOR INDIVIDUAL CELL OPERATION. PURCHASER MUST INFORM THE MARLEY COMPANY IF BASIN PARTITIONS ARE POURED TO INSURE PROPER TOWER FABRICATION. TOP OF PARTITION WALLS MUST BE TO INSTRUMENT LEVEL WITH TOLERANCE NO GREATER THAN + OR - 1/8 INCH.

LOAD SCHEDULE	TOWER MODEL 451	452	453	454	456	457	458	459
MAX. DEAD LOAD ANY COLUMN BEARING POINT	2830	2700	2705	2645	3280	3190	3190	3145
MAX. LIVE LOAD ANY COLUMN BEARING POINT *	3100	3340	3880	3880	3045	3500	4040	4040
MAX. NET UPLIFT ANY SINGLE ANCHOR BOLT	1275	1470	1680	1680	1350	1545	1760	1760
MAX. HORIZ. LOAD ANY SINGLE ANCHOR BOLT	1805	2050	2330	2330	2010	2255	2535	2535

* VERTICAL COMPRESSION

LTR.	DATE	REVISIONS	BY	CHECKED	S.M.
C	1-5-73	ERR 73-90	TK	RBF	
B	4-25-67	ERR 67-271	JKH	MJR	
A	11-3-65	ERR 8492	DWL	PBS	

CONCRETE BASIN DIMENSIONS AND LOAD SCHEDULE FOR SERIES 15 WOOD DOUBLE-FLOW

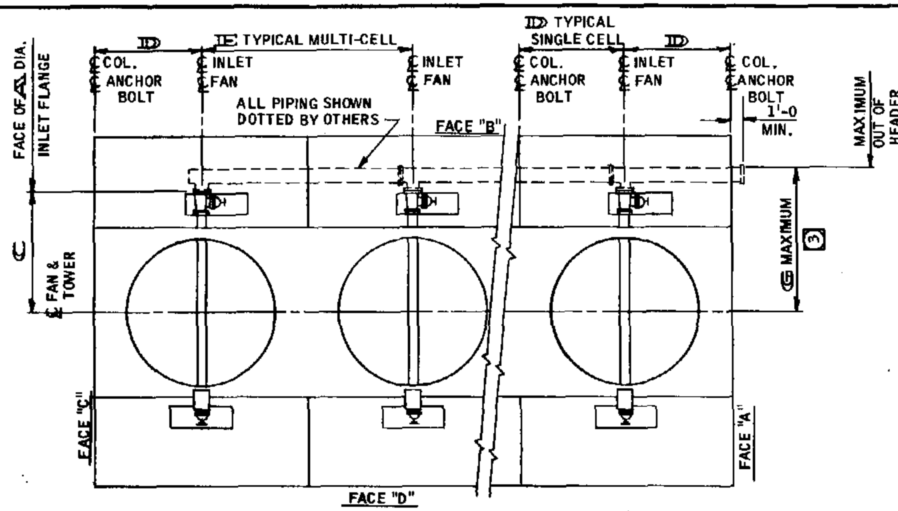
THE MARLEY COMPANY

MASTER FILE MISSION, KANSAS 66202 FOREIGN FILE

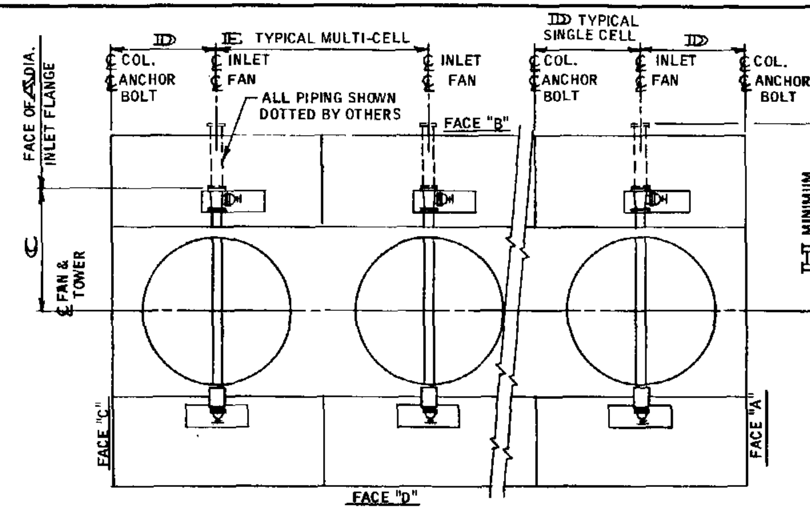
SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	1-26-65	STOTTS	MJR	RGR

Drawing No. 5-3249

.00= Drawing No. 5-3249 Rev. C



PIPING ARRANGEMENT PLAN II
INLET OVER CASED WALL



PIPING ARRANGEMENT PLAN III
INLET OVER LOUVERED WALL

	TOWER MODEL	A*	B	C*	D	E	F	G	H
	451	10	8	9'-0 1/2	6'-0	12'-0	14'-5 3/4	10'-9	13'-6
*	452	10	8	10'-0 1/2	8'-0	16'-0	14'-5 3/4	11'-9	14'-6
	453	12	10	11'-4 1/2	10'-0	20'-0	14'-4 3/4	12'-9	15'-6
*	454	12	10	11'-4 1/2	12'-0	24'-0	14'-4 3/4	12'-9	15'-6
	456	10	8	9'-0 1/2	6'-0	12'-0	14'-5 3/4	12'-9	15'-6
	457	10	8	10'-0 1/2	8'-0	16'-0	14'-5 3/4	13'-9	16'-6
*	458	12	10	11'-4 1/2	10'-0	20'-0	14'-4 3/4	14'-9	17'-6
*	459	12	10	11'-4 1/2	12'-0	24'-0	14'-4 3/4	14'-9	17'-6

*FOR GPM'S THAT EXCEED 3690 GPM PER CELL FOR MODEL 452, 5300 GPM PER CELL FOR MODEL 454, 5300 GPM PER CELL FOR MODEL 458 AND 5300 GPM PER CELL FOR MODEL 459, TABLE BELOW MUST BE USED.

TOWER MODEL	A	B	C	D	E	F	G	H
452	12	8	10'-6 1/2	8'-0	16'-0	14'-5 3/4	11'-9	14'-6
454	14	10	11'-4 1/2	12'-0	24'-0	14'-4 3/4	12'-9	15'-6
458	14	10	11'-4 1/2	10'-0	20'-0	14'-4 3/4	14'-9	17'-6
459	14	10	11'-4 1/2	12'-0	24'-0	14'-4 3/4	14'-9	17'-6

CAUTION
DO NOT SUPPORT RISER FROM TOWER STRUCTURE

SUPPORTS ON TOWER FOR HEADER AND CROSSOVER FURNISHED BY THE MARLEY CO.

GENERAL NOTES

1. PUMPING HEAD

   PUMPING HEAD WILL VARY ACCORDING TO TOWER G.P.M. PUMPING HEAD REQUIRED FOR MARLEY PIPEWORK ONLY WILL BE FURNISHED AT TIME OF PROPOSAL. FOR STATIC LIFT SEE DIMENSION F IN TABLE.

2. HEADER LOCATION

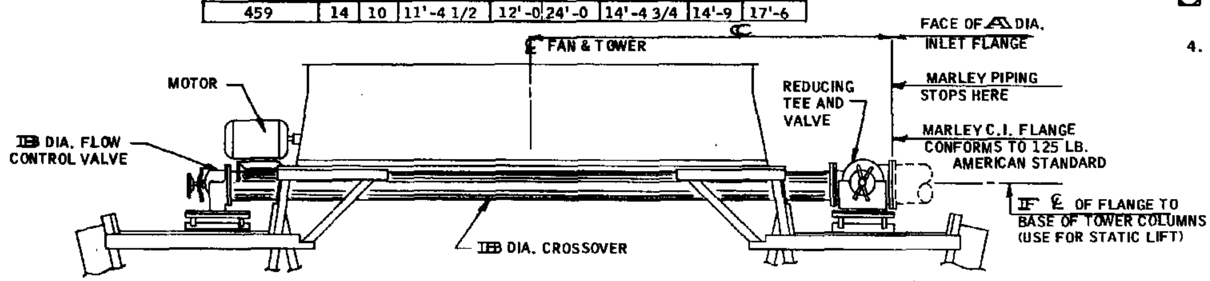
   HEADER SHOULD BE LOCATED OPPOSITE MOTOR WHEN POSSIBLE FOR BETTER DISTRIBUTION OF TOWER DEAD LOADS.

3. HEADER CLEARANCE

   IF G DIMENSION IS EXCEEDED, PLAN III PIPING MUST BE USED.

4. HEADER SIZE

   MAXIMUM HEADER SIZE IS 20 DIAMETER UNLESS ECCENTRIC CONN. TO CROSSOVER IS FURNISHED. CONSULT MARLEY ENGINEERING IF HEADER PIPE EXCEEDS 24 DIA. SPECIAL SUPPORTS MUST BE FURNISHED.



CROSS SECTION OF DISTRIBUTION SYSTEM

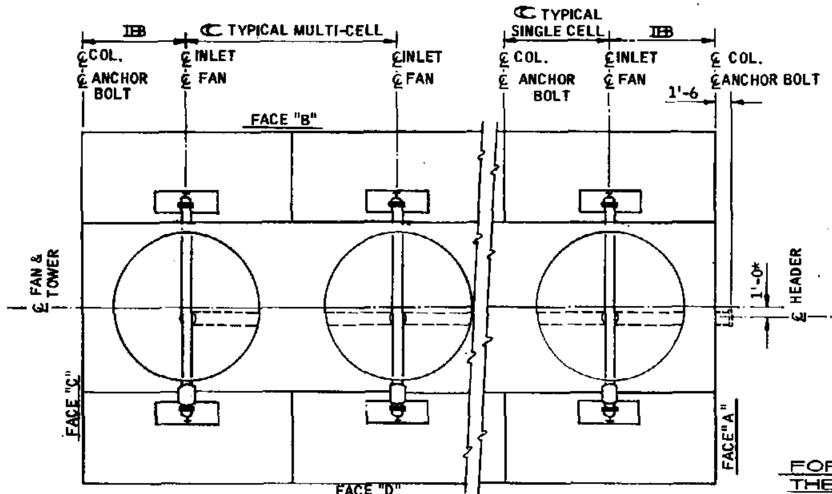
LTR.	DATE	REVISIONS	BY	CHECKED	
C	4-22-74	ERR 74-389	RBF	WES	
B	6-20-73	ERR 73-483	MRC	WES	
A	3-12-69	ERR 69-263	PWM	KAV	

EXTERNAL PIPING ARRANGEMENT
PLAN II & PLAN III PIPING
SERIES 15, M15, & F15 DOUBLE-FLOW
THE MARLEY COMPANY
MASTER FILE ____ MISSION, KANSAS 66202 FOREIGN FILE ____

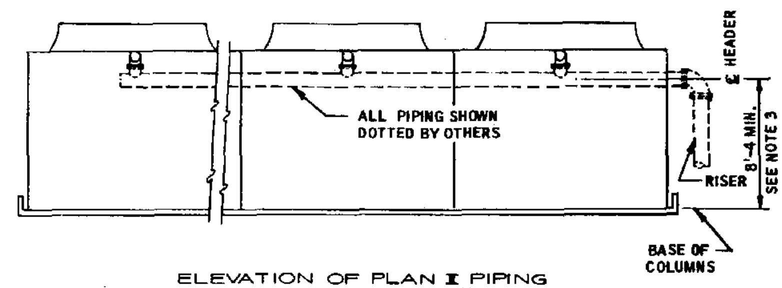
SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	10-4-60	R.L. FRANK	WAW	ARM

Drawing No. O-811

.00# ____ Drawing No. O-811 Rev. C



PIPING ARRANGEMENT PLAN I



ELEVATION OF PLAN I PIPING

CAUTION

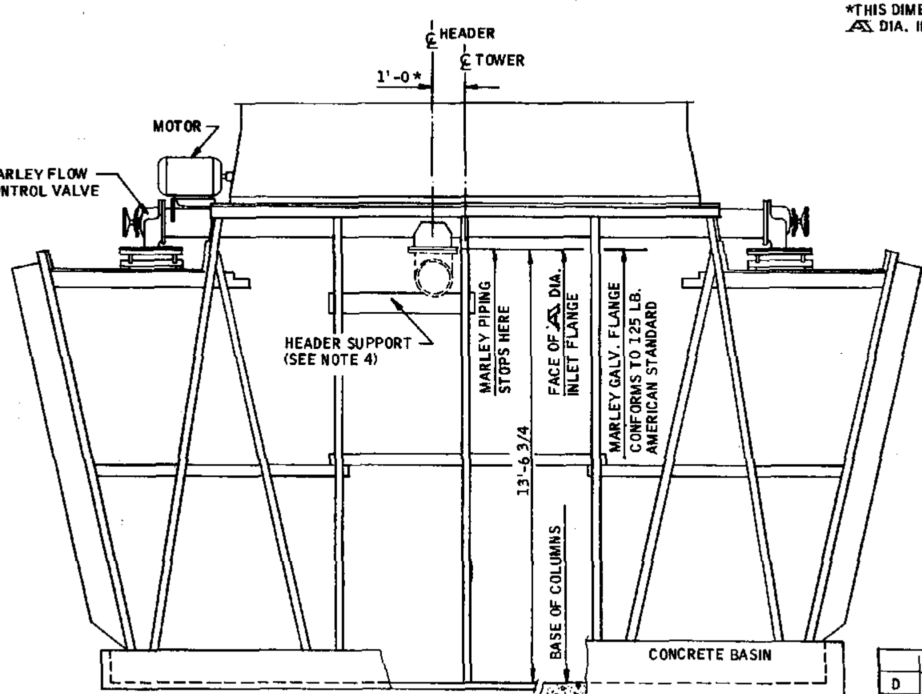
FOR MAXIMUM FAN EFFICIENCY THE HEADER PIPE SIZE SHOULD NOT EXCEED 20 INCH DIAMETER

GPM RANGE MIN.	GPM RANGE MAX.	A
240	900	6
901	1600	8
1601	2500	10
2501	3500	12
3501	4800	14
4801	6000	16

GPM PER CELL

TOWER MODEL	B	C
451	6'-0	12'-0
452	8'-0	16'-0
453	10'-0	20'-0
454	12'-0	24'-0
456	6'-0	12'-0
457	8'-0	16'-0
458	10'-0	20'-0
459	12'-0	24'-0

*THIS DIMENSION WILL VARY WHEN A DIA. INLET EXCEEDS 10".



CROSS SECTION OF DISTRIBUTION SYSTEM

GENERAL NOTES

1. PUMPING HEAD:

   PUMPING HEAD WILL VARY ACCORDING TO TOWER G.P.M. PUMPING HEAD REQUIRED FOR MARLEY PIPEWORK ONLY WILL BE FURNISHED AT TIME OF PROPOSAL. STATIC LIFT IS 14'-6 FROM BASE OF TOWER COLUMNS.

2. INLET LOCATION: *

   INLET WILL ALWAYS BE OFFSET ONE FOOT ON MOTOR SIDE OF TOWER.

3. HEADER ELEVATION:

   HEADER MAY BE LOCATED AT ANY CONVENIENT ELEVATION ABOVE 8'-4 FROM BASE OF TOWER COLUMNS.

4. HEADER SUPPORTS:

   HEADER SUPPORTS INSIDE OF TOWER WILL BE FURNISHED BY THE MARLEY COMPANY ON WOOD TOWERS AND MUST BE FURNISHED BY OTHERS ON STEEL TOWERS. DO NOT SUPPORT RISER FROM TOWER PROPER.

LTR.	DATE	REVISIONS	BY	CHECKED	E.M.
D	6-20-73	ERR 73-483	MRC	WES	
C	3-6-72	ERR 72-176	KBW	MJR	
B	8-23-65	ERR 8427	DKS	PBS	
A	3-1-61	ERR 5942	RLF	WAW	

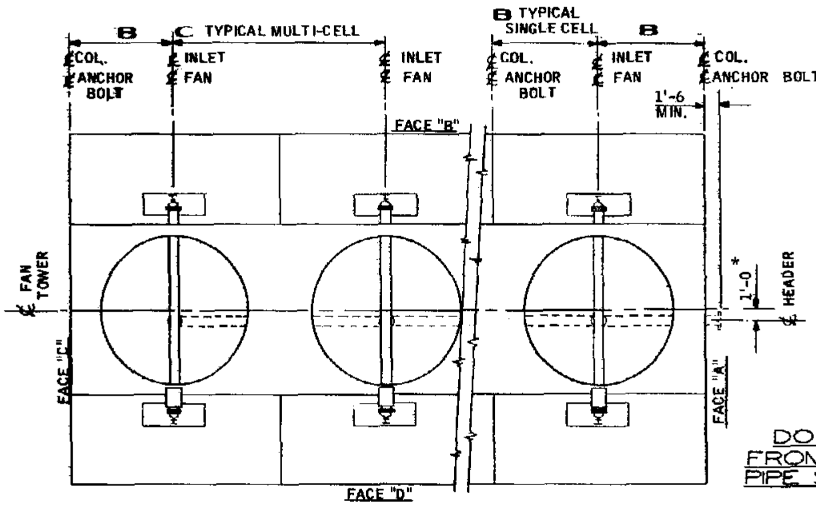
INTERNAL PIPING ARRANGEMENT PLAN I
SERIES 15, M15, & F15 DOUBLE-FLOW

THE MARLEY COMPANY
MASTER FILE ____ MISSION KANSAS 66202 FOREIGN FILE ____

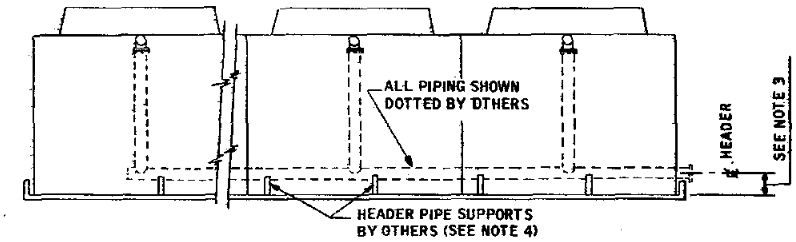
SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	3-1-61	R. L. FRANK	WAW	ARM

Drawing No. 9-3786

.00= ____ Drawing No. 9-3876 Rev. D



PIPING ARRANGEMENT PLAN V
INLET THROUGH CASED WALL



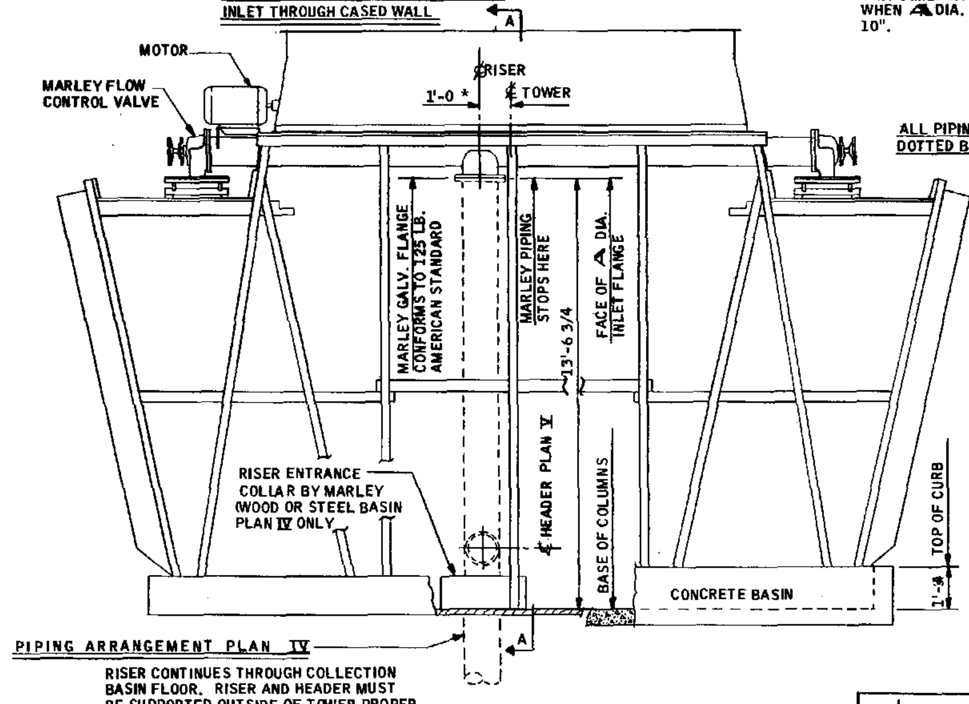
ELEVATION OF PLAN V PIPING

CAUTION
DO NOT SUPPORT PIPING FROM TOWER STRUCTURE
PIPE SUPPORTS BY OTHERS

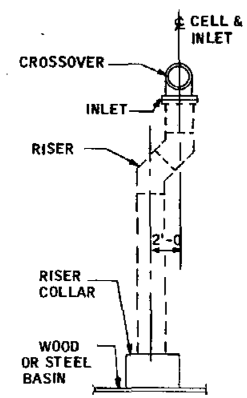
*THIS DIMENSION WILL VARY WHEN A DIA. INLET EXCEEDS 10".

GPM RANGE MIN.	GPM RANGE MAX.	A
240	900	6
901	1600	8
1601	2500	10
2501	3500	12
3501	4800	14
4801	6000	16

TOWER MODEL	B	C
451	6'-0	12-0
452	8'-0	16'-0
453	10'-0	20'-0
454	12'-0	24'-0
456	6'-0	12'-0
457	8'-0	16'-0
458	10'-0	20'-0
459	12'-0	24'-0



CROSS SECTION OF DISTRIBUTION SYSTEM



SECTION A-A
OFFSET RISER COLLAR TOWARD FACE "A" (MODELS 452, 454, 457 & 459 ONLY)

GENERAL NOTES

1. PUMPING HEAD
   PUMPING HEAD WILL VARY ACCORDING TO TOWER GPM. PUMPING HEAD REQUIRED FOR MARLEY PIPEWORK ONLY WILL BE FURNISHED AT TIME OF PROPOSAL. STATIC LIFT IS 14'-6 FROM BASE OF TOWER COLUMNS.
2. RISER LOCATION *
   RISER MUST BE OFFSET 1'-0 ON MOTOR SIDE OF TOWER (ALL MODELS) (PLAN IV & V). ALSO, SEE SECTION "A-A" FOR RISER OFFSET FOR MODELS 452, 454, 457 & 459 (PLAN IV).
3. HEADER ELEVATION (PLAN V)
   HEADER MUST CLEAR COLLECTION BASIN CURB WHICH IS 1'-4 ABOVE BASE OF TOWER COLUMN.
4. HEADER SUPPORTS (PLAN V)
   CONCRETE BASIN - SUPPORTS MAY BE LOCATED TO SUIT AS REQUIRED.
   WOOD BASIN - SUPPORTS MUST BE LOCATED ON 4'-0 CENTERS AT COLUMN LINES.
   STEEL BASIN - SUPPORTS MUST BE LOCATED ON 4'-0 CENTERS AT COLUMN LINES.

LTR.	DATE	REVISIONS	BY	CHECKED	S.M.
D	6-20-73	ERR 73-483	MRC	WES	
C	3-6-72	ERR 72-176	KBW	MJR	
B	9-12-67	ERR 67-262	CCH	MJR	
A	8-23-65	ERR 8427	DKS	PBS	

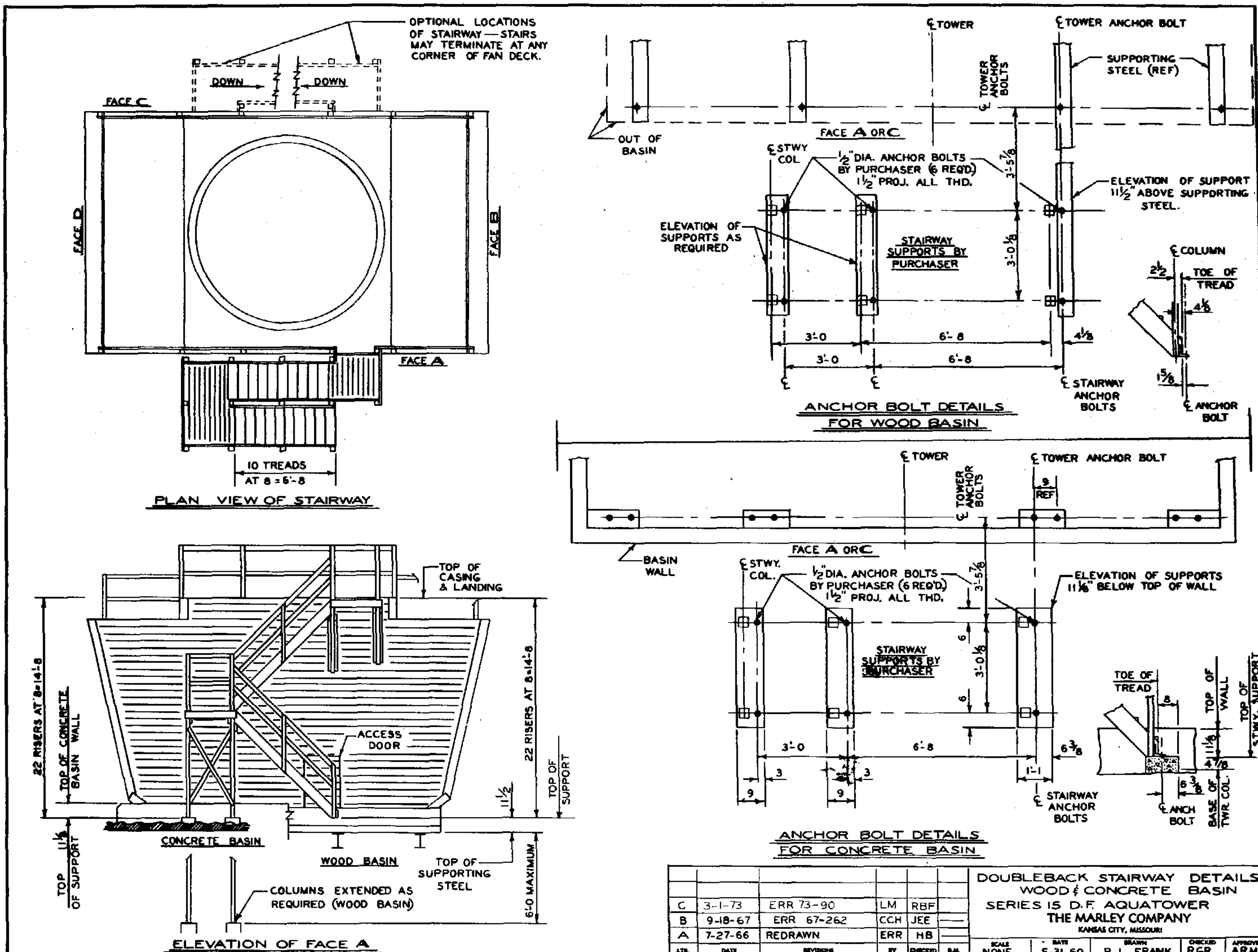
INTERNAL PIPING ARRANGEMENT
PLAN IV AND PLAN V PIPING
SERIES 15, M15, & F15 DOUBLE-FLOW

THE MARLEY COMPANY
MASTER FILE ____ KANSAS CITY, MISSOURI FOREIGN FILE ____

SCALE	DATE	DRAWN	CHECKED	APPROVED
NONE	10-7-60	R. L. FRANK	WAW	ARM

Drawing No. 0-812

.00# ____ Drawing No. 0-812 Rev. D



.00# Drawing No. O-3707 Rev. C

II.C.2 FLUIDS INVENTORY FOR COLLECTION SYSTEM

FLUID INVENTORY OPTION I CASCADED

The fluid inventory represents a total volumetric count of the Therminol 66 in the system. The system is defined as the collector field, thermal storage vessel, and the associated piping in the distribution system.

Given: 62,500 square meters (6.725×10^5 square feet) collector.

Using: 2.921 cm (1.15 in) as absorber tube ID and internal plug diameter 2.15 cm (0.847 in), the net area is 3.04 cm^2 (0.472 in^2).

It follows that if the basic collector module is 3.6 meters (12 feet) long then each collector unit contains 1.114×10^3 cm^3 (67.968 in^3). With 8170 units, the total volume would be 9.101×10^6 cm^3 (5.55×10^5 in^3) or 9.101 $meter^3$ (3.212×10^2 $feet^3$); an internal distribution plumbing network should double these figures, raising the volume to 18.2 $meter^3$ (6.424×10^2 $feet^3$).

Routing the fluid to and from the collector field will be accomplished by a fluid tunnel. The volume of the fluid contained within this tunnel would be approximately 4.168 $meter^3$ (1.472×10^2 $feet^3$); thus, total volumes less storage would be 22.37 x $meter^3$ (7.896×10^2 $feet^3$).

Volume collector field	18.2 $meter^3$ (6.424×10^2 $feet^3$)
Volume fluid routing	4.168 $meter^3$ (1.472×10^2 $feet^3$)
Volume thermal storage	1280 $meter^3$ (4.52×10^4 $feet^3$)
Volume total	1302.37 $meter^3$ (4.598×10^4 $feet^3$)

FLUID INVENTORY OPTION I NONCASCADED

Given: 47,000 square meters (5.06×10^5 square feet) collector.

Using: 2.921 cm (1.15 in) as absorber tube ID and internal plug diameter 2.15 cm (0.847 in), the net area is 3.04 cm^2 (0.472 in^2).

It follows that if the basic collector module is 3.6 meters (12 feet) long then each collector unit contains 1.114×10^3 cm^3 (67.968 in^3). With 6144 units, the total volume would be 6.844×10^6 cm^3 (4.18×10^5 in^3) or 6.844 $meter^3$ (2.42×10^2 $feet^2$); an internal distribution plumbing network should double these figures, raising the volume to 13.68 $meter^3$ (4.84×10^2 $feet^3$).

Routing the fluid to and from the collector field will be accomplished by a fluid tunnel. The volume of the fluid contained within this tunnel would be approximately 3.134 $meters^3$ (1.11×10^2 $feet^3$).

Volume collector field	13.68 $meter^3$ (4.84×10^2 $feet^3$)
Volume fluid routing	3.134 $meter^3$ (1.11×10^2 $feet^3$)
Volume thermal storage	970 $meter^3$ (3.43×10^4 $feet^3$)
Volume total	986.8 $meter^3$ (3.49×10^4 $feet^3$)

FLUID INVENTORY OPTION II

Given: 29,500 square meters (3.174×10^5 square feet) collector area.

Using: 2.126 x 3.6 meters (9 feet x 12 feet) as collector unit dimension. The number of units required is 2940.

Using: 2.921 cm (1.15 inch) as absorber tube ID and internal plug 2.15 cm (0.847 in), the net area is 3.04 cm^2 (0.472 in^2).

It follows that if the basic collector module is 3.6 meters (12 feet) long then each collector unit contains 1.114×10^3 cm^3 (67.968 in^3). With 2940 units, the total volume would be 3.275×10^6 cm^3 (1.998×10^5 in^3) or 3.275 $meter^3$ (1.156×10^2 $feet^3$). All internal plumbing should double the amount present, raising in-field volume to 6.55 $meter^3$ (2.312×10^2 $feet^3$).

Routing the fluid to and from the collector field will be accomplished by a fluid tunnel. The volume of fluid contained within this tunnel would be approximately 1.5 $meter^3$ (5.3 x ft^3); thus, total volumes less storage would be 8.05 $meter^3$ (2.842×10^2 $feet^3$).

Volume collector field	6.55 $meter^3$ (2.312×10^2 $feet^3$)
Volume fluid routing	1.5 $meter^3$ (5.3 x 10 $feet^3$)
Volume thermal storage	6.5×10^2 $meter^3$ (2.295×10^4 $feet^3$)
Volume total	6.58×10^2 $meter^3$ (2.323×10^4 $feet^3$)

II.C.3 TANKAGE FOR LOW TEMPERATURE ENERGY STORAGE

Fluid storage at temperatures up to 88°C (190°F), as outlined under Option II noncascaded solar total energy system, would be required for running the absorption air conditioning, heating and hot water system. The typical working fluid for these systems would be water, and care would be needed in protecting the interior surfaces of steel tanks.

Two options are available: (1) the use of a fiberglass lined steel tank, and (2) the use of a totally fiberglass tank. In dealing with water elevated to 88°C (190°F), corrosion at the water to surface point is a problem. To resolve this a fiberglass liner can be added to the steel tank. The approximate cost per square foot of surface is $5.58 for the lining.

The second option, the use of a fiberglass vessel, would remove the problem of water to steel corrosion. Cost factors, provided, can be used to scale up or down the price of 25,000 litre (6,604 gallon) vessel.

Pressure Rating	Weight	Cost
1.76 kgs/sq. cm (25 psi)	(1845 lb)	$3600
2.45 kgs/sq. cm (35 psi)	(2522 lb)	$4900
3.86 kgs/sq. cm (55 psi)	(3880 lb)	$7560
5.27 kgs/sq. cm (75 psi)	(5233 lb)	$10,200

III.A.4 INSTRUMENTATION FOR DATA ACQUISITION ON ENERGY SYSTEM

A. CONTROL AND INSTRUMENTATION

Control of the system is attained by regulating the fluid transfer system. Control will be broken down into three (3) major levels.

1. Commercial controllers represent the lowest level of control capability. Pump speed and flow-control valve settings are varied by single-channel commercial or industrial controllers. These controllers vary the settings to achieve a constant temperature and most of them have proportional, integral (reset), and rate features.
2. Delta® System 2000 Honeywell control-monitor equipment (or comparable system hardware) is the middle level of control. The Delta® system can:

   Change set points on the controllers

   Monitor process temperatures and flow rates

   Send alarms if any process variable is out of safe tolerance or a motor is not running, etc.

   Present slides of circuits which are in alarm mode.
3. a. The minicomputer, at the highest level of control, has the capability to change set points of the controllers through the Delta® system 2000, or it can bypass both the Delta® and the controllers and directly

control selected motors or valves through simple digital-to-analog converters. The minicomputer can then control by algorithms. Thus, optimum control strategies or characteristics can be developed through minicomputer programs, eliminating the need for hardware modification or adjustment.

b. An additional capability of the minicomputer which may be used in controlling output temperatures of the collector field is the ability to temporarily defocus selected groups of collectors. This option may be especially useful when a long series string of collectors is used on partly cloudy days.

The first two levels will control the system. The third level will be used for data acquisition, testing, performance calculation, etc.

B. <u>DEFINITION OF CONTROL FIELD CONTROL MODES</u>

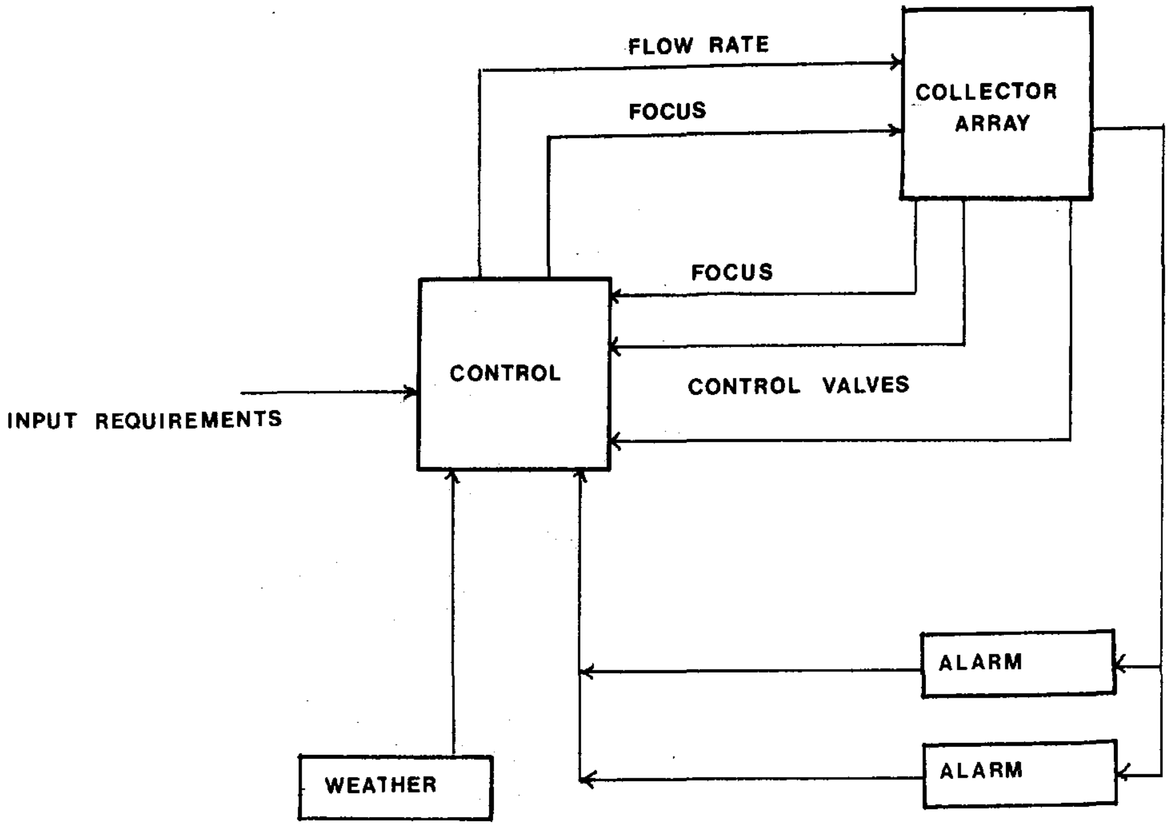
The control mode shall be capable of several varied start up sequences, and an analytical model will be generated as part of the minicomputer software to compare projected performance versus actual operation levels. The control input to the field is the flow rate, i.e.; the output temperature of the collector array will be controlled by adjusting the flow rates through the various modules.

The controller will monitor the temperature gradient across the absorber tubes and other parameter such as solar flux and use these parameters in conjunction with output temperatures to determine the optimum flow rate adjustments. The use of both the temperature gradients across the absorber tube and solar flux in the control algorithm should improve start up and operational stability.

This "Feed forward" technique should increase anticipation of system changes and thus reduce time delays associated with the thermal lag inherent with large thermal loop systems.

The data storage and retrieval systems is defined such that:

All instrument outputs will be recorded on magnetic disc or computer-compatible magnetic tape.
Instrument outputs required for operation will be presented on digital meters.
Instrument outputs required for analysis of rapidly changing transient conditions will be presented on continuous chart recordings.
Any outputs desired may be printed out on the minicomputer control terminal or the line printer.
Any plots desired may be made on the minicomputer control terminal.
Further analysis may be made at a later time by playing back the magnetic tape to either this system or the larger scientific computers, CDC 6600.



C. ADDITIONAL SYSTEM CAPACITY

The system as defined in Section A-two in conjunction with Section A-one will monitor the various building and system levels of functions as they apply to the total solar thermal power, collection, and storage routine.

In conunction with the data acquisition and storage mode, multiple alarms will be required linking the turbo generator (organic Rankine cycle (O.R.C.)) to the system through digital to analog converters. This portion of the system is not yet refined by Stearns Rogers, but is anticipated to be complex.

Additional features of the system will be:

1. Digital to analog interpretation of thermocouple and flow meter signal on the fluid loop from thermal storage to and from O.R.C. turbine generator.
2. Digital to analog interpretations of thermocouple signals down the isocline within the thermal storage tank employing three banks of thermocouples, one at the tank surface and two internal, spaced vertically at 5 cm, transmitting thermal intepreted signals up to 344^{o} C.
3. Digital to analog intepretation of pressure generated within the thermal storage unit through the introduction of the nitrogen blanket.

D. SYSTEM ALARMS

These defined alarms will require immediate machine intervention, and summons of proper personnel. They include but are not inclusive of:

1. An over temperature alarm for the collector field which will initiate defocus of the affected collector or collectors.
2. Severe weather alarm which will initiate protective measures, such as inverting the collector field in the case of hail.
3. Leak detectors, which will truncate the affected section of the collector field.
4. Overpressure alarm which will trigger a reduction of flow to the affected units.

5. A toluene vapor sniffer in the turbogenerator (O.R.C.) building will detect and shut down the turbine and if necessary defocus the collector field.
6. Overload protection equipment which might be included in the software to protect the turbogenerator system (to be specified by Stearns Rogers).
7. An overpressure alarm will trigger actuation of a pressure bleed-off device incorporated with the high temperature thermal storage.
8. An overtemperature alarm will be required should fiberglass tanks or other materials which posses a low tolerance to extreme temperatures be used.

E. SPECIFICATION SCOPE

GENERAL SPECIFICATIONS

1.0 The Central Control and Monitoring System (CCMS) specified under this section shall be totally solid-state using computer oriented digital technology to insure long life and low maintenance costs to be consistent with this project's life cycle costing concepts. The system must be standard with the manufacturer to insure on-going parts availability and trained technical support. The initial installation must include all pushbuttons, indicators, switches, pilot indicators, digital and analog value displays, transmission line interface equipment and software, etc., to make up a completely operable system. The initial installation shall have the capacity to handle the point specified in the input/output summary plus 25% additional. CCMS must be designed in a modular fashion to insure future expansion capability whether it be additional data gethering panels (DGP's) or central console function capability. The CCMS is specified herein to help insure proper and efficient utilization of the mechanical and electrical systems (and/or to insure a high level of life and property protection).

1.1 The CCMS shall be tolerant of power failures up to one hour duration. On power restoration, the system shall automatically come on-line without operator intervention or execution of manual re-start procedures.

1.2 The CCMS shall be designed to operate on standby backup battery power. All portions of the CCMS; the CPU, the operator terminal, alarm printer annunciator modules, and designated DGP's shall be designed to operate for a minimum of 12 hours on battery power. Upon failure of normal 120v ac commercial power the system shall automatically and instantly revert to battery power. The fact that the system is operating on backup power shall be annunciated on the Operators Terminal and recorded on the alarm printer.

With restoration of commercial power, the system shall automatically switch from battery power to 120v ac. The CCMS shall be supplied with an automatic battery charging capability. This battery recharging capability shall be designed to fully charge the standby batteries in a maximum of 12 hours.

2.0 DATA TRANSMISSION SYSTEM

2.1 All data transmitted between the CCMS (Central Control and Monitor System) central processing unit (CPU) and the remote data gathering panels must be transmitted in digital form. A double transmission, echo transmission, or multiparity bit technique must be used to insure message integrity. Transmission system failure must be annunciated immediately as a "No Response" with display and/or printout of time and address of the area failing to respond. For systems with a printer, an hourly log of all remote groups not responding shall be provided.

All analogs must be converted to digital values within 250 feet of the sensing point to insure against stray voltage pick up and/or signal degradation. The same reliability measures stated for digital signal transmission apply to the converted analog signals, i.e., double transmission, echo transmission, or parity check must be provided.

2.2 The data transmission system provided must meet the requirements of NFPA and local fire codes.

2.3A The data transmission system must be compatible with and capable of operating over standard voice grade leased telephone lines. The system shall be capable of operating over half duplex series 3000, type 3002 data transmission channel.

2.3B The system must be supplied complete with phone line compatible modems that will meet the following general characteristics. It is the intention of this specification that the modems be supplied under this contract and be owned by the user.

The general characteristics shall be:

1. Connections - two or four wire connection.
2. Impedence at 1000 Hz, 600 ohms.
3. Transmitting level 10 $\pm$ 2 dbm

Phone line service required shall be:

1. Type - Data
2. Direction - two way alternate (half duplex).
3. Maximum speed - 1200 baud.

The system shall be designed so that an additional leased line interface can be added to the system at any time in the future. All capabilities outlined in the above specifications except for intercom shall be carried over a single set of voice-grade communication lines.

Loss of data communications transmission over the phone line shall be immediately annunciated and printed out at the central processor as specified above.

OPERATORS TERMINAL

2.4 An Operators Terminal (OPT) shall be provided and will be considered the main man-machine interface. The OPT shall be designed for ease of system operation and understanding. The terminal shall have point address selection buttons, a series of function buttons, a locking capability, and a digital readout display as described herein.

The OPT shall be supplied with digital indicators and light emitting diodes for pilot indication and temperature value indication to insure long life and minimum maintenance. Systems using incandescent lights for pilot lamp or back-lighted digital displays shall have supervised filaments with discrete alarm point assignment.

2.5 System Entry (Touch Dial)

Serial entry touch dial selection buttons shall be supplied with the system for: access to remote control and data points; adding, deleting or resetting of alarm limits in memory; resetting program start-stop times; and adding or deleting start-stop program channels. Serial entry selection buttons shall be provided so that future expansion will not require additional buttons to be mounted on the control console.

2.6 Function Button Control

Clearly identified individual function buttons shall be provided to make the system easier to operate and more easily understood.

The system shall contain the following individual control buttons:

Start	Intercom Off
Stop	Alarm Summary
Reset/Auto	Data Display
Increase/Open	Graphics-On
Decrease/Close	Graphics-Off
Alarm Acknowledge	Lamp Test
Intercom On	Display-Time

Systems that require the operator to type out an instruction i.e., (ALA SUM) on a typewriter type keyboard as a standard item shall include appropriate interface to perform the above specified single-entry capability.

2.7 Analog Indication

The system shall have the capability of addressing and digitally displaying analog values and their engineering parameter such as degrees, RH, PSI, KW, etc. To insure ease of system operation and understanding, systems not displaying point identification, point value, and engineering unit simultaneously are not acceptable. The system shall have a minimum vocabulary of 16 units as listed below and shall be field programmable.

Degrees F	Percent
Degrees Cecius	Gallons per minute
Relative Humidity	Tons
Pounds per square inch	Kilowatts
Inches	Amps
Wet Bulb	Volts
Dew Point	Btu's
Hours	Kilowatt hours

The transmission of temperature, pressure or other analog values from remote data gathering panels to the central processor shall be in true digital form to eliminate transmission error. The analog sensing, transmission, and display system must have end to end accuracy of ± 1F.

2.8 Real Time Display

The system shall display real clock time in 24-hour format. The time and calendar date shall be resettable by simple keyboard entry.

2.9 Start-Stop Control, Two-and Three-Mode

Two- and three-mode control capability shall be provided for remote control of motor loads or change-over functions, such as on-off, occupied-unoccupied, summer-winter, ON-OFF-AUTO, HTG-CLG, etc. Selection of a specific control point shall cause the display of the address and the current operating status.

The CPU shall automatically lock out alarms for a period of time after an automatic or manual start command has been issued to a remote piece of equipment. This time delay shall eliminate false alarming of equipment and allow for the transfer of differential pressure or flow switches.

2.10 Secure-Access Control

The CCMS shall be furnished with the ability to perform secure-access switching of remote security alarm systems. Intrusion while in the secure mode shall report as an alarm. Line supervision shall be provided for each secure-access point as described herein.

2.11 Test-Reset Control

The CCMS shall be capable of performing test-reset functions of remote fire and security systems. On performing the test, the system shall report the test, the type of system (fire or security), and the completion of the test.

2.12 Digital Setpoint Adjustment (CPA) and Damper Position Adjustment (DPA)

The system shall have the capability of digitally resetting the control point of remote controllers or dampers and other operators from the central console. It shall be capable of resetting and reading the control position by a positive feedback circuit from the remote local loop controls. Positive feedback from the DGP of the new position after reset shall be displayed in a digital form in the readout window.

2.13 Alarm Capability

The CCMS shall have the capability to continuously monitor analog and digital alarm conditions. Upon alarm condition the system will immediately sound the audible alarm, and show the point identification number in alarm and also the engineering unit associated with that specific alarm. The capability to indicate whether an alarm value is high or low shall also be included.

The digital display shall flash as long as the point is selected and still in alarm condition. The audible alarm will sound until the acknowledge button has been depressed. At the same time the point is being digitalized on the readout window, the printer, if included, shall print the alarm information as described herein. All alarms shall be recognized and recorded on a change-of-state basis.

The CCMS shall have the capability of setting individual alarm limits for each analog input point resettable from the Operators Terminal (OPT). Authorized console operators shall have the capability of assigning or changing alarm limits at any time without interrupting system operations. It shall also be possible to read back assigned high and low alarm limits at any time. The system shall also have the capability to assign analog lockout on a point by point basis. The lockout of an analog point shall be assignable to any digital point within the DGP. Analog lockout is required to prevent false alarm conditions.

2.14 Audible Alarm

The system shall contain a solid state audible alarm which shall be initiated with every new alarm indication. Each new contact or analog alarm shall resound the audible alarm which shall be silenced by the manual alarm acknowledge button on the central control console. The audible alarm shall not sound on the return to normal for mechanical system type alarms but must sound on return to normal of fire alarms.

2.15 Pilot Light Test

The OPT shall be furnished with a single push-button which shall light all pilot indicators or light emitting diodes (LED's) when operated.

2.16 CCMS Operator Access Levels

The CCMS shall be supplied with at least three locking levels for operator access.

With level one disabled the CCMS shall receive and record alarms and automatically program equipment, but the point selection, alarm acknowledgement, and all function buttons shall be inoperative. With level one enabled all point selection and function buttons shall be operative to perform normal system operation.

Level two shall enable/disable the programming of analog alarm limit and automatic time programs. By enabling this level the operator can assign new analog alarm limits and reprogram start/ stop times. With this level disabled the system will automatically compare limits and operate equipment at its programmed time.

Level three allows for the addition and deletion of system input/output points and control of display and printout assignments.

F. SYSTEM SOFTWARE

Memory for accumulation of totalized values must be nonvolatile to prevent loss of data during normal or abnormal shutdown. It must also be possible to preset values and reset totalizers through the operators console.

Totalized value printout is to occur at 8 hour, 24 hour or 30 day intervals as selected by the operator and entered through the operators terminal. Operator demanded totals logs shall be available at any time through the operators console. It shall also be possible to assign limits in memory for totals inputs and provide an alarm output when limit value is exceeded.

CONTROL INTERPRETER LANGUAGE

Provide the ability, using the values of analog and binary points associated with the Supervisory Data Center, constants and real time, to perform calculations such as: addition, subtraction, division, multiplication, and square roots. The outputs shall be new analog or binary points, displayed, alarmed and/or logged. Standard calculations which shall be provided are BTU, flow, efficiency, totalize, averaging, and differential temperature. Standard abstract functions shall be provided, such as: greater than, less than, equal to, AND functions, and OR functions.

The control interpreter language programs shall be standard. During submittal and review, the engineer shall select those points, constants, calculations, and outputs required for the automation system.

SECTION I

ENERGY CONSERVATION EMPLOYED IN DESIGN

A. SITE

ITEM	Yearly Energy Savings	Cost
1. Cover exterior surfaces with earth and/or vegetation.	Heating 2×10^9 BTU's " 2.1×10^{12} Joules Cooling 1×10^9 BTU's " 1.1×10^{12} Joules	
2. Locate building to minimize wind effects on exterior surfaces.	Heating 4.7×10^7 BTU's " 5×10^{10} Joules Cooling 8.0×10^7 BTU's " 8.4×10^{10} Joules	
3. Select site which has high air quality to enhance natural ventilation.	*	
4. Select setting which has topographical features to provide natural wind breaks.	*	
5. Utilize sloping site to partially bury building or use earth berms to reduce heat transmission.	ITEM A.1 Section 1	
6. Extensive use of deciduous trees for summer shade and winter heat gains.	Heating 3.0×10^7 BTU's " 3.2×10^{10} Joules Cooling 5.0×10^7 BTU's " 5.3×10^{10} Joules	
7. Consider the use of adjacent lake for condensor cooling. Rejected due to poor water quality.	*	
8. Consider using a site which borders on a proposed rapid transit corridor.	*	
9. Utilize on-site water for landscaping and irrigation rather than using piped in utility service.	Electric 8.0×10^7 BTU's " 8.4×10^{10} Joules Thermal 2.4×10^8 BTU's " 2.5×10^{11} Joules	
0. Use large bodies of nearby water to provide sensible cooling.	Cooling 2.5×10^7 BTU's " 2.6×10^{10} Joules	

B. BUILDING

ITEM	Yearly Energy Savings	Cost
1. Construct building with minimum exposed surface to minimize heat transmission for a given enclosed volume.	*	
2. Select a building configuration to give minimum exposed north wall area, thus minimizing transmission heat losses.	See Item Section 1 (A.1)	
3. Place insulation between roof membrane and concrete slab to damp thermal changes in roof mass.	*	
4. Construct exterior walls, ceilings, floors of high density material.	*	
5. Use slab on grade for all ground floors.	Heating 1.0×10^7 BTU's " 1.1×10^{10} Joules Cooling 2.5×10^7 BTU's " 2.6×10^{10} Joules	
6. Provide solar control for windows and walls.	Cooling 1.6×10^8 BTU's " 1.7×10^{11} Joules	
7. Use permanently sealed windows.	Heating 6.0×10^6 BTU's " 6.3×10^9 Joules Cooling 1.0×10^7 BTU's " 1.1×10^{10} Joules	

C. PLANNING

ITEM	Yearly Energy Savings	Cost
1. Rooms grouped so that the same ventilation air can be used more than once before exhausting, i.e., cascading from office space to corridor to toilet.	4.6×10^9 BTU's 4.9×10^{12} Joules	
2. Major equipment room separated from bulk of facility to reduce unwanted heat gain.	*	
3. Utilize deep ceiling voids for the use of low velocity ductwork. Plus, deep ceiling voids act to enhance the thermal performance of the roof system.	*	
4. Processes which have temperature and humidity requirements different from normal physiological needs grouped together and served by one common system.	*	
5. Reduce ceiling height to decrease area required to heat-cool and illuminate.	*	

D. VENTILATION AND INFILTRATION

ITEM	Yearly Energy Savings	Cost
1. To minimize infiltration, balance mechanical ventilation so that supply air quantity equals or exceeds exhaust air quantity.	*	
2. Take credit for infiltration as part of the outdoor air requirement for the building occupants.	*	
3. Transfer air from "clean" areas to more contaminated areas.	Heating & Cooling 30×10^8 BTU's 3.2×10^{11} Joules	

E. HEATING, VENTILATION AND AIR CONDITIONING

ITEM	Yearly Energy Savings	Cost
1. Select air handling system which operates at the lowest possible air velocities.	*	
2. Exhaust air through lighting fixtures and use this air as heating of pre-heat elsewhere in the facility.	*	
3. Locate the cooling tower in an area where air currents are not adversely affected by the placement of other structures.	*	
4. Did not use electric re-heating units.	*	
5. Ventilation cycle. Use outside air for sensible cooling when outdoor conditions permit.	Combined 2×10^9 BTU's 2.1×10^{12} Joules	

F. LIGHTING AND POWER

ITEM	Yearly Energy Savings	Cost
1. Consider a selective lighting system in reference to the following.	*	
A. Reduce the overall lighting level to best suit each task.	Electric 5.2×10^9 BTU's " 5.5×10^{12} Joules Thermal 1.6×10^{10} BTU's " 1.6×10^{13} Joules	
B. Group similar tasks together for similar lighting levels.	*	
C. Design switching circuits for turning off unneeded lighting.	*	
D. Provide timer which will turn off limited time, task lighting. Rejected due to operational constraints.	*	
E. Use only light colored wall finishes on interior surfaces.	*	
2. Select furniture and interior appointments that do not have glossy surfaces or those which give specular reflection.	*	
3. Consider the use of 250 watt mercury vapour or "Lucolux" lamps for special application.	*	
4. Match motor size to equipment shaft power requirements and select to operate at the most efficient point.	*	
5. Use liquid cooled transformers.	*	
TOTAL SAVED IN DESIGN	2.7×10^{10} BTU's Thermal 2.8×10^{13} Joules	

SECTION II

RETRO-FITTING OF ADDED ENERGY CONSERVATION TECHNIQUES

B. BUILDING

ITEM		Yearly Energy Savings	Cost
1. Utilize double glazing to retard heat transmission during winter and summer.		Heating 9.00×10^8 BTU's	$60K
		" 9.5×10^{11} Joules	
		Cooling 4.80×10^8 BTU's	
		" 5.1×10^{11} Joules	
2. Improve performance, or place- of thermal insulation.			
	Walls	Heating 1.4×10^9 BTU's	$150K
		" 1.5×10^{12} Joules	
		Cooling 1.25×10^8 BTU's	
		" 1.3×10^{11} Joules	
	Roofs	Heating 1.4×10^9 BTU's	
		" 1.5×10^{12} Joules	
		Cooling 5.00×10^8 BTU's	
		" 5.3×10^{11} Joules	
3. Change in the roof color to minimize heat gain (summer).		Cooling 1.60×10^8 BTU's	$25K
		" 1.7×10^{11} Joules	

C. PLANNING

ITEM	Yearly Energy Savings	Cost
1. Spaces of similar function, locate on same floor to discourage the use of elevator. Also schedule elevator so that only paraplegic and maintenance personnel can use.		
2. Rejected. Previous experience in trying to implement such a system led to operational difficulties. In fact after this mode of restricted use of elevator was abandoned, an increase in elevator usage was not observed.		

D. VENTILATION AND INFILTRATION

ITEM	Yearly Energy Savings	Cost
1. Provide controls to shut down all air handling systems at night, weekends, and holidays, i.e., "System 7".	Heating 9.00×10^{8} BTU's " 9.5×10^{11} Joules Cooling 1.6×10^{9} BTU's " 1.7×10^{12} Joules	$75K

Refer to Section 3 which gives the operation requirements for this item. Since this item relies on the proper implementing of economical operations, values can be higher or lower depending on operating modes.

E. HEATING, VENTILATION AND AIR-CONDITIONING

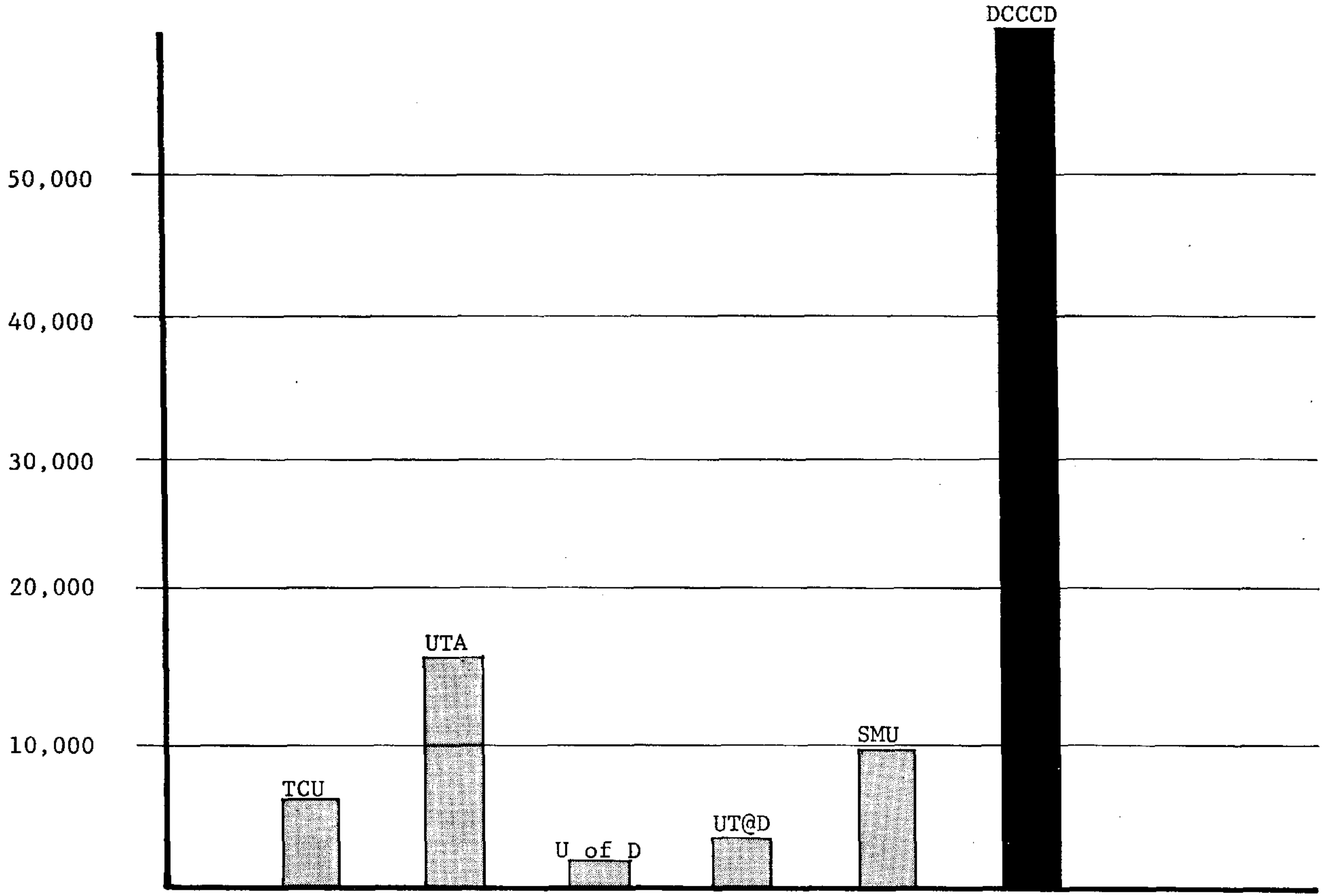
ITEM	Yearly Energy Savings	Cost
1. In the summer when the outdoor air temperature is lower than indoor, use full outdoor air for ventilation.	*	
2. Schedule air delivery so that exhaust from primary spaces (offices) are used to heat, pre-heat or boost heat delivery to secondary spaces.	Combined 5.0×10^7 BTU's " 5.3×10^{10} joules	$40K
3. Provide 105 degree water to all general use as well as showers.	5.00×10^8 BTU's 5.3×10^{11} joules	$10K
4. Supply only cold to lavatories for hand washing.	5.0×10^7 BTU's 5.3×10^{10} joules	$2K
5. Provide chilled water, and hot water storage. Heat extracted from condenser. Chilled water generated at night when chiller can operate at higher efficiences due to colder condensor water temperature.	Heating 9.00×10^8 BTU's " 9.5×10^{11} joules Cooling 1.6×10^8 BTU's " 1.7×10^{11} joules	
6. Locker room heat recovery. Since college requires 100% fresh air, usage of a thermal wheel for exhausted air can reduce energy expenditures.	Heating 3.20×10^8 BTU's " 3.4×10^{11} joules	$10K
7. Extract heat from forced fed boiler flue gas.	2×10^9 BTU's 2.1×10^{12} joules	$107K
TOTAL ENERGY SAVINGS	1.14×10^{10} BTU's thermal 1.2×10^{13} joules thermal	$629K
ANNUAL ENERGY SAVINGS 1975 Dollars	$150,000/Year	

SECTION III

BUILDING OPERATION MODES

ITEM	Yearly Energy Savings	Cost
1. Heat building to only 68° F (winter).	*	
2. Heat building to no more than 60°F when occupied.	*	
3. Cool building to no less than 78°F during summer.	*	
4. Do not cool building when unoccupied.	*	
5. Schedule morning start up in winter so that the building is at 63°F when occupants arrive and building is up to 68°F during first hour of operation.	*	
6. Limit pre-cooling start up in morning to give 5°F less than outdoor or 80°F whichever is greater.	*	
7. Turn off heating 30 minutes before the end of period of area occupancy.	*	
8. Allow internal structure R. H. (relative humidity) to vary naturally between 20% R.H. and 65%, only add or remove when humidity exceeds these levels.	*	
9. Use cool night air to flush the building and assist in pre-cooling cycle.	*	
10. Select controls that will allow variable temperature differentials (3° is suggested).	*	
11. Shut off unused lighting.	*	
12. Schedule cleaning and maintenance only during periods of natural light.	*	

ITEM	Yearly Energy Savings	Cost
13. Utilize an economizer cycle whenever waste heat cannot be stored.	*	
14. Maintain equipment in a new condition.	*	
15. Clean air filter, thermal wheels, etc. to prevent an energy increase in their use.	*	



STUDENT ENROLLMENT DALLAS METROPLEX

NORTH LAKE CAMPUS

283 ACRES

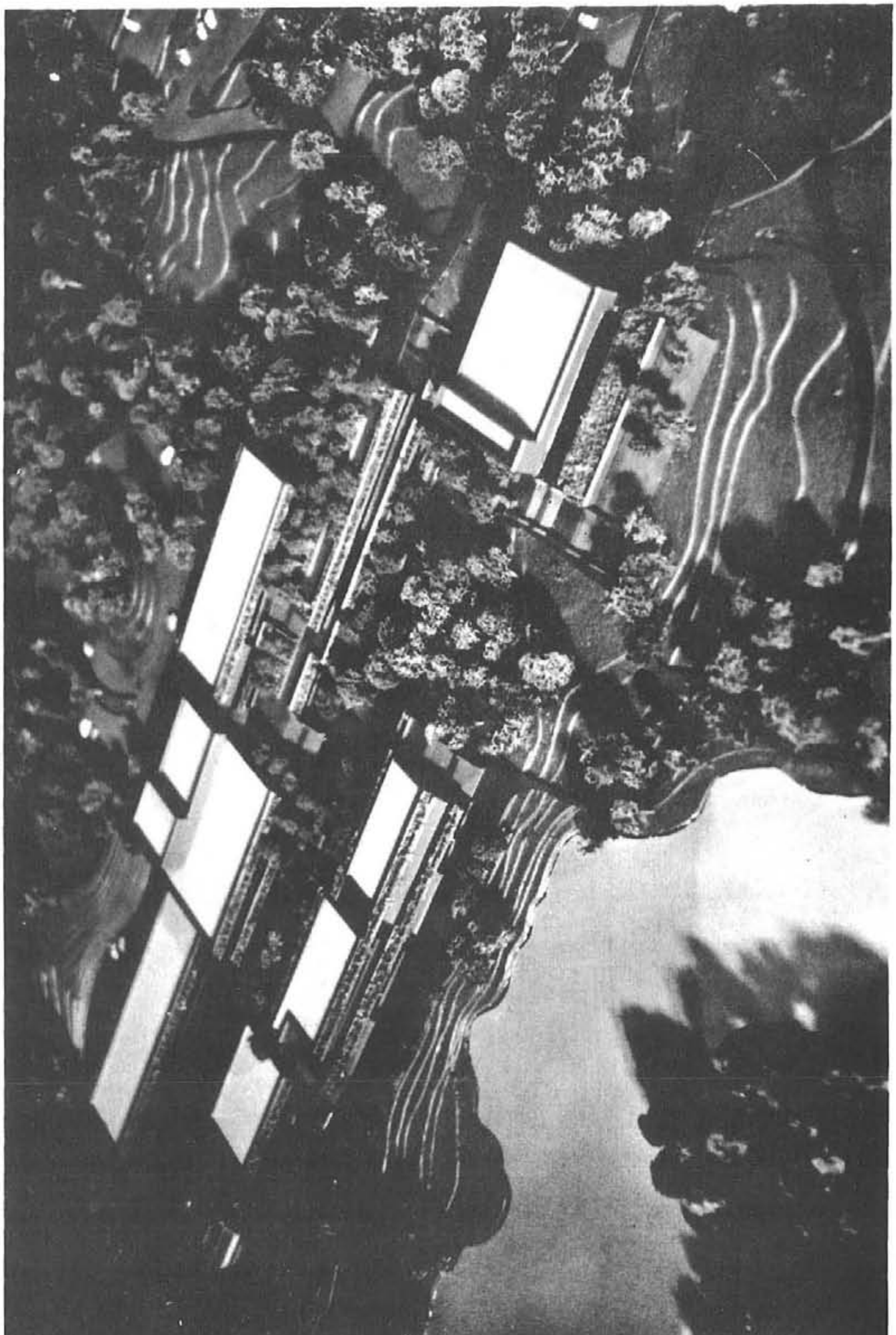
250,000 FT^2 CAMPUS FLOOR SPACE

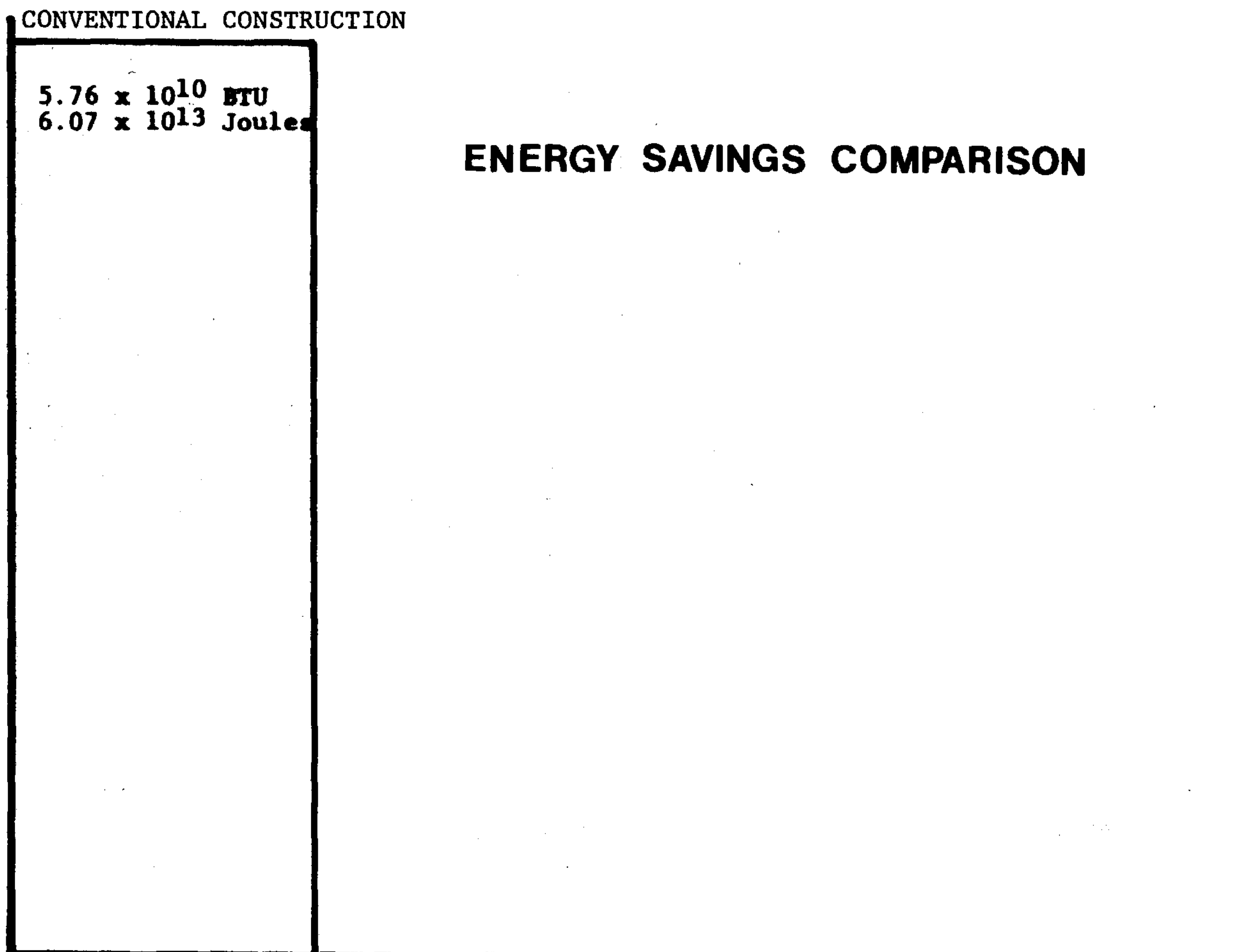
25% OF MASTER PLAN

3600 FTE STUDENT (PRESENT) 14,000 ULTIMATE

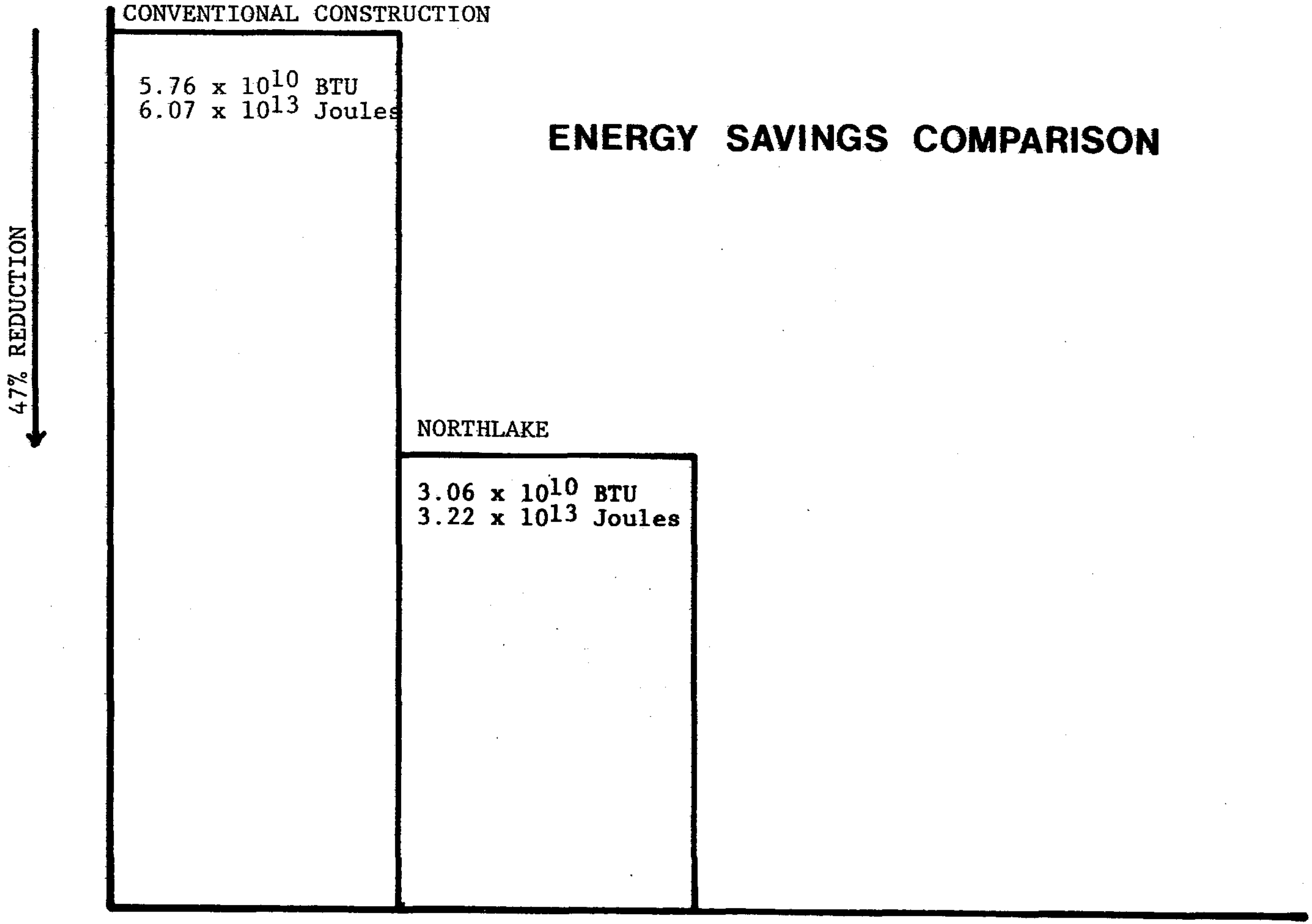
CONSTRUCTION TO BE COMPLETED IN FALL 1977

CONSTRUCTION PRESENTLY REPRESENTS 30% OF COMPLETION

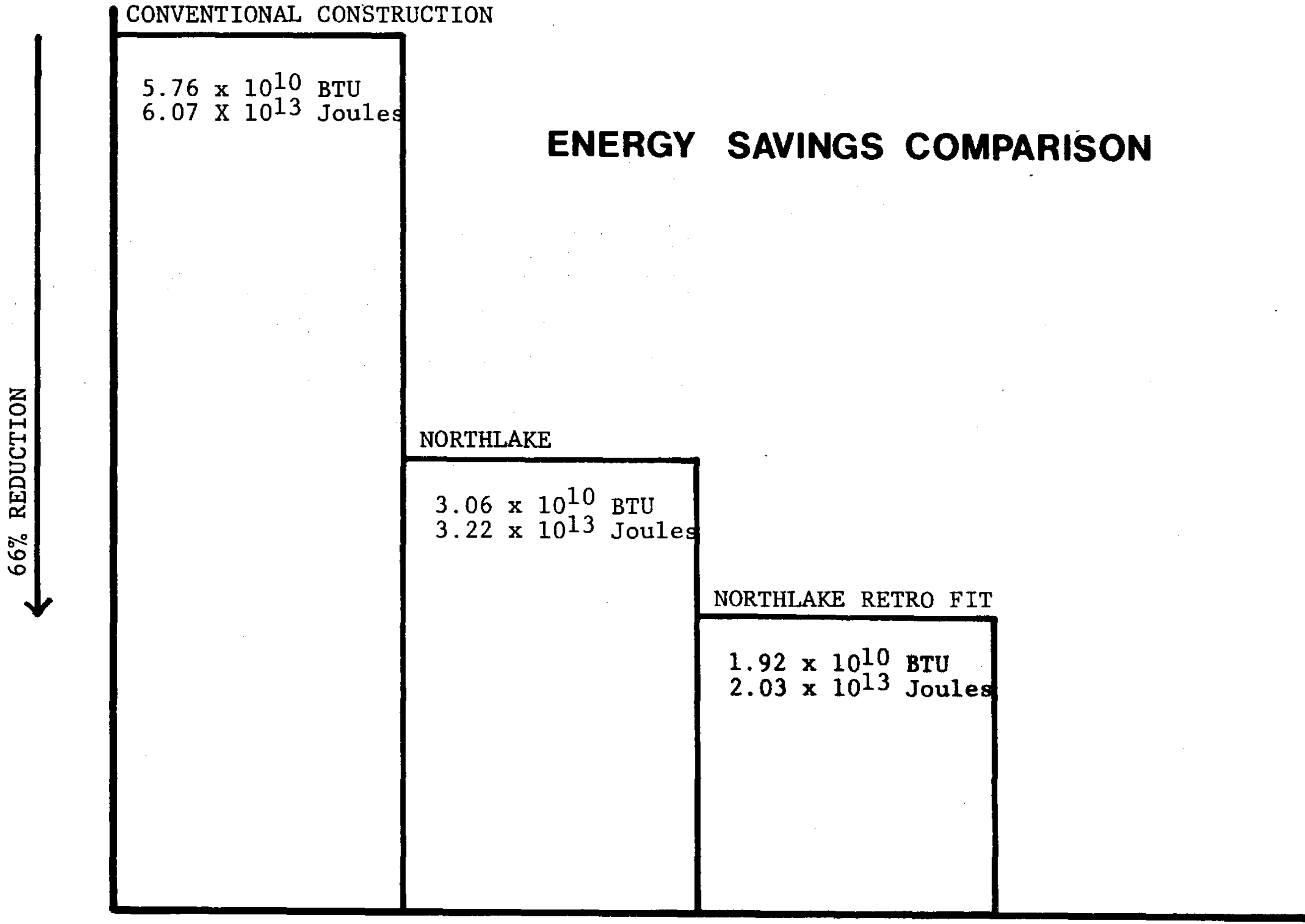


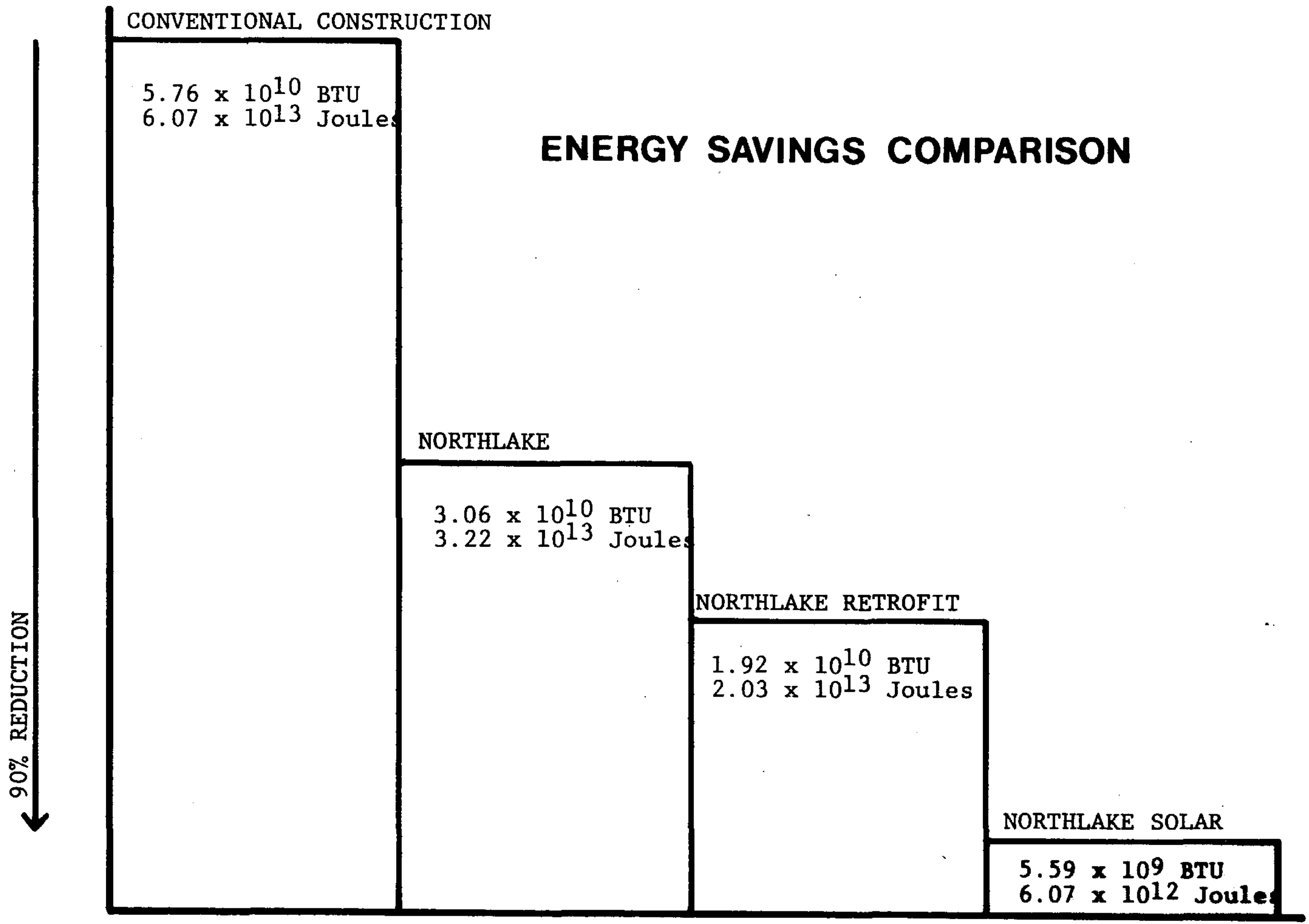

CONVENTIONAL CONSTRUCTION
5.76 x 10^10 BTU
6.07 x 10^13 Joules
ENERGY SAVINGS COMPARISON

ENERGY SAVINGS COMPARISON

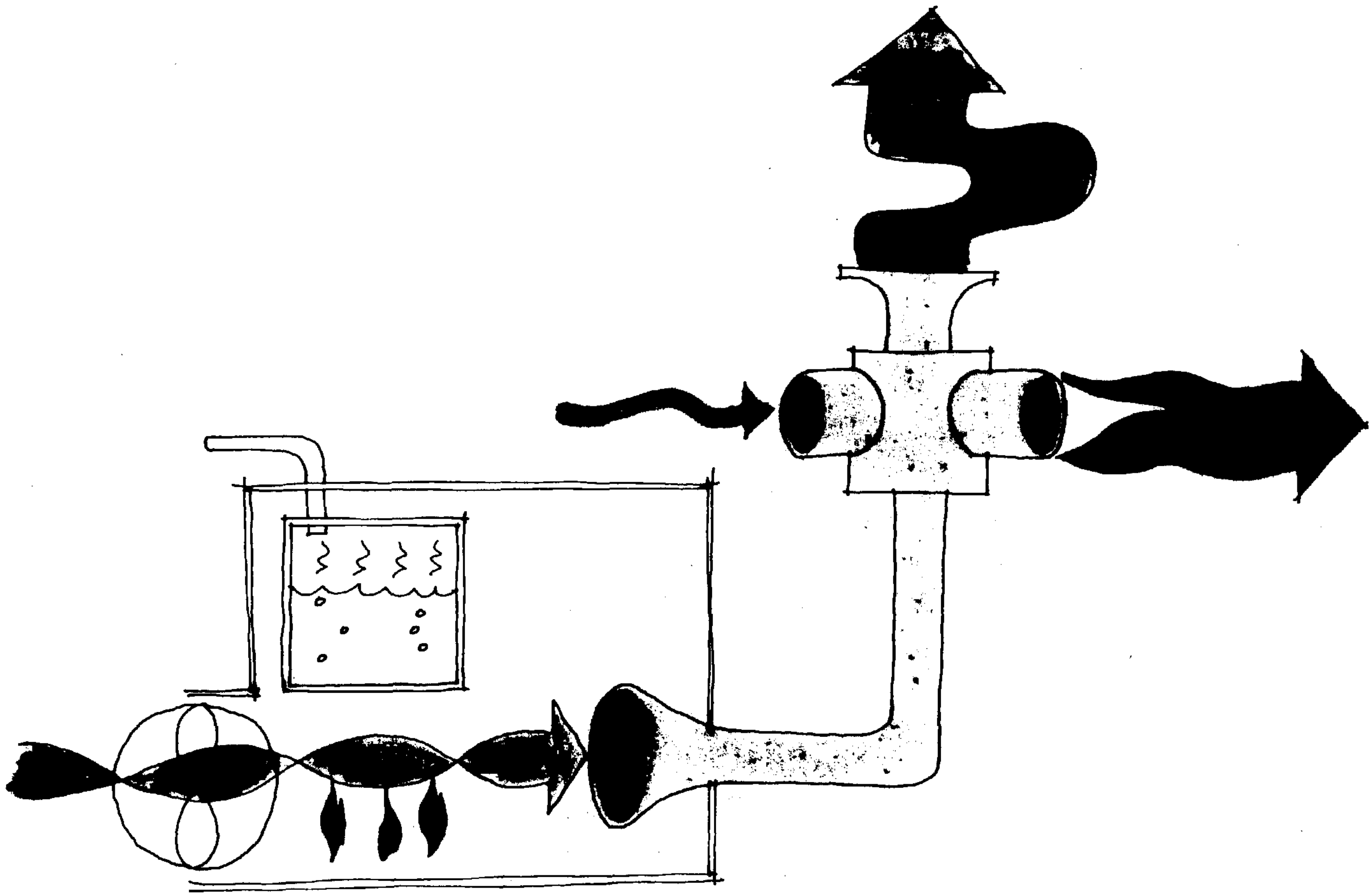


ENERGY SAVINGS COMPARISON

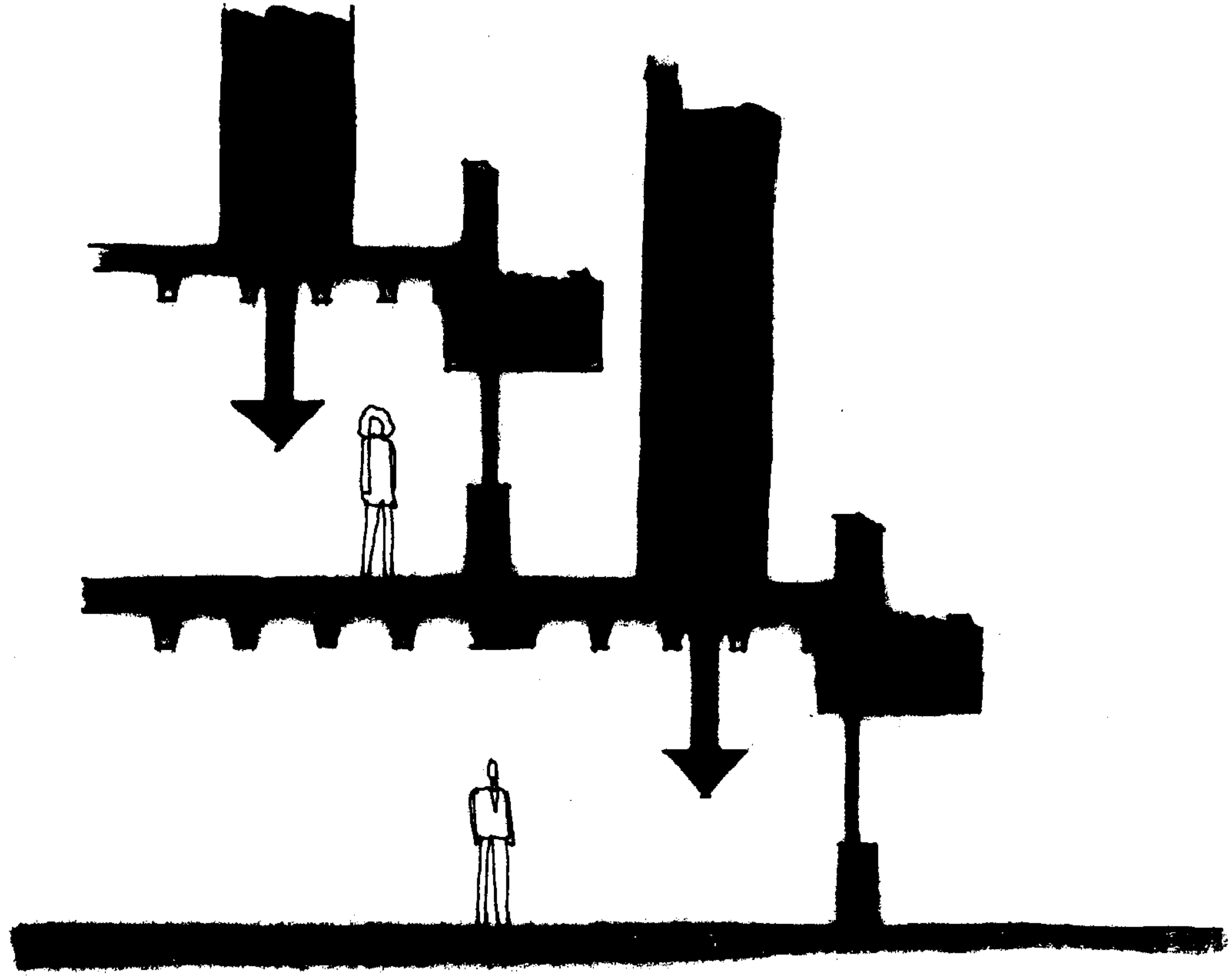




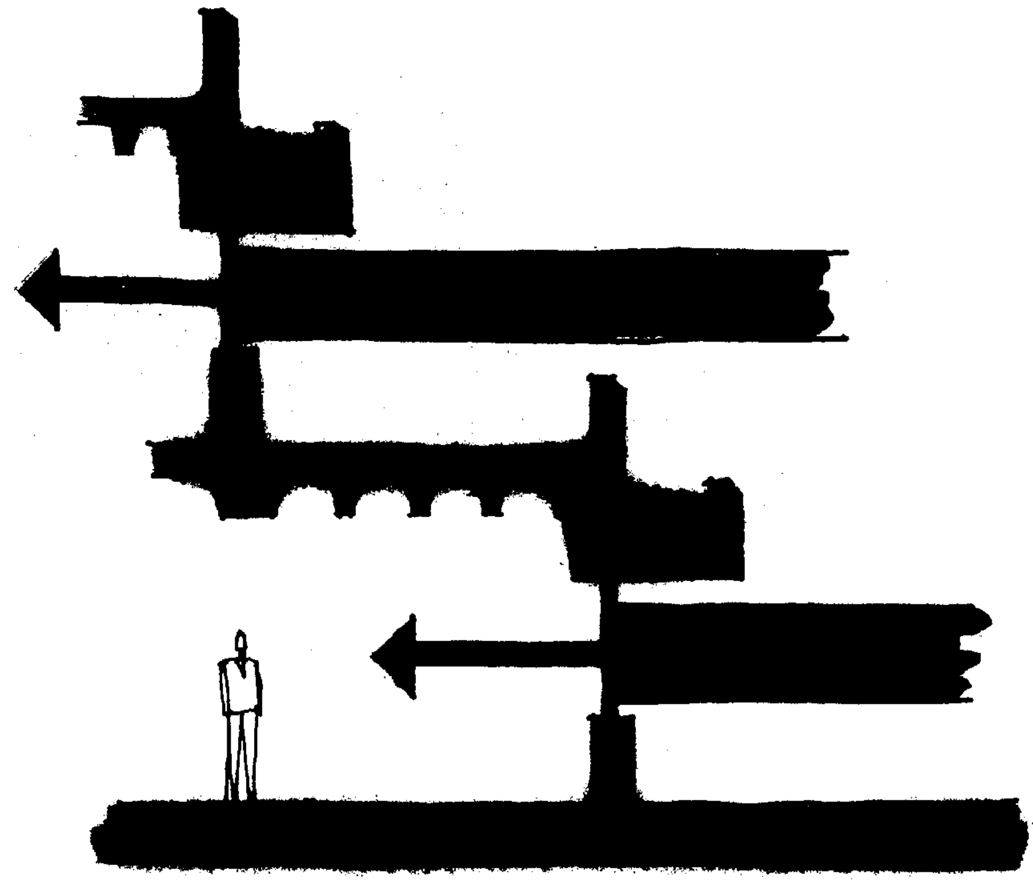
ENERGY SAVINGS COMPARISON



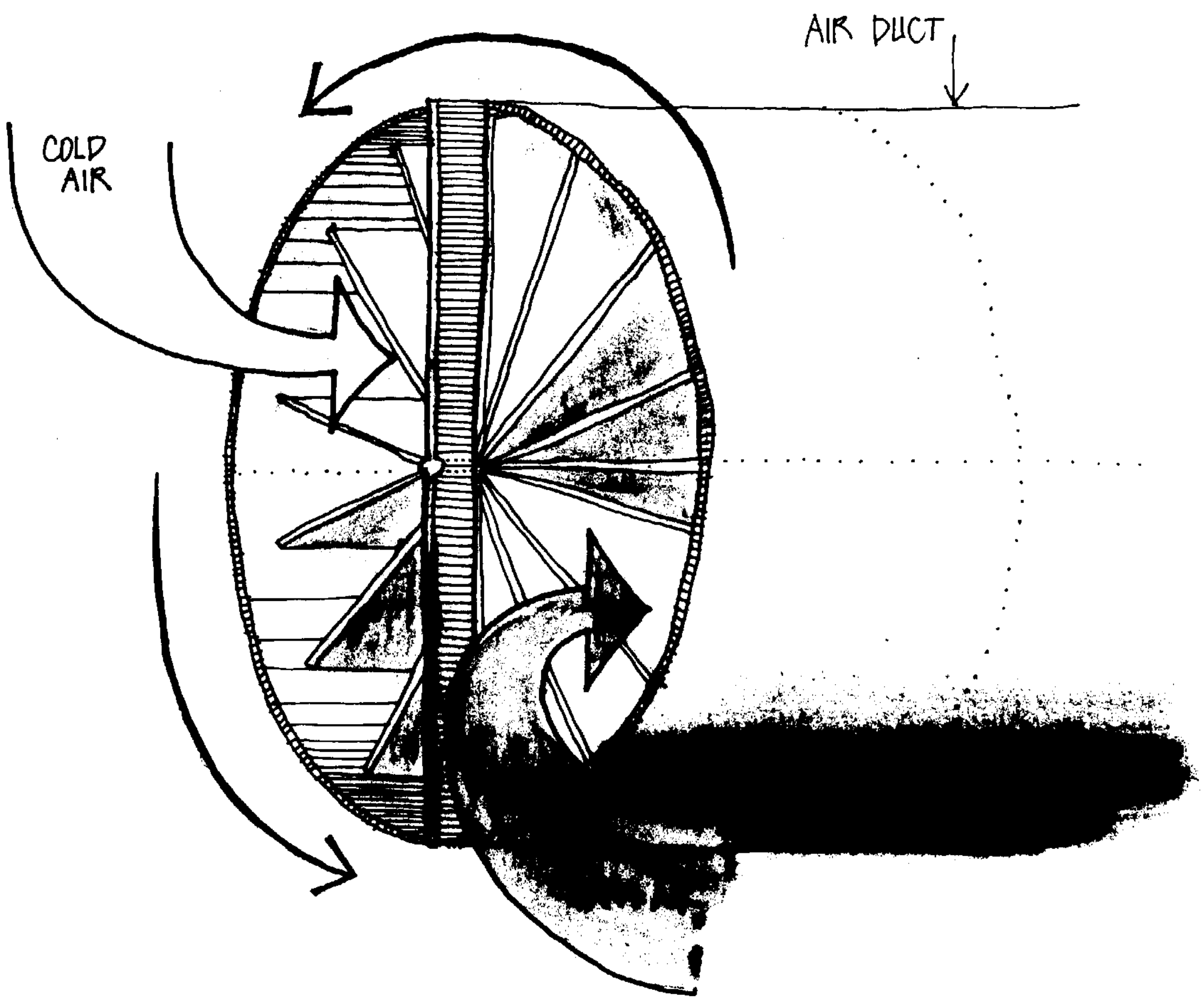
BOILER WASTE HEAT RECOVERY SYSTEM



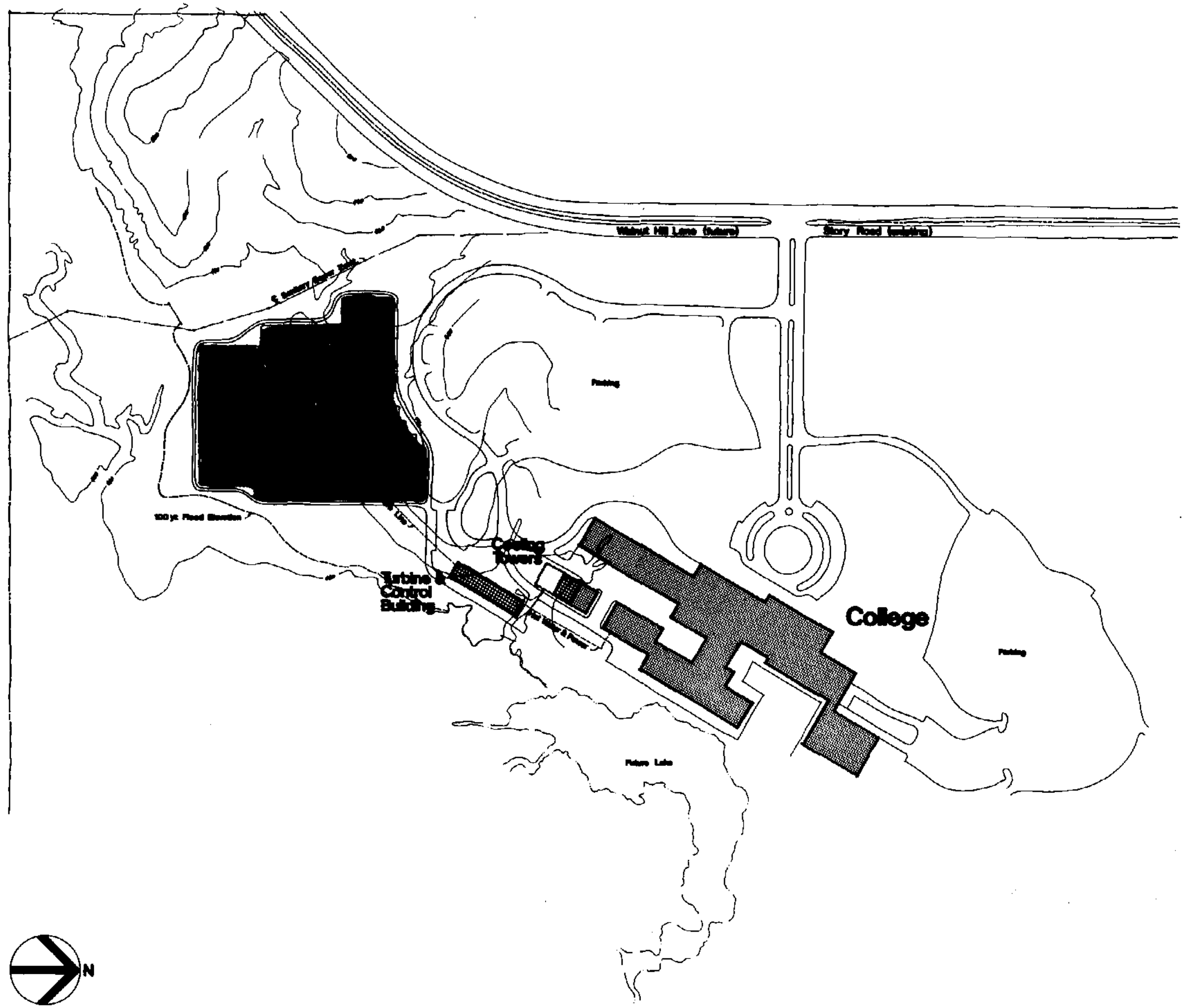
REDUCTION OF THERMAL ENERGY FLOW BY ADDITIONAL INSULATION



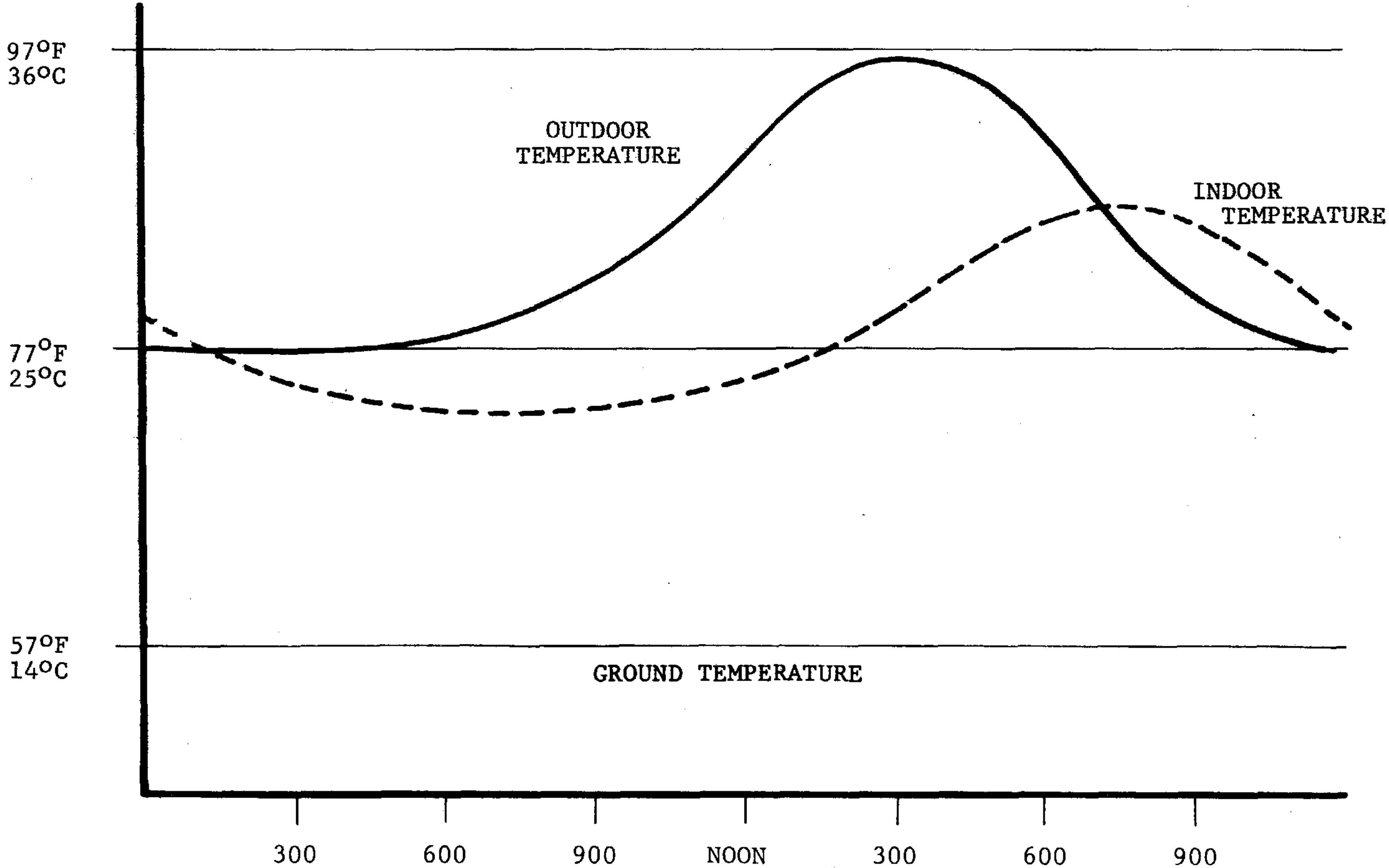
REDUCTION OF THERMAL ENERGY FLOW BY DOUBLE GLAZING



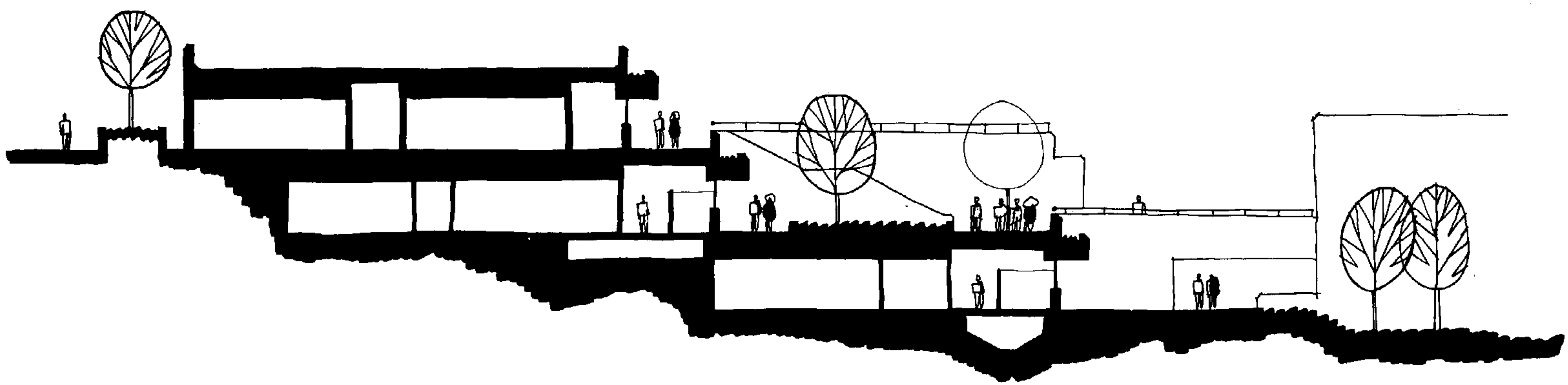
THERMAL WHEEL



SOLAR THERMAL EQUIPMENT LOCATION

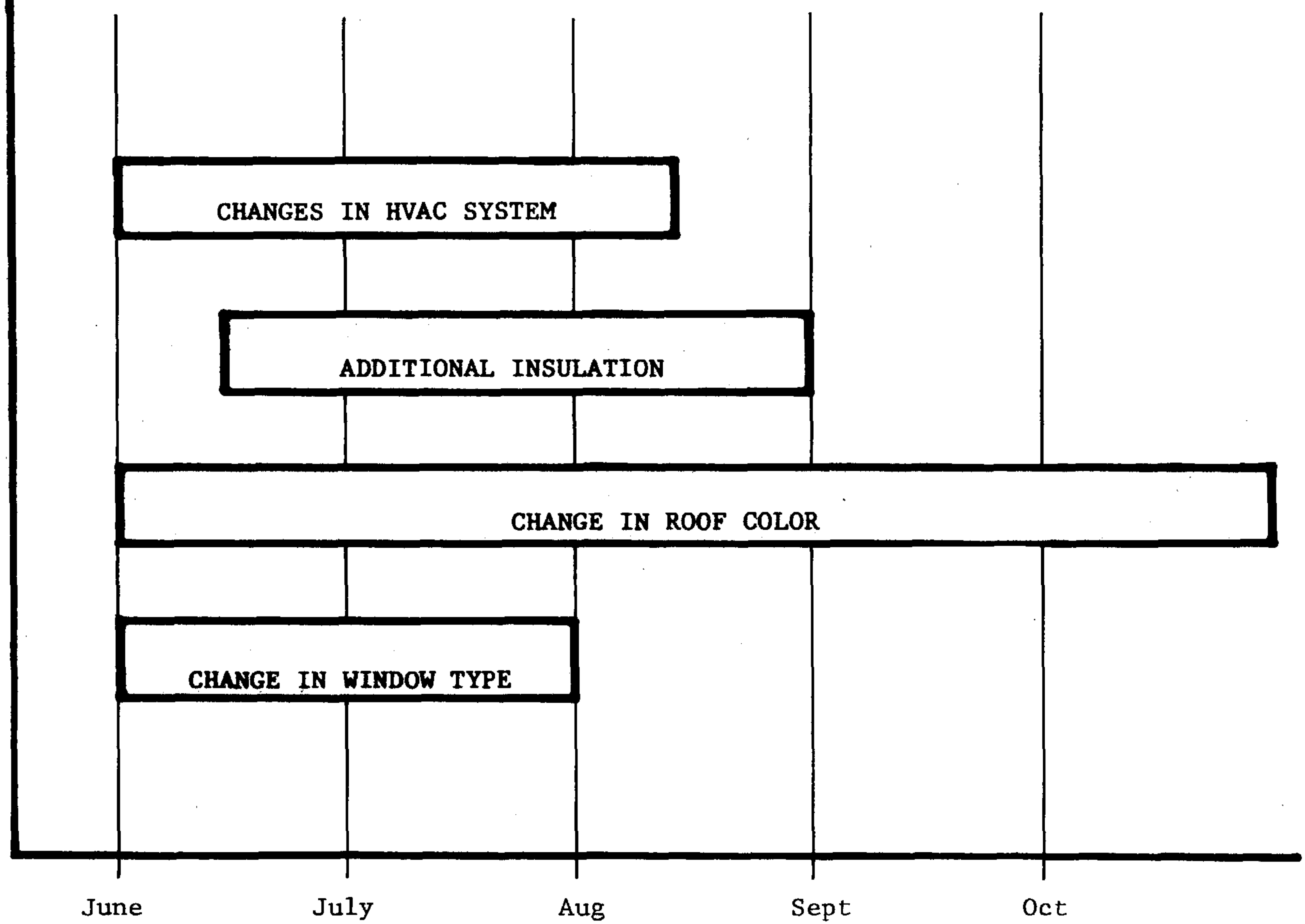


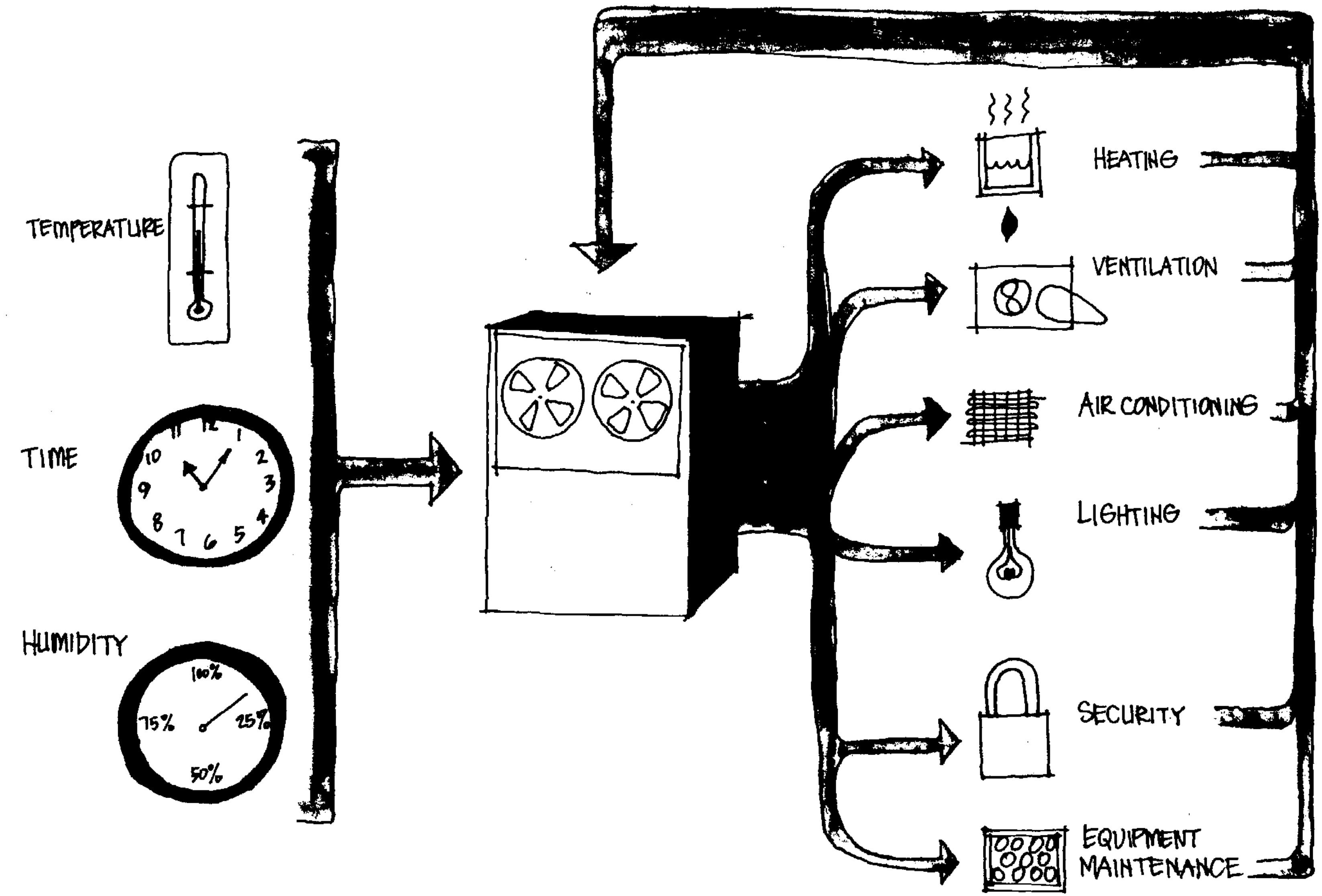
EARTH BUFFERED INTERIOR THERMAL MASS



EARTH MASS THERMAL BUFFER

CRITICAL TIME LIMITATIONS





COMPUTER·AIDED BUILDING OPERATION

APPENDIX B

STEARNS-ROGERS, INC., REPORT

SOLAR THERMAL ELECTRIC POWER SYSTEMS
NORTH LAKE CAMPUS
DALLAS COUNTY
COMMUNITY COLLEGE DISTRICT

FOR

SANDIA LABORATORIES
ALBUQUERQUE, NEW MEXICO
SANDIA CONTRACT NO. 02-7805

STEARNS-ROGER INCORPORATED

JUNE 1976

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SECTION 1

INTRODUCTION

This report is prepared to assist Sandia Laboratories in preparation of a conceptual design for a solar total energy system at the new North Lake Campus of the Dallas County Community College District. This campus is under construction in Irving, Texas. As presently designed, the campus energy requirements are provided by conventional means. This project will investigate the feasibility of displacing some part of the conventional energy supply with a solar total energy system.

This report presents the technical and cost analysis of thermal-to-electric power conversion systems applicable to this project and its integration with the existing energy supply network at the North Lake Campus.

Specific tasks contained in this report include the following:

1. Development and selection of thermodynamic cycles. Both steam and organic Rankine cycles are investigated.

2. Determination of equipment availability.

3. Definition of control functions.

4. Definition of electrical intertie between the solar electric system and public utility.

5. Cost comparison of alternate cycle plants.

6. Plant configurations are developed for selected options.

Campus load data (i.e. heating, cooling, electric power, and hot water) and architectural support was furnished by Envirodynamics, Inc., a study participant.

Information developed in this study will be integrated into the solar total energy system by Sandia Laboratories, who is responsible for the solar energy system definition and performance evaluation. Discussion of the solar collector and thermal storage subsystem design and selection is the responsibility of Sandia Laboratories and is beyond the scope of this study.

SECTION 2

SUMMARY AND RECOMMENDATIONS

Three basic operational concepts for the thermo-electric power conversion part of the solar total energy system were investigated. These concepts are:

I. **Cascaded System A**

Utilize electrical power generated from solar heated high temperature (600°F) storage system to provide the lighting and miscellaneous load plus the space cooling load, provide a condenser output of 190°F water to meet the space heating and domestic hot water campus loads. Total net generation is 2000 KW.

II. **Cascaded System B**

Utilize electrical power generated from a solar heated high temperature (600°F) storage system to provide the lighting and miscellaneous load plus the space cooling load, utilize the lowest practical ambient conditions for the condenser operation. The additional campus loads will be met through a supplemental capability utilizing either solar or fossil fuel thermal energy. Total net generation is 2000 KW.

III. **Noncascaded System C**

Utilize electrical power generated from a solar heated high temperature (600°F) storage system to provide the lighting and miscellaneous load only. Utilize the lowest practical ambient conditions for the condenser operation. Total net generation is 1250 KW.

In addition to the above concepts, the use of condenser waste heat and turbine extraction steam, Systems D and E, respectively, utilizing lithium bromide absorption chillers was also studied. The net generation for these two cases is 1250 KW.

The thermal-to-electric conversion systems analyzed in this study were selected to give a broad range of alternative cycles capable of operating within the level of available solar energy input. Approximately 16 steam Rankine cycles and 36 organic Rankine cycles (9 Toluene and 27 Trifluoroethanol) were developed in this study for the integration into the solar total energy system.

Of the thermoelectric conversion cycles considered in this study, the steam cycles resulted in the lowest capital costs, while the organic Rankine cycles using Toluene resulted in the highest cycle efficiencies (lowest cycle heat input). On the basis of this study, however, it is our recommendation that steam cycles be used for the North Lake Campus solar thermal electric power generation system.

In addition to the capital cost advantage, the steam electric plants offer proven equipment design and reliability compared to the organic Rankine cycle plants. Since no organic Rankine cycle power generation plants of this size range operate in the United States, the system concept must be considered in the developmental stage and, as such, is not recommended for installation at North Lake Campus.

Steam cycles A2 and B2, utilizing a two-heater extraction cycle, are favored for Cascaded System A and B respectively, because of the slightly higher cycle efficiencies realized over the single heater cycles A1 and B1. For Noncascaded System C, cycle C1 is recommended.

Of the vapor absorption steam cycles considered, cycle D1, utilizing 190°F condenser cooling water to the absorption chiller, results in the highest cycle efficiency and lowest capital investment, compared to automatic extraction steam cycles E1, E2 and E3. Whether or not absorption chillers can be economically justified in the thermoelectric conversion cycle, however, remains to be determined.

Of the organic Rankine cycles, Toluene cycles A2-ORC-T, B2-ORC-T and C2-ORC-T are favored for Cascaded Systems A and B, and Noncascaded System C respectively. These cycles offer the highest cycle efficiencies of the organic cycles studied. Also, Toluene is currently being successfully used as the working fluid in other smaller ORC applications (viz. Sundstrand) at elevated pressures and temperatures, however, little is known about Trifluoroethanol (TFE).

The supercritical TFE cycles show a higher cycle efficiency over the subcritical TFE cycles and offer an apparent advantage in evaporator design (utilizing a "once-through" design in lieu of a multiphase fluid boiler arrangement). However, the operating problems associated with once-through boilers, particularly on cycling units (as the solar plant would be) become significant.

SECTION 3

SYSTEM DESCRIPTIONS

Three basic operational concepts are presented herein for the thermoelectric power conversion part of the solar energy system. These concepts are:

I. **Cascaded System A**

Utilize electrical power generated from solar heated high temperature (600°F) storage system to provide the lighting load plus the space cooling load (existing electrically driven vapor compression water chilling equipment) provide a condenser output of 190°F water to meet the space heating and domestic hot water campus loads.

II. **Cascaded System B**

Utilize electrical power generated from a solar heated high temperature (600°F) storage system to provide the lighting load plus the space cooling load, and utilize the lowest practical ambient conditions for the condenser operation. The additional campus load will be met through a supplemental capability utilizing either solar or fossil fuel thermal energy.

III. **Noncascaded System C**

Utilize electrical power generated from a solar heated high temperature (600°F) storage system to provide the lighting and miscellaneous load only. Utilize the lowest practical ambient conditions for the condenser operation. The additional campus load—space cooling, space heating, and domestic hot water—will be met through low-temperature solar energy collection or auxiliary fossil fuel thermal input.

In addition to the above concepts, the use of condenser waste heat and turbine extraction steam for space cooling, systems D and E, respectively, utilizing lithium bromide absorption chillers, was also studied.

SECTION 4

SYSTEM REQUIREMENTS

The solar energy input to the thermoelectric power conversion system will be in the form of heat transfer fluid (Therminol 66) supplied at a maximum temperature of approximately 600°F from thermal storage.

The campus energy load requirements (exclusive of the solar power plant auxiliary power) used in this study are defined as follows:

Lighting Plus Miscellaneous Electrical Power:

Peak Load	1.25 MW_e (4.3 x 10^6 BTU/hr.)
Daily Consumption	20.0 MWH_e (68 x 10^6 BTU)

Air Conditioning:

Summer

Peak Load	3.1 MW_t (10.6 x 10^6 BTU/hr.)
Daily Consumption	52.0 MWH_t (177 x 10^6 BTU)

Winter

Peak Load	1.65 MW_t (5.6 x 10^6 BTU/hr.)
Daily Consumption	19.0 MWH_t (65 x 10^6 BTU)

Space Heating:

Peak Load	1.75 MW_t (6.0 x 10^6 BTU/hr.)
Daily Consumption	13.0 MWH_t (44 x 10^6 BTU)

Domestic Hot Water:

Peak Load	0.52 MW_t (1.8 x 10^6 BTU/hr.)
Daily Consumption	8.0 (27 x 10^6 BTU)

The annual load requirements for the campus have been estimated as follows:

Electric Lighting and Miscellaneous Power:

5.4 x 10^6 KWH*

*These values are estimated by scaling actual consumption levels of other campuses in the District to the equivalent North Lake Campus area.

Domestic Hot Water:

Natural Gas Input 7.2×10^9 BTU*

Space Heating:

Natural Gas Input 9.35×10^9 BTU*

Space Cooling:

Electrical Power Input 4.7×10^6 KWH*

SOLAR POWER PLANT AUXILIARY POWER

For the purpose of this study, a plant auxiliary or parasitic power requirements of 13.5 percent of gross generation was assumed for the steam turbine plants. This is the power required to drive the plant auxiliary equipment, such as boiler feed pumps, condensate hotwell pumps, condenser circulating water pumps, cooling tower fans, lighting, miscellaneous power, etc., which must be added to the net generation required.

For the organic fluid cycles, an auxiliary power requirement of 15 percent was assumed, except for the supercritical organic cycles where 18 percent auxiliary power was used, primarily due to higher pumping power.

The above auxiliary power requirements were assumed to be constant for all cases considered. Slight variations in auxiliary power would exist with each case considered; however, this would have little or no effect on the cycle selection.

*These values are estimated by scaling actual consumption levels of other campuses in the District to the equivalent North Lake Campus area.

SECTION 5

THERMODYNAMIC CYCLES

STEAM RANKINE CYCLES

Utilizing the high temperature (600°F) heat transfer fluid from thermal storage, it was determined that steam at 470 psig and 555°F could be generated for use in a steam Rankine cycle for power generation. The turbine backpressure used was 25 inches Hg abs for System A, D, E1, and E2, and 3 inches Hg abs for Systems B, C, and E3. Alternate steam cycles using lower turbine throttle steam pressures were also investigated. The comparative heat rates (cycle efficiencies) for the various steam cycles considered were calculated based on methods outlined in a published paper.[1]

In all cases, except where automatic extraction turbines are used (System E), the steam turbines in this study are standard straight condensing, multistage, with one or two uncontrolled extractions, as required, coupled to an electric generator through a speed reducer gear. The single automatic turbine is similar, except that the extraction pressure is controlled to a constant pressure independent of load.

A summary of performance for the alternate steam turbine cycles studied is shown in Table 5–1.

The process flow diagrams for the steam cycles are presented in Figures 5–1 through 5–16.

ORGANIC RANKINE CYCLES

The selection of the working fluid for the organic Rankine cycles considered in this study was made by Sandia Laboratories based on previous investigations and experience with organic working fluids. The two working fluids considered in this report are Toluene and Trifluoroethanol.

ORGANIC FLUID COMPARISON

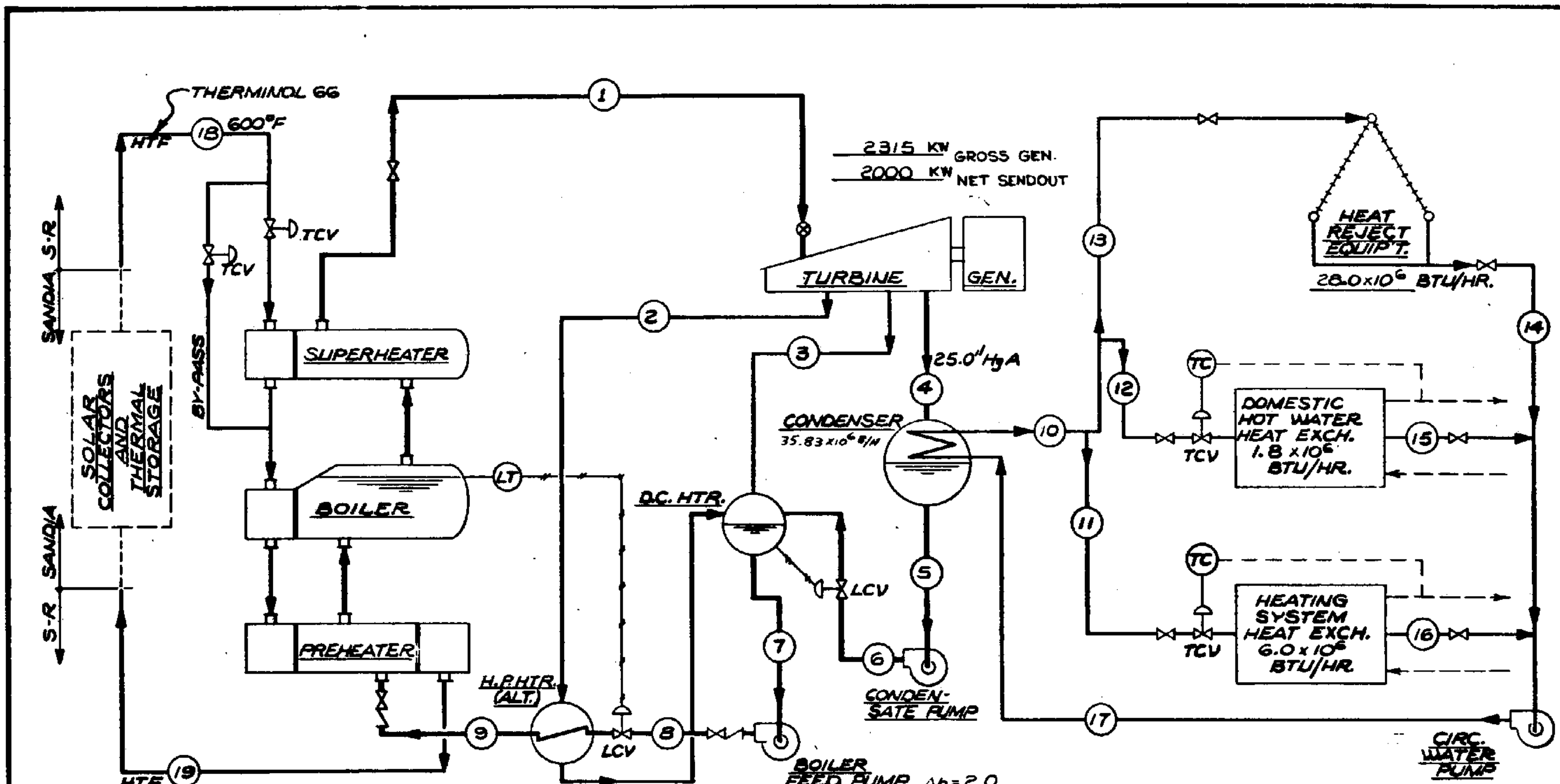
		Toluene ($C_6H_5CH_3$)	Trifluoroethanol (CF_3CH_2OH)
Ignition Temperature	°F	997	Not Available
Flash Point	°F	40	105.0
Boiling Temperature @ 1 Atm	°F	231	164.5
Density @ 100°F	lb/ft^3	53.9	64.0
Specific Heat @ 100°F	BTU/lb° E	0.388	0.419
Critical Pressure	PSIA	595.9	715.0
Critical Temperature	°F	605.4	440.0

[1]E.V. Pollard, Calculation of Comparable Heat Rates of Steam Turbines - Heat Rate Correction Factors, General Electric Company, reprinted from *Industry and Power*, December, 1952 and January, 1953.

Cycle No.	A1	A2	A3	A4	B1	B2	B3	B4
Gross Generation, KW	2,315	2,315	2,315	2,315	2,315	2,315	2,315	2,315
Auxiliary Power, KW	315	315	315	315	315	315	315	315
Net Generation, KW	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Gross Turbine Heat Rate, BTU/KWH	18,950	18,603	19,779	20,895	14,353	14,055	15,026	15,855
Throttle Pressure, PSIG	450	450	350	255	450	450	375	280
Throttle Temperature, °F	550	550	550	550	550	550	550	550
Condenser Pressure, In. HgA	25.0	25.0	25.0	25.0	3.0	3.0	3.0	3.0
Throttle Steam Flow, Lb/Hr	43,760	44,590	44,780	46,410	31,380	32,210	32,400	33,570
No. of Feedwater Heaters	1	2	1	1	1	2	1	1
Heat Input to Cycle, 10^6 BTU/Hr	43.87	43.06	45.79	48.37	33.23	32.54	34.78	36.71
Heat Rejected to Cond., 10^6 BTU/Hr	31.83	35.10	37.79	40.33	25.58	24.92	27.34	29.17
Therminol Temp. Diff., °F	147.5	141.8	175.0	200.0	156.1	148.6	175.0	200.0
Therminol Flow, Lb/Hr	502,800	512,300	442,800	402,600	360,800	370,000	338,700	302,050
Net Cycle Efficiency, %	15.56	15.85	14.90	14.11	20.54	20.98	19.62	18.59

Cycle No.	C1	C2	C3	C4	D1	D2	D3	D4
Gross Generation, KW	1,450	1,450	1,450	1,450	1,450	1,450	1,450	1,450
Auxiliary Power, KW	200	200	200	200	200	200	200	200
Net Generation, KW	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250
Gross Turbine Heat Rate, BTU/KWH	14,350	14,047	15,032	15,835	18,951	20,998	22,449	20,996
Throttle Pressure, PSIG	450	450	375	280	450	450	350	450
Throttle Temperature, °F	550	550	550	550	550	550	550	550
Condenser Pressure, In. HgA	3.0	3.0	3.0	3.0	25.0	25.0	25.0	3.0
Throttle Steam Flow, Lb/Hr	19,650	20,160	20,300	21,000	27,410	29,000	30,700	29,000
No. of Feedwater Heaters	1	2	1	1	1	1	1	1
Heat Input to Cycle, 10^6 BTU/Hr	20.81	20.37	21.80	22.96	27.47	30.45	32.55	30.44
Heat Rejected to Cond., 10^6 BTU/Hr	15.97	15.60	16.85	18.06	22.44	10.14	11.86	9.40
Therminol Temp. Diff., °F	156.1	148.6	175.0	200.0	147.5	154.1	175.0	154.1
Therminol Flow, Lb/Hr	225,800	231,600	212,200	195,500	314,900	339,000	318,850	339,000
Net Cycle Efficiency, %	20.50	20.95	19.56	18.57	15.52	14.00	13.10	14.01

TABLE 5–1. SUMMARY OF PERFORMANCE - STEAM CYCLES



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LBS/HR	43,760	0	4300	39460	39460	39,460	43760	43760	43760	1,194,300	200,000	60,000	934,300	934,300	60,000
PRESS.	PSIA	465		63.2	12.3	12.3	110	63.2	550	550	60	60	60	60	25	25
TEMP.	°F	550		296.1	203.1	203.1	203.1	296.1	297.3	297.3	190.0	190.0	190.0	190.0	160.0	160.0

		16	17	18	19
FLOW	LBS/HR	200,000	1,194,300	502,800	502,800
PRESS.	PSIA	25	70	100	80
TEMP.	°F	160.0	160.0	600.0	452.5

HEAT INPUT TO CYCLE	43.87×10^6 BTU/HR
BTHR	18950 BTU/KWH
EFF. (GROSS)	18.01 %
EFF. (NET)	15.56 %

ORDER NO	C17686
SCALE	NONE
DRAWN HOTE	CHECK BDR
APPROVED Aunl 5/27/76	

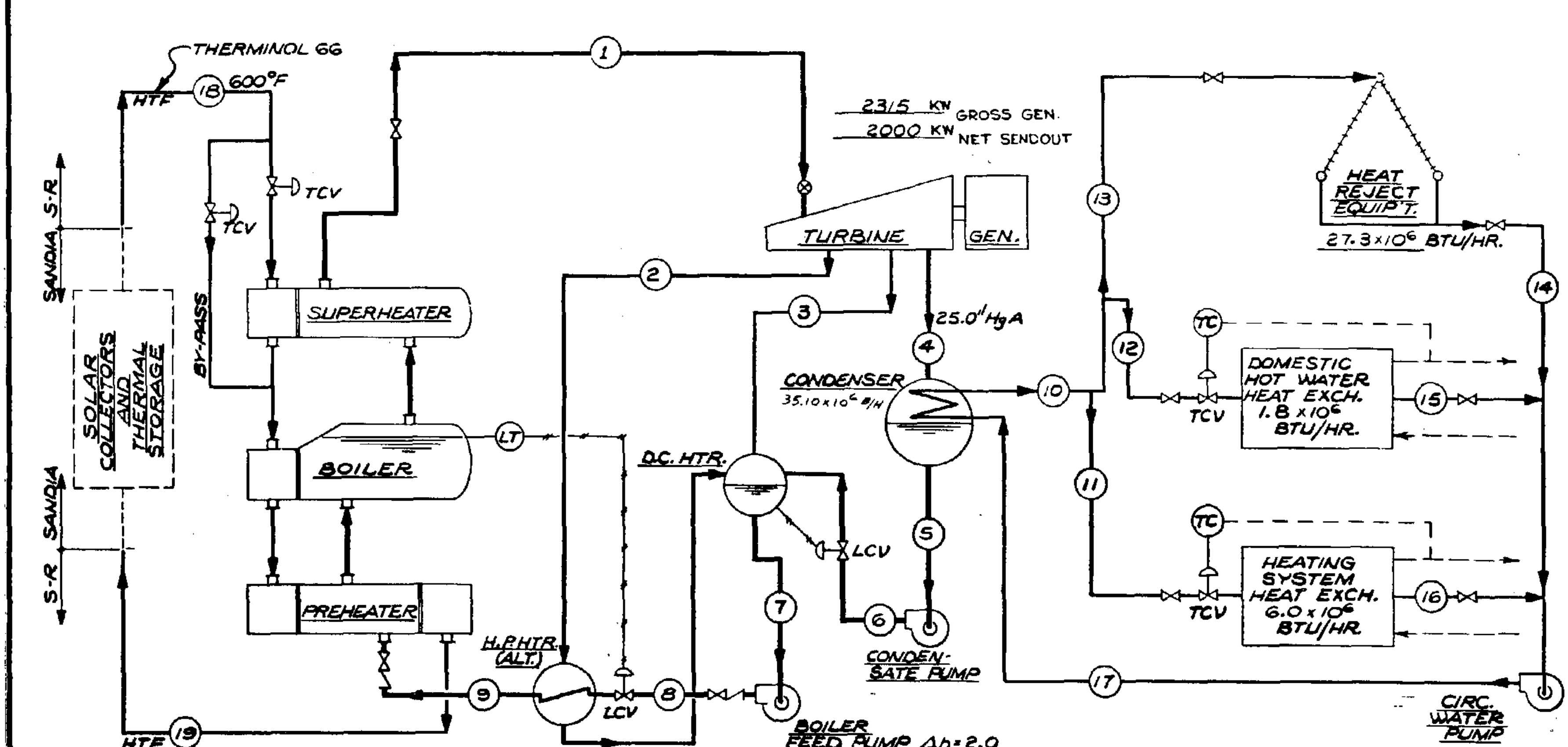
STEAM CYCLE A1

PROCESS FLOW DIAGRAM
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger

DRAWING NO A1

FIGURE 5–1. STEAM CYCLE A1 PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LBS/HR	44,590	3250	2550	38790	38790	38790	44590	44590	44590	1,170,000	200,000	60,000	910,000	910,000	60,000
PRESS.	PSIA	465	220	35.4	12.3	12.3	90	35.4	560	550	60	60	60	60	25	25
TEMP.	°F	550	420.0	259.8	203.1	203.1	203.1	259.8	261.0	334.2	190.0	190.0	190.0	190.0	160.0	160.0

		16	17	18	19
FLOW	LBS/HR	200,000	1,170,000	512,300	512,300
PRESS.	PSIA	25	70	100	80
TEMP.	°F	160.0	160.0	600.0	458.2

HEAT INPUT TO CYCLE	43.06×10^6 BTU/HR
GTHR	18,603 BTU/KWH
EFF. (GROSS)	18.35%
EFF. (NET)	15.85%

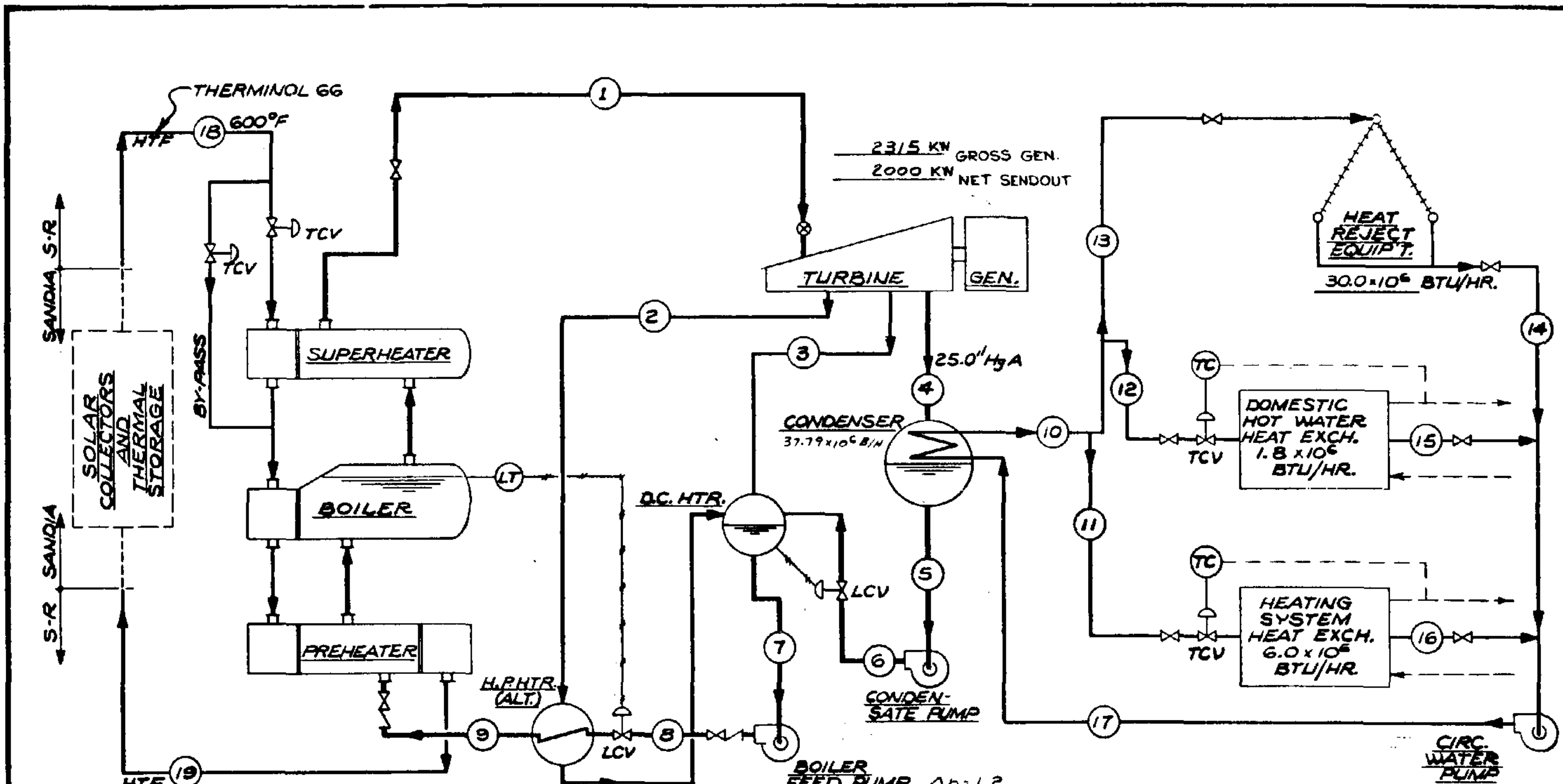
STEAM CYCLE A2

ORDER NO. C17686
SCALE NONE
DRAWN XOTE CHECK BDR
APPROVED Hum 5/27/76

PROCESS FLOW DIAGRAM
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger DRAWING NO. A2

FIGURE 5–2. STEAM CYCLE A2 PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LBS/HR	44780	0	4030	40750	40750	40750	44780	44780	44780	1,260,000	200,000	60,000	1,000,000	1,000,000	60,000
PRESS.	PSIA	365		56	12.3	12.3	110	56	460	460	60	60	60	60	25	25
TEMP.	°F	550		288.8	203.1	203.1	203.1	28.8	289.5	289.5	190.0	190.0	190.0	190.0	160.0	160.0

		16	17	18	19
FLOW	LBS/HR	200,000	1,260,000	442,800	442,800
PRESS.	PSIA	25	70	100	80
TEMP.	°F	160.0	160.0	600.0	425.0

STEAM CYCLE A3

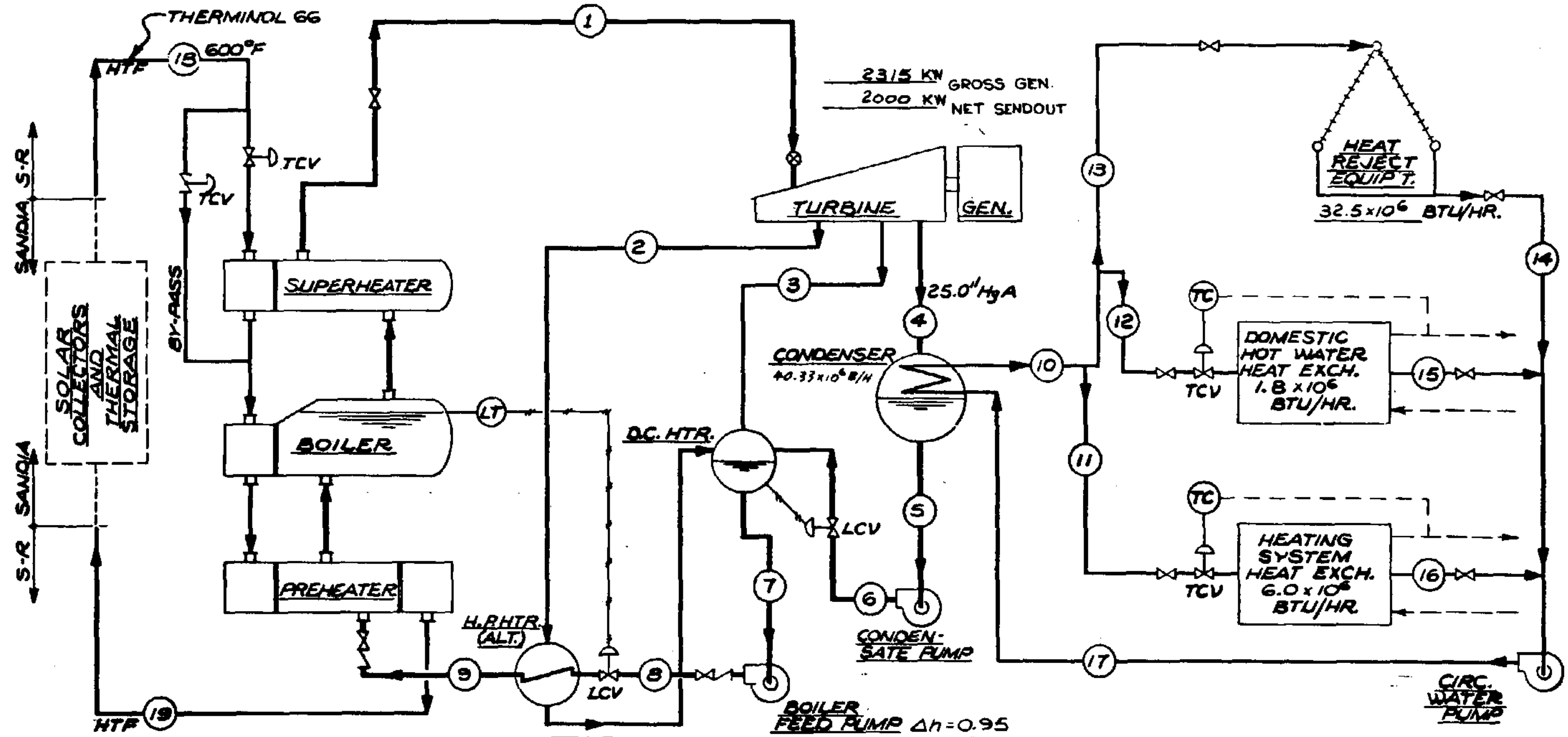
HEAT INPUT TO CYCLE	45.79×10^6 BTU/HR
GTHR	19,779 BTU/KWH
EFF. (GROSS)	17.25%
EFF. (NET)	14.90%

ORDER NO. C17686
SCALE NONE
DRAWN MOTE CHECK BDR
APPROVED Awn 5/27/76

PROCESS FLOW DIAGRAM
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger DRAWING NO. A3

FIGURE 5–3. STEAM CYCLE A3 PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LBS/HR	46410	0	3990	42,420	42,420	42,420	46,410	46,410	46,410	1,344,300	200,000	60,000	1,084,300	1,084,300	60,000
PRESS.	PSIA	270		47.8	12.3	12.3	100	47.8	350	350	60	60	60	60	25	25
TEMP.	°F	550		278.2	203.1	203.1	203.1	278.2	278.7	278.7	190.0	190.0	190.0	190.0	160.0	160.0

STEAM CYCLE A4

		16	17	18	19
FLOW	LBS/HR	200,000	1,344,300	402,600	402,600
PRESS.	PSIA	25	70	100	80
TEMP.	°F	160.0	160.0	600.0	400.0

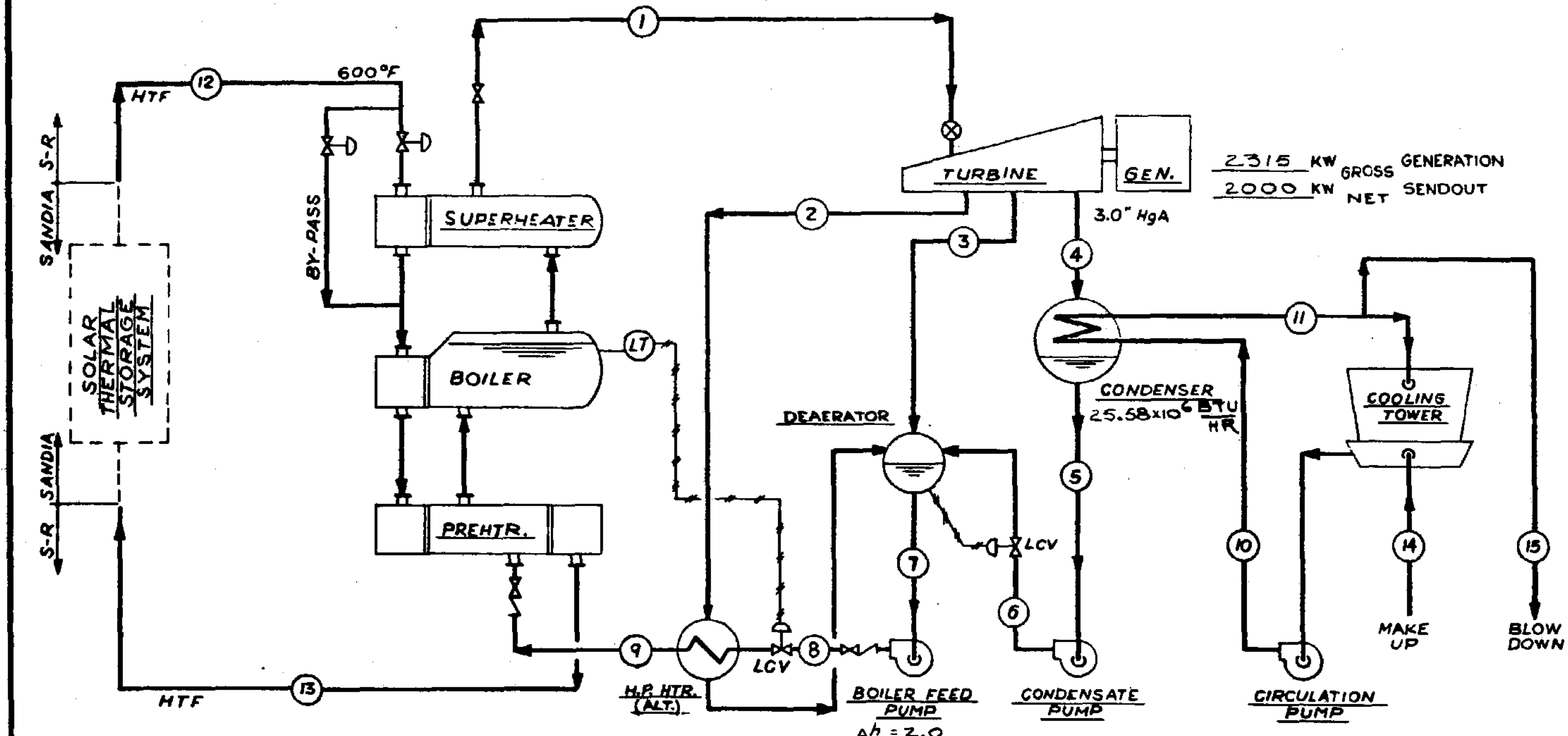
HEAT INPUT TO CYCLE	48.37 x 10⁶ BTU/HR
GTHR	20,895 BTU/KWH
EFF. (GROSS)	16.33%
EFF. (NET)	14.11%

ORDER NO	C 17686
SCALE	NONE
DRAWN XOTE	CHECK BDR
APPROVED	AWM 5/27/76

PROCESS FLOW DIAGRAM
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger — DRAWING NO A4

FIGURE 5–4. STEAM CYCLE A4 PROCESS FLOW DIAGRAM

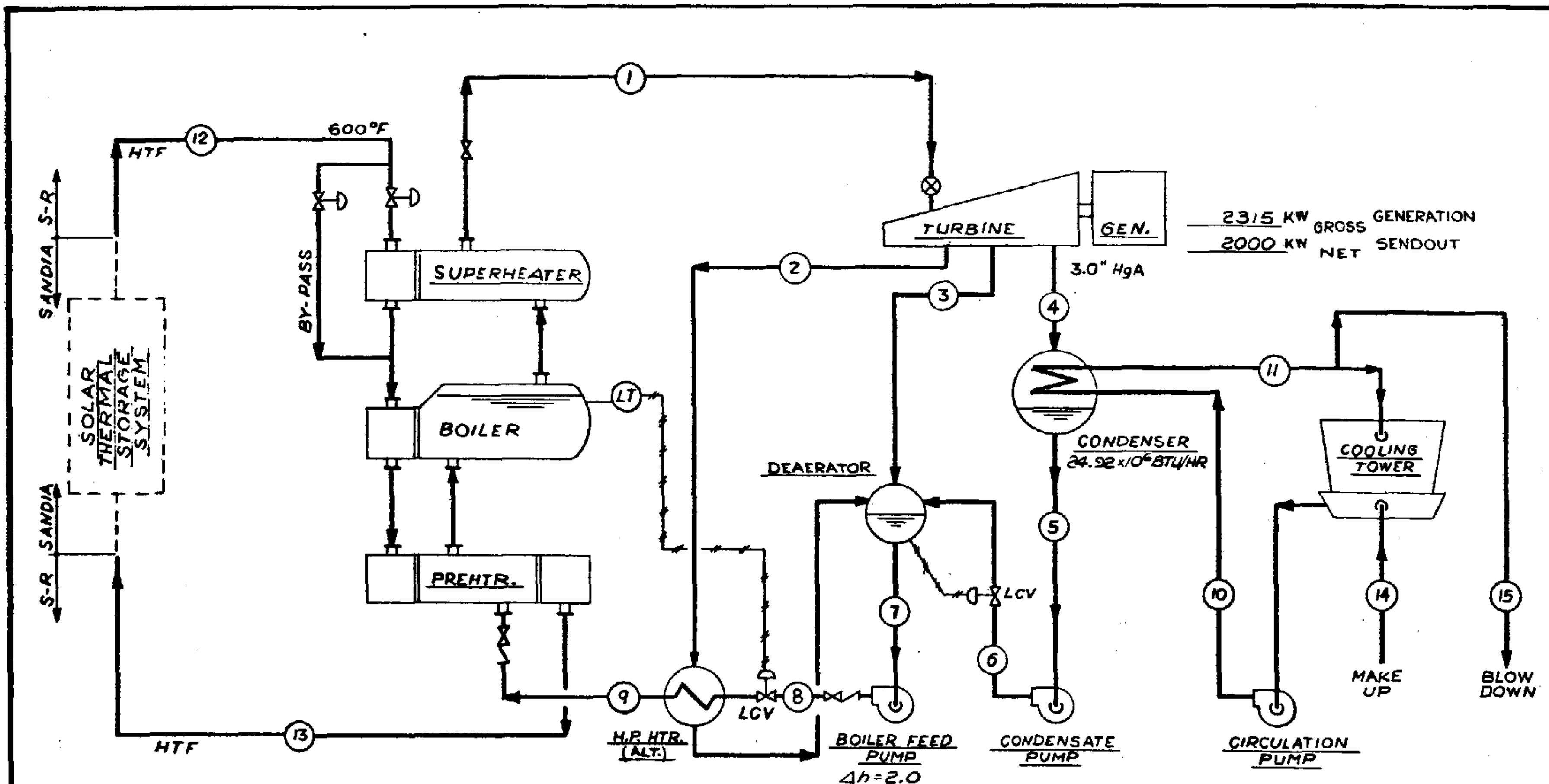


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	31,380	0	3970	27,410	27,410	27,410	31,380	31,380	31,380	1,421,100	1,421,100	360,800	360,800	32,950	5185
PRESSURE	PSIA	465		26.0	1.47	1.47	55	26.0	550	550	40	30	100	80	15	25
TEMPERATURE	°F	550		242.3	115.1	115.1	115.1	242.3	243.5	243.5	90.0	108.0	600.0	443.9	87.0	108.0

STEAM CYCLE B1

HEAT INPUT TO CYCLE	33.23×10^6 BTU/HR	ORDER NO. C 17 686		PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	14,353 BTU/KWH	SCALE NONE		
EFF. (GROSS)	23.78 %	DRAWN SS	CHECK BDR	Stearns-Roger
EFF. (NET)	20.54 %	APPROVED AWM 5/27/76		DRAWING NO. B1 △

FIGURE 5—5. STEAM CYCLE B1 PROCESS FLOW DIAGRAM

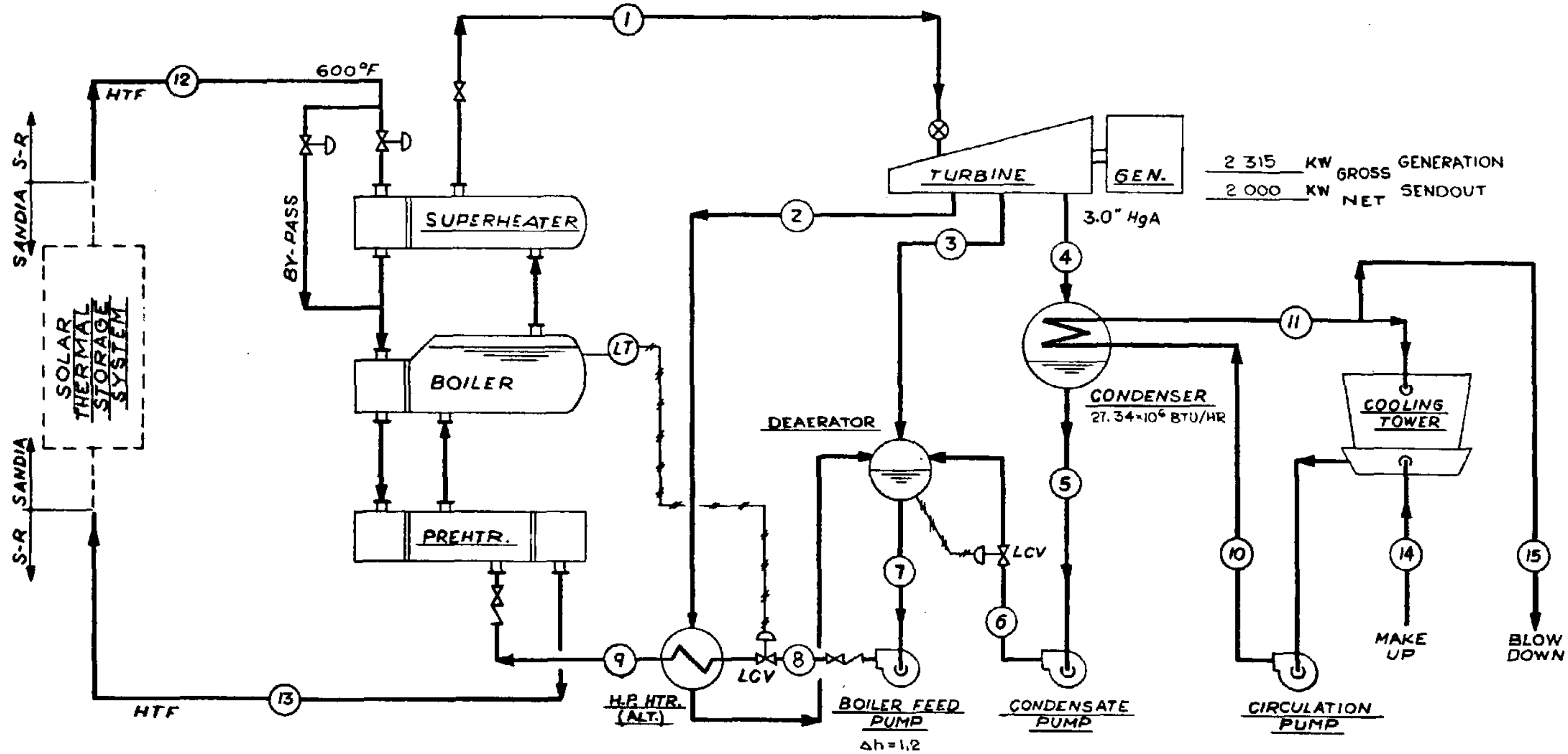


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	32,210	1410	4000	26,800	26,800	26,800	32,210	32,210	32,210	1,384,400	1,384,400	370,000	370,000	32,050	5000
PRESSURE	PSIA	465	63.5	30	1.47	1.47	60	30	560	550	40	30	100	80	15	25
TEMPERATURE	°F	550	266.0	253.1	115.1	115.1	115.1	253.1	254.3	291.4	90.0	108.0	600.0	451.4	87.0	108.0

STEAM CYCLE B2

HEAT INPUT TO CYCLE	32.54x10^6 BTU/HR	ORDER NO. C 17 686		PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	14,055 BTU/KWH	SCALE NONE		
EFF. (GROSS)	24.28%	DRAWN SS	CHECK BDR	Stearns-Roger — DRAWING NO. B2
EFF. (NET)	20.98%	APPROVED [illegible] 5/27/76		

FIGURE 5–6. STEAM CYCLE B2 PROCESS FLOW DIAGRAM

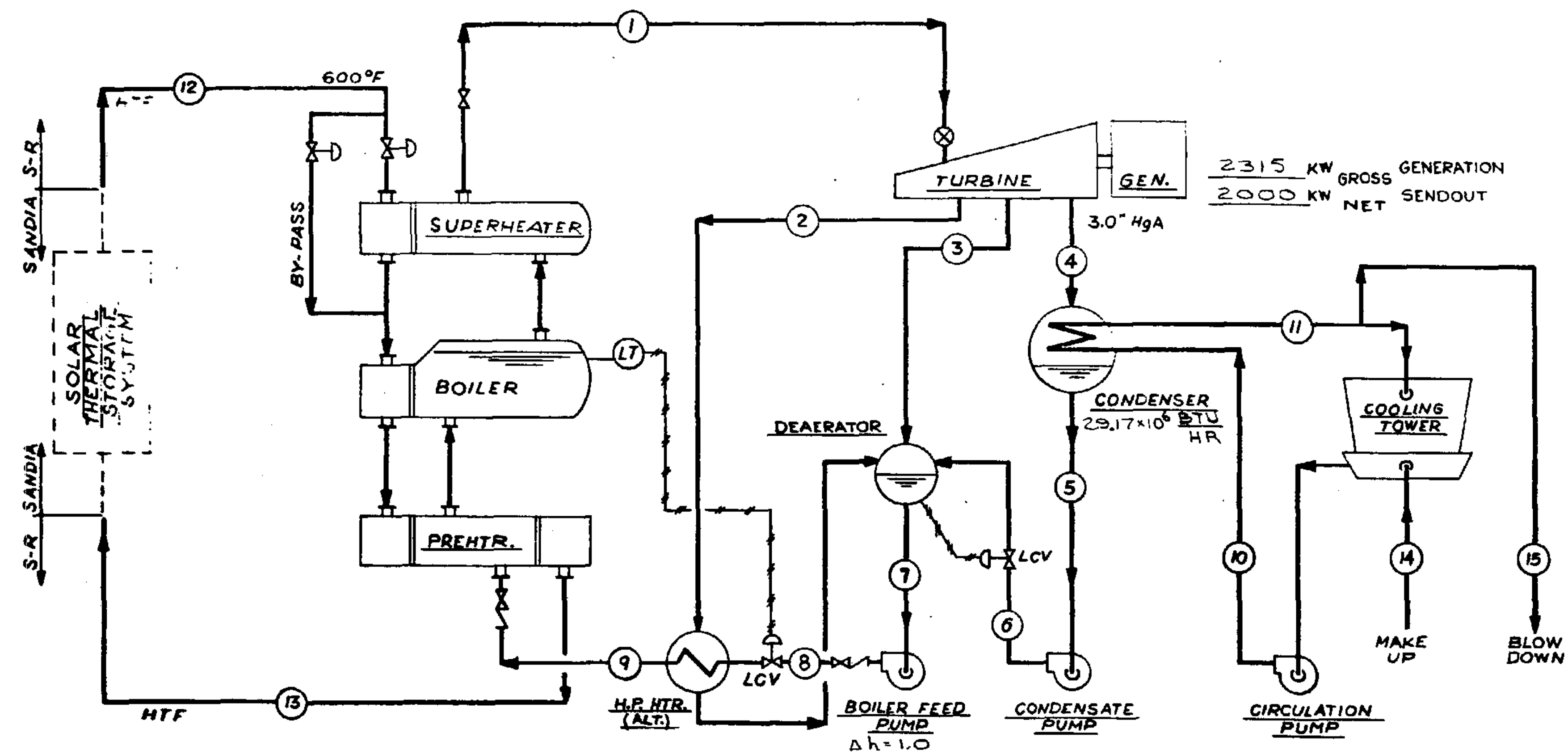


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	32,400	0	3,950	28,450	28,450	28,450	32,400	32,400	32,400	1,518,900	1,518,900	338,700	338,700	35,250	5 550
PRESSURE	PSIA	390		23.2	1.47	1.47	60	23.2	460	460	40	30	100	80	15	25
TEMPERATURE	°F	550		235.9	115.1	115.1	115.2	235.9	236.6	236.6	90.0	108.0	600.0	425.0	87.0	108.0

STEAM CYCLE B3

HEAT INPUT TO CYCLE	34.78×10^6 BTU/HR	ORDER NO. C 17 686	PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	15,026 BTU/KWH	SCALE NONE	
EFF. (GROSS)	22.71 %	DRAWN SS CHECK BDR	Stearns-Roger
EFF. (NET)	19.62 %	APPROVED A. H. 5/27 76	DRAWING NO. B3

FIGURE 5–7. STEAM CYCLE B3 PROCESS FLOW DIAGRAM

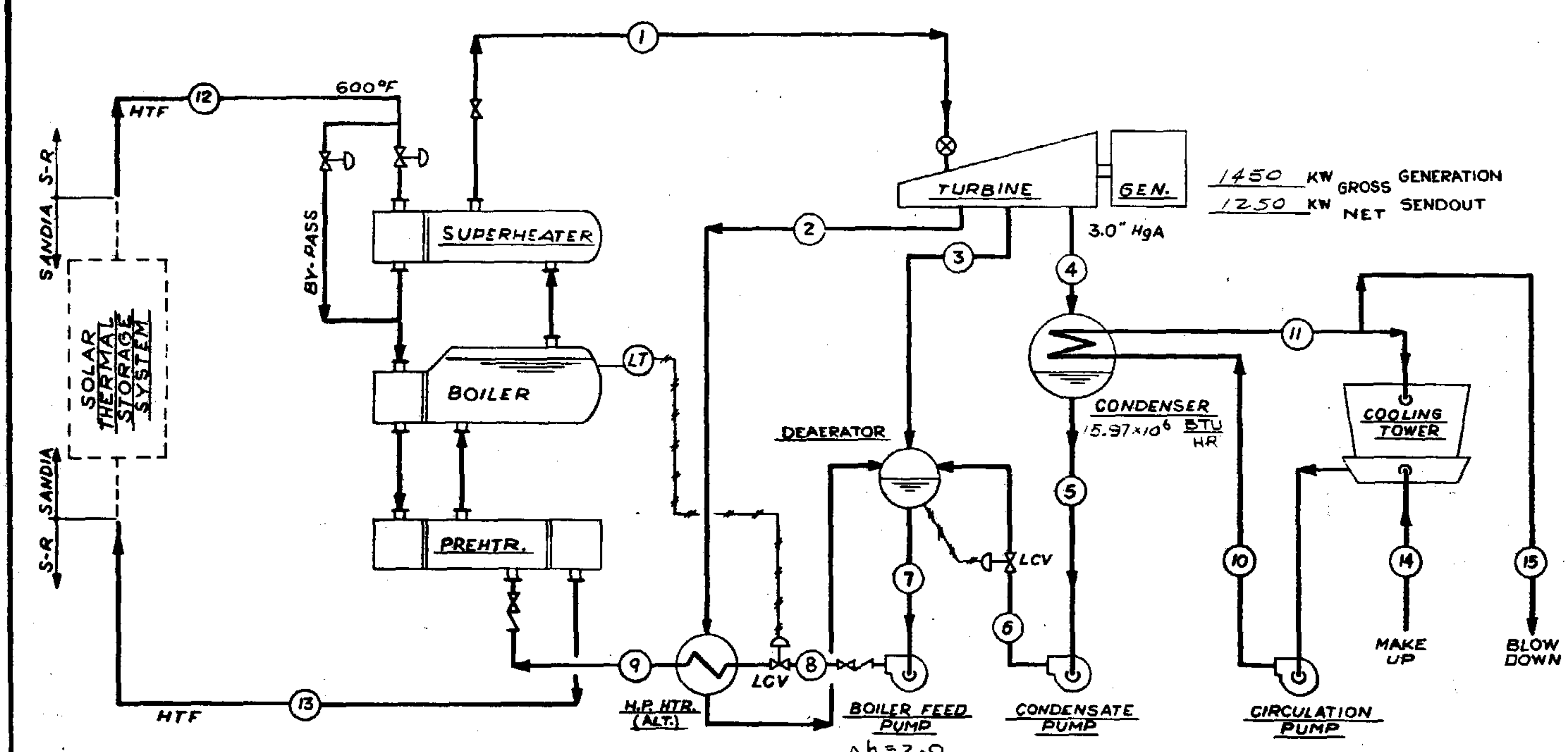


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	33,570	0	3740	29,830	29,830	29,630	33,570	33,570	33,570	1,620,550	1,620,550	302,050	302050	37,600	5480
PRESSURE	PSIA	295		19	1.47	1.47	60	19	350	350	40	30	100	80	15	25
TEMPERATURE	°F	550		225.5	115.1	115.1	115.1	225.5	226.1	226.1	90.0	108.0	600.0	400.0	87.0	108.0

STEAM CYCLE B4

HEAT INPUT TO CYCLE	36.71×10^6 BTU/HR	ORDER NO. C 17 686	PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	15,855 BTU/KWH	SCALE NONE	
EFF. (GROSS)	21.52 %	DRAWN SS CHECK BDR	
EFF. (NET)	18.59 %	APPROVED Aum 5/27/76	Stearns-Roger DRAWING NO. B4

FIGURE 5–8. STEAM CYCLE B4 PROCESS FLOW DIAGRAM

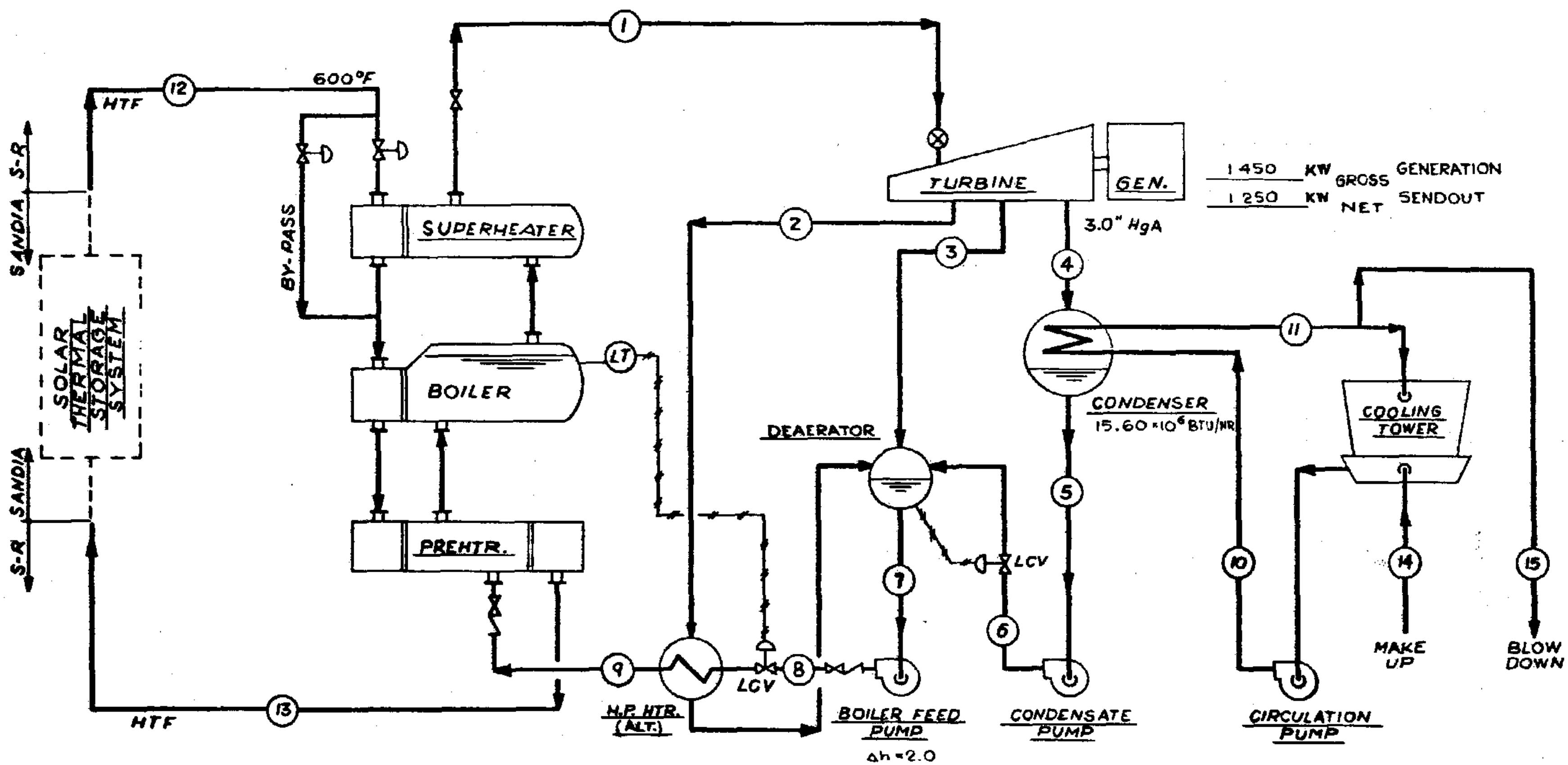


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	19,650	0	2470	17,180	17,180	17,180	19,650	19,650	19,650	877,200	877,200	225,800	225,800	20,600	3200
PRESSURE	PSIA	465		26	1.47	1.47	55	26	550	550	40	30	100	80	15	25
TEMPERATURE	°F	550		242.3	115.1	115.1	115.1	242.3	243.5	243.5	90.0	108.0	600.0	443.9	87.0	108.0

STEAM CYCLE C1

HEAT INPUT TO CYCLE	20.81×10^6 BTU/HR	ORDER NO. C 17 686		PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	14350 BTU/KWH	SCALE NONE		
EFF. (GROSS)	23.78 %	DRAWN SS	CHECK BDR	
EFF. (NET)	20.50 %	APPROVED [illegible] 5/27/76		Stearns-Roger · DRAWING NO. C1 △

FIGURE 5–9. STEAM CYCLE C1 PROCESS FLOW DIAGRAM

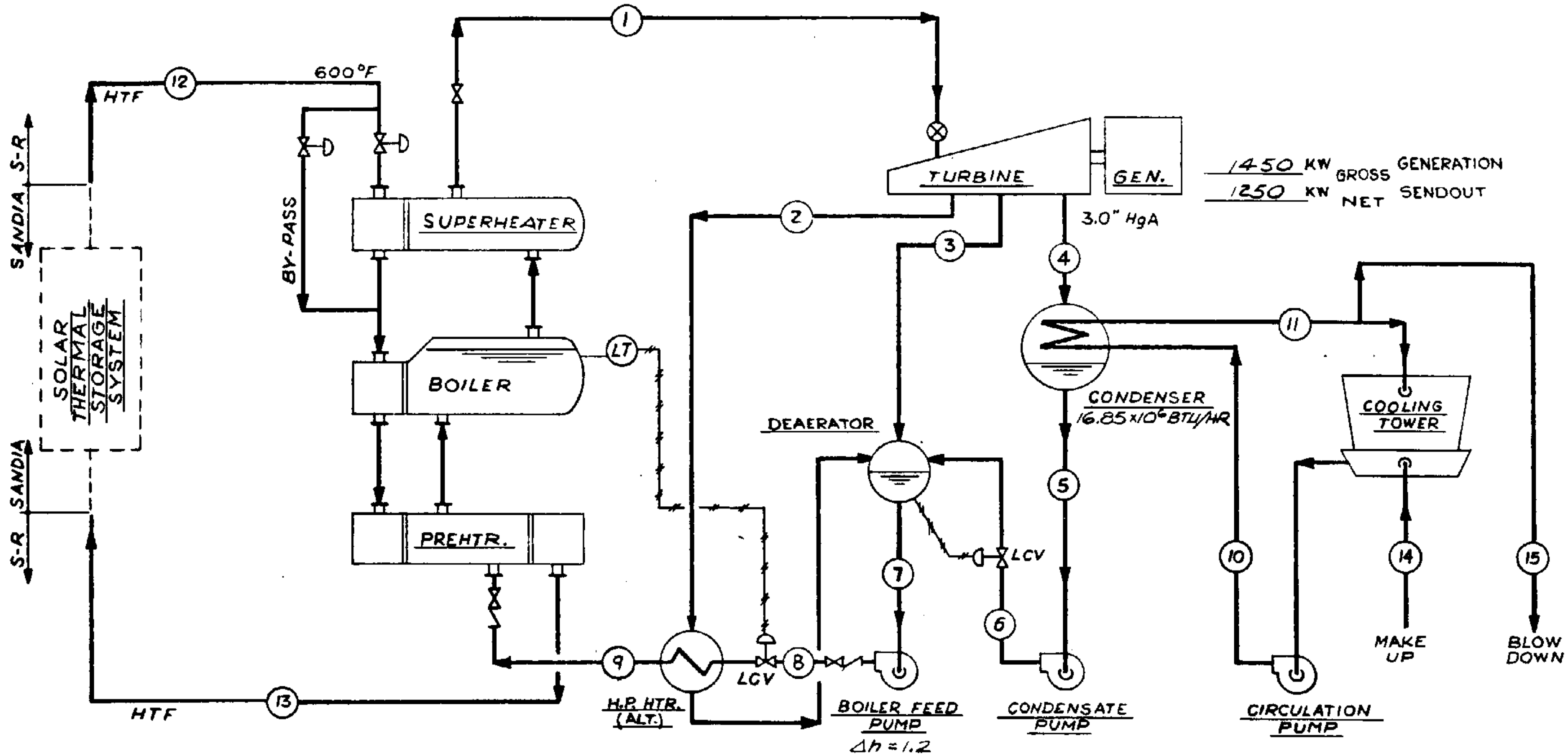


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	20,160	880	2 500	16,780	16,780	16,780	20,160	20,160	20,160	866,700	866,700	231,600	231 600	20,100	3100
PRESSURE	PSIA	465	63.5	30	1.47	1.47	60	30	560	550	40	30	100	80	15	25
TEMPERATURE	°F	550	266.0	253.1	115.1	115.1	115.1	253.1	254.3	291.4	90.0	108.0	600.0	451.4	87.0	108.0

STEAM CYCLE C2

HEAT INPUT TO CYCLE	20.37×10⁶ BTU/HR	ORDER NO. C 17 686		PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	14,047 BTU/KWH	SCALE NONE		
EFF. (GROSS)	24.30 %	DRAWN SS	CHECK BDR	Stearns-Roger
EFF. (NET)	20.95 %	APPROVED [illegible] 5/27/76		DRAWING NO. C2 △

FIGURE 5–10. STEAM CYCLE C2 PROCESS FLOW DIAGRAM

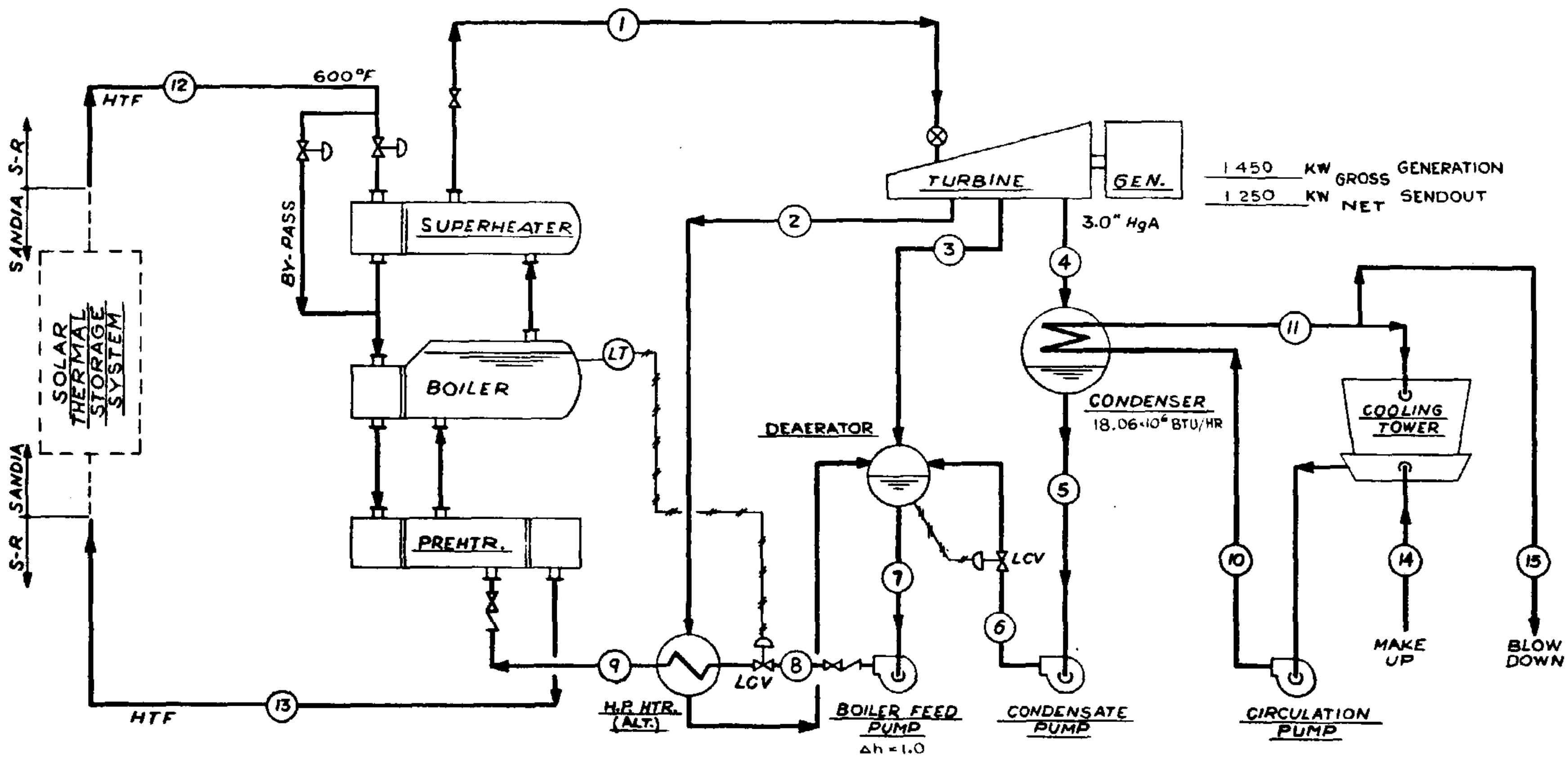


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	20,300	0	2450	17,850	17,850	17,850	20,300	20,300	20,300	936,100	936,100	212,200	212,300	21,700	3400
PRESSURE	PSIA	390		23.2	1.47	1.47	60	23.2	460	460	40	30	100	80	15	25
TEMPERATURE	°F	550		235.9	116.1	116.1	115.2	235.9	236.6	236.6	90.0	108.0	600.0	425.0	87.0	108.0

STEAM CYCLE C3

HEAT INPUT TO CYCLE	21.80x10^6 BTU/HR	ORDER NO. C 17 686		PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	15,032 BTU/KWH	SCALE NONE		
EFF. (GROSS)	22.70 %	DRAWN SS	CHECK BDR	Stearns-Roger
EFF. (NET)	19.56 %	APPROVED AWM 5/27/76		DRAWING NO. C3

FIGURE 5–11. STEAM CYCLE C3 PROCESS FLOW DIAGRAM



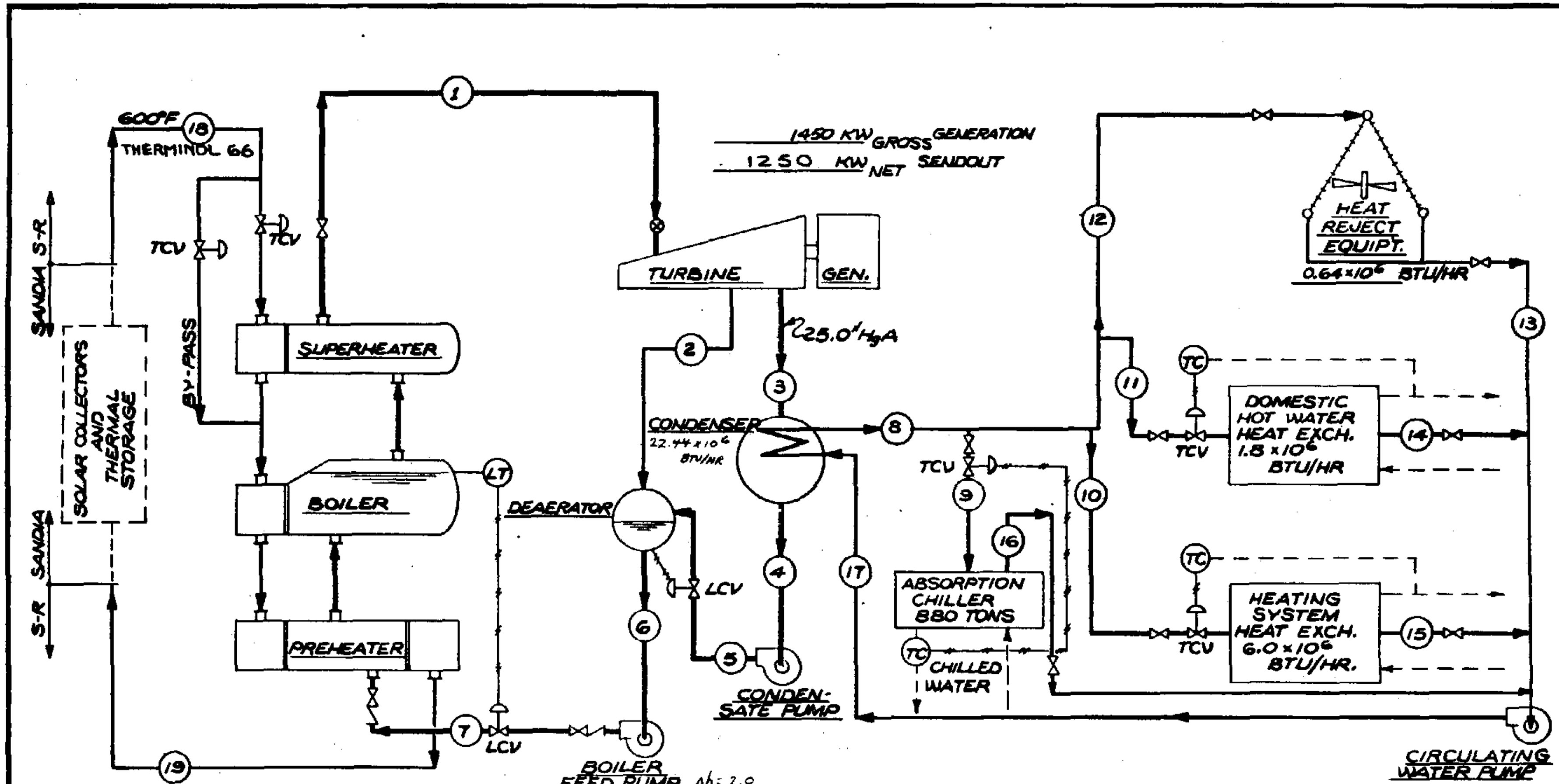
		1	2	3	4	5	6	7	8
FLOW	LB/HR	21,000	0	2 340	18,660	18,660	18,660	21,000	21,000
PRESSURE	PSIA	295		19	1.47	1.47	60	19	350
TEMPERATURE	°F	550		225.5	115.1	115.1	115.1	225.5	226.1

		9	10	11	12	13	14	15
FLOW	LB/HR	21,000	1,003,300	1,003,300	195,500	195,500	23,300	3 800
PRESSURE	PSIA	350	40	30	100	80	5	25
TEMPERATURE	°F	226.1	90.0	108.0	600.0	400.0	87.0	83.5

STEAM CYCLE C4

HEAT INPUT TO CYCLE	22.96×10⁶ BTU/HR	ORDER NO. C 17 686	PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	15.835 BTU/KWH	SCALE NONE	
EFF. (GROSS)	21.55 %	DRAWN SS CHECK BDR	Stearns-Roger
EFF. (NET)	18.57 %	APPROVED Hu ~ 5/27/76	DRAWING NO. C4 △

FIGURE 5–12. STEAM CYCLE C4 PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LBS./HR	27,410	2,610	24,800	24,800	24,800	27,410	27,410	1,781,000	1,500,000	200,000	60,000	21,300	2,300	60,000	200,000
PRESS.	PSIA	465	65	12.3	12.3	100	65	550	50	50	50	50	50	20	20	20
TEMP.	°F	550	297.6	203.1	203.1	203.1	297.6	298.8	190.0	190.0	190.0	190.0	190.0	160.0	160.0	160.0

STEAM CYCLE D1

		16	17	18	19
FLOW	LBS./HR	1,500,000	1,781,000	314,900	314,900
PRESS.	PSIA	20	60	100	80
TEMP.	°F	180.7	177.4	600.0	452.5

HEAT INPUT TO CYCLE	27.47×10^6 BTU/HR
GTHR	18,951 BTU/HR
EFF. (GROSS)	18.00 %
EFF. (NET)	15.52 %

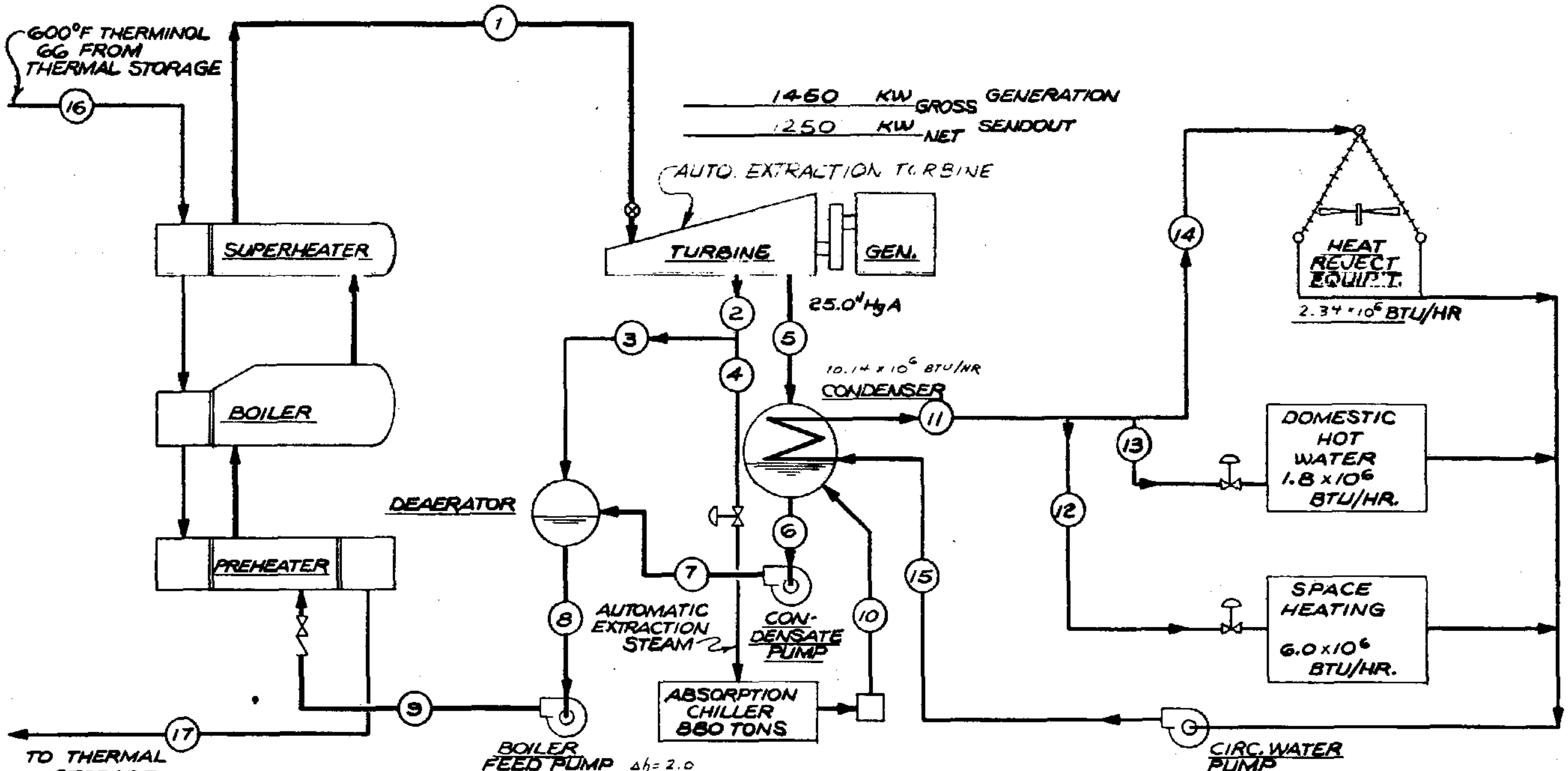
ORDER NO.	C 17686
SCALE	NONE
DRAWN	KOTE
CHECK	
APPROVED	5/27/76

PROCESS FLOW DIAGRAM
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger

DRAWING NO. D1

FIGURE 5–13. STEAM CYCLE D1 PROCESS FLOW DIAGRAM



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW LBS./HR	29,000	18,500	1,500	17,000	10,500	27,500	27,500	29,000	29,000	17,000	338,000	200,000	60,000	78,000
PRESSURE PSIA	465	30	30	30	12.3	12.3	60	30	550	25	60	60	60	60
TEMPERATURE °F	550	250.3	250.3	250.3	203.1	203.1	203.1	250.3	251.3	240.0	190.0	190.0	190.0	190.0

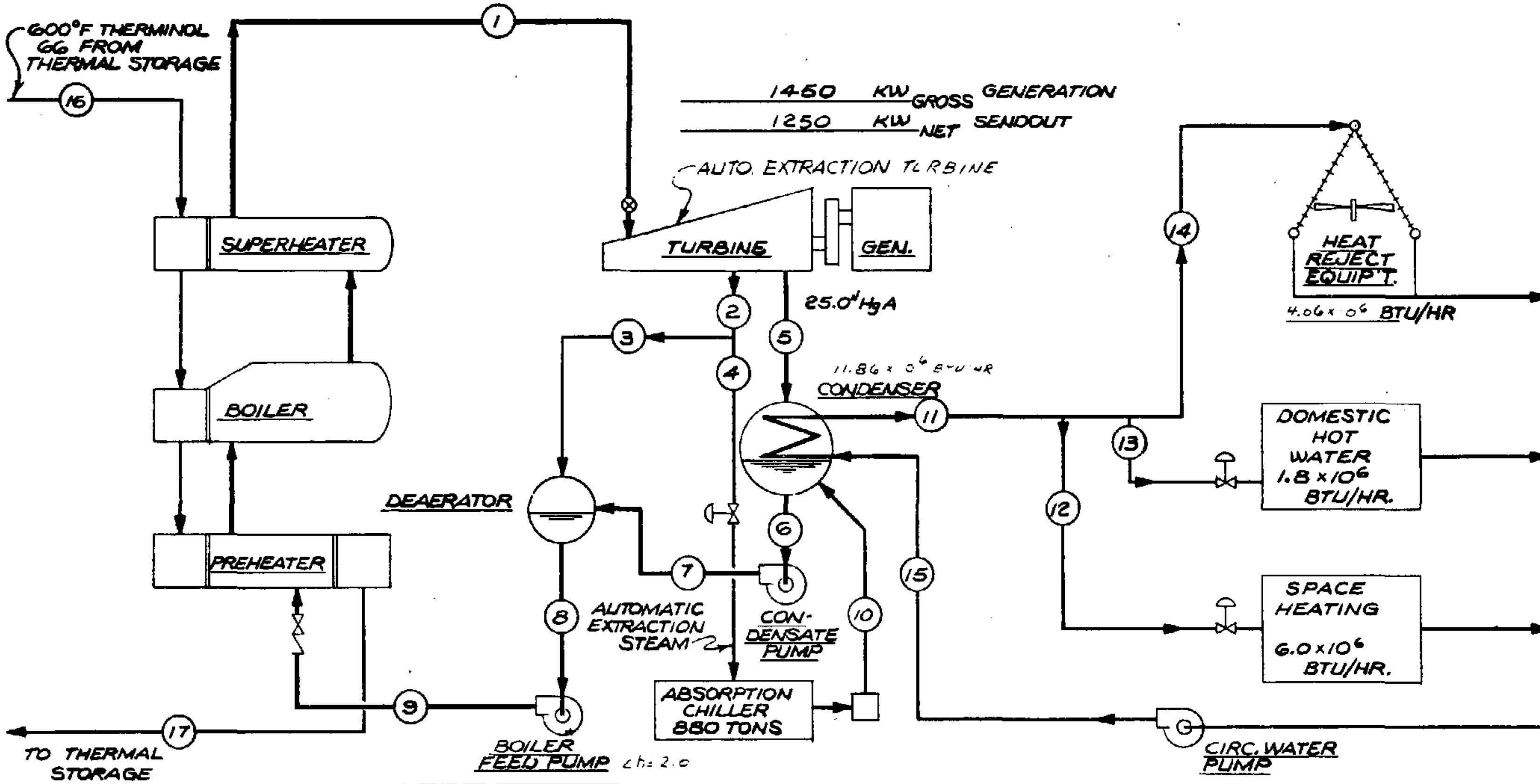
	15	16	17
FLOW LBS./HR	338,000	339,000	339,000
PRESSURE PSIA	70	100	80
TEMPERATURE °F	160.0	600.0	445.9

HEAT INPUT TO CYCLE	30.45×10^6 BTU/HR
GTHR	20,998 BTU/KWH
EFF. (GROSS)	16.25%
EFF. (NET)	14.00%

STEAM CYCLE E1

ORDER NO. C17686		PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD	
SCALE NONE			
DRAWN KOTE	CHECK BDR		
APPROVED AWM 5/27/76		Stearns-Roger	DRAWING NO. E1

FIGURE 5–14. STEAM CYCLE E1 PROCESS FLOW DIAGRAM



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW LBS./HR	30,700	18,600	1,600	17,000	12,100	29,100	29,100	30,700	30,700	17,000	335,000	200,000	[illegible]	[illegible]
PRESSURE PSIA	365	30	30	30	2.3	2.3	60	30	550	[illegible]	60	60	60	[illegible]
TEMPERATURE °F	550	250.3	250.3	250.3	203.1	203.1	203.1	250.3	[illegible]	240.0	190.0	140.0	90.0	190.0

STEAM CYCLE E2

	15	16	17
FLOW LBS./HR	395,000	318,850	318,850
PRESSURE PSIA	70	100	80
TEMPERATURE °F	160.0	600.0	425.0

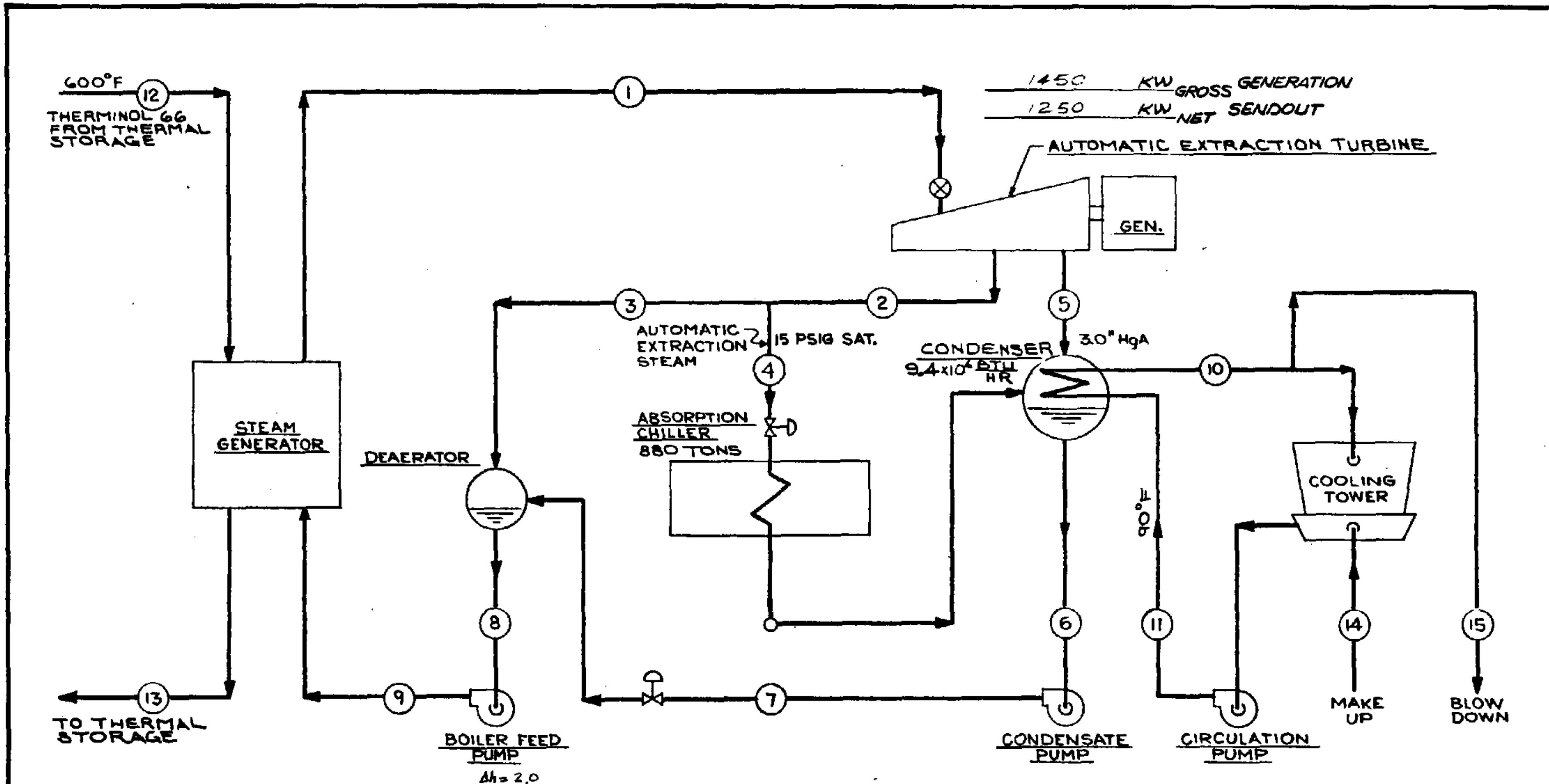
HEAT INPUT TO CYCLE	32.55×10^6 BTU/HR
GTHR	22,449 BTU/KWH
EFF. (GROSS)	15.20 %
EFF. (NET)	13.10 %

ORDER NO. C17686
SCALE NONE
DRAWN NOTE CHECK BDR
APPROVED AWM 5/27/76

PROCESS FLOW DIAGRAM
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger DRAWING NO. E2

FIGURE 5–15. STEAM CYCLE E2 PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LB/HR	29,000	21,100	4,100	17,000	7,900	24,900	24,900	29,000	29,000	533,000	533,000	339,000	339,000	12,000	1900
PRESSURE	PSIA	465	30	30	30	1.47	1.47	60	30	550	30	40	100	80	15	25
TEMPERATURE	°F	550	250.3	250.3	250.3	115.1	115.1	115.1	250.3	251.5	108.0	90.0	600.0	445.9	87.0	108.0

STEAM CYCLE E3

HEAT INPUT TO CYCLE	30.44×10^6 BTU/HR	ORDER NO. C 17 686	PROCESS FLOW DIAGRAM SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	20,996 BTU/KWH	SCALE NONE	
EFF. (GROSS)	16.25 %	DRAWN SS CHECK BDR	Stearns-Roger
EFF. (NET)	14.01 %	APPROVED RWM 5/27/76	DRAWING NO. E3

FIGURE 5–16. STEAM CYCLE E3 PROCESS FLOW DIAGRAM

The type of organic turbine used would be a full admission high speed, impulse or reaction type turbine with one or two stages. Multiple turbine-generator units would be used for the power level required.

A turbine expansion efficiency of 75 percent was used for all organic Rankine cycles considered. Discussions with two organic turbine suppliers indicates that this efficiency is reasonable and on the conservative side.

TOLUENE CYCLES

For the Toluene cycles, subcritical operating pressures of 200 psia and 250 psia were selected with temperatures of 500 and 550°F. A condenser temperature of 200°F (8.7 psia) was used for System A and 120°F (1.7 psia) for Systems B and C.

A description of the Toluene cycles investigated and the corresponding process flow diagrams follow. A summary of performance for the Toluene Rankine cycles studied is shown in Table 5–2.

Organic cycle process flow diagrams for Toluene cycles A2-ORC-T, B2-ORC-T and C2-ORC-T are presented in Figures 5–17 through 5–19.

TRIFLUOROETHANOL CYCLES

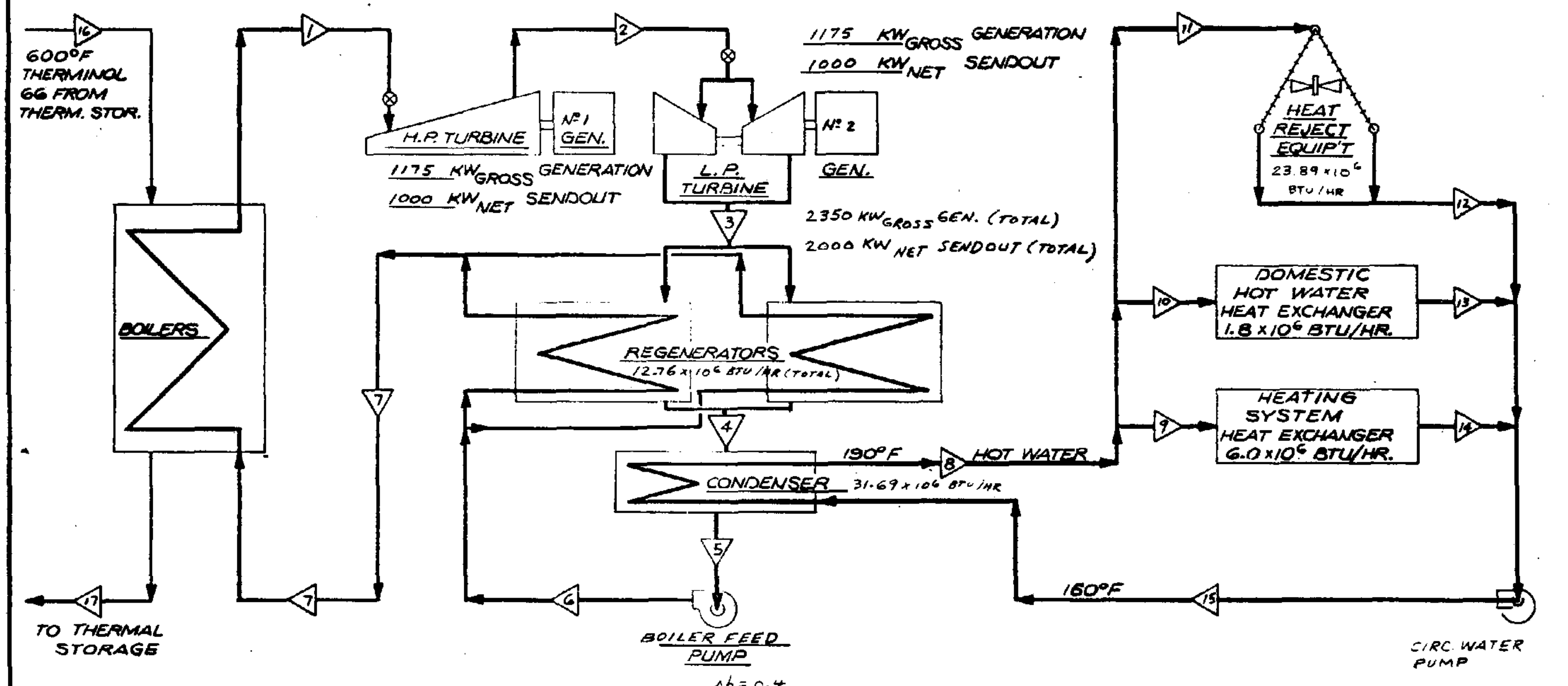
For the Trifluoroethanol cycles, both subcritical and supercritical pressure cycles were investigated. Operating pressures and temperatures for the subcritical cycles range from 300 to 400 psia, and 400 to 450°F. The supercritical cycles were calculated at 800 and 1000 psia, at 500 and 550°F. A condenser temperature of 200°F (31.7 psia) was used for System A and 120°F (5.7 psia) for System B and C.

A summary of performance for the Trifluoroethanol Rankine cycles studied is shown in Tables 5–3 and 5–4. Process flow diagrams for subcritical Trifluoroethanol cycles A7-ORC-TFE, B7-ORC-TFE and C7-ORC-TFE, and supercritical cycles A5-ORC-TFE, B5-ORC-TFE and C5-ORC-TFE are presented in Figures 5–20 through 5–25.

Cycle No.	A1-ORC-T	A2-ORC-T	A3-ORC-T	B1-ORC-T	B2-ORC-T	B3-ORC-T
Gross Generation, KW	2,350	2,350	2,350	2,350	2,350	2,350
Auxiliary Power, KW	350	350	350	350	350	350
Net Generation, KW	2,000	2,000	2,000	2,000	2,000	2,000
Gross Turbine Heat Rate, BTU/KWH	17,671	17,012	18,934	13,609	13,268	14,186
Throttle Pressure, PSIA	200	250	200	200	250	200
Throttle Temperature, °F	550	550	500	550	550	500
Condenser Pressure, PSIA	8.7	8.7	8.7	1.7	1.7	1.7
Condenser Temperature, °F	200.0	200.0	200.0	120.0	120.0	120.0
Throttle Flow, Lb/Hr	188,120	179,440	204,950	127,950	123,700	135,300
Heat Input to Cycle, 10^6 BTU/Hr	41.53	39.98	44.49	31.98	31.18	33.34
Heat Rejected to Cond., 10^6 BTU/Hr	33.22	31.69	36.19	23.67	22.88	25.03
Therminol Temp. Diff., °F	171.3	154.1	202.0	195.0	175.2	230.3
Therminol Flow, Lb/Hr	412,700	445,450	379,000	280,700	307,000	250,300
Net Cycle Efficiency, %	16.43	17.07	15.34	21.34	21.89	20.47

Cycle No.	C1-ORC-T	C2-ORC-T	C3-ORC-T
Gross Generation, KW	1,470	1,470	1,470
Auxiliary Power, KW	220	220	220
Net Generation, KW	1,250	1,250	1,250
Gross Turbine Heat Rate, BTU/KWH	13,501	13,161	14,072
Throttle Pressure, PSIA	200	250	200
Throttle Temperature, °F	550	550	500
Condenser Pressure, PSIA	1.7	1.7	1.7
Condenser Temperature, °F	120.0	120.0	120.0
Throttle Flow, Lb/Hr	79,400	76,740	83,950
Heat Input to Cycle, 10^6 BTU/Hr	19.85	19.35	20.68
Heat Rejected to Cond., 10^6 BTU/Hr	14.69	14.20	15.53
Therminol Temp. Diff., °F	195.0	175.2	230.3
Therminol Flow, Lb/Hr	174,200	190,500	155,200
Net Cycle Efficiency, %	21.50	22.04	20.61

TABLE 5–2. SUMMARY OF PERFORMANCE - ORGANIC RANKINE CYCLES (TOLUENE)



		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW	LBS./HR.	179,440	179,440	179,440	179,440	179,440	179,440	179,440	1,055,000	200,000	60,000	795,000	795,000	60,000	200,000
PRESSURE	PSIA	250	40	8.7	8.7	8.7	330	310	60	60	60	60	25	25	25
TEMPERATURE	°F	550	~480	420.4	240.0	200.0	200.8	341.5	190.0	190.0	190.0	190.0	160.0	60.0	160.0
DENSITY	LBS./FT³	2.65	0.380	0.085	0.110	50.4	50.5	44.7	60.4	60.4	60.4	60.4	61.1	61.0	61.0

		15	16	17
FLOW	LBS./HR.	1,055,000	445,450	445,450
PRESSURE	PSIA	70	100	80
TEMPERATURE	°F	160.0	600.0	445.9
DENSITY	LBS./FT³	61.0	48.1	52.5

HEAT INPUT TO CYCLE	39.98 x 10^6 BTU/HR
GTHR	17,012 BTU/KWH
EFF (GROSS)	20.06 %
EFF (NET)	17.07 %

CYCLE A2-ORC-T TOLUENE

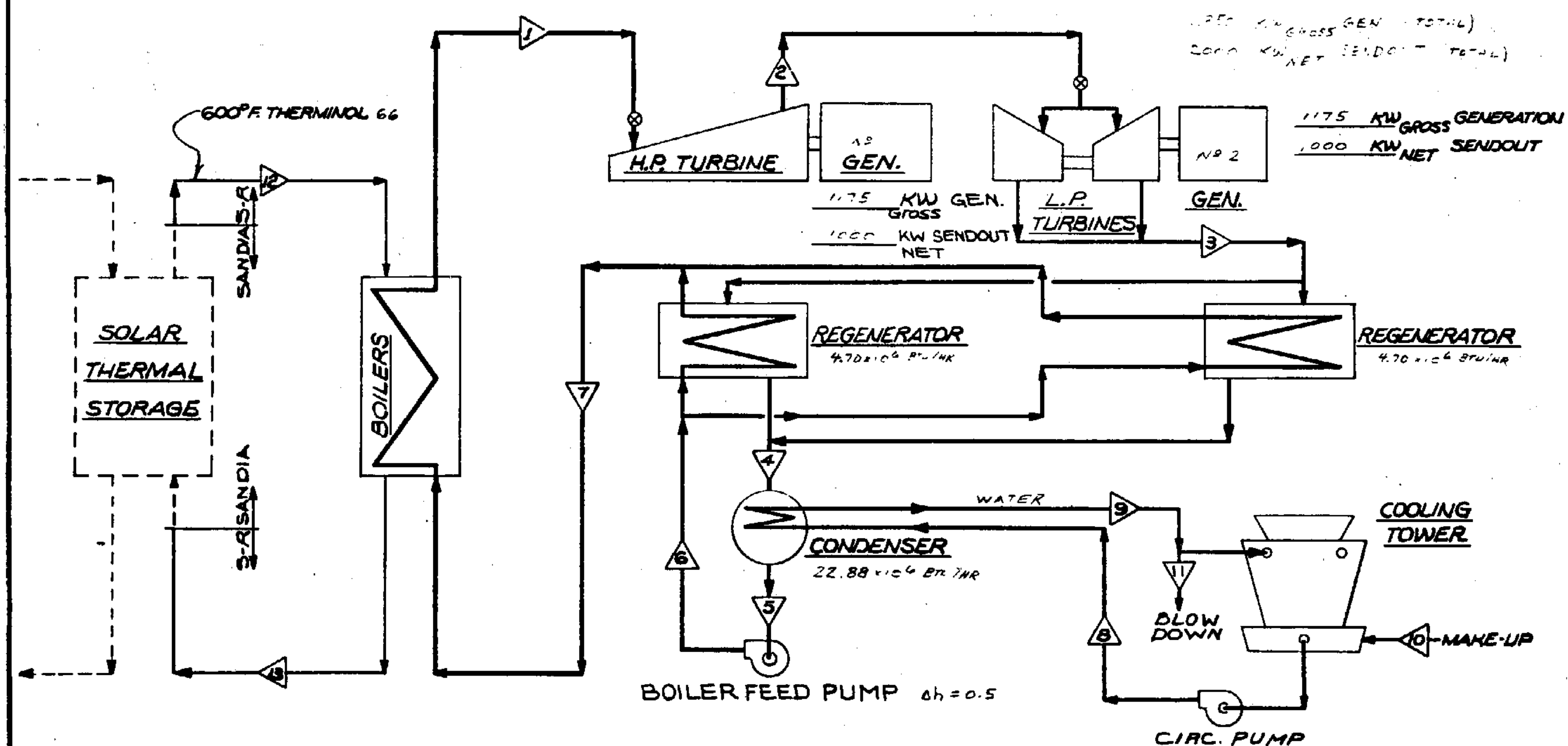
ORDER NO. C 17686
SCALE NONE
DRAWN KOTE CHECK BDR
APPROVED [illegible] 7/27/76

PROCESS FLOW DIAGRAM
SUBCRITICAL ORGANIC RANKINE CYCLE
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger

DRAWING NO. A2-ORC-T

FIGURE 5–17. CYCLE A2-ORC-T TOLUENE SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM

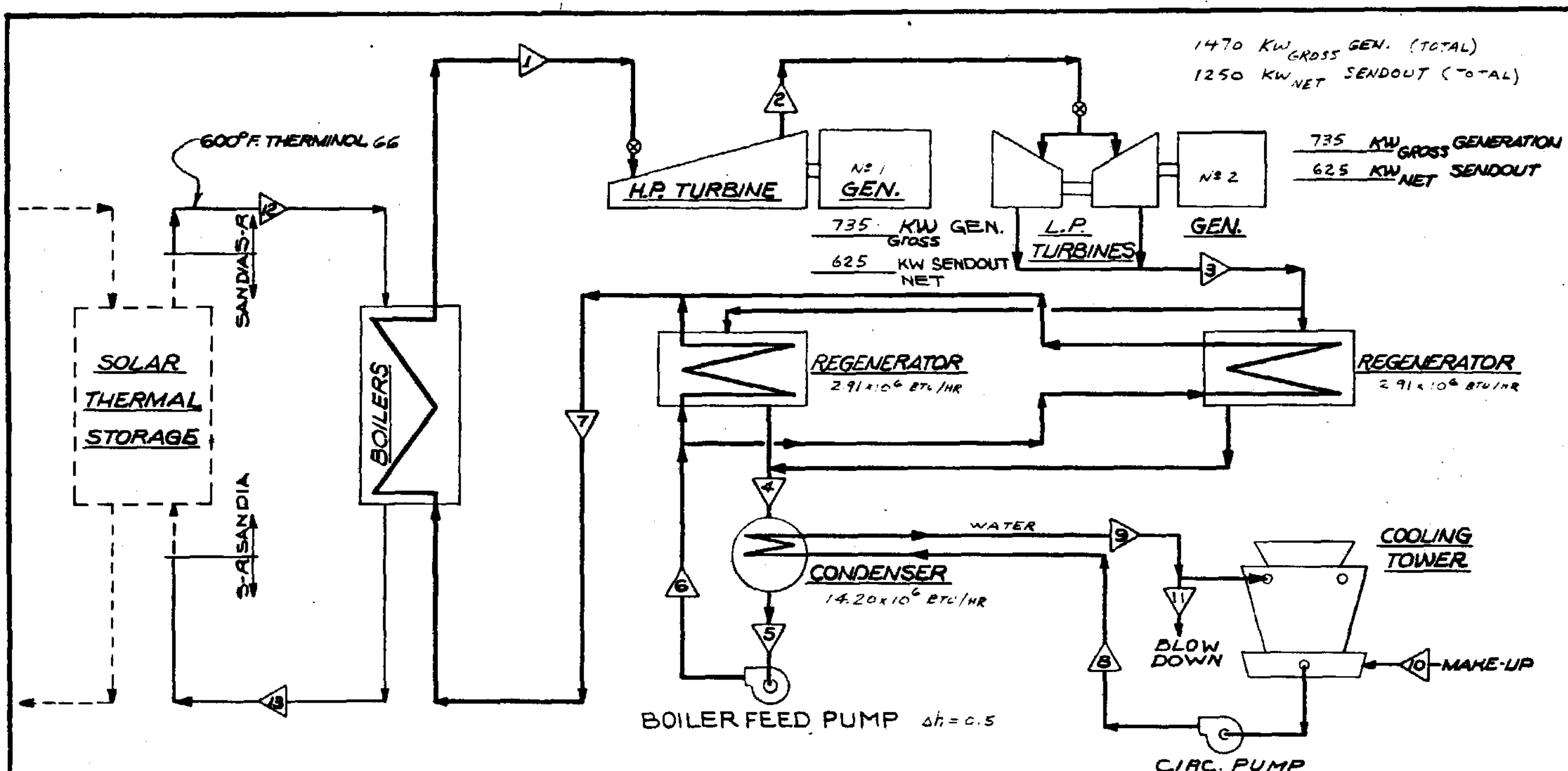


		1	2	3	4	5	6	7	8	9	10	11	12	13	
FLOW	LBS./HR.	123,700	123,700	123,700	123,700	123,700	123,700	123,700	1,270,000	1,270,000	29,500	4650	307,000	307 000	
PRESSURE	PSIA	250	20	1.7	1.7	1.7	330	310	40	30	5	25	100	80	
TEMPERATURE	°F	550	~450	369.6	160.0	120.0	121.1	286.1	90.0	108.0	87.0	108.0	600.0	424.8	
DENSITY	LB./FT³	2.65	0.192	0.021	0.027	53.1	53.2	46.7	62.1	61.7	62.1	61.7	48.1	53.0	

CYCLE B2-ORC-T TOLUENE

HEAT INPUT TO CYCLE	31.18×10^6 BTU/HR	ORDER NO. C 17686		PROCESS FLOW DIAGRAM SUBCRITICAL ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	13,268 BTU/KWH	SCALE NONE		
EFF (GROSS)	25.72 %	DRAWN KOTE	CHECK BDR	Stearns-Roger
EFF (NET)	21.89 %	APPROVED AWM 5/27/76		DRAWING NO. B2-ORC-T △

FIGURE 5–18. CYCLE B2-ORC-T TOLUENE SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	
FLOW	LBS./HR.	76,740	76,740	76,740	76,740	76,740	76,740	76,740	788,000	788,000	18,300	2,840	90,500	190,500	
PRESSURE	PSIA	250	20	1.7	1.7	1.7	330	310	40	30	15	25	100	80	
TEMPERATURE	°F	550	~450	369.6	160.0	120.0	121.1	286.1	90.0	108.0	87.0	108.0	600.0	424.8	
DENSITY	LB./FT³	2.65	0.192	0.021	0.027	53.1	53.2	46.7	62.1	61.7	62.1	61.7	48.1	53.0	

CYCLE C2-ORC-T TOLUENE

HEAT INPUT TO CYCLE	19.35×10^6 BTU/HR	ORDER NO. C 17686		PROCESS FLOW DIAGRAM SUBCRITICAL ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
STHR	13,161 BTU/KWH	SCALE NONE		
EFF. (GROSS)	25.93 %	DRAWN KOTE	CHECK BDR	Stearns-Roger
EFF. (NET)	22.04 %	APPROVED Aum 5/27/76		DRAWING NO. C2-ORC-T

FIGURE 5–19. CYCLE C2-ORC-T TOLUENE SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM

Cycle No.	A1-ORC-TFE	A2-ORC-TFE	A3-ORC-TFE	A7-ORC-TFE	A8-ORC-TFE	A9-ORC-TFE
Gross Generation, KW	2,350	2,350	2,350	2,350	2,350	2,350
Auxiliary Power, KW	350	350	350	350	350	350
Net Generation, KW	2,000	2,000	2,000	2,000	2,000	2,000
Gross Turbine Heat Rate, BTU/KWH	26,031	24,576	22,508	20,953	25,055	23,255
Throttle Pressure, PSIA	300	300	400	400	400	300
Throttle Temperature, °F	400	450	450	500	400	500
Condenser Pressure, PSIA	31.7	31.7	31.7	31.7	31.7	31.7
Condenser Temperature, °F	200.0	200.0	200.0	200.0	200.0	200.0
Throttle Flow, Lb/Hr	332,350	310,850	280,600	257,300	317,940	291,350
Heat Input to Cycle, 10^6 BTU/Hr	61.17	57.75	52.89	49.24	58.88	54.65
Heat Rejected to Cond., 10^6 BTU/Hr	53.00	49.55	44.73	41.00	50.68	46.44
Therminol Temp. Diff., °F	256.7	313.2	333.5	290.2	388.4	277.3
Therminol Flow, Lb/Hr	294,350	314,900	271,700	293,100	317,940	341,900
Net Cycle Efficiency, %	11.16	11.82	12.90	13.86	11.59	12.49

Cycle No.	B1-ORC-TFE	B2-ORC-TFE	B3-ORC-TFE	B7-ORC-TFE	B8-ORC-TFE	B9-ORC-TFE
Gross Generation, KW	2,350	2,350	2,350	2,350	2,350	2,350
Auxiliary Power, KW	350	350	350	350	350	350
Net Generation, KW	2,000	2,000	2,000	2,000	2,000	2,000
Gross Turbine Heat Rate, BTU/KWH	18,373	17,089	16,358	15,876	18,100	16,568
Throttle Pressure, PSIA	300	300	400	400	400	300
Throttle Temperature, °F	400	450	450	500	400	500
Condenser Pressure, PSIA	5.7	5.7	5.7	5.7	5.7	5.7
Condenser Temperature, °F	120.0	120.0	120.0	120.0	120.0	120.0
Throttle Flow, Lb/Hr	199,100	181,800	172,150	165,600	195,370	174,750
Heat Input to Cycle, 10^6 BTU/Hr	43.18	40.16	38.44	37.31	42.53	38.93
Heat Rejected to Cond., 10^6 BTU/Hr	34.94	31.90	30.21	29.06	34.29	30.66
Therminol Temp. Diff., °F	422.7	376.0	397.8	343.6	457.4	333.5
Therminol Flow, Lb/Hr	176,400	183,150	166,600	188,550	161,900	201,300
Net Cycle Efficiency, %	15.80	16.99	17.75	18.30	16.03	17.53

TABLE 5–3. SUMMARY OF PERFORMANCE - ORGANIC RANKINE CYCLES, (TRIFLUOROETHANOL, SUBCRITICAL) (Sheet 1 of 2)

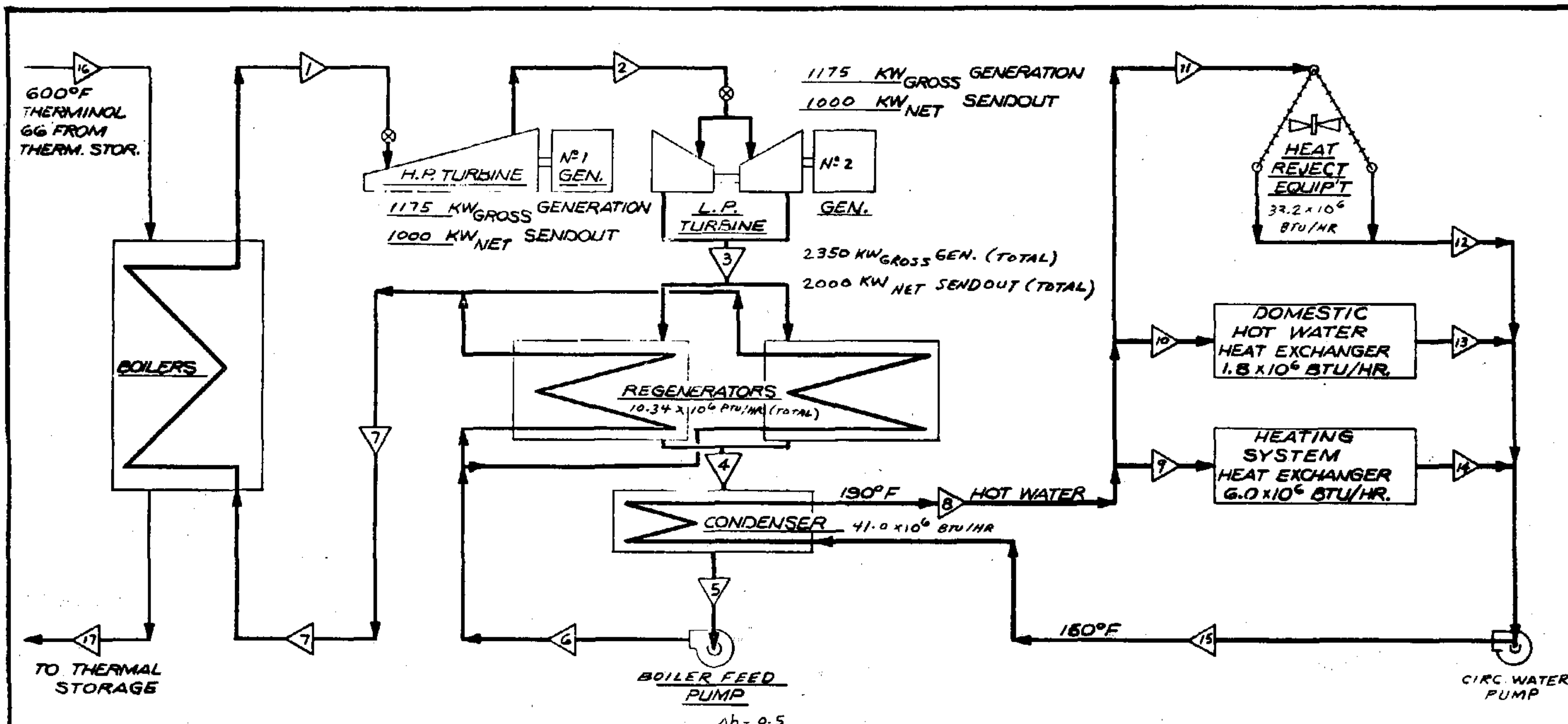
Cycle No.	C1-ORC-TFE	C2-ORC-TFE	C3-ORC-TFE	C7-ORC-TFE	C8-ORC-TFE	C9-ORC-TFE
Gross Generation, KW	1,470	1,470	1,470	1,470	1,470	1,470
Auxiliary Power, KW	220	220	220	220	220	220
Net Generation, KW	1,250	1,250	1,250	1,250	1,250	1,250
Gross Turbine Heat Rate, BTU/KWH	18,222	16,951	16,216	15,736	17,943	16,434
Throttle Pressure, PSIA	300	300	400	400	400	300
Throttle Temperature, °F	400	450	450	500	400	500
Condenser Pressure, PSIA	5.7	5.7	5.7	5.7	5.7	5.7
Condenser Temperature, °F	120.0	120.0	120.0	120.0	120.0	120.0
Throttle Flow, Lb/Hr	123,520	112,800	106,750	102,660	121,130	108,400
Heat Input to Cycle, 10^6 BTU/Hr	26.79	24.92	23.84	23.13	26.37	24.15
Heat Rejected to Cond., 10^6 BTU/Hr	21.68	19.80	18.73	18.02	21.26	19.02
Therminol Temp. Diff., °F	422.7	376.0	397.8	343.6	457.4	333.5
Therminol Flow, Lb/Hr	109,450	113,600	103,400	116,900	100,300	124,850
Net Cycle Efficiency, %	15.93	17.11	17.89	18.44	16.16	17.65

TABLE 5–3. SUMMARY OF PERFORMANCE - ORGANIC RANKINE CYCLES, (TRIFLUOROETHANOL, SUBCRITICAL) (Sheet 2 of 2)

Cycle No.	A4-ORC-TFE	A5-ORC-TFE	A6-ORC-TFE	B4-ORC-TFE	B5-ORC-TFE	B6-ORC-TFE
Gross Generation, KW	2,450	2,450	2,450	2,450	2,450	2,450
Auxiliary Power, KW	450	450	450	450	450	450
Net Generation, KW	2,000	2,000	2,000	2,000	2,000	2,000
Gross Turbine Heat Rate, BTU/KWH	19,111	18,132	21,881	15,548	14,406	21,881
Throttle Pressure, PSIA	800	800	1,000	800	800	1,000
Throttle Temperature, °F	500	550	500	500	550	500
Condenser Pressure, PSIA	31.7	31.7	31.7	5.7	5.7	5.7
Condenser Temperature, °F	200.0	200.0	200.0	120.0	120.0	120.0
Throttle Flow, Lb/Hr	244,500	229,100	275,200	170,900	154,600	186,600
Heat Input to Cycle, 10^6 BTU/Hr	46.82	44.42	53.61	38.09	35.30	43.00
Heat Rejected to Cond., 10^6 BTU/Hr	39.00	36.52	46.10	30.00	27.12	35.08
Therminol Temp. Diff., °F	327.3	287.5	370.1	395.0	359.5	450.0
Therminol Flow, Lb/Hr	260,100	275,900	268,250	181,950	181,800	186,600
Net Cycle Efficiency, %	14.57	15.36	12.73	17.91	19.33	15.86

Cycle No.	C4-ORC-TFE	C5-ORC-TFE	C6-ORC-TFE
Gross Generation, KW	1,525	1,525	1,525
Auxiliary Power, KW	275	275	275
Net Generation, KW	1,250	1,250	1,250
Gross Turbine Heat Rate, BTU/KWH	15,596	14,446	17,594
Throttle Pressure, PSIA	800	800	1,000
Throttle Temperature, °F	500	550	500
Condenser Pressure, PSIA	5.7	5.7	5.7
Condenser Temperature, °F	120.0	120.0	120.0
Throttle Flow, Lb/Hr	106,700	96,500	116,400
Heat Input to Cycle, 10^6 BTU/Hr	23.78	22.03	26.83
Heat Rejected to Cond., 10^6 BTU/Hr	18.72	16.93	21.88
Therminol Temp. Diff., °F	395.0	359.5	450.0
Therminol Flow, Lb/Hr	113,600	113,500	114,700
Net Cycle Efficiency, %	17.93	19.37	15.91

TABLE 5—4. SUMMARY OF PERFORMANCE - ORGANIC RANKINE CYCLES (TRIFLUOROETHANOL, SUPERCRITICAL)



		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW	LBS./HR.	257,300	257,300	257,300	257,300	257,300	257,300	257,300	1,367,000	200,000	60,000	1,107,000	1,107,000	60,000	200,000
PRESSURE	PSIA	400	120	31.7	31.7	31.7	500	480	60	60	60	60	25	25	25
TEMPERATURE	°F	500	~430	365.0	225.0	200.0	201.0	287.6	190.0	190.0	190.0	190.0	160.0	160.0	160.0
DENSITY	LBS./FT³	4.61	1.35	0.360	0.440	58.5	65.6	62.4	60.4	60.4	60.4	60.4	61.0	61.0	61.0

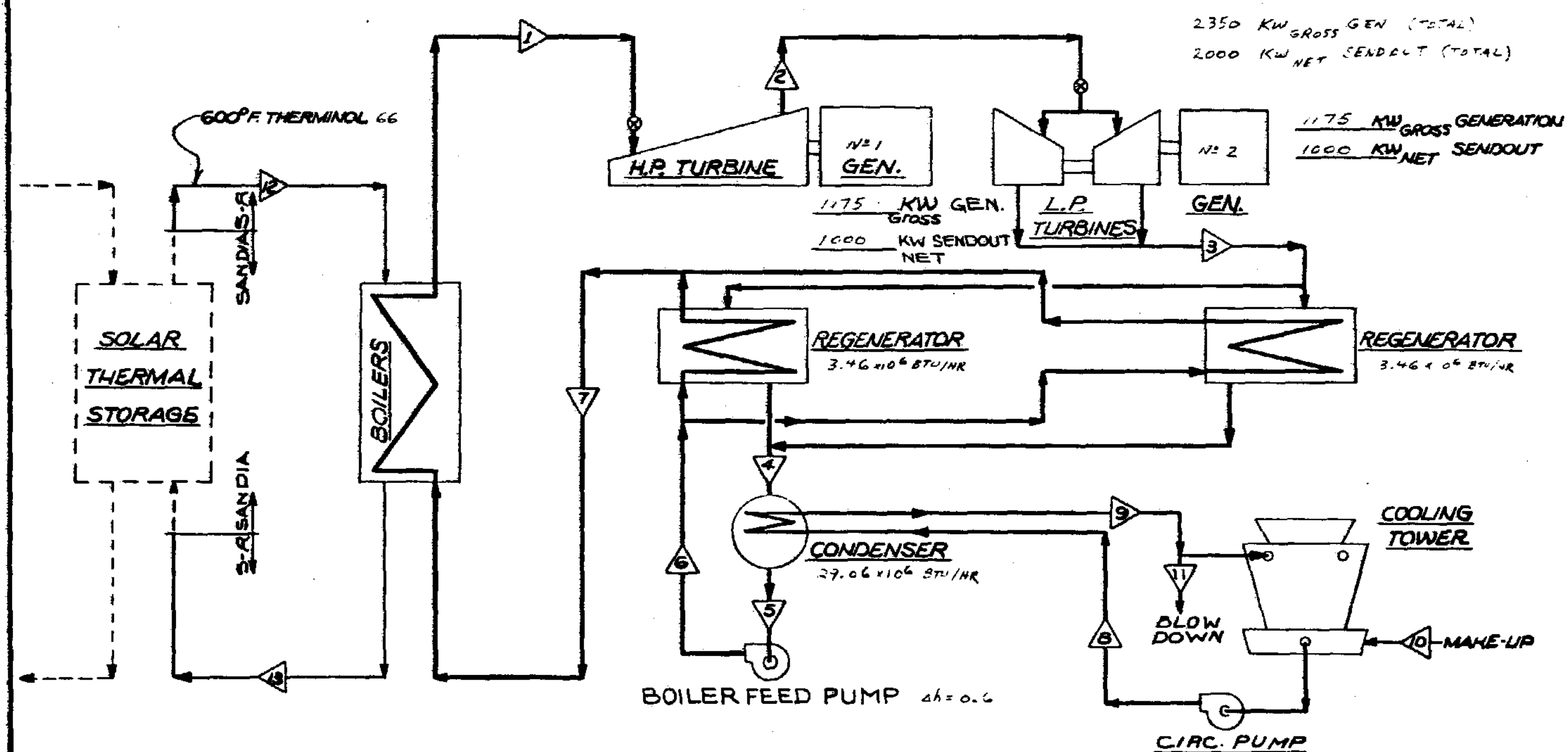
		15	16	17
FLOW	LBS./HR.	1,367,000	293,100	293,100
PRESSURE	PSIA	70	100	80
TEMPERATURE	°F	160.0	600.0	309.8
DENSITY	LBS./FT³	61.0	48.1	56.8

HEAT INPUT TO CYCLE	49.24×10^6 BTU/HR
GTHR	20,953 BTU/KWH
EFF (GROSS)	16.29 %
EFF (NET)	13.86 %

CYCLE A7-ORC-TFE TRIFLUOROETHANOL

ORDER NO. C 17686		PROCESS FLOW DIAGRAM SUBCRITICAL ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
SCALE NONE		
DRAWN KOTE	CHECK BDR	**Stearns-Roger** — DRAWING NO. A7-ORC-TFE
APPROVED AWM 5/27/76		

FIGURE 5–20. CYCLE A7-ORC-TFE (TRIFLUOROETHANOL) SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM

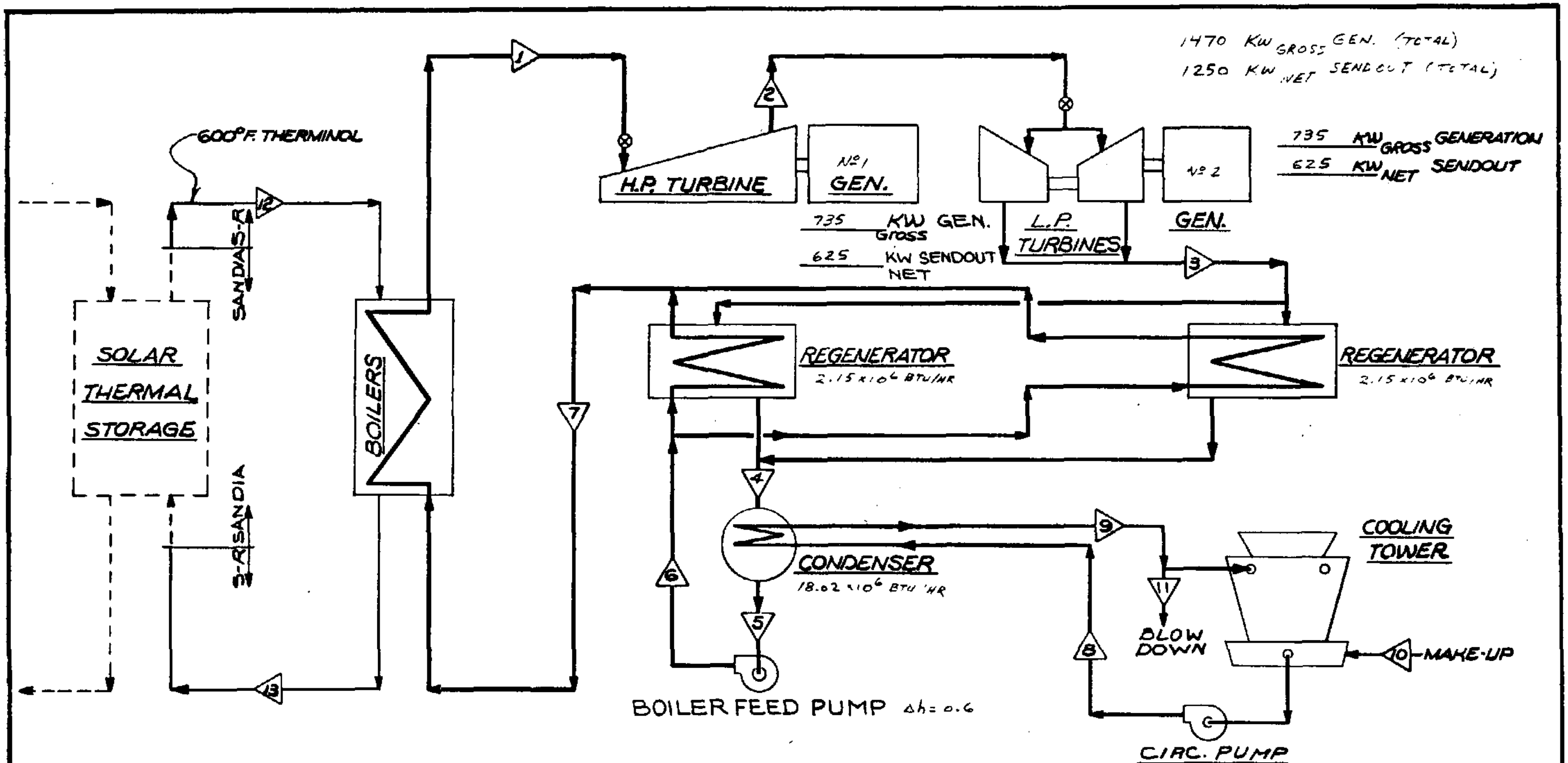


		1	2	3	4	5	6	7	8	9	10	11	12	13	
FLOW	LBS./HR.	165,600	165,600	165,600	165,600	165,600	165,600	165,600	1,610,000	1,610,000	37,500	5,800	188,550	88,550	
PRESSURE	PSIA	400	55	5.7	5.7	5.7	520	490	40	30	15	25	100	80	
TEMPERATURE	°F	500	~390	290.0	145.0	120.0	121.4	212.8	90.0	108.0	87.0	108.0	600.0	256.4	
DENSITY	LB./FT³	4.61	0.555	0.062	0.080	62.65	67.0	65.7	62.1	61.7	62.1	61.7	48.1	58.0	

CYCLE B7-ORC-TFE TRIFLUOROETHANOL

HEAT INPUT TO CYCLE	37.31 x10⁶ BTU/HR	ORDER NO. C 17686		PROCESS FLOW DIAGRAM SUBCRITICAL ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	15,876 BTU/KWH	SCALE NONE		
EFF. GROSS,	21.50 %	DRAWN MOTE	CHECK BDR	Stearns-Roger
EFF (NET)	18.30 %	APPROVED AWM 5/27/76		DRAWING NO. B7-ORC-TFE

FIGURE 5–21. CYCLE B7-ORC-TFE (TRIFLUOROETHANOL) SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM

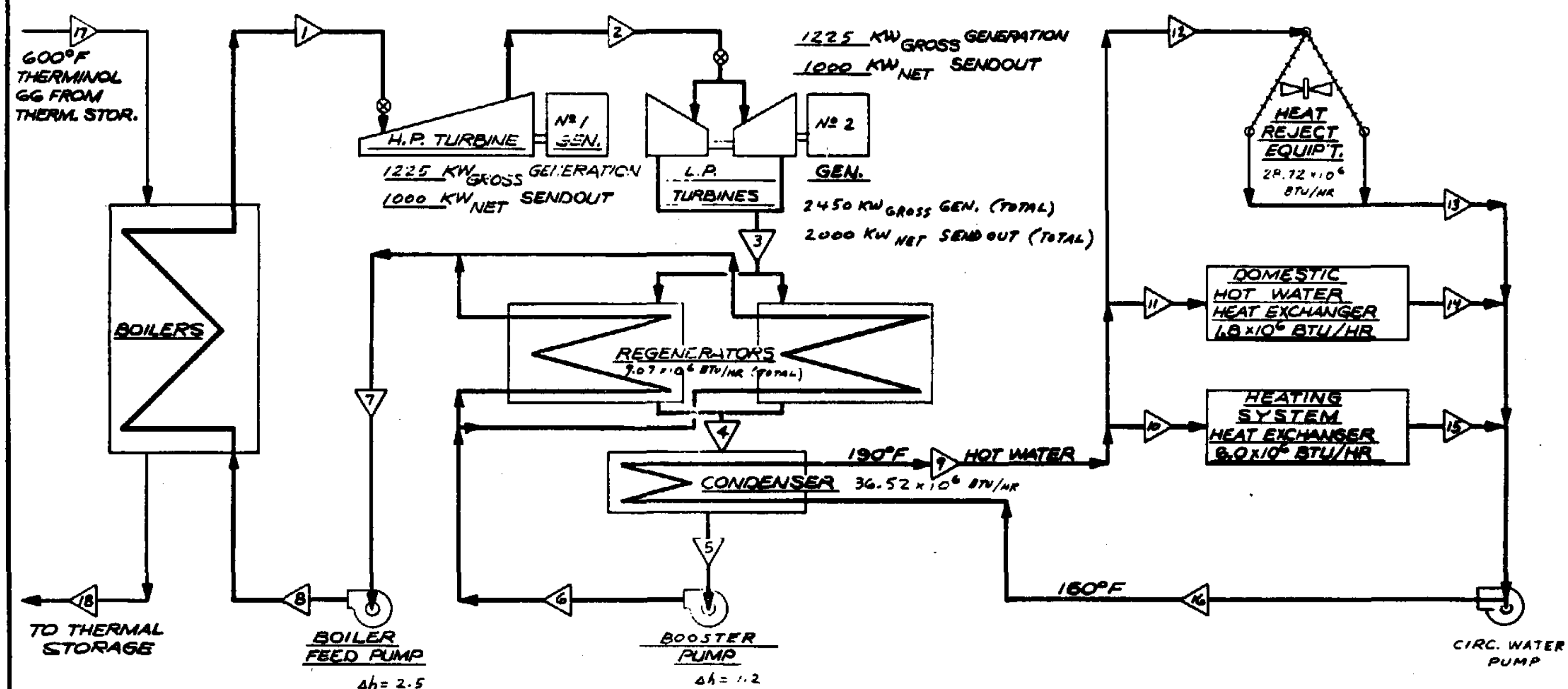


		1	2	3	4	5	6	7	8	9	10	11	12	13	
FLOW	LBS./HR.	102,660	102,660	102,660	102,660	102,660	102,660	102,660	1,000,000	1,000,000	23,200	3,600	116,900	116,900	
PRESSURE	PSIA	400	55	5.7	5.7	5.7	520	490	40	30	15	25	100	80	
TEMPERATURE	°F	500	~390	290.0	145.0	120.0	121.4	212.8	90.0	108.0	87.0	108.0	600.0	256.4	
DENSITY	$LB./FT^3$	4.61	0.555	0.062	0.080	62.65	67.0	65.7	62.1	61.7	62.1	61.7	48.1	58.0	

CYCLE C7-ORC-TFE TRIFLUOROETHANOL

HEAT INPUT TO CYCLE	23.13×10^6 BTU/HR	ORDER NO. C 17686		PROCESS FLOW DIAGRAM SUBCRITICAL ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	15,736 BTU/KWH	SCALE NONE		
EFF. (GROSS)	21.69 %	DRAWN KOTE	CHECK BDR	Stearns-Roger
EFF (NET)	18.44 %	APPROVED AWM 5/27/76		DRAWING NO. C7-ORC-TFE △

FIGURE 5–22. CYCLE C7-ORC-TFE (TRIFLUOROETHANOL) SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
FLOW	LBS/HR.	229,100	229,100	229,100	229,100	229100	229,100	229,100	229,100	1,215,000	200,000	60,000	155,000	955,000	60,000	200,000
PRESSURE	PSIA	800	125	31.7	31.7	31.7	320	300	920	60	60	60	60	25	25	25
TEMPERATURE	°F	550	~ 430	362.8	225.0	200.0	201.5	284.0	287.5	190 0	190.0	190.0	190.0	160.0	160.0	160.0
DENSITY	LBS/FT³	12.6	1.41	0.364	0.440	58.5	64.3	61.3	64.1	60.4	60.4	60.4	60.4	61.1	61.1	61.1

		16	17	18
FLOW	LBS/HR	1,215,000	275,900	275,900
PRESSURE	PSIA	70	100	80
TEMPERATURE	°F	160.0	600.0	312.5
DENSITY	LBS/FT³	61.0	48.1	56.8

HEAT INPUT TO CYCLE	44.42×10^6 BTU/HR
GTHR	18,132 BTU/KWH
EFF. (GROSS)	18.82 %
EFF. (NET)	15.36 %

CYCLE A5-ORC-TFE TRIFLUOROETHANOL

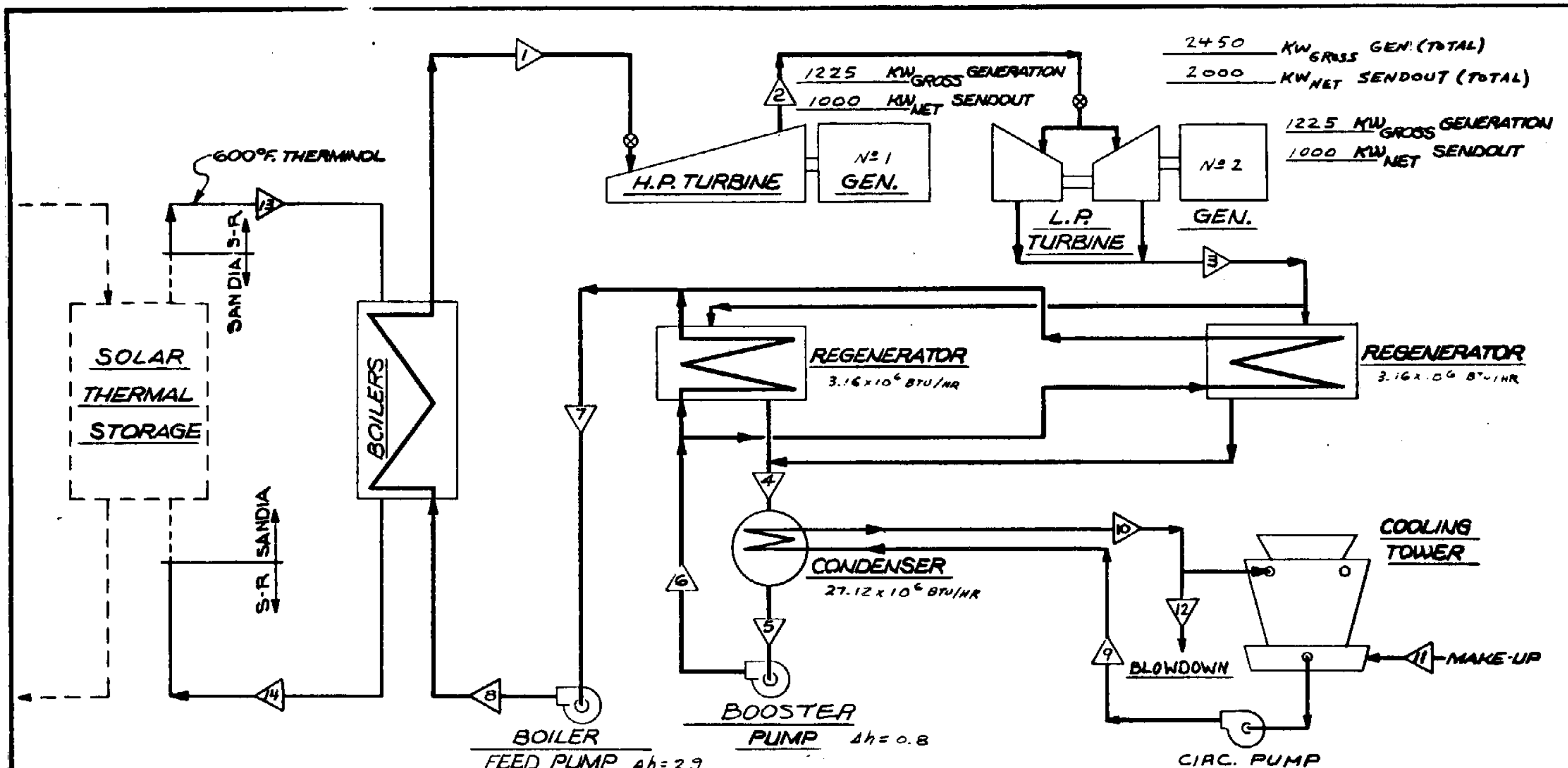
ORDER NO. C 17686	
SCALE NONE	
DRAWN KOTE	CHECK BDR
APPROVED AWM 5/27/76	

PROCESS FLOW DIAGRAM
SUPERCRITICAL ORGANIC RANKINE CYCLE
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger

DRAWING NO. AS-ORC-TFE

FIGURE 5–23. CYCLE A5-ORC-TFE (TRIFLUOROETHANOL) SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM

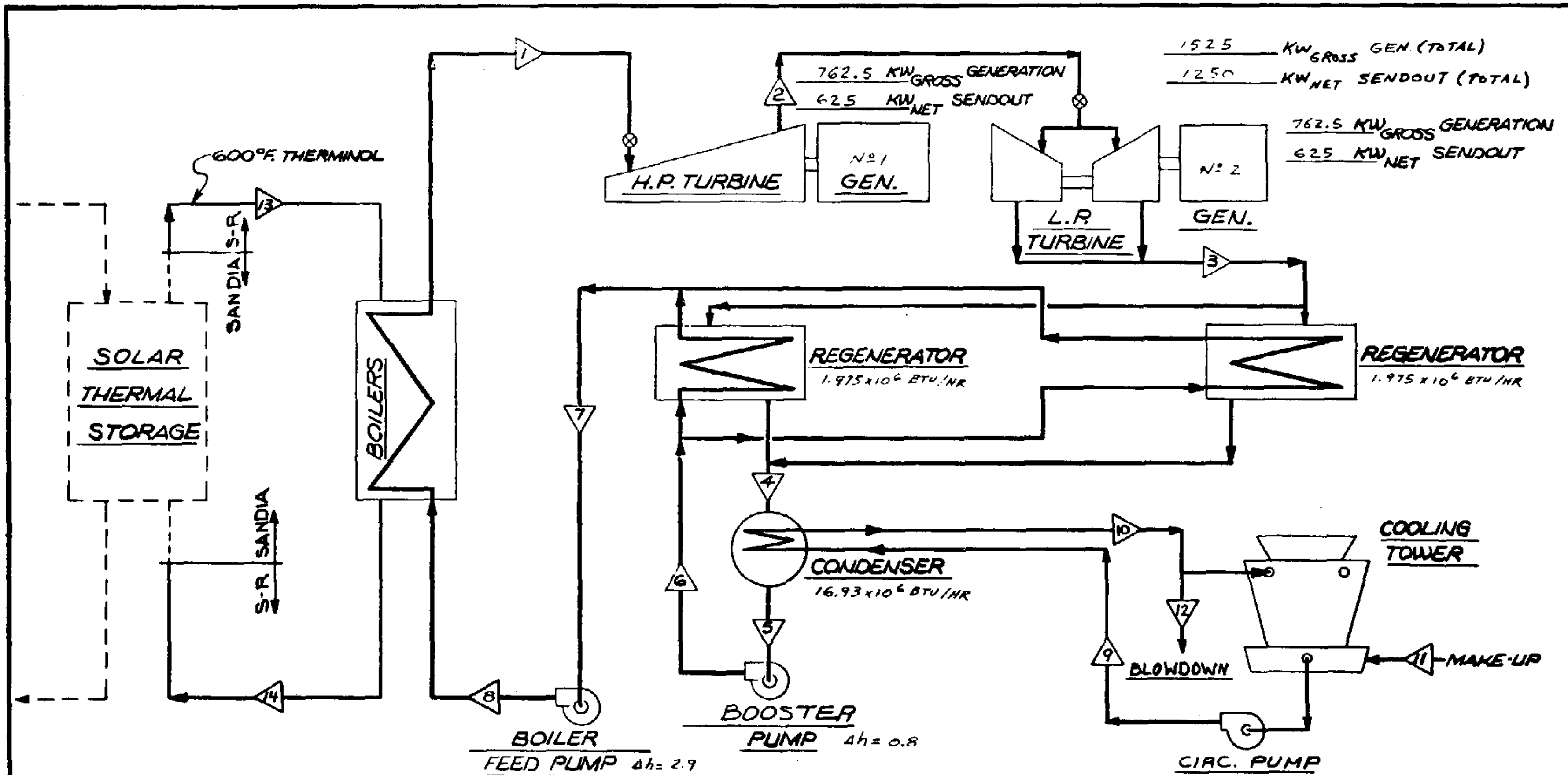


		1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW	LBS./HR.	154,600	154,600	154600	154,600	154,600	154,600	154,600	154,600	1,500,000	1,500,000	35,000	5,300	181,800	181,800
PRESSURE	PSIA	800	62	5.7	5.7	5.7	220	200	920	40	30	15	25	100	80
TEMPERATURE	°F.	550	~400	297.2	145.0	120.0	121.0	212.2	215.5	90.0	108.0	87.0	108.0	600.0	240.5
DENSITY	LBS./FT³	12.6	0.690	0.070	0.087	62.65	65.6	63.4	67.6	62.1	61.7	62.1	61.7	48.1	58.3

CYCLE B5-ORC-TFE TRIFLUOROETHANOL

HEAT INPUT TO CYCLE	35.30×10⁶ BTU/HR	ORDER NO. C 17686		PROCESS FLOW DIAGRAM SUPERCRITICAL ORGANIC RANKINE CYCLE SOLAR TOTAL ENERGY SYSTEM NORTH LAKE CAMPUS, DCCCD
GTHR	14,406 BTU/KWH	SCALE NONE		
EFF (GROSS)	23.69%	DRAWN KOTE	CHECK BDR	Stearns-Roger
EFF. (NET)	19.33%	APPROVED AWM 5/27/76		DRAWING NO. B5-ORC-TFE

FIGURE 5–24. C[illegible]LE B5-ORC-TFE (TRIFLUOROETHANOL) SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLOW LBS./HR.	96,500	96,500	96,500	96,500	96,500	96,500	96,500	96,500	940,000	940,000	21,800	3,400	113,500	113,500
PRESSURE PSIA	800	62	5.7	5.7	5.7	220	200	920	40	30	15	25	100	80
TEMPERATURE °F.	550	~400	297.2	145.0	120.0	121.0	212.2	215.5	90.0	108.0	87.0	108.0	600.0	240.5
DENSITY LBS./FT³	12.6	0.69	0.070	0.087	62.65	65.6	63.4	67.6	62.1	61.7	62.1	61.7	48.1	58.3

CYCLE C5-ORC-TFE TRIFLUOROETHANOL

HEAT INPUT TO CYCLE	22.03 × 10⁶ BTU/HR
GTHR	14,446 BTU/KWH
EFF (GROSS)	23.62 %
EFF. (NET)	19.37 %

ORDER NO. C 17686
SCALE NONE
DRAWN KOTE CHECK BDR
APPROVED AWM 5/27/76

PROCESS FLOW DIAGRAM
SUPERCRITICAL ORGANIC RANKINE CYCLE
SOLAR TOTAL ENERGY SYSTEM
NORTH LAKE CAMPUS, DCCCD

Stearns-Roger

DRAWING NO. C5-ORC-TFE

FIGURE 5–25. CYCLE C5-ORC-TFE (TRIFLUOROETHANOL) SUBCRITICAL ORGANIC RANKINE CYCLE PROCESS FLOW DIAGRAM

SECTION 6

EQUIPMENT AVAILABILITY

STEAM CYCLES

For the steam cycles considered, all components are of standard design and are commercially available. The lead times required for the major equipment items and typical manufacturers are listed below.

Equipment	Lead Time (Weeks)
Steam Turbine-Generator	70 to 80
DeLaval Turbine Terry Steam Turbine Co. Turbodyne Corp. Westinghouse Electric Corp.	
Steam Generator (Heat Exchanger)	42 to 52
Graham Mfg. Co. Thermxchanger, Inc. Yuba Heat Transfer Corp.	
Surface Condenser	42 to 52
American Standard Basco, Inc. Graham Mfg. Co.	
Deaerator	18 to 24
Chicago Heater Co. Cochrane Div., Crane Co. Permutit Co.	
Boiler Feed Pumps	28 to 42
Bingham-Willamette Co. Byron Jackson Pumps, Inc. Goulds Pumps, Inc.	
Cooling Tower	15 to 20
Ecodyne Marley Co.	

Equipment	Lead Time (Weeks)
Air-Cooled Exchangers	10 to 20
Happy Div., Therma Technology, Inc. Perfex Corp.	
Feedwater Heater, Closed	30 to 40
Patterson-Kelley Co. Yuba Heat Transfer Corp.	
Main Power Transformer	30 to 40
General Electric Co. Westinghouse Electric Co.	
5KV Switchgear	40 to 50
I T E Imperial Corp. General Electric Co. Westinghouse Electric Corp.	
480 V Load Center	30 to 35
Allis Chalmers General Electric Co. Westinghouse Electric Co.	
480 V Motor Control Centers	20 to 30
General Electric Co. Cutler-Hammer Inc. Westinghouse Electric Corp.	

ORGANIC CYCLES

Unlike steam turbines, prime movers for organic Rankine cycles are not commercially in the power levels required in this study. Two manufacturers, Rotoflow Corporation and Sundstrand Energy Systems, have proposed systems to meet our requirements using multiple units. Other experienced organic turbine manufacturers may exist but were not contacted because of time limitations.

Rotoflow Corporation, Los Angeles, California, is a major manufacturer of turboexpanders. Turboexpanders have been primarily used in the gas processing industry as gas expanders to drive compressors. Work is also being done with turboexpanders in organic Rankine cycles utilizing geothermal energy. For the North Lake Campus application, Rotoflow has proposed using two turboexpanders, (Unit 1, a single-stage machine, and Unit 2, a double expander), piped in series. Each unit is coupled to its electric generator through a speed reducer gear. Both units are mounted on a single fabricated steel baseplate. Approximate scheduling would be: preliminary drawings within three to four months of order; equipment shipped 12 to 15 months after final drawing approval.

Sundstrand Energy System, Division of Sundstrand Corporation, located in Rockford, Illinois, has done considerable work in organic Rankine cycle (ORC) systems, having produced eight different ORC systems over the past 15 years using various organic fluids. Sundstrand supplied the ORC total energy system unit currently operating at Sandia Laboratories, Albuquerque, using Toluene as a working fluid. The unit is rated at 32 KW electrical and utilizes natural gas or solar energy as a heat source.

Sundstrand is currently developing a 100 KW gas-fired organic Rankine cycle total energy system which is now in its field test phase and a 600 KW unit which generates power from water heater sources (industrial, gas turbines, and diesels). Both of these units use Toluene as a working fluid. The latter system is proposed by Sundstrand for North Lake Campus and would meet the requirements by using multiple units. Three or four 600 KW turbine, pump, generator assemblies could probably be made available in late 1978 or 1979 with an 8 to 12 month lead time.

Other major components in the ORC, e.g. boilers, regenerators, pumps, have about the same lead time as comparable equipment used in the steam cycles.

SECTION 7

CONTROL SYSTEMS

The proposed control systems described below define the basic control philosophy for the major control parameters (heat input, turbine throttle pressure and temperature, and boiler water levels) for both the steam and organic cycle power plants.

The electrical control system relating to the electrical interchange with the public utility (Texas Power and Light Co.) is discussed in Section 8.

STEAM CYCLE CONTROL SYSTEMS (Figure 7–1)

The boiler water level control system will be a three-element, cascaded, feedforward loop which will control boiler water level by maintaining water flow input to the boiler equal to feedwater demand. The system will utilize first stage pressure (steam flow) together with the difference in normal water level as a feedforward demand. This demand for feedwater flow is compared with the actual feedwater flow and any difference is used to control the feedwater control valve.

The turbine throttle pressure control system will be a two-element type wherein the feedforward demand (first stage pressure or steam flow) is modified from throttle pressure error in the establishment of the demand for BTU input to the boiler from thermal storage. The system shall also match this demand with the actual KW load being generated.

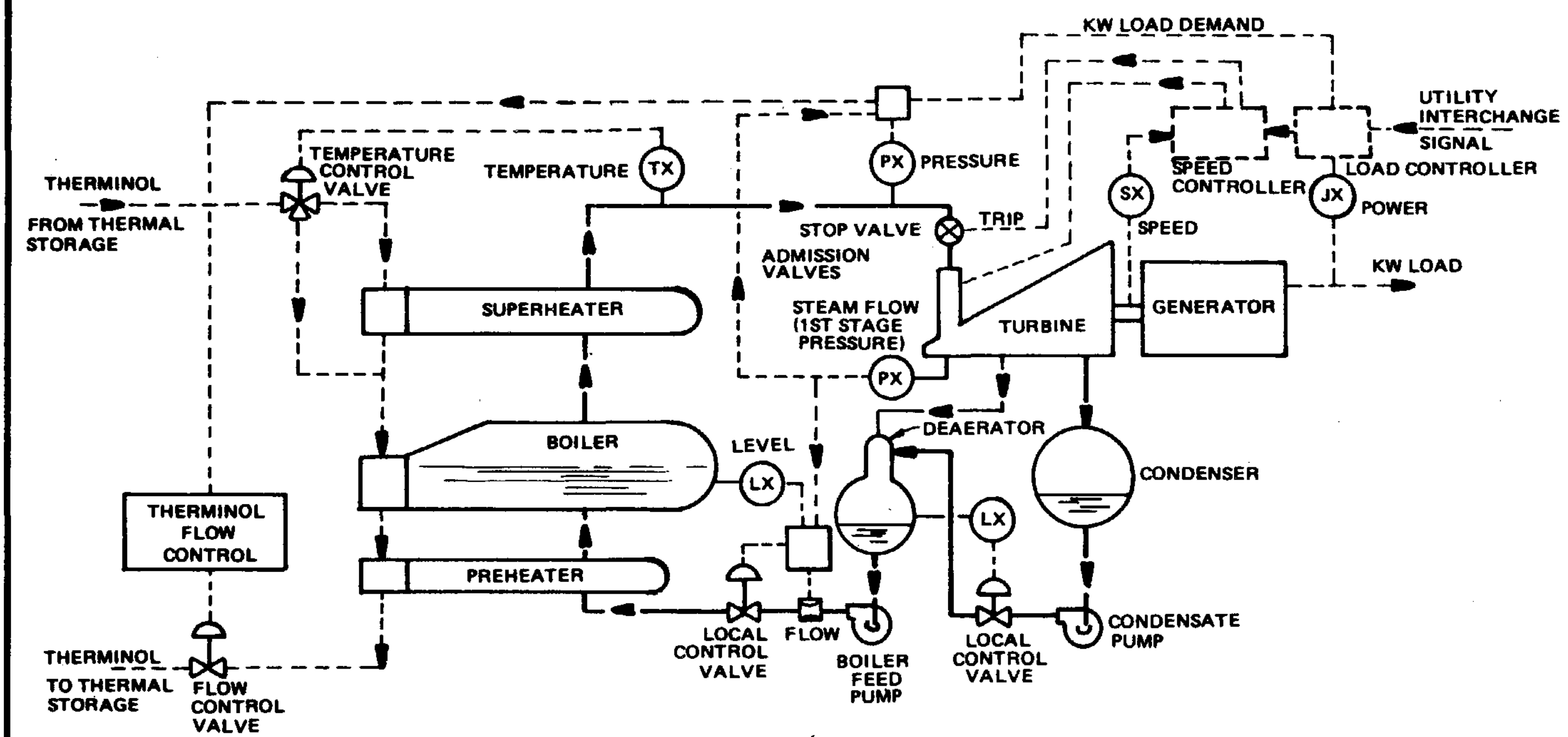
Steam temperature control will be single-element with the temperature controller varying the amount of Therminol flow through the superheater to maintain the steam temperature at set point. Generation will be controlled to equal KW load or the load limited to the capability of the unit.

ORGANIC RANKINE CYCLE CONTROL SYSTEMS (Figure 7–2)

Turbine throttle pressure control will be a coordinated control system with KW load demand applied to both the turbine and the boiler in parallel. Initial pressure control will be assigned to the turbine valves. The KW demand is converted to a boiler demand by correcting it from throttle pressure error to produce a change in working fluid and energy input to the boiler.

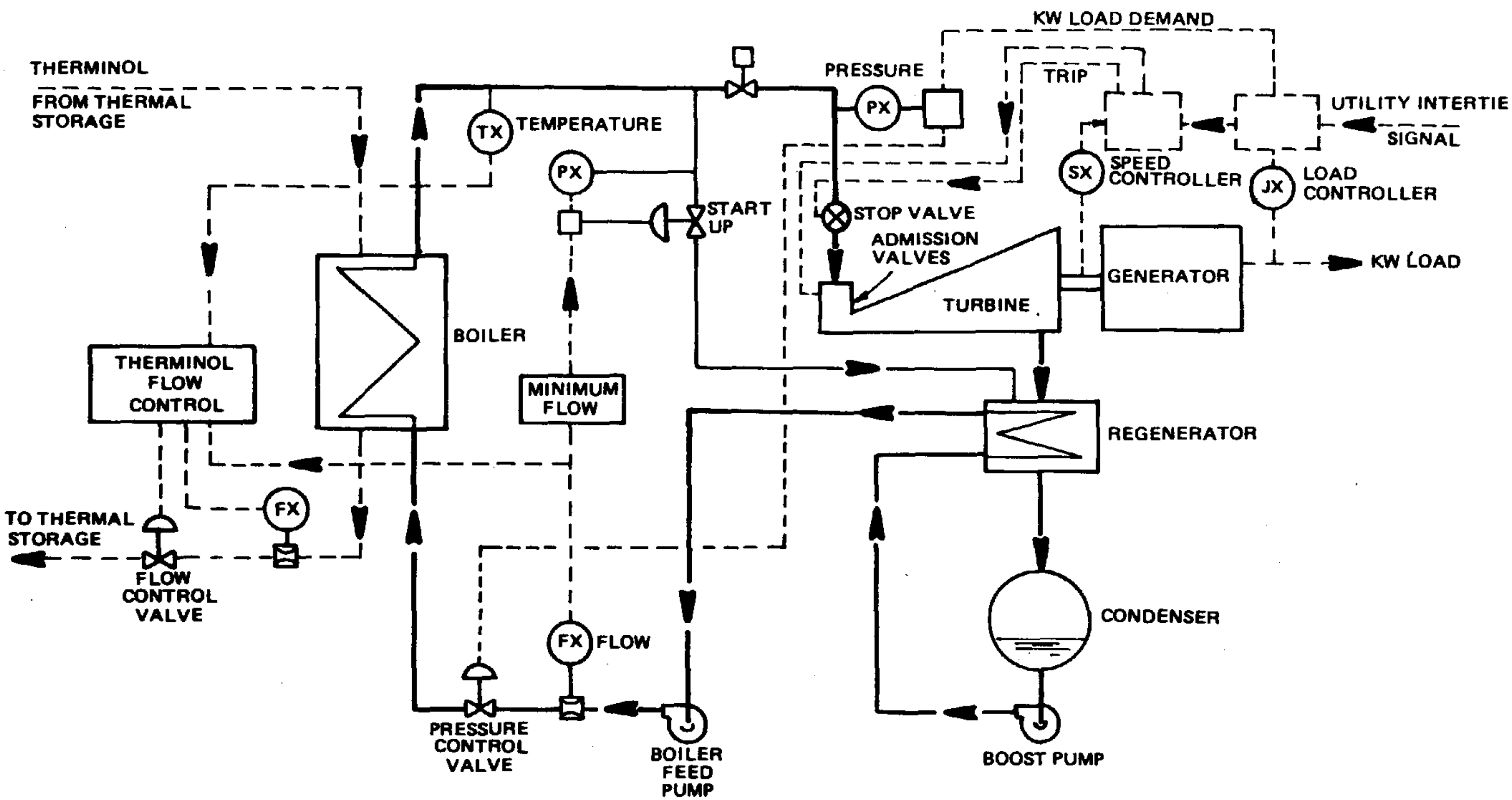
Fluid temperature control will be a two-element system with a feedforward control loop providing control of Therminol flow from thermal storage in response to changes in working fluid flow through the boiler. The feedwater control signal (working fluid flow) anticipates load changes and begins control action in the proper direction in advance. The fluid temperature measurement corrects for any imbalance in fluid input to Therminol input caused by any transients or valve characteristics.

The startup control system will function to provide warming fluid vapor to heat the lines and initially roll the turbine. This system will bypass the working fluid to the regenerator,



CONTROL SYSTEM	
BOILER WATER LEVEL	3-ELEMENT CONTROL: BOILER LEVEL/FEEDWATER FLOW/STEAM FLOW
TURBINE THROTTLE PRESSURE	MAINTAINED BY VARYING THERMINOL FLOW THROUGH BOILER (HEAT INPUT) WITH LOAD INDEX
STEAM TEMPERATURE	CONTROLLED BY VARYING THERMINOL FLOW THROUGH SUPERHEATER
GENERATION	TO EQUAL LOAD OR LOAD LIMIT SELECTED ON LOAD CONTROLLER

FIGURE 7–1. STEAM CYCLE CONTROL SYSTEM



CONTROL SYSTEM	
TURBINE THROTTLE PRESSURE	COORDINATED CONTROL: KW DEMAND, FEED FLOW, HEAT INPUT
VAPOR TEMPERATURE	TWO ELEMENT CONTROL: THERMINOL FLOW/FEED FLOW
STARTUP	MINIMUM FLOW BYPASS AND BOILER PRESSURE CONTROL
GENERATION	TO EQUAL LOAD OR LOAD LIMIT SELECTED ON LOAD CONTROLLER

FIGURE 7–2. ORGANIC RANKINE CYCLE CONTROL SYSTEM

better matching of fluid vapor temperature to turbine metal temperature prior to rolling the turbine. By rejecting the flow to regenerator, and recirculating the working fluid through the boiler, there will be a buildup of enthalpy in the system until the pressure reaches the desired setpoint. To protect the boiler tubes, the controls will have an override feature to ensure that there is always a minimum flow through the boiler regardless of the load on the turbine.

Generation will be controlled to equal KW load or the load limited to the capability of the unit as in the steam cycle system.

SECTION 8

SOLAR/UTILITY ELECTRICAL INTERTIE

The proposed method of connecting the solar-electric system to the Texas Power and Light system is shown schematically on Figure 8–1 (Alternates A and B) and 8–2 (Alternate C). The generator is connected to a 2.4/24.5 KV transformer. A generator circuit breaker, startup and unit transformers are connected as shown. Motors over 100 HP are supplied from the 480V load center; motors 100 HP and under are supplied from the motor control center (MCC).

Normal operation of the generator will be in parallel with Texas Power and Light. Generation will be controlled by an industrial "tie lineload controller" located in the main control console. The controller receives an interchange signal (kilowatt) from the interchange control point, and raises or lowers the turbine governor setting to maintain a set interchange at the interchange control point. It is proposed to provide two control points: one at the metering points, and one at the generator. The control point will be established by a selector switch, also located on the main control console. The normal mode will be controlling interchange at the metering points. The alternate will permit maintaining fixed generation. Generation will always be limited by available steam.

The generator will be protected by differential, negative sequence, reverse power, generator ground, and three voltage restrained overcurrent relays. Other protection must be coordinated with Texas Power and Light.

The generator will be grounded by a neutral distribution transformer and secondary resistor.

A service entrance circuit breaker (at the point where Texas Power and Light feeder enters the campus property) may be desirable, depending on the degree of reliability desired, and whether or not other load is connected. If other load is not connected to the feeder, a service entrance circuit breaker has little advantage, and is not recommended. If, however, other load is connected to the feeder, a service entrance circuit breaker will permit isolation of the campus, and continuity of electrical service following interruptions of the TP&L system. In any case, without other feeder load or a service entrance circuit breaker, service can be restored in a few minutes by manually operating the switches at the service entrance and then restoring service. This might require 10 or 15 minutes.

Automatic synchronizing will be provided for the 2400V circuit breaker(s) to parallel the generator with the system. If a service entrance circuit breaker is provided, provision for automatic synchronizing will be provided when the generator is carrying the campus load. This will permit the service entrance circuit breaker to be synchronized and closed. If a service entrance circuit breaker is not provided, it will be necessary to interrupt the campus system and transfer load to TP&L, and then synchronize and close the 2400V circuit breaker.

Underfrequency relays will be provided to isolate power from TP&L, and for load shedding (reducing load to available generation) during isolated operations.

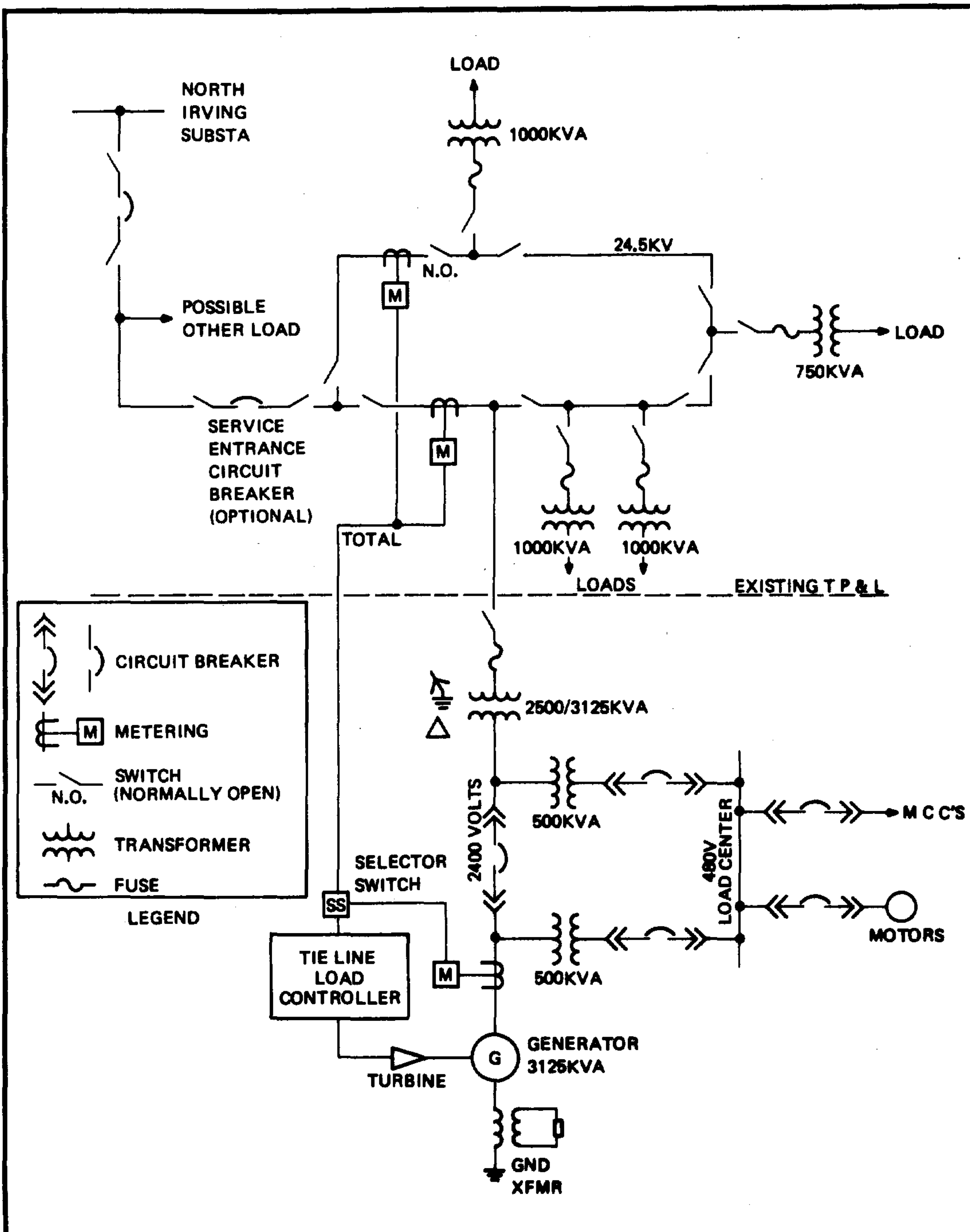


FIGURE 8–1. SOLAR/UTILITY ELECTRICAL INTERTIE - ALTERNATES A AND B

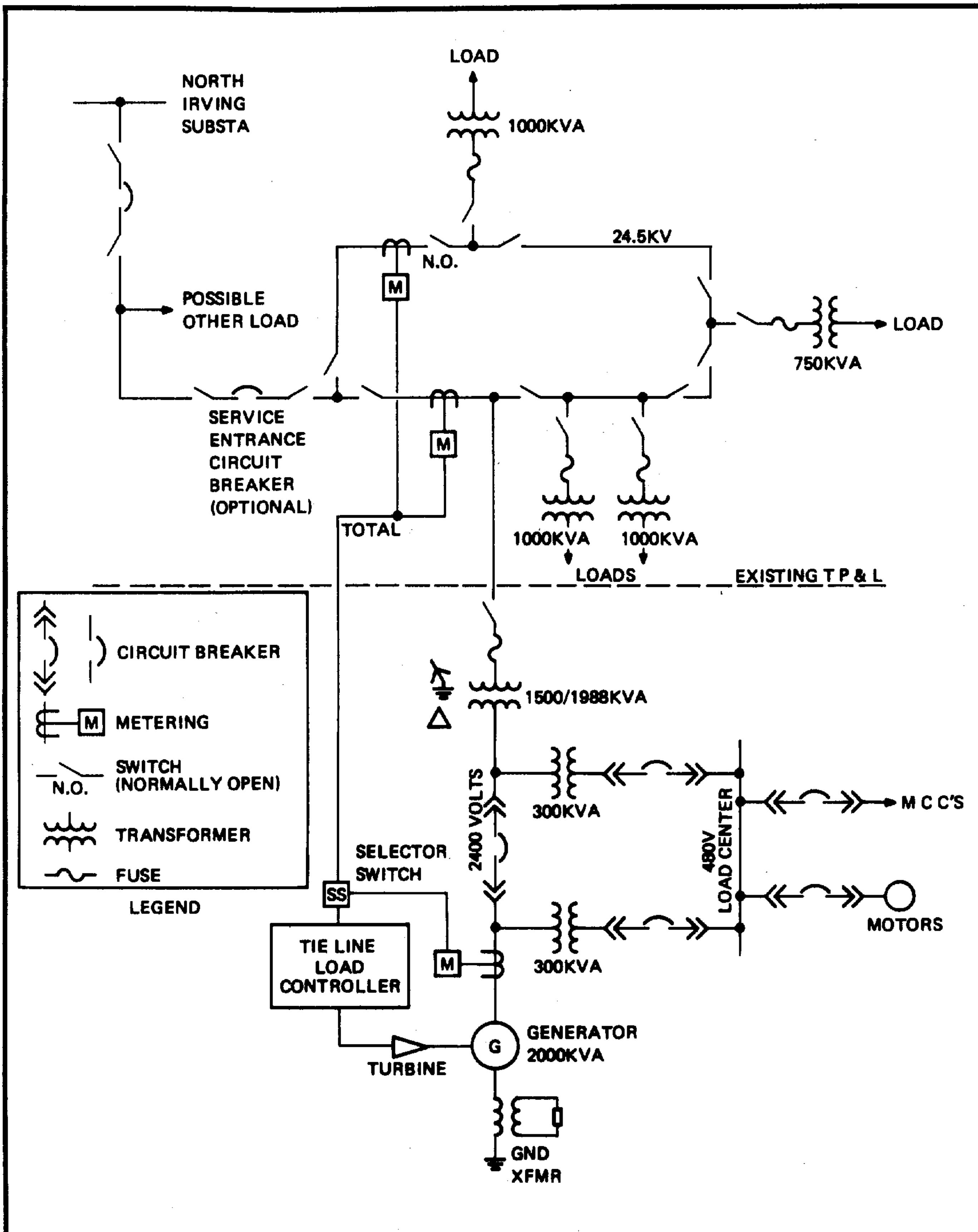


FIGURE 8–2. SOLAR/UTILITY ELECTRICAL INTERTIE - ALTERNATE C

If the system is isolated from TP&L, the tieline load controller is no longer effective, and the turbine governor is responsive to frequency. If sufficient steam is available, the solar system will supply the load. If steam is insufficient, the underfrequency will reduce the load to available generation.

The 500 HP chiller motors (Alternates A and B only) cannot be started from the 3125 KVA generator without excessive voltage drop unless special provision is made. A solution is to limit starting to times when they can be started from the utility system (at all times except when the utility system is not operational).

If starting of the chiller motors from the generator is desired, the generator can be specified to start the motors (by increasing KVA rating or increasing excitation), or reduced voltage starting can be provided.

The proposed method of connecting the solar-electric system on the organic Rankine cycle plants is shown schematically on Figure 8–3 (Alternate A and B) and 8–4 (Alternate C). In the organic cycle, two generator circuit breakers and one main transformer circuit breaker are required because of the multiple generator arrangement. However, with the scheme shown, a single-ended 480V load center incorporating a single 500 KVA or 300 KVA, 2400/480V combination startup and unit transformer can be used in lieu of a double-ended load center as proposed for the steam plants. The generator operation and electrical intertie with TP&L will be as previously described.

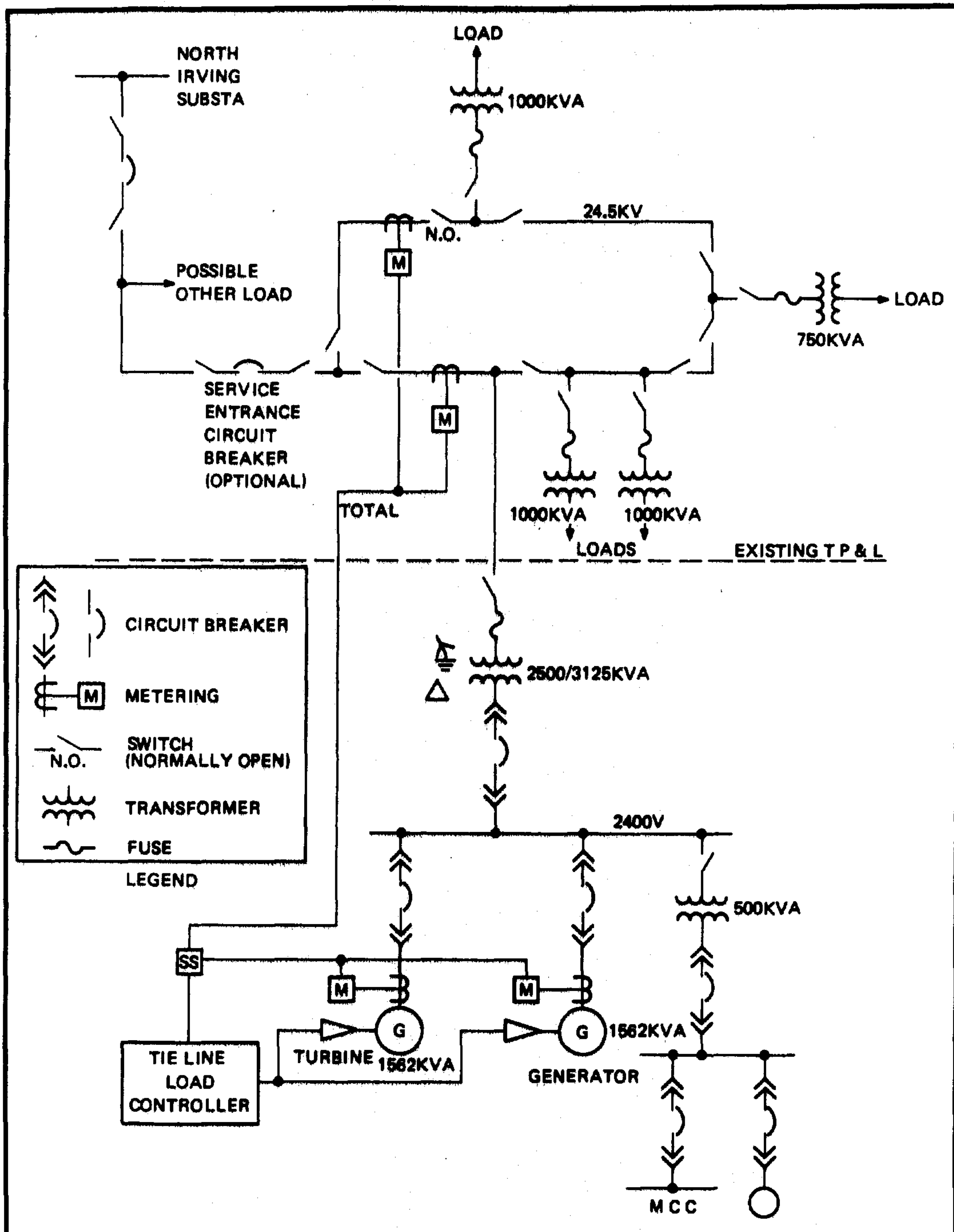


FIGURE 8–3. SOLAR/UTILITY ELECTRICAL INTERTIE (ORGANIC RANKINE CYCLES)

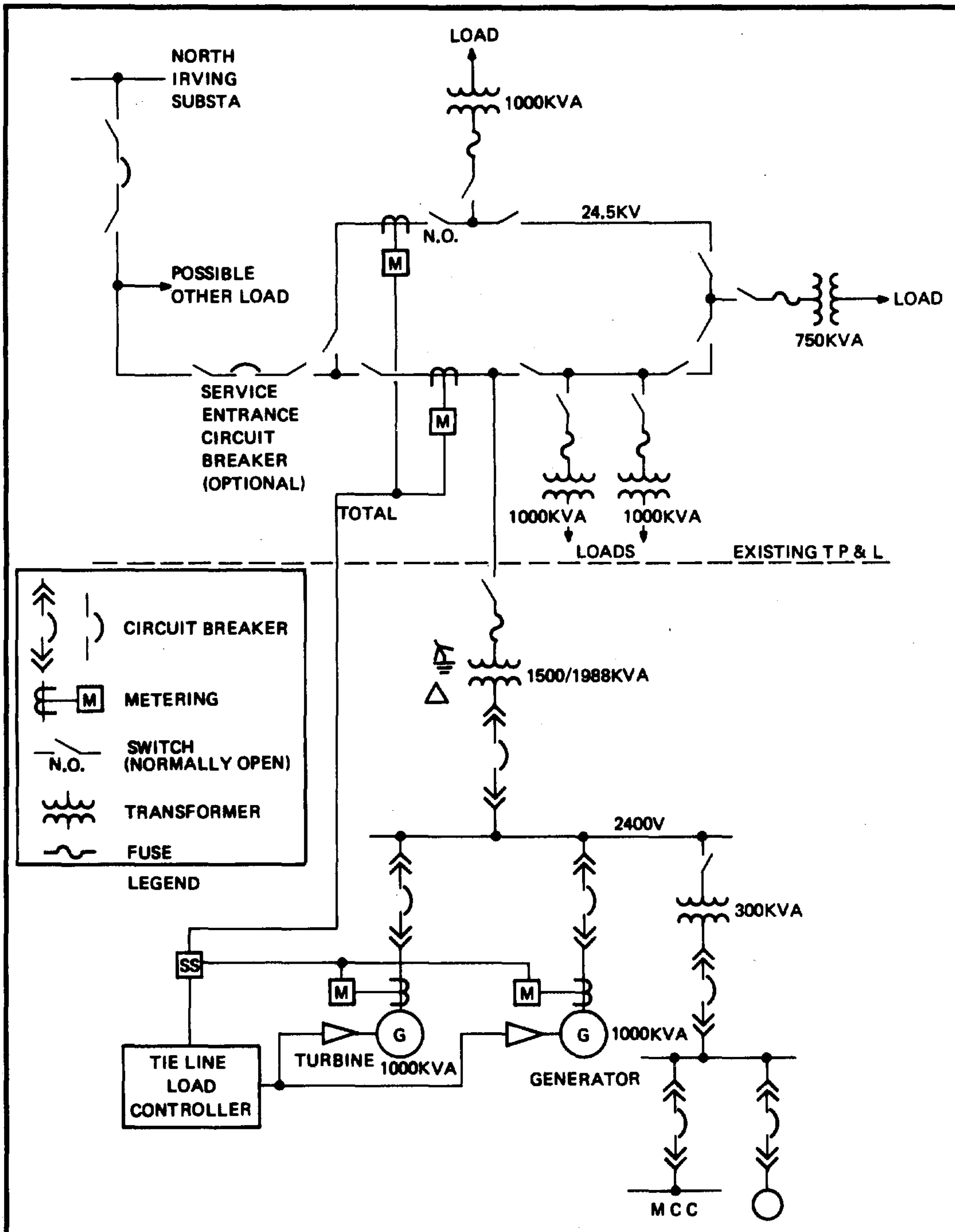


FIGURE 8–4. SOLAR/UTILITY ELECTRICAL INTERTIE (ORGANIC RANKINE CYCLES) - ALTERNATE C

SECTION 9

COST COMPARISONS

Budget cost estimates have been prepared for each thermoelectric cycle considered herein for the purpose of determining an optimum overall solar total energy system concept. The costing methodology used is based on establishing the cost of major process equipment for each cycle and prorating this cost to other categories, such as earthwork, structures, piping, electrical, etc., and indirect costs and engineering, to arrive at a total plant estimated cost, based on Stearns-Roger's previous extensive electric power plant cost experience for units of this size range. All costs are in current dollars (May 1976).

Table 9–1 shows the budget cost estimates for the steam cycle plants considered.

Organic Rankine cycle plant cost estimates are shown in Tables 9–2, 9–3, and 9–4. Table 9–2 is for the Toluene cycle plants, and Tables 9–3 and 9–4 are for the Trifluoroethanol plants, subcritical and supercritical, respectively.

A summary of the total budget cost range for the three basic systems studied is as follows:

TOTAL ESTIMATED PLANT COST*
(Thousand Dollars)

Plant Type	Cascaded System A	Cascaded System B	Non-Cascaded System C
Steam	2461 - 2545	2175 - 2248	1748 - 1782
ORC (Toluene)	2908 - 3003	2508 - 2673	1845 - 1941
ORC (TFE, subcritical)	2961 - 3499	2519 - 2779	1822 - 1946
ORC (TFE, supercritical)	3204 - 3438	2785 - 2958	2050 - 2137

*Electrical Power Generation Subsystem only: Solar Collector and Thermal Storage Subsystems not included.

Cycle No.	A1	A2	A3	A4	B1	B2	B3	B4
Earthwork & Concrete	$ 128	$ 131	$ 130	$ 132	$ 113	$ 116	$ 115	$ 117
Buildings & Structures	92	94	94	95	81	83	83	84
Process Equipment	919	941	937	951	812	834	830	840
Piping	184	188	187	190	162	167	166	168
Electrical	267	273	272	276	236	242	241	244
Instruments & Controls	92	94	94	95	81	83	83	84
Plant Items, Painting, & Insulation	73	75	75	76	66	67	66	67
Direct Field Cost (Items 1 - 7)	$1,755	$1,796	$1,789	$1,815	$1,551	$1,592	$1,584	$1,604
Indirect Field Cost (Incl. O.H. & Profit)	440	450	448	455	489	399	397	401
Total Field Cost (Items 8 - 9)	$2,195	$2,246	$2,237	$2,270	$1,940	$1,991	$1,981	$2,005
Engineering	197	202	201	204	174	179	178	180
Sales Tax	69	70	70	71	61	63	62	63
Total Cost	$2,461	$2,518	$2,508	$2,545	$2,175	$2,233	$2,221	$2,248

Cycle No.	C1	C2	C3	C4	D1	E1	E2	E3
Earthwork & Concrete	$ 91	$ 92	$ 92	$ 92	$ 162	$ 191	$ 193	$ 185
Buildings & Structures	65	66	66	66	116	138	139	134
Process Equipment	653	665	659	666	1,163	1,596	1,610	1,548
Piping	131	133	132	133	233	275	277	266
Electrical	189	193	191	193	337	399	403	387
Instruments & Controls	65	67	66	67	116	138	139	133
Plant Items, Painting, & Insulation	52	53	53	53	93	110	111	107
Direct Field Cost (Items 1 - 7)	$1,246	$1,269	$1,259	$1,270	$2,220	$2,847	$2,872	$2,760
Indirect Field Cost (Incl. O.H. & Profit)	310	318	314	319	557	682	688	640
Total Field Cost (Items 8 - 9)	$1,556	$1,587	$1,573	$1,589	$2,777	$3,529	$3,560	$3,400
Engineering	140	143	141	143	249	317	320	307
Sales Tax	49	50	49	50	87	111	112	108
Total Cost	$1,745	$1,780	$1,763	$1,782	$3,113	$3,957	$3,992	$3,815

TABLE 9–1. BUDGET COST ESTIMATE FOR STEAM PLANTS
(Thousand Dollars)

Cycle No.	A1-ORC-T	A2-ORC-T	A3-ORC-T	B1-ORC-T	B2-ORC-T	B3-ORC-T
Earthwork & Concrete	$ 138	$ 134	$ 131	$ 123	$ 119	$ 116
Buildings & Structures	100	97	94	89	86	83
Process Equipment	1,245	1,206	1,180	1,109	1,075	1,040
Piping	199	193	189	177	172	166
Electrical	299	289	283	266	258	250
Instruments & Controls	100	97	94	89	86	83
Plant Items, Painting, & Insulation	80	77	76	71	69	67
Direct Field Cost (Items 1 - 7)	$2,161	$2,093	$2,047	$1,924	$1,865	$1,805
Indirect Field Cost (Incl. O.H. & Profit)	517	501	490	460	447	432
Total Field Cost (Items 8 - 9)	$2,678	$2,594	$2,537	$2,384	$2,312	$2,237
Engineering	241	233	228	214	207	201
Sales Tax	84	81	80	75	73	70
Total Cost	$3,003	$2,908	$2,845	$2,673	$2,592	$2,508

Cycle No.	C1-ORC-T	C2-ORC-T	C3-ORC-T
Earthwork & Concrete	$ 89	$ 87	$ 85
Buildings & Structures	64	63	61
Process Equipment	805	784	766
Piping	129	125	122
Electrical	193	198	187
Instruments & Controls	64	63	61
Plant Items, Painting, & Insulation	51	50	48
Direct Field Cost (Items 1 - 7)	$1,397	$1,360	$1,328
Indirect Field Cost (Incl. O.H. & Profit)	334	326	317
Total Field Cost (Items 8 - 9)	$1,731	$1,686	$1,645
Engineering	156	151	148
Sales Tax	54	53	52
Total Cost	$1,941	$1,890	$1,845

TABLE 9–2. BUDGET COST ESTIMATE FOR ORGANIC RANKINE CYCLE PLANTS (TOLUENE)
(Thousand Dollars)

Cycle No.	A1-ORC-TFE	A2-ORC-TFE	A3-ORC-TFE	A7-ORC-TFE	A8-ORC-TFE	A9-ORC-TFE
Earthwork & Concrete	$ 145	$ 154	$ 142	$ 148	$ 136	$ 161
Buildings & Structures	109	115	106	111	102	120
Process Equipment	1,314	1,392	1,279	1,333	1,229	1,452
Piping	210	222	204	213	196	232
Electrical	315	334	307	320	295	348
Instruments & Controls	105	112	103	107	99	116
Plant Items, Painting, & Insulation	84	89	82	85	79	93
Direct Field Cost (Items 1 - 7)	$2,282	$2,418	$2,223	$2,317	$2,136	$2,522
Indirect Field Cost (Incl. O.H. & Profit)	543	574	527	548	504	598
Total Field Cost (Items 8 - 9)	$2,825	$2,992	$2,750	$2,865	$2,640	$3,120
Engineering	254	269	247	258	238	281
Sales Tax	88	94	86	90	83	98
Total Cost	$3,167	$3,355	$3,083	$3,213	$2,961	$3,499

Cycle No.	B1-ORC-TFE	B2-ORC-TFE	B3-ORC-TFE	B7-ORC-TFE	B8-ORC-TFE	B9-ORC-TFE
Earthwork & Concrete	$ 118	$ 120	$ 116	$ 122	$ 121	$ 128
Buildings & Structures	88	91	87	91	91	96
Process Equipment	1,064	1,097	1,045	1,099	1,094	1,153
Piping	170	175	167	176	175	184
Electrical	255	263	250	264	262	277
Instruments & Controls	85	88	84	88	88	92
Plant Items, Painting, & Insulation	68	70	67	70	70	74
Direct Field Cost (Items 1 - 7)	$1,848	$1,904	$1,816	$1,910	$1,901	$2,004
Indirect Field Cost (Incl. O.H. & Profit)	439	453	431	452	451	474
Total Field Cost (Items 8 - 9)	$2,287	$2,357	$2,247	$2,362	$2,352	$2,478
Engineering	206	212	202	213	212	223
Sales Tax	72	74	70	74	74	78
Total Cost	$2,565	$2,643	$2,519	$2,649	$2,638	$2,779

TABLE 9–3. BUDGET COST ESTIMATE FOR ORGANIC RANKINE CYCLE PLANTS (TRIFLUOROETHANOL, SUBCRITICAL) (Sheet 1 of 2)

Cycle No.	C1-ORC-TFE	C2-ORC-TFE	C3-ORC-TFE	C7-ORC-TFE	C8-ORC-TFE	C9-ORC-TFE
Earthwork & Concrete	$ 85	$ 87	$ 84	$ 86	$ 83	$ 89
Buildings & Structures	64	65	63	65	62	67
Process Equipment	770	785	756	780	750	808
Piping	123	125	121	125	120	129
Electrical	185	188	181	187	180	194
Instruments & Controls	62	63	61	63	60	65
Plant Items, Painting, & Insulation	49	50	48	50	48	52
Direct Field Cost (Items 1 - 7)	$1,338	$1,363	$1,314	$1,356	$1,303	$1,404
Indirect Field Cost (Incl. O.H. & Profit)	318	323	311	320	310	332
Total Field Cost (Items 8 - 9)	$1,656	$1,686	$1,625	$1,676	$1,613	$1,736
Engineering	149	152	146	151	145	156
Sales Tax	52	53	51	53	50	54
Total Cost	$1,857	$1,891	$1,822	$1,880	$1,808	$1,946

TABLE 9–3. BUDGET COST ESTIMATE FOR ORGANIC RANKINE CYCLE PLANTS (TRIFLUOROETHANOL, SUBCRITICAL) (Sheet 2 of 2)

Cycle No.	A4-ORC-TFE	A5-ORC-TFE	A6-ORC-TFE	B4-ORC-TFE	B5-ORC-TFE	B6-ORC-TFE
Earthwork & Concrete	$ 147	$ 158	$ 147	$ 128	$ 136	$ 129
Buildings & Structures	107	114	107	93	99	93
Process Equipment	1,330	1,427	1,330	1,156	1,228	1,164
Piping	212	228	212	185	196	186
Electrical	319	342	319	277	295	279
Instruments & Controls	107	114	107	93	99	93
Plant Items, Painting, & Insulation	85	91	85	74	79	74
Direct Field Cost (Items 1 - 7)	$2,307	$2,474	$2,307	$2,006	$2,132	$2,018
Indirect Field Cost (Incl. O.H. & Profit)	550	592	550	477	505	484
Total Field Cost (Items 8 - 9)	$2,857	$3,066	$2,857	$2,483	$2,637	$2,502
Engineering	257	276	257	224	238	225
Sales Tax	90	96	90	78	83	78
Total Cost	$3,204	$3,438	$3,204	$2,785	$2,958	$2,805

Cycle No.	C4-ORC-TFE	C5-ORC-TFE	C6-ORC-TFE
Earthwork & Concrete	$ 94	$ 98	$ 95
Buildings & Structures	68	71	68
Process Equipment	851	887	854
Piping	136	142	136
Electrical	204	213	205
Instruments & Controls	68	71	69
Plant Items, Painting, & Insulation	54	57	55
Direct Field Cost (Items 1 - 7)	$1,475	$1,539	$1,482
Indirect Field Cost (Incl. O.H. & Profit)	353	366	355
Total Field Cost (Items 8 - 9)	$1,828	$1,905	$1,837
Engineering	165	172	165
Sales Tax	57	60	57
Total Cost	$2,050	$2,137	$2,059

TABLE 9–4. BUDGET COST ESTIMATE FOR ORGANIC RANKINE CYCLE PLANTS (TRIFLUOROETHANOL, SUPERCRITICAL)

SECTION 10

DISCUSSION

GENERAL

The thermal-to-electric conversion systems analyzed in this study were selected to give a broad range of alternative cycles capable of operating within the level of available solar energy input. Approximately 16 steam Rankine cycles and 36 organic Rankine cycles (9 Toluene and 27 Trifluoroethanol) were developed in this study for integration into the solar total energy system.

During the course of this study, it was determined that a reasonable design value for North Lake Campus peak electrical load is 2316 KW, rather than the 2000 KW peak load capacity on which this conceptual study is based. Although this represents a 16 percent increase in peak load, it was mutually agreed among the study participants that this discrepancy would not invalidate the results of the comparative studies being conducted on alternate solar collector, thermal storage, and turbogenerator systems.

STEAM CYCLES

A comparison of the steam cycles studied (Table 5–1) indicates that for Cascaded System A, Cycle A2, operating at 450 psig - 550°F throttle steam and a turbine exhaust pressure of 25 in. HgA, and utilizing a two-heater extraction cycle, offers the highest cycle efficiency. The addition of a second feedwater heater decreases the gross turbine heat rate by approximately 350 BTU/KWH, or approximately two percent, compared to the single-heater cycle A1. Cycle A3 and A4 operate at lower throttle pressures, 350 psig and 255 psig, respectively, and consequently have higher turbine heat rates and lower efficiencies.

Similarly for Cascaded System B, Cycle B2 operating on 450 psig - 550°F throttle steam and exhausting at 3 in. HgA, with a two-heater cycle, offers the highest efficiency of the cycles studied.

For Noncascaded System C, the two-heater Cycle C2, appears the best choice; however, it has been determined during discussions with various turbine manufacturers that because of the relatively small turbine size required for Case C, a two-extraction machine is a nonstandard product. Consequently, Cycle C1, operating at the same steam conditions as Cycle B2, is considered the best selection based on efficiency and availability.

Figure 10–1 shows a comparison of turbine net cycle efficiency and cycle heat input vs. delta T across the Therminol system. From the standpoint of increased cycle efficiency (consequently lower cycle heat input) it is desirable to minimize the temperature difference across the Therminol system. However, from the standpoint of the solar collector system and thermal storage system, it is desirable to operate with a high temperature difference. A high delta T has the affect of reducing the Therminol flow, thus reducing pumping power and line sizes, and minimizing the thermal storage volume requirements since a sensible heat storage system is planned. It may be, therefore, that the cycle offering the highest efficiency will not result in the lowest evaluated cost overall.

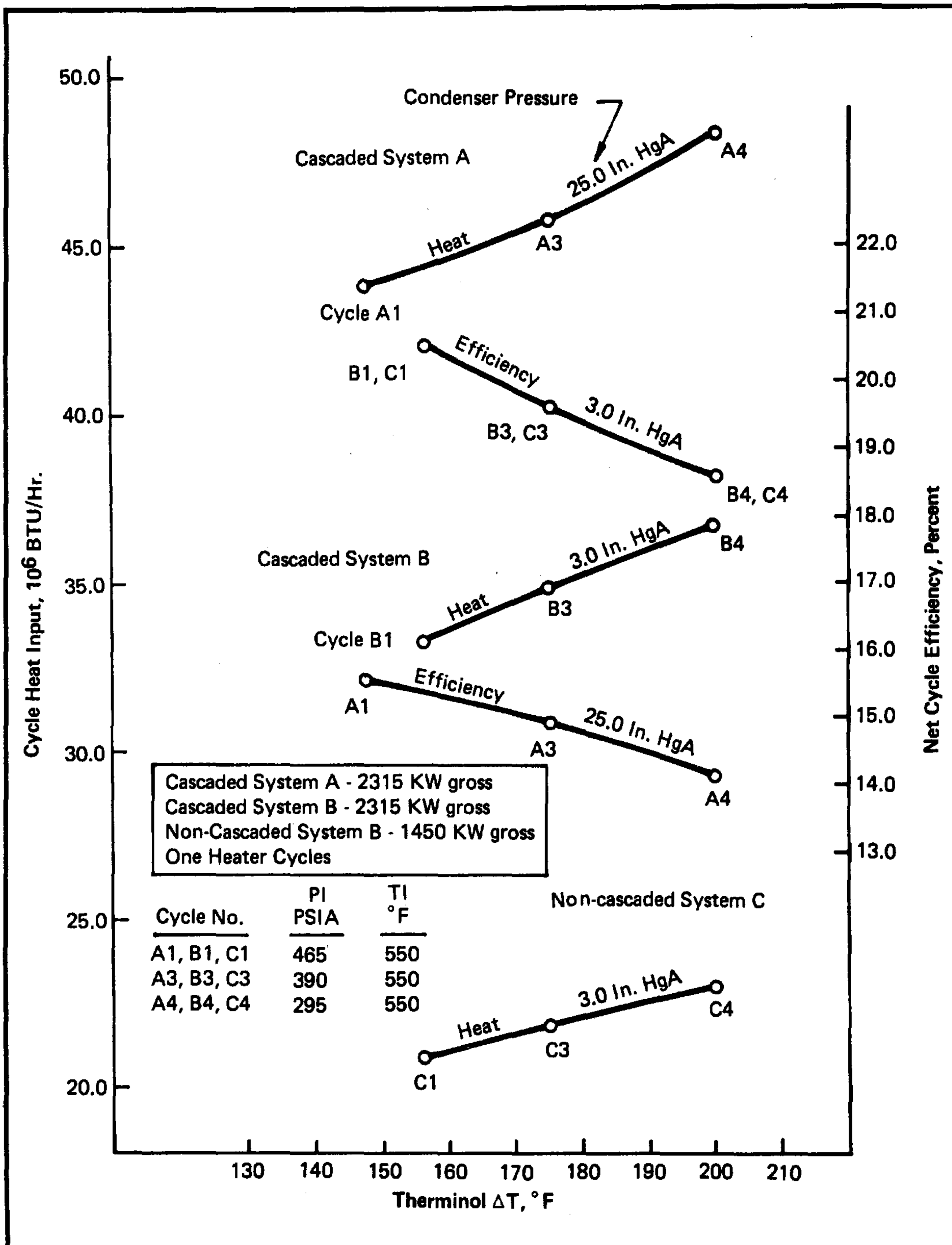


FIGURE 10–1. SUMMARY OF PERFORMANCE STEAM CYCLES

Figure 10–2 shows steam generator pressure plotted against Therminol delta T. To increase the Therminol delta T, it is necessary to decrease the steam generator pressure, thus decrease the cycle efficiency as seen in Figure 10–1.

Cycle D1 was prepared to show the utilization of 190°F circulating water leaving the condenser for absorption cooling, space heating, and domestic hot water heating. This is similar to Cycle A1 except the generation drops to 1250 KW (net) to carry the lighting and miscellaneous power load only. The existing electric-driven centrifugal chillers would not be required to operate.

A review of Cycle D1 indicates that there is marginal capability to supply the waste heat required, since the total peak heat consumption very nearly equals the heat rejected in the condenser. Furthermore, the performance of lithium bromide absorption chillers is low when operating with 190°F water. Consequently, the cost of the lithium bromide system operating with 190°F water is very high compared to a unit of equal capacity operating with steam, as will be shown later.

The use of lithium bromide absorption chillers operating with turbine extraction steam presents another alternative. Cycles E1, E2, and E3 utilize the automatic extraction steam turbine for this purpose, supplying extraction steam at 15 psig - 250°F to absorption units, in addition to feedwater heating. Cycles E1 and E2 are cascaded systems operating at 25 in. HgA backpressure and utilize condenser waste heat for space heating and domestic hot water heating. Cycle E2 operates at 3 in. HgA condenser pressure and rejects waste heat to a cooling tower. The generation in each of the above three cases is 1450 KW gross, or approximately 1250 KW net, for campus lighting and miscellaneous power demands.

Automatic extraction cycles E1 and E3, operating on 450 psig - 550°F steam supply, give the same overall cycle efficiency, 14 percent (net), and an HTF (Therminol 66) delta T of 154.1°F. Cycle E2 operates at 350 psig - 550°F, resulting in a net cycle efficiency of 13.10 percent, while increasing the HTF delta T to 175°F.

For the absorption systems utilizing turbine extraction steam, a backup gas-fired, low pressure steam boiler is required to supplement or replace extraction steam when solar power is unavailable.

ORGANIC RANKINE CYCLES

As demonstrated by the preceeding cycle studies, the organic Rankine cycle appears promising for use in low temperature solar-thermal power systems. The organic Rankine cycle is a relatively simple cycle, consisting of a boiler (or vaporizer), turbine-generator, regenerator (not used in all Rankine cycles), condenser, and feed pump. The organic turbine, in particular, is less complex than a multistage steam turbine, utilizing only one (or two) stage(s) to achieve a relatively high power level. Also, organic fluids characteristically have a positive sloped saturated vapor line (see Figure 10–3). This permits the fluid expansion through the turbine to take place completely within the superheat region, thus avoiding moisture formation in the turbine as is experienced with steam turbines.

Figure 10–3 shows the Rankine cycle on a typical organic T-S diagram, identifying the thermodynamic processes for subcritical and supercritical cycles.

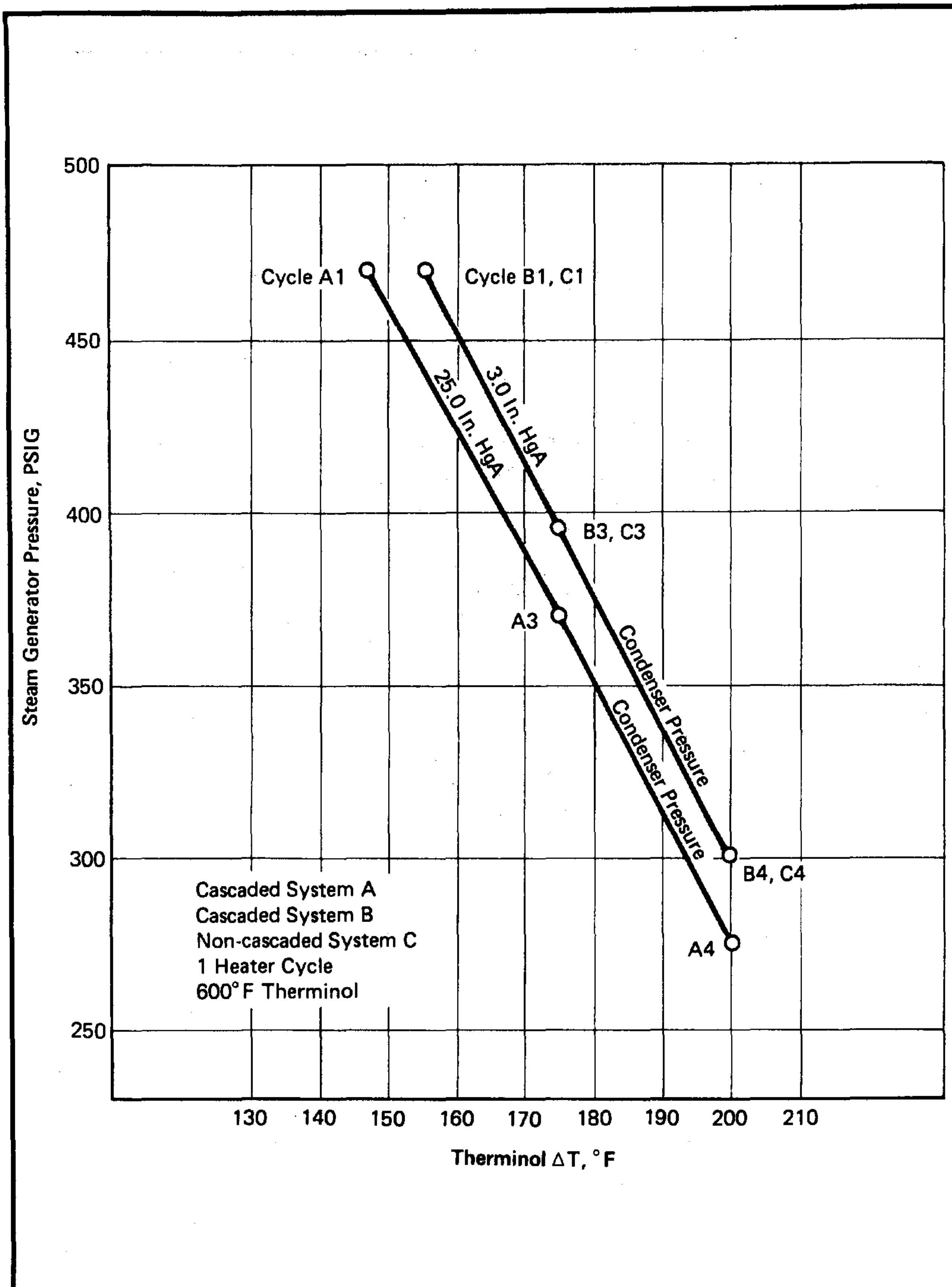


FIGURE 10–2. STEAM GENERATOR PRESSURE VS. THERMINOL ΔT

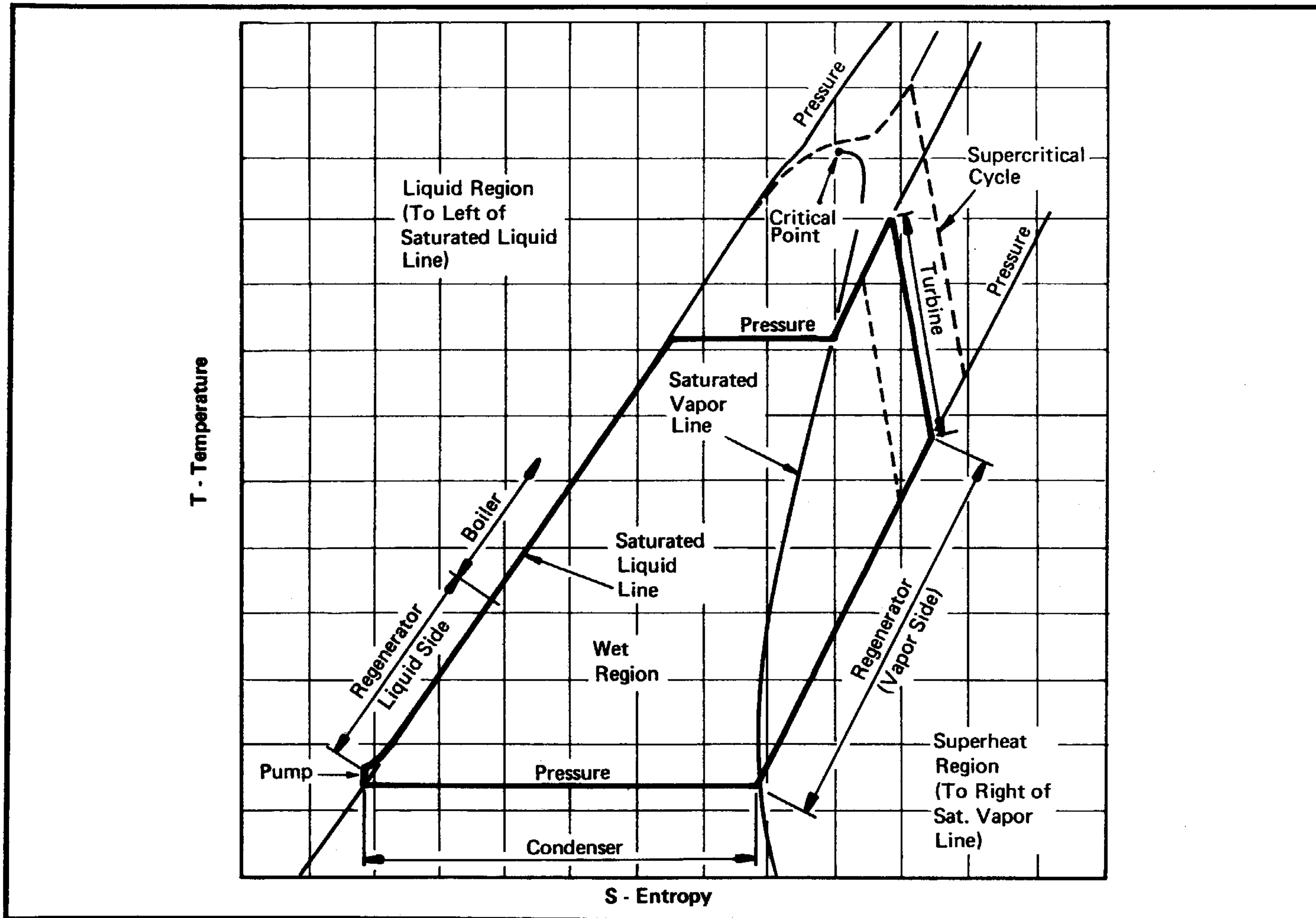


FIGURE 10–3. ORGANIC RANKINE CYCLE ON-T-S DIAGRAM (TYPICAL)

TOLUENE

Of the two organic working fluids studied (Toluene and Trifluoroethanol), Toluene offers the best cycle performance. A comparison of the Toluene cycles studied, (Table 5–2), indicates that alternate cycle A2-ORC-T, B2-ORC-T and C2-ORC-T, operating at 250 psia and 550°F result in the highest cycle efficiency.

Cycles A1-ORC-T, A2-ORC-T and A3-ORC-T operating at 200 psia and 550°F, show a slightly poorer efficiency; resulting, however, in a higher Therminol (HTF) temperature difference, which is desirable. Probably the main disadvantage of Cycles A1-ORC-T, B1-ORC-T and C1-ORC-T, however, is the high degree of superheat. As superheat increases, the regenerator size is increased (as seen in Figure 10–3), and the boiler superheater surface increases, resulting in higher capital cost for heat exchange equipment and greater space requirements.

Toluene Cycles A3-ORC-T, B3-ORC-T and C3-ORC-T operate at 200 psia and 500°F, and have the lowest efficiencies of the cases considered; however, the HTF temperature difference is the highest.

A plot of cycle heat input and net cycle efficiency vs. Therminol delta T for the Toluene cases is shown in Figure 10–4.

TRIFLUOROETHANOL

As previously mentioned, both subcritical and supercritical organic Rankine cycles using Trifluoroethanol were studied. Subcritical cycles using working fluid pressure/temperature combinations of 300 psia/400°F, 300 psia/450°F, and 400 psia/450°F were used for each of the three system options. The relatively low vapor temperature of Trifluoroethanol resulted in the relatively low superheated vapor temperatures leaving the boiler superheater. The use of a higher degree of superheat would result in an abnormally large amount of boiler superheater surface, as well as increased regenerator surface.

The subcritical Trifluoroethanol cycles investigated all resulted in cycle efficiencies less than those obtained using Toluene as the working fluid.

However, supercritical Rankine cycles operating at 800 psia and 550°F (cycles A5, B5, and C5-ORC-TFE) compare favorably in cycle efficiencies to the best Toluene cycles studied. Also the supercritical pressure permits the use of a simpler boiler design and more stable operation since no two-phase flow exists in the boiler. For supercritical cases A6, B6, and C6-ORC-TFE, a pressure of 1000 psia at 500°F was used. The higher operating pressure at the 500°F temperature permits the deletion of the regenerator since the turbine expansion line terminates close to the saturated vapor line at condenser pressure. However, the 1000 psia - 500°F cycle results in a lower cycle efficiency, primarily due to less available energy across the turbine, and secondarily from the deletion of the regenerator.

A plot of the cycle heat input and net cycle efficiencies vs. Therminol delta T is shown on Figures 10–5 and 10–6, respectively.

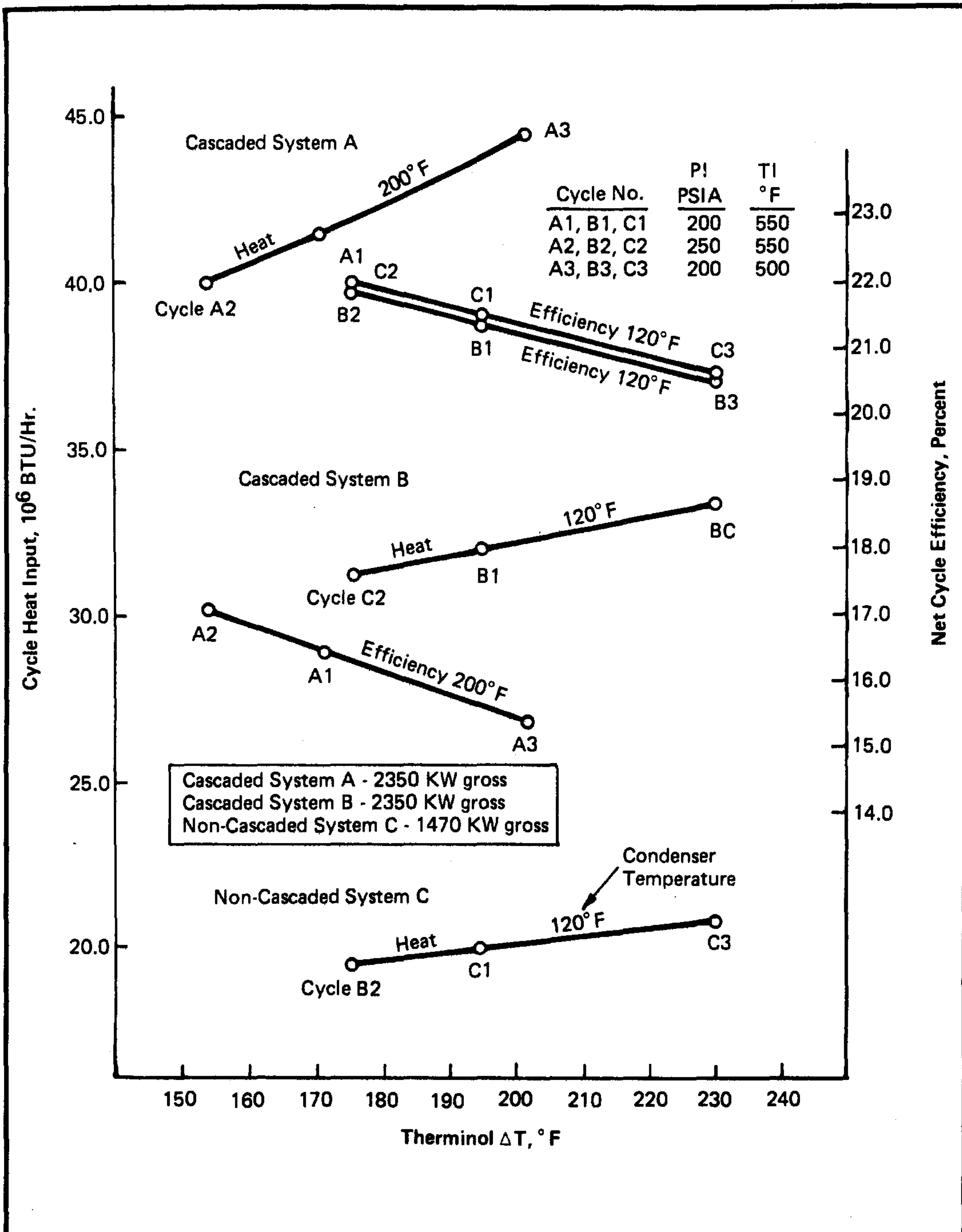


FIGURE 10–4. SUMMARY OF PERFORMANCE ORGANIC RANKINE CYCLES (TOLUENE)

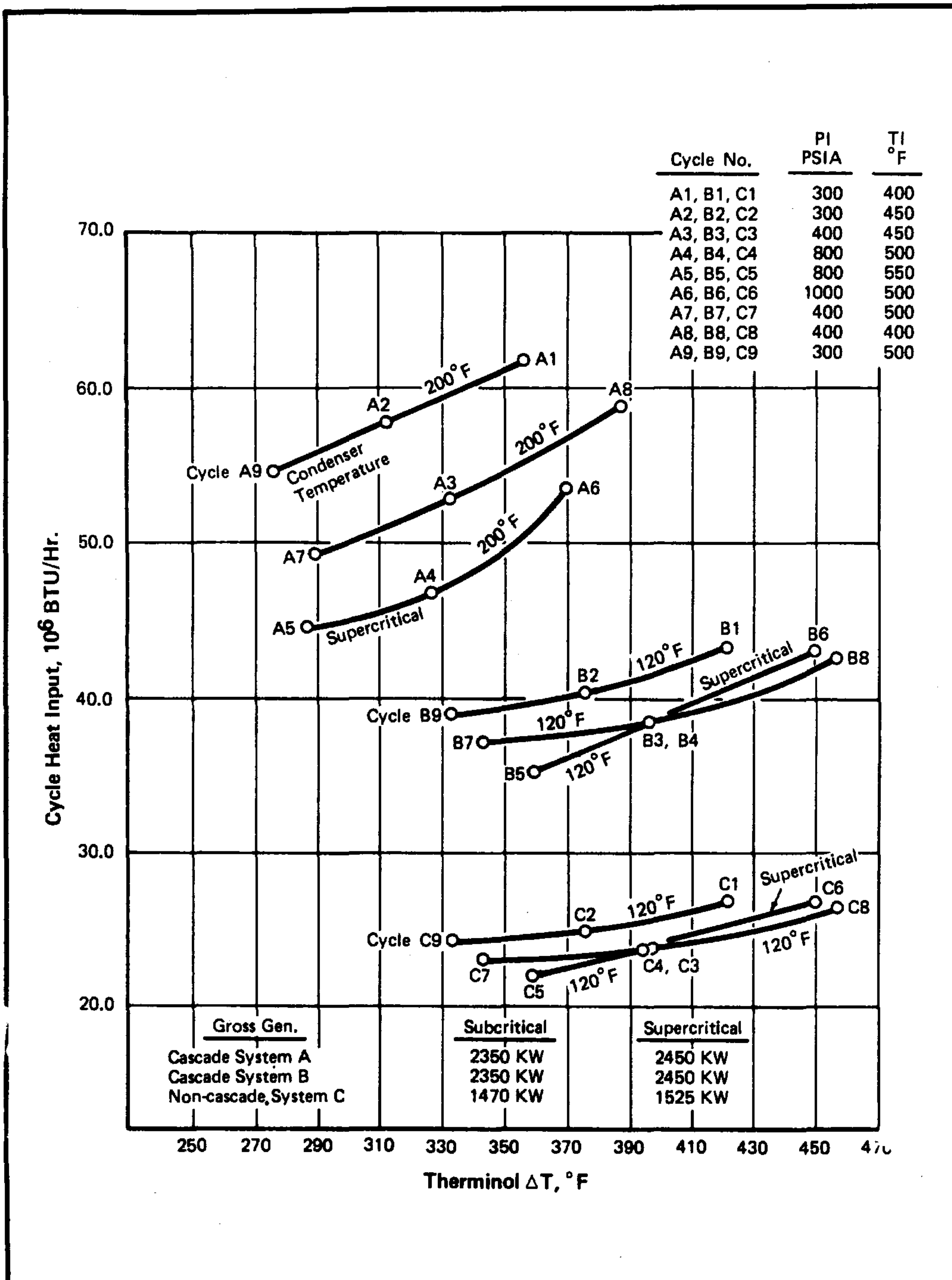
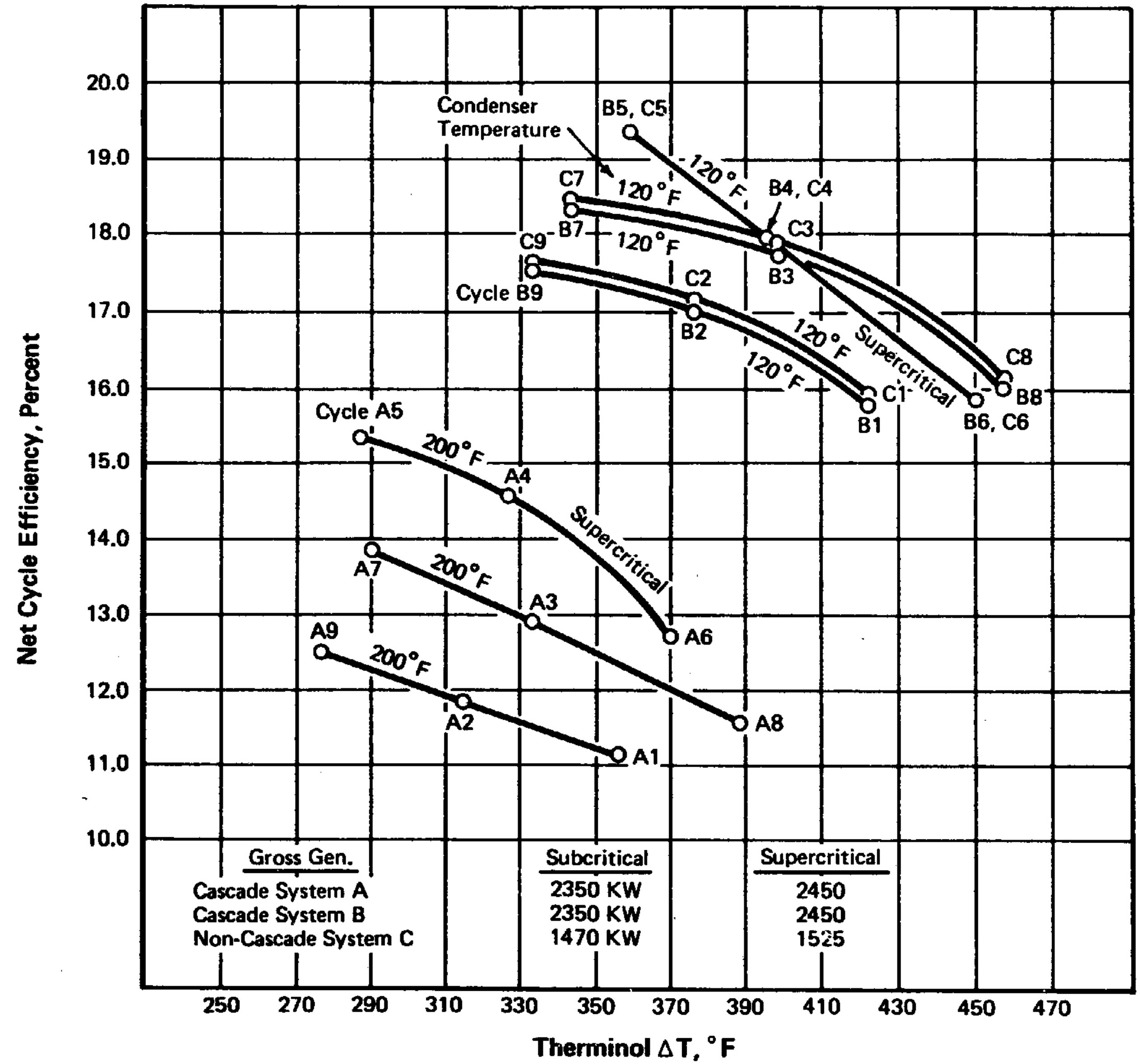


FIGURE 10–5. SUMMARY OF PERFORMANCE ORGANIC RANKINE CYCLES (TRIFLUOROETHANOL)



Cycle No.	TI PSIA	PI °F
A1, B1, C1	300	400
A2, B2, C2	300	450
A3, B3, C3	400	450
A4, B4, C4	800	500
A5, B5, C5	800	550
A6, B6, C6	1000	500
A7, B7, C7	400	500
A8, B8, C8	400	400
A9, B9, C9	300	500

FIGURE 10–6. SUMMARY OF PERFORMANCE ORGANIC RANKINE CYCLES (TRIFLUOROETHANOL)

EQUIPMENT AVAILABILITY AND PROBLEM AREAS

As previously mentioned in Section 6, equipment availability for the steam cycle components pose no major problems in the areas of equipment selection, design, and procurement.

Organic Rankine cycle components, however, pose several problems with respect to design and availability in the size range required. First, as previously discussed, organic turbine designers and manufacturers are limited in number. Rotoflow Corporation has proposed using two of their "Standard" turboexpanders for this application, and delivery is estimated at 16 to 20 months, including design drawing time. Presumably, no development work would be required by Rotoflow for this organic Rankine cycle operation.

Sundstrand Energy Systems, the second organic turbine manufacturer contacted, is currently in the design and development stage of a 600 KW organic Rankine cycle total energy system; however, this system will not be available until late 1978 or 1979, and will require 8 to 12 months lead time.

System options B and C, which operate at low backpressures, present design problems principally in organic turbines and regenerators due to the large volumetric flow that must be passed. This is of particular concern in the Toluene cycles because of its high specific volume at low exhaust pressures.

High volumetric flows experienced in the low backpressure cycles make regenerator selection difficult, if not impossible, because of the very low pressure drop available, low heat transfer coefficients, and the high effectiveness (85 to 90 percent) required for efficient performance. Yuba Heat Transfer Corp. submitted cost and performance data for the System A high pressure regenerator but declined to quote the low pressure regenerators required in Systems B and C. Both Basco, Inc. and Graham Manufacturing declined to quote on organic regenerators.

On the basis of equipment availability, then, it appears that organic Rankine cycles should be limited to high (about 200°F) condensing temperature cycles as utilized in Cascaded System A.

ORGANIC FLUID CONSIDERATIONS

In addition to the thermodynamic properties of the organic working fluids, consideration must also be given to other fluid characteristics, such as its fire and explosion hazard, life hazard, and storage and handling requirements.

Toluene is a colorless liquid with aromatic benzene-like odor and is flammable. Toluene vapors form explosive mixtures with air; flammable limits are 1.4 percent and 6.7 percent. Toluene, having a flash point of 40°F, can be ignited under almost all normal temperature conditions. Toluene vapor is heavier than air (vapor-air density at 100°F is 1.2) and may travel considerable distance to a source of ignition and flash back. As a life hazard, Toluene is an eye and respiratory irritant. Extreme inhalation of vapors may cause death by paralysis of the respiratory center. Toluene is shipped in drums, tank cars, and tank trucks; and is considered noncorrosive. Outside or detached storage is preferable.

Trifluoroethanol is not listed under the NFPA Fire Protection Guide on Hazardous Materials (5th Edition), therefore, little is known about its fire and explosion hazard. However, as a life hazard, Trifluoroethanol can cause eye irritation and is toxic if inhaled in large doses. Nothing specific can be found in regard to storage and handling of Trifluoroethanol; however, this study assumes that standard materials of construction can be used.

Other areas of concern with regard to organic fluids is their stability at the required operating temperature ranges, vapor recovery systems, shaft sealing systems, and the effect on lubricating oil, as no currently available seals are 100 percent effective in preventing contamination.

LITHIUM BROMIDE ABSORPTION CHILLERS

The use of lithium bromide absorption chillers for campus space cooling in lieu of existing electric motor-driven centrifugal chillers was considered in Cycles D1, E1, E2, and E3. A comparison of three representative absorption units, one operating on 190°F water, and two operating on steam is shown below:

	Cycle D1	Cycles E1, E2 & E3	
	190°F Water One Stage	12 PSIG Steam One Stage	125 PSIG Steam Two Stage
No. of Units	2	1	1
Cooling Load, Each Unit, 10^6 BTU/Hr. (Tons)	5.3 (442)	10.6 (884)	10.6 (884)
Chilled Water ΔT, °F	10 (45 - 55)	18 (42 - 60)	10 (44 - 54)
Chilled Water Flow, Each Unit, GPM	1060	1200	2120
Hot Water ΔT, °F	9.3 (190.0 - 180.7)	N/A	N/A
Hot Water Flow, Each Unit, GPM	1510	N/A	N/A
Steam Flow, Lb/Hr.	N/A	17,000	11,300
Condenser Water ΔT, °F	9 (86 - 95)	13 (90 - 103)	13 (88 - 100)
Condenser Water Flow, Each Unit, GPM	2500	4000	3526
INSTALLED COSTS			
Chiller Equipment	$275,000	$121,000	$160,000
Cooling Tower	60,000	55,000	50,000
Condenser Pumps and Piping	50,000	35,000	35,000
TOTAL COST	$385,000	$211,000	$245,000

The annual electrical power input for space cooling using electric motor-driven chillers is estimated at 4.7 x 10^6 KWH. Assuming that 50 percent of this electric load could be saved by utilizing absorption chillers and solar energy, a reduction in annual electrical consumption of 2.35 x 10^6 KWH would result. Based on an energy charge of $0.02/KWH, this represents a savings of $47,000 per year, which, assuming a 15 percent fixed charge rate, is equivalent to a capital investment of $313,300.

The above analyses would indicate that a steam absorption system could be justified, however, to accomplish this utilizing an automatic etraction turbine (Cases E1, E2 and E3) would incur an additional cost of approximately $505,000 for the autoextraction turbine above that of a non-automatic extraction turbine (Case D1). It may be, however, that steam generated from either solar or fossil fuel thermal energy could economically justify the absorption chiller system.

WATER TREATMENT SYSTEMS

To ascertain the water treating requirements for the steam cycle systems studied, as well as cooling tower circulating water treatment methods, a well water analysis (Pope Testing Laboratories, Inc.) for North Lake Campus was supplied by Envirodynamics, Inc. Additionally, the silica concentration, not shown in the referenced analysis, was assumed to be 20 ppm as SiO_2.

A. Boiler Water Treatment

The boiler chemical feed system would include chelant, sodium sulfite-sodium hydroxide, and amine feed chemicals, all fed to the boiler feed pump suction. The chemical feed and blowdown will be manually controlled, with a high conductivity alarm for boiler water. If the assumption of 20 ppm silica in the well water is correct, blowdown requirements will be 50 to 55 percent of the makeup water.

B. Boiler Makeup Water Treatment

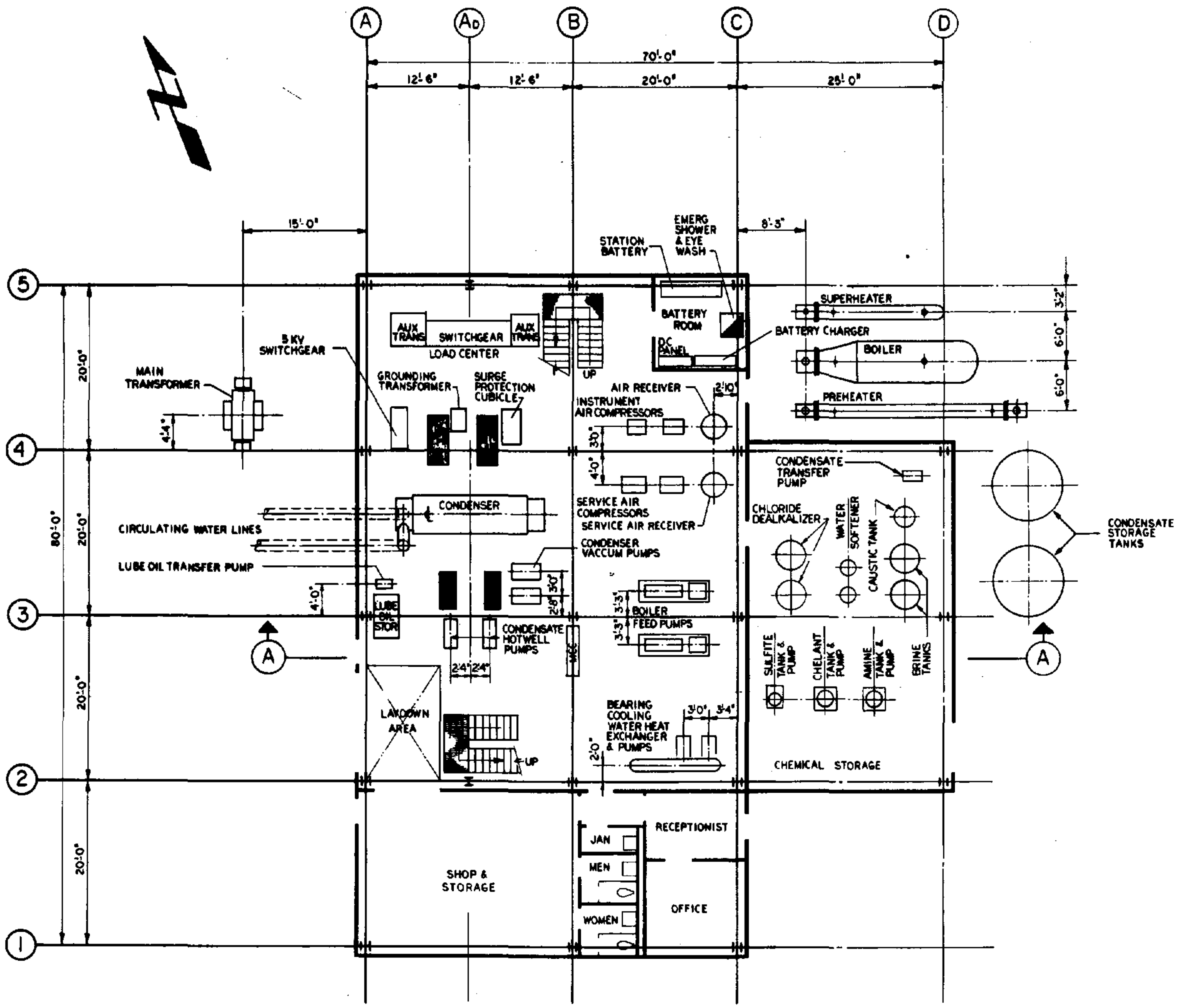
The boiler makeup water treatment system selected consists of two sodium cycle softeners and two chloride dealkalizers, all skid-mounted, and use salt as the primary regenerant. Other techniques exist for treating the boiler makeup water, some of which might conceivably have lower operating costs; however, indications are that their initial installed cost would be greater. All of them require sulfuric acid as a regenerant, presenting additional handling and potential waste disposal problems.

C. Condensate Polishing System

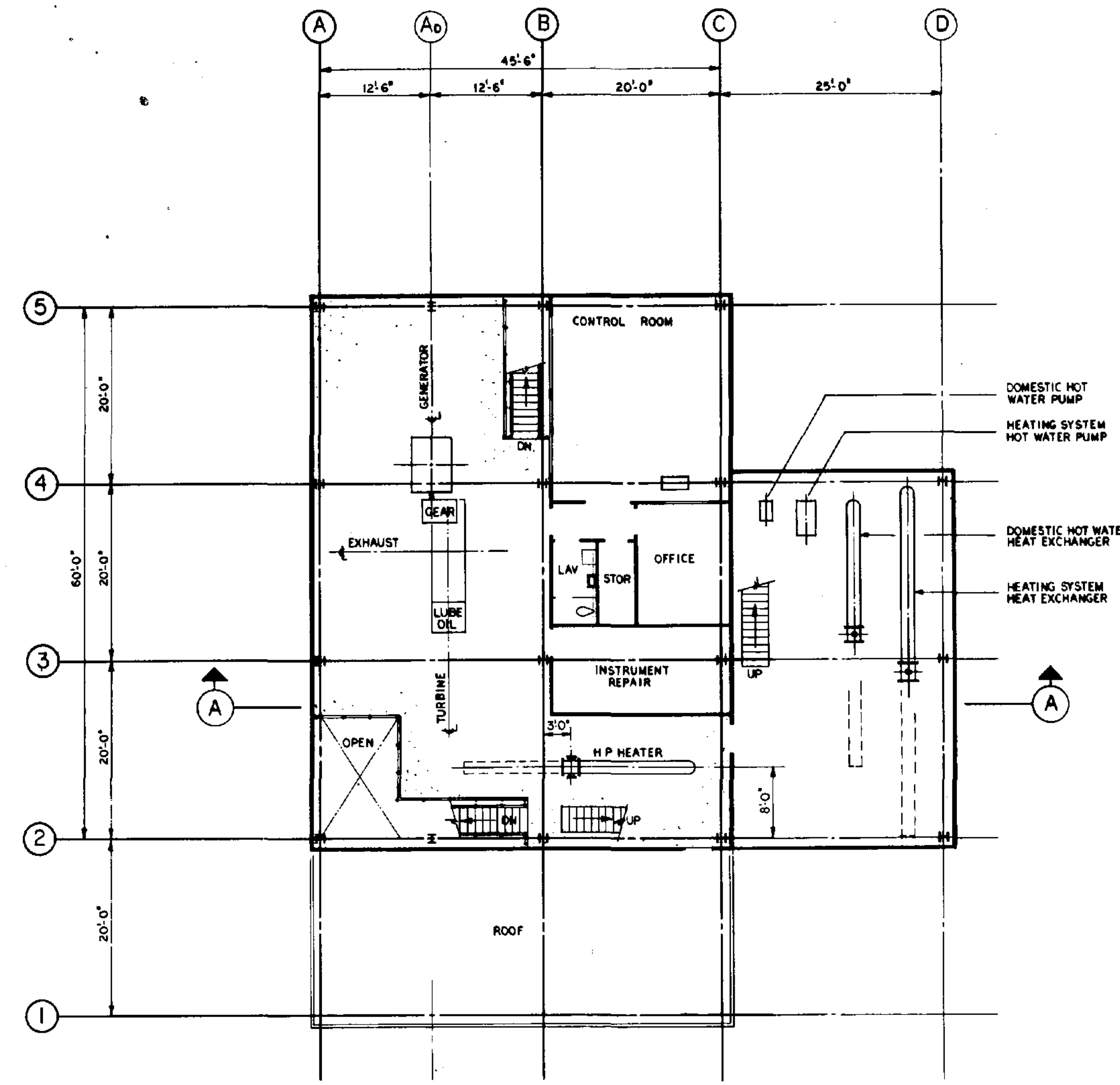
Because of the daily startups and shutdowns of the solar electric generating plant, it is recommended that a condensate polisher be installed in the condensate circuit to minimize iron deposits on heat transfer surfaces and throttling components (control valves, orifices, etc.) and removal of suspended solids. The condensate polishers consist of a sodium cycle unit, made up of a polisher vessel, brine tank, and sodium sulfite-sodium hydrosulfite feed system.

D. Cooling Tower Water Treatment

Cooling tower water treatment would consist of a sulfuric acid feed system for pH control, and a scale inhibitor feed system. Cooling tower water treatment assumes that the circulating water systems will be constructed of corrosion resistant materials such as FRP or lined steel circulating water pipe, coated and cathodically protected water boxes, and Admiralty or 90-10 copper nickel condenser tubes. This will permit operation without such corrosion inhibitors as sodium chromate, whose use might be prohibited. Five cycles appears to be a reasonable level of concentrations at which to operate.



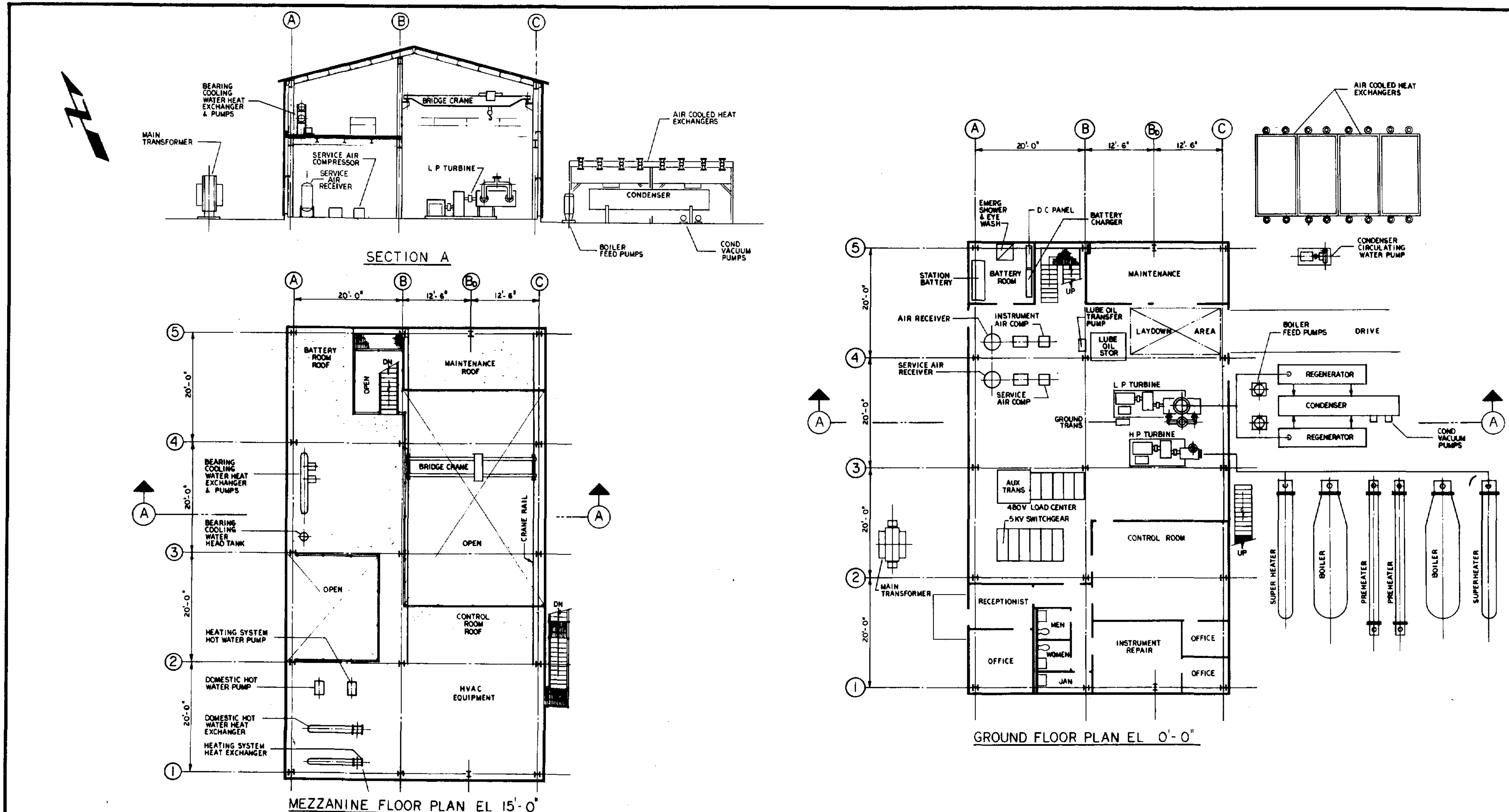
EL 0'-0"
GROUND FLOOR



EL 15'-0"
OPERATING FLOOR

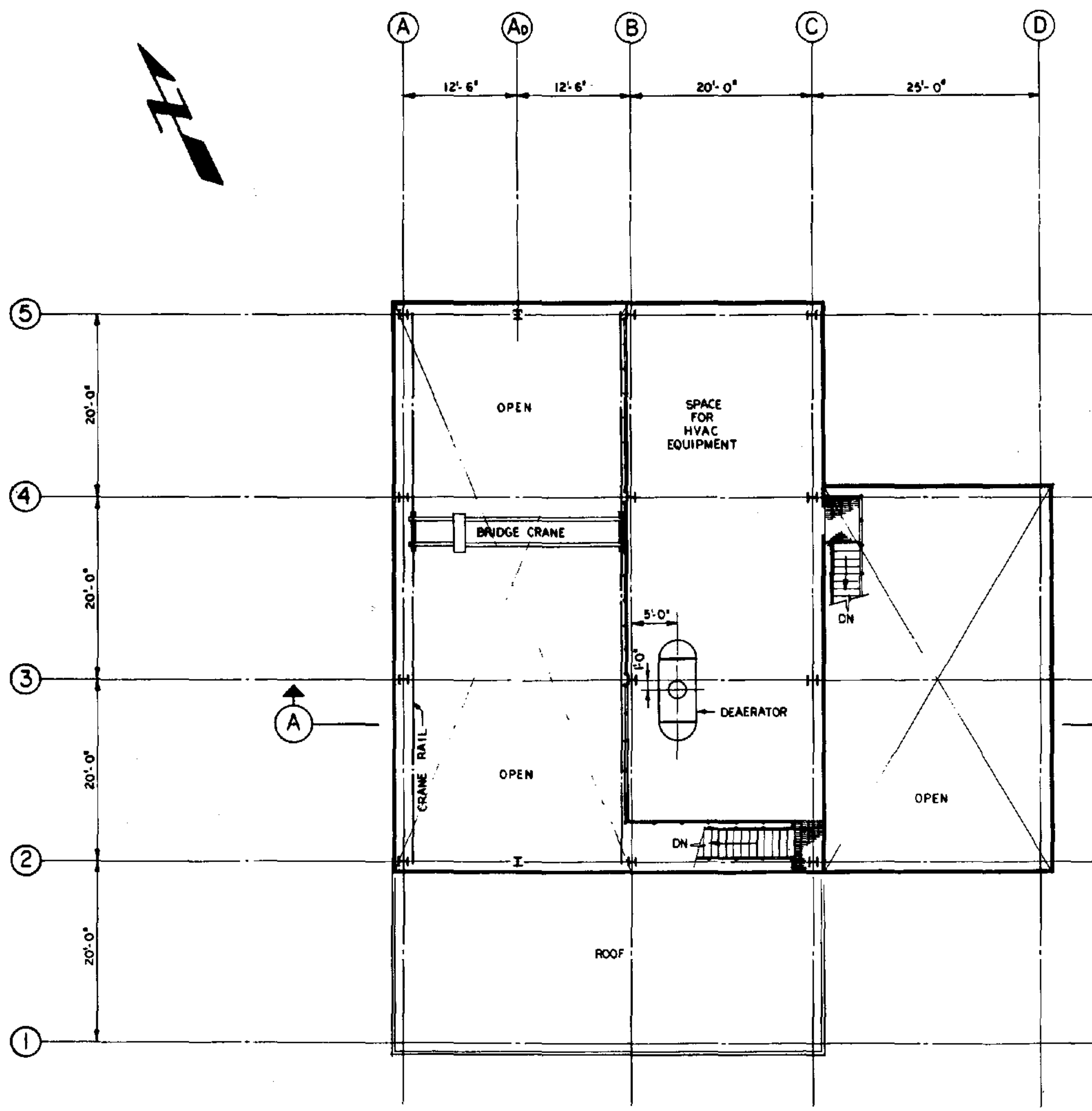
GENERAL ARRANGEMENT GROUND AND OPERATING FLOOR PLANS

A–1

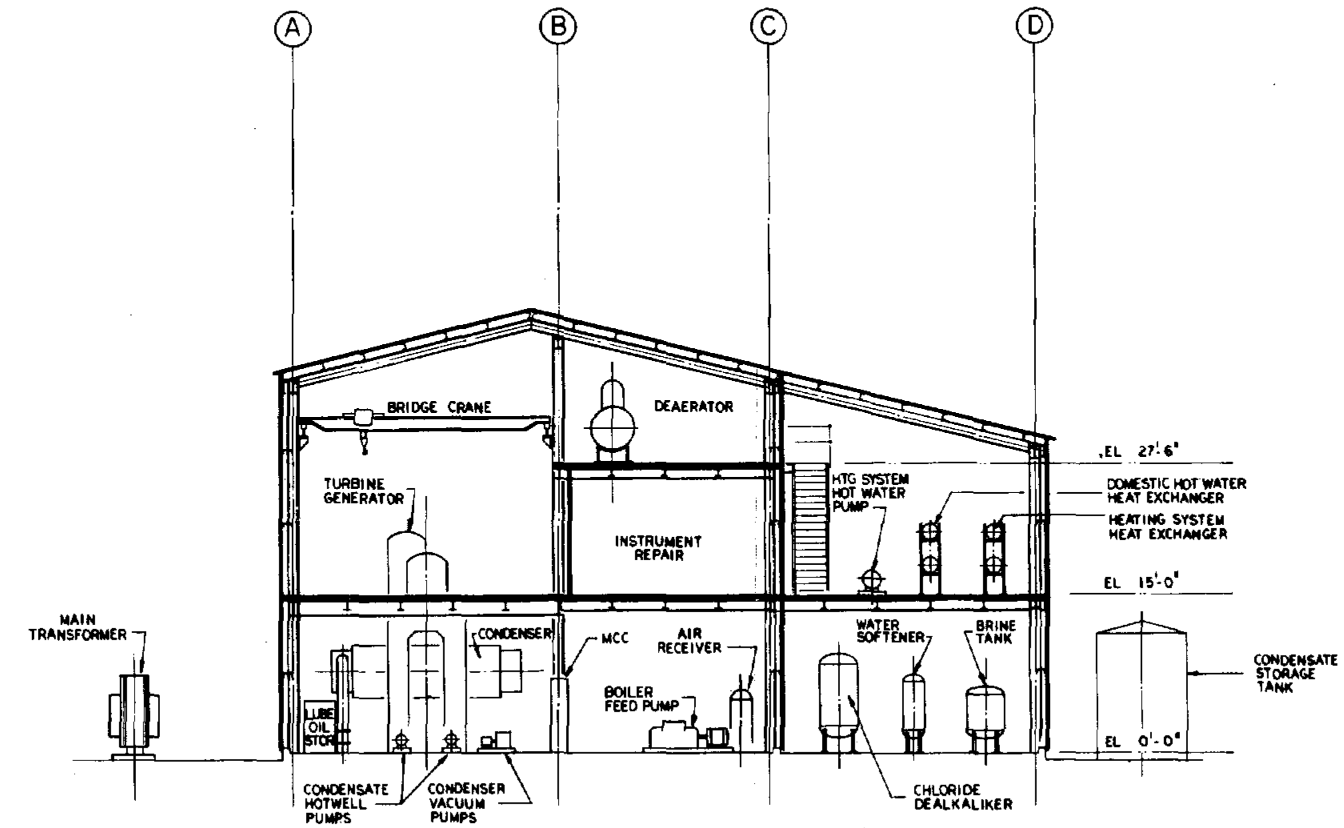


GENERAL ARRANGEMENT GROUND AND MEZZANINE FLOOR PLANS AND SECTION A

A–2



EL 27'-6"



SECTION A

GENERAL ARRANGEMENT MEZZANINE FLOOR PLAN AND SECTION A

A–3

APPENDIX C

CONCEPTUAL DESIGN OF CENTRAL RECEIVER SYSTEM
FOR THE NORTH LAKE CAMPUS OF THE
DALLAS COUNTY COMMUNITY COLLEGE DISTRICT

PREPARED BY
C. T. YOKOMIZO
SOLAR ENERGY TECHNOLOGY
DIVISION 8184

CONCEPTUAL DESIGN OF CENTRAL RECEIVER SYSTEM
FOR THE NORTH LAKE CAMPUS OF THE
DALLAS COUNTY COMMUNITY COLLEGE DISTRICT

As part of the conceptual design study for the application of a solar total energy system at the Dallas Community College, a system has been designed using the central receiver method of solar collection. In the central receiver concept, solar energy is redirected from a large array if individually controlled mirrors (called heliostats) to a central zone. Energy can be concentrated to values greater than 1000 kW/m^2, allowing it to be collected efficiently at very high temperatures (greater than $500^{\circ}C$). This high quality energy can be subsequently used in relatively efficient thermodynamic cycles to produce electricity.

Presently, investigators conclude that the most economically sized heliostat would have approximately 30 to 50 m^2 of reflective surface. This large size implies that the systems for producing electricity efficiently would have to generate more than 100 mW of electricity per each tower in order to preserve the desired collector field optics (i. e., high concentration ratio). For the Dallas Community College, a peak rate of 1. 25 mWe is required. However, since there is a large requirement for thermal energy for air conditioning and space heating, the central receiver system can be operated as in the total energy concept, using energy collected at lower temperatures. This will lower the electrical generation efficiency but can provide a balance between the electrical and thermal energy required.

A small central receiver system has been designed that would provide 15 mWe/hr of electricity (at a rate of 1. 25 mWe) and provide 56 mWt/hr of thermal energy on an average clear day to provide for the energy demands of the Dallas Community College. Figure C-1 is a schematic representation of the proposed system. Concentrated solar energy is absorbed in a working fluid circulating through the receiver. Although only one receiver is shown, actually six tower mounted receivers are required to provide the necessary thermal energy. The height of the tower-receiver structure is limited to 41 m due to the proximity of the college to the Dallas/Ft. Worth Regional Airport. The six receivers are connected in parallel. The working fluid is Hitec, a eutectic salt, produced by DuPont. This material has a low vapor pressure and a recommended useful range up to 454°C. It costs approximately 61¢/kg. Although less expensive fluids may be found for future systems, Hitec has the advantages of commercial availability and over 30 years of operational experience. Hitec solidifies at 142°C, which requires that all lines where freezing might be anticipated should be heat traced.

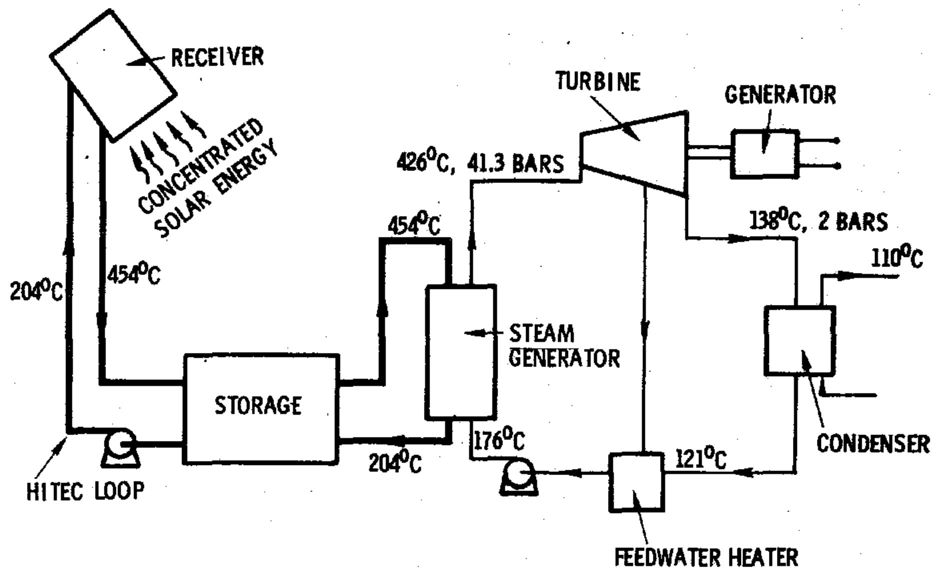


Figure C-1. Central Receiver Hitec - Water/Steam Schematic

The working fluid is also the media in which energy is stored as sensible heat. Steam is produced in the steam generator which is charged by the working fluid from either storage or the receiver. A conventional turbine generator is driven by the 426°C, 41-bar steam. Thermal energy extracted from the condenser is used either to provide energy for space heating, air conditioning, and domestic hot water needs, or discharged.

Using a fluid to remove energy from the receiver offers several advantages over generating steam directly in the receiver. These include the following.

1. Energy used to charge the steam generator from either the receiver or storage is of the same quality (i.e., thermodynamic state); therefore, steam is produced at a single pressure and temperature, allowing the turbine to be optimized for these inlet conditions. When steam is generated in the receiver and transferred to a storage media, it must be reconverted to steam for later use. These transfers reduce the quality of the steam; therefore, electricity cannot be produced at as high an efficiency when using steam from storage.

2. Using Hitec as both the heat transfer fluid and a storage media allows variations in load demand and insolation to be decoupled, since the storage can effectively act as a buffer between the system input and outputs.

3. Because Hitec has low vapor pressure at the temperatures of interest, thin wall tubing can be used in the receiver to reduce both receiver weight and cost. Also, piping in the field and riser and downcomer piping in the tower can be smaller and thinner walled.

Subsystem Description

The system would operate most economically if only a single tower could be used. However, because of height limitations, six central receiver modules are specified. Each module covers approximately 7700 m^2 of land. The geometry of each module is governed by the height of the tower and receiver configuration. The further the heliostats are located from the tower, the greater the spacing between heliostats in order to reduce shadowing and blocking from adjacent heliostats. Mirrors at greater slant ranges produce larger images and require larger receiver apertures, reducing the concentration power of the collector field.

A possible layout of five modules is shown in Figure C-2. The average mirror density (i.e., ratio of reflective area to ground area) is 0.33, which implies that about 2540 m^2 of mirror area are required per module. Heliostats are assumed to have a reflectance of 0.85 and to be focused.

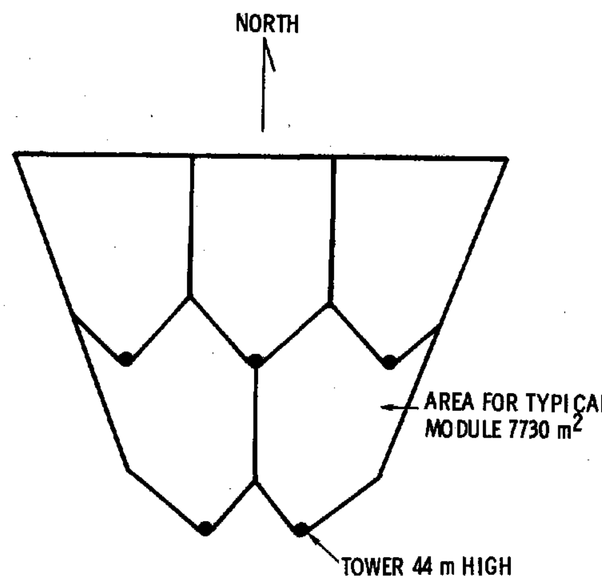


Figure C-2. 1.25 mWe Field Layout - 5 Modules

The tower mounted receiver is located on the south edge of the field, with the receiver facing toward the north and tilted downward about 40 degrees. The top of the receiver would be at 44 m. A cross section of the receiver is shown in Figure 3. The receiver is a right circular, cylindrical cavity with a 3-m diameter aperture and is 4 m deep. Tubing made of mild steel alloy, such as Crolloy 2-1/4, lines the inner walls of the cavity in a spiral pattern. Hitec can be contained with mild steel up to 454°C when oxygen is excluded, but since the receiver may have hot spots, Crolloy is specified. Flux maldistributions are smoothed by the spiral tube configuration. The tubes would be coated with a high absorptive material (e.g., Pyromark, $\alpha > .92$). Based on a two zone model, approximately 92.5% of the incident flux should be absorbed by the cavity. This estimation neglects convective losses, which should be low. Each receiver would be capable of absorbing a peak power of 2 mWt. Because the height of the tower (~40 m) is relatively low and the weight of the receiver is not excessive, a free standing steel tower probably is the least expensive type to construct. The riser and downcomer can be made of mild steel if Hitec fluid temperatures can be kept at 454°C or below.

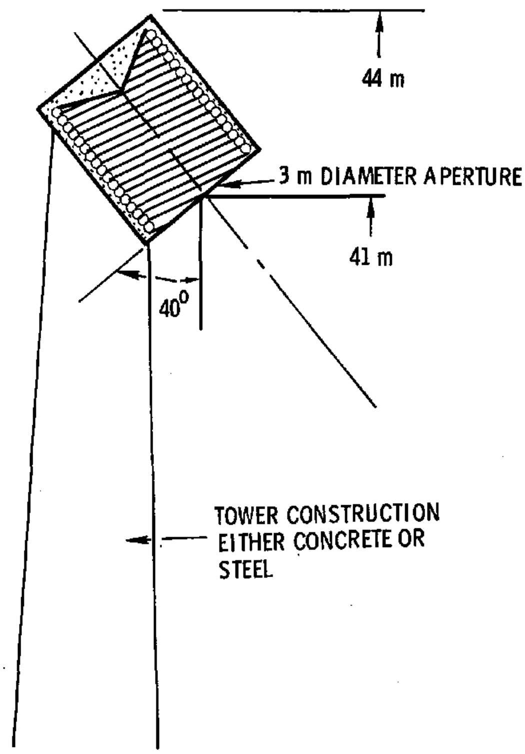


Figure C-3. Typical Tower/Receiver Configuration

The quantity of storage has not been optimized. For the purpose of this study, the amount of capacity was assumed to be 33 mWt/hr. Based on the properties of Hitec (thermal capacity = 0.373 cal/gm °C, density = 1.9 - 1.7 gm/cc -- depending on temperature) and the 250°C temperature change in the storage tanks, approximately 180 m^3 of Hitec are required. This can be accomodated in four 4-m diameter by 4-m high tanks. This includes additional volume for nitrogen filled ullage. Five tanks are used in the storage system so that the hot and cool Hitec is separated by using the empty rank during transition periods. The tanks are made of carbon steel and employ a submerged pump (to minimize bearing seal problems) in each tank to transfer the Hitec. Pressure created by the gravity head in the downcomer is isolated from storage so that low pressure design can be used for the storage tanks. Because of the small size of the tanks and the high temperature, double walled tank construction with vacuum insulation is recommended.

In the water-steam loop, a conventional turbine is used, with the low pressure stages removed. Inlet steam conditions to the turbine are 426°C at 41.3 bars. Exit conditions are predicted to be 138°C at 2 bars. The condenser will operate at roughly 2 bars to provide hot water at 110°C for absorption air conditioning and other thermal requirements. Based on the inlet and outlet condition above, the turbine generator should be able to operate at roughly 17 to 20 percent efficiency. This provides the needed balance between electrical and thermal demand. Another philosophy might be to exhaust the turbine into a more conventional low pressure condenser and extract energy at an intermediate stage to provide energy at the desired temperature for AC, heating, etc. Excess electrical energy produced at higher efficiency when thermal demand is as low could be sold to the local utility.

Schedule

	Months From Authorization to Proceed
	0 10 20 30 40
Preliminary Design	- - - -
Component Testing	- - - - - - - -
Detail Design	- - - - - - - - -
Phased Construction	- - - - - - - - - - -
Checkout	- - - -
	▲ Operational

During the preliminary design phase, subsystem sizing can be optimized and the subsystems can be studied in more detail to insure optimum operational flexibility. During the component testing phase, design of the Hitec cooled receiver (and possibly the steam generator) can be tested. Components for the remainder of the system are either "off-the-shelf" or are being tested extensively under the 10-mWe solar power plant preliminary design contracts. Items that fall into this category include heliostats, Hitec storage, and Hitec-to-steam heat exchangers.

Estimated costs for the system are shown in Table C-I. It should be noted that heliostat costs are based on current reflective surface estimates of $\$350/m^2$, and the remainder of the solar portion of the plant's costs are also inflated for this first-of-a-kind installation.

TABLE C-I

Cost Estimate (in thousands) for 1.25 mWe
Central Receiver Option 2

1.	Heliostat Field	4,600
2.	Electrical Generation Equipment	2,500
3.	Thermal Storage Material	200
4.	Remainder of Plant • Storage Tanks • Towers & Receivers • Steam Generator • Site Improvements	3,000
5.	Contingency (20%)	2,060
		12,360

Conclusions

1. The use of the central receiver system for applications such as the Dallas Community College offers the advantage that the energy can be produced efficiently enough to provide a balance between the thermal and electrical demands.
2. The initial cost of the system is high, since this is a first-of-a-kind installation.
3. Additional design work must be pursued to balance the sizes of the various portions of the plant with the expected input and desired output.
4. A possible disadvantage of the system is the potential safety and eye hazard problem associated with this type of installation, especially since it is close to the Dallas/ Ft. Worth Regional Airport.

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