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Stirling Total Energy Systems Study

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**Final Report
for Period May 15, 1976 - June 13, 1977**

August 1977

Prepared For

UNITED STATES DEPARTMENT OF ENERGY

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for Period May 15, 1976 - June 13, 1977

D. Lehrfeld

PHILIPS LABORATORIES
A Division of North American Philips Corporation
Briarcliff Manor, New York 10510

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ABSTRACT

Philips Laboratories investigated the application of Stirling cycle prime movers to total energy power generation systems. Electrical, heating, and cooling demand profiles for a typical residential complex, hospital, and office building were studied, and alternative Stirling total energy systems were conceptualized for each site. These were analyzed in detail and contrasted with purchased-power systems for these sites to determine fuel-energy savings and investment attractiveness. The residential complex and hospital would be excellent candidates for total energy systems, and prime movers in the 1000 kW output range would be required. Stirling engines with so large an output have not been built to date, although there would be no fundamental technical barrier to prevent this. However, careful consideration must be given to the following technological decision areas before arriving at a final design, if its potential is to be realized: engine configuration, hot-side heat exchange interface, engine control system, internal gas seals, and advanced coal combustion technology. The principle advantage of a Stirling prime mover in this application, in view of national concern over present and future dependence on oil, is that it could utilize low-grade liquid fuels and coal.

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1. INTRODUCTION

A total energy system (TES), in its broadest sense, is an on-site electrical power generation plant fulfilling the site electrical requirements while utilizing the waste heat from the prime mover to supply the site heating and/or cooling demands. This heat-recovery, power-generation concept is not a new one. While there can be many reasons for a user to select on-site power generation (including unavailability of purchased power, "free" fuels from process wastes, etc.), one reason for governmental acceleration of interest in such systems today is to minimize waste of the energy content of fossil fuels. This "minimization" is one of the primary thrusts of energy conservation. Most public utility power plants do not operate in a heat recovery mode, with the result that approximately 70% of the energy content of the fuel they burn is unused.

Total energy systems can be composed of a variety of equipment mixes. Turbines using steam generated from boilers, turbines using high temperature combustion gases, and internal combustion engines can be used as prime movers for driving electric generators and refrigeration compressors. Heating requirements can be satisfied with hot water, steam or electric resistance heaters. Cooling can be satisfied with refrigeration compressors or through the use of absorption water chillers which employ waste heat without the need of a prime mover.

The majority of these systems in operation utilize fossil fuels, gas and oil, as their prime energy source. Power systems which need not rely on oil and natural gas are increasingly receiving favorable attention. In 1973, 76% of the nation's energy requirements were derived from oil and natural gas. By the year 2000, it is (hopefully) estimated that these fuels will account for only 35% of the then larger total⁽¹⁾. Coal and nuclear energy are expected to comprise the most significant fraction of the balance. Therefore, power systems capable of utilizing domestically available coal and coal-derived fuels are of particular interest. Under contract to

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the Conservation Division of the U.S. Energy Research and Development Administration, Philips Laboratories has studied the application of Stirling cycle prime movers to total energy systems.

The main objective of this study was to evaluate the theoretical performance of Stirling cycle engine/generators in TES configurations. Typical seasonal demand profiles for three diverse sites were supplied by the contracting agency, and alternative TES conceptual designs were formulated for each site. These concepts were compared to conventional (purchased power) systems and analyzed to determine energy savings potential and investment attractiveness. The size of the Stirling engine/generator most compatible with these sites was identified, and recommendations prepared regarding how best to proceed with its development.

2. TASK I - STIRLING TES CONCEPTUAL DESIGNS

2.1 TES Stirling Engine Characteristics

The Stirling engine is a piston engine based on a closed cycle system, converting heat into mechanical power⁽²⁾. Part of the engine is kept at a high temperature level by supplying heat continuously to the system through the wall of a heat exchanger, while another part of the engine is kept at a lower temperature by extracting heat from the system through the walls of another heat exchanger. By compression of the working gas at low temperature and expansion at high temperature, mechanical power is produced. Mechanical energy is extracted from the system by means of a rotating shaft (see Appendix G).

The Stirling engine has characteristics that differ from those energy converters working on the basis of an open cycle, such as the gasoline and diesel engines⁽³⁾. These characteristics make the Stirling engine a likely candidate for a total-energy-system prime mover. The external heat supply makes the engine suitable for a wide variety of heat sources without any essential modification of the engine being necessary. Apart from heating the engine from non-conventional heat sources such as solar heating, heating by a radioisotope, or by a heat storage unit, the engine can be heated by a variety of fuels. All liquid and solid fossil fuels, synthetic and non-synthetic, can be combusted in the engine under very favorable circumstances, e.g., continuous combustion, atmospheric conditions, hot walls surrounding the burner, possibility of large excess air and of recirculation of the exhaust. The engine has good efficiency under part load and rejects most of its waste heat to the cooling water. The engine is insensitive to dust in the combustion air, consumes no lubricating oil, and requires no oil changes. The absence of intermittent explosive combustion, the presence of a sinusoidal pressure variation of the working medium, and the facility to completely balance the mass forces results in the Stirling engine being silent in operation and practically free from vibration.

In order to calculate the performance of Stirling total energy systems, "typical" Stirling engine performance characteristics had to be established. The approach chosen was to utilize the data from an actual Stirling engine--the Philips 4-215 engine developed for automotive application⁽⁴⁾.

Figure 2-1 is a performance map of the engine--showing torque, power output, and efficiency as a function of speed and charge pressure. The power and efficiency are net, i.e., all automotive auxiliary loads have been subtracted. The performance data for this engine was examined and replotted to represent operation in a stationary electrical generation mode, i.e., efficiency at constant speed vs. part load. First, the data was extracted from the performance map at 1750 rpm, where the peak power output is 74 kW. Figure 2-2 shows the interim data. Next, the automotive auxiliary loads (power steering pump, alternator, etc.) were subtracted, the efficiencies recalculated, and the output expressed as a percentage of rated load. This is shown in Figure 2-3. At 80°C, this results in a net efficiency at full load of 33.6%.

Figure 2-4 shows the Stirling engine characteristics used in the study. Shaft efficiency is shown as a function of heat rejection temperature and percent of rated load. The shaft load is the net load imposed by the generator, since all combustion, lubrication, and internal cooling auxiliary loads have been included in these efficiencies. The fraction of input fuel energy not recoverable (as work or heat) by the system (defined as the "inefficiency") includes the heat leaving in the exhaust after passing through the air preheater, certain auxiliary equipment loads, and radiation from the engine structure. The schematic representation shown in Figure 2-5 shows an energy balance for the engine and the definitions of the key performance parameters.

The 4-215 engine, as an automotive power plant, is one wherein the engine design was not optimized for maximum efficiency. Rather, specific-power and maximum power requirements had to be

met as well. Further, the efficiency of larger engines (where the proportion of thermal and mechanical losses are a small fraction of the heat input and power production) will tend to be higher than that of small engines. It is with these points well understood that one can say, without reservations, that higher efficiencies than those represented in Figure 2-3 would be possible for a large engine optimized for efficiency at the same technology level as the 4-215. However, for the purposes of the Stirling TES study, it was decided to conservatively use this 4-215 data as it existed, not as it would exist with reoptimization. This position was adopted to prevent lengthly "discussion" of this point and lend credibility to the conclusions to be drawn at the end of Task II. Also, in heat recovery applications, the overall energy utilization is found to be a more important indication of performance to the user than shaft efficiency.

Figure 2-1: Performance diagram-Philips 4-215 engine.

Figure 2-2: Efficiency* of Philips 4-215 Stirling engine vs. net shaft output.

Figure 2-3: Efficiency* of Philips 4-215 Stirling engine modified for application to TES.

Figure 2-4: Efficiency and effective burner/pre-heater/auxiliary load inefficiency of Stirling total energy system prime mover vs. shaft load.

$$\text{Engine Efficiency} = \frac{W_s \times 100}{\dot{Q}_F}$$

$$\text{Heat Recovery Factor} = \frac{\dot{Q}_R}{W_s}$$

$$\text{Burner/Preheater/Auxiliary-Load Inefficiency} = \frac{(\dot{Q}_{EX} + W_{AUX}) \times 100}{\dot{Q}_F}$$

Figure 2-5: Schematic diagram of Stirling burner/preheater-engine system.

2.2 Study-Site Data

Three sites were selected for study as potential candidates for Stirling total energy systems: a high density residential/commercial community (an actual site in Jersey City, New Jersey), an office building (proposed federal office building in Anchorage, Alaska), and a hospital (proposed military hospital in Fairfield, California). For all of these sites, ERDA supplied hourly ambient air temperature and net demand profiles (for heating, cooling, and electricity) for different seasons of the year. From the data, typical daily demand profiles and seasonal maxima were established. Appendix A contains a complete tabulation of this site data.

Table 2-1 is a summary of the pertinent demand data from each site. The peak demand for the typical day, the integrated demand for that day, the average temperature, and the design electric, heating, and cooling demands (used to size the conventional system concepts) are given in the table. The sites vary considerably in design demands. The residential site has a design electric demand of less than 1 MW, the office building 2.5 MW, and the hospital 7.8 MW.

The premise of this study was that an evaluation of the performance of the Stirling total energy system concepts for these three distinct sites would yield sufficient data upon which general conclusions could be drawn. In order to broaden the applicability of these conclusions, and get the most out of the limited-site characterization data, the data for each site was "massaged" to ~~permit it to~~ represent the same site in different climates. The number of degree days represented by each typical seasonal day at each site was computed. Then, the number of spring, summer, fall, and winter days needed to represent a typical year in a "cold", "moderate", or "warm" climate were determined. "Cold", "moderate", and "warm" climates were defined as ones having heating seasons of 6000 - 7000, 4000 - 5000, and 2000 - 3000 degree days, respectively. In "cold"

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climates, more winter and fall days were chosen, while in "warm" climates, more summer and spring days were used. Table 2-2 shows exactly how these annual energy requirements were determined for each site. The basic data for the Anchorage office building was so inherently representative of a cold climate that it could not be manipulated in any defensible way to represent data for a warm climate.

Table 2-1.

SITE DATA SUMMARIES

<u>SITE</u>	<u>ELECTRICITY</u>		<u>HEATING</u>		<u>COOLING</u>		<u>MEAN TEMP. °C (°F)</u>
	PEAK DEMAND, kW	INTEGRATED DEMAND, kW-h	PEAK DEMAND, kW	INTEGRATED DEMAND, kW-h	PEAK DEMAND, kW	INTEGRATED DEMAND, kW-h	
<u>1. HOSPITAL:</u>							
JANUARY DAY	5,570	81,800	16,100	169,000	1,030	6,120	6. (44.)
APRIL DAY	5,630	87,000	14,700	129,000	1,170	8,980	14. (57.)
JULY DAY	7,770	112,000	9,820	89,500	8,060	89,100	23. (73.)
OCTOBER DAY	6,590	95,800	11,400	92,700	4,830	35,600	18. (65.)
DESIGN DEMANDS:	7,770		17,900		8,410		
<u>2. OFFICE BUILDING:</u>							
FEBRUARY DAY	2,390	30,100	1,990	20,300	—	—	-6. (21.)
JULY DAY	2,490	30,200	690	3,110	997	6,690	13. (56.)
DESIGN DEMANDS:	2,535		3,340		2,050		
<u>3. RESIDENTIAL / COMMERCIAL COMPLEX:</u>							
JANUARY DAY	915	16,600	3,180	65,000	—	—	-6. (22.)
APRIL DAY	780	14,600	2,025	39,800	—	—	7. (44.)
AUGUST DAY	620	11,500	565	10,500	360	6,880	24. (75.)
NOVEMBER DAY	805	13,100	2,120	40,500	—	—	12. (54.)
DESIGN DEMANDS:	960		3,220		474		

Table 2-2.

TRANSFORMATION OF SITE DATA TO REPRESENT DIFFERING CLIMATES

<u>SITE</u>	<u>COLD (6000-7000DD)</u>	<u>MODERATE (4000-5000DD)</u>	<u>WARM (2000-3000DD)</u>
<u>1. HOSPITAL:</u>			
JANUARY DAYS	300.	200.	90.
APRIL DAYS	0.	60.	95.
JULY DAYS	50.	70.	100.
OCTOBER DAYS	15.	35.	80.
<u>2. OFFICE BUILDING:</u>			
FEBRUARY DAYS	100.	40.	—
JULY DAYS	265.	325.	—
<u>3. RESIDENTIAL/COMMERCIAL COMPLEX)</u>			
JANUARY DAYS	95.	40.	5.
APRIL DAYS	90.	105.	90.
AUGUST DAYS	90.	115.	180.
NOVEMBER DAYS	90.	105.	90.

2.3 Technical Approach to Systems Conceptualization

The technical approach employed for the Task I conceptualization study was as follows:

(a) Two firm ground rules were established by mutual agreement with ERDA:

- No selective energy systems would be considered.
- Only system components utilizing commercially available technology would be considered (with the exception of the Stirling prime mover).

In order to assure that accepted industry practices were applied to the design of the systems, a decision was made to utilize the services of a consulting engineering firm, recognized in the field of heating, ventilation, air conditioning, and total energy systems, in the conceptual design stage of the study. The firm of Syska & Hennessy was placed under subcontract to Philips Laboratories for this purpose. The efforts at the subcontractor's facility were under the direction of a principal of the firm, C. Stephens, Vice President for Mechanical Engineering.

(b) The three sites described in Par. 2.2 were the ones subjected to study. Electrical and thermal demand profiles, representing four typical seasonal days, were provided for the residential and hospital sites. Demand data representing two typical seasonal days were provided for the office building site. This data is contained in Appendix A.

(c) The electrical and thermal demand profiles for the sites were analyzed to establish the needs for:

- heating
- cooling
- electricity
- excess heat rejection
- supplementary heating
- supplementary cooling
- thermal storage

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(d) Central plant total energy system designs using the Stirling engine as a prime mover were conceptualized, satisfying the needs identified in (c) above.

(e) Central plant equipment was established, major auxiliaries were sized, and central plant electrical power and heating requirements were estimated for each of the conceptual site operating systems.

(f) The central plant electric and heating requirements were incorporated with the site requirements as a first iteration of the calculations, establishing new, combined demand profiles. The conceptual designs were then re-evaluated, specifically in the areas of supplementary heating and thermal storage needs.

(g) Conventional systems (using purchased electric power) were established for each site as a baseline for the comparative analyses to be performed as Task II.

(h) The required level of component redundancy was defined for each site. This information was needed for later computations of capital cost.

The number of units installed in a system to ensure continuous operation during periods of maintenance or breakdown is a function of the degree of reliability required for each specific site application. This degree of reliability is commonly referred to as firm capacity plus first or second contingency. Under a first contingency plan, a standby unit is provided equal in size to the largest unit installed. Under a second contingency plan, two standby units are provided equal in size to the largest unit.

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For the sites in this conceptual design, the following contingencies were assumed:

	<u>Contingency</u>		
	Electricity	Heating	Cooling
Residential Complex Jersey City, New Jersey	1	1	0
Office Building Anchorage, Alaska	1	1	0
Hospital Fairfield, California	2	1	1

2.4 System Concepts

Appendices B through E present the systems data developed in Task I. The results of Task I are summarized in this section.

Appendix B describes the subsystem components used as building blocks in the systems conceptualized in this study, and defines the symbols which represent these components in the system diagrams. The Appendix also contains descriptions of the typical subsystems used in the system block diagrams. Explanations of how the subsystems operate (automatically, for the most part) are also given.

Appendices C, D and E contain detailed descriptions, system diagrams, and information on component numbers and sizes for all the systems conceptualized for the residential/commercial, office building, and hospital sites, respectively.

In conceptualizing systems for detailed study later in the program, many combinations of basic equipment were considered. Either absorption or mechanical refrigeration units were utilized, systems with and without heat and cooling storage were considered, and both fuel-fired and electrically-powered supplementary boilers were used. In all, a total of more than twenty systems were conceptualized for the three sites.

In these conceptual designs, two Stirling engine heat recovery temperatures were considered. A "high" heat recovery temperature of 120°C was assumed when needed to supply heat to absorption refrigeration machinery. (At present, manufacturers are researching and developing low-temperature absorption units, requiring hot water at temperatures lower than 100°C. As these units become commercially available, they will have a direct and favorable impact on the operating conditions of the Stirling engine). During operation, when absorption cooling is not required, or mechanical refrigeration machinery is used instead, a "low" heat recovery temperature of 80°C was assumed to permit effective distribution to heat within the site.

Heat pumps were not considered in the conceptual design of central plant systems due to their low heat-recovery temperature levels (40 - 50°C). This temperature was considered too low for economical site distribution systems considering the specific sites under study.

Various criteria were applied to this selection process, to whittle down the original concepts to a manageable number for study in Task II. Some were obvious for technical reasons, other depended more on judgement. For example, all the residential options utilizing thermal storage were discarded when it became obvious that supplementary heat was either always required or never required on any given day. Those concepts which depended up a "small" Stirling engine dedicated to driving a refrigeration machine, with other "large" Stirling engines serving to drive generators, were discarded. It was felt that since these Stirling prime movers are not yet commercially available, any conceptual system should only contain identically sized units, and not presume that a full range of sizes would be available. Also, those concepts in which a refrigeration unit was directly driven from the output shaft of a Stirling engine which in turn was driving a generator were discarded in favor of only motor-driven refrigeration units. This decision too was judgemental. It was felt that systems

utilizing only motor-driven refrigeration units would be far more flexible and acceptable to users, since the numbers of refrigeration units and Stirling engines in any system could be optimized independantly, as could the choice of their locations within the central plants.

Table 2-3 summarizes the systems concepts which survived the conceptualization phase to be studied further in Task II. In addition, the table defines the conventional power systems which were assumed would exist at each site in the absence of a total energy system. These systems were identified by the Task I subcontractor, considering the various energy costs, energy availabilities, and relative initial costs which exist in the regions in which the actual sites are located.

Figure 2-6 is a systems schematic illustrating a typical system concept (refer to Appendix B for symbol definitions). In such an installation, the Stirling engine (SE) and absorption refrigeration unit (AU) are representative of banks of several equally sized units. Typically for such a system, the operating engineer would bring equipment on line and shut it down manually, in accordance with profiles established from operating experience for the site. When the site demand reaches the range of 80-85% of equipment capacity and is on the increase, the next unit would be brought on line. In the case of the Stirling engine, the operator would press a "start" button to initiate an automatic sequence of events which would bring the engine/generator to operating temperature and speed, awaiting connections to the power bus. This latter step would be done manually. After initial activation of equipment, automatic control devices would regulate equipment outputs to meet the site demands.

Table 2-3: Stirling - TES Options Studied.

<u>SITE</u>	<u>OPTION #</u>	<u>DESCRIPTION</u>
RESIDENTIAL (JERSEY CITY)	1A	ABSORPTION REFRIGERATION, FUEL-FIRED SUPPLEMENTARY HEATING
	1A-I	ABSORPTION REFRIGERATION, ELECTRIC SUPPLEMENTARY HEATING
	3A	MOTOR-DRIVEN MECHANICAL REFRIGERATION, FUEL-FIRED SUPPLEMENTARY HEATING
	3A-I	MOTOR-DRIVEN MECHANICAL REFRIGERATION, ELECTRIC SUPPLEMENTARY HEATING
	CONVENTIONAL	PURCHASED ELECTRICITY, ABSORPTION REFRIGERATION, FUEL-FIRED HEATING
OFFICE BUILDING (ANCHORAGE)	4	ABSORPTION REFRIGERATION, HEAT STORAGE
	4A	ABSORPTION REFRIGERATION, ELECTRICAL SUPPLEMENTARY HEATING
	6	MOTOR-DRIVEN MECHANICAL REFRIGERATION, HEAT STORAGE
	6A	MOTOR-DRIVEN MECHANICAL REFRIGERATION, ELECTRIC SUPPLEMENTARY HEATING
	CONVENTIONAL	PURCHASED ELECTRICITY, MOTOR-DRIVEN MECHANICAL REFRIGERATION, FUEL-FIRED HEATING
HOSPITAL (FAIRFIELD)	7	ABSORPTION REFRIGERATION, HEAT STORAGE
	7A	ABSORPTION REFRIGERATION, FUEL-FIRED SUPPLEMENTARY HEATING
	11	MOTOR-DRIVEN MECHANICAL REFRIGERATION, HEAT STORAGE, COOLING STORAGE, ELECTRIC SUPPLEMENTARY HEAT
	CONVENTIONAL	PURCHASED ELECTRICITY, MOTOR-DRIVEN MECHANICAL REFRIGERATION, FUEL-FIRED HEATING

Figure 2-6: Site Fairfield option No. 7.

3. TASK II - EVALUATION OF BASIC DESIGN

3.1 Technical Approach

The purpose of Task II was to determine the "best" system design for each site and the best site for a Stirling TES system, considering overall thermal efficiency, investment potential, and fuel conservation potential. Thermal performance calculations were performed for each Stirling TES to determine the fuel-savings potential for each site system when compared to its conventional power system. Comparative cost analyses were performed to determine whether, and under what conditions, investment in a Stirling TES would be attractive. Also, these cost and performance analyses were combined to identify the investment cost required to realize a unit level of fuel consumption.

The approach taken to accomplish the above objectives was as follows:

- Part-load performance characteristics were defined for all major system components.
- Detailed performance calculations were performed for each site concept, utilizing the hourly site demands as a starting point. The applicable operating-system component demands (hot water pumps, fans, chilled water pumps, etc.) were added to site demands whenever that component was operating. Additionally, electrical and thermal demand of the central power plant area itself were estimated and added as a burden to the basic site demands.
- Daily and yearly fuel-energy requirements for each candidate Stirling TES concept and conventional system were determined (for each site).
- Capital costs and annual operating costs for every candidate Stirling TES system concept and conventional system were calculated.
- After the fuel-energy requirements, capital costs, and annual operating costs were determined for each Stirling TES and conventional system for each site, three indices of investment attractiveness were computed.

The results of each step in the approach to Task II, as well as the conclusions from these activities, are present in the following subsections.

3.2 Part-Load Performance Characteristics of Stirling TES Components

The part-load performance characteristics of the key Stirling TES components were defined and considered in deciding how to proceed with the system performance calculations. With the exception of the Stirling prime mover, these characteristics were defined with the expert assistance of the Task I subcontractor. Ultimately, constant conversion efficiencies were adapted for all components with the exception of the Stirling prime mover and mechanical and absorption refrigeration units.

The efficiency of the Stirling TES engine and its effective burner/preheater/auxiliary-load inefficiency were previously defined and presented in Figure 3-1 as a function of part-load and heat recovery temperature. From the data in Figure 3-1, another useful parameter, the heat recovery factor, can be derived. The heat recovery factor is defined as the number of kW-hrs of heat energy recovered for every kW-hr of delivered mechanical energy. This parameter is shown in Figure 3-1 as a function of heat recovery temperature and part load. It is interesting to note that while the efficiency of the Stirling prime mover is lower at a heat recovery temperature of 120°C rather than 80°C, the heat recovery factor is higher. Indeed, the sum of delivered mechanical energy and heat recovery are equal in both cases. Thus, when all the recovered heat can be utilized (as when supplementary heat is always required), engine efficiency is not of paramount importance, since the same fraction of the input fuel energy will be utilized in both cases. However, when the recovered heat cannot be utilized in full, a higher prime-mover efficiency minimizes the fraction of fuel energy which must be thrown away.

Figure 3-1: Heat recovery factor* for TES Stirling prime mover vs. heat recovery temperature and shaft load.

Figure 3-2 shows the part-load performance curve of a typical absorption refrigeration machine. At 100% load, the coefficient of performance (COP) was taken to be 0.6. (A COP of 0.6 means 1 kW of input heat produces 0.6 kW of cooling). On "hot" site days, the upper curve was utilized; the lower curve was used when the ambient temperatures were lower.

Figure 3-3 is the part-load performance curve of a typical mechanical refrigeration machine. At full load, the COP was assumed to be 2.6 for electric motor-driven machines and 2.9 for mechanically driven units.

Figure 3-4, shows the range of performance of typical oil-fired boilers as a function of part-load. Generally, efficiencies increase with unit size and sophistication (cost). For the purpose of the detailed calculations to be performed in Task II, a constant efficiency of 80% was assumed.

Electrical generator efficiencies typically vary from 85 to greater than 95%. A constant generator efficiency of 90% was assumed.

The conversion efficiency of an electric boiler used as a supplementary heater was taken to be 100%.

In order to convert the site energy demands to fuel energy requirements for conventional systems, the conversion efficiency of a typical utility power plant had to be defined. For this purpose, and after much investigation, it was decided to use 30% as the ratio of delivered electrical energy to fuel energy consumed at the plant.

Figure 3-2: Typical part load curve of an absorption refrigeration machine.

Figure 3-3: Typical part load curve of a centrifugal refrigeration machine.

Figure 3-4: Typical part load curve of an oil-fired boiler.

3.3 Performance Analysis of System Concepts

The detailed thermal performance was computed for each site concept utilizing the hourly site demands, operating system component demands, central plant demands, and part-load performance characteristics of the system components. By this method, daily fuel-energy requirements for each total energy and conventional system concept were determined for each site. By utilizing the definitions of "cold", "moderate", and "warm" climates for each site, given in Table 2-2 of Par. 2.2, the yearly fuel-energy requirements were defined for each system concept as well.

Appendix F contains the detailed calculation sheets in which the hourly demands were converted into fuel-energy requirements for every typical day of every system concept for every site. In all, fourteen system concepts were analyzed (eleven Stirling total energy systems and three conventional systems). The data in Appendix F is grouped by site and system concept.

Tables 3-1, 3-2, and 3-3 summarize the daily and annual fuel-energy requirements for all system concepts developed for the residential/commercial, office building, and hospital sites, respectively. The first four rows (two rows for the office building site) show the fuel energy consumption in each typical seasonal day, while the last three rows (two rows for the office building site) show the total annual fuel energy for sites in cold, moderate, and warm climates. While the total energy systems require fuel energy only, conventional systems require purchased electricity and fuel. To determine a "fuel equivalent" figure for the conventional system, the electric energy requirements were divided by the utility-plant thermal efficiency of 0.3 to determine the fuel required at the utility plant. This figure was then added to the on-site fuel requirement.

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As can be seen in Table 3-1, the total energy options for the residential site in all climates offer significant potential for fuel-energy savings (29 to 33% of the conventional system requirements). As is obvious in Table 3-3, results similar to the residential site were found for the hospital site (25 to 34% energy savings).

However, the office building, with its high electrical energy requirements and relatively low thermal demands, proved to be a very poor candidate for the total energy system. At best, only 5% of the conventional system fuel energy requirements could be saved. Since this site thus represented nearly one order of magnitude lower energy conservation potential than the residential and hospital sites, it was eliminated from further study at this point.

Table 3-1.

RESIDENTIAL / COMMERCIAL COMPLEX (JERSEY CITY)
DAILY AND ANNUAL FUEL-ENERGY REQUIREMENTS FOR EACH OPTION

<u>DAY</u>	<u>CONVENTIONAL</u>	<u>1A</u>	<u>1A-1</u>	<u>3A</u>	<u>3A-1</u>
JANUARY	17,100 KWH ELEC. 103,000 KWH FUEL (160,000 KWH FUEL EQUIV.)	101,000 KWH FUEL	99,500 KWH FUEL	101,000 KWH FUEL	99,500 KWH FUEL
APRIL	15,100 KWH ELEC. 49,800 KWH FUEL (100,000 KWH FUEL EQUIV.)	66,300 KWH FUEL	66,500 KWH FUEL	66,300 KWH FUEL	66,500 KWH FUEL
AUGUST	13,000 KWH ELEC. 24,700 KWH FUEL (68,000 KWH FUEL EQUIV.)	49,100 KWH FUEL	49,100 KWH FUEL	51,000 KWH FUEL	51,000 KWH FUEL
NOVEMBER	14,000 KWH ELEC. 50,600 KWH FUEL (97,300 KWH FUEL EQUIV.)	68,500 KWH FUEL	68,300 KWH FUEL	68,500 KWH FUEL	68,300 KWH FUEL
COLD CLIMATE	5.41X10 ⁶ KWH ELEC. 21.0X10 ⁶ KWH FUEL (39.0 X10 ⁶ KWH FUEL EQUIV)	26.1X10 ⁶ KWH FUEL	26.0X10 ⁶ KWH FUEL	26.3X10 ⁶ KWH FUEL	26.2X10 ⁶ KWH FUEL
MODERATE CLIMATE	5.23X10 ⁶ KWH ELEC. 17.5X10 ⁶ KWH FUEL (34.9X10 ⁶ KWH FUEL EQUIV)	23.8X10 ⁶ KWH FUEL	23.8X10 ⁶ KWH FUEL	24.0X10 ⁶ KWH FUEL	24.0X10 ⁶ KWH FUEL
WARM CLIMATE	5.04X10 ⁶ KWH ELEC. 14.0X10 ⁶ KWH FUEL (30.8X10 ⁶ KWH FUEL EQUIV.)	21.5X10 ⁶ KWH FUEL	21.5X10 ⁶ KWH FUEL	21.8X10 ⁶ KWH FUEL	21.8X10 ⁶ KWH FUEL

Table 3-2.

OFFICE BUILDING (ANCHORAGE)
DAILY AND ANNUAL FUEL-ENERGY REQUIREMENTS FOR EACH OPTION

<u>DAY</u>	<u>CONVENTIONAL</u>	<u>4</u>	<u>4A</u>	<u>6</u>	<u>6A</u>
FEBRUARY	30,500 KWH ELEC. 28,300 KWH FUEL (130,000 KWH FUEL EQUIV.)	105,000 KWH FUEL	106,000 KWH FUEL	105,000 KWH FUEL	106,000 KWH FUEL
JULY	33,900 KWH ELEC. 3,880 KWH FUEL (117,000 KWH FUEL EQUIV.)	122,000 KWH FUEL	122,000 KWH FUEL	117,000 KWH FUEL	117,000 KWH FUEL
COLD CLIMATE	12.0x10 ⁶ KWH ELEC 3.86x10 ⁶ KWH FUEL (43.9x10 ⁶ KWH FUEL EQUIV.)	42.8x10 ⁶ KWH FUEL	42.9x10 ⁶ KWH FUEL	41.5x10 ⁶ KWH FUEL	41.6x10 ⁶ KWH FUEL
MODERATE CLIMATE	12.2x10 ⁶ KWH ELEC. 2.39x10 ⁶ KWH FUEL (43.1x10 ⁶ KWH FUEL EQUIV.)	43.9x10 ⁶ KWH FUEL	43.9x10 ⁶ KWH FUEL	42.2x10 ⁶ KWH FUEL	42.3x10 ⁶ KWH FUEL

Table 3-3.

HOSPITAL (FAIRFIELD)				
DAILY AND ANNUAL FUEL-ENERGY REQUIREMENTS FOR EACH OPTION				
DAY	CONVENTIONAL	7	7A	II
JANUARY	86,800kWH ELEC. 211,000kWH FUEL (500,000kWH FUEL EQUIV.)	317,000kWH FUEL	341,000 kWH FUEL	309,000kWH FUEL
APRIL	94,900kWH ELEC. 161,000kWH FUEL (477,000kWH FUEL EQUIV.)	343,000kWH FUEL	362,000 kWH FUEL	310,000kWH FUEL
JULY	150,000kWH ELEC. 112,000kWH FUEL (612,000kWH FUEL EQUIV.)	456,000kWH FUEL	471,000kWH FUEL	517,000kWH FUEL
OCTOBER	112,000kWH ELEC. 116,000kWH FUEL (489,000kWH FUEL EQUIV.)	383,000kWH FUEL	383,000 kWH FUEL	383,000kWH FUEL
COLD CLIMATE	35.2x10 ⁶ kWH ELEC. 706x10 ⁶ kWH ELEC. (188x10 ⁶ kWH FUEL EQUIV.)	124x10 ⁶ kWH FUEL	132 x10 ⁶ kWH FUEL	124 x10 ⁶ kWH FUEL
MODERATE CLIMATE	37.5x10 ⁶ kWH ELEC. 638x10 ⁶ kWH FUEL (189x10 ⁶ kWH FUEL EQUIV.)	129x10 ⁶ kWH FUEL	136 x10 ⁶ kWH FUEL	130 x10 ⁶ kWH FUEL
WARM CLIMATE	40.8x10 ⁶ kWH ELEC. 54.8x10 ⁶ kWH FUEL (191x10 ⁶ kWH FUEL EQUIV.)	137 x10 ⁶ kWH FUEL	143 x10 ⁶ kWH FUEL	140 x10 ⁶ kWH FUEL

3.4 Comparative Cost Analysis Methodology

Next, the capital and annual operating costs for every system concept (both total energy and conventional) of the surviving two sites were calculated.

To compute the capital costs of the system, typical current component costs were determined on the basis of dollar per unit capacity with the help of the Task I consultant. Table 3-4 shows these unit costs. The cost of the TES Stirling engine was estimated to be twice that of the diesel engine. Note that the installed cost of a complete engine/generator plant is many times the cost of the engine alone. If the assumed cost of the Stirling engine can be realized, the installed cost of the quiet, clean-burning Stirling engine/generator plant might therefore prove to be only 10% higher than that of a complete diesel engine/generator plant with noise and vibration attenuation.

Table 3-4. Typical unit capital costs for comparative cost analysis.

<u>UNIT</u>	<u>COST (1976/1977 \$)</u>
1. FUEL-FIRED BOILER	\$ 70/ BOILER HP*
2. COMPLETE BOILER PLANT, INSTALLED, INCL. BOILER, ETC.	\$ 300/ BOILER HP
3. ABSORPTION OR MECHANICAL REFRIGERATION UNIT	\$ 125/ TON**
4. COMPLETE REFRIGERATION SYSTEM, INSTALLED WITHIN PLANT, INCL. UNIT, ETC.	\$ 500/ TON
5. ELECTRIC MOTORS	\$ 70/ kW
6. STIRLING ENGINE	\$ 100/ kW
7. GENERATOR	\$ 50/ kW
8. COMPLETE INSTALLED STIRLING ENGINE-GENERATOR PLANT, INCL. UNITS, BUILDING, ETC.	\$ 275/ kW
9. STORAGE TANKS, INSTALLED	\$ 1/ GALLON
10. HEAT REJECTORS, INSTALLED	\$ 10/ kW
11. ELECTRIC BOILER, INSTALLED	\$ 20/ kW
12. DIESEL ENGINE	\$ 50/ kW
13. HOUSING TO ATTENUATE DIESEL ENGINE	\$ 25/ kW
14. COMPLETE INSTALLED DIESEL-GENERATOR PLANT	\$ 225/ kW

*9.9KW

**3.5KW

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To establish the annual operating cost of each system, estimates of labor, maintenance, repair, property taxes, insurance, and fuel cost had to be made. Table 3-5 itemizes the unit costs assigned to each of these items. The base for these unit costs is fiscal year 1977.

Labor, maintenance, and repair were estimated as a fixed percentage of the capital cost of the system. It was conservatively decided not credit the Stirling prime mover with lower maintenance cost than currently available prime movers, although this would most likely prove to be the case. These costs for large total energy plants ($> \$2$ million) were estimated at 5% of the capital costs and 10% for small ($< \$1$ million) ones; for large conventional plants, 3%, and for small ones, 6%.

Insurance and property taxes were estimated at 2% of the capital cost, using rough national averages. The actual rates vary substantially with geographical location.

A fuel oil cost of 35 cents per gallon (41 kW-h per gallon heating value) was assumed to be typical for FY-1977. A range of purchased electrical energy costs was used (2 to 8 cents per kW-h) in the detailed calculations to determine the sensitivity of the cost analysis to this parameter.

After the capital costs and annual operating cost of each alternative were calculated, three indices of investment attractiveness were computed: the standard rate of return on investment, the incremental rate of return on investment, and the incremental dollar investment needed to conserve one gallon of oil per year for each year that the total energy system remains in operation.

The standard rate of return on investment is computed from the useful life of the total energy system, the savings in annual operating costs resulting from the decision to install a total energy system rather than a conventional system, and the total capital cost of the total energy system, as shown in Equation (1).

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Table 3-5: Task II. Typical annual unit operating costs for comparative cost analyses.

ITEM

1. OPERATION, MAINTENANCE, REPAIRS:

a) BOILER OR REFRIG.	4% OF CAPITAL COST (IF < \$1M)
PLANT ALONE	2% " " " (IF > \$2M)
b) BOILER AND REFRIG.	6% OF CAPITAL COST (IF < \$1M)
	3% (IF > \$2M)
c) TES PLANT	10% OF CAPITAL COST (IF < \$1M)
	5% " " " (IF > \$2M)

2. PROPERTY TAXES + INSURANCE: 2% OF CAPITAL COST

3. FUEL:

BASELINE: OIL	\$.35 / GAL (140,000 BTU / GAL)
COAL	\$ 27 / TON (12,000 BTU / LB.)
GAS	\$.23 / CCF (1,000 BTU / CF)
ELECTRICITY	a) \$.08 / kW-h
	b) \$.04 / kW-h
	c) \$.02 / kW-h

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$$\frac{i}{1 - (1 + i)^{-n}} = \frac{\Delta A}{P} , \quad (1)$$

where, i = rate of return on investment
 n = useful life of TES
 A = annual operating cost (conventional-TES)
 P = TES capital cost

The various subsystems in a typical system exhibit different useful lives. For the purposes of the computations in this study, an average life of 25 years was assumed. However, the results would have remained essentially unchanged had 20 or even 15 years been assumed instead.

This is so since Equation (1) above simplifies to,

$$i \approx \frac{\Delta A}{P} , \quad (2)$$

when n is greater than 20 years, or when n is 15 years and $\Delta A/P > 0.2$.

The "rate-of-return" index of investment is most often used in comparative cost analysis; however, it changes the total capital cost of the total energy system against the annual operating cost savings of the total energy system versus a conventional system. This presumes that the investor is free to install a total energy system and realize a certain operating cost savings, or to decide to install nothing (total TES capital costs or nothing).

A more meaningful index in this analysis is the incremental rate-of-return on investment. The difference can be illustrated with Equation (3),

$$\frac{i}{1 - (1 + i)^{-n}} = \frac{\Delta A}{\Delta P} , \quad (3)$$

where, i , n , ΔA are as previously defined, and ΔP = capital cost (TES - conventional).

The use of this index implies that the investor has committed himself to proceed with his site, (hospital, residential complex, etc.) and is only free to choose between a conventional plant or a total energy plant (not "nothing"). Thus, since he must invest at least the cost of the conventional plant, only the difference in investment between the TES plant and the conventional plant (i.e., the discretionary amount) is charged against the annual operating cost savings.

For the benefit of the reader, both rates of return have been computed.

The third index was defined to show the present incremental capital investment which would result in a fuel energy savings equivalent to one gallon of oil for each year that the TES remains in operation. This index is independent of the present cost of fuel energy, and allows the reader to evaluate whether this method of conserving fuel is cost-effective in terms of today's dollar. The index is calculated by first determining the difference between the capital investment required for a site's TES system and its conventional system, and dividing the difference by the computed annual energy savings from operation of the total energy system instead of the conventional one. This annual energy savings is expressed in terms of gallons of oil per year.

An examination of these three indices led to the identification of the "best" Stirling total energy system for each site. As expected, in all cases, the best system ranked highest in all three indices. Next, the annual operating costs and investment indices were recalculated for the "best" systems to determine the sensitivity of these indices to future energy costs. Three scenarios were assumed: a) the "base line" in which the capital costs and fuel and electricity costs were calculated from current values, b) a time in the future when the ratio of the cost of fuel and electricity divided by the capital costs will have increased 50% over the base line case, and c) a time when this same ratio has increased 100% over the base line case.

3.5 Cost Analysis Results

Table 3-6 shows the capital cost of the conventional and total energy systems considered for the residential site.

Table 3-7 presents the annual operating costs for each residential site option in "cold", "moderate", and "warm" climates in present (baseline) dollars.

Table 3-8 shows the computed rate-of-return on investment (i_1) and incremental rate-of-return on investment (i_2) for each residential site option in all three climates as a function of the cost of a kW-h of electrical energy. The analysis is based on present (baseline) dollars.

Table 3-9 presents the incremental investment needed to realize a unit conservation level for each residential site option in each climate.

Examination of Tables 3-8 and 3-9 reveals total energy system option 1A (absorption refrigeration) to rank highest in all three indices.

Table 3-10 shows the sensitivity of the rate of return and incremental rate of return indices to energy cost scenarios 50% and 100% higher than the present (baseline) case for residential site option 1A.

Tables 3-11 through 3-15 present the same information for the hospital site. Tables 3-13 and 3-14 show that total energy system Option 7 (absorption cooling with thermal storage) ranks highest in all three indices.

Table 3-6

RESIDENTIAL SITE
STIRLING TES EQUIPMENT SIZES AND CAPITAL COSTS

TASK 2

ITEM	CONVENTIONAL	1A	1A-1	3A	3A-1
SITE ELECTRIC DEMAND	960kW	_____	_____	_____	_____
ENGINE/GENERATOR PLANT	_____	3*-500kW (\$412,500)	4*-500kW (\$550,000)	3*-500kW (\$412,500)	4*-500kW (\$550,000)
FUEL-FIRED BOILER PLANT	2*-330BHP UNITS (\$122,100)	2*-200BHP (\$74,000)	_____	2*-200BHP (\$74,000)	_____
ELECTRIC BOILER	_____	_____	2*-730kW (\$14,600)	_____	2*-730kW (\$14,600)
REFRIGERATOR PLANT	1-140 TON (\$70,000)	1-140 TON (\$70,000)	1-140 TON (\$70,000)	1-140 TON (\$70,000)	1-140 TON (\$70,000)
ELECTRIC MOTOR	_____	_____	_____	1-170kW (\$11,900)	1-170kW (\$11,900)
HEAT REJECTOR	_____	2*-700kW (\$14,000)	2*-700kW (\$14,000)	2*-1200kW (\$24,000)	2*-1200kW (\$24,000)
TOTAL CAPITAL \$	\$192,100	\$570,500	\$648,600	\$592,400	\$670,500
Δ CAPITAL \$	0	\$378,400	\$456,500	\$400,300	\$478,400

* = 1 CONTINGENCY UNIT

Table 3-7

RESIDENTIAL SITE
ANNUAL OPERATING COSTS (BASELINE)

TASK 2

ITEM	CONVENTION	1A	1A-1	3A	3A-1
CAPITAL COST	\$ 192,100	\$ 570,500	\$ 648,600	\$ 592,400	\$ 670,500
OPERATION MAINT., AND REPAIR	\$ 11,500	\$ 57,100	\$ 64,900	\$ 59,200	\$ 67,100
TAXES & INSURANCE	\$ 3,840	\$ 11,400	\$ 13,000	\$ 11,800	\$ 13,400
<u>COLD CLIMATE:</u>					
FUEL, OIL- GAL.	512,000	637,000	634,000	641,000	639,000
FUEL, COST	\$ 179,000	\$ 223,000	\$ 222,000	\$ 224,000	\$ 224,000
a) ELEC. @ 8¢/kWH	\$ 433,000				
b) ELEC. @ 4¢/kWH	\$ 217,000				
c) ELEC. @ 2¢/kWH	\$ 108,000				
<u>MODERATE CLIMATE:</u>					
FUEL, OIL- GAL.	427,000	580,000	580,000	585,000	585,000
FUEL, COST	\$ 149,000	\$ 203,000	\$ 203,000	\$ 205,000	\$ 205,000
a) ELEC. @ 8¢/kWH	\$ 418,000				
b) ELEC. @ 4¢/kWH	\$ 209,000				
c) ELEC. @ 2¢/kWH	\$ 105,000				
<u>WARM CLIMATE:</u>					
FUEL, OIL- GAL.	341,000	524,000	524,000	532,000	532,000
FUEL, COST	\$ 129,000	\$ 183,000	\$ 183,000	\$ 186,000	\$ 186,000
a) ELEC. @ 8¢/kWH	\$ 403,000				
b) ELEC. @ 4¢/kWH	\$ 202,000				
c) ELEC. @ 2¢/kWH	\$ 101,000				

Table 3-8

RESIDENTIAL SITE

RATE OF RETURN ON INVESTMENT (i_1)
AND INCREMENTAL RATE-OF-RETURN ON
INVESTMENT (i_2) FOR ALL OPTIONS

SCENARIO	CONVENTIONAL	1A i_1/i_2	1A-1 i_1/i_2	3A i_1/i_2	3A-1 i_1/i_2
<u>COLD CLIMATE</u>					
a) ELEC. = \$.08/kWH	_____	59/89%	52/72%	56/83%	48/67%
b) ELEC. = \$.04/kWH	_____	21/31%	18/24%	20/29%	16/22%
c) ELEC. = \$.02/kWH	_____	LOSS	LOSS	LOSS	LOSS
<u>MODERATE CLIMATE</u>					
a) ELEC. = \$.08/kWH	_____	54/82%	48/66%	52/76%	44/62%
b) ELEC. = \$.04/kWH	_____	18/27%	16/20%	16/24%	13/18%
c) ELEC. = \$.02/kWH	_____	LOSS	LOSS	LOSS	LOSS
<u>WARM CLIMATE</u>					
a) ELEC. = \$.08/kWH	_____	52/78%	46/63%	49/72%	42/59%
b) ELEC. = \$.04/kWH	_____	17/25%	15/19%	13/22%	11/17%
c) ELEC. = \$.02/kWH	_____	LOSS	LOSS	LOSS	LOSS

Table 3-9.

RESIDENTIAL SITE
ANNUAL FUEL SAVINGS (GPY)* AND INCREMENTAL CAPITAL
COST PER GPY SAVED

<u>SCENARIO</u>	<u>1A</u>	<u>1A-1</u>	<u>3A</u>	<u>3A-1</u>
<u>COLD CLIMATE</u>	314,000 \$1.21	317,000 \$1.44	310,000 \$1.29	312,000 \$1.53
<u>MODERATE CLIMATE</u>	271,000 \$1.40	271,000 \$1.68	266,000 \$1.50	266,000 \$1.80
<u>WARM CLIMATE</u>	227,000 \$1.67	227,000 \$2.01	219,000 \$1.83	219,000 \$2.18

* GALLONS OF OIL PER YEAR

Table 3-10

RESIDENTIAL SITE (STIRLING-TES OPTION 1A)
ANNUAL FUEL COSTS AND RATE-OF-RETURN ON INVESTMENT
VS. CLIMATE AND ENERGY - COST SCENARIOS

	BASELINE			50% HIGHER			100% HIGHER		
	CONVENTIONAL	1A	i ₁ /i ₂	CONVENTIONAL	1A	i ₁ /i ₂	CONVENTIONAL	1A	i ₁ /i ₂
<u>COLD CLIMATE</u>									
FUEL OIL :	\$179,000	\$223,000		\$259,000	\$335,000		\$358,000	\$446,000	
ELECT :									
a)	\$433,000 @ 8¢		59/89.	\$650,000 @ 12¢		93/140.	\$866,000 @ 16¢		127/192.
b)	\$217,000 @ 4¢		21/31.	\$326,000 @ 6¢		36/55.	\$434,000 @ 8¢		51/77.
c)	\$108,000 @ 2¢		LOSS	\$162,000 @ 3¢		6/10.	\$216,000 @ 4¢		13/20.
<u>MODERATE CLIMATE</u>									
FUEL OIL :	\$149,000	\$203,000		\$224,000	\$305,000		\$298,000	\$406,000	
ELECT :									
a)	\$418,000 @ 8¢		54/82.	\$627,000 @ 12¢		86/130.	\$836,000 @ 16¢		118/178.
b)	\$209,000 @ 4¢		18/27.	\$314,000 @ 6¢		31/48.	\$418,000 @ 8¢		45/68.
c)	\$105,000 @ 2¢		LOSS	\$158,000 @ 3¢		0/4.	\$210,000 @ 4¢		7/13.
<u>WARM CLIMATE</u>									
FUEL OIL :	\$129,000	\$183,000		\$194,000	\$275,000		\$258,000	\$366,000	
ELECT :									
a)	\$403,000 @ 8¢		52/78.	\$605,000 @ 12¢		82/124.	\$806,000 @ 16¢		113/170.
b)	\$202,000 @ 4¢		17/25.	\$303,000 @ 6¢		30/46.	\$404,000 @ 8¢		43/64.
c)	\$101,000 @ 2¢		LOSS	\$152,000 @ 3¢		0/1.	\$202,000 @ 4¢		5/10.

Table 3-11

HOSPITAL SITE
STIRLING TES EQUIPMENT SIZES AND CAPITAL COSTS

TASK 2

ITEM	CONVENTIONAL I	7	7A	II	CONVENTION. II
SITE ELECTRIC DEMAND	7,770kW	_____	_____	_____	7,770kW
ENGINE/GENERATOR PLANT	_____	** 11-1,000kW (\$3,025,000)	** 11-1000kW (\$3,025,000)	** 12-1000kW (\$3,300,000)	_____
FUEL-FIRED BOILER PLANT	2* - 1840 BHP (\$681,000)	_____	2* - 920 BHP (\$340,000)	_____	2* - 1840BHP (\$681,000)
ELECTRIC BOILER	_____	_____	_____	2,000 kW (\$40,000)	_____
REFRIGERATOR PLANT	4* - 800 TON UNITS (\$1,600,000)	4* - 800 TON (\$1,600,000)	4* - 800 TON (\$1,600,000)	3* - 550 TON (\$825,000)	3* - 550 TON (\$825,000)
ELECTRIC MOTOR	_____	_____	_____	3* - 190 kW (\$40,000)	_____
HEAT REJECTOR	_____	2* - 9,000 kW (\$180,000)	2* - 9,000 kW (\$180,000)	2* - 14,000 kW (\$280,000)	_____
HEAT STORAGE	_____	150,000 Gal. (\$150,000)	_____	300,000 Gal. (\$300,000)	_____
COLD STORAGE	_____	_____	_____	400,000 Gal. (\$400,000)	400,000 Gal. (\$400,000)
TOTAL CAPITAL \$	\$2,281,000	\$4,955,000	\$5,145,000	\$5,185,000	\$1,906,000
Δ CAPITAL \$	0	\$2,674,000	\$2,864,000	\$3,279,000	_____

* = 1 CONTINGENCY UNIT
** = 2 CONTINGENCY UNITS

Table 3-12

HOSPITAL SITE

TASK 2

ANNUAL OPERATING COSTS (BASELINE)

ITEM	CONVENT. I	7	7A	II	CONVENT. II
CAPITAL COST	\$2,281,000	\$4,955,000	\$5,145,000	\$5,185,400	\$1,906,000
OPERATION, MAINT., AND REPAIR	\$ 68,400	\$ 248,000	\$ 257,000	\$ 259,000	\$ 57,200
TAXES & INSURANCE	\$ 45,600	\$ 99,100	\$103,000	\$104,000	\$ 38,100
<u>COLD CLIMATE:</u>					
FUEL, OIL - GAL.	1.76×10^6	3.02×10^6	3.22×10^6	3.02×10^6	1.72×10^6
FUEL, COST	\$ 602,000	\$1,057,000	\$1,127,000	\$1,057,000	\$ 602,000
a) ELEC. @ 8¢/kWH	\$ 2,816,000				\$ 2,816,000
b) ELEC. @ 4¢/kWH	\$ 1,408,000				\$ 1,408,000
c) ELEC. @ 2¢/kWH	\$ 704,000				\$ 704,000
<u>MODERATE CLIMATE:</u>					
FUEL, OIL - GAL.	1.56×10^6	3.15×10^6	3.32×10^6	3.17×10^6	1.56×10^6
FUEL, COST	\$ 546,000	\$1,103,000	\$1,162,000	\$1,110,000	\$ 546,000
a) ELEC. @ 8¢/kWH	\$3,000,000				\$3,000,000
b) ELEC. @ 4¢/kWH	\$ 1,500,000				\$ 1,500,000
c) ELEC. @ 2¢/kWH	\$ 750,000				\$ 750,000
<u>WARM CLIMATE:</u>					
FUEL, OIL - GAL.	1.34×10^6	3.34×10^6	3.49×10^6	3.41×10^6	1.34×10^6
FUEL, COST	\$ 469,000	\$1,169,000	\$1,222,000	\$1,194,000	\$ 469,000
a) ELEC. @ 8¢/kWH	\$3,264,000				\$3,264,000
b) ELEC. @ 4¢/kWH	\$1,632,000				\$1,632,000
c) ELEC. @ 2¢/kWH	\$ 816,000				\$ 816,000

Table 3-13

TASK 2
HOSPITAL SITE

RATE OF RETURN ON INVESTMENT (i_1) AND
INCREMENTAL RATE-OF-RETURN ON INVEST. (i_2)

<u>SCENARIO</u>	<u>CONVENTIONAL</u>	<u>7</u> <u>i_1/i_2</u>	<u>7A</u> <u>i_1/i_2</u>	<u>II</u> <u>i_1/i_2</u>
<u>COLD CLIMATE</u>				
a) ELEC = \$.08 / KWH	—	43 / 80 %	40 / 71 %	40 / 64 %
b) ELEC = \$.04 / KWH	—	15 / 27 %	12 / 22 %	13 / 21 %
c) ELEC = \$.02 / KWH	—	% / LOSS	LOSS	LOSS
<u>MODERATE CLIMATE</u>				
a) ELEC = \$.08 / KWH	—	45 / 83 %	42 / 75 %	42 / 67 %
b) ELEC = \$.04 / KWH	—	14 / 27 %	12 / 22 %	12 / 21 %
c) ELEC = \$.02 / KWH	—	LOSS	LOSS	LOSS
<u>WARM CLIMATE</u>				
a) ELEC = \$.08 / KWH	—	47 / 87 %	44 / 79 %	44 / 70 %
b) ELEC = \$.04 / KWH	—	14 / 26 %	12 / 22 %	12 / 20 %
c) ELEC = \$.02 / KWH	—	LOSS	LOSS	LOSS

Table 3-14

HOSPITAL SITE

ANNUAL FUEL SAVINGS (GPY) AND
INCREMENTAL CAPITAL COST PER GPY SAVED

<u>SCENARIO</u>	<u>7</u>	<u>7A</u>	<u>II</u>
<u>COLD CLIMATE</u>	1.56×10^6 \$ 1.71	1.37×10^6 \$ 2.09	1.56×10^6 \$ 2.04
<u>MODERATE CLIMATE</u>	1.46×10^6 \$ 1.83	1.29×10^6 \$ 2.22	1.44×10^6 \$ 2.28
<u>WARM CLIMATE</u>	1.32×10^6 \$ 2.03	1.17×10^6 \$ 2.45	1.24×10^6 \$ 2.64

Table 3-15

HOSPITAL SITE (STIRLING - TES OPTION 7)
ANNUAL FUEL COSTS AND RATE-OF RETURN ON INVESTMENT
VS. CLIMATE AND ENERGY- COST SCENARIOS

	BASELINE			50 % HIGHER			100 % HIGHER		
	CONVENTIONAL	7	i ₁ /i ₂	CONVENTIONAL	7	i ₁ /i ₂	CONVENTIONAL	7	i ₁ /i ₂
<u>COLD CLIMATE</u>									
FUEL OIL ELECT	\$602,000	\$1,057,000		\$903,000	\$1,586,000		\$1,204,000	\$2,114,000	
a)	\$2,816,000@8¢	43/80.		\$4,224,000@12¢	67/124.		\$5,632,000@16¢	91/168.	
b)	\$1,408,000@8¢	15/27.		\$2,112,000@6¢	24/45.		\$2,816,000@8¢	34/63.	
c)	\$704,000@2¢	0/0		\$1,056,000@3¢	0/2		\$1,408,000@4¢	2/9	
<u>MODERATE CLIMATE</u>									
FUEL OIL ELECT	\$546,000	\$1,103,000		\$819,000	\$1,655,000		\$1,092,000	\$2,206,000	
a)	\$3,000,000@8¢	45/83.		\$4,500,000@12¢	69/128.		\$6,000,000@16¢	94/174.	
b)	\$1,500,000@4¢	14/27		\$2,250,000@6¢	24/44.		\$3,000,000@8¢	33/62.	
c)	\$750,000@2¢	LOSS.		\$1,125,000@3¢	0/0		\$1,500,000@4¢	0/3	
<u>WARM CLIMATE</u>									
FUEL OIL ELECT	\$469,000	\$1,169,000		\$704,000	\$1,754,000		\$938,000	\$2,338,000	
a)	\$3,264,000@8¢	47/87.		\$4,896,000@12¢	73/135.		\$6,528,000@16¢	99/183.	
b)	\$1,632,000@4¢	14/26.		\$2,448,000@6¢	24/44.		\$3,264,000@8¢	33/61.	
c)	\$816,000@2¢	LOSS		\$1,224,000@3¢	LOSS		\$1,632,000@4¢	LOSS	

3.6 Conclusions

Table 3-16, in summary form, shows the results of the economic analyses for the "best" Stirling total energy system concept for each of the three sites. The sensitivity of the investment-attractiveness indices to the cost of electricity and fuel both today and in the future are all given in this table.

A detailed examination of these results and those presented in Paragraphs 3.3 and 3.5 leads logically to the following conclusions regarding the applicability of Stirling total energy systems to the study sites:

- a) Office building total energy sites are far inferior, in terms of energy saving potential, to the others studied.
- b) The residential and hospital sites are equally attractive candidates for TE in terms of both fuel-energy savings and investment incentive.
- c) Residential TE sites offer slightly greater energy savings potential and investment incentive in cold climates.
- d) Hospital TE sites offer slightly greater energy savings in cold climates, but have higher investment incentives in warm climates.
- e) The 80°C and 120°C Stirling TE heat recovery systems (mechanical vs. absorption refrigeration) offer nearly equal energy savings, but at 120°, heat recovery systems consistently offer greater investment incentive.
- f) At today's energy costs, Stirling TE systems offer attractive investment incentives so long as purchased electricity costs more than 4 cents per kW-h. Most of the United States today falls into this category, with several densely populated regions closer to 8 cents per kW-h. In those areas where electric energy is available for as little as 2 cents per kW-h, there is no investment incentive. However, such cheap electricity would probably come from hydroelectric power plants, and there is less energy conservation reason for seeking to "compete" with hydro systems.
- g) At higher relative energy costs (in the future), the investment incentives for TE systems become enormous.

- h) Stirling engine/generator units rated at 1000 kW output would fit well into both the residential and hospital systems. The peak electrical demands for the residential and hospital sites differed considerably. Accordingly, the most cost-effective and practical size engine/generator unit for each differ. An engine/generator set of 500 kW would be optimum for the residential site, while a 3000 kW unit would be optimum for the hospital studied. Both, however, would operate with no loss in thermal efficiency with 1000 kW units.

The conclusions above, with minor exceptions, could hold equally well for many types of total energy systems. Why then the Stirling? It is necessary to reiterate that in this application, the single most striking advantage of the Stirling prime mover is its multiple-fuel capability. Its ability to burn low-grade fuels cleanly, and with proper design, to present its owner with a choice of fuels to use within the same engine (the choice depending on lowest price at any one time) is the advantage that the available prime movers presently lack. The disadvantage of the Stirling prime mover is that it is not commercially available.

Table 3-16
TASK 2 SUMMARY

	RESIDENTIAL (1A)				OFFICE BUILDING	HOSPITAL (7)			
	$\frac{1}{2}$ /GPY	$i_1/i_2\%$				$\frac{1}{2}$ /GPY	$i_1/i_2\%$		
		BASELINE	1.5X	2X			BASELINE	1.5X	2X
<u>COLD CLIMATE</u>									
ELEC. @ 8 †	1.21	59/89	93/140	127/192	NOT ADVANTAGEOUS ↓	1.71	43/80	67/124	91/168
ELEC. @ 4 †	1.21	21/31	36/55	51/77		1.71	15/27	24/45	34/63
ELEC. @ 2 †	1.21	LOSS	6/10	13/20		1.71	0/0	0/2	2/9
<u>MODERATE CLIMATE</u>									
ELEC. @ 8 †	1.40	54/82	86/130	118/178	NOT ADVANTAGEOUS ↓	1.83	45/83	69/128	94/174
ELEC. @ 4 †	1.40	18/27	31/48	45/68		1.83	14/27	24/44	33/62
ELEC. @ 2 †	1.40	LOSS	0/4	7/13		1.83	LOSS	0/0	0/5
<u>WARM CLIMATE</u>									
ELEC. @ 8 †	1.67	52/78	82/124	113/170	NOT ADVANTAGEOUS ↓	2.03	47/87	73/135	99/183
ELEC. @ 4 †	1.67	17/25	30/45	43/64		2.03	14/26	24/44	33/61
ELEC. @ 2 †	1.67	LOSS	0/1	5/10		2.03	LOSS	LOSS	LOSS

4. TECHNOLOGICAL DECISION AREAS IN DEVELOPMENT
OF A 1000 kW STATIONARY ENGINE/GENERATOR

The study of Stirling total energy systems conducted in Tasks I and II suggests the applicability of engine/generators in the 500 to 3000 kW output range, with a 1000 kW unit suitable for all the sites studied.

Though a Stirling engine of this size has not been built to date, there is no fundamental technical reason why one could not be built. However, the test of any new stationary power plant in the market place can be expected to be very demanding; particularly in the overall area of "cost of ownership", not efficiency alone. Therefore, rather than embark hastily upon the design of this power plant by scaling up previous embodiments, it is recommended that careful consideration be given to each of several fundamental technological decisions which must be made in arriving at the recommended final design. Only in this way can one be assured that the selected final design will permit maximum realization of the potential differential advantages that the Stirling prime mover has to offer, while assuring that it meets the performance demands of the marketplace.

The technological decision areas which require further study are:

- (a) Selection of optimum basic configuration.
- (b) Selection of optimum hot-side heat exchange interface.
- (c) Identification of power/speed control requirements and optimum control system.
- (d) Selection of the internal gas seal.
- (e) Assessment of available coal combustion technology and selection of the optimum engine-combustor interface.

These areas are discussed in the following paragraphs.

4.1 Configuration Selection

The most fundamental decision to be made regarding the 1000 kW stationary Stirling prime mover is the choice of its configuration. The Stirling cycle can be embodied in either single-acting or double-acting configurations; these configurations can be mechanized as single-cylinder or multi-cylinder engines, actuated by a variety of drives, including the Philips rhombic, crank, and swashplate types. Background information on the thermodynamic cycle and mechanical design of various Stirling cycle configurations is presented in Appendix G.

Preliminary designs for each of the following 1000 kW configurations should be prepared:

- one cylinder, single acting;
- multi-cylinder, single-acting,
- multi-cylinder, double-acting, crank drive,
- multi-cylinder, double-acting, swashplate drive.

These designs should then be ranked considering their relative performance in the areas of estimated production cost, efficiency, control-problems, maintainability, growth potential, and multi-fuel adaptability.

A recommended configuration can be selected based upon an interpretation of the results of this ranking.

4.2 Hot-Side Heat Exchange Interface

In simple terms, in scaling-up an engine, the power produced and heat rate to be dealt with increases with the cube of the lineal scale factor, while the available heat exchange area increases with the square of the scale factor. This "thermal pinch" effect is one which must be dealt with in the hot-side heat exchanger design. (The same effect occurs in the cold-side heat exchanger as well, but is a less severe problem since it is not compounded by high-temperature material restrictions.)

The effort in this area would be aimed at identifying the problems associated with transferring large quantities of heat while limited by requirements for high engine efficiency, multiple fuel compatibility, high reliability and low cost. Heat pipe coupling and the use of ceramic materials should be addressed in this study.

The objective would be to arrive at a recommended hot-side configuration.

4.3 Control System

Stirling engine/generators, in a limited sense, will represent an alternative source of conditioned electrical power to their purchaser. One may expect that the purchaser will expect this alternative source to function at least as well as presently available alternatives in the quality of conditioned power it provides.

In this task, performance requirements (goals) should be established for the engine power control system, the various control options available to Stirling engine designers should be evaluated, and the most cost-effective method of power control selected, consistent with the design requirements.

The Institute of Electrical and Electronics Engineers publishes specifications covering speed-governing of prime movers. One typical specification is Standard 126, "Specification for Speed Governing of Internal Combustion Engine-Generator Units". A brief examination of its requirements provides a feel for typical control system performance requirements.

There are two classes of speed governing, "isochronous" in which the mean speed remains constant versus load, and "steady state speed regulation" in which the mean speed increases as load is shed. The latter applies here. Table 4-1 presents the speed-governing requirements of IEEE Standard 126 for engine generators in industrial, commercial, and utility service.

PHILIPS LABORATORIES

Table 4-1: Speed-Governing Requirements of IEEE Standard 162.

	<u>Industrial- Commercial Service</u>	<u>Utility Service</u>
Steady State Speed Regulation	3-6%	2-5%
Steady-State Governing Speedband (10-100% or rated load)	$\pm 0.5\%$	$\pm 0.33\%$
Momentary Overspeed (Complete load drop)	$< 8\%$	$< 8\%$
Momentary Underspeed (25% of rated load step-size)	$< 3\%$	$< 2\%$
Recovery Time (to $\pm 0.6\%$ speedband)	$< 4 \text{ sec}$	$< 3 \text{ sec}$
Adjustable Speed Set Point	Yes	Yes
Automatic Start-up Capability (Auto. speed adjust to ready- to-load condition)	Yes	Yes

A number of ways are available to achieve the desired degree of speed governing,

- variation of average cycle pressure
- variation of sweep of the piston
- variation of phase shift between compression and expansion spaced
- dead volume control
- short circuit control.

Any of the above, or combinations thereof, may prove to be optimum for this application.

4.4 Internal Gas Seals

The function of the internal seal in the Stirling engine is two-fold: a) to prevent leakage of working fluid into the crankcase, and (b) to prevent contamination of the hot space by lubrication oil from the crankcase.

The objective of this activity will be to consider all potential seal embodiments and select the one most suitable considering its impact on the design complexity and cost of the prime mover, as well as its performance potential (life) in high temperature (80 to 120°C) heat recovery systems.

For more than ten years at Philips, the seal selected for this application has been the rolling diaphragm seal (see Fig. 4-1). A pumping ring pumps oil into the cavity under the seal, while

Figure 4-1: Rolling diaphragm seal.

a control valve sees that the oil pressure is always a few atmospheres lower than the gas pressure. Thus, the working space can be at very high pressure, while the crankcase is at ambient pressure. Its disadvantage is that its life is limited by creep, and this is aggravated at elevated temperatures (greater than 80°C). Auxiliary cooling systems may be necessary for this seal.

Alternatively, a clearance or scraper seal, which permits a slow leakage of working fluid into the crankcase, may be advantageous in this application.

A third alternative is a more recent development, a magnetic fluid shaft seal which may prove to be superior in this application.

The selection of the internal seal should only be made after careful consideration of the alternatives. The final selection will have a great impact on the maintainability, first cost, and cost of ownership of the end product.

4.5 Assessment of Coal Combustion Technology

Stirling engine/generators in the 500 to 3000 kW output range will require burners in the 1000-10,000 kW heat-rate range. The objective of this activity should be to assess the state-of-the-art in the field of direct combustion of solid coal in the stated heat-rate range, select the technology most compatible with the Stirling engine requirements, develop preliminary specifications for the combustor, and develop a preliminary design for the combustor/engine interface.

A Stirling engine can be readily adapted to a direct coal combustion system⁽⁵⁾. The design and power density of the coal combustion system are determined by the way in which the combustion heat is transferred from the fire to the engine. In principle it is possible to place the heater tubes of the ~~engine directly on a heap of burning coal, which does away with~~ the need for a heat transport system between the engine and the fire. The power density of systems of this kind, however, is restricted by the low heat transfer coefficient between the coal fire and heater tubes and the surface area of the heater tubes. Furthermore, temperature control of such "static" coal fires is slow and unable to prevent hot spots, so that overheating and damage of the heater tubes may occur.

Higher power density and greater reliability are possible if the engine and coal fire are separated and the coal fire is of the fluidized-bed type. However, even with a fluidized-bed fire, the heat transfer rate may be too low to provide a good thermal flux through the heater tubes of the engine; thus, a heat transport system is needed which would be capable of acting as a heat flux transformer. The application of the heat pipe principle is a good solution here, due to its high heat transfer capability and its ability to transform heat fluxes.

In the fluidized-bed type of coal fire with an inert fluidizing medium, rapid temperature control can easily be achieved by variation in the rate of supply of coal, while hot spots are suppressed by the intense mixing of the particles in the bed. Furthermore, complete combustion can be achieved with low values of CO in the exhaust while, due to the low bed temperature (below 1000°C), the production of oxides of nitrogen is low.

According to the literature, fluidized combustion makes it possible to burn coal with a high sulfur content without getting a high SO₂ content in the flue gases if regenerable additives such as limestone or dolomite are introduced into the bed.

Other combustion technologies under development may prove to offer similar favorable advantages for coal combustion.

N. V. Philips of Eindhoven, The Netherlands, has initiated work in applying fluidized-bed coal combustion systems to the generation of heat for Stirling engines⁽⁵⁾. They have demonstrated a system in which a heat pipe was used to transport the heat from the fluidized-bed combustor to the engine heater tubes.

5. REFERENCES

1. Proceeding of Conference on Magnitude and Deployment Schedule of Engery Resources, Portland, Oregon, July 1975.
2. R. J. Meyer, "The Philips Stirling Engine", De Ingenieur, Vol. 81, Page 69-79, and 81-93 (Nos. 18-19).
3. R. J. Meyer, C. L. Spigt, "The Potential of the Philips Stirling Engine for Polution Reduction and Energy Conservation", Proceeding of Second Symposium on Zero Polution Power Systems Development, Dusseldorf, Nov. 4-8, 1978.
4. N. D. Postma, R. van Giessel, F. Reinink, "The Stirling Engine for Passager Car Application", SAE Paper #730648, June 1973.
5. G. A. A. Asselman, "Fludized Bed Coal Combustion as a Heat Source for Stirling Engines", presented at 11th IECEC, State Line, Nevada, Sept. 1976.

APPENDIX A

Site Data

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PHILIPS LABORATORIES

Jersey City Site (Residential)
Data Tabulation
Typical January Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW		
Extreme Site Heating Loads for Month, kW	3,220	580
Extreme Site Electrical Loads for Month, kW	960	460

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	590	2,385		21
2	540	2,260		
3	530	2,205		
4	525	2,260		20
5	530	2,290		
6	555	2,395		
7	620	2,605		19
8	655	2,895		
9	650	3,150		
10	660	3,030		22
11	680	2,950		
12	680	2,800		
13	670	2,785		26
14	685	2,660		
15	700	2,505		
16	740	2,550		26
17	845	2,655		
18	915	2,850		
19	905	3,140		21
20	870	3,180		
21	850	3,015		
22	805	2,935		19
23	730	2,780		
24	660	2,680		

* Rev. A

PHILIPS LABORATORIES

Jersey City Site (Residential)
Data Tabulation
Typical April Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW		
Extreme Site Heating Loads for Month, kW	1,880	520
Extreme Site Electrical Loads for Month, kW	840	330

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	520	1,560		40
2	480	1,485		
3	465	1,435		
4	465	1,470		38
5	470	1,435		
6	495	1,520		
7	530	1,675		39
8	570	1,805		
9	600	2,025		
10	600	1,880		46
11	610	1,765		
12	615	1,665		
13	610	1,625		49
14	605	1,510		
15	610	1,425		
16	640	1,455		53
17	685	1,495		
18	750	1,670		
19	780	1,885		47
20	780	1,935		
21	755	1,865		
22	730	1,780		42
23	675	1,680		
24	600	1,725		

* Rev. A

PHILIPS LABORATORIES

Jersey City Site (Residential)
Data Tabulation
Typical August Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW	474	175
Extreme Site Heating Loads for Month, kW	565	255
Extreme Site Electrical Loads for Month, kW	810	245

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	395	310	265	67
2	370	285	255	
3	350	255	255	
4	335	285	245	63
5	340	255	235	
6	345	255	220	
7	380	285	215	71
8	410	340	220	
9	430	565	225	
10	500	510	235	78
11	520	450	260	
12	490	400	300	
13	480	400	325	83
14	480	340	340	
15	480	285	350	
16	540	285	360	85
17	575	285	360	
18	615	340	345	
19	620	450	335	81
20	610	480	320	
21	610	425	315	
22	585	370	310	74
23	530	310	305	
24	465	400	285	

* Rev. A

PHILIPS LABORATORIES

Jersey City Site (Residential)
Data Tabulation
Typical November Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW		
Extreme Site Heating Loads for Month, kW	3,010	590
Extreme Site Electrical Loads for Month, kW	860	360

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	510	1,460		54
2	475	1,405		
3	470	1,335		
4	465	1,345		51
5	455	1,305		
6	480	1,425		
7	550	1,545		51
8	570	1,825		
9	525	2,120		
10	535	1,990		54
11	570	1,880		
12	570	1,725		
13	560	1,610		58
14	540	1,575		
15	540	1,340		
16	600	1,565		57
17	720	1,640		
18	805	1,795		
19	790	1,990		53
20	760	2,060		
21	720	1,985		
22	685	1,855		51
23	650	1,755		
24	580	1,725		

* Rev. A

PHILIPS LABORATORIES

Anchorage Site (Office Building)
Data Tabulation
Typical February Day

	Max	Min
Extreme Site Cooling Loads for Month, kW	0	0
Extreme Site Heating Loads for Month, kW	3,340	446
Extreme Site Electrical Loads for Month, kW	2,500	215

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	323	353		29
2	323	365		29
3	323	377		29
4	323	388		27
5	323	400		25
6	670	412		23
7	1,617	1,059		21
8	1,984	1,444		19
9	2,351	1,830		17
10	2,365	1,990		17
11	2,380	1,445		16
12	2,394	1,107		16
13	2,372	770		17
14	2,351	727		18
15	2,388	685		23
16	2,426	642		22
17	1,483	1,172		22
18	741	1,637		22
19	635	1,147		21
20	614	658		20
21	593	369		19
22	458	411		18
23	323	454		17
24	323	497		16

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Anchorage Site (Office Building)
Data Tabulation
Typical July Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW	2,051	0
Extreme Site Heating Loads for Month, kW	750	0
Extreme Site Electrical Loads for Month, kW	2,535	274

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	295	66	0	53
2	274	66	0	52
3	274	66	0	52
4	274	66	0	54
5	274	66	0	53
6	274	394	0	53
7	454	690	83	52
8	634	427	166	52
9	1,584	164	187	53
10	2,017	149	208	54
11	2,451	135	263	55
12	2,465	121	319	55
13	2,479	106	374	56
14	2,493	92	648	58
15	2,451	78	931	61
16	2,535	63	964	61
17	2,440	49	997	61
18	2,345	65	902	61
19	1,500	82	648	59
20	740	16	0	58
21	695	24	0	57
22	527	32	0	56
23	359	41	0	54
24	317	49	0	53

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Fairfield Site (Hospital)
Data Tabulation
Typical January Day

	Max	Min
Extreme Site Cooling Loads for Month, kW	1,758	0
Extreme Site Heating Loads for Month, kW	17,873	1,465
Extreme Site Electrical Loads for Month, kW	5,860	1,025

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	1,318	3,516	440	40
2	1,318	2,344	293	40
3	1,318	2,344	293	40
4	1,318	2,344	293	41
5	2,307	6,934	0	41
6	3,296	11,524	0	41
7	4,285	16,115	0	40
8	5,274	14,357	0	39
9	5,274	12,599	0	38
10	5,420	10,841	0	41
11	5,567	10,548	0	43
12	5,333	10,255	0	47
13	5,479	10,328	0	48
14	5,215	10,401	0	49
15	4,365	8,130	0	51
16	3,516	5,860	0	52
17	3,369	6,006	0	53
18	3,223	6,153	1,025	47
19	2,930	3,076	842	46
20	2,930	3,003	660	44
21	2,637	2,930	660	43
22	2,344	3,028	660	45
23	2,344	3,028	660	46
24	1,465	3,223	293	48

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Fairfield Site (Hospital)
Data Tabulation
Typical April Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW	3,062	0
Extreme Site Heating Loads for Month, kW	16,701	1,406
Extreme Site Electrical Loads for Month, kW	6,739	73

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	1,465	3,076	400	51
2	1,465	2,490	343	49
3	1,465	2,490	286	48
4	1,465	5,530	228	47
5	2,735	8,570	171	46
6	4,004	11,610	114	45
7	5,274	14,650	57	47
8	5,274	12,108	0	50
9	5,274	9,571	256	54
10	5,626	7,032	512	57
11	5,421	6,922	769	61
12	5,714	6,812	1,025	64
13	5,274	6,703	878	67
14	5,391	6,593	732	71
15	5,508	2,198	1,172	72
16	3,956	2,110	782	74
17	3,809	1,758	391	71
18	3,662	1,406	0	65
19	2,637	2,314	0	62
20	2,539	3,223	0	58
21	2,442	3,223	0	55
22	2,344	2,930	190	54
23	2,491	3,076	381	53
24	1,758	2,637	293	52

* Rev. A

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Fairfield Site (Hospital)
Data Tabulation
Typical July Day*

	Max	Min
Extreme Site Cooling Loads for Month, kW	8,409	0
Extreme Site Heating Loads for Month, kW	11,427	730
Extreme Site Electrical Loads for Month, kW	7,765	1,318

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	1,758	733	1,026	61
2	1,758	733	879	61
3	1,758	733	733	60
4	2,754	3,004	586	60
5	3,750	5,275	586	59
6	4,747	7,545	586	58
7	5,743	9,816	1,653	62
8	6,739	8,498	2,721	66
9	6,886	7,179	3,788	70
10	7,032	7,033	4,856	74
11	7,618	6,886	5,923	76
12	7,325	6,740	6,990	78
13	7,765	6,593	8,058	82
14	7,325	4,103	8,058	84
15	6,300	1,612	8,058	85
16	5,274	1,905	8,058	86
17	4,249	1,465	8,058	85
18	4,029	1,444	3,956	84
19	3,809	1,423	3,516	82
20	3,590	1,402	3,077	80
21	3,370	1,382	2,637	78
22	3,150	1,361	2,198	76
23	2,930	1,340	1,758	73
24	2,051	1,319	1,318	70

* Rev. B

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Fairfield Site (Hospital)
Data Tabulation
Typical October Day

	Max	Min
Extreme Site Cooling Loads for Month, kW	5,567	0
Extreme Site Heating Loads for Month, kW	13,038	732
Extreme Site Electrical Loads for Month, kW	7,032	1,465

Time of Day, Hour	Site Electrical Load, kW	Site Heating Load, kW	Site Cooling Load, kW	Outside Air Temperature °F
1	1,611	1,318	0	57
2	1,758	1,172	0	55
3	1,758	1,172	293	53
4	1,758	1,172	293	51
5	2,051	1,172	293	49
6	3,321	4,590	293	51
7	4,590	8,009	0	52
8	5,860	11,427	0	56
9	6,043	9,376	0	61
10	6,226	7,325	2,783	65
11	6,409	7,179	2,783	69
12	6,592	7,032	2,783	72
13	6,592	6,886	4,834	75
14	6,446	5,225	4,248	78
15	6,592	3,565	4,541	79
16	5,054	1,904	3,418	79
17	3,516	2,197	2,295	80
18	3,311	1,465	1,172	77
19	3,105	1,582	1,270	74
20	2,900	1,699	1,367	70
21	2,695	1,817	1,465	66
22	2,490	1,934	977	64
23	2,637	2,051	488	61
24	2,490	1,465	0	58

APPENDIX B

Operating System Components and Subsystem Descriptions

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OPERATING SYSTEM COMPONENTS AND SUBSYSTEM DESCRIPTIONS

1. OPERATING SYSTEM COMPONENTS

The symbols employed for each component on the system block diagrams and a description of the component function are given below:

- a. Stirling Engine OR

This component serves as the total energy system prime mover. The number in parenthesis (120 C) and (80 C) refers to the heat recovery temperature of the jacket coolant system.

- b. Generator

Driven by the prime mover, this component generates electricity to satisfy the site electrical demand.

- c. Jacket Water Pump JW

The jacket water pump can be integral with the Stirling engine or a separate electric motor-driven pump as presented in this conceptual design. This pump serves to transfer waste heat from the jacket of the engine coolant system to the site heating and cooling systems through a heat exchanger.

- d. Heat Exchanger

The heat exchanger serves to transfer heat from the jacket water coolant system to the site hot water system. This component is required to isolate the two systems due to pressure differences. It can be omitted if the engine jacket can be designed to accommodate 125 psig working pressure.

- e. Automatic Control Valve OR

This component is an automatic temperature controlled valve used to throttle, divert, mix or regulate the flow of fluid through the various systems.

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f. Automatic Control Valve

This component is an automatic pressure controlled valve which modulates to maintain minimum flow to prevent system overpressurization and subsequent damage to site user valves.

g. Automatic Control Valve

This component is an automatic flow controlled valve used to isolate equipment from the system when said equipment is not in use.

h. Hot Water Pump HW

The hot water pump, electric motor driven, is the main system pump used to circulate water through the site heating system, storage system, heat rejection system, supplementary heating system and/or the absorption unit cooling system.

i. Heat Rejector

This component consists of a closed circuit water-to-air heat exchanger and electric motor-driven fan. This unit is remotely located and is used to reject nonusable waste heat to the outdoor air.

j. Storage Tank

A horizontal tank used for the storage of excess waste heat for use at such times when the site demand for heating or cooling exceeds the available heat rejected from the prime mover. Through baffling or tank configuration design, mixing of entering and leaving fluids is minimized and stratification is maximized for efficient tank operation.

k. Boiler

A supplementary hot water heating device using fossil fuels for combustion. The boiler adds heat to the hot water system when waste heat from the prime mover is insufficient to satisfy site heating or cooling loads. A motor-driven draft fan and fuel oil pump are the major subcomponent users of electricity of this unit.

1. Electric Heater.

EH

A supplementary heating device which can be used in lieu of a boiler. This component, an electric resistance heater, converts generated electricity directly to heat, enabling the engine-generator system to satisfy the supplementary heating requirement.

m. Absorption Unit

AU

The absorption unit is a water-chilling machine using water as a refrigerant and a salt solution such as lithium bromide as an absorbent. This unit, without the use of a prime mover, can use heat directly from the hot water system. The hot water temperature should be in the range of 110°-120°C (230°-250°F). A motor-driven solution pump is the prime user of electricity for this unit.

n. Chilled Water Pump

CHW

This electric motor-driven component is used to circulate water through the absorption unit and site piping system to supply chilled water to satisfy the site cooling requirements.

o. Condenser Water Pump

CW

This electric motor-driven component is used to transfer heat rejected from the absorption unit, through a piped water system to a cooling tower.

p. Cooling Tower

This is a heat rejection device utilizing the principle of cooling through evaporation of water, which transfers rejected heat from the absorption unit/condenser water system to the outdoor air. A motor-driven propeller fan is the prime user of electricity.

q. Refrigeration Unit

RU

The refrigeration unit is a centrifugal compressor-type water chilling machine.

2. SUBSYSTEM DESCRIPTION AND OPERATING PROCEDURES

The components described in Section 1 of this Appendix are parts of the various subsystems used in the conceptual designs of the total energy system. This section describes the method of operation for each subsystem included in the block diagrams.

2.1 Suggested Operating Practices

(a) Start/Stop

Generally, for the projects defined for this site, the Owner would retain a first class operating engineer. The engineer would bring equipment on line and shut down equipment, manually, in accordance with profiles established from operating experience for the site.

After initial activation of equipment, automatic capacity control devices regulate the subsystem equipment outputs to meet site demands. When the site demand reaches the range of 80-85% of equipment capacity and is on the increase, the next unit will be brought on line. The units will be loaded manually based on efficiencies and operator judgement. For example, at 80% load, the operator has the option of running two machines at 40% load, or one machine at 80% load with the other machine at "spinning" load. The decision is based on actual equipment selected and best overall efficiency of the combination. Generally, two units at 40% are more efficient than one at 80% and one spinning.

2.2 Subsystem Description

(a) Stirling Engine/Generator

In the conceptual designs, Stirling engines were considered with operating temperatures of 80°C and 120°C depending on system components. During operations when cooling is not required, those engines operating at temperatures of 120°C could

be lowered to 80°C to increase equipment life and decrease fuel consumption.

The generator satisfies the site electrical demand through the use of a governor which controls the prime mover speed.

(b) Jacket Water System

As schematically depicted, the jacket water pump operates in conjunction with Stirling engine operation. Valve T-1, regulated by a temperature sensor in the heat exchanger supply water circuit, bypasses water around the heat exchanger under part load operation. This method of control results in a fixed constant heat exchanger supply water temperature, a constant flow through the jacket coolant system and a constant power requirement for the jacket water pump.

(c) Hot Water Heating System

The hot water pump operates whenever the Stirling engine is in operation. Heat from the jacket water system is transferred through the heat exchange surface to the hot water system. The conceptual design with hot water available at 120°C assumes a primary/secondary pumping system serving the site in combination with a blending control at the user. Under this arrangement, the hot water pump is capable of circulating water to and from the site buildings. At the respective building, a secondary pump is used to circulate water through the building systems proper. The primary supply system is at a higher temperature (240°F) than the user system (180°F). Hence, an amount of supply water proportionate to the user load is injected into the building system and blended with a proportionate amount of return water (160°F). The return water not mixed at the building is sent back to the heat exchanger for reheating.

As user, loads are throttled, valve P-1 opens to maintain minimum flow to prevent over pressurization in the piping system and possible resultant leakage at down stream user valves. The hot water pump operates at a relatively constant load.

It should be noted that the secondary system serving the buildings does not form part of this conceptual design analysis as it is assumed to be common for all total energy systems which may be subsequently compared.

The conceptual designs with hot water available at 80°C assume a primary/secondary pumping system without blending control at

the building. The hot water is pumped directly to the building for use directly as a heating media and returned to the heat exchanger for reheating.

(d) Heat Rejection System

This subsystem serves to remove excess heat from hot water systems, as can occur whenever the site electrical demands exceed the site heating and cooling demands. The heat rejector (effectively an air cooled radiator) and valves T-2 and T-3 are controlled by a temperature sensor located in the hot water supply circuit. At a predetermined temperature, say 245°F, the rejector is activated, modulating valve T-2 opens and modulating valve T-3 closes to reject the excess heat to the outdoor air.

(e) Supplementary Heating System

This subsystem serves to add heat to the hot water supply system whenever the supply water temperature falls below a predetermined setpoint, say 190°F. A temperature sensor,

located in the hot water supply, closes modulating valve T-3 and opens modulating valve T-4 to maintain the proper hot water supply temperature. The boiler is manually activated, based on site operating profiles, to satisfy the supplementary heating requirements.

(f) Alternate Supplementary Heating System

This subsystem functions similar to the supplementary system employing a boiler, with the exception that the heat source is the Stirling engine generated electricity. A temperature sensor activates the electric resistance heater and modulates the valves to satisfy the supplementary heating requirement.

This arrangement has the advantage of eliminating the need for a complete, separate heating system with its appurtenances and may in the final analysis prove economical as a supplementary heat source.

(g) Alternate Supplementary Heating System

As 80°C to 120°C solar collectors are made available on the market, the need for a supplementary boiler and its energy consuming appurtenances is reduced or even eliminated. A solar collector connected to the hot water heating system or the heat storage tank could either supply the supplementary heat needs directly or store it for later use.

However, such solar collectors were not considered in the system concepts; it was agreed they are not "commercially available" components in the context established in the study ground rules.

(h) Heat Storage System

When storage of available heat is desirable for use at other times, when the heating demand exceeds the waste heat available directly from the prime mover, the depicted arrangement could be used. A sensor, located in the tank outlet, closes modulating valve T-5 and opens modulating valve T-6 to allow hot water to enter the tank for storage of heat. Valve T-7 remains in the closed position. When the tank is full, i.e., when the tank has reached predetermined temperature, say 240°F, valve T-6 closes and valve T-5 opens.

On a call for heat from the tank, valve T-5 modulates towards the closed position and valve T-7 opens to allow tank water to enter the hot water supply system. Valve T-6 remains in the closed position. On a drop in temperature to, say 190°F, valve T-7 closes and valve T-5 opens, thereby, isolating the tank from the system. The storage cycle is repeated when excess

heat becomes available. The controls are arranged to give priority to storage of heat over heat rejection to the atmosphere.

(i) Absorption Refrigeration System

The absorption unit system is started manually by the operating engineer, based on site operating profiles. The chilled water pump circulates water to the site to satisfy the site cooling demand. A primary/secondary pumping system (similar in operation to the system previously described in the Hot Water Heating System) was assumed. As site loads are reduced and the system throttled, valve P-2 opens to maintain minimum flow to prevent over-pressurization and resultant damage to downstream site valves. The chilled water pump operates at a relatively constant load and power consumption.

A sensing element in the chilled water leaving the absorption unit maintains a fixed predetermined supply water temperature, say 44°F, by modulating valve T-8 and valve T-5 or T-5A in the hot water system.

The condenser water pump and cooling tower work in conjunction with the absorption unit. The condenser water temperature is allowed to float with the outdoor weather conditions to a

minimum level. At a predetermined temperature of the condenser water to the absorption unit, say 65°F, valve T-9 modulates open to bypass hot condenser water from the absorption unit back into the supply system to maintain said minimum temperature of 65°F.

The condenser water pump and cooling tower fan were assumed to be operating at a relatively constant power consumption whenever the cooling system is on.

(j) Mechanical Refrigeration System

The mechanical refrigeration system is operated in a similar manner to the absorption unit system. The major difference is the drive, which in any conceptual design could be either a Stirling engine or electric motor (the electric motor driven version is pictured) and the method of capacity control. For the refrigeration machine the temperature sensing element in the chilled water modulates control devices within the machine to throttle refrigerant flow to maintain a fixed chilled water temperature leaving the machine.

(k) Chilled Water Storage

This subsystem operates similar to the Heat Storage System described in Paragraph h.

APPENDIX C

Conceptual Designs for Residential/Commercial Site

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CONCEPTUAL DESIGNS FOR RESIDENTIAL/COMMERCIAL SITE

1. DESCRIPTION AND OPTIONS

Total energy system options conceptualized for the residential complex located at the Jersey City, N. J. site are described below. The options using thermal storage were subsequently discarded since supplementary heating was found to be required at all times during the heating season, while excess heat had to be rejected at all times during the cooling season.

1.1 Option No. 1

The Stirling engine with an operating temperature of 120°C drives a generator to satisfy the site electrical requirements. The rejected heat from the engine is transferred through the heat exchanger to the hot water system. The hot water can take one or more of the following circuits by means of valve control:

- to the site directly to satisfy heating requirements.
- to the storage tank for future use when the heating demand exceeds the available heat from the engine.
- to the heat rejector for removal of excess heat.
- to the absorption unit to satisfy site cooling requirements.
- to the supplementary heater for the addition of heat to satisfy site demands.

1.2 Option No. 1A

Similar to Option No. 1, except heat storage capability is not provided, hence requiring an increased use of the heat rejector during hours of excess heat and an increased use of the supplementary heater during periods of shortages of heat.

1.3 Option No. 2

A Stirling engine with an operating temperature of 80°C drives a generator to satisfy the site electrical requirements. The rejected heat from the engine is transferred through the heat exchanger to the hot water system. The hot water can take one or more of the following circuits by means of valve control:

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- to the site directly to satisfy heating requirements.
- to the storage tank for future use when the heating demand exceeds the available heat from the engine.
- to the heat rejector for removal of excess heat.
- to the supplementary heater for the addition of heat to satisfy site demands.

Another Stirling engine with an operating temperature of 80°C drives a refrigeration unit directly to satisfy the site cooling requirements. As the engine-generator set satisfies the site heating demand, the engine-chiller heat is rejected to the atmosphere at all times.

1.4 Option No. 2A

Similar to Option No. 2, except heat storage capacity is not provided, necessitating the increased use of the heat rejector and supplementary heater.

1.5 Option No. 3

A Stirling engine with an operating temperature of 80°C is used to drive either:

- a generator and refrigeration unit, mechanically connected in tandem to satisfy a combination of site electric and cooling requirements, or
- a generator alone, with the refrigeration unit driven by an electric motor supplied from the generator.

This option will perform similar to Option No. 2. However, the fuel consumption may be reduced since the single engine of this option may run more fully loaded than the multiple engines of Option No. 2.

Rejected engine heat is transferred through the heat exchanger to the hot water system for use in one or more of the following circuits:

- to the site directly to satisfy heating requirements.
- to the storage tank for future use when the heating demand exceeds the available heat from the engine.
- to the heat rejector for removal of excess heat.
- to the supplementary heater for the addition of heat to satisfy site demands.

1.6 Option No. 3A

Similar to Option No. 3, except heat storage capacity is not provided, necessitating the increased use of the heat rejector and the supplementary heater. This option will perform similar to Option No. 2A.

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2. EQUIPMENT SIZES

2.1 Options No. 1 and 1A

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For electric generation and heating:			
1. Stirling Engine	2	555 kW	-
2. Generator	2	500 kW	-
3. Jacket Water Pump	2	7-1/2 hp	-
4. Hot Water Pump	2	15 hp	8 kW
5. Boiler	2	175 bhp	-
6. Boiler Draft Fan	2	10 hp	8 kW
7. Boiler Fuel Pump	2	1 hp	1 kW
8. Heat Rejector	2	3 hp	2 kW
9. Storage Tank	1	5,000 gal	-
10. Resistance Heater	-	315 kW	-

For cooling:

11. Absorption Unit	1	140 t	-
12. Chilled Water Pump	1	15 hp	5 kW
13. Condenser Water Pump	1	10 hp	5 kW
14. Solution Pump	1	7-1/2 hp	4 kW
15. Cooling Tower	1	25 hp	18 kW

2.2 Options No. 2 and 2A

For electric generation and heating:

1. Stirling Engine	2	555 kW	-
2. Generator	2	500 kW	-
3. Jacket Water Pump	2	7-1/2 hp	-
4. Hot Water Pump	2	15 hp	8 kW
5. Boiler	2	175 bhp	-
6. Boiler Draft Fan	2	10 hp	8 kW
7. Boiler Fuel Pump	2	1 hp	1 kW
8. Heat Rejector	2	3 hp	2 kW
9. Storage Tank	1	5,000 gal	-
10. Resistance Heater		315 kW	-

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Options No. 2 and 2A (Cont.)

	<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For cooling:				
11.	Refrigeration Unit	1	140 t	-
12.	Stirling Engine	1	100 kW	-
13.	Chilled Water Pump	1	15 hp	5 kW
14.	Condenser Water Pump	1	7-1/2 hp	4 kW
15.	Cooling Tower	1	15 hp	12 kW
16.	Jacket Water Pump	1	2 hp	1 kW
17.	Heat Rejector	1	7-1/2 hp	4 kW

2.3 Options No. 3 and 3A

For electric generator and heating:

1.	Stirling Engine	2	555 kW	-
2.	Generator	2	500 kW	-
3.	Jacket Water Pump	2	7-1/2 hp	-
4.	Hot Water Pump	2	15 hp	8 kW
5.	Boiler	2	175 bhp	-
6.	Boiler Draft Fan	2	10 hp	8 kW
7.	Boiler Fuel Pump	2	1 hp	1 kW
8.	Heat Rejector	2	3 hp	2 kW
9.	Storage Tank	1	5,000 gal	-
10.	Resistance Heater		315 kW	-

For cooling:

11.	Electric Motor (optional)	1	125 hp	
12.	Refrigeration Unit	1	140 t	
13.	Chilled Water Pump	1	15 hp	5 kW
14.	Condenser Water Pump	1	7-1/2 hp	4 kW
15.	Cooling Tower	1	15 hp	12 kW

TABLE NO 1

Syska & Hennessy

Syska & Hennessy, Inc., Engineers 110 West 50 Street, New York, N.Y.

Job	Sheet no.	of	sheets
System	By	Date	

JERSEY CITY

EQUIPMENT SIZING ASSUMPTIONS

EQUIPMENT	PARAMETERS	OPTION 1 & 1A	OPTION 2 & 2A	OPTION 3 & 3A
• STIRLING ENGINE	PEAK DESIGN SIZE	ACTUAL SIZES	AS INSTALLED	→
• GENERATORS	PEAK DESIGN SIZE	ACTUAL SIZES	AS INSTALLED	→
• JACKET WATER PUMPS	HEAT ΔT HEAD	4,380,570 BTU/H 15° 40'		→
• HOT WATER PUMPS	HEAT ΔT HEAD	4,380,570 BTU/H 20° 100'		→
• ABSORPTION UNIT	PEAK DESIGN SIZE	ACTUAL SIZE AS INSTALLED	—	—
• CHILLED WATER PUMPS	COOLING ΔT HEAD	2,412,000 BTU/H 14° 100'		→
• CONDENSER WATER PUMPS	HEAT REJECTED ΔT HEAD	32,000 BTU/TON OF REFR. 10,332,000 BTU/H	15,000 BTU/TON OF REFR. 7,842,000 BTU/H	→
• FILLUP PUMPS	DESIGN SIZE	MFG PACKAGE W/ ABSORPTION UNIT	—	—
• COOLING WATER	DESIGN CONDITIONS GPM ΔT	73° WB 1370 13°	877	877
• STORAGE TANK	ΔT	50°		→
• STIRLING ENGINE FOR REFRIG.	DESIGN SIZE	—	83 HP/TON	→
• CENTRIFUGAL REFR. MAKING	PEAK DESIGN SIZE	—	SAME LOAD AS	ABSORPTION UNIT
• JACKET WATER PUMP FOR REFR. S.E.	HEAT ΔT HEAD	— — —	2,419,500 BTU/H 15° 40'	→
• BOILER	DESIGN SIZE	ACTUAL SIZE	AS INSTALLED	→
• BOILER DRAFT FAN & FUEL PUMP	DESIGN SIZE	MANUFACTURER	PACKAGE WITH	BOILER
		C-11		

Syska & Hennessy

Syska & Hennessy, Inc., Engineers 110 West 50 Street, New York, N.Y.

Job	Sheet no.	of	sheets
System	By	Date	

HEAT REJECTOR FOR ELECT GEN. STIR. ENG.	ΔT_{AIR} ΔT_{WATER} FACE VELOCITY	50° 80° 1000 fpm	50° 40° 1000 fpm	50° 40° 1000 fpm
HEAT REJECTOR FOR REFRIG. STIR. ENG.	ΔT_{AIR} ΔT_{WATER} FACE VELOCITY	- - -	50° 40° 1000 fpm	50° 40° 1000 fpm
RESISTANCE HEATER CENTRAL RANT LOADS	DESIGN LOAD LIGHTS VENTILATION HEATING	1/3 OF MAXIMUM HEATING LOAD 7.5 KW 12 KW 105 KW / 85 KW (OFF PEAK)		→ → → →

NOTES

- #1 DISTRIBUTION LOSSES ASSUMED TO BE PART OF SITE DEMANDS
- #2 HEAT REJECTED FROM ABSORPTION UNIT & REFRIGERATION UNIT ASSUMED TO BE DIRECTLY PROPORTIONAL TO LOAD

APPENDIX D

Conceptual Designs for Office Building Site

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CONCEPTUAL DESIGNS FOR OFFICE BUILDING SITE

1. DESCRIPTION OF OPTIONS

The total energy system designs conceptualized for the office building located at the Anchorage, Alaska site are as follows:

1.1 Option No. 4

The Stirling engine with an operating temperature of 120°C drives a generator to satisfy the site electrical requirements. The rejected heat from the engine is transferred through the heat exchanger to the hot water system. The hot water can take one or more of the following circuits by means of valve control:

- to the site directly to satisfy heating requirements.
- to the storage tank for future use when the heating demand exceeds the available heat from the engine.
- to the heat rejector for removal of excess heat.
- to the absorption unit to satisfy site cooling requirements.

No supplementary heating is required for this site with the use of heat storage.

1.2 Option No. 4A

Similar to Option No. 4 except heat storage capability is not provided. Hence, a supplementary heater must be added to make up for the insufficiency of engine heat during certain hours as shown in the tabulated data.

1.3 Option No. 5

A Stirling engine with an operating temperature of 80°C drives a generator to satisfy the site electrical requirements. The rejected heat from the engine is transferred through the heat exchanger to the hot water system. The hot water can take one or more of the following circuits by means of valve control:

- to the site directly to satisfy heating requirements.
- to the storage tank for future use when the heating demand exceeds the available heat from the engine.
- to the heat rejector for removal of excess heat.

No supplementary heating is required for this site with the use of heat storage.

Another Stirling engine with an operating temperature of 80°C drives a refrigeration unit directly to satisfy the site cooling requirements. As the engine-generator set satisfies the site heating demands, the engine-chiller heat is rejected to the atmosphere at all times.

1.4 Option No. 5A

Similar to Option No. 5, except heat storage capability is not provided. Hence, a supplementary heater must be added to make up for the insufficiency of engine heat at certain winter hours.

1.5 Option No. 6

A Stirling engine with an operating temperature of 80°C is used to drive, either:

- a generator and refrigeration unit, mechanically connected in tandem to satisfy a combination of site electric and cooling requirements, or
- a generator alone, with the refrigeration unit driven by an electric motor supplied from the generator.

This option will perform similar to Option No. 5. However, the fuel consumption may be reduced as the single engine of this option may run more fully loaded as compared with the multiple engines of Option No. 5.

Rejected engine heat is transferred through the heat exchanger to the hot water system for use in one or more of the following circuits:

- to the site directly to satisfy heating requirements.

- to the storage tank for future use when the heating demand exceeds the available heat from the engine.
- to the heat rejector for removal of excess heat.

1.6 Option No. 6A

Similar to Option No. 6, except heat storage capability is not provided. Hence a supplementary heater must be added to make up for the insufficiency of engine heat at certain winter hours.

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2. EQUIPMENT SIZES

2.1 Options No. 4 and 4A

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For electric generation and heating:			
1. Stirling Engine	3	1110 kW	-
2. Generator	3	1000 kW	-
3. Jacket Water Pump	3	15 hp	-
4. Hot Water Pump	3	40 hp	17 kW
5. Heat Rejector	1	30 hp	20 kW
6. Storage Tank	1	900 gal	-
7. Resistance Heater		30 kW	-
For cooling:			
8. Absorption Unit	2	320 t	-
9. Chilled Water Pump	2	40 hp	13 kW
10. Condenser Water Pump	2	40 hp	22 kW
11. Solution Pump	2	7-1/2 hp	7 kW
12. Cooling Tower	2	2 @ 20 hp	2 @ 15 kW

2.2 Options No. 5 and 5A

For electric generation and heating:

1. Stirling Engine	3	1110 kW	-
2. Generator	3	1000 kW	-
3. Jacket Water Pump	3	15 hp	-
4. Hot Water Pump	3	40 hp	17 kW
5. Heat Rejector	1	40 hp	22 kW
6. Storage Tank	1	900 gal	-
7. Resistance Heater		30 kW	-

For cooling:

8. Stirling Engine	2	225 kW	
9. Refrigeration Unit	2	320 t	
10. Jacket Water Pump	2	5 hp	2 kW
11. Heat Rejector	1	3 hp	2 kW
12. Chilled Water Pump	2	40 hp	13 kW
13. Condenser Water Pump	2	15 hp	10 kW
14. Cooling Tower	2	25 hp	19 kW

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2.3 Options No. 6 and 6A

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For electric generation and heating:			
1. Stirling Engine	3	1110 kW	-
2. Generator	3	1000 kW	-
3. Jacket Water Pump	3	15 hp	-
4. Hot Water Pump	3	40 hp	17 kW
5. Heat Rejector	1	40 hp	22 kW
6. Storage Tank	1	900 gal	
7. Resistance Heater		30 kW	
For cooling:			
8. Electric Motor	2	400 hp	-
9. Refrigeration Unit	2	320 t	
10. Chilled Water Pump	2	40 hp	13 kW
11. Condenser Water Pump	2	15 hp	10 kW
12. Cooling Tower	2	25 hp	19 kW

TABLE NO. 2

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Job	Sheet no.	of	sheets
System	By	Date	

ANCHORAGE

EQUIPMENT SIZING ASSUMPTIONS

EQUIPMENT	PARAMETERS	OPTION 4 & 4A	OPTION 5 & 5A	OPTION 6 & 6A
• STIRLING ENGINE	DESIGN HOUR	JULY, 16TH HOUR		→
• GENERATOR	DESIGN HOUR	JULY, 16TH HOUR		→
	EFFICIENCY	93%		→
• JACKET WATER PUMP	HEAT	7,169,400 BTH		→
	ΔT	15°		→
	HEAD	50'		→
• HOT WATER PUMP	HEAT	7,169,400 BTH		→
	ΔT	20°		→
	HEAD	135'		→
• ABSORPTION UNIT	DESIGN HOUR	EXTREME SITE COOLING LOAD FOR JULY	-	-
• CHILLED WATER PUMP	COOLING	3,840,000 BTH		→
	ΔT	14°		→
	HEAD	125'		→
• CONDENSER WATER PUMP	HEAT REJECTED	3200 BTH/TON OF REFR. 10,240,000 BTH	15000 BTH/TON OF REFR. 4,800,000 BTH	→
	ΔT	18°	19°	→
	HEAD	100'	100'	→
• SOLUTION PUMPS	DESIGN SIZE	MFG. PACKAGE WITH ABSORPTION UNIT	-	-
• COOLING TOWER	DESIGN CONDITIONS	63° WB		→
	GPM	1138	533	533
	ΔT	18°		→
• STORAGE TANK	ΔT	50°		→
• STEEL. ENG. FOR REFRIG.	DESIGN SIZE	-	.83 HP/TON	→
• CENTRIFUGAL REFR. MACHING	PEAK DESIGN SIZE	-	SAME LOAD AS ABSORPTION UNIT	→
• JACKET WATER PUMP FOR REFR. S.E.	HEAT	-	1,523,110 BTH	→
	ΔT	-	15°	→
	HEAD	-	50'	→
• HEAT REJECTOR FOR REFR. GEN	ΔT AIR	80°		→
• STEEL. ENG.	ΔT WATER	40°		→
	FACE VELOCITY	D-1120		→

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sheets

Date _____

HEAT REJECTOR FOR STIR. ENG	ΔT_{AIR}	-	80	→
FOR REFRIG	ΔT_{WATER}	-	40	→
RESISTANCE	FACE VELOCITY	-	1000	→
HEATER	DESIGN LOAD	$\frac{1}{3}$ OF MAXIMUM		→
CENTRAL	LIGHTS	5 KW		→
PLANT	VENTILATION	8 KW		→
LOADS	HEATING	95 KW		→

NOTES

- #1 DISTRIBUTION LOSSES ASSUMED TO BE PART OF SITE DEMANDS
- #2 HEAT REJECTED FROM ABSORPTION UNIT & REFRIGERATION UNIT ASSUMED TO BE DIRECTLY PROPORTIONAL TO LOAD

APPENDIX E

Conceptual Designs for Hospital Site

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CONCEPTUAL DESIGNS FOR HOSPITAL SITE

1. DESCRIPTION OF OPTIONS

The total energy system options conceptualized for the hospital located at the Fairfield, California site are as follows:

1.1 Option No. 7

The Stirling engine with an operating temperature of 120°C drives a generator to satisfy the site electrical requirements. Heat rejected from the engine is transferred through the heat exchanger to the hot water system. The hot water can take one or more of the following circuits by means of valve control:

- to the site directly to satisfy heating requirements.
- to the heat rejector for removal of excess heat.
- to the storage tank for future use as a source for heating or cooling depending on site demands.

1.2 Option No. 7A

Similar to Option No. 7, except heat storage capability is not provided, necessitating the increased use of the heat rejector and the supplementary heater.

1.3 Option No. 8

This site differs from the other sites, in that both cooling and heating are simultaneously required on site with an insufficient engine-generator operating capacity to satisfy all needs. To meet this situation, the following option is presented. A Stirling engine with an operating temperature of 120°C drives a refrigeration unit to satisfy the site cooling requirements in January, in order to provide sufficient waste heat to the engine-generator set to meet the simultaneous site heating requirements. This situation can be seen in the tabulated data.

The hot water flows through circuits as described in Option No. 7. The chilled water circuit contains a chilled water

storage tank to reduce the size of the refrigeration unit. Under this option, the undersized refrigeration unit would operate for the full 24 hours at full load, storing chilled water for use at times when the site demand exceeds the equipment size.

During the remaining typical, seasonal days, the refrigeration unit would supplement the absorption unit to satisfy the site cooling demands.

1.4 Option No. 8A

Similar to Option No. 8, except heat storage and chilled water storage capabilities are not provided, necessitating the increased use of heat rejectors and supplementary heaters. In addition, the refrigeration unit must be sized to handle the peak January demand.

1.5 Option No. 9

Stirling engines with operating temperatures of 80°C drive separately a generator and a refrigeration unit. The combined heat rejected from the engines is transferred through the heat exchanger to the hot water system where it can be:

- used to satisfy the site heating demands directly.
- rejected through the heat rejection system
- stored for future use.

The refrigeration unit with chilled water storage capability would be undersized and operated continuously in conjunction with the stored water to satisfy the site cooling demands.

Inherent in this design is the capability of satisfying the site heating requirements without the addition of a separate supplementary heater. The cooling system provides the supplementary heat.

1.6 Option No. 9A

Similar to Option No. 9, except heat storage and chilled water storage capabilities are not provided, necessitating the addition of a supplementary heating source, increased refrigeration unit size and the increased use of supplementary and rejection equipment.

1.7 Option No. 10

A Stirling engine with an operating temperature of 80°C drives a generator to satisfy the site electrical demands. Heat rejected from the engine is transferred through a heat exchanger to the hot water system. The hot water can take one or more of the following circuits:

- to the site directly to satisfy heating requirements.
- to the heat rejector for removal of excess heat.
- to the supplementary heat exchanger for the addition of heat to satisfy site heating demands, as required.

In lieu of a Stirling engine drive, as in Options 8, 8A, 9 and 9A for a refrigeration unit, this option considers the use of a boiler to:

- generate heat (in the form of steam or hot water) to operate a steam or hot water absorption chilling unit to satisfy the site cooling requirements.
- generate supplementary heat (in the form of steam or hot water) to satisfy the site heating demands when the engine-generator heat is insufficient.

Heat and/or chilled water storage is not indicated as an option. However, should this Option No. 10 prove economically feasible in the later phases of the study, storage should be considered as a means of reducing equipment sizes.

1.8 Option No. 11

Similar to Option No. 9, except the refrigeration units are motor-driven.

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2. EQUIPMENT SIZES

2.1 Options No. 7 and 7A

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For electric generation and heating:			
1. Stirling Engine	9	1110 kW	-
2. Generator	9	1000 kW	-
3. Jacket Water Pump	9	15 hp	-
4. Hot Water Pump	9	30 hp	13 kW
5. Supplemental Hot Water Pump	1	10 hp	7 kW
6. Heat Rejector	1	29 @ 5 hp	29 @ 3 kW
7. Boiler	1	700 bhp	-
8. Boiler Draft Fan	1	30 hp	22 kW
9. Boiler Feed Pump	1	1 hp	1 kW
10. Storage Tank	1	170,000 gal	-

For cooling:

11. Absorption Unit	3	798 t	-
12. Chilled Water Pump	3	60 hp	32 kW
13. Condenser Water Pump	3	100 hp	48 kW
14. Solution Pump	3	15 hp	11 kW
15. Cooling Tower	3	3 @ 40 hp	3 @ 30 kW

2.2 Options No. 8 and 8A

For electric generation and heating:

1. Stirling Engine	9	1110 kW	-
2. Generator	9	1000 kW	-
3. Jacket Water Pump	9	15 hp	-
4. Hot Water Pump	9	30 hp	13 kW
5. Supplemental Hot Water Pump	1	10 hp	7 kW
6. Heat Rejector	1	29 @ 5 hp	29 @ 3 kW
7. Boiler	1	700 bhp	-
8. Boiler Draft Fan	1	30 hp	22 kW
9. Boiler Feed Pump	1	1 hp	1 kW
10. Storage Tank	1	140,000 gal	-

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2.2 Options No. 8 and 8A (Cont.)

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For cooling:			
11. Absorption Unit	3	798 t	-
12. Chilled Water Pump	3	60 hp	32 kW
13. Condenser Water Pump #2	3	100 hp	48 kW
14. Solution Pump	3	15 hp	11 kW
15. Cooling Tower #1	3	3 @ 40 hp	3 @ 30 kW

(Option No. 8)

16. Stirling Engine	1	53 kW	
17. Refrigeration Unit	1	80 t	
18. Chilled Water Pump #2	1	5 hp	3 kW
19. Condenser Water Pump #1	1	5 hp	2 kW
20. Cooling Tower #2	1	7-1/2 hp	6 kW
21. Chilled Water Storage Tank	1	50,000 gal	-
22. Jacket Water Pump	1	1 hp	-

(Option No. 8A)

23. Stirling Engine	1	210 kW	-
24. Refrigeration Unit	1	320 t	-
25. Chilled Water Pump #2	1	30 hp	13 kW
26. Condenser Water Pump #2	1	15 hp	7 kW
27. Cooling Tower #1	1	25 hp	19 kW
28. Jacket Water Pump	1	2 hp	1 kW
29. Hot Water Pump	1	5 hp	3 kW

2.3 Option No. 9

For electric generation and heating:

1. Stirling Engine	9	1110 kW	-
2. Generator	9	1000 kW	-
3. Jacket Water Pump	9	15 hp	-
4. Hot Water Pump	9	30 hp	13 kW
5. Heat Rejector	1	23 @ 20 hp	23 @ 11 kW
6. Storage Tank	1	140,000 gal	

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2.3 Option No. 9 (Cont.)

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For cooling:			
7. Stirling Engine	2	375 kW	-
8. Jacket Water Pump	2	5 hp	-
9. Refrigeration Unit	2	550 t	-
10. Chilled Water Pump	2	75 hp	45 kW
11. Condenser Water Pump	2	30 hp	16 kW
12. Cooling Tower	2	2 @ 20 hp	2 @ 15 kW
13. Chilled Water Storage Tank	1	420,000 gal	-
14. Hot Water Pump	2	7-1/2 hp	5 kW

2.4 Option No. 9A

For electric generation and heating:

1. Stirling Engine	9	1110 kW	-
2. Generator	9	1000 kW	-
3. Jacket Water Pump	9	15 hp	-
4. Hot Water Pump	9	30 hp	13 kW
5. Heat Rejector	1	27 @ 15 hp	27 @ 11 kW
6. Boiler	1	700 bhp	-
7. Boiler Draft Fan	1	30 hp	22 kW
8. Boiler Feed Pump	1	1 hp	1 kW

For cooling:

9. Stirling Engine	3	560 kW	-
10. Jacket Water Pump	3	7 1/2 hp	-
11. Refrigeration Unit	3	798 t	-
12. Chilled Water Pump	3	60 hp	32 kW
13. Condenser Water Pump	3	40 hp	23 kW
14. Cooling Tower	3	4 @ 15 hp	4 @ 12 kW
15. Hot Water Pump	3	15 hp	7 kW

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2.5 Option No. 10

<u>Equipment</u>	<u>Number of Units</u>	<u>Unit Size</u>	<u>Operating Demand</u>
For electric generation and heating:			
1. Stirling Engine	9	1110 kW	-
2. Generator	9	1000 kW	-
3. Jacket Water Pump	9	15 hp	-
4. Hot Water Pump	9	30 hp	13 kW
5. Heat Rejector	1	22 @ 20 hp	22 @ 11 kW

For cooling:

6. Boiler	2	700 bhp	-
7. Boiler Draft Fan	2	30 hp	22 kW
8. Boiler Feed Pump	2	11 hp	1 kW
9. Hot Water Pump	2	50 hp	22 kW
10. Absorption Unit	2	798 t	-
11. Chilled Water Pump	3	60 hp	32 kW
12. Condenser Water Pump	3	100 hp	48 kW
13. Solution Pump	3	15 hp	11 kW
14. Cooling Tower	3	3 @ 40 hp	3 @ 30 kW

2.6 Option No. 11

For electric generation and heating:

1. Stirling Engine	9	1110 kW	-
2. Generator	9	1000 kW	-
3. Jacket Water Pump	9	15 hp	-
4. Hot Water Pump	9	30 hp	13 kW
5. Heater Rejector	1	23 @ 20 hp	23 @ 11 kW
6. Storage Tank	1	140,000 gal	-

For cooling:

7. Electric Motor	2	375 kW	-
8. Refrigeration Unit	2	550 t	-
9. Chilled Water Pump	2	75 hp	45 kW
10. Condenser Water Pump	2	30 hp	16 kW
11. Cooling Tower	2	2 @ 20 hp	2 @ 15 kW
12. Chilled Water Storage Tank	1	420,000 gal.	-

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TABLE NO 3

Job	Sheet no.	of	sheets
System FAIRFIELD SITE	By	Date	

EQUIPMENT SIZING ASSUMPTIONS

EQUIPMENT	PARAMETERS	OPTION 7 & 7A	OPTION 8 & 8A	OPTION 9 & 9A	OPTION 10
STIRLING ENGINE GENERATOR	DESIGN HR DESIGN HR EFFICIENCY	JULY 13 TH HR JULY 13 TH HR 95%	JULY 13 TH HR JULY 13 TH HR 95%	JULY 13 TH HR JULY 13 TH HR 95%	JULY 13 TH HR JULY 13 TH HR 95%
JACKET WATER PUMP	HEAT ΔT HEAD	7,169,400 BTUH 15° 50'	7,169,400 BTUH 15° 50'	7,169,400 BTUH 15° 50'	7,169,400 BTUH 15° 50'
HOT WATER PUMP	HEAT ΔT HEAD	7,169,400 BTUH 20° 100'	7,169,400 BTUH 20° 100'	7,169,400 BTUH 20° 100'	7,169,400 BTUH 20° 100'
SUPPLEMENTAL HOT WATER PUMP	DESIGN HR HEAT ΔT HEAD	JULY HR #13 3,834,000 BTUH 20° 100'	JULY HR #13 3,834,000 BTUH 20° 100'	- - -	- - -
HOT WATER STORAGE TANK	ΔT	50°	50°	50°	-
ABSORPTION UNIT	DESIGN HR	EXTREME SITE COOLING LOAD FOR JULY	EXTREME SITE COOLING LOAD FOR JULY	-	EXTREME SITE COOLING LOAD FOR JULY
CHILLED WATER PUMP	COOLING ΔT HEAD	9,576,000 BTUH 14° 125'	9,576,000 BTUH 14° 125'	- - -	9,576,000 BTUH 14° 125'
CONDENSER WATER PUMP	HEAT ΔT HEAD	32,000 $\frac{BTUH}{TON}$ 25,336,000 BTUH 18°	32,000 $\frac{BTUH}{TON}$ 25,336,000 BTUH 18°	- - -	32,000 $\frac{BTUH}{TON}$ 25,336,000 BTUH 18°
SOLUTION PUMP	SELECTION	INCLUDED BY MFG. WITH ABSORP. MACH.	INCLUDED BY MFG. WITH ABSORP. MACH.	-	INCLUDED BY MFG. WITH ABSORP. MACH.
COOLING TOWER	DESIGN GPM ΔT	71°WB 2837 18°	71°WB 2837 18°	- - -	71°WB 2837 18°
HEAT REJECTOR	ΔT_{AIR} ΔT_{WATER} FACE VEL	40° 30° 1000 fpm E-14	40° 30° 1000 fpm	40° 40° 1000 fpm	40° 40° 1000 fpm

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cb		Sheet no.		of		sheets
System		By		Date		
BOILER BOILER DRAFT FAN & FUEL PUMP	DESIGN H ₂	JAN. 7 TH H ₂ INCLUDED BY MFG WITH BOILER	JAN. 7 TH H ₂ INCLUDED BY MFG WITH BOILER	JAN. 7 TH H ₂ INCLUDED BY MFG WITH BOILER	JULY 13 TH H ₂ INCLUDED BY MFG WITH BOILER	
CENTRIFUGAL REFRIGERATION MACHINE	DESIGN H ₂	-	OPT B: JAN HOURLY AVG. COOLING REQMT OPT BA: JAN, H ₂ #18	OPT C: JULY HOURLY AVG. COOLING REQMT OPT CA: EXTREME SITE COOLING LOAD FOR JULY	-	
STIRLING ENGINE FOR REFRIGERATION	POWER REQMT	-	.88 HP/TON	.88 HP/TON	-	
CHILLED WATER PUMP	COOLING	-	OPT B: 100,000 BTUH OPT BA: 3,840,000 BTUH 14°	OPT C: 13,200,000 BTUH OPT CA: 9,576,000 BTUH 14°	-	
JACKET WATER PUMP FOR REFR.	ΔT HEAD	-	125'	125'	-	
STIRLING ENGINE	HEAT	-	OPT B: 361,884 BTUH OPT CA: 1,433,360 BTUH 15°	OPT C: 2,500,500 BTUH OPT CA: 3,330,200 BTUH 15°	-	
HOT WATER PUMP FOR REFRIG	ΔT HEAD	-	30'	40'	-	
CONDENSER WATER PUMP	HEAT	-	OPT B: 361,884 BTUH OPT CA: 1,433,360 BTUH 20°	OPT C: 2,500,500 BTUH OPT CA: 3,330,200 BTUH 20°	-	
COOLING TOWER FOR REFRIG. MACH	ΔT HEAD	-	100'	100'	-	
HILLED WATER STORAGE TANK	HEAT	-	15000 BTUH / TON	15000 BTUH / TON	-	
	ΔT HEAD	-	OPT B: 1,200,000 BTUH OPT CA: 4,800,000 BTUH 18°	OPT C: 8,257,000 BTUH OPT CA: 11,970,000 BTUH 18°	-	
	DESIGN GPM	-	70'	90'	-	
	ΔT SIZING	-	71°WB OPT B: 134 GPM OPT CA: 534 GPM	71°WB OPT C: 917 GPM OPT CA: 1322 GPM	-	
		E-15	50 GALS / TON	50 GALS / TON	-	

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Job	Sheet no.	of	sheets
System	By	Date	

CENTRAL PLANT LOADS:	LIGHTS	10kw	10kw	10kw	10kw
	VENTILATION	20kw	20kw	20kw	20kw
	HEATING	0 kw	0kw	0kw	0 kw

APPENDIX F

Performance Calculation Sheets

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PERFORMANCE CALCULATION TABULATIONS

Definition of column titles for following performance tables.

1. Hour. Time of day.
2. Heat Load. Includes heat required for site plus heating of plant. In conventional system, heat load includes only heat required for site.
3. Refrigeration Load. Cooling requirements for site.
4. Refrigeration Load. Refrigeration load divided by capacity of refrigeration unit (or units) employed.
5. Refrigeration Capacity Factor. Part-load performance characteristics of refrigeration unit, whether absorption type or mechanical refrigeration type.
6. Power for Refrigeration. Defined as:

$$\frac{\% \text{ refrig. load (Col. 4)} \times \text{Refrig. capacity factor (Col. 5)}}{0.6 \text{ (coef. of performance)}}$$
 for an absorption unit, and

$$\frac{\% \text{ refrig. load (Col. 4)} \times \text{Refrig. capacity factor (Col. 5)}}{2.06 \text{ (coef. of performance)}}$$
 for a motor-driven refrigeration unit.
7. Site Electric Load. Site electrical demand.
8. Central Plant Load. Electric power needed for lighting and ventilation of plant.
9. Auxiliary Loads. Consists of electrical power required to operate system components, including the following: hot water pump, boiler draft fan, boiler fuel pump, heat rejection, chilled water pump, condenser water pump, and cooling tower, whenever they are functioning.
10. Electric Boiler Load. Electrical power required for supplementary heating in those options where an electric boiler is used.
11. Total Electric Load. Sum of following: site electric load, central plant load, auxiliary loads, electric boiler load (if one is used), and power for refrigeration (if a mechanical refrigeration unit is employed).
12. Number of Operational Units. Number of Stirling engine/generators activated.

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13. Generator Capacity. Total electric load divided by capacity of engine/generators activated.
14. Heat Recovery Factor. Obtained from shaft efficiency and combustion chamber/auxiliary load inefficiency characteristics for Stirling engine. It is number of kW of heat recoverable per kW shaft load.
15. Total Recoverable Heat. Rate at which heat is recovered from Stirling engine (or engines). It is calculated as:
- $$\frac{\text{Heat recovery factor (Col. 4)} \times \text{Total electric load (Col. 11)}}{0.9 \text{ (generator eff.)}}$$
16. Total Heat Load. Sum of all heat requirements. These include site plus plant, and heat required for cooling when an absorption unit is employed.
17. Heat Rejection. Rate at which heat is rejected to atmosphere (Col. 15-16). Where a parenthesis is shown, that heat is not rejected, but indicates rate at which heat is put into storage (in those options where storage capability is assumed).
18. Supplementary Heat Required. Rate at which supplementary heat is required whether from a fuel-fired boiler, an electric boiler, or from a storage tank (Col. 16-15).
19. Engine Efficiency. Shaft efficiency vs. part-load percentage and heat recovery temperature of the Stirling engine. This part-load percentage is obtain from Col. 13.
20. Fuel Consumption Rate. Rate at which fuel energy is consumed by Stirling engine (or engines). It is calculated from:

$$\frac{\text{Total electric load (Col. 11)}}{0.9 \text{ (generator eff.)} \times \text{Engine eff. (Col. 19)}}$$

Fuel Energy Required for Boiler. (a) For conventional system is summation of Col. 2 divided by assumed boiler efficiency of 0.8, (b) for a Stirling total energy system is summation of Col. 18 divided by 0.8 (when a fuel-fired boiler is assumed).

Fuel Energy Required for Utility Plant. Pertains only to conventional system. It is summation of Col. 11 divided by 0.3, the assumed efficiency of the utility plant in generating and transmitting electric power.

Total Fuel Energy Required. (a) for conventional system is addition of fuel energy required for boiler and fuel energy required for utility plant; (b) for Stirling total energy system is summation of Col. 20 plus fuel energy required for boiler (if a fuel-fired boilers is assumed).

SITE: Jersey CityOPTION: 1AMONTH: January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	2835	0	0	0	0	590	20	34		644	2	64.4	1.65	1181		0	1204	33.3	2149
2	2261					540				594		59.4	1.67	1102			1159	33.2	1988
3	2206					530				584		58.4	1.68	1090			1116	33.1	1960
4	2261					525				579		57.9	1.68	1081			1180	33.1	1944
5	2291					530				584		58.4	1.68	1090			1201	33.1	1960
6	2396					555				609		60.9	1.67	1130			1266	33.2	2038
7	2606					620				674		67.4	1.63	1221			1385	33.4	2242
8	2895					655				709		70.9	1.62	1276			1619	33.4	2359
9	3151					650				704		70.4	1.62	1267			1884	33.4	2342
10	3028					660				714		71.4	1.61	1277			1751	33.4	2375
11	2948					680				734		73.4	1.61	1313			1635	33.5	2434
12	2799					680				734		73.4	1.61	1313			1486	33.5	2434
13	2784					670				724		72.4	1.61	1295			1489	33.5	2401
14	2660					685				739		73.9	1.61	1322			1338	33.5	2451
15	2506					700				754		75.4	1.60	1340			1166	33.5	2501
16	2551					740				794		79.4	1.59	1403			1148	33.6	2626
17	2656					845				899		89.9	1.56	1558			1098	33.6	2973
18	2850					915				969		96.9	1.53	1647			1203	33.6	3204
19	3138					905				959		95.9	1.53	1630			1508	33.6	3171
20	3177					870				924		92.4	1.54	1581			1596	33.6	3056
21	3014					850				904		90.4	1.56	1567			1447	33.6	2989
22	2934					805				859		85.9	1.57	1498			1436	33.6	2841
23	2780					730				784		78.4	1.59	1385			1395	33.6	2593
24	2679					660				714		71.4	1.61	1277			1402	33.4	2375
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma =$	33,112		$\Sigma =$ 59,406

Fuel Energy Req'd. for
Boiler = 41,390 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 100,796 kW-h

SITE: Jersey CityOPTION: 1AMONTH: April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Reccv. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Ccns. Rate (kW)
1	1559	0	0	0	0	520	20	25		565	2	56.5	1.69	1061		0	498	33.0	1902
2	1484					480				525		52.5	1.72	1003			481	32.8	1778
3	1433					465				510		51.0	1.73	930			453	32.7	1733
4	1469					465				510		51.0	1.73	930			489	32.7	1733
5	1433					470				515		51.5	1.73	930			443	32.7	1750
6	1518					495				540		54.0	1.71	1026			492	32.8	1829
7	1675					530				575		52.5	1.72	1099			576	33.0	1936
8	1804					570				615		61.5	1.66	1134			670	33.2	2058
9	2026					600				645		64.5	1.65	1183			844	33.3	2152
10	1881					600				645		64.5	1.65	1182			699	33.3	2152
11	1765					610				655		65.5	1.64	1197			571	33.3	2186
12	1665					615				660		66.0	1.64	1206			462	33.3	2202
13	1625					610				655		65.5	1.64	1197			431	33.3	2186
14	1509					605				650		65.0	1.64	1188			325	33.3	2169
15	1424					610				655		65.5	1.64	1157			230	33.3	2186
16	1454					640				685		68.5	1.63	1244			213	33.4	2279
17	1494					685				730		73.0	1.61	1309			188	33.5	2421
18	1669					750				795		79.5	1.58	1399			273	33.5	2637
19	1885					780				825		82.5	1.58	1452			437	33.6	2728
20	1935					780				825		82.5	1.58	1452			487	33.6	2728
21	1865					755				800		80.0	1.58	1403			461	33.6	2646
22	1779					730				775		77.5	1.59	1373			416	33.5	2570
23	1679					675				720		72.0	1.61	1292			391	33.5	2388
24	1725					600				645		64.5	1.64	1179			550	33.3	2152
$\Sigma =$																	$\Sigma = 11,071$		$\Sigma = 52,503$

Fuel Energy Req'd. for
Boiler = 13,842 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 66,345 kW-h

SITE: Jersey CityOPTION: 1AMONTH: AUGUST

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	311	265	53.9	53.0	435	395	20	42		457	1	91.4	1.88	955	746	209	0	29.7	1701
2	283	255	51.8	51.0	418	370		42		432	1	86.4	1.90	912	701	211		29.7	1616
3	254	255	51.8	51.0	418	350		42		412	1	82.4	1.91	874	672	202		29.7	1541
4	283	245	49.8	49.0	402	335		42		397	1	79.4	1.92	847	685	162		29.7	1485
5	254	235	47.8	47.5	390	340		42		402	1	80.4	1.92	858	644	214		29.7	1504
6	254	220	44.7	45.0	369	345		42		407	1	81.4	1.92	868	623	245		29.7	1523
7	283	215	43.7	44.0	361	380		42		442	1	88.4	1.89	928	644	284		29.7	1654
8	339	220	44.7	45.0	369	410		42		472	1	94.4	1.88	986	708	278		29.7	1766
9	565	225	45.7	46.0	377	430		50		500	1	100.0	1.86	1033	942	91		29.7	1871
10	509	235	47.8	47.5	390	500		50		562	2	56.2	2.02	1261	899	362		29.4	2124
11	452	260	52.8	52.5	431	520		50		590	2	59.0	2.01	1318	883	435		29.4	2230
12	396	300	61.0	59.0	484	490		50		560	2	56.0	2.02	1257	880	377		29.4	2116
13	396	325	66.1	64.0	525	480		50		550	2	55.0	2.03	1241	921	320		29.3	2086
14	339	340	69.1	67.0	549	480		50		550	2	55.0	2.03	1241	888	353		29.3	2086
15	283	350	71.1	69.0	566	480		50		550	2	55.0	2.03	1241	849	392		29.3	2086
16	283	360	73.2	71.0	582	540		50		610	2	61.0	2.00	1356	865	491		29.4	2305
17	283	360	73.2	71.0	582	575		50		645	2	64.5	1.98	1419	865	554		29.5	2429
18	339	345	70.1	68.0	558	615		50		685	2	68.5	1.97	1499	897	602		29.6	2571
19	452	335	68.1	66.0	541	620		50		690	2	69.0	1.97	1510	993	517		29.6	2590
20	480	320	65.0	63.0	517	610		50		680	2	68.0	1.97	1488	997	491		29.6	2553
21	424	315	64.0	62.0	508	610		50		680	2	68.0	1.97	1488	932	556		29.6	2553
22	367	310	63.0	61.0	500	585		50		655	2	65.5	1.98	1441	867	574		29.6	2459
23	311	305	62.0	60.0	492	530		50		600	2	60.0	2.00	1333	803	530		29.4	2268
24	396	285	57.9	56.5	456	465		50		535	2	53.5	2.04	1213	852	361		29.3	2029

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 49,146$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 49,146 kW-h

SITE: Jersey CityOPTION: 1AMONTH: November

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1515	0	0	0	0	510	20	25		555	2	55.5	1.70	1048		0	467	33.0	1869
2	1461					475		25		520	2	52.0	1.72	994			467	32.8	1762
3	1391					470		25		515	2	51.5	1.72	984			407	32.7	1750
4	1401					465		25		510	2	51.0	1.73	980			421	32.7	1733
5	1401					455		17		492	1	98.4	1.52	831			570	33.6	1627
6	1481					480		25		525	2	52.5	1.72	1003			478	32.8	1778
7	1601					550		25		595	2	59.5	1.67	1104			497	33.1	1997
8	1880					570		25		615	2	61.5	1.66	1134			747	33.2	2058
9	2176					525		25		570	2	57.0	1.69	1070			1106	33.0	1919
10	2043					535		25		580	2	58.0	1.68	1083			960	33.1	1947
11	1933					570		25		615	2	61.5	1.66	1134			799	33.2	2058
12	1779					570		25		615	2	61.5	1.66	1134			645	33.2	2058
13	1664					560		25		605	2	60.5	1.68	1129			535	33.2	2025
14	1630					540		25		585	2	58.5	1.68	1092			538	33.1	1964
15	1591					540		25		585	2	58.5	1.68	1092			499	33.1	1964
16	1621					600		25		645	2	64.5	1.65	1183			439	33.3	2152
17	1696					720		25		765	2	76.5	1.60	1360			336	33.5	2537
18	1850					805		25		850	2	85.0	1.57	1483			367	33.6	2811
19	2048					790		25		835	2	83.5	1.57	1457			591	33.6	2761
20	2117					760		25		805	2	80.5	1.58	1413			704	33.6	2662
21	2039					720		25		765	2	76.5	1.60	1360			679	33.5	2537
22	1909					685		25		730	2	73.0	1.61	1306			603	33.5	2421
23	1810					650		25		695	2	69.5	1.62	1251			559	33.4	2312
24	1779					580		25		625	2	62.5	1.66	1153			626	33.2	2092
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma = 14,140$		$\Sigma = 50,794$	

Fuel Energy Req'd. for
Boiler = 17,675 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 68,469 kW-h

SITE: Jersey CityOPTION: 1A-1MONTH: JANUARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	2385	0	0	0	0	590	20	36	391	1037	3	69.1	1.73	1993			391	32.2	3578
2	2261					540		36	371	967	3	64.5	1.76	2262			371	32.0	3358
3	2206					530		24	423	997	2	99.7	1.61	2206			423	32.6	3398
4	2261					525		36	381	960	3	64.1	1.76	2262			381	32.0	3340
5	2291					530		36	387	973	3	64.7	1.76	2290			387	32.0	3378
6	2396					555		36	418	1029	3	68.6	1.73	2396			418	32.2	3551
7	2606					620		36	458	1144	3	76.3	1.69	2606			458	32.4	3923
8	2895					655		36	557	1268	3	84.5	1.66	2896			557	32.6	4322
9	3151					650		36	659	1365	3	91.0	1.64	3147			659	32.6	4652
10	3028					660		36	611	1327	3	87.5	1.64	3029			611	32.6	4523
11	2948					680		36	564	1300	3	86.7	1.65	2947			564	32.6	4431
12	2799					680		36	506	1241	3	82.7	1.66	2795			506	32.5	4243
13	2784					670		36	503	1229	3	81.9	1.67	2783			503	32.5	4202
14	2660					685		36	450	1191	3	79.4	1.67	2660			450	32.5	4072
15	2506					700		36	381	1133	3	75.5	1.68	2504			381	32.3	3897
16	2551					740		36	372	1168	3	77.9	1.68	2552			372	32.4	4005
17	2656					845		36	350	1251	3	83.4	1.68	2657			350	32.5	4277
18	2850					915		36	388	1359	3	90.5	1.63	2849			388	32.6	4632
19	3138					905		36	509	1472	3	98.0	1.61	3139			509	32.6	5017
20	3177					870		36	545	1471	3	98.1	1.61	3176			545	32.6	5014
21	3014					850		36	489	1395	3	93.0	1.63	3015			489	32.6	4755
22	2934					805		36	484	1345	3	89.7	1.64	2935			484	32.6	4584
23	2780					730		36	468	1254	3	83.6	1.66	2781			468	32.5	4287
24	2679	↓	↓	↓	↓	660	↓	36	468	1184	3	78.9	1.68	2678			468	32.5	4048

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 99,487$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 99,487 kW-h

SITE: Jersey CityOPTION: 1A-1MONTH: April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1559	0	0	0	0	520	20	24	168	732	2	73.2	1.71	1559			168	32.3	2518
2	1484					480			163	687		68.7	1.73	1484			163	32.2	2371
3	1433					465			151	660		66.0	1.75	1434			151	32.0	2292
4	1469					465			165	674		67.4	1.74	1468			165	32.3	2319
5	1433					470			147	661		66.1	1.75	1432			147	32.0	2295
6	1518					495			168	707		70.7	1.72	1519			168	32.0	2455
7	1674					530			210	784		78.4	1.68	1673			210	32.4	2687
8	1804					570			239	853		85.3	1.65	1803			239	32.6	2907
9	2026					600			310	954		95.4	1.62	2027			310	32.6	3252
10	1881					600			251	895		89.5	1.64	1882			251	32.6	3050
11	1765					610			200	854		85.4	1.65	1766			200	32.6	2911
12	1665					615			155	814		81.4	1.67	1665			155	32.5	2783
13	1625					610			144	798		79.8	1.67	1625			144	32.5	2728
14	1509					605			98	747		74.7	1.70	1509			98	32.3	2570
15	1424					610			60	714		71.4	1.72	1425			60	32.3	2456
16	1454					640			56	740		74.0	1.70	1454			56	32.3	2546
17	1494					685			46	775		77.5	1.68	1493			46	32.4	2658
18	1669					750			75	869		86.9	1.68	1668			75	32.6	2962
19	1885					780			144	968		96.8	1.62	1886			144	32.6	3299
20	1935					780			165	989		98.9	1.61	1934			165	32.6	3371
21	1865					755			152	951		95.1	1.62	1864			152	32.6	3241
22	1779					730			134	908		90.8	1.62	1779			134	32.6	3095
23	1679					675			124	843		84.3	1.66	1679			124	32.6	2873
24	1725					600			189	833		83.3	1.66	1725			189	32.5	2814

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 66,453$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 66,453 kW-h

SITE: Jersey CityOPTION: 1A-1MONTH: AUGUST

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	311	265	53.9	53.0	435	395	20	42		457	1	91.4	1.83	955	746	209	0	29.7	1701
2	283	255	51.8	51.0	418	370		42		432	1	86.4	1.90	912	701	211		29.7	1616
3	254	255	51.8	51.0	418	350		42		412	1	82.4	1.91	874	672	202		29.7	1541
4	283	245	49.8	49.0	402	335		42		397	1	79.4	1.92	847	685	162		29.7	1485
5	254	235	47.8	47.5	390	340		42		402	1	80.4	1.92	858	644	214		29.7	1504
6	254	220	44.7	45.0	369	345		42		407	1	81.4	1.92	868	623	245		29.7	1523
7	283	215	43.7	44.0	361	380		42		442	1	88.4	1.89	928	644	284		29.7	1654
8	339	220	44.7	45.0	369	410		42		472	1	94.4	1.88	986	708	278		29.7	1766
9	565	225	45.7	46.0	377	430		50		500	1	100.0	1.86	1033	942	91		29.7	1871
10	509	235	47.8	47.5	390	500		50		562	2	56.2	2.02	1261	899	362		29.4	2124
11	452	260	52.8	52.5	431	520		50		590	2	59.0	2.01	1318	883	435		29.4	2230
12	396	300	61.0	59.0	484	490		50		560	2	56.0	2.02	1257	880	377		29.4	2116
13	396	325	66.1	64.0	525	480		50		550	2	55.0	2.03	1241	921	320		29.3	2086
14	339	340	69.1	67.0	549	480		50		550	2	55.0	2.03	1241	888	353		29.3	2086
15	283	350	71.1	69.0	566	480		50		550	2	55.0	2.03	1241	849	392		29.3	2086
16	283	360	73.2	71.0	582	540		50		610	2	61.0	2.00	1356	865	491		29.4	2305
17	283	360	73.2	71.0	582	575		50		645	2	64.5	1.98	1419	865	554		29.5	2429
18	339	345	70.1	68.0	558	615		50		685	2	68.5	1.97	1499	897	602		29.6	2571
19	452	335	68.1	66.0	541	620		50		690	2	69.0	1.97	1510	993	517		29.6	2590
20	480	320	65.0	63.0	517	610		50		680	2	68.0	1.97	1488	997	491		29.6	2553
21	424	315	64.0	62.0	508	610		50		680	2	68.0	1.97	1488	932	556		29.6	2553
22	367	310	63.0	61.0	500	585		50		655	2	65.5	1.98	1441	867	574		29.6	2459
23	311	305	62.0	60.0	492	530		50		600	2	60.0	2.00	1333	803	530		29.4	2268
24	396	285	57.9	56.5	456	465		50		535	2	53.5	2.04	1213	852	361		29.3	2029

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 49,146$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 49,146 kW-h

SITE: Jersey CityOPTION: 1A-1MONTH: NOVEMBER

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1515	0	0	0	0	510	20	24	157	711	2	71.1	1.72	1516			157	32.2	2453
2	1461					475		24	156	675	2	67.5	1.74	1461			156	32.1	2336
3	1391					470		24	131	645	2	64.5	1.76	1392			131	32.0	2239
4	1401					465		24	137	646	2	64.6	1.76	1400			137	32.0	2243
5	1401					455		24	145	644	2	64.4	1.76	1402			145	32.0	2236
6	1481					480		24	162	686	2	68.6	1.73	1480			162	32.1	2375
7	1601					550		24	169	763	2	76.3	1.69	1602			169	32.4	2617
8	1880					570		24	270	884	2	88.4	1.64	1881			270	32.6	3013
9	2176					525		24	415	984	2	98.4	1.61	2175			415	32.6	3354
10	2043					535		24	357	936	2	93.6	1.62	2042			357	32.6	3190
11	1933					570		24	292	906	2	90.6	1.63	1933			292	32.6	3088
12	1779					570		24	227	841	2	84.1	1.66	1778			227	32.6	2866
13	1664					560		24	187	791	2	79.1	1.68	1664			187	32.5	2704
14	1630					540		24	185	769	2	76.9	1.69	1629			185	32.4	2637
15	1591					540		24	172	756	2	75.6	1.69	1592			172	32.4	2593
16	1621					600		24	146	790	2	79.0	1.68	1621			146	32.5	2701
17	1696					720		24	108	872	2	87.2	1.64	1697			108	32.6	2972
18	1850					805		24	115	964	2	96.4	1.62	1850			115	32.6	3286
19	2048					790		36	137	983	3	65.5	1.75	2048			137	32.0	3413
20	2117					760		36	180	996	3	66.4	1.75	2117			180	32.0	3458
21	2039					720		24	241	1005	2	100.5	1.61	2039			241	32.6	3425
22	1909					685		24	212	942	2	94.2	1.62	1909			212	32.6	3211
23	1810					650		24	193	887	2	88.7	1.64	1809			193	32.6	3023
24	1779					580		24	221	845	2	84.5	1.66	1780			221	32.6	2880

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 68,313$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 68,313 kW-h

SITE: Jersey CityOPTION: 3AMONTH: January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	2835	0	0	0	0	590	20	34		644	2	64.4	1.65	1181		0	1204	33.3	2149
2	2261					540				594		59.4	1.67	1102			1159	33.2	1988
3	2206					530				584		58.4	1.68	1090			1116	33.1	1960
4	2261					525				579		57.9	1.68	1081			1180	33.1	1944
5	2291					530				584		58.4	1.68	1090			1201	33.1	1960
6	2396					555				609		60.9	1.67	1130			1266	33.2	2038
7	2606					620				674		67.4	1.63	1221			1385	33.4	2242
8	2895					655				709		70.9	1.62	1276			1619	33.4	2359
9	3151					650				704		70.4	1.62	1267			1884	33.4	2342
10	3028					660				714		71.4	1.61	1277			1751	33.4	2375
11	2948					680				734		73.4	1.61	1313			1635	33.5	2434
12	2799					680				734		73.4	1.61	1313			1486	33.5	2434
13	2784					670				724		72.4	1.61	1295			1489	33.5	2401
14	2660					685				739		73.9	1.61	1322			1338	33.5	2451
15	2506					700				754		75.4	1.60	1340			1166	33.5	2501
16	2551					740				794		79.4	1.59	1403			1148	33.6	2626
17	2656					845				899		89.9	1.56	1558			1098	33.6	2973
18	2850					915				969		96.9	1.53	1647			1203	33.6	3204
19	3138					905				959		95.9	1.53	1630			1508	33.6	3171
20	3177					870				924		92.4	1.54	1581			1596	33.6	3056
21	3014					850				904		90.4	1.56	1567			1447	33.6	2989
22	2934					805				859		85.9	1.57	1498			1436	33.6	2841
23	2780					730				784		78.4	1.59	1385			1395	33.6	2593
24	2679					660				714		71.4	1.61	1277			1402	33.4	2375
$\Sigma =$										$\Sigma =$				$\Sigma =$			$\Sigma = 33,112$		$\Sigma = 59,406$

Fuel Energy Req'd. for
Boiler = 41,390 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 100,796 kW-h

SITE: Jersey CityOPTION: 3AMONTH: April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1559	0	0	0	0	520	20	25		565	2	56.5	1.69	1061		0	498	33.0	1902
2	1484					480				525		52.5	1.72	1003			481	32.8	1778
3	1433					465				510		51.0	1.73	980			453	32.7	1733
4	1469					465				510		51.0	1.73	980			489	32.7	1733
5	1433					470				515		51.5	1.73	990			443	32.7	1750
6	1518					495				540		54.0	1.71	1026			492	32.8	1829
7	1675					530				575		52.5	1.72	1099			576	33.0	1936
8	1804					570				615		61.5	1.66	1134			670	33.2	2058
9	2026					600				645		64.5	1.65	1183			844	33.3	2152
10	1881					600				645		64.5	1.65	1182			699	33.3	2152
11	1765					610				655		65.5	1.64	1197			571	33.3	2186
12	1665					615				660		66.0	1.64	1206			462	33.3	2202
13	1625					610				655		65.5	1.64	1197			431	33.3	2186
14	1509					605				650		65.0	1.64	1188			325	33.3	2169
15	1424					610				655		65.5	1.64	1197			230	33.3	2186
16	1454					640				685		68.5	1.63	1244			213	33.4	2279
17	1494					685				730		73.0	1.61	1309			188	33.5	2421
18	1669					750				795		79.5	1.58	1399			273	33.5	2637
19	1885					780				825		82.5	1.58	1452			437	33.6	2728
20	1935					780				825		82.5	1.58	1452			487	33.6	2728
21	1865					755				800		80.0	1.58	1408			461	33.6	2646
22	1779					730				775		77.5	1.58	1373			416	33.5	2570
23	1679					675				720		72.0	1.61	1292			391	33.5	2388
24	1725					600				645		64.5	1.64	1179			550	33.3	2152
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma = 11,071$		$\Sigma = 52,503$	

Fuel Energy Req'd. for
Boiler = 13,842 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 66,345 kW-h

SITE: Jersey CityOPTION: 3AMONTH: AUGUST

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	311	265	53.9	50.1	95	395	20	39		549	2	54.9	1.70	1037		726	0	32.9	1854
2	283	255	51.8	49.0	93	370		39		522	2	52.2	1.72	998		715		32.8	1768
3	254	255	51.8	49.0	93	350		31		494	1	99.0	1.58	667		613		33.6	1634
4	283	245	49.8	47.0	89	335		31		475	1	95.0	1.59	839		556		33.6	1571
5	254	235	47.8	46.0	87	340		31		478	1	95.6	1.59	844		590		33.6	1581
6	254	220	44.7	44.0	83	345		31		479	1	95.8	1.59	846		592		33.6	1584
7	283	215	43.7	43.0	81	380		39		520	2	52.0	1.70	982		699		32.8	1762
8	339	220	44.7	44.0	83	410		39		552	2	55.2	1.70	1043		704		32.9	1864
9	565	225	45.7	45.0	85	430		39		574	2	57.4	1.68	1071		506		33.0	1933
10	509	235	47.8	46.0	87	500		39		646	2	64.6	1.65	1184		675		33.3	2155
11	452	260	52.8	50.0	95	520		39		674	2	67.4	1.63	1221		769		33.4	2242
12	396	300	61.0	56.0	106	490		39		655	2	65.5	1.64	1194		798		33.3	2186
13	396	325	66.1	61.0	115	480		39		654	2	65.4	1.64	1192		796		33.3	2182
14	339	340	69.1	64.0	121	480		39		660	2	66.0	1.64	1203		864		33.3	2202
15	283	350	71.1	66.0	125	480		39		664	2	66.4	1.64	1210		927		33.3	2216
16	283	360	73.2	69.0	131	540		39		730	2	73.0	1.61	1306		1023		33.5	2421
17	283	360	73.2	69.0	131	575		39		765	2	76.5	1.60	1360		1077		33.5	2537
18	339	345	70.1	65.0	123	615		39		797	2	79.7	1.58	1399		1060		33.6	2636
19	452	335	68.1	63.0	119	620		39		798	2	79.8	1.58	1401		949		33.6	2639
20	480	320	65.0	60.0	113	610		39		782	2	78.2	1.59	1382		902		33.6	2586
21	424	315	64.0	59.0	112	610		39		781	2	78.1	1.59	1380		956		33.6	2583
22	367	310	63.0	58.0	110	585		39		754	2	75.4	1.60	1340		973		33.5	2501
23	311	305	62.0	57.0	108	530		39		697	2	69.7	1.62	1255		944		33.4	2319
24	396	285	57.9	54.0	102	465		39		626	2	62.6	1.60	1155		759		33.2	2095
$\Sigma =$																			$\Sigma = 51,051$

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 51,051 kW-h

SITE: Jersey CityOPTION: 3AMONTH: November

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1515	0	0	0	0	510	20	25		555	2	55.5	1.70	1048		0	467	33.0	1869
2	1461					475		25		520	2	52.0	1.72	994			467	32.8	1762
3	1391					470		25		515	2	51.5	1.72	984			407	32.7	1750
4	1401					465		25		510	2	51.0	1.73	980			421	32.7	1733
5	1401					455		17		492	1	98.4	1.52	831			570	33.6	1627
6	1481					480		25		525	2	52.5	1.72	1003			478	32.8	1778
7	1601					550		25		595	2	59.5	1.67	1104			497	33.1	1997
8	1880					570		25		615	2	61.5	1.66	1134			747	33.2	2058
9	2176					525		25		570	2	57.0	1.69	1070			1106	33.0	1919
10	2043					535		25		580	2	58.0	1.68	1083			960	33.1	1947
11	1933					570		25		615	2	61.5	1.66	1134			799	33.2	2058
12	1779					570		25		615	2	61.5	1.66	1134			645	33.2	2058
13	1664					560		25		605	2	60.5	1.68	1129			535	33.2	2025
14	1630					540		25		585	2	58.5	1.68	1092			538	33.1	1964
15	1591					540		25		585	2	58.5	1.68	1092			499	33.1	1964
16	1621					600		25		645	2	64.5	1.65	1183			439	33.3	2152
17	1696					720		25		765	2	76.5	1.60	1360			336	33.5	2537
18	1850					805		25		850	2	85.0	1.57	1483			367	33.6	2811
19	2048					790		25		835	2	83.5	1.57	1457			591	33.6	2761
20	2117					760		25		805	2	80.5	1.58	1413			704	33.6	2662
21	2039					720		25		765	2	76.5	1.60	1360			679	33.5	2537
22	1909					685		25		730	2	73.0	1.61	1306			603	33.5	2421
23	1810					650		25		695	2	69.5	1.62	1251			559	33.4	2312
24	1779					580		25		625	2	62.5	1.66	1153			626	33.2	2092
$\Sigma =$																	$\Sigma = 14,140$		$\Sigma = 50,794$

Fuel Energy Req'd. for
Boiler = 17,675 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 68,469 kW-h

SITE: Jersey CityOPTION: 3A1MONTH: JANUARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	2385	0	0	0	0	590	20	36	391	1037	3	69.1	1.73	1993			391	32.2	3578
2	2261					540		36	371	967	3	64.5	1.76	2262			371	32.0	3358
3	2206					530		24	423	997	2	99.7	1.61	2206			423	32.6	3398
4	2261					525		36	381	960	3	64.1	1.76	2262			381	32.0	3340
5	2291					530		36	387	973	3	64.7	1.76	2290			387	32.0	3378
6	2396					555		36	418	1029	3	68.6	1.73	2396			418	32.2	3551
7	2606					620		36	458	1144	3	76.3	1.69	2606			458	32.4	3923
8	2895					655		36	557	1268	3	84.5	1.66	2896			557	32.6	4322
9	3151					650		36	659	1365	3	91.0	1.64	3147			659	32.6	4652
10	3028					660		36	611	1327	3	87.5	1.64	3029			611	32.6	4523
11	2948					680		36	564	1300	3	86.7	1.65	2947			564	32.6	4431
12	2799					680		36	506	1241	3	82.7	1.66	2795			506	32.5	4243
13	2784					670		36	503	1229	3	81.9	1.67	2783			503	32.5	4202
14	2660					685		36	450	1191	3	79.4	1.67	2660			450	32.5	4072
15	2506					700		36	381	1133	3	75.5	1.68	2504			381	32.3	3897
16	2551					740		36	372	1168	3	77.9	1.68	2552			372	32.4	4005
17	2656					845		36	350	1251	3	83.4	1.68	2657			350	32.5	4277
18	2850					915		36	388	1359	3	90.5	1.63	2849			388	32.6	4632
19	3138					905		36	509	1472	3	98.0	1.61	3139			509	32.6	5017
20	3177					870		36	545	1471	3	98.1	1.61	3176			545	32.6	5014
21	3014					850		36	489	1395	3	93.0	1.63	3015			489	32.6	4755
22	2934					805		36	484	1345	3	89.7	1.64	2935			484	32.6	4584
23	2780					730		36	468	1254	3	83.6	1.66	2781			468	32.5	4287
24	2679					660		36	468	1184	3	78.9	1.68	2678			468	32.5	4048
Σ																			99,487

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 99,487 kW-h

SITE: Jersey CityOPTION: 3A-1MONTH: April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1559	0	0	0	0	520	20	24	168	732	2	73.2	1.71	1559			168	32.3	2518
2	1484					480			163	687		68.7	1.73	1484			163	32.2	2371
3	1433					465			151	660		66.0	1.75	1434			151	32.0	2292
4	1469					465			165	674		67.4	1.74	1468			165	32.3	2319
5	1433					470			147	661		66.1	1.75	1432			147	32.0	2295
6	1518					495			168	707		70.7	1.72	1519			168	32.0	2455
7	1674					530			210	784		78.4	1.68	1673			210	32.4	2687
8	1804					570			239	853		85.3	1.65	1803			239	32.6	2907
9	2026					600			310	954		95.4	1.62	2027			310	32.6	3252
10	1881					600			251	895		89.5	1.64	1882			251	32.6	3050
11	1765					610			200	854		85.4	1.65	1766			200	32.6	2911
12	1665					615			155	814		81.4	1.67	1665			155	32.5	2783
13	1625					610			144	798		79.8	1.67	1625			144	32.5	2728
14	1509					605			99	747		74.7	1.70	1509			98	32.3	2570
15	1424					610			60	714		71.4	1.72	1425			60	32.3	2456
16	1454					640			56	740		74.0	1.70	1454			56	32.3	2546
17	1494					685			46	775		77.5	1.68	1493			46	32.4	2658
18	1669					750			75	869		86.9	1.68	1668			75	32.6	2962
19	1885					780			144	968		96.8	1.62	1886			144	32.6	3299
20	1935					780			165	989		98.9	1.61	1934			165	32.6	3371
21	1865					755			152	951		95.1	1.62	1864			152	32.6	3241
22	1779					730			134	908		90.8	1.62	1779			134	32.6	3095
23	1679					675			124	843		84.3	1.66	1679			124	32.6	2873
24	1725					600			189	833		83.3	1.66	1725			189	32.5	2814
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma =$		$\Sigma =$	66,453

Fuel Energy Req'd. for
Boiler = kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 66,453 kW-h

SITE: Jersey CityOPTION: 3A-1MONTH: AUGUST

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20																														
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)																														
1	311	265	53.9	50.1	95	395	20	39		549	2	54.9	1.70	1037		726	0	32.9	1854																														
2	283	255	51.8	49.0	93	370		39		522	2	52.2	1.72	998		715		32.8	1768																														
3	254	255	51.8	49.0	93	350		31		494	1	99.0	1.58	667		613		33.6	1634																														
4	283	245	49.8	47.0	89	335		31		475	1	95.0	1.59	839		556		33.6	1571																														
5	254	235	47.8	46.0	87	340		31		478	1	95.6	1.59	844		590		33.6	1581																														
6	254	220	44.7	44.0	83	345		31		479	1	95.8	1.59	846		592		33.6	1584																														
7	283	215	43.7	43.0	81	380		39		520	2	52.0	1.70	982		699		32.8	1762																														
8	339	220	44.7	44.0	83	410		39		552	2	55.2	1.70	1043		704		32.9	1864																														
9	565	225	45.7	45.0	85	430		39		574	2	57.4	1.68	1071		506		33.0	1933																														
10	509	235	47.8	46.0	87	500		39		646	2	64.6	1.65	1184		675		33.3	2155																														
11	452	260	52.8	50.0	95	520		39		674	2	67.4	1.63	1221		769		33.4	2242																														
12	396	300	61.0	56.0	106	490		39		655	2	65.5	1.64	1194		798		33.3	2186																														
13	396	325	66.1	61.0	115	480		39		654	2	65.4	1.64	1192		796		33.3	2182																														
14	339	340	69.1	64.0	121	480		39		660	2	66.0	1.64	1203		864		33.3	2202																														
15	283	350	71.1	66.0	125	480		39		664	2	66.4	1.64	1210		927		33.3	2216																														
16	283	360	73.2	69.0	131	540		39		730	2	73.0	1.61	1306		1023		33.5	2421																														
17	283	360	73.2	69.0	131	575		39		765	2	76.5	1.60	1360		1077		33.5	2537																														
18	339	345	70.1	65.0	123	615		39		797	2	79.7	1.58	1399		1060		33.6	2636																														
19	452	335	68.1	63.0	119	620		39		798	2	79.8	1.58	1401		949		33.6	2639																														
20	480	320	65.0	60.0	113	610		39		782	2	78.2	1.59	1382		902		33.6	2586																														
21	424	315	64.0	59.0	112	610		39		781	2	78.1	1.59	1380		956		33.6	2583																														
22	367	310	63.0	58.0	110	585		39		754	2	75.4	1.60	1340		973		33.5	2501																														
23	311	305	62.0	57.0	108	530		39		697	2	69.7	1.62	1255		944		33.4	2319																														
24	396	285	57.9	54.0	102	465		39		626	2	62.6	1.60	1155		759		33.2	2095																														
Σ=										Σ=										Σ=										Σ=										Σ= 51,051									

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 51,051 kW-h

SITE: Jersey CityOPTION: 3A1MONTH: NOVEMBER

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1515	0	0	0	0	510	20	24	157	711	2	71.1	1.72	1516			157	32.2	2453
2	1461					475		24	156	675	2	67.5	1.74	1461			156	32.1	2336
3	1391					470		24	131	645	2	64.5	1.76	1392			131	32.0	2239
4	1401					465		24	137	646	2	64.6	1.76	1400			137	32.0	2243
5	1401					455		24	145	644	2	64.4	1.76	1402			145	32.0	2236
6	1481					480		24	162	686	2	68.6	1.73	1480			162	32.1	2375
7	1601					550		24	169	763	2	76.3	1.69	1602			169	32.4	2617
8	1880					570		24	270	884	2	88.4	1.64	1881			270	32.6	3013
9	2176					525		24	415	984	2	98.4	1.61	2175			415	32.6	3354
10	2043					535		24	357	936	2	93.6	1.62	2042			357	32.6	3190
11	1933					570		24	292	906	2	90.6	1.63	1933			292	32.6	3088
12	1779					570		21	227	841	2	84.1	1.66	1778			227	32.6	2866
13	1664					560		21	187	791	2	79.1	1.68	1664			187	32.5	2704
14	1630					540		21	185	769	2	76.9	1.69	1629			185	32.4	2637
15	1591					540		24	172	756	2	75.6	1.69	1592			172	32.4	2593
16	1621					600		24	146	790	2	79.0	1.68	1621			146	32.5	2701
17	1696					720		24	108	872	2	87.2	1.64	1697			108	32.6	2972
18	1850					805		24	115	964	2	96.4	1.62	1850			115	32.6	3286
19	2048					790		35	137	983	3	65.5	1.75	2048			137	32.0	3413
20	2117					760		35	180	996	3	66.4	1.75	2117			180	32.0	3458
21	2039					720		24	241	1005	2	100.5	1.61	2039			241	32.6	3425
22	1909					685		24	212	942	2	94.2	1.62	1909			212	32.6	3211
23	1810					650		24	193	887	2	88.7	1.64	1809			193	32.6	3023
24	1779					530		24	221	845	2	84.5	1.66	1780			221	32.6	2880
$\Sigma =$																			$\Sigma = 68,313$

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 68,313 kW-h

SITE: JERSEY CITYOPTION: CONVENTIONALMONTH: JANUARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20										
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)										
1	2280					590		18		608																			
2	2156					540				558																			
3	2101					530				548																			
4	2156					525				543																			
5	2186					530				548																			
6	2291					555				573																			
7	2501					620				638																			
8	2790					655				673																			
9	3046					650				668																			
10	2843					660				678																			
11	2923					680				698																			
12	2694					680				698																			
13	2679					670				688																			
14	2555					685				703																			
15	2401					700				718																			
16	2446					740				758																			
17	2551					845				863																			
18	2745					915				933																			
19	3033					905				923																			
20	3072					870				888																			
21	2909					850				868																			
22	2829					805				823																			
23	2675					730				748																			
24	2574					660		18		778																			
Σ= 82,436																				Σ= 17,122				Σ=		Σ=		Σ=	

Fuel Energy Req'd. for
Boiler = 103045 kW-hFuel Energy Req'd. for
Utility Plant = 57,073 kW-hTotal Fuel Energy
Req'd. = 160118 kW-h

SITE: JERSEY CITYOPTION: CONVENTIONALMONTH: APRIL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Cper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1559					520		18		538									
2	1484					480				498									
3	1433					465				483									
4	1469					465				483									
5	1433					470				488									
6	1518					495				513									
7	1674					530				548									
8	1804					570				588									
9	2026					600				618									
10	1881					600				618									
11	1765					610				628									
12	1665					615				633									
13	1625					610				628									
14	1509					605				623									
15	1424					610				628									
16	1454					640				658									
17	1494					685				703									
18	1669					750				768									
19	1885					780				798									
20	1935					780				798									
21	1865					755				773									
22	1779					730				748									
23	1679					675				693									
24	1725					600		18		618									
$\Sigma = 39,804$										$\Sigma = 15,072$				$\Sigma =$		$\Sigma =$		$\Sigma =$	

Fuel Energy Req'd. for
Boiler = 49,756 kW-hFuel Energy Req'd. for
Utility Plant = 50,240 kW-hTotal Fuel Energy
Req'd. = 99,996 kW-h

SITE: JERSEY CITYOPTION: CONVENTIONALMONTH: AUGUST

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	311	265	53.9	53.0	435	395		50		445					746				
2	283	255	51.8	51.0	418	370		50		420					701				
3	254	255	51.8	51.0	418	350				400					672				
4	283	245	49.8	49.0	402	335				485					685				
5	254	235	47.8	47.5	390	340				490					644				
6	254	220	44.7	45.0	369	345				495					623				
7	283	215	43.7	44.0	361	380				430					644				
8	339	220	44.7	45.0	369	410				460					708				
9	565	225	45.7	46.0	377	430				480					942				
10	509	235	47.8	47.5	390	500				550					899				
11	452	260	52.8	52.5	431	520				570					883				
12	396	300	61.0	59.0	484	490				540					880				
13	396	325	66.1	64.0	525	480				530					921				
14	339	340	69.1	67.0	549	480				530					888				
15	283	350	71.1	69.0	566	480				530					849				
16	283	360	73.2	71.0	582	540				590					865				
17	283	360	73.2	71.0	582	575				625					865				
18	339	345	70.1	68.0	558	615				665					897				
19	452	335	68.1	66.0	541	620				670					993				
20	480	320	65.0	63.0	517	610				660					997				
21	424	315	64.0	62.0	508	610				660					932				
22	367	310	63.0	61.0	500	585				635					867				
23	311	305	62.0	60.0	492	530				580					803				
24	396	285	57.9	56.5	456	465		50		515					852				

 $\Sigma =$ $\Sigma = 12,955$ $\Sigma = 19,756$ $\Sigma =$ $\Sigma =$ Fuel Energy Req'd. for
Boiler = 24,695 kW-hFuel Energy Req'd. for
Utility Plant = 43,183 kW-hTotal Fuel Energy
Req'd. = 67,878 kW-h

SITE: JERSEY CITYOPTION: CONVENTIONALMONTH: NOVEMBER

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1460					510		18		528									
2	1406					475				493									
3	1336					470				488									
4	1346					465				483									
5	1346					455				473									
6	1426					480				498									
7	1546					550				568									
8	1825					570				588									
9	2121					525				543									
10	1988					535				553									
11	1878					570				588									
12	1724					570				588									
13	1609					560				578									
14	1575					540				558									
15	1536					540				558									
16	1566					600				618									
17	1641					720				738									
18	1795					805				823									
19	1993					790				808									
20	2062					760				778									
21	1984					720				738									
22	1854					685				703									
23	1755					650				668									
24	1724					580		18		598									
$\Sigma = 40,456$								$\Sigma = 13,969$											

Fuel Energy Req'd. for
Boiler = 50,570 kW-hFuel Energy Req'd. for
Utility Plant = 46,563 kW-hTotal Fuel Energy
Req'd. = 97,133 kW-h

SITE: AnchorageOPTION: 4MONTH: February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (kW)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	448	0	0	0	0	323	13	37		373	1	37.3	1.87	775		327		31.3	1324
2	460					323		37		373	1	37.3	1.87	775		315		31.3	1324
3	472					323		37		373	1	37.3	1.87	775		303		31.3	1324
4	483					323		37		373	1	37.3	1.87	775		292		31.3	1324
5	495					323		37		373	1	37.3	1.87	775		280		31.3	1324
6	507					670		37		720	1	72.0	1.61	1288		781		33.5	2388
7	1154					1617		54		1684	2	84.2	1.57	2938		1784		33.6	5569
8	1539					1984		71		2068	3	68.9	1.63	3745		2206		33.4	6880
9	1925					2351		71		2435	3	81.2	1.58	4275		2350		33.6	8052
10	2085					2365		71		2449	3	81.6	1.58	4299		2214		33.6	8099
11	1540					2380		71		2464	3	82.1	1.58	4326		2786		33.6	8148
12	1202					2394		71		2478	3	82.6	1.58	4350		3148		33.6	8194
13	865					2372		71		2456	3	81.9	1.58	4312		3447		33.6	8122
14	822					2351		71		2435	3	81.2	1.58	4275		3453		33.6	8052
15	780					2388		71		2472	3	82.4	1.58	4340		3560		33.6	8175
16	737					2426		71		2510	3	83.7	1.57	4379		3642		33.6	8300
17	1267					1483		54		1550	2	77.5	1.59	2738		1471		33.6	5126
18	1732					741		17		771	1	77.1	1.60	1371			361	33.5	2557
19	1242					635		17		665	1	66.5	1.64	1212			30	33.4	2212
20	753					614		37		664	1	66.4	1.64	1209		457		33.4	2209
21	464					593		37		643	1	64.3	1.65	1179		715		33.3	2145
22	506					458		37		508	1	50.8	1.73	976		428		32.7	1726
23	549					323		17		353	1	35.3	1.90	745		(238)		31.0	1265
24	592					323		17		353	1	35.3	1.90	745		(153)		31.0	1265

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 105,104$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 105,104 kW-h

SITE: Anchorage

OPTION: 4

MONTH: July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	66	0	0	0	0	295	13	37		345	1	34.5	2.20	843	66	777	0	28.0	1369
2	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
3	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
4	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
5	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
6	394	0	0	0	0	274		37		324	1	32.4	2.24	806	394	412		27.6	1304
7	690	83	7.3	18.0	338	454		94		561	1	56.1	2.02	1259	1028	231		29.4	2120
8	427	166	14.8	22.5	422	634		94		741	1	74.1	1.94	1597	849	748		29.6	2782
9	164	187	16.6	23.5	441	1584		111		1708	2	85.4	1.90	3606	605	3001		29.7	6390
10	149	208	18.5	25.0	469	2017		128		2158	3	71.9	1.96	4700	618	4082		29.6	8101
11	135	263	23.4	28.0	525	2451		128		2592	3	86.4	1.90	5472	660	4812		29.7	9697
12	121	319	28.4	32.0	600	2465		128		2606	3	86.9	1.90	5502	721	4781		29.7	9749
13	106	374	33.2	35.5	666	2479		128		2620	3	87.3	1.89	5502	772	4730		29.7	9802
14	92	648	57.6	55.5	1041	2493		143		2649	3	88.3	1.89	5563	1133	4430		29.7	9910
15	78	931	82.7	81.0	1519	2451		143		2607	3	86.9	1.90	5504	1597	3907		29.7	9753
16	63	964	85.7	84.0	1575	2535		143		2691	3	89.7	1.89	5651	1638	4013		29.7	10067
17	49	997	88.6	86.5	1622	2440		143		2596	3	86.5	1.90	5480	1671	3809		29.7	9712
18	65	902	80.2	78.5	1472	2345		143		2501	3	83.4	1.91	5308	1537	3771		29.7	9357
19	82	648	57.6	56.0	1050	1500		126		1639	2	82.0	1.92	3497	1132	2365		29.7	6132
20	16	0	0	0	0	740		37		790	1	79.0	1.93	1694	16	1678		29.7	2955
21	24	0	0	0	0	695		37		745	1	74.5	1.94	1606	24	1582		29.7	2787
22	32	0	0	0	0	527		37		577	1	57.7	2.02	1295	32	1263		29.4	2181
23	41	0	0	0	0	359		37		409	1	40.9	2.13	968	41	927		28.7	1583
24	49	0	0	0	0	317		37		367	1	36.7	2.17	885	49	836		28.2	1446

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 122,413$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 122,413 kW-h

SITE: AnchorageOPTION: 4AMONTH: February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	448	0	0	0	0	323	13	37	0	373	1	37.3	1.87	775		327		31.3	1324
2	460					323		37		373	1	37.3	1.87	775		315		31.3	1324
3	472					323		37		373	1	37.3	1.87	775		303		31.3	1324
4	483					323		37		373	1	37.3	1.87	775		292		31.3	1324
5	495					323		37		373	1	37.3	1.87	775		280		31.3	1324
6	507					670		37		720	1	72.0	1.61	1288		781		33.5	2388
7	1154					1617		54		1684	2	84.2	1.57	2938		1784		33.6	5569
8	1539					1984		71		2068	3	68.9	1.63	3745		2206		33.4	6880
9	1925					2351		71		2435	3	81.2	1.58	4275		2350		33.6	8052
10	2085					2365		71		2449	3	81.6	1.58	4299		2214		33.4	8099
11	1540					2380		71		2464	3	82.1	1.58	4326		2786		33.6	8148
12	1202					2394		71		2478	3	82.6	1.58	4350		3148		33.6	8194
13	865					2372		71		2456	3	81.9	1.58	4312		3447		33.6	8122
14	822					2351		71		2435	3	81.2	1.58	4275		3453		33.6	8052
15	780					2388		71		2472	3	82.4	1.58	4340		3560		33.6	8175
16	737					2426		71		2510	3	83.7	1.57	4379		3642		33.6	8300
17	1267					1483		54		1550	2	77.5	1.59	2738		1471		33.6	5126
18	1732					741		17	148	919	1	91.9	1.55	1731			148	33.6	3039
19	1242					635		17	13	678	1	67.8	1.63	1241			13	33.4	2255
20	753					614		37	0	664	1	66.4	1.64	1209		457		33.4	2209
21	464					593		37		643	1	64.3	1.65	1179		715		33.3	2145
22	506					458		37		508	1	50.8	1.73	976		470		32.7	1726
23	549					323		37		373	1	37.3	1.87	775		226		31.3	1324
24	592					323		37		373	1	37.3	1.87	775		183		31.3	1324
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma =$		$\Sigma =$	105,747

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 105,747 kW-h

SITE: Anchorage

OPTION: 4A

MONTH: July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	66	0	0	0	0	295	13	37		345	1	34.5	2.20	843	66	777	0	28.0	1369
2	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
3	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
4	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
5	66	0	0	0	0	274		37		324	1	32.4	2.24	806	66	740		27.6	1304
6	394	0	0	0	0	274		37		324	1	32.4	2.24	806	394	412		27.6	1304
7	690	83	7.3	18.0	338	454		94		561	1	56.1	2.02	1259	1028	231		29.4	2120
8	427	166	14.8	22.5	422	634		94		741	1	74.1	1.94	1597	849	748		29.6	2782
9	164	187	16.6	23.5	441	1584		111		1708	2	85.4	1.90	3606	605	3001		29.7	6390
10	149	208	18.5	25.0	469	2017		128		2158	3	71.9	1.96	4700	618	4082		29.6	8101
11	135	263	23.4	28.0	525	2451		128		2592	3	86.4	1.90	5472	660	4812		29.7	9697
12	121	319	28.4	32.0	600	2465		128		2606	3	86.9	1.90	5502	721	4781		29.7	9749
13	106	374	33.2	35.5	666	2479		128		2620	3	87.3	1.89	5502	772	4730		29.7	9802
14	92	648	57.6	55.5	1041	2493		143		2649	3	88.3	1.89	5563	1133	4430		29.7	9910
15	78	931	82.7	81.0	1519	2451		143		2607	3	86.9	1.90	5504	1597	3907		29.7	9753
16	63	964	85.7	84.0	1575	2535		143		2691	3	89.7	1.89	5651	1638	4013		29.7	10067
17	49	997	88.6	86.5	1622	2440		143		2596	3	86.5	1.90	5480	1671	3809		29.7	9712
18	65	902	80.2	78.5	1472	2345		143		2501	3	83.4	1.91	5308	1537	3771		29.7	9357
19	82	648	57.6	56.0	1050	1500		126		1639	2	82.0	1.92	3497	1132	2365		29.7	6132
20	16	0	0	0	0	740		37		790	1	79.0	1.93	1694	16	1678		29.7	2955
21	24	0	0	0	0	695		37		745	1	74.5	1.94	1606	24	1582		29.7	2787
22	32	0	0	0	0	527		37		577	1	57.7	2.02	1295	32	1263		29.4	2181
23	41	0	0	0	0	359		37		409	1	40.9	2.13	968	41	927		28.7	1583
24	49	0	0	0	0	317		37		367	1	36.7	2.17	885	49	836		28.2	1446
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma =$		$\Sigma = 122,413$	

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 122,413 kW-h

SITE: AnchorageOPTION: 6MONTH: February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	448	0	0	0	0	323	13	37		373	1	37.3	1.87	775		327		31.3	1324
2	460					323		37		373	1	37.3	1.87	775		315		31.3	1324
3	472					323		37		373	1	37.3	1.87	775		303		31.3	1324
4	483					323		37		373	1	37.3	1.87	775		292		31.3	1324
5	495					323		37		373	1	37.3	1.87	775		280		31.3	1324
6	507					670		37		720	1	72.0	1.61	1288		781		33.5	2388
7	1154					1617		54		1684	2	84.2	1.57	2938		1784		33.6	5569
8	1539					1984		71		2068	3	68.9	1.63	3745		2206		33.4	6880
9	1925					2351		71		2435	3	81.2	1.58	4275		2350		33.6	8052
10	2085					2365		71		2449	3	81.6	1.58	4299		2214		33.6	8099
11	1540					2380		71		2464	3	82.1	1.58	4326		2786		33.6	8148
12	1202					2394		71		2478	3	82.6	1.58	4350		3148		33.6	8194
13	865					2372		71		2456	3	81.9	1.58	4312		3447		33.6	8122
14	822					2351		71		2435	3	81.2	1.58	4275		3453		33.6	8052
15	780					2388		71		2472	3	82.4	1.58	4340		3560		33.6	8175
16	737					2426		71		2510	3	83.7	1.57	4379		3642		33.6	8300
17	1267					1483		54		1550	2	77.5	1.59	2738		1471		33.6	5126
18	1732					741		17		771	1	77.1	1.60	1371			361	33.5	2557
19	1242					635		17		665	1	66.5	1.64	1212			30	33.4	2212
20	753					614		37		664	1	66.4	1.64	1209		457		33.4	2209
21	464					593		37		643	1	64.3	1.65	1179		715		33.3	2145
22	506					458		37		508	1	50.8	1.73	976		428		32.7	1726
23	549					323		17		353	1	35.3	1.90	745		(238)		31.0	1265
24	592					323		17		353	1	35.3	1.90	745		(153)		31.0	1265
$\Sigma =$										$\Sigma =$				$\Sigma =$		$\Sigma =$		$\Sigma = 105,104$	

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 105,104 kW-h

SITE: AnchorageOPTION: 6MONTH: July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	66	0	0	0	0	295	13	37		345	1	34.5	1.91	732		666	0	30.8	1245
2	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184
3	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184
4	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184
5	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184
6	394	0	0	0	0	274		37		324	1	32.4	1.95	702		308		30.4	1184
7	690	83	7.4	25.0	108	454		79		654	1	65.4	1.64	1192		502		33.3	2182
8	427	166	14.8	28.0	121	634		79		847	1	84.7	1.57	1478		1051		33.6	2801
9	164	187	16.6	29.0	125	1584		96		1818	2	90.9	1.55	3131		2967		33.6	6012
10	149	208	18.5	29.5	128	2017		113		2271	3	75.7	1.60	4037		3888		33.5	7532
11	135	263	23.4	31.5	136	2451		113		2713	3	90.4	1.56	4703		4568		33.6	8972
12	121	319	28.4	34.0	147	2465		113		2738	3	91.3	1.55	4715		4594		33.6	9054
13	106	374	33.2	36.5	158	2479		113		2763	3	92.1	1.55	4759		4653		33.6	9137
14	92	648	57.6	53.5	231	2493		113		2850	3	95.0	1.54	4877		4785		33.6	9425
15	78	931	82.7	79.5	344	2451		113		2921	3	97.4	1.54	4998		4920		33.6	9659
16	63	964	85.7	83.0	359	2535		113		3020	3	100.7	1.53	5134		5071		33.6	9987
17	49	997	88.6	86.5	374	2440		113		2940	3	98.0	1.53	4998		4949		33.6	9722
18	65	902	80.2	76.5	331	2345		113		2802	3	93.4	1.55	4826		4761		33.6	9266
19	82	648	57.6	53.5	231	1500		96		1840	2	92.0	1.55	3169		3087		33.6	6085
20	16	0	0	0	0	740		37		790	1	79.0	1.59	1396		1380		33.6	2612
21	24	0	0	0	0	695		37		745	1	74.5	1.60	1324		1300		33.5	2471
22	32	0	0	0	0	527		37		577	1	57.7	1.68	1077		1045		33.0	1943
23	41	0	0	0	0	359		37		409	1	40.9	1.83	832		791		31.8	1429
24	49	0	0	0	0	317		37		367	1	36.7	1.88	767		718		31.2	1307

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 116,761$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 116,761 kW-h

SITE: Anchorage						OPTION: 6A						MONTH: February							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	448	0	0	0	0	323	13	37	0	373	1	37.3	1.87	775		327		31.3	1324
2	460					323		37		373	1	37.3	1.87	775		315		31.3	1324
3	472					323		37		373	1	37.3	1.87	775		303		31.3	1324
4	483					323		37		373	1	37.3	1.87	775		292		31.3	1324
5	495					323		37		373	1	37.3	1.87	775		280		31.3	1324
6	507					670		37		720	1	72.0	1.61	1288		781		33.5	2388
7	1154					1617		54		1684	2	84.2	1.57	2938		1784		33.6	5569
8	1539					1984		71		2068	3	68.9	1.63	3745		2206		33.4	6880
9	1925					2351		71		2435	3	81.2	1.58	4275		2350		33.6	8052
10	2085					2365		71		2449	3	81.6	1.58	4299		2214		33.4	8099
11	1540					2380		71		2464	3	82.1	1.58	4326		2786		33.6	8148
12	1202					2394		71		2478	3	82.6	1.58	4350		3148		33.6	8194
13	865					2372		71		2456	3	81.9	1.58	4312		3447		33.6	8122
14	822					2351		71		2435	3	81.2	1.58	4275		3453		33.6	8052
15	780					2388		71		2472	3	82.4	1.58	4340		3560		33.6	8175
16	737					2426		71		2510	3	83.7	1.57	4379		3642		33.6	8300
17	1267					1483		54		1550	2	77.5	1.59	2738		1471		33.6	5126
18	1732					741		17	148	919	1	91.9	1.55	1731			148	33.6	3039
19	1242					635		17	13	678	1	67.8	1.63	1241			13	33.4	2255
20	753					614		37	0	664	1	66.4	1.64	1209		457		33.4	2209
21	464					593		37		643	1	64.3	1.65	1179		715		33.3	2145
22	506					458		37		508	1	50.8	1.73	976		470		32.7	1726
23	549					323		37		373	1	37.3	1.87	775		226		31.3	1324
24	592					323		37		373	1	37.3	1.87	775		183		31.3	1324
$\Sigma =$						$\Sigma =$						$\Sigma =$				$\Sigma =$		$\Sigma = 105,747$	

Fuel Energy Req'd. for
Boiler = _____ kW-h

Fuel Energy Req'd. for
Utility Plant = _____ kW-h

Total Fuel Energy
Req'd. = 105,747 kW-h

SITE: Anchorage						OPTION: 6A						MONTH: July																																					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20																														
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Pcwer for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)																														
1	66	0	0	0	0	295	13	37		345	1	34.5	1.91	732		666	0	30.8	1245																														
2	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184																														
3	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184																														
4	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184																														
5	66	0	0	0	0	274		37		324	1	32.4	1.95	702		636		30.4	1184																														
6	394	0	0	0	0	274		37		324	1	32.4	1.95	702		308		30.4	1184																														
7	690	83	7.4	25.0	108	454		79		654	1	65.4	1.64	1192		502		33.3	2182																														
8	427	166	14.8	28.0	121	634		79		847	1	84.7	1.57	1478		1051		33.6	2801																														
9	164	187	16.6	29.0	125	1584		96		1818	2	90.9	1.55	3131		2967		33.6	6012																														
10	149	208	18.5	29.5	128	2017		113		2271	3	75.7	1.60	4037		3888		33.5	7532																														
11	135	263	23.4	31.5	136	2451		113		2713	3	90.4	1.56	4703		4568		33.6	8972																														
12	121	319	28.4	34.0	147	2465		113		2738	3	91.3	1.55	4715		4594		33.6	9054																														
13	106	374	33.2	36.5	158	2479		113		2763	3	92.1	1.55	4759		4653		33.6	9137																														
14	92	648	57.6	53.5	231	2493		113		2850	3	95.0	1.54	4877		4785		33.6	9425																														
15	78	931	82.7	79.5	344	2451		113		2921	3	97.4	1.54	4998		4920		33.6	9659																														
16	63	964	85.7	83.0	359	2535		113		3020	3	100.7	1.53	5134		5071		33.6	9987																														
17	49	997	88.6	86.5	374	2440		113		2940	3	98.0	1.53	4998		4949		33.6	9722																														
18	65	902	80.2	76.5	331	2345		113		2802	3	93.4	1.55	4826		4761		33.6	9266																														
19	82	648	57.6	53.5	231	1500		96		1880	2	92.0	1.55	3169		3087		33.6	6085																														
20	16	0	0	0	0	740		37		790	1	79.0	1.59	1396		1380		33.6	2612																														
21	24	0	0	0	0	695		37		745	1	74.5	1.60	1324		1300		33.5	2471																														
22	32	0	0	0	0	527		37		577	1	57.7	1.68	1077		1045		33.0	1943																														
23	41	0	0	0	0	359		37		409	1	40.9	1.83	832		791		31.8	1429																														
24	49	0	0	0	0	317		37		367	1	36.7	1.88	767		718		31.2	1307																														
Σ=										Σ=										Σ=										Σ=										Σ=116,761									

Fuel Energy Req'd. for
Boiler = _____ kW-h

Fuel Energy Req'd. for
Utility Plant = _____ kW-h

Total Fuel Energy
Req'd. = 116,761 kW-h

SITE: ANCHORAGEOPTION: CONVENTIONALMONTH: FEBRUARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	448					323		18		341									
2	460					323				341									
3	472					323				341									
4	483					323				341									
5	495					323				341									
6	507					670				688									
7	1154					1617				1635									
8	1539					1984				2002									
9	1925					2351				2369									
10	2085					2365				2383									
11	1540					2380				2398									
12	1202					2394				2412									
13	865					2372				2390									
14	822					2351				2369									
15	780					2388				2406									
16	737					2426				2444									
17	1267					1483				1501									
18	1732					741				759									
19	1242					635				653									
20	753					614				632									
21	464					593				611									
22	506					458				476									
23	549					323				341									
24	592					323		18		341									
$\Sigma = 22,619$		$\Sigma = 30,515$										$\Sigma =$		$\Sigma =$		$\Sigma =$			

Fuel Energy Req'd. for
Boiler = 28,274 kW-hFuel Energy Req'd. for
Utility Plant = 101,717 kW-hTotal Fuel Energy
Req'd. = 129,991 kW-h

SITE: AnchorageOPTION: ConventionalMONTH: July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	66	0	0	0	0	295		18		313									
2						274				292									
3																			
4																			
5																			
6	394																		
7	690	83	7.4	25.0	108	454		60		622									
8	427	166	14.8	28.0	121	634				815									
9	164	187	16.6	29.0	125	1584				1769									
10	149	208	18.5	29.5	128	2017				2205									
11	135	263	23.4	31.5	136	2451				2647									
12	121	319	28.4	34.0	147	2465				2672									
13	106	374	33.2	36.5	158	2479				2697									
14	92	648	57.6	53.5	231	2493				2784									
15	78	931	82.7	79.5	344	2451				2855									
16	63	964	85.7	83.0	359	2535				2954									
17	49	997	88.6	86.5	374	2440				2874									
18	65	902	80.2	76.5	331	2345				2736									
19	82	648	57.6	53.5	231	1500				1791									
20	16	0	0	0	0	740		18		758									
21	24					695				713									
22	32					527				545									
23	41					359				377									
24	49					317				335									
$\Sigma = 3107$										$\Sigma = 33922$	$\Sigma =$								

Fuel Energy Req'd. for
Boiler = 3,884 kW-hFuel Energy Req'd. for
Utility Plant = 113,073 kW-hTotal Fuel Energy
Req'd. = 116,957 kW-h

SITE: FairfieldOPTION: 7MONTH: January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elec. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3516	440	15.7	19.0	889	1318	36	154		1508	2	75.4	1.94	3251	3956		695	29.7	5642
2	2344	293	10.4	16.0	748	1318		156		1510	2	75.5	1.94	3255	2637	618			5649
3	2344	293	10.4	16.0	748	1318		156		1510	2	75.5	1.94	3255	2637	618			5649
4	2344	293	10.4	16.0	748	1318		156		1510	2	75.5	1.94	3255	2637	618			5649
5	6934	0	0	0	0	2307		46		2389	3	79.6	1.92	5097	6934		1837		8938
6	11524					3296		59		3391	4	84.8	1.90	7159	11524		4365		12686
7	16115					4285		72		4393	5	87.9	1.89	9225	16115		6890		16435
8	14357					5274		85		5395	6	89.9	1.89	11330	14357		3028		20183
9	12599					5274		85		5395	6	89.9	1.89	11330	12599		1270		20183
10	10841					5420		78		5534	6	92.2	1.88	11560	10841	(719)			20703
11	10548					5567		78		5681	6	94.7	1.87	11804	10548	(1256)			21253
12	10255					5333		78		5447	6	90.8	1.88	11378	10255	(1123)			20378
13	10328					5479		78		5593	6	93.2	1.88	11683	10328	(1355)			20924
14	10401					5215		78		5329	6	88.8	1.89	11191	10401	(790)			19936
15	8130					4365		65		4466	5	89.3	1.89	9379	8130	(1249)			16708
16	5860					3516		52		3604	4	90.1	1.88	7528	5860	(1668)			13483
17	6006					3369		52		3457	4	86.4	1.90	7298	6006	(1292)			12933
18	6153	1025	36.5	32.0	1497	3233		59		3330	4	83.2	1.91	7067	7650		583		12458
19	3076	842	30.0	28.0	1309	2930		52		3018	4	75.5	1.94	6505	4385	(2120)			11291
20	3003	660	23.5	24.0	1122	2930		52		3018	4	75.5	1.94	6505	4125	(2380)			11291
21	2930	660	23.5	24.0	1122	2637		39		2712	3	90.4	1.88	5665	4052	(1613)			10146
22	3028	660	23.5	24.0	1122	2344		39		2419	3	80.6	1.92	5161	4150	(1777)			9050
23	3028	660	23.5	24.0	1122	2344		42		2422	3	80.7	1.92	5167	4150	251			9061
24	3028	293	10.4	16.0	748	1465		154		1655	2	82.8	1.91	3512	3776		264		6192

 $\Sigma =$ 300 kW capacity per 3 kW heat rejector. $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ 316,821

7 kW supplement heat pump req'd when supplying heat from storage.

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 316,821 kW-h

SITE: FairfieldOPTION: 7MONTH: April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3076	400	14.3	17.5	818	1465	36	154		1655	2	82.8	1.91	3512	3894		381	29.7	6192
2	2490	343	12.2	17.0	795	1465		150		1651	2	82.6	1.91	3510	3285	225			6177
3	2490	286	10.2	16.0	748	1465		150		1651	2	82.6	1.91	3510	3238	272			6177
4	5530	228	8.1	14.5	678	1465		154		1655	2	82.8	1.91	3512	6208		2696		6192
5	8570	171	6.1	13.0	608	2735		167		2938	3	97.9	1.87	6105	9178		3073		10991
6	11610	114	4.1	12.0	561	4004		193		4233	5	84.7	1.91	8983	12171		3188		15836
7	14650	57	2.0	10.0	468	5274		206		5516	6	91.9	1.88	11522	15118		3597		20636
8	12108	0	0	0	0	5274		85		5395	6	89.9	1.89	11330	12108		779		20183
9	9571	256	9.1	15.0	702	5274		199		5509	6	91.8	1.88	11508	10273	(1234)			20610
10	7032	512	18.2	20.0	935	5626		199		5861	6	97.7	1.87	12178	7967	(4211)			21927
11	6922	769	27.4	26.5	1239	5421		199		5656	6	94.3	1.88	11815	8161	(3654)			21160
12	6812	1025	36.5	32.5	1520	5714		229		5979	6	99.7	1.87	12423	8332	(4595)			22368
13	6703	878	31.3	28.5	1333	5274		229		5539	6	92.3	1.88	11570	8036	3010			20722
14	6593	732	26.1	25.5	1193	5391		238		5665	6	94.4	1.87	11771	7786	3985			21193
15	2198	1172	41.8	36.0	1684	5508		313		5857	6	97.6	1.87	12170	3882	8288			21912
16	2110	782	27.9	26.5	1239	3956		243		4235	5	84.7	1.91	8988	3349	5639			15844
17	1758	391	13.9	18.0	842	3809		249		4094	5	81.9	1.92	8734	2600	6134			15316
18	1406	0	0	0	0	3662		118		3816	4	95.4	1.87	7929	1406	6523			14276
19	2314	0	0	0	0	2637		75		2748	3	91.6	1.88	5740	2314	3426			10281
20	3223	0	0	0	0	2539		63		2638	3	87.9	1.89	5540	3223	2317			9869
21	3223	0	0	0	0	2442		63		2541	3	84.7	1.91	5393	3223	2170			9506
22	2930	190	6.8	13.5	631	2344		181		2561	3	85.4	1.90	5406	3561	1846			9581
23	3076	381	13.6	17.5	818	2491		178		2684	3	89.5	1.89	5636	3894	1742			10041
24	2637	293	10.4	16.0	748	1758		156		1950	2	97.5	1.88	4073	3385	688			7295
$\Sigma =$																			$\Sigma = 343,285$

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 343,285 kW-h

SITE: FairfieldOPTION: 7MONTH: JULY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	733	1026	36.6	38.5	1801	1758	36	147		1941	2	97.1	1.87	4033	2534	(1499)		29.7	7262
2	733	879	31.3	33.5	1567	1758		147		1941	2	97.1	1.87	4033	2300	(1733)			7262
3	733	733	26.1	30.0	1403	1758		147		1941	2	97.1	1.87	4033	2136	(1897)			7262
4	3004	586	20.9	26.5	1239	2754		160		2950	3	98.3	1.87	6129	4243	(1886)			11036
5	5275	586	20.9	26.5	1239	3750		173		3959	4	99.0	1.86	8182	6514	(1668)			14811
6	7545	586	20.9	26.5	1239	4747		186		4969	5	99.4	1.86	10269	8784	(1485)			18590
7	9816	1653	58.9	57.5	2689	5743		242		6021	7	86.0	1.90	12711	12505	(2064)			22525
8	8498	2721	97.0	96.0	2943	6739		290		7075	8	88.4	1.89	14858	11491	1509			26468
9	7179	3788	65.7	65.5	6126	6886		457		7379	8	92.2	1.88	15414	13305	2109			27606
10	7033	4856	86.6	85.0	7950	7032		475		7543	8	94.3	1.88	15756	14983	773			28219
11	6886	5923	70.4	68.5	9611	7618		669		8323	9	92.4	1.88	17386	16497	889			31137
12	6740	6990	83.0	81.5	11434	7325		667		8028	9	89.2	1.89	16859	18174		1315		30034
13	6593	8058	95.7	95.0	13329	7765		667		8468	9	94.1	1.88	17689	19922		2233		31680
14	4103	8058	95.7	95.0	13329	7325		667		8028	9	89.2	1.89	16859	17432		573		30034
15	1612	8058	95.7	95.0	13329	6300		641		6977	7	99.7	1.86	14419	14941		521		26102
16	1905	8058	95.7	95.0	13329	5274		628		5938	6	99.0	1.86	12272	15234		2962		22215
17	1465	8058	95.7	95.0	13329	4249		615		4900	5	98.0	1.87	10181	14794		4613		18331
18	1444	3956	70.5	68.5	6407	4029		445		4510	5	90.2	1.89	9471	7851	1620			16872
19	1423	3516	62.7	61.0	5706	3809		418		4263	5	85.3	1.90	9000	7129	1871			15948
20	1402	3077	54.3	53.0	4957	3590		421		4047	5	80.9	1.92	8634	6359	2275			15140
21	1382	2637	94.0	93.0	4349	3370		254		3660	4	91.5	1.88	7645	5731	1914			13692
22	1361	2198	78.3	76.5	3578	3150		257		3443	4	86.0	1.90	7269	4939	2330			12881
23	1340	1758	62.7	60.1	2811	2930		230		3196	4	79.8	1.92	6818	4151	2667			11957
24	1319	1318	47.0	47.0	2198	2051		205		2292	3	76.4	1.94	4941	3517	1424			8575

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 455,639$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 455,639 kW-h

SITE: FairfieldOPTION: 7MONTH: October

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1318	0	0	0	0	1611	36	50		1697	2	84.9	1.91	3601	1318	2283		29.7	6349
2	1172	0	0	0	0	1758		53		1847	2	92.4	1.88	3858	1172	2686			6910
3	1172	293	10.4	19.5	912	1758		168		1962	2	98.1	1.87	4077	2084	1993			7340
4	1172	293	10.4	19.5	912	1758		168		1962	2	98.1	1.87	4077	2084	1993			7340
5	1172	293	10.4	19.5	912	2051		190		2277	3	75.9	1.94	4908	2084	2824			8519
6	4590	293	10.4	19.5	912	3321		194		3551	4	88.8	1.89	7457	5502	1955			13285
7	8009	0	0	0	0	4590		89		4715	5	94.3	1.87	9797	8009	1788			17639
8	11427	0	0	0	0	5860		87		5983	6	99.7	1.86	12365	11427	938			22383
9	9376	0	0	0	0	6043		130		6209	7	88.6	1.89	13039	9376	3663			23229
10	7325	2783	99.2	98.5	4607	6226		290		6552	7	93.5	1.88	13086	11932	1754			24512
11	7179	2783	99.2	98.5	4607	6409		296		6741	7	96.3	1.87	14006	11786	2220			25219
12	7032	2783	99.2	98.5	4607	6592		299		6927	7	99.0	1.87	14393	11639	2754			25915
13	6886	4834	86.1	84.5	7904	6592		469		7097	8	88.7	1.89	14304	14790	114			26551
14	5225	4248	75.7	73.5	6875	6446		487		6959	7	99.5	1.86	14382	12100	2282			26034
15	3565	4541	80.9	79.0	7389	6592		508		7136	8	89.3	1.89	14986	10954	4032			26697
16	1904	3418	60.9	59.0	5518	5054		452		5542	6	92.3	1.87	11515	7422	4093			20733
17	2197	2295	81.8	80.0	3741	3516		254		3806	4	95.2	1.87	7908	5938	1970			14239
18	1465	1172	41.8	42.5	1988	3311		245		3592	4	89.8	1.89	7543	3453	4090			13438
19	1582	1270	45.3	45.5	2128	3105		239		3380	4	84.5	1.91	7173	3710	3463			12645
20	1699	1367	48.7	48.0	2245	2900		233		3169	4	79.2	1.92	6761	3945	2816			11856
21	1817	1465	52.2	51.5	2408	2695		211		2942	3	98.1	1.87	6113	4225	1888			11006
22	1934	977	34.8	37.0	1730	2490		211		2737	3	91.2	1.88	5717	3664	2053			10239
23	2051	488	17.4	24.0	1122	2637		190		2863	3	95.4	1.87	5949	3173	2776			10711
24	1465	0	0	0	0	2490		81		2607	3	86.9	1.90	5504	1465	4039			9753

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 382,542$ Fuel Energy Req'd. for
Boiler = kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 382,542 kW-h

SITE: FairfieldOPTION: 7AMONTH: January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3516	440	15.7	19.0	889	1318	3.6	170		1524	2	76.2	1.94	3285	3956		671	29.7	5701
2	2344	293	10.4	16.0	748	1318		156		1510	2	75.5	1.94	3255	2637	618		29.7	5649
3	2344	293	10.4	16.0	748	1318		156		1510	2	75.5	1.94	3255	2637	618		29.7	5649
4	2344	293	10.4	16.0	748	1318		156		1510	2	75.5	1.94	3255	2637	618		29.7	5649
5	6934	0	0	0	0	2307		62		2405	3	80.2	1.92	5131	6934		1803	29.7	8997
6	11524					3296		75		3407	4	85.2	1.92	7268	11524		4256	29.7	12746
7	16115					4285		88		4409	5	88.2	1.89	9259	16115		6856	29.7	16495
8	14357					5274		101		5411	6	90.2	1.89	11363	14357		2994	29.7	20243
9	12599					5274		101		5411	6	90.2	1.89	11363	12599		1236	29.7	20243
10	10841					5420		87		5543	6	92.4	1.88	11579	10841	738		29.7	20737
11	10548					5567		93		5696	6	94.9	1.88	11893	10548	1350		29.7	21309
12	10255					5333		90		5459	6	91.0	1.89	11464	10255	1209		29.7	20423
13	10328					5479		93		5608	6	93.5	1.88	11714	10328	1386		29.7	20980
14	10401					5215		87		5338	6	89.0	1.89	11210	10401	809		29.7	19970
15	8130					4365		80		4481	5	89.6	1.89	9410	8130	1280		29.7	16764
16	5860					3516		70		3622	4	90.6	1.89	7606	5860	1746		29.7	13550
17	6006					3369		67		3472	4	86.8	1.90	7330	6006	1324		29.7	12989
18	6153	1025	36.5	32.0	1497	3233		75		3344	4	83.6	1.91	7097	7650		553	29.7	12510
19	3076	842	30.0	28.0	1309	2930		76		3042	4	76.1	1.94	6557	4385	2172		29.7	11380
20	3003	660	23.5	24.0	1122	2930		79		3045	4	76.1	1.94	6564	4125	2439		29.7	11392
21	2930	660	23.5	24.0	1122	2637		57		2730	3	91.0	1.88	5703	4052	1651		29.7	10213
22	3028	660	23.5	24.0	1122	2344		51		2431	3	81.0	1.92	5186	4150	1036		29.7	9095
23	3028	660	23.5	24.0	1122	2344		51		2431	3	81.0	1.92	5186	4150	1036		29.7	9095
24	3028	293	10.4	16.0	748	1465		147		1648	2	82.4	1.91	3497	3776		279	29.7	6165
$\Sigma =$										$\Sigma =$									
										$\Sigma =$									

Fuel Energy Req'd. for
Boiler = 23,310 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 341,254 kW-h

MONTH: April

$$\Sigma = 345,253$$

Total Fuel Energy
Req'd. = 362,276 kW-h

SITE: FairfieldOPTION: 7AMONTH: July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	733	1026	36.6	38.5	1801	1758	36	162		1956	2	97.8	1.87	4064	2534	1530		29.7	7318
2	733	879	31.3	33.5	1567	1758		165		1959	2	98.0	1.87	4070	2300	1770			7329
3	733	733	26.1	30.0	1403	1758		168		1962	2	98.1	1.87	4077	2136	1941			7340
4	3004	586	20.9	26.5	1239	2754		181		2971	3	99.0	1.87	6173	4243	1930			11115
5	5275	586	20.9	26.5	1239	3750		191		3977	4	99.4	1.86	8219	6514	1705			14878
6	7545	586	20.9	26.5	1239	4747		201		4984	5	99.7	1.86	10300	8784	1516			18646
7	9816	1653	58.9	57.5	2689	5743		245		6024	7	86.1	1.90	12717	12505	212			22536
8	8498	2721	97.0	96.0	2993	6739		311		7086	8	88.6	1.89	14881	11491	3390			26510
9	7179	3788	67.5	65.5	6126	6886		457		7379	8	92.2	1.88	15414	13305	2109			27606
10	7033	4856	86.6	85.0	7950	7032		475		7543	8	94.3	1.88	15756	14983	773			28219
11	6886	5923	70.4	68.5	9611	7618		669		8323	9	92.4	1.88	17386	16497	889			31137
12	6740	6990	83.0	81.5	11434	7325		683		8044	9	89.4	1.89	16992	18174		1282		30094
13	6593	8058	95.7	95.0	13329	7765		683		8484	9	94.3	1.89	17316	19922		2106		31740
14	4103	8058	95.7	95.0	13329	7325		683		8044	9	89.4	1.89	16892	17432		540		30094
15	1612	8058	95.7	95.0	13329	6300		657		6993	7	99.9	1.86	14452	14941		489		26162
16	1905	8058	95.7	95.0	13329	5274		644		5954	6	99.2	1.87	12371	15234		2863		22275
17	1465	8058	95.7	95.0	13329	4249		631		4916	5	98.3	1.87	10214	14794		4580		18391
18	1444	3956	70.5	68.5	6407	4029		445		4510	5	90.2	1.89	9471	7851	1620			16872
19	1423	3516	62.7	61.0	5706	3809		418		4263	5	85.3	1.90	9000	7129	1871			15948
20	1402	3077	54.3	53.0	4957	3590		421		4047	5	80.9	1.92	8634	6359	2275			15140
21	1382	2637	94.0	93.0	4349	3370		254		3660	4	91.5	1.88	7645	5731	1914			13692
22	1361	2198	78.3	76.5	3578	3150		257		3443	4	86.0	1.90	7269	4939	2330			12881
23	1340	1758	62.7	60.1	2811	2930		230		3196	4	79.8	1.92	6818	4151	2667			11957
24	1319	1318	47.0	47.0	2198	2051		205		2292	3	76.4	1.94	4941	3517	1424			8575

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 11,860$ $\Sigma = 456,455$ Fuel Energy Req'd. for
Boiler = 14,825 kW-hFuel Energy Req'd. for
Utility Plant = kW-hTotal Fuel Energy
Req'd. = 471,280 kW-h

SITE: Fairfield						OPTION: 7A						MONTH: October									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)		
1	1318	0	0	0	0	1611	36	50		1697	2	84.9	1.91	3601	1318	2283		29.7	6349		
2	1172	0	0	0	0	1758		53		1847	2	92.4	1.88	3858	1172	2686			6910		
3	1172	293	10.4	19.5	912	1758		168		1962	2	98.1	1.87	4077	2084	1993			7340		
4	1172	293	10.4	19.5	912	1758		168		1962	2	93.1	1.87	4077	2084	1993			7340		
5	1172	293	10.4	19.5	912	2051		190		2277	3	75.9	1.94	4908	2084	2824			8519		
6	4590	293	10.4	19.5	912	3321		194		3551	4	88.8	1.89	7457	5502	1955			13285		
7	8009	0	0	0	0	4590		89		4715	5	94.3	1.87	9797	8009	1788			17639		
8	11427	0	0	0	0	5860		87		5983	6	99.7	1.86	12365	11427	938			22383		
9	9376	0	0	0	0	6043		130		6209	7	88.6	1.89	13039	9376	3663			23229		
10	7325	2783	99.2	98.5	4607	6226		290		6552	7	93.5	1.88	13686	11932	1754			24512		
11	7179	2783	99.2	98.5	4607	6409		296		6741	7	96.3	1.87	14006	11786	2220			25219		
12	7032	2783	99.2	98.5	4607	6592		299		6927	7	99.0	1.87	14393	11639	2754			25915		
13	6886	4834	86.1	84.5	7904	6592		469		7097	8	88.7	1.89	14904	14790	114			26551		
14	5225	4248	75.7	73.5	6875	6446		487		6959	7	99.5	1.86	14382	12100	2282			26034		
15	3565	4541	80.9	79.0	7389	6592		508		7136	8	89.3	1.89	14986	10954	4032			26697		
16	1904	3418	60.9	59.0	5518	5054		452		5542	6	92.3	1.87	11515	7422	4093			20733		
17	2197	2295	81.8	80.0	3741	3516		254		3806	4	95.2	1.87	7908	5938	1970			14239		
18	1465	1172	41.8	42.5	1988	3311		245		3592	4	89.8	1.89	7543	3453	4090			13438		
19	1582	1270	45.3	45.5	2128	3105		239		3380	4	84.5	1.91	7173	3710	3463			12645		
20	1699	1367	48.7	48.0	2245	2900		233		3169	4	79.2	1.92	6761	3945	2816			11856		
21	1817	1465	52.2	51.5	2408	2695		211		2942	3	98.1	1.87	6113	4225	1888			11006		
22	1934	977	34.8	37.0	1730	2490		211		2737	3	91.2	1.86	5717	3664	2053			10239		
23	2051	488	17.4	24.0	1122	2637		190		2863	3	95.4	1.87	5949	3173	2776			10711		
24	1465	0	0	0	0	2490		81		2607	3	86.9	1.90	5504	1465	4039			9753		
Σ=						Σ=						Σ=				Σ=				Σ=382,542	

Fuel Energy Req'd. for
Boiler = _____ kW-h

Fuel Energy Req'd. for
Utility Plant = _____ kW-h

Total Fuel Energy
Req'd. = 382,542 kW-h

SITE: FairfieldOPTION: 11MONTH: JANUARY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3516	440	100	100	745	1318	36	139	0	2238	3	74.6	1.60	3979		(463)		33.5	7423
2	2344	293	100	100	745	1318		139	0	2238	3	74.6	1.60	3979		(1635)		33.5	7423
3	2344	293	100	100	745	1318		139	0	2238	3	74.6	1.60	3979		(1635)		33.5	7423
4	2344	293	15.7	28.5	212	1318		102	0	1668	2	83.4	1.57	2910		(566)		33.6	5516
5	6934	0	0	0	0	2307		46	0	2389	3	79.6	1.59	4221			2713		7900
6	11524					3296		59	0	3391	4	84.8	1.57	5915			5609		11214
7	16115					4285		104	3120	7545	8	94.3	1.55	16114			3120		24950
8	14357					5274		104	1849	7263	8	90.7	1.55	14358			1849		24018
9	12599					5274		91	1211	6612	7	94.4	1.55	12599			1211		21865
10	10841					5420		85	225	5766	6	96.1	1.54	10842			225		19067
11	10548					5567		85	0	5688	6	94.8	1.54	9733			815		18810
12	10255					5333		85	0	5454	6	90.9	1.55	9393			862		18036
13	10328					5479		85	0	5600	6	93.3	1.55	9644			684		18519
14	10401					5215		85	0	5336	6	89.9	1.56	9249			1152		17646
15	8130					4355		72	0	4473	5	89.4	1.56	7753			377		14792
16	5860					3516		52	0	3604	4	90.1	1.56	6247		(387)			11918
17	6006					3369		52	0	3457	4	86.4	1.57	6031		(25)			11432
18	6153	1025	OFF	OFF	OFF	3233		59	0	3338	4	83.1	1.58	5846			307		11005
19	3076	842				2930		52	0	3018	4	75.5	1.60	5365		(2289)		33.5	10010
20	3003	660				2930		52	0	3018	4	75.5	1.60	5365		(2362)		33.5	10010
21	2930	660				2637		39	0	2712	3	90.4	1.56	4701		(1771)		33.6	8968
22	3028	660				2344		39	0	2419	3	80.6	1.58	4247		(1219)		33.6	7999
23	3028	660				2344		39	0	2419	3	80.6	1.58	4247		(1219)		33.6	7999
24	3028	293				1465		33	0	1534	2	76.7	1.60	2727			301	33.5	5088

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 309,031$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 309,031 kW-h

SITE: FairfieldOPTION: 11MONTH: APRIL

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3076	400	100	100	745	1465	36	152		2398	3	79.9	1.59	4236		1160		33.6	7930
2	2490	343	100	100	745	1465		163		2409	3	80.3	1.58	4229		1739			7966
3	2490	286	100	100	745	1465		163		2409	3	80.3	1.58	4229		1739			7966
4	5530	228	100	100	745	1465		137		2383	3	79.4	1.59	4210			1320		7880
5	8570	171	63.3	58.5	436	2735		150		3357	4	83.9	1.57	5856			2714		11101
6	11610	114	OFF	OFF	OFF	4004		72		4112	5	82.2	1.58	7219			4391		13598
7	14650	57	OFF	OFF	OFF	5274		85		5395	6	89.9	1.56	9351			5299		17841
8	12108	0	0	0	0	5274		85		5395	6	89.9	1.56	9351			2757		17841
9	9571	256	OFF	OFF	OFF	5274		85		5395	6	89.9	1.56	9351			220		17841
10	7032	512				5626		78		5740	6	95.7	1.54	9822		(2790)			18981
11	6922	769				5421		78		5535	6	92.3	1.55	9533		(2611)			18304
12	6812	1025				5714		78		5828	6	97.1	1.54	9972		(3160)			19272
13	6703	878				5274		78		5388	6	89.8	1.56	9339		(2636)			17817
14	6593	732				5391		78		5505	6	91.8	1.55	9481		(5504)			18204
15	2198	1172				5508		177		5721	6	95.4	1.54	9789		4975			18919
16	2110	782				3956		164		4156	5	83.1	1.58	7296		5186			13743
17	1758	391				3809		151		3996	4	99.9	1.53	6793		5035			13214
18	1406	0	0	0	0	3662		151		3849	4	96.2	1.54	6586		5180			12728
19	2314	0	0	0	0	2637		83		2756	3	91.9	1.55	4746		2432			9114
20	3223	0	0	0	0	2539		72		2647	3	88.2	1.56	4588		1365			8753
21	3223	0	0	0	0	2442		61		2539	3	84.6	1.57	4429		1206			8396
22	2930	190	OFF	OFF	OFF	2344		72		2452	3	81.7	1.58	4305		1375			8108
23	3076	381	OFF	OFF	OFF	2491		72		2599	3	86.6	1.57	4534		1458			8595
24	2637	293	OFF	OFF	OFF	1758		37		1831	2	91.6	1.55	3153		516			6055

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 310,167$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 310,167 kW-h

SITE: FairfieldOPTION: 11MONTH: JULY

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	733	1026	100	100	1490	1758	36	344		3628	4	90.7	1.56	6289		5556	0	33.6	11997
2	733	879				1758		344		3628	4	90.7	1.56	6289		5556			11997
3	733	733				1758		344		3628	4	90.7	1.56	6289		5556			11997
4	3004	586				2754		346		4626	5	92.5	1.55	7967		4963			15298
5	5275	586				3750		348		5624	6	93.7	1.55	9686		4411			18598
6	7545	586				4747		350		6623	7	94.6	1.54	11333		3788			21901
7	9816	1653				5743		352		7621	8	95.3	1.54	13040		3224			25202
8	8498	2721				6739		420		8685	9	96.5	1.54	14861		6363			28720
9	7179	3788				6886		453		8865	9	98.5	1.53	15071		7892			29315
10	7033	4856				7032		477		9035	10	90.4	1.56	15661		8628			29878
11	6886	5923				7618		488		9632	10	96.3	1.54	16481		9595			31852
12	6740	6990				7325		488		9339	10	93.4	1.55	16084		9344			30883
13	6593	8058				7765		499		9790	10	97.9	1.54	16752		10159			32374
14	4103	8058				7325		532		9383	10	93.8	1.55	16160		12057			31028
15	1612	8058				6300		541		8367	9	93.0	1.55	14410		12798			27669
16	1905	8058				5274		484		7284	8	91.0	1.55	12545		10640			24087
17	1465	8058				4249		449		6224	7	88.9	1.56	10788		9323			20582
18	1444	3956				4029		425		5980	6	99.7	1.53	10166		8722			19775
19	1423	3516				3809		414		5749	6	95.8	1.54	9837		8414			19011
20	1402	3077				3590		414		5530	6	92.2	1.55	9524		8122			18287
21	1382	2637				3370		403		5299	6	88.3	1.56	9185		7803			17523
22	1361	2198				3150		403		5079	6	84.7	1.57	8860		7499			16796
23	1340	1758	98.2	98.0	1460	2930		247		4673	5	93.5	1.55	8048		6708			15453
24	1319	1318	OFF	OFF	OFF	2051		94		2181	3	72.5	1.61	3902		2583		33.5	7234

 $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma =$ $\Sigma = 517,457$ Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 517,457 kW-h

SITE: FairfieldOPTION: 11MONTH: OCTOBER

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1318	0	0	0	0	1611	36	59		1706	2	85.3	1.57	2975		1658	0	33.6	5642
2	1172	0	0	0	0	1758		70		1864	2	93.2	1.55	3210		2038			6164
3	1172	293	OFF	OFF	OFF	1758		70		1864	2	93.2	1.55	3210		2038			6164
4	1172	293	OFF	OFF	OFF	1758		70		1864	2	93.2	1.55	3210		2038			6164
5	1172	293	36.7	38.5	287	2051		181		2555	3	85.2	1.57	4457		3285			8449
6	4590	293	100	100	745	3321		211		4313	5	86.3	1.57	7524		2934			14263
7	8009	0				4590		202		5573	6	92.9	1.55	9593		1589			18429
8	11427	0				5860		193		6834	7	97.6	1.54	11694		267			22599
9	9376	0				6043		250		7074	8	88.4	1.56	12262		2886			23393
10	7325	2783				6226		294		7301	8	91.3	1.55	12574		5249			24144
11	7179	2783				6409		305		7495	8	93.7	1.55	12903		5729			24785
12	7032	2783				6592		316		7689	8	96.2	1.54	13157		6125			25427
13	6886	4834				6592		316		7689	8	96.2	1.54	13157		6271			25427
14	5225	4248				6446		338		7565	8	94.6	1.55	13023		7804			25017
15	3565	4541				6592		371		7744	8	96.8	1.54	13251		9686			25608
16	1904	3418				5054		347		6182	7	88.3	1.56	10715		8811			20443
17	2197	2295				3516		266		4563	5	91.2	1.55	7851		5662			15089
18	1465	1172				3311		266		4358	5	87.2	1.56	7554		6089			14411
19	1582	1270				3105		266		4152	5	83.0	1.58	7289		5707			13730
20	1699	1367				2900		242		3925	4	98.1	1.53	6673		4974			12979
21	1817	1465				2695		231		3707	4	92.7	1.55	6384		4567			12259
22	1934	977				2490		220		3491	4	87.3	1.56	6051		4117			11544
23	2051	488	↓	↓	↓	2637		220		3639	4	91.0	1.55	6267		4216			12034
24	1465	0	0	0	0	2490	↓	105		2631	3	87.7	1.56	4560		3095	↓	↓	8700

Σ=

Σ=

Σ=

Σ=

Σ= 382,864

Fuel Energy Req'd. for
Boiler = _____ kW-hFuel Energy Req'd. for
Utility Plant = _____ kW-hTotal Fuel Energy
Req'd. = 382,864 kW-h

SITE: FairfieldOPTION: ConventionalMONTH: January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3516	440	15.7	29.0	313	1318		90		1721									
2	2344	293	10.4	26.0	280	↓		↓		1688									
3	2344	293	10.4	26.0	280	↓		↓		1688									
4	2344	293	10.4	26.0	280	↓		↓		1688									
5	6934	0	0	0	0	2307		23		2330									
6	11524					3296		↓		3319									
7	16115					4285		↓		4308									
8	14357					5274		↓		5297									
9	12599					5274		↓		5297									
10	10841					5420		↓		5443									
11	10548					5567		↓		5590									
12	10255					5333		↓		5356									
13	10328					5479		↓		5502									
14	10401					5215		↓		5238									
15	8130					4365		↓		4388									
16	5860					3516		↓		3539									
17	6006	↓	↓	↓	↓	3369		↓		3392									
18	6153	1025	36.5	39.0	421	3233		102		3756									
19	3076	842	30.0	35.0	378	2930		102		3410									
20	3003	660	23.5	32.0	345	2930		90		3365									
21	2930	↓	↓	↓	↓	2637		↓		3072									
22	3028	↓	↓	↓	↓	2344		↓		2779									
23	3028	↓	↓	↓	↓	2344		↓		2779									
24	3028	293	10.4	26.0	280	1465		↓		1835									
$\Sigma = 168692$		$\Sigma = 86780$									$\Sigma =$		$\Sigma =$		$\Sigma =$				

Fuel Energy Req'd. for
Boiler = 210,865 kW-hFuel Energy Req'd. for
Utility Plant = 289,267 kW-hTotal Fuel Energy
Req'd. = 500,132 kW-h

SITE: FairfieldOPTION: ConventionalMONTH: April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	3076	400	14.3	28.0	302	1465		90		1857									
2	2490	343	12.2	27.0	291					1846									
3	2490	286	10.2	26.0	280					1835									
4	5530	228	8.1	25.0	270					1825									
5	8570	171	6.1	25.0	270	2735				3095									
6	11610	114	4.1	24.0	259	4004				4353									
7	14650	57	2.0	23.0	248	5274				5612									
8	12108	0	0	0	0	5274		23		5297									
9	9571	256	9.1	26.0	280	5274		90		5644									
10	7032	512	18.2	29.0	313	5626		90		6029									
11	6922	769	27.4	33.0	356	5421		102		5879									
12	6812	1025	36.5	39.0	421	5714				6237									
13	6703	878	31.3	36.0	388	5274				5764									
14	6593	732	26.1	33.0	356	5391				5849									
15	2198	1172	41.8	42.0	453	5508				6063									
16	2110	782	27.9	34.0	367	3956				4425									
17	1758	391	13.9	28.0	302	3809		90		4201									
18	1406	0	0	0	0	3662		23		3685									
19	2314					2637				2660									
20	3223					2539				2562									
21	3223					2442				2465									
22	2930	190	6.8	25.0	270	2344		90		2709									
23	3076	381	13.6	28.0	302	2491				2883									
24	2637	293	10.4	26.0	230	1758				2128									
$\Sigma = 129032$										$\Sigma = 94898$									

Fuel Energy Req'd. for
Boiler = 161,290 kW-hFuel Energy Req'd. for
Utility Plant = 316,327 kW-hTotal Fuel Energy
Req'd. = 477,617 kW-h

SITE: FairfieldOPTION: ConventionalMONTH: July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Hour	Heat Load (kW)	Refrg. Load (kW)	Feefrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	Nc. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	733	1026	36.6	39.0	421	1758		102		2281									
2	733	879	31.3	36.0	388	1758		102		2248									
3	733	733	26.1	33.0	356	1758		102		2216									
4	3004	586	20.9	31.0	225	2754		90		3069									
5	5275	586	20.9	31.0	225	3750		90		4065									
6	7545	586	20.9	31.0	225	4747		90		5062									
7	9816	1653	58.9	51.0	635	5743		114		6492									
8	8498	2721	97.0	97.0	1046	6739		126		7911									
9	7179	3788	67.5	63.0	1359	6886		205		8450									
10	7033	4856	36.5	84.0	1812	7032		229		9073									
11	6886	5923	70.4	66.0	2136	7618		296		10050									
12	6740	6990	33.0	80.0	2589	7325		332		10246									
13	6593	8058	35.7	95.0	3075	7765				11172									
14	4103					7325				10732									
15	1612					6300				9707									
16	1905					5724				8682									
17	1465					4249				7656									
18	1444	3956	70.5	66.0	1424	4029		205		5658									
19	1423	3516	52.7	58.0	1251	3809		205		5265									
20	1402	3077	54.8	51.0	1100	3590		205		4895									
21	1382	2637	94.0	93.0	1003	3370		126		4499									
22	1361	2198	78.3	75.0	809	3150		126		4085									
23	1340	1758	62.7	58.0	626	2930		114		3670									
24	1319	1318	47.0	45.0	485	2051		102		2638									

 $\Sigma = 89524$ $\Sigma = 149821$ $\Sigma =$ $\Sigma =$ $\Sigma =$ Fuel Energy Req'd. for
Boiler = 111,905 kW-hFuel Energy Req'd. for
Utility Plant = 499,403 kW-hTotal Fuel Energy
Req'd. = 611,308 kW-h

SITE: FAIRFIELDOPTION: CONVENTIONALMONTH: OCTOBER

Hour	Heat Load (kW)	Refrg. Load (kW)	Refrg. Load (%)	Refrg. Cap. Factor	Power for Refrg. (kW)	Site Elect. Load (kW)	Cent. Plant Load (kW)	Aux. Loads (kW)	Elec. Boiler Load (kW)	Total Elect. Load (kW)	No. of Oper. Units	Gen. Cap. (%)	Heat Recov. Factor	Total Recov. Heat (kW)	Total Heat Load (kW)	Heat Rej. (kW)	Suppl. Heat Req'd. (kW)	Eng. Eff. (%)	Fuel Cons. Rate (kW)
1	1318	0	0	0	0	1611		23		1634									
2	1172	0	0	0	0	1758		23		1781									
3	1172	293	10.4	26.0	280	1758		90		2128									
4	1172	293	10.4	26.0	280	1758		90		2128									
5	1172	293	10.4	26.0	280	2051		90		2421									
6	4590	293	10.4	26.0	280	3321		90		3691									
7	8009	0	0	0	0	4590		23		4613									
8	11427	0	0	0	0	5860		23		5883									
9	9376	0	0	0	0	6043		23		6066									
10	7325	2783	99.2	99.0	1068	6226		126		7420									
11	7179	2783	99.2	99.0	1068	6409		126		7603									
12	7032	2783	99.2	99.0	1068	6592		126		7786									
13	6886	4834	86.1	83.0	1791	6592		229		8612									
14	5225	4248	75.7	72.0	1554	6446		229		8229									
15	3565	4541	80.9	77.0	1661	6592		229		8482									
16	1904	3418	60.9	56.0	1208	5054		205		6467									
17	2197	2295	81.8	79.0	852	3516		126		4494									
18	1465	1172	41.8	42.0	453	3311		102		3866									
19	1582	1270	45.3	44.0	475	3105		102		3682									
20	1699	1367	48.7	47.0	507	2900		102		3509									
21	1817	1465	52.2	49.0	529	2695		114		3338									
22	1934	977	34.8	38.0	410	2490		102		3002									
23	2051	488	17.4	29.0	313	2637		90		3040									
24	1465	0	0	0	0	2490		23		2513									

 $\Sigma = 92,734$ $\Sigma = 112,388$ $\Sigma =$ $\Sigma =$ $\Sigma =$ Fuel Energy Req'd. for
Boiler = 115,918 kW-hFuel Energy Req'd. for
Utility Plant = 374,626 kW-hTotal Fuel Energy
Req'd. = 490,545 kW-h

APPENDIX G

Background Information on Stirling Engine Configurations

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1. Principles of Operation of Stirling Engine

The heat required for operation is supplied to the working gas of a Stirling engine from the outside, through a wall. Owing to the heat capacity of the wall, it is not possible to heat and cool the gas simply by the rapid heating and cooling of the wall. However, the gas temperature can be varied cyclically by using a displacer piston to transfer the working gas back and forth between two spaces, one at a fixed high temperature and the other at a fixed low temperature, as illustrated in Figure 1.

Figure 1: Diagram illustrating the principle of the displacer

If the displacer piston of Figure 1 is raised, the working gas will flow from the hot space via the heater and cooler ducts into the cold space. If the displacer piston is now moved downwards, the gas will return to the hot space along the same path. During the first transfer stroke the working gas has to yield a large quantity of heat; an equal quantity of heat has to be taken up during the second stroke. The regenerator shown in Figure 1 is inserted between the heater duct and cooler duct in order to prevent unnecessary waste of heat. It is a space filled with porous material to which the hot gas yields heat before entering the cooler; when the gas streams back, it takes up the stored heat again prior to its entry into the heater.

To generate power, the displacer, which serves to heat and cool the gas cyclically, is combined with a piston that compresses the gas while it is in the cold space and allows it to expand while in the hot space. Since compression takes place at a lower temperature than expansion, a surplus of work results.

Figure 2 shows four phases of the Stirling cycle through which the whole system passes if a discontinuous movement of the piston and the displacer is assumed:

Figure 2: Diagrams illustrating the four phases of the Stirling cycle

- I Power piston is in lowest, displacer piston in highest position. All the gas is in the cold space.
- II The displacer piston is still in the highest position. The power piston has compressed the gas while it is at low temperature.
- III The power piston is still in its highest position. The displacer piston has pushed the gas through the cooler, regenerator, and heater into the hot space.
- IV The hot gas has expanded, and the power and displacer pistons have together returned to the lowest position. While the power piston remains there, the displacer piston will now push the gas through heater, generator and cooler into the cold space, whereupon situation I will have been restored.

The displacements illustrated in Figure 2 are plotted as functions of time in Figure 3; the ordinates in band E represent the variation in the volume of the hot space, and those in band C the variation in the volume of the cold space. The volume variations are plotted separately in the lower part of the diagram. Figure 4 is the p-V diagram of the cycle (V is the total volume of the gas).

Figure 3: The discontinuous movements of piston (P) and displacer (D) plotted as functions of time

Figure 4: The p-V diagram of the Stirling cycle represented by Fig. 3

In a practical version of the engine, the movements of the piston and those of the displacer must of course be continuous, not discontinuous, as they have been assumed to be in the above figures. The continuous movements can be obtained with the aid of either a conventional crank and connecting-rod mechanism or other suitable drives. It will then not be possible to distinguish any transitions between the four phases, but this will not alter the principle of the cycle or detract from its

efficiency. The movements of power piston and displacer might now be as indicated in Figure 5 in which the volume variations of the cold and hot spaces have again been plotted separately. The only essential condition for obtaining a surplus of work is that the volume variation of the hot space should have a phase lead with respect to that of the cold space; this is equivalent to requiring the appropriate p-V diagram, shown in Figure 6, to be traced out in a clockwise direction.

Figure 5: The continuous movements of piston (P) and displacer (D) plotted as functions of crank angle

Figure 6: The p-V diagram of the cycle represented by Fig. 5

2. Stirling Engine with Rhombic Drive

The Stirling system described in Figure 2 is characteristic of a single-acting machine, i.e., one in which the compression and expansion are carried out by a piston, and the displacement of the working gas by a displacer. One of the most effective mechanization of a single-acting system is accomplished with the aid of the rhombic drive, described next.

The rhombic drive converts reciprocating into rotary motion. Its output is normally coupled to a rotary load, for instance, electric generators, which are connected to the drive's two identical, parallel crankshafts; the latter are coupled to each other with gears for synchronous rotation in opposite directions. The crankshafts are located symmetrically about a plane parallel to their axis and passing through the center line of the driven machine.

The mechanism also contains two pairs of connecting rods, each pair driven by a crankshaft with the aid of crank pins; the ends of the connecting rods are interconnected by yokes, which in turn are attached to the reciprocating elements.

Figure 7 is a schematic diagram of the mechanism. Fixed to piston 1 by way of piston 2 is a yoke 3. One end of the yoke is linked by connecting rod 4 to crank 5, the other end by connecting rod 4' to crank 5'. The displacer (not shown) is actuated by a similar arrangement: the displacer rod 7, which passes through the hollow piston rod 2, is coupled to a yoke 8 which is linked to cranks 5 and 5' by connecting rods 9 and 9', respectively. If 9 and 9' are given the same length as 4 and 4', the two pairs of connecting rods will form a configuration similar to a rhombus, only the angles of which vary when the system is in motion. Gears 10-10' ensure exact symmetry of the system at all times. Although the two crankshafts are geared together for synchronous movement, power output can be obtained either on one shaft, or on both shafts simultaneously. In the latter case, no power is transmitted through the gears.

Figure 7: Schematic diagram of conventional rhombic drive mechanism

The rhombic drive can be completely balanced for all the forces acting on the mechanism and for all their moments -- "completely" in the sense that both the fundamentals and all the higher harmonics can be balanced.

Figure 8 shows a cross-section through a rhombic driven, fossil fueled, single acting Stirling engine, designed and developed at the Philips Research Laboratories in Eindhoven, Holland. As indicated, the piston, displacer, regenerator, and cooler tubes are arranged concentrically, for compactness. The coupling of the piston and the displacer to the rhombic drive are clearly shown. Three engines of this configuration were constructed: a 10 hp unit operating at 3000 rpm, a 40 hp at 2500 rpm, and a 90 hp engine running at 1500 rpm.

It should be noted that the rhombic configuration has been adapted to multi-cylinder engines. Specifically, a four cylinder 160 hp Stirling engine was incorporated and tested in a city bus by Philips.

Figure 8: Section through the single-cylinder Stirling engine with a rhombic drive

3. Stirling Engine with Swashplate Drive

Another embodiment of the Stirling cycle is the double acting engine; its operational characteristics are illustrated in Figure 9.

Figure 9: Schematic representation of a double-acting, four-cylinder, Stirling engine

As indicated, there is only one piston per cylinder. This piston acts as a compressor and expander as well as a displacer, by means of an inter-action between adjacent cylinders.

The operation of a double-acting engine can be described by starting (see Figure 9) with the volume above one piston, for instance in cylinder 1; this volume is the expansion space. The external passages with the usual cooler, regenerator, heater sequence connect to the volume below the piston in another cylinder, number 2, and this is the cold compression space. The compression and expansion spaces reach their maximum volumes at top dead center and bottom dead center of the respective pistons. Additional combinations are formed by the expansion and compression spaces of cylinders 2 and 3, 3 and 4, and 4 and 1, respectively. Figure 9 of course represents a 4 cylinder engine.

To provide the required fundamental relationship of a Stirling cycle, i.e., that the expansion spaces lead their respective compression spaces, it is only necessary to arrange for the pistons to move in a manner which allows the expansion-space piston to reach bottom dead center before the compression-space piston of the same thermodynamic unit reaches top dead center. Referring to Figure 9, piston 2 should reach bottom dead center before piston 1 reaches top dead center; and similarly for piston 3 and 2, 4 and 3, and 1 and 4.

To realize these kinematic requirements of the double-acting Stirling cycle, a swashplate-drive mechanism can be used. A typical swashplate-drive configuration is depicted in Figure 10. The swashplate is fastened to the output shaft of the engine at an angle determined by the centerline of the cylinder bore and

the stroke of the pistons. As indicated, the piston rods straddle the swashplate and are in contact with it by circular slider bearings. These bearings allow the piston rods to pivot in spite of the constantly changing angle of the rotating swashplate which slides freely between the bearings. As the drive shaft and the swashplate rotate, they impart simple harmonic motion to the pistons. The combined kinetic energy of three or more equi-placed units is of constant magnitude, so that the total inertia effect may be likened to that of a flywheel.

Figure 10: Configuration of swashplate drive

A swashplate-driven, 40 hp engine built at the Philips Research Laboratories in Eindhoven, Netherlands, is shown in Figure 11. The swashplate itself, the slider bearings, and the thrust bearings are clearly shown.

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Figure 11: 40 hp Stirling engine with swashplate drive