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CASE HISTORY STUDY OF TOTAL ENERGY SYSTEM AT
WESTERN MALL SHOPPING CENTER,
SIOUX FALLS, SOUTH DAKOTA

ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS
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CASE HISTORY STUDY OF TOTAL ENERGY SYSTEM AT
WESTERN MALL SHOPPING CENTER,
SIoux FALLS, SOUTh DAKOTA

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1 INTRODUCTION

1.1 SCOPE OF PLANT SERVICES

Western Mall Total Energy Plant, located in Sioux Falls, South Dakota, serves an enclosed mall shopping center of 462,000 ft². The plant, shown in Fig. 1.1, provides most of the mall and tenants with electricity, space heating, and air-conditioning services from a natural-gas-fueled engine-generator plant with hot water heat recovery, supplementary gas-fueled boiler, and absorption water chiller. One large anchor tenant with 98,600 ft² of space no longer is served from the total energy plant; this tenant had been an electricity customer only and has rooftop, gas-heated, electric-drive, air-conditioning equipment.

1.2 PLANT CAPACITY

The total energy plant has four 750 kW generators producing 480-V, 60 Hz power with maximum peak load of approximately 1,800 kW. Heating load served by the plant is calculated to be 15,000,000 Btu at -30° F winter design condition with 70° F space temperature. Maximum observed cooling load at 100° F, 75° W.B. outdoor conditions is about 750 tons of refrigeration. Engine heat is recovered in a water system operated at 210°-240° F; an auxiliary scotch marine type, firetube gas-fueled boiler provides up to 14,000,000 Btu/hr of supplementary heat. An absorption chiller with nominal rating of 900 tons operates on 240° F or lower, entering water temperature. The thermal delivery system is a four pipe configuration with separate heating and cooling coils and no provisions for reheat control. All tenant fan systems are equipped for up to 100% outdoor air intake for economizer operation.

1.3 PLANT PRODUCTION

Energy customers recently have begun to exercise considerable control over their uses of electricity with more careful operation of lighting and appliances and with some replacement of illumination devices with more efficient equipment. The occupancy of stores has changed somewhat with replacement of a high energy-using food market with less intensive retail establishments. Substantial additions to the mall have been made in the last four years, and the increased loads were added to the original total energy plant without increas-

Fig. 1.1. Western Mall Shopping Center

ing plant capacity. An indication of plant output can be obtained from Table 1.1 showing electricity produced, electricity billed to tenants, and hours of use of the boiler and chiller.

1.4 SERVICE AND MAINTENANCE

For the past four years, the plant has assumed responsibility for servicing and maintaining the air-handling equipment and temperature controls in tenant spaces. The costs of furnishing heating and cooling energy are entirely the responsibility of the TE Plant because the tenants are charged on the basis of store area and occupancy factors negotiated at the time of leasing. Furthermore, damage to individual coils or piping in the large central chilled and hot water systems could cause serious failures to all tenants. Under the original contracts for serving tenants with heating and cooling, the tenant was solely responsible for operation, service, and maintenance of all equipment in his leasehold. Because there was no motivation to spend money and effort on periodic servicing of outdoor air dampers, control valves, etc., the central plant chilled and hot water systems were subjected to unnecessary burdens and exposed to serious damage. Under the present arrangement, the plant staff is responsible for control adjustment and the condition of supply air handling equipment and has reduced the unnecessary exposures to serious damage. Moreover, the plant staff is responsible for control adjustment and the condition of supply air handling equipment and has reduced the unnecessary exposures to serious damage resulting from freezing coils in extreme cold weather.

TABLE 1.1 Plant Production

WESTERN MALL TOTAL ENERGY PLANT					SIOUX FALLS, SOUTH DAKOTA			
Mo.	1975-1976				1976-1977			
	kWh Produced	kWh Billed	Boiler Hours	Chiller Hours	kWh Produced	kWh Billed	Boiler Hours	Chiller Hours
Sept.	688,455	594,735	200	280	668,309	564,629	204	284
Oct.	655,930	586,930	120	75	633,619	555,859	122	75
Nov.	628,405	556,645	130	0	670,769	577,689	133	0
Dec.	614,647	535,567	200	0	678,351	587,751	183	0
Jan.	676,579	587,299	148	0	676,958	585,998	334	0
Feb.	682,362	602,202	148	0	677,301	576,501	126	0
Mar.	614,052	553,332	119	0	508,971	450,891	99	0
Apr.	642,426	580,626	96	1	552,930	482,370	142	145
May	653,060	564,740	207	271	578,065	477,025	256	345
June	673,099	574,219	313	376	584,440	481,120	372	444
July	656,768	537,248	449	494	570,603	440,763	343	481
Aug.	714,116	590,036	407	461	577,777	475,897	258	397
Totals	7,899,899	6,863,579	2,537	1,958	7,378,093	6,267,493	2,572	2,171

2 BACKGROUND AND MANAGEMENT

In 1967, the Hattis Engineering Company, with help from the gas utility, promoted the concept of serving the shopping center with a total energy plant using low-cost, natural gas fuel. The architect and owner considered the proposal and negotiated an agreement whereby Hattis was to design, construct, own and operate the TE Plant, pay the developer an annual rental, and share profits (over a reasonable minimum base) with the developer. The developer was to save initial costs because the central plant burden was not his. However, the developer failed to complete the construction, and a new partnership -- including the architect and general contractor -- assumed control. By 1969, the building was built and the loads developed, substantially as planned.

During early operation, many tenants disputed their energy charges and withheld payment; the energy consumption of the tenants was less than anticipated thereby further reducing revenue; and there were many serious machinery failures that increased operating costs and decreased service reliability compared to utility-furnished power. Some of the largest tenants were in litigation with the Hattis organization over disputed charges of thousands of dollars. By 1972, the financial burden of operating this plant, and others very like it, had depleted the resources of the Hattis organization. The shopping center owners determined that their interests would be best served if they purchased the plant from Hattis at a price basis on which operations could be self-supporting. For a time, Hattis Service Company continued to operate the plant; but in 1973, that organization declared bankruptcy, and the owner had to find another way to manage the operation.

An agreement was reached between the Western Mall Properties and Charles J.R. McClure and Associates, Inc., Consulting Engineers, wherein the TE Plant was made a separate division of the owning company with management by the engineer in cooperation with the owners. Outstanding energy services accounts were settled with each disputant by the new management. New service agreements with the tenants were negotiated, new rate schedules, billing procedures, operating cost controls and staff responsibilities were established. The shopping center manager created an independent accounting system and performed the business office functions of purchasing, payroll preparation, billing, collecting and dealing with the customers. The consulting engineer directed the technical

staff and developed some plant modifications. The engineering firm participates in the benefits of operating cost controls by an incentive fee based on net margin. For the past four years, this arrangement has exceeded the net revenue goals established in the annual budget.

In practice, the present arrangement requires considerable interaction among the owner, the center manager, and the consulting engineer. Extensive efforts to satisfy the tenants' needs have been made. Personnel changes in the plant have resulted in the present chief operating engineer being a member of the consulting engineer's staff (although this is considered a temporary condition). The plant is run by a three-man staff directed by the consulting engineer; business affairs are handled by the shopping center manager and her staff, with approval of the consulting engineer on rates, purchasing, salaries, personnel, etc. The owner makes frequent inspections and monitors progress in all aspects of the operation. Finally, an annual audit of the Western Mall Total Energy Plant Division is performed by a certified public accountant.

Figure 2.1 outlines the management organization involving the total energy plant operation.

Fig. 2.1. Management Organization,
Western Mall Shopping Center

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3 TOTAL ENERGY PLANT FACILITIES

Electrical power distribution for the Mall is a 480-V 3-phase system with radial feeders originating in the main distribution board in the plant. Each feeder serves an area of the Mall and terminates in a meter room where groups of individual tenant meters are mounted on distribution panels. Transformers to provide 208/120-V service for smaller stores are located ahead of the area distribution panels and meters. Larger tenants receive 480/3/60 service and have their own small 120-V transformers for convenience outlets and special loads. Figure 3.1 illustrates the power distribution system.

The original electrical design included a load reduction concept that was to interrupt operation of air-handling motors and selected lighting automatically if the power load exceeded the available capacity in service in the plant. A network of signal cables, relays, and motor-starter interconnections provided for instant load trimming of about 250 kW. This scheme was not effective because the quantity of load to be shed was too small to save the plant generation system when one unit (750 kW capacity) faltered while operating in parallel with one or two other machines.

A remarkable feature of the engine heat recovery system design is the extension of the single water system that cools each of the four engines to the boiler and chiller and then to all the heating terminal units throughout the Mall. In this design, any leak in a tenant unit heater or air handling unit will drain the jacket coolant from all four engines. Figure 3.2 illustrates the extent of this system and its vulnerability to catastrophic failure.

The single circuit concept also restricts the opportunity to reset heating water temperatures to lower levels in moderate weather. In the original design, two engine-driven pumps were provided to circulate the heating system water. Similar pumps, each with nominal 100 horsepower natural gas engine drives, were provided for chilled water and condenser water circuits. One of the heating pumps has been converted to 30 hp, 1,140 rpm electric motor drive and this unit is used at all times except for pump and motor maintenance periods.

Figure 3.3 illustrates the chilled-water system, and Fig. 3.4 the condenser water system. The chilled-water system is designed for constant rate of flow with no control valves on most of the coils; with a single chiller, a

Fig. 3.1. Electric Power Distribution System

Fig. 3.2. Heat Recovery and Engine Jacket Water System

Fig. 3.3. Chilled-Water System

Fig. 3.4. Condenser Water Flow Diagram

chilled-water pump, and a condenser water pump. The chilled-water system is operated only when the shopping center is open for business and the outdoor temperature will exceed 60° for more than four hours. When the weather is below freezing, the chilled-water pump runs continuously to avoid coil freeze-up.

Originally, one induced-draft, two-cell, cooling tower with a single drain pan and sump was provided for both engine heat rejection and absorption machine condensing. As a result, the tower basin could be cleaned only when the power plant was shut down. Separate pumps circulated condenser water through engine lube oil coolers and jacket water heat rejection exchangers. An additional cooling tower was added to supplement the capacity of the original tower and to provide a low-power use engine heat rejector. Extremely cold winters represent a particular problem to uninterrupted operation of atmospheric cooling. Special controls are necessary to avoid overcooling and freezing of the tower which must be available at all times to dispose of lube oil and turbocharger heat.

Listed in Table 3.1 is a summary of the major plant components.

TABLE 3.1. Summary of Western Mall Total Energy Plant Equipment

Item	Manufacturer	Specifications
Engine-Generators (4)	White Motor Corporation	750 kW White Superior, 8 GT-825-4 cycle, 900 rpm, 750 kW, 3-phase, 60 cycle, 480 volt
Hot Water Boiler and Burner	Kewanee Gordon Piatt	Kewanee No. KGP-88 Forced Draft; Type: Turbo Ring, Model F 16-6-75-FPE 230; FLA Gas; Gas Train Burner Motor 7-1/2 hp, 3 phase 60 cycle, 480 volt
Heat Recovery Boilers (4)	Engineering Controls	Special ECX-500; 310 gpm ent. 250°/1vng. 257°
Absorption Chiller	Carrier	Model No. 16HA090 - 900 Ton Ch. W. entering 61°; Ch. W. leaving 43°, 1,200 gpm; Cond. water entering 86.7°; Cond. water leaving 103.4°, 3,310 gpm; Generator water entering 270°; Generator water leaving 230°, 910 gpm
Cooling Tower	Marley	No. 452-202, 3,310 gpm; Condenser water entering 104.1°; Condenser water leaving 86° at 76° W.B.; 2 - 40 hp fan motors, 3 phase, 60 cycle, 480 volt
Cooling Tower	Baltimore Air Coil Co., Inc.	Model VAT-385A, 935 gpm; Condenser water entering 103°; Condenser water leaving 85° at wet bulb 75°; 2 - 10 hp fans/tower, 3 phase, 60 cycle, 480 volt
Hot Water Pumps (2)	Allis-Chalmers	No. 8 x 5 x 17 Cust V Series, axially split single stage pump, 930 gpm at 225' head Motor 30 hp, 1,200 rpm, 3 phase, 60 cycle, 480 volt Engine M-M HD504GA, 103 hp, natural gas

TABLE 3.1. Summary of Western Mall Total Energy Plant Equipment (Contd.)

Item	Manufacturer	Specifications
Lube Oil Cooler Pumps (2)	Allis-Chalmers	No. 8 x 5 x 12 Maxeal 5,000 Series, axially split, single stage, 532 gpm at 100' head Motor 25 hp, 3 phase, 60 cycle, 480 volt
Chilled Water Pump	Allis-Chalmers	No. 8 x 5 x 17 Custom 5,000 Series, axially split, single stage pump, 1,200 gpm at 175' head, double extended shaft pump Motor 75 hp, 230/460 volt, T-Frame open drip-proof motor, 1,750 rpm Engine: MM 504A-GA, 103 hp, natural gas
Condenser Water Pump	Allis-Chalmers	No. 12 x 10 x 12 Maxeal 7,000 Series, axially split, single stage, 3,310 gpm at 100' head Engine: MM 504-GA, 103 hp, natural gas
Heat Recovery Boilers (4)	Engineering Controls	Special ECX-500; 310 gpm entering 250°/leaving 257°
Air Compressor	Worthington	No. 10 AUEM, 10 hp, 3 phase, 60 cycle, 460 volt, 250 psig discharge pressure

4 PLANT PRODUCTION

The shopping center is open for business seven days each week, but activity is very light from 10:00 P.M. to 9:00 A.M. daily. The electrical load profile in Fig. 4.1 indicates the very small changes that occur on weekends.

Fig. 4.1. Daily Electric Load Profiles

Some variations in customer use are observed seasonally as shown on the three yearly electric production and sales graphs shown here in Figs. 4.2, 4.3, and 4.4. The abrupt change in sales and production in March, 1977 reflects the loss of the flood market tenant and delay in achieving full occupancy of the vacated space. The spread between production and sales of electricity increases in the summer months because operation of electric-driven cooling tower fans

Fig. 4.2. 1974-1975 Electric Production and Sales

Fig. 4.3. 1975-1976 Electric Production and Sales

Fig. 4.4. 1976-1977 Electric Production and Sales

and absorption machine auxiliaries shows up at this season (see Fig. 4.4). The electric-drive chilled water pump is operated in cold weather as well as in warm weather in an effort to minimize coil freezing.

Fuel consumption generally follows the rate of electricity production. The graph in Fig. 4.5 shows a generally parallel alignment; however, the influence of weather can also be seen. Note that December, 1976 establishes a new high rate of consumption of fuel reflecting the worst weather on record in Sioux Falls.

Summer use of fuel usually has exceeded winter use. It has been necessary to fire the auxiliary boiler during much of the time the absorber has been in service. Recent changes in operating and maintenance account for the substantial reduction in summer fuel use. A rigorous program of condenser water treatment has resulted in lower condensing temperatures and a routine of reducing heating water temperatures entering the machine so that the solution control is normally in full-load position are effective energy-conservation techniques. Moreover, more careful control of outdoor air quantities in hot weath-

Fig. 4.5. Electric Production and Fuel Consumption

er and mixed air temperature control set points for cold weather have contributed to reducing the required cooling and heating loads.

Operational and usage data are compared for 1976 and 1977 in Figs. 4.6 and 4.7. Plant operations were monitored by use of elapsed time hour meters that are connected across motor starters to total the hours each major motor is run. Appendix A summarizes failure reports for 1975, 1976, and 1977.

Every effort is made to run the engines at near full load and to minimize the operation of three machines when only two can serve the loads. Decreased engine operating hours to serve the same electrical load results in lower fuel consumption, cooler exhaust valve temperatures, improved wear rates on engines, and lower maintenance costs. Boiler and chiller use is substantially the result of weather conditions. Note that water use follows chiller operating hours because the only significant water use in the plant is for cooling tower makeup.

Fig. 4.6. 1976 Operational and Usage Data

Fig. 4.7. 1977 Operational and Usage Data

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5 FUEL MANAGEMENT

Western Mall is a single-source energy facility and is entirely dependent on natural gas supplied by a regulated public utility company. The fuel is obtained from Northern Natural Gas Company, a large pipeline and producer firm that serves a substantial portion of the north-central region of the United States. Gas is obtained from producers in the south and southwestern regions of the United States, Kansas, Wyoming, and Canada. There has been no problem in obtaining adequate fuel supply; and recent discussions indicate no immediate shortage of this service.

Gas costs have escalated a great deal since the plant was started up, as illustrated in Fig. 5.1.

Fig. 5.1. Fuel Cost Escalation (1969-1978)

The current gas service contract is a demand and commodity rate. The costs were adjusted, subject to rebate, as of 10/27/77 to the following:

Monthly Charge per MCF contract daily demand---- \$4.619

Cost per MCF for all gas purchased----- \$1,5142

The contract daily demand has been 470 MCF for many years. Analysis of the use in 1975 and 1976 indicates an annual load factor as calculated below:

$$\frac{\text{annual use 123000 MCF}}{365 \text{ days} \times 470} = .72 \quad (\text{Eq. 5.1})$$

The regularity of gas use at the plant is indicated by the average daily use of gas as shown in Fig. 4.5. This quantity, average daily use of gas, is obtained by dividing the total fuel consumed, according to the gas bill, by the number of days in the billing period covered. Where the billing period includes some days in two calendar months, the appropriate allocation of use to the proper month is made on a straight proportional basis. For the past three years, the lowest average daily use has been 280 MCF and the highest has been 390 MCF.

Alternate fuel sources considered practically possible for the plant are limited to #2 fuel oil or propane. At late 1977 prices, the cost comparison is as follows:

Natural Gas @ \$1.80 per MCF	=	\$1.80/MBtu
#2 Fuel Oil @ \$0.37 per gallon	=	\$2.68/MBtu
Propane @ \$0.38 per gallon	=	\$4.15/MBtu
Electricity @ \$0.02 per kWh	=	\$5.86/MBtu

It may be economically attractive to the owner to install a #2 oil burner assembly and storage tank for the supplementary boiler if a reduced-contract daily demand quantity can be negotiated. Use of the oil fuel would be limited to those hours of operation necessary to avoid exceeding the new contract daily demand. If only a few hours of burner use will result in substantial demand charge avoidance, the oil burning installation should be advantageous both to the gas supplier and the Total Energy Plant.

6 LABOR

Because the plant operates continuously under automatic fail-safe control, the facility is unattended at night. For the past four years, the plant has been staffed with three full-time employees and occasional part-time helpers. A chief engineer, in charge of daily operations, including scheduling work, programming use of machinery, evaluating performance, and analyzing deficiencies, is responsible for the performance of air-handling equipment, temperature controls and power service entrances at tenant premises, as well as the entire total energy plant and distribution systems.

The normal program has been to have an operator/maintenance employee on duty from 8:00 A.M. to 8:00 P.M., Monday through Friday, and 8:00 A.M. to 6:00 P.M. on weekends and holidays. The chief engineer has worked a regular turn with the other two employees. All repairs, replacements, overhauls, adjustments, and routine service have been performed by this staff during regular 40-hr work weeks. Occasionally the plant staff has taken on additional tasks such as making plant improvements, servicing tenant fixtures and equipment, modifying distribution services to accommodate tenant changes, etc. Part-time helpers have been employed from time-to-time to assist in this work.

Pay scales for the three-person staff have been rather steady at the following rates:

Chief Engineer	\$8.50 per hour plus fringe benefits
Senior Operator	\$7.50 per hour plus fringe benefits
Junior Operator	\$6.50 per hour plus fringe benefits

Recent changes to the operating program have been instituted to take advantage of the rehabilitated automatic control system. The weekend shift has been reduced to a twice-a-day inspection on Saturdays, Sundays, and holidays. This change has made it possible to have two employees available more often to work together on two-person tasks.

Technical skills required for plant maintenance have been developed on the job. However, each employee has brought to the plant a different background of experience and training. By utilizing detailed as-built drawings and control diagrams, manufacturer's maintenance instruction manuals and tech-

nical supervision from the consulting engineer, the plant staff has developed a skilled routine for handling the many problems that develop in operating the plant components. Codifying these accumulated experiences through the planned maintenance program and carefully prepared logs of machinery tests and evaluation provides a continuity independent of the individual employees.

7 SYSTEM CONTROL

The original project design included:

- (1) an automated control system for the power generation system that encompassed automatic start-stop of generating units;
- (2) load division between units;
- (3) voltage and frequency control;
- (4) malfunction alarm and shutdown features;
- (5) synchronizing and paralleling;
- (6) load measurement; and
- (7) automatic time correction.

This combined system provided for sequencing program selection to order each of the four units into any priority of operation and also included a load shedding system. Engine performance difficulties rendered the system inoperative from start-up until four years later. Operator confidence in the machinery was low, and the usual mode of operation was manual with sufficient spinning reserve to accommodate load fluctuation and engine instability. Costs of operating in this mode were very high because the fuel consumption rate is poor at low engine loads and the service requirements of engines are increased by low load operation and by increased number of engine operating hours.

Over the past three years, the automation system gradually has been restored, and it is now substantially in use as originally intended. The plant now monitors load change and shuts down unneeded units automatically. Time correction instrumentation maintains accuracy within a few seconds at all times. Fault signals are sensed and displayed in the order of occurrence and the load shed relay is again operational.

Although automatic start of additional units is available, it is not normally used, because the load changes are predictable and increases occur when operators are on duty. The automatic start is now used only on weekends and holidays.

Load shedding, as originally conceived, was to reduce the plant load sufficiently that the automation system could start a new unit, bring it on line, and then reapply the full load. In practice, this has proven undesirable because the inability of the plant to carry full load is usually in the

result of a malfunction of one engine-generator. A fault detected in an operating engine must cause that machine to disconnect from the bus and shut down instantaneously. The load reduction has to be in the same magnitude as the capacity of the unit that shuts off to prevent loss of the entire plant. Original design arranged for automatic load shed when the load sensing (optical relay on an ammeter) detected more load than the equipment could handle. This signal has been replaced with two low-frequency detection relays, one set at 57 Hz with a 3-sec time delay and one set at 55 Hz with no time delay. The quantity of electrical load that can be dumped is not as large as is desirable and may vary somewhat, depending on the season because cooling tower fans and chilled-water pumps represent a big share of the non-firm load.

Voltage regulation is very stable, ± 2 -V over the entire load range. Frequency stability is good with momentary offset of .3 Hz when large motors in the mall are started or stopped. Automatic stopping of one engine when two have been handling the load (this occurs every evening about 9:30 P.M.) causes a load shift of about 300 kW, and the frequency drops to 57.5 Hz and oscillates for about 3-sec before stabilizing. This change is apparent on TV pictures, movie screens, and sound systems. When the second machine is manually shut down, the operator can adjust the speed control to gradually shift load to the other machine and avoid the frequency dip.

Fault alarms are monitored at a remote panel in the chief engineer's office, and these are arranged for connection to an answering service and the Mall security office. The operator on call is provided with a "beeper" radio signal receiver to alert him to respond if a malfunction alarm is received.

8 MAINTENANCE PROGRAM

In 1973, when new management assumed direction of the Western Mall Total Energy Plant, the plant had been in operation for about five years. The equipment reflected a lack of care and maintenance and the effects of the financial situation of the service agency previously operating the installation. The operating staff that stayed on were aware that a deterioration of operating standards had been taking place.

Immediate efforts were directed at servicing the plant equipment and upgrading the maintenance to achieve better operating reliability. Tenant relations with respect to quality of service as well as rate structures presented a sensitive area requiring prompt improvement. Some plant modifications also were effected to improve plant reliability.

A comprehensive maintenance program and schedule were generated. A systems designation of the total energy plant equipment was used to organize the maintenance tasks, provide for a record of maintenance, and initiate a performance history of the devices. The tenant heating, ventilating, and air-conditioning equipment was included in the maintenance program. Servicing the tenant equipment has contributed significantly to reduced energy consumption, the quality of service to the tenants, and better tenant/landlord relations.

A sample of the Master Maintenance Schedule, record-keeping material, and maintenance check lists is presented in Fig. 8.1. The philosophy of the maintenance program follows a systems approach to the maintenance effort. The mechanic is assigned total responsibility for service and operation of a system, including all devices, motors, pumps, valves, controls, etc. The responsible mechanic may require help from specialists, but the performance responsibility is not diluted. By use of the check lists, a thorough procedure and an effective service effort is assured. The calendar-related schedule assigns a regular interval, as required, for the maintenance. The clerical work is mainly an office staff task thus allowing the maintenance and operating personnel to expand their efforts in maintenance and operation.

The plant operating staff at Western Mall represents a unique fund of proficiencies and skills. With few exceptions, all plant equipment from engine-generators, control panels, chiller, etc. to the simplest item are serviced and repaired in house. The engineering-management provides consultation

MASTER MAINTENANCE SCHEDULE

FOR

Western Mall, Sioux Falls, So. Dak.

TAG No.	SYSTEM	Maintenance Frequency	Hours per Year	MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TAG No.
1	Weekly Operational Checks	Weekly			1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
2	Plant (Mechanical) Rooms, Heating				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
3	Chemical Water Treatment				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
4	Water Softeners				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
5	Engine - Generator - Control Panels #1	Eng. Mts	Overhaul		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
6	Engine - Generator - Control Panels #2		2500 hrs		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
7	Engine - Generator - Control Panels #3				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
8	Engine - Generator - Control Panels #4				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
9	Main Control Panel - Alarm Panel	6 Months	16		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
10	Plant Quench Tank	6 Months	16		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
11	Engine Jacket - Heating Water	Monthly			1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
12	Heat Recovery Exchangers and Boilers				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
13	Heat Rejection				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
14	Oil Coolers - Air Separators - Water				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
15	Condenser - Water				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
16	Cooling Towers				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
17	Absorption Chiller				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
18	Chilled Water				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
19	Air compressors & Combs	Planned Maintenance			1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
20	Dr. Bellows & Chargers	Equipment Check List			1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
21	Plant Ventilation				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
22	Duplex Pump Pumps				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
23	Emergency Generator				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
24	Domestic Cold Water				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
25	Electric Switch Gear				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
26	Fire Sprinkling System				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
27	AHU's Walgreen's (6 Units)				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
28	AHU's Mall Entrance (3 Units)				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
29	AHU's Bldg's (4 Units)				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
30	AHU - Evansco Hallmark Co.				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
31	AHU Singer				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
32	AHU Hildebrand				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
33	AHU Musicland				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
34	AHU Russell Stover				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
35	AHU's Old Gracery Store (2)				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
36	AHU's Texaco (2 Units)				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
37	AHU Zales				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
38	AHU Mulligan's Hardware, Job Serv.				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
39	AHU U.S. M. Liquors				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
40	AHU (3 Rooms) Cardiac - Hardware				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
41	AHU Book Gallery				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
42	AHU Studios				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
43	AHU W.M. Theatres (2 units)				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
44	AHU Kresge				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
45	AHU Wilson - Hardware				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
46	AHU Thrift Stores				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
47	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
48	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
49	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
50	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
51	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
52	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
53	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
54	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
55	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
56	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
57	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
58	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
59	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
60	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
61	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
62	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
63	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
64	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
65	AHU (3 Rooms) Shoes				1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	
66	AHU (3 Rooms) Shoes																

in resolving specific problems, research of equipment deficiencies to achieve better performance, and engineering for plant modifications when required to upgrade plant reliability and performance. The engineering-management effort also includes working with the mall management in dealing with tenant disputes related to tenant utilities' services in addition to setting plant operation — and maintenance policy.

Western Mall Total Energy Plant has presented some interesting challenges. The engines required an extensive amount of time and attention as a result of their poor service history. The composite repair and overhaul record shown in Appendix B tabulates the engine performance history.

Many innovations were initiated to improve the engine service life. Lubricating oil type was changed twice to eliminate liner scuffing and short bearing life. New oil filters were installed. The original forty-five degree angle valves and seat faces were replaced by thirty degree angle valves and seat surfaces to increase valve life. Fuel-air mixtures were adjusted to achieve lower exhaust gas temperatures. Revised engine operating procedures were introduced to achieve maximum unit loading and coolest exhaust temperatures. Intake air filters were modified to reduce the possible ingestion of abrasives with engine air.

Engine repair and overhaul have been a large cost burden. Initially, this situation was accepted as having been caused by previous neglected maintenance. The turbo-chargers provide a good example. Maintenance inspections are now performed at 4,000 hr., and reconditioning is required at 8,000 hr. Service records for the Western Mall engines indicate no maintenance up to 35,000 hr. for the turbos. As a result, three of the turbo-chargers had to be extensively overhauled and rebuilt in late 1975 and early 1976 at considerable expense.

Liners, pistons, valves, guides, seats, and bearings all have had relatively short service lives. The engine manufacturer has not supplied much corrective information.

For the years 1974 through the first nine months of 1977, during which the engines ran about 56,000 hours, costs for repair and overhaul totalled \$81,289 or \$1.45 for each engine operating hour. These costs reflect mainly the cost of parts for the engines. The first nine months of 1977 required

10,349 hr of engine time with parts' costs of \$7,217 or \$.70/hr of engine time. In addition to the obvious lower parts cost per engine hour, operating procedures will effect a reduction of total engine time by about 1,000 hr/yr.

Although significant progress has been made, an effort to improve the engines at Western Mall continues. The maintenance program has done much to stabilize engine performance.

Another important aspect of neglected maintenance at Western Mall was the water treatment. Required retubing of the boiler after only about five years indicates a lack of water conditioning.

An effective water treatment program was started as part of the overall maintenance and has been carried on by the plant staff. Recent monitoring reports of the effectiveness of the water treatment indicated minimal corrosion in the closed systems and good control of scale and corrosion of the condenser water system. Physical inspection of heat exchanger surfaces shows good condition for heat transfer.

At the time of the plant management change, a cost accounting procedure for plant operating expenses was initiated; a summary of plant expenses over the last four years is presented in Table 8.1. Fuel costs and taxes have been omitted in this tabulation to better present real operating expenses for the total energy plant. An equipment use and materials use accounting system has also been instituted and is providing valuable control data.

TABLE 8.1. Plant Operating Expenses
(Fuel Excluded)

<u>WESTERN MALL TOTAL ENERGY PLANT</u>		<u>SIOUX FALLS, SOUTH DAKOTA</u>			
Kind of Expense		Cost Per Year			
		<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977 (6 mos.)</u>
Wages, Benefits, Payroll Taxes		\$ 44,496	\$ 49,628	\$ 53,000	\$ 27,833
Engineering and Administration		\$ 16,187	\$ 11,529	\$ 13,712	\$ 12,001
Contracted Services - Specialists		\$ 4,904	\$ 135	\$ 1,200	\$ 0
Business Office		\$ 5,000	\$ 5,100	\$ 5,100	\$ 5,384
Insurance, Casualty		\$ 6,381	\$ 8,218	\$ 8,400	\$ 4,620
Non-Recurring Plant Improvements		\$ 13,760	\$ 13,182	\$ 2,110	\$ 610
Water-Sewer Charges		\$ 1,666	\$ 2,580	\$ 3,860	\$ 1,410
Chemicals and Lubricants		\$ 11,917	\$ 17,817	\$ 12,450	\$ 2,593
Parts, Supplies, Tools- Other Than Engine Overhaul		\$ 25,574	\$ 16,939	\$ 11,700	\$ 3,231
Engine Overhaul and Rebuilding		\$ 14,161	\$ 37,276	\$ 22,635	\$ 7,216
Totals		\$144,046	\$162,404	\$134,167	\$ 64,898 (6 mos.)

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9 FINANCIAL CONSIDERATIONS

Purchase of the total energy plant from the original owner was made at a price developed from the projected net return. Revenue received from the tenants for electricity is based on metered use at a rate identical to the local regulated utility company. The tenants also pay for heating and air conditioning energy and services based on costs per square foot of rental area and subject to escalation in costs of fuel and labor. In the early years of the plant operation, annual revenue from electrical sales was about 55%; heating and air-conditioning sales were 45% of the annual total. Electric sales were profitable; the cost of natural gas was low, 4.5¢ per 100 ft³, so fuel costs were about \$.006 per kWh. At present prices of 18¢ per 100 ft³, fuel costs are \$.024/kWh, and electric sales are not profitable. The regulated selling price of electricity has not increased as much as that of gas. Changes in fuel costs have increased the value of heating and air-conditioning services; annual revenue from this source is now about 60% of the total. The adjustment of revenues from heating and air-conditioning services has enabled the plant to maintain its required net return.

Major efforts have been made to control the operating expenses of the plant. A budget for expense items is established each year, and costs are monitored continuously to keep on budget. Table 8.1 shows the operating cost breakdown for the past three and a half years.

Fuel costs are such a large part of the total budget that continuous effort must be made to conserve energy in the plant. The plant customers also have energy conservation programs, and some have made dramatic reductions in purchases of electricity, mainly by improving illumination equipment and operation. However, tenant energy conservation has reduced plant revenues. Even though the plant efficiency improves, a study of the budget shows that many costs are not sensitive to reductions in product production.

Of much greater significance is the uncoupling of electricity sales price from production costs. The utility whose rates are used for sales pricing has an average fuel cost of \$.00787 per kWh, or 33% of the cost that Western Mall Total Energy Plant must spend at present rates. There is no basis for expecting the tenants to pay more for Total Energy Plant electricity than for power from the utility company. The average selling price of electricity in the Mall

is now \$.0328 per kWh. The tiny margin of \$.0088 per kWh must support the service, maintenance, operation, investment, and overhead expenses with a credit representing the value of heat recovered from the generation process. Using the same costs and fuel rates as were applied to obtain the fuel costs per kWh, the value of recovered heat is \$.0089 per kWh.

Some of the heat that is recovered is not used because the climatic conditions require no space heating or cooling. When this heat is used in the absorption cooling system, its value is considerably less than indicated above. The desired refrigerating effect could be obtained by using gas fuel in the engine to develop electricity which would then operate a conventional electrically driven, water-cooled, compression-type chiller. With such a scheme, a ton hour of refrigeration can be developed for each .75 kWh, or at a cost of $.75 \times \$.024 = \$.018$. The recovered heat from one kWh used in an absorption chiller produces:

$$\frac{4,000 \text{ Btu}}{18,000 \text{ Btu}} = 0.22 \text{ ton-hr of refrigeration.}$$

The dollar value of this recovered heat is only:

$$0.22 \times \$.018 = \$.004/\text{kWh.}$$

It is reasonable to say that Western Mall TE Plant uses 55% of the recovered heat for space heating, 35% for space cooling, and has no use for the remaining 10% each year. On this basis, the cost of fuel per average kWh is \$.024 minus 55% of .0089 and minus 35% of .004 = \$.0177. With these assumptions, the current margin of selling price of electricity is $\$.0328 - .0177 = \$.0151$ per kWh for fuel cost only.

Continued financial viability of this plant is dependent on control of operating costs. Selling prices of the plant product are limited by the alternative systems that merchants use in other shopping centers. Fuel costs represent more than half the operating budget, and these are certain to increase. With limited revenue potential and unlimited costs of operation, the profit opportunity questionable.

10 REGULATORY CONTROL

In South Dakota, state and municipal agencies have had no interest in the private business relationship of the Western Mall Total Energy Plant or its customers. Original ownership of the plant was separate from the Mall property owner; however, entire electrical and thermal distribution system has been within the boundaries of the Mall property. Several tenants on the property have opted for electrical service from the regulated public utility, but these services come from the public streets directly to the customer and do not conflict with the TE plant distribution. Several years ago a large tenant in the Mall was removed from the TE plant power system and changed over to the utility service without incident.

Tenant leases include stipulations that require the tenant to obtain heating, cooling, and electricity from the Total Energy Plant. General terms of these leases require that the cost of these services be no higher than conventional alternatives and that the quality of electric service be the same as utility standards. Heating and cooling performance required is stated in terms of temperatures to be maintained in the stores during occupied times.

As a practical matter, the Total Energy Plant has always charged for electricity at the same rates as would be available from the regulated utility. Heating and cooling charges have been based on a unit cost per square foot of rental area, and there have been numerous instances of complaint over costs at Western Mall compared to cost experience at other shopping centers. There problems usually are resolved by: (1) explaining the added maintenance and repair services provided by the Total Energy Plant, and (2) performing comparative cost studies for the individual customer's circumstances.

The State has a 5% sales tax that applies to electricity and gas sales, but has not been applied to the charges for thermal services. Real estate and personal property taxes are assessed on the basis of acquisition cost and have been fairly stable in the past three years. Water and sewer service charges have increased by a substantial percentage in the past two years.

Because the plant burns natural gas only, there has been no problem with atmospheric pollution. Engine and boiler exhausts are above the shopping center roof and the huge parking areas effectively separate the plant from adjoining property. Some minor irritations from noise have been caused by engine

operation, in warm weather particularly. If the operators leave the large loading door open at night, the plant noise is directed toward a residential area about 750 ft away, and some residents are affected. The engine exhaust noise is adequately muffled by the heat recovery unit and auxiliary muffler in series on each engine exhaust line.

City building inspectors are required to review new installations, but they have limited their interests to conventional building code requirements. Fire department inspections are only cursory because the property is fully sprinklered. The owners casualty insurance inspectors have been thorough in searching out possible hazards that would cause machinery failures or damage to adjacent property.

11 PERFORMANCE EVALUATION

After the shopping center owners acquired the Total Energy Plant and made extensive changes, there has been a positive cash flow from the plant operations. Before 1974, however, the Total Energy Plant was a continuing source of irritation to the owner because the tenants complained about costs and quality and the owners got none of the projected profits. In the past four years, however, the plant has been furnishing the required services at an acceptable level of quality, and the tenant complaints have been mostly limited to alleged temperature-control performance deficiencies.

Total Energy Plant ownership by the landlord, has clarified the tenant cost/benefit situation. Each merchant has an identified total cost for operating his facility that includes rent, common services (mall, parking lot, institutional promotion, etc.) and utilities, all of which the landlord furnishes at Western Mall. The Mall manager uses this composite cost when negotiating lease agreements, and the tenant agrees to a contract that defines his expenses. The electrical costs are based on metered use and thus cause no controversy. Thermal services charges are unit costs, the same as rental costs, except for the escalation feature in heating and cooling rates. On this point there is a developing controversy because the charges added by escalation of fuel costs are now in the order of 50% of the base heating and air-conditioning costs established in the lease agreements. Further escalation of cost of natural gas seems inevitable, and this will be a source of conflict between the landlord and tenant.

In other shopping centers where tenants have individual heating and air-conditioning systems, the tenant has full responsibility for the costs without landlord involvement. Those tenants who have experienced costly or unsatisfactory maintenance or repair or who have had great increases in energy rates from oil, gas or electricity suppliers have to resolve those problems without the landlord. Some shopping centers have deteriorated because of unresolved difficulties with the tenant mechanical systems and then the landlord has been unable to preserve his property investment.

Investment costs in the Total Energy Plant at Western Mall were borne by the TE plant owner-operator. The shopping center developer was supposed to have had *lower* construction costs because he would have to furnish only the distribu-

tion systems costs and would have less expensive heating and air-conditioning systems to provide each tenant. The center developer claims that his costs to build the facility were higher with the central plant design than they would have been with conventional rooftop systems. When the Mall owners bought the Total Energy Plant, it was estimated that the purchase price was at least 35% less than the construction cost of the plant four years before. The purchase price was determined as a multiple of projected net revenue from the operation. The original investors in the TE plant were losers to the extent that there were never any profits from the plant operation, and the selling price of the property was much less than its cost. At current costs of construction, the replacement cost of the Total Energy Plant, even allowing for improvement in sizing and design for the now evident actual loads, would be greater than the initial construction cost. It appears that a new center could not afford to duplicate the Western Mall concept of a Total Energy Plant.

At Western Mall, there are several other ways that the present facility could be used to furnish required energy services to the tenants. Analysis of possible alternatives should begin with a comparison of the relative energy use effectiveness of the several systems, because the long-range value of the central plant must be conservation of energy or the use of more plentiful sources of energy. For the past year, the plant has operated on natural gas, and the effectiveness of the system in converting energy from that source to the products the tenants want is calculated to be 46%. Table 11.1 compares costs of alternate operating modes.

The product, shown at the right edge of Fig. 11.1 is 6,932,915 kWh electricity to the tenants, mall, parking areas, heating and cooling pumps, etc; plus 20.7×10^9 Btu (GB) of heating for space heat and ventilation; plus 10.4×10^9 Btu of cooling for space air-conditioning. The electrical product has been converted into Btu also (by multiplying kWh by 3,413 Btu) so that all three products can be summed as 54.76×10^9 Btu. The product that the customers wanted was all obtained from the Total Energy Plant, and the burdens of furnishing the product are indicated in the center portions of Fig. 11.1. Cooling was obtained from an absorption chiller with a coefficient of performance (COP) of 1.5; therefore, the TE plant had to furnish 1.5×10.4 GB = 15.6 GB to the chiller in the form of heat. The TE plant also had to generate an additional 445,178 kWh of electricity (1.5 GB) to serve the electric power-

TABLE 11.1. Western Mall Shopping Center Alternate Operating Modes
Annual Total Energy Plant Operating Costs (Typical Year)

Items	Case I (Present Mode)	Case II (Purchase Elec. Absorp. Chiller)	Case III (Purchase Elec. Elec. Chiller)	Case IV (Co-Generation Absor. Chiller)
Wages	\$ 53,000	\$ 30,000	\$397,093	\$349,949
Fuel	\$152,650	\$ 57,812	\$ 39,561	\$144,020
Energy				
Electricity	\$ 0	\$171,528	\$194,232	\$ 19,329
Water-Sewer	\$ 3,860	\$ 3,300	\$ 3,000	\$ 3,800
Chem-Lube	\$ 12,450	\$ 8,500	\$ 8,500	\$ 12,000
Parts	\$ 11,700	\$ 8,500	\$ 8,500	\$ 10,000
Services	\$ 1,200	\$ 1,200	\$ 1,200	\$ 1,200
Engine Overhaul	\$ 7,500	\$ 0	\$ 0	\$ 7,500
Non-Recurring	\$ 2,100	\$ 2,100	\$ 2,100	\$ 2,100
Business Office	\$ 4,555	\$ 4,500	\$ 4,500	\$ 4,500
Admin.-Engineering	\$ 13,712	\$ 6,500	\$ 6,500	\$ 10,000
Cap. Recovery	\$ 65,000	\$ 65,000	\$ 87,500	\$ 65,000
Insurance	\$ 8,400	\$ 3,500	\$ 3,500	\$ 8,400
Taxes	\$ 9,110	\$ 8,000	\$ 8,500	\$ 9,100
Totals	\$345,237	\$370,440	\$397,093	\$349,949

Fig. 11.1. Case 1 - 1976-1977 Operation -
Onsite Electric Generation

producing equipment. The total amount of electricity produced by the plant, 7,378,093 kWh, required 99.6 GB of gas fuel (left edge of Fig. 11.1) to be burned in the engines. Part of this heat, 25.6 GB, was recovered in the plant and delivered to the thermal system; but some of the recovered heat came at times the plant could not use it, so 5.39 GB of heat was rejected by the thermal system. The thermal requirement of the plant, 20.7 + 15.6 GB, used the remainder of the recovered heat and required 15.9 GB additional that had to be supplied from the supplementary boiler; gas fuel input to the boiler was 19.8 GB. From these data, the energy use effectiveness of the plant, Case 1, was

$$E_e = \frac{\text{Product } 54.76 \text{ GB}}{\text{Fuel } 119.4 \text{ GB}} = 46\%$$

The owner could elect to shut down the power generating facility and purchase electricity from the public utility company. This would require very little investment if the power were delivered to the present distribution

switchboard. All other features of the plant would be retained and this scheme is Case 2, with energy use effectiveness of 42% as indicated below in Fig. 11.2. The same technique of calculation has been used to develop the Ee, but the conversion efficiency of the utility company, Northern States Power Company, has been taken from recent public records. The net heat rate per delivered kWh is 10,980 Btu for the NSP system serving Sioux Falls, and distribution losses of 10% have been added.

Fig. 11.2. Case 2 - 1976-1977 Operation -
Purchased Electricity, Gas-Fired
Boiler for Heating and Absorption
Cooling

Use of absorption air-conditioning with high cost fuel is uneconomic. The owner could elect Case 3 as a variation where the plant would purchase all its power needs including additional electricity to operate electric-driven chillers in lieu of the existing absorption machine. For the same end-use product, the plant Ee = 47% as shown in Case 3 in Fig. 11.3.

In both Cases 2 and 3, the owner is abandoning an expensive power-generating facility. There is some merit in continuing to use this equipment

Fig. 11.3. Case 3 - 1976-1977 Operation -
Purchased Electricity Gas-Fired
Boiler for Heating

to minimize the plant peaking burden on the public utility company system. A cogeneration concept is illustrated in Case 4 (Fig. 11.4) where the TE plant would continue in use in periods when the full value of heat recovery could be obtained and even deliver an additional 1,000 kW of power to the utility when that system is at peak load. The power generation units at Western Mall would be shut down at times where there is no benefit from the recovered heat, and the utility network is off peak. Such a system is illustrated in Fig. 11.4 and shows $E_e = 48\%$.

Energy use effectiveness indicates Case 4 as best, and Case 2 as least desirable of the four alternatives. Because Case 3, which substitutes electric refrigeration for absorption, shows improvement over Case 2, it would be possible that some combination of cogeneration, Case 4, with some electric-driven refrigeration might be the most efficient way to convert source energy.

The economic relations of these alternatives using 1977 pricing is presented in Table 11. Note that the cost of Case 2 is very near the present mode and the owner delegates responsibility for the electrical production problem to the utility company.

Fig. 11.4. Case 4 - 1976-1977 Operation -
Cogeneration Interconnection
with NSP

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12 CONCLUSIONS

Central heating and air-conditioning facilities such as are installed at Western Mall provide the owner with an assured means for serving the shopping center, regardless of which energy source is most economical or least available. The hot water and chilled water can be obtained from gas fuel as at present, with fuel oil, propane, all electric or coal firing. Adapting the conversion equipment is difficult only for coal because of the space requirement for storage and handling that fuel.

The power generating capacity in place is an asset that should be used to serve the tenants because it reduces the public utility company need for expanded capacity. If the plant could be used as an efficient energy converter when the utility company is required to use its less efficient, liquid-fueled peaking plants, the public benefit is apparent. As a business venture for other developers to emulate, Western Mall Total Energy Plant must be considered a very poor risk under present fuel availability conditions and relative costs of energy.

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APPENDIX A

APPENDIX A
WESTERN MALL TOTAL ENERGY PLANT
FAILURE REPORTS SUMMARY
1975

Date	Time	Duration	Status of Plant at Failure	Failure Indication	Corrective Action and Remarks
4/13/75	3:30 P.M.	6 min.	#1, #3 units on line	Jacket and turbo water flow both units	#3 unit tuned
6/23/75	1:45 P.M. 2:45 P.M. 6:30 P.M. 7:15 P.M.	5 min. each; dump load only	#1, #2, and #3 units on line	#3 overspeed caused dump action	Speed switch re- placed Dump circuits re- set
11/12/75	8:50 P.M.	15 min.	#1, #4 units on line	No indication	
11/13/75	4:40 A.M.	45 min.	#4 unit on line	Dump action	Dump circuits re- set
11/13/75	5:05 P.M.	6 min.	#3, and #4 on line	No indication	Dump circuits re- set
11/13/75	7:55 P.M.	3 min.	#1, #3, and #4 on line	Dump action No indication	Dump circuits re- set
11/16/75	5:00 P.M.	5 min.	#3, and #4 units on line	No indication	
11/23/75	1:10 P.M.	4 min.	#1, and #3 units on line	#1 Breaker trip #3 Overspeed	
12/24/75	10:15 P.M.	5 min.	#1, and #4 units on line	None #1 dropped off after #4 was shut down No indication	Turbo charger per- formance suspected

APPENDIX A (CONTD.)
WESTERN MALL TOTAL ENERGY PLANT
FAILURE REPORTS SUMMARY
1976

Date	Time	Duration	Status of Plant at Failure	Failure Indication	Corrective Action and Remarks
1/29/76	6:00 A.M.	30 min.	#1 unit on line	Turbo pump overload shut down	Switch in main board replaced Heater coils re- placed
1/31/76	8:10 A.M.	15 min.	#2, and #4 units on line	#2 Jacket water flow #4 underspeed	Restarted using #1 and #4 units
1/31/76	11:50 P.M.	15 min.	#4 unit on line	Underspeed	Replaced speed switch
4/14/76	10:00 A.M.	4 min.	#1, and #2 units on line		Britts and Tempo shut down to get cycles up and plant restored
4/15/76	10:05 P.M.	5 min.	#1 unit on line	Jacket water flow	Plant restarted; overload suspected, no further incidents
4/15/76	7:40 A.M.	8 min.	#1 unit on line	Jacket water flow	Overload suspected; Eng. not picking up large fan load Eng. valves getting bad
10/26/76	11:32 A.M.	4 min.	#2, and #3 units on line	Jacket water flow	

APPENDIX A (CONTD.)
 WESTERN MALL TOTAL ENERGY PLANT
 FAILURE REPORTS SUMMARY
 1976

Date	Time	Duration	Status of Plant at Failure	Failure Indication	Corrective Action and Remarks
11/1/76	10:30 A.M.	4 min.	#1, and #2 units on line	Jacket water flow	Air gap result- ing from system drain to install valve in hot wa- ter line in pent- house suspected
11/3/76	5:30 P.M.	4 min.	#1, and #2 units on line	Jacket water flow	Air in hot water lines

APPENDIX A (CONTD.)
WESTERN MALL TOTAL ENERGY PLANT
FAILURE REPORTS SUMMARY
1977

Date	Time	Duration	Status of Plant at Failure	Failure Indication	Corrective Action and Remarks
2/16/77	5:43 P.M.	5 min.	#2, and #3 units on line	Jacket water flow	Replaced coupling motor to pump and realigned
2/9/77	8:00 A.M.	4 min.	#3 unit on line		Manual parallel- ing operation Operator error
4/5/77	8:15 A.M.	10 min.	#1 unit on line		Penthouse fan un- scheduled start Clocks had been changed 3-3-77 Start of fan caused overload and shutdown
5/4/77	11:18 A.M.	4 min.	#2, and #3 units on line	Underspeed	Restarted same engines
5/31/77	12:40 P.M.	5 min.	#1, and #3 units on line	Jacket water flow	Working on ABS unit 3-way valve at time - Valve operation to be replaced 6-2-77
6/21/77	11:22 P.M.	5 min.	#1, and #3 units on line	#3 jacket and turbo water flow	#1 engine would not restart Spent 1 hr check- ing out unit when it did start No recurrence of problems in 3 days

APPENDIX A (CONTD.)
WESTERN MALL TOTAL ENERGY PLANT
FAILURE REPORTS SUMMARY
1977

Date	Time	Duration	Status of Plant at Failure	Failure Indication	Corrective Action and Remarks
7/13/77	8:40 P.M.	15 min.	#1, and #2 units on line	#1 - gas pressure #2 - low oil pressure	#1 unit started first - Hot wa- ter alarm on at start up - 250° water to chiller which cut back overheated eng. water
7/17/77	2:45 A.M.	15 min.	#1 unit on line	High water temperature	
7/31/77	11:50 A.M.	Partial 2 min.	#1, and #3 units on line	Jacket water temperature	#1 backfired several times and stopped - New Mall sec- tion shut down to pick up cycles and #2 unit put on line
8/17/77	8:58 P.M.	4 min.	#1, and #2 units on line	#1 Jacket water flow #2 overloaded	#27 wire high water temp #1 unit removed - TRW board then cleared - With board cleared reset and re- started #1 unit

APPENDIX A (CONTD.)
WESTERN MALL TOTAL ENERGY PLANT
FAILURE REPORTS SUMMARY
1977

Date	Time	Duration	Status of Plant at Failure	Failure Indication	Corrective Action and Remarks
9/10/77	9:10 A.M.	3 min.	#3 unit on line	Overload - Checking dump system	Checking out time delay on dump system - Readjusted dump delay time

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APPENDIX B

APPENDIX B
ENGINE SERVICE RECORD

#1 S/N 19525		#2 19526		#3 19527		#4 19528	
Date	Tach	Date	Tach	Date	Tach	Date	Tach
10/ /70	9532	12/ /69	6200	9/11/70	9388	5/10/70	8920
All heads replaced		Jacket water pump seal		All heads replaced		Gas couplings replaced	
11/23/70	9700	5/9/70	8737		14300	10/3/70	11927
Liners & pistons		Gov. repaired		#1 piston, liner, rod		#1 piston, liner, rod	
1, 2, 3		5/11/70	8979	bearing replaced		bearing replaced	
2/ /71	10725	Jacket water pump		5/27/71	14487	All heads replaced	
Gas couplings replaced		repaired		# 5 piston, liner,		10/20/70	12228
4/ /71	11696	9/ /70	10733	replaced		"Magtronic" Magneto	
#5 piston & liner		Overhaul		5/28/71	14489	installed	
replaced		All heads replaced; crank-		Overhaul		15561	
5/20/71	12161	shaft replaced, pistons		Crankshaft replaced		New type main	
#5 butterfly		new rings; liners honed		New type main		bearings installed	
coupling replaced		4/8/71	13825	bearings installed		6/9/71	16220
New type main		Pistons & liners #1,		8/28/71	15311	Overhaul	
bearings inst.		#2, #8		#2, 6 liners replaced		#1, 3, 4, 5 liners &	
6/5/71	12506	5/ /71	14929	(scored)		pistons replaced,	
Governor changed		"Magtronic" Mag.		7/ /71	14590	#5 main bearing replaced	
6/8/71	12542	installed		"Magtronic" Magneto		7/16/71	16636
#3 main bearing		5/30/72	21596	installed		New main bearings	
changed		#5 head replaced		1/ /74	26822	installed	
6/10/71	12560	New type main bearings		Head overhaul		9/16/71	17862
Rod bearing		installed		3/ /74	27847	#4 piston & liner	
changed		6/2/71	21700	Oil cooler hose replaced;		replaced (scored)	
2/19/72	16296	All heads replaced		butterfly bushings & #4		6/10/72	22,335
Jacket water pump		8/13/73	28762	new coupling		All heads replaced	
repaired		#3 head replaced		8/ /74	29014	1/11/73	26675
3/12/72	16746	11/ /73	29719	New oil filter installed		#5 head replaced	
#3, #6 Heads		Bottom half main		12/ /74	30124	7/8/73	30004
replaced		bearings		Upper rod bearings		#3, 6, 7 lower main	
5/19/72	17572	11/ /73	29726	Lower main bearings		bearings, #5 liner,	
"Magtronic Mag-		All upper rod bearings;		New thrust bearing		piston,	
neto installed		#4 lower rod bearing				#5 main bearing	
						All top rod bearings	

APPENDIX B (CONTD.)
ENGINE SERVICE RECORD

1969-1977							
#1	S/N 19525	#2	19526	#3	19527	#4	19528
Date	Tach	Date	Tach	Date	Tach	Date	Tach
9/4/72	13913	12/ /73	30100	2/ /75	30994	8/6/73	30674
Overhaul		#1 head replaced		New oil filter;		#5, 7, 8 liners, pistons	
All liners & pistons replaced		3/ /74	30651	GEO 444 oil		1/ /74	33354
1/20/74	26020	Heat overhaul, butterfly valves, gas valves re-built, water hdr. gaskets		2/ /75	31486	Overhaul	
#2 piston replaced		7/ /74	32264	Mag. shaft oil seal replaced		Pistons, liners, heads, bearings	
2/ /74	26020	Gov. drive shaft replaced		2/ /75	31494	2/ /74	34101
Gen. serviced		5/ /75	34891	Flx. water line, turbo to aftercool.		#1 piston, liner replaced (scored)	
4/ /74	26090	Water leak #2 head		3/ /75	31528	5/ /74	36167
Head overhaul, valves seats, guides		7/ /75	35827	#3 gas valve rebuilt		Jacket water pump rebuilt	
5/ /74	26155	Jacket water pump seal		3/ /75	32999	1/ /75	41387
Insp. #2 rod bearing		7/ /75	36165	Oil pressure adj. 35-37 psi		Head overhaul, valves, seats, guides	
7/ /74	26276	8/ /75	36675	8/6/75	33490	5/ /75	43479
#2 rod installed		New spark coil #5 cyl.		1,000 hr. check - liners		Liners inspected	
9/ /74	26519	Oil pressure adj. to 35-37 psi	36028	#1, #2, #4, #6 scored		Oil press. adj. 35-37 psi	
#2 rod bearing		12/ /75	36000	6/9/76	34569	10/17/75	43999
1/ /75	26600	Overhaul		Rebuilt turbo installed S/N H9028-11		Replace turbo pump & motor (motor bearing failure)	
Overhaul		Rebuilt turbo charger inst. S/N H9028-3. Engine overhaul; heads rebuilt with 30° valves & seats. New rod upper bearings. New main lower thrust bearings. New 4 ring pistons & liners. New oil filter GEO 444 oil used		5/14/76	34,465	10/28/75	44326
Rebuild crankshaft & installed; Mains 2, 3, 5 upper ½; 2, 3, 7 bottom ½; Rod bearings top ½; Pistons, liners, rings (used); Heads overhauled - valves, guides, seats; Gas vlvs - new seals, reseal valves; New oil filter installed GEO 444 oil				Overhaul		1,000 hr check - #5 liner scored	
				Major overhaul - 30° valves & seats, new liners, 4-ring pistons; Gen. cleaned & lubricated. Thermocouple wiring replaced. Speed switch replaced. Rebuilt turbo. Jacket wtr. pump new bearings. Engine put on Pegesus 490 oil. All new rod bearings top half		12/30/75	45326
						1,000 hr check - #5 1 liner scored, #5, #7 main bearings & thrust bearings replaced with used bearings. #7 rod b bearing replaced with new bearing. Turbo charger	

APPENDIX B (CONTD.)
ENGINE SERVICE RECORD

#1 S/N 19525		#2 19526		#3 19527		#4 19528	
Date	Tach	Date	Tach	Date	Tach	Date	Tach
3/ /75	26708	1/ /76	37190	5/24/76	34561	Inspected and cleaned Nozzle ring observed to be cracked. #9, #11, #12 thermocouples replaced. Crankshaft strain gage data within tolerances	
Rod & main bearings checked		1,000 Hr check. 30° valves show little sink or wear		Replaced Magneto S/N 6168 Installed. Old Magneto had bad bearings.			
28075		2/ /76	38165	6/28/76	34803		
Oil press. adj. 35-37 psi		Engine put on Pegasus 490 oil		Speed switch set for 980 RPM shut down		1/ /76	45336
6/7/75	27601	3/31/76	38887	7/31/76	35480	Speed switch replaced Turbo charger in service S/N 9198-3	
#4 liner scored - 1000 hr check		Replaced 1 1/4" air start valve		1000 Hr check - very little valve adjustment		4/19/76	46357
6/12/75	27626	4/22/76	39170	8/25/76	35774	1000 Hr. check - Bearings inspected. Valve service 4962 hrs.; Bearings service 12,995 Hrs.	
#4 liner & piston replaced		1000 Hr. check - 30° valves need very little adjustment		Gov. drive gear failure. Drive spring failed. Gear & spring replaced. Oil change		Engine put on Pegasus 490 oil.	
1/29/76	30900	4/17/76	39120	10/24/76	36448	Coolant hose for turbo charger replaced.	
Turbo water pump repaired. New heater coils; new switch		Replaced Ignition coil #7		1000 Hr. check - see log for valve adjustments		#5 liner scored	
1/8/76	30544	6/24/76	40042	2/7/77	38376	6/30/76	46911
1000 hr check - timing chain adjusted #1 liner scored		Speed switch adjusted for 980 RPM shut down		1000 Hr. check - see log for valve adjustment		Speed switch adjusted to 980 RPM shut down	
1/20/76	30622	7/3/76	40429	5/13/77	39448	7/7/76	47037
Engine put on Mobil Pegasus 490		1000 Hr. check - valves wearing well. Little adjustment required		1000 Hr. check - see log for valve adjustment		Turbo and oil cooler heat exchanger cleaned. First cleaning since new water treatment.	
2/25/76	31190	7/26/76	40429	8/22/77	40479		
Rebuilt turbo installed S/N H9028-7		Oil change 1250 hr. service		1000 Hr. check - see log for valve adjustment			
Intake Man. press. 10 psi @ 920 A.		8/13/76					
2/14/76	30982	Magneto S/N 6779 in service on this engine					
3-way valve, diaphragm & packing replaced.		9/7/76	41170				
		1000 Hr. - See log for valve adjustment					

APPENDIX B (CONTD.)
ENGINE SERVICE RECORD

1969-1977

#1 S/N 19525		#2 19526		#3 19527		#4 19528	
Date	Tach	Date	Tach	Date	Tach	Date	Tach
3/1/76	31254	10/6/76	41562			8/13/76	
Mag. coupling re- placed. Mixture adjusted; Eng. running lean.		Thermocouple #4 replaced				Magneto S/N 6167 in service on this unit.	
		10/18/76	42190			9/9/76	47898
		oil change & 1000 Hr. check				Crankshaft measured for distortion. Within tolerance. See log.	
3/2/76	31266	6/5/77	44309			9/16/76	47916
#8 cylinder. New thermo couple 3/22/		1000 Hr. check (see log for valve adjustment)				New thermocouples on #5, #7, #8 cylinders	
3/22/76	31626					10/20/76	47978
1000 Hr. check; #3 rod bearing inspected no wear.						#3 head replaced. In- take valve burned through. Used head installed.	
3/29/76	31696					9/1/77	48609
#8 cylinder bent push rods replaced; Mag front bearing worn; replaced Mag S/N 8093 installed						Unit designated as standby. Scheduled for head overhaul winter of 1977-78	
4/9/76	31959						
Lube oil cooling pump rebuilt							
5/8/76	32598						
1000 Hr. check - #1 liner scored but stable- No change since Pegasus 490 started.							
6/20/76	33419						
Engine backfiring - scheduled for head overhaul							

APPENDIX B (CONTD.)
ENGINE SERVICE RECORD

#1 S/N 19525		#2 19526		#3 19527		#4 19528	
Date	Tach	Date	Tach	Date	Tach	Date	Tach
6/ /76	33419						
Head overhaul - Valves seats, guides. Wellman parts - rebuilt speed switch - "o" rings for liners replaced. Bear- ings checked found satisfactory. Valves stuck at startup. Head overhaul repeated							
9/15/76	33864						
Thermocouple #8 cylinder replaced							
9/17/76	33898						
Gas valves & eng. valves checked							
9/22/76	34018						
Paper filter installed for air intake							
9/23/76	34035						
Gas valves #3, #4, #8 replaced							
10/15/76	34462						
1000 Hr. check. Valves needed very little adjustment.							
11/4/76	34711						
Turbo pump rebuilt							
11/29/76	34777						
Excessive oil con- sumption. Valve							

APPENDIX B (CONTD.)
ENGINE SERVICE RECORD

1969-1977

#1 S/N 19525		#2 19526		#3 19527		#4 19528	
Date	Tach	Date	Tach	Date	Tach	Date	Tach
stems loose. Engine removed from service and overhauled.							
1/77 to 2/77 . 34777 Overhaul All heads rebuilt - White parts used 30° valves & seats installed. All new lower main bearings and upper rod bearings All 4 ring pistons used. Liners with new "o" rings installed. Pistons & liners new. Start up and run in normal							
4/16/77 35909 1000 Hr. check							
7/27/77 37869 1000 Hr. check Replace spark plugs.