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ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

Informal Report ANL/CNSV-TM-1

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CASE HISTORY STUDY OF COGENERATION FACILITY AT SOUTHEAST MISSOURI STATE UNIVERSITY CAPE GIRARDEAU, MISSOURI

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ABSTRACT

This report examines the Southeast Missouri State University total energy plant, its fuel, control, production, operation, and maintenance. A financial analysis looks at comparative operating costs for central heating (case 1), stand alone (case 2), and cogeneration (case 3). Finally an evaluation of the performance of the plant indicates continuation of operation with some modifications.

1 INTRODUCTION

Southeast Missouri State University is a State-owned university in Cape Girardeau, Missouri, about 125 miles south of St. Louis, on the Mississippi River. The University academic campus includes 200 acres in the city; about 35% of this land is developed with academic and student housing facilities. The 1977 student population included 3150 residents and 4850 non-residents.

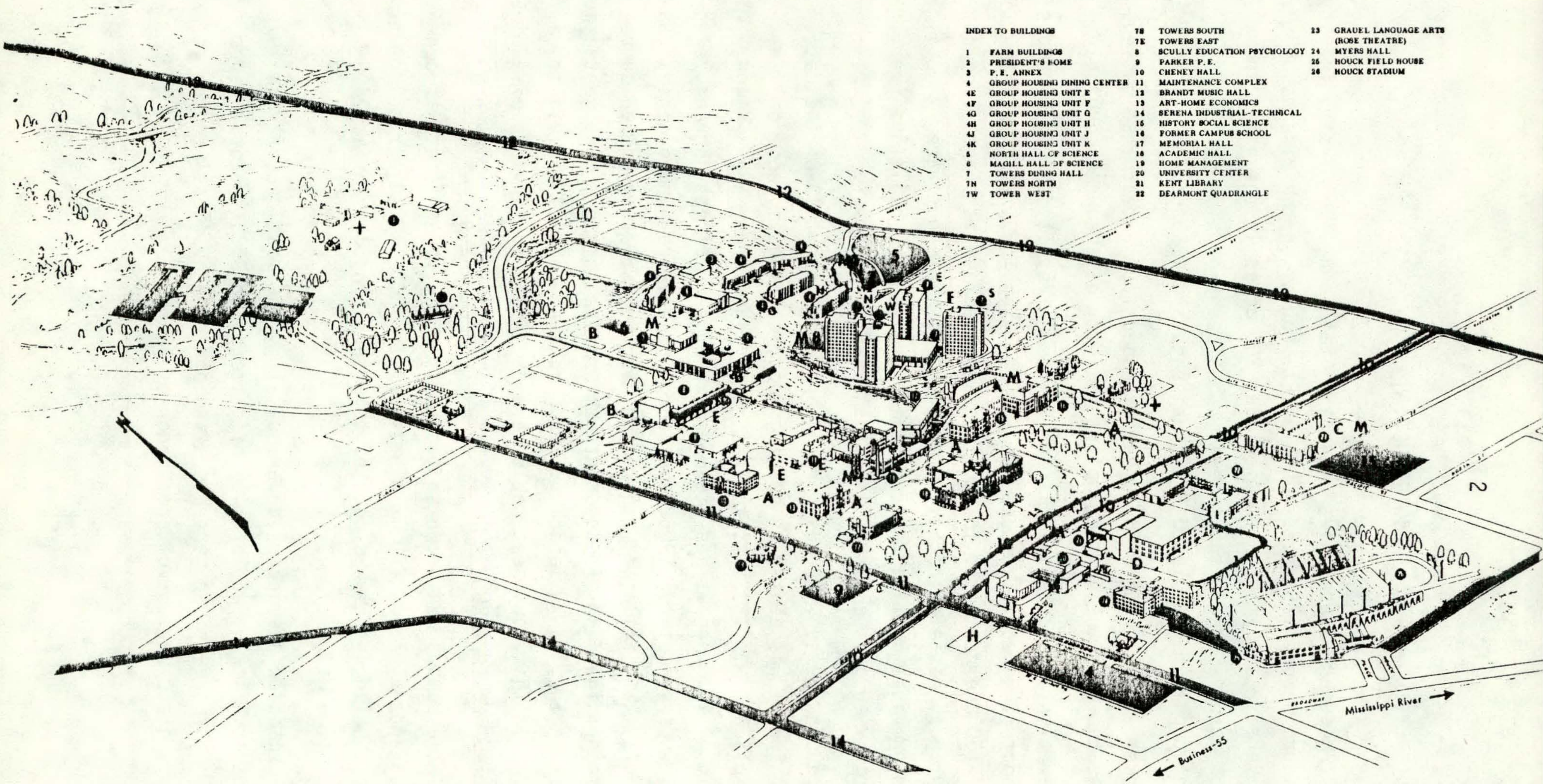
The Campus, established in 1873, has expanded from a teachers' college to university status, and the physical plant facility has grown accordingly.

The power plant at Southeast Missouri State University serves a campus community of about 8000 people composed of faculty, service staff, and students, of whom 3150 are residents in facilities served by the plant. The central power plant provides electricity, steam, and domestic hot water to all the campus and also provides chilled water for air conditioning buildings near the plant. A general view of the campus is illustrated on Fig. 1.1.

The Board of Regents' minutes for the academic year 1880-81 indicate that the Normal School was heated by burning wood, catalogues, and coal in stoves and fireplaces. In 1887, steam heating was installed, and by 1903, there were steam piping tunnels and steam-engine-driven, direct-current, electric generators in service. In 1905, the State legislature funded central water distribution system facilities, including deep wells, steam-driven pumps, a water tower, water mains, and fire hydrants to provide suitable fire protection. The first diesel engine, 25 kW capacity, was purchased in 1929 because it was believed that . . . "This equipment would save the fuel and services of a fireman during the summer . . ."

By 1949, the campus had grown so much that a new power plant was constructed with a capacity of 30,000 lb of steam/h and 1000 kW electrical generation. The distribution system was changed to alternating current at 2400 V although the generation was only 440 V.

Further expansion has occurred periodically, and most recently in 1976. The present capacity is 230,000 lb/h 400 psig steam and 9500 kW total capacity in the two steam-turbine-driven generators and one 1000-kW diesel engine generator. The Campus distribution voltage is now at 15 kV.



STUDENT PARKING AREAS

1. Myers Hall (East Side)
2. Myers Hall (West Side)
3. Farm Lot
4. Henderson Lot
5. Towers Lower Lot
6. Magill Lot
7. Group Housing Lot
8. Upper Towers Lot
9. Quarry Lot
10. Normal Street
11. Henderson Street
12. Sprigg Street
13. Bellevue Street
14. West End Blvd. Street
15. Watkins Dr. Lot

MOTORCYCLE PARKING AREAS

ALL MOTORCYLCE AREAS ARE MARKED BY "M"
"M"-Area #8 (Upper Towers Lot)
"M"-Area #6 (Magill Lot)
"M"-Area #7 (Group Lot)
"M"-Area #10 (in front of Library)
"M"-Area "A" (Cheney Dr.)
"M"-Area "A" (Old Campus School Lot)
REGISTERED MOTORCYCLES MAY PARK IN ANY OF ABOVE AREAS

FACULTY

A. Cheney Dr., Academic Hall Circle, Old Campus School Lot
B. Magill Hall, North Hall, P.E. Service Building, Scully Education Psychology Building (small lot)
C. Grauel Language Arts Building
D. Library faculty areas, (Myers Drive) Dearmont Faculty Lot
E. Power Plant, Bus Garage Areas, Parker P.E.
F. Residence Hall Parking (Staff)
H. Faculty, University Center

Fig. 1.1 Southeast Missouri State University Campus (Student & Faculty Parking)

In 1962, an interconnection with the local public utility company was provided, and interchange of electricity for other than power interruptions was begun in 1973.

The interconnection was expanded in 1966 to 3750 kVa capacity at 34.5 kV. In December, 1975, the University shut down the power generation equipment for an extended period for the first time in years. Since that time, the plant has been operated as a steam heating source at all times; electrical generation has been limited to periods when the Missouri Utilities Co system peaks during the air-conditioning season. In 1976, the power generation plant was operated 6000 hours on coal and 2760 hours on gas. Although the University prefers to generate electricity only when on gas fuel, curtailed gas supplies have forced the use of both coal and gas in a combined combustion chamber.

Because the University has always considered the power plant as an overhead expense, no effort has been made to relate the value of services provided to the costs of those services. Most construction and repair money is obtained by specifically identified appropriations from the Missouri State Legislature. Some capital improvement funds are obtained from other budgets. Funds for labor, fuel, and other plant supplies are taken from general appropriations and revenue from academic services.

A Board of Regents, appointed by the State Governor, is the agency responsible for all University activity and property; the University President, as the Board's executive officer, directs the entire enterprise. The power plant is under the Director of Buildings & Grounds, who reports to the Vice-President of Administration. A chief engineer is in charge of the production operations of the plant. Various departments are charged with the operation and maintenance of distribution systems and the building mechanical and electrical systems.

Currently, the operating budget separates the power plant operation and its costs from the delivered products -- heat, light, air conditioning, etc. The users of the university builders have no responsibility for paying the costs of the services provided. The Building & Grounds Division has no measure of energy use because individual buildings or departments are not metered.

A review of the major power plant construction programs with the retired university president and examination of Board of Regents' meeting minutes for the past 90 years indicated that the heat, light, and power problem has been delegated to the Director of Buildings & Grounds. For the 40 years before 1968, that office was held by V. A. Chapman who has determined the scope of services and methods of production for the power plant. He, his predecessors, and successors have all used technical consultants to supplement the engineering skills of the University staff. However, all fundamental decisions of planning for the utility systems to serve the University have been made by the Board of Regents in conformance with the recommendations of the Director of Buildings & Grounds. The present administration is trying to develop a different management scheme wherein the executive has several alternatives and supporting data from which to draw the conclusions concerning energy systems, conservation, sources of energy, and related matters.

In recent years, all new buildings have been air conditioned, and the old buildings have been remodeled to include cooling. Because the power plant design and operation was for isolated operation, the effort to balance steam load with electrical load for best use of extracted steam resulted in the installation of absorption water chillers in most projects. The steam distribution system was found to be adequately sized for these loads, and no further expansion of electric power generation was required by the steam-powered refrigeration equipment. Plant consumption of steam has been reasonably uniform through the year. Annual electric load growth, tabulated below, reflects the addition of new buildings to the campus and the provision of utility services to more students.

Table 1.1 Annual Electric Load Growth

Year	Campus Use kWh	Peak Campus kW	Peak Production kW	Lb Steam Produced
1973-4*	16,941,450	4100	5500	408,535,020
1974-5	17,121,020	4100	5800	283,190,200
1975-6	18,322,280	4000	6300	253,232,300
1976-7	19,962,085	4000	6250	312,087,076

*Last year of 12-month operation as an isolated power plant

Since 1906, the concept of central utility services has been a fundamental plan for Southeast Missouri State University. The initial steam heating plant which arranged for hand-fired coal to be delivered to the coal bins in wagons, was expanded to serve new buildings through a network of utility tunnels. Early fire losses of the original frame Normal school buildings prompted the establishment of a central water system for fire protection and domestic use. The steam-driven water pumps and direct-current "dynamos" gave the campus a level of comfort, convenience, and safety that was noticibly better than other facilities in the area. Placed in historical perspective, the strategy of burning coal in a central steam heating plant rather than using wood- or coal-burning stoves in every room was an obvious advantage. By combining the concept of power from steam, with local steam engines to drive pumps for water and large fans for the elaborate heating and ventilating system for the main building, and finally, using the same steam system to provide electric illumination, an integrated total energy plant evolved naturally.

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2 CENTRAL PLANT FACILITIES

The present configuration of the integrated utilities system includes the centralized production facility, an underground steam distribution system, underground electrical distribution system, several central water chiller systems with distribution systems, and a domestic water distribution system. The physical relation of these components is illustrated on three site plans and a power plant layout, included as Appendix A.

Principal components of the power plant production are listed in Table 2.1.

Table 2.1 Principal Components of Power Plant Production

Boilers:	combination chain grate coal stokers and natural gas burners, water tube type, 400 psig, 750°F steam boilers, one each of 20,000, 30,000, 55,000, and 125,000 lb/h capacity.
Fuel Handling Equipment:	underground coal bunkers, top loaded by tipping semi-trailer trucks, bucket conveyor delivery to stoker hoppers.
Ash Handling Equipment:	steam-jet-powered pneumatic conveyor with cyclone separator and elevated ash storage for gravity loading of ash-carrying dump truck.
Feedwater:	demineralized treatment of make-up water, steam heated deaerator, steam and electric driven feedwater pumps, automatic boiler water level control.
#1 Generator:	diesel engine driven 1000 kW 480-V unit.
#2 Generator:	1500 kW capacity turbine driven 2400-V unit with 2000 kW generator.
#3 Generator:	6250 kW capacity turbine driven 13,800-V unit with 7500 kW generator.
Outdoor Switchyard:	6250 kVa transformer 13.8/2.4 kV 500 kVa transformer 2.4/.48 kV 2 @ 300 kVa transformer 2.4/.48 kV 3750 kVa transformer 34.5/2.4 kV 7500 and 2000 kW generator circuit breakers 2.4 kV transfer switches and breaker for utility tie.
Cooling Towers:	induced draft, wood fill with concrete basins.
Water Chiller:	low-pressure, steam heated, 375-ton-capacity absorption chiller.

The electrical system diagram, Fig. 2.1, illustrates the power management possibilities. Under isolated plant operating mode, the campus load normally is served by operation of the 6250 kW unit at 13.8 kV; the "city" tie breaker is open; 480-V power for plant auxiliaries and the nearby building services is obtained by transformation to 2.4 kV and again to .48 kV.

When the plant is delivering power to the utility grid, the same equipment is operated, but the city tie breaker is closed and power is delivered through the 34.5-kV transformer. If the utility demand is high, the 1000-kW, 480-V diesel unit is also operated, and that output enters the system through the 2.4/.48-kV transformers and 13.8/2.4-kV transformer.

It is not possible to run the 1500-kW, 2.4-kV generator unit with the 6250-kW unit for increasing utility delivery quantity because of the 2.4-kV system capacity limitations. To deliver power from the larger machine, it is necessary to transform down from 13.8 kV to 2.4 kV and then step up to 34.5 kV from 2.4 kV.

It is possible to serve the campus loads, up to 2500 kW (about 60% of maximum) by operating only the 1500 kW and 1000 kW units.

When power is obtained from the utility company, the tie breaker is closed and the plant may operate none, one, or more of the generator units, if desired.

A steam system diagram, Fig. A.4 (Appendix A), illustrates the source and distribution of steam in the power plant. All steam is produced at 400 psig, 750°F. If either of the steam turbine driven generators is in operation, steam may be extracted at intermediate stage at 100 psig. The smaller turbine may also furnish 5 psig extraction steam. The steam turbines driving feedwater pumps and forced-draft fans exhaust to the 5 psig header. Auxiliary pressure reducing stations with desuperheaters maintain output pressures at predetermined points.

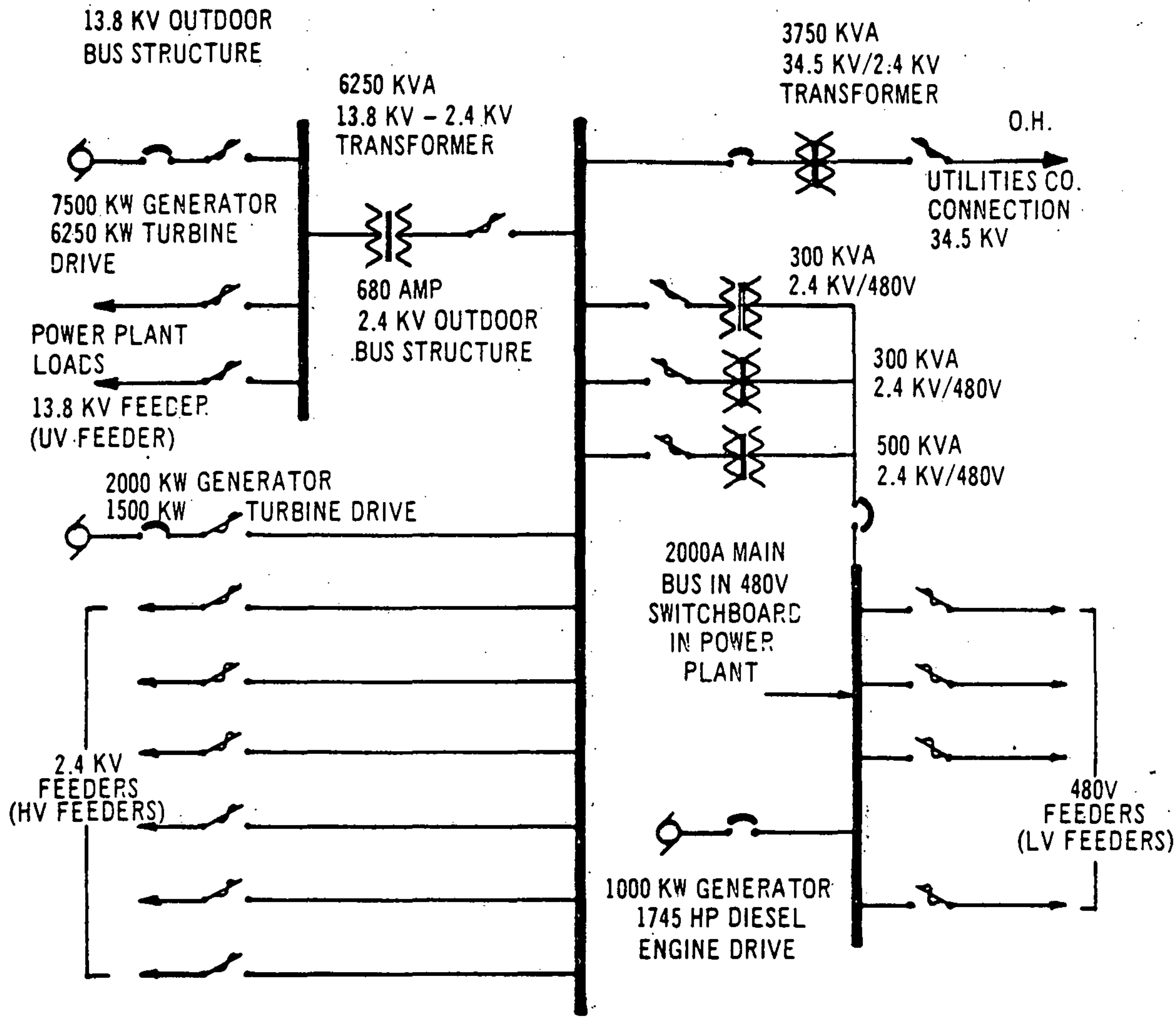

Fig. 2.1 Electric Distribution System Diagram

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3 SYSTEM CONTROL

The steam plant operates automatically to maintain 415 psig steam drum pressure. Boilers are started manually, and it requires several hours to bring a cold boiler on line. Steam, flowing from the boiler drum through a superheater, loses 15 psi while heating to 750°. Boiler pressure is sensitive to sudden load changes because the coal burning rate is loosely a function of the depth of coal on the chain grate and the length of active fire bed in the boiler. Increased loads are accommodated by increasing the depth of coal on the conveyor and increasing the conveyor speed with the reverse process for lower steam production. When the boiler has reached a load balance, the chain grate speed control can readily follow minor slow changes in load. However, a sudden decrease in steam load must be handled by relief-valve operation to blow off the steam being produced by coal already in the combustion chamber. A sudden increase in steam load causes boiler pressure to drop and upsets the performance of the combustion process and the turbine generators. When the boilers are fired with natural gas the response rate is much quicker and less troublesome.

The electric generators are manually started, brought up to synchronous speed and electrically paralleled with the plant bus, or utility bus, by manually operated motorized generator breakers. After the on-coming generator is connected to the bus, the generator excitation is adjusted manually to the desired loading on the prime mover. By using variable excitation, there are no sudden load changes on the electrical or steam systems. Synchronization is determined by observing blinking synch lights as they turn off indicating synchronous performance. After the plant electrical output is established, the automatic steam throttle controls the turbine speed by adjusting steam flowrate into the turbine. Generator units have governor controls to permit automatic load sharing with one unit base-loaded and another set to respond to load changes.

Generator protection includes automatic sensing of: over-current, overtemperature, differential current, overspeed, and vibration. Reverse power relay functions, provided at the utility tie, are deactivated when power is delivered to the utility. It appears there is no reverse power protection in use. The operators are instructed to clear the generator breaker manually on unit malfunction to avoid motorizing the turbine. A sizeable load drop, such as opening the utility tie breaker, may cause turbine overspeed and safety shutdown of the steam throttle valve; in this case, manual opening of the generator breaker is essential.

The plant may automatically shed all the 2400-V service to campus buildings in response to underfrequency relay signals.

The University has installed local automatic transfer switches and small size service connections to Missouri Utilities power for the emergency lighting and alarm functions of several residence buildings. Recent investigations indicated that malfunctions in these systems had gone undetected for some time.

Automatic pressure-reducing stations in the power plant control distribution steam pressure. Desuperheater injection of feedwater into the superheated, reduced pressure line is provided to prevent excessive temperatures in the piping systems and campus buildings. Piping expansion loops were designed for saturated steam temperatures, and absorption chillers were selected for 250°F, maximum steam temperatures.

Absorption chillers have been equipped with load-limiting control devices to prevent extreme steam load demands on chiller startup. These controls prevent full steam flow to the chiller for a timed interval (about 30 min) so that intermittent chiller operation at low loads can be accommodated without going from no load to 150% of design maximum steam load as happens when an absorption machine starts up normally.

4 FUEL

From initial firing with wood, the generating facility at Southeast Missouri State University used coal as the main fuel until about 1970. The cost of coal in 1968 was $6.85 per ton. The 1969 and 1970 higher coal prices indicated that installation of natural gas service could save approximately $17,000 against $8.25/ton coal in 1969 and $48,000 against $10.95/ton coal for 1970 using natural gas at $.336 per MCF for fuel. So the natural gas service was installed, and the fuel change was made. The new 125,000 lb/h steam generator was installed with dual fuel equipment, and the 55,000 lb/h boiler was retrofitted with gas burners.

The use of natural gas as a prime fuel was short-lived as a result of curtailments and the rising price of gas. By the mid-1970s any cost savings had been cancelled, and coal again became the prime generating plant fuel.

By 1974, the cost of coal had risen to $24.00/ton and to $26.50/ton in 1977. Coal is readily obtained from any of several Southern Illinois mines within 100 miles of the campus. The current high coal prices have encouraged the University to seek the lowest coal expenditures. The coal is being presently transported by university-owned and -operated equipment.

Stockpiling is being tried to ensure against production interruptions as well as to win more favorable contract considerations. Because the University is sensitive to its community responsibility concerning the environment, various qualities of coal are being tried to achieve an acceptable compromise between economy and objectionable plant emissions.

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5 PLANT PRODUCTION

Monthly production of steam and electric energy has undergone extensive change since 1973. Installation of the 3750 kVa transformer for interchange of electricity with Missouri Utilities Co in 1966 and the major expansion of the power plant in 1971 that added the 125,000-lb/h #4 boiler and the 6250-kW #3 generator made profound differences in plant capacity and strategy of operation.

Figures 5.1 and 5.2 show the dramatic effects of cogeneration as followed by Southeast Missouri State University in 1975-77. Higher fuel costs have made purchasing electricity in the utility company's off-peak load period more economical than continued operation of the power producing equipment because of the unique contractual arrangement reducing MPU purchased power.

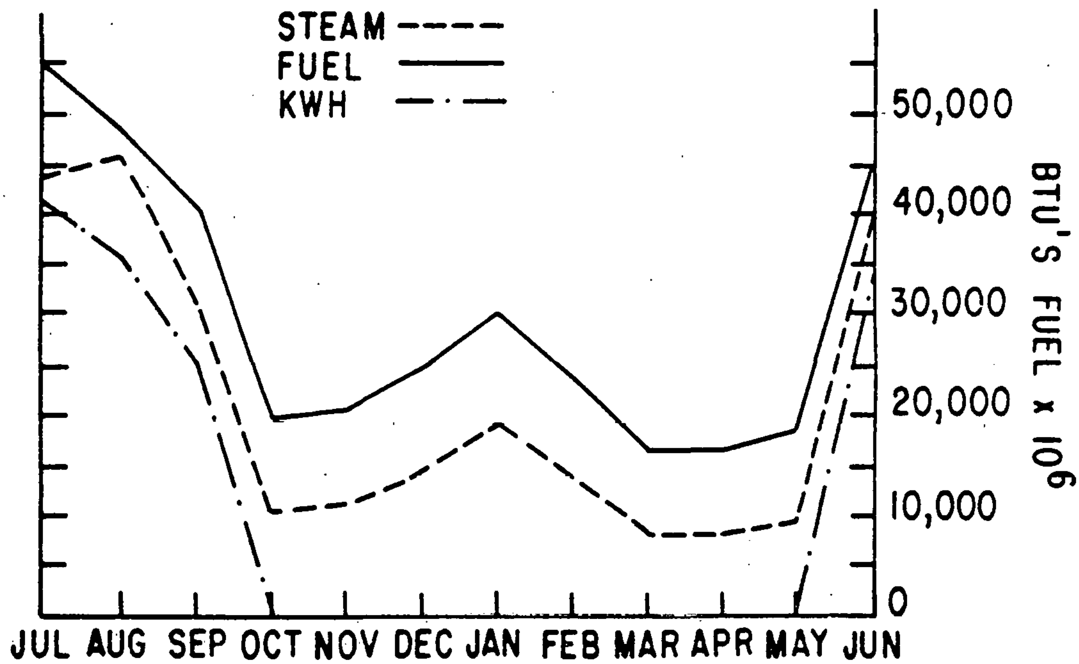

Fig. 5.1 Plant Production, 1975 - 1976

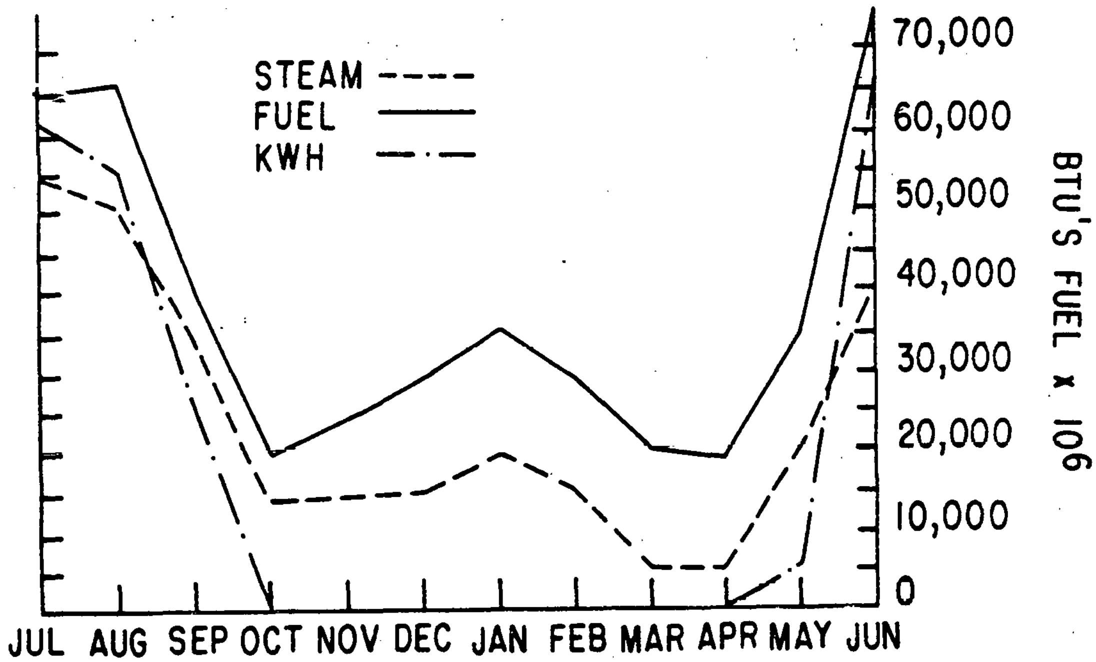

Fig. 5.2 Plant Production, 1976 - 1977

5.1 CAMPUS WATER SYSTEM

When it became evident several years ago that the available utility service was of better quality and less costly than continued use of the campus wells, the campus water system was shut down. A large, above-ground reservoir had been installed adjacent to the campus, but the utility water is obtained from a sophisticated city (municipal) plant using Mississippi River water. Clarity, taste, and hardness all are superior to the well water. Maintenance expenses on the well pumps, clear well, softeners, and deionizers were greater than the cost of purchased water so the campus water distribution system is now interconnected with Missouri Utilities, and the campus water producing equipment is in reserve.

5.2 CAMPUS STEAM SYSTEM

Performance of the campus steam system has been excellent. The plant used to be shut down for scheduled maintenance only during academic vacation times. Delivery of steam to the user buildings has very seldom been interrupted other than the annual one week maintenance period and that has not been necessary since 1973.

5.3 CAMPUS ELECTRICAL SERVICE

Electrical service reliability is good. When the plant is operated in parallel with the utility company and any bad weather is forecast, the plant disconnects from the grid so that transmission line failures are not reflected to the plant, because any power failure causes boiler shutdown and a time delay to get the steam service re-established. Table 5.1 shows system malfunctions since 1973.

Table 5.1 Summary of Outage Record, 1973-1977

Date	Configuration	Remarks	Duration (hours)
1973			
May 29	#3 Turbine; #4 Blr.	Lost control air - compressor starter failed. Burner malfunction.	1
June 19	#2 Turbine	Electric storm; city breaker opened Turbine bogged down.	2
July 2	#3 Turbine; #4 Blr.	City blackout; Burner malfunction.	9
July 10	#3 Turbine; #4 Blr.	600-A Breaker MCC opened on O.L., Dumped load on high rise.	1
July 25	#3 Turbine; #4 Blr.	Bus Bar exploded on MCC while shifting I.D. fan motors. Lost #4 Boiler & Turbine auxiliary equipment.	
July 31	#3 Turbine; #4 Blr.	Flame failure.	No outage
Aug. 12	#3 Turbine; #4 Blr.	Fan changeover; flame failure.	No outage
Aug. 27	#3 Turbine; #4 Blr.	Fuel change; fire failure; procedure error.	2
Aug. 28	#3 Turbine; #4 Blr.	600-A Breaker opened.	
1974			
June 22	#3 Turbine; #4 Blr.	Burner Failure - Right burner #4 Blr.	No outage

Table 5.1 (Cont'd)

Date	Configuration	Remarks	Duration (hours)
June 23	#3 Turbine; #4 Blr.	Burner Failure - Right burner #4 Blr.	No outage
June 24	#3 Turbine; #4 Blr.	Burner Failure - Right burner #4 Blr.	No outage
June 25	#3 Turbine; #4 Blr.	Burner Failure - Right burner #4 Blr. 6 times.	No outage
June 27	#3 Turbine; #4 Blr.	Burner Failure - Right burner #4 Blr. 4 times.	No outage
June 28	#3 Turbine; #4 Blr.	Burner Failure - Right burner #4 Blr. 4 times.	No outage
July 1	#3 Turbine; #4 Blr.	Lightning strike; SEMO to utility breaker opened - Turbine down on overspeed.	8
Dec. 13	#4 Blr.	#1 Burner Failure.	No outage
Dec. 18	#4 Blr.	#1 Burner Failure Failed 2 times.	No outage
Dec. 19	#4 Blr.	#1 Burner Failure Failed 2 times.	No outage
Dec. 24	#4 Blr.	#1 Burner Failure Failed 4 times.	No outage
<u>1975</u>			
Feb. 23	#4 Blr.	#1 Burner Failure.	No outage
Feb. 24	#4 Blr.	#1 Burner Failure.	No outage
Sept. 4	#4 Blr.	#1 Burner Failure.	3
<u>1976</u>			
Jan. 3	#1 Blr.	Electronic control system for flame control malfunction. Tube failure.	Boiler down 1/2
June 10	#3 Turbine; #4 Blr.	Burners failure; Operator polishing control panel.	1
Oct. 1	#4 Blr.	Squirrel on Mo Utility feeder	1/3
Oct. 20	#4 Blr.	Mo Utility failure.	3/4
<u>1977</u>			
July	#3 Turbine; #4 Blr.	MCC bus equipment failure. Cooling water pump electric supply lost. (Plant reduced to 90% output).	1

The quality of University-produced electrical service has been excellent. For many years, the University has operated a computer facility and an elaborate seismograph instrument on the campus power supply with no difficulties. Voltage and frequency are stable at ± 2% voltage with no apparent frequency deviation. Startup of the 350-ton 208-V, electric chiller used to be a problem before the 1971 plant expansion; moreover, intermittent operation of large absorption chillers was a problem to steam pressure control when the boilers were burning coal only. Sudden load changes require a change in firing rate of the boilers, and the chain grate stokers are not as responsive as gas burners to abrupt load change.

As the price of fuel has risen and the availability of natural gas has decreased, the University has turned to coal as its main source of energy. However, when generating with coal at high load levels, visible emission problems exist. At least one notice of violation for excessive visible emissions was issued by the Missouri Department of Natural Resources. Recently, July 1977, the University experimented with a less costly fuel containing a higher level of fines and this produced greater emission at high firing levels. Use of this coal was discontinued as soon as increased emissions were observed. The excessive stack emission was reported to the local news media, and news coverage was given to the incident.

The administration of the University is sensitive to the environmental problem and feels its responsibility to prevent any adverse conditions in this area. To relieve an odor problem on the campus proper, plans are pending to raise #1, #2, and #3 boiler stack heights to resolve this condition.

Annual reports are filed with the Missouri Air Conservation Commission, and these indicate alternative costs of grades of coal, i.e., low sulfur, no fines.

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6 SCOPE OF PLANT SERVICES AND LOAD DATA

6.1 ELECTRICITY PRODUCTION

Electricity at Southeast Missouri State University is produced primarily by steam-turbine-driven generators, and the power production levels vary considerably because the University now interchanges electricity with the Missouri Utilities Company, a subsidiary of a large, privately owned, regulated power company, Union Electric Co. Figure 6.1 illustrates the variation in power generated for each year since 1973, which was the last year that the University operated its plant substantially as the sole source of campus electricity. In late 1974, the plant power production was curtailed and then shut down until April 1975. Since then, the University has elected to shut down its power generation system from October to May of each year.

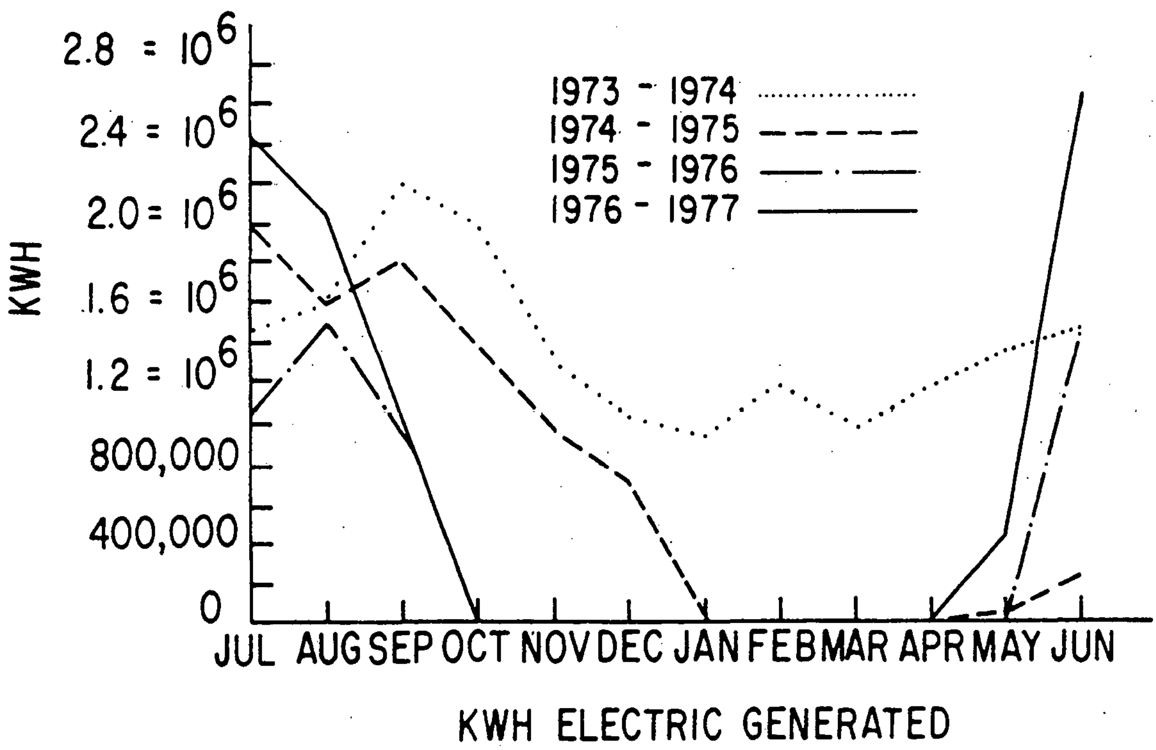


Fig. 6.1 Variations of Power Generated, 1973 -- 1977

6.2 STEAM PRODUCTION

Steam production quantities vary greatly because of weather and the use of the steam turbine generators as shown on Fig. 6.2. The summer peaks of 1976 and 1977 show the impact of power production for delivery to the utility during its peak load season in addition to the power produced for all on campus use. Winter loads, even in 1973 when the campus power was all generated by plant steam, are lower than summer loads. Much of the campus is air conditioned and uses steam absorption chillers served by the 100 psig or 5 psig steam distribution systems originating in the plant. The main steam turbines are arranged with extraction stages followed by condensing stages; the 100 psig line is normally served by this source when power is generated. Auxiliary steam turbines driving feedwater pumps are non-condensing type and exhaust to the 5 psig line. The flow diagram in Fig. 6.3 illustrates the plant steam system and major plant components.

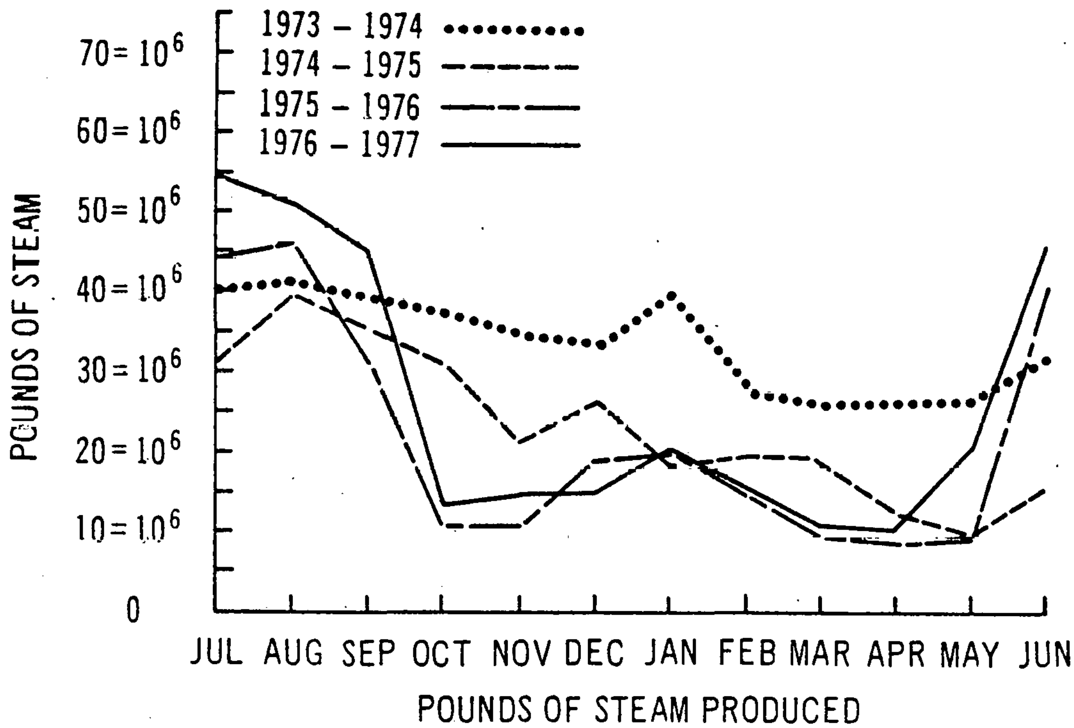


Fig. 6.2 Variations of Steam Production, 1973 -- 1977

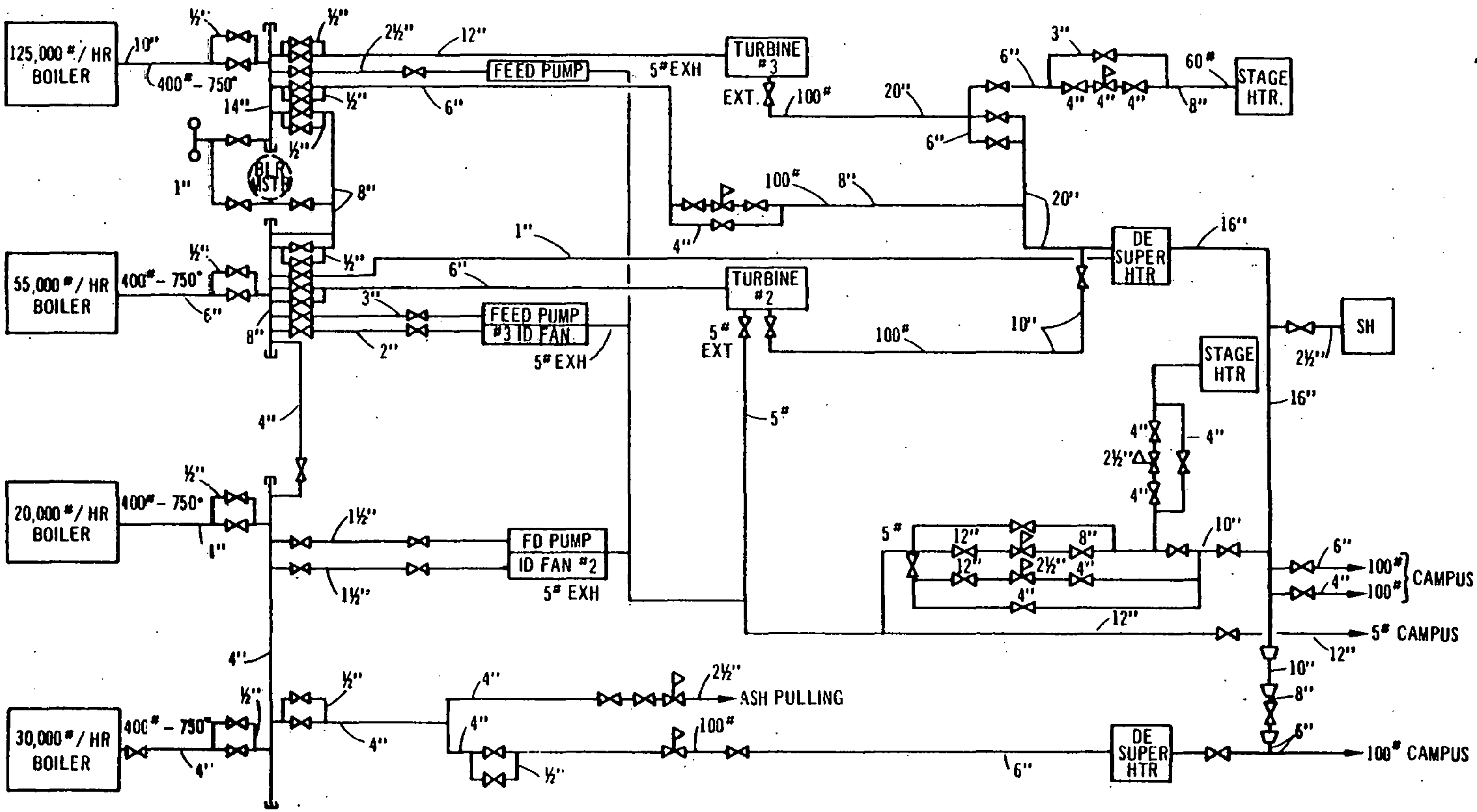


Fig. 6.3 In-plant Steam System

Before 1974, the University power plant was operated to follow the campus electrical load, as shown in Fig. 6.4, except for minor quantities of electricity purchased when the plant was shut down for scheduled maintenance. In December, 1974, the University experimented with shutting down the generation system and buying all electricity from Missouri Utilities. The experiment continued to May, 1975, as illustrated in Fig. 6.5.

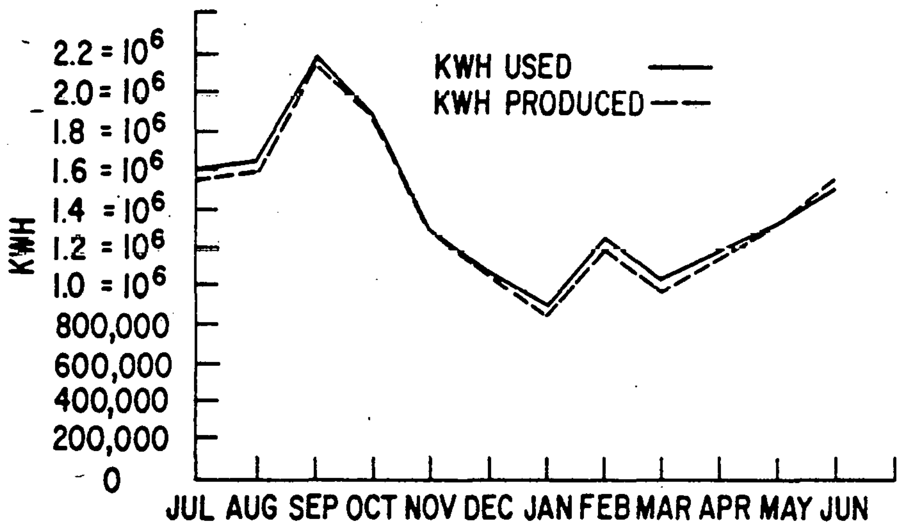


Fig. 6.4 Electric Generation and Use, 1973 - 1974

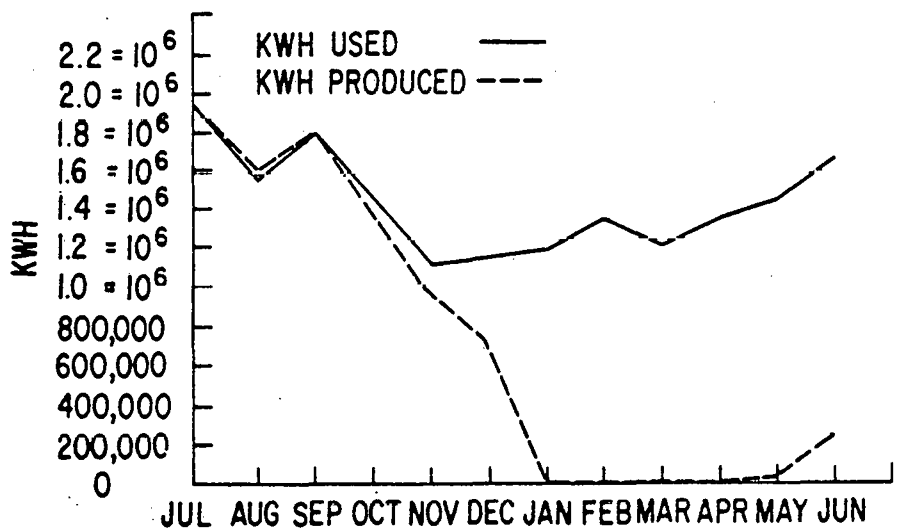


Fig. 6.5 Electric Generation and Use, 1974 - 1975

As shown in Fig. 6.6, the following year, 1976, the University used more electricity than was produced in every month, and there was no plant production for eight months. In the summers of 1976 and 1977 (Fig. 6.7) the University produced more electricity than it consumed during July and August, and shut down for seven winter months. This increase in power production and earlier startup was in response to requests from the Missouri Utilities Company.

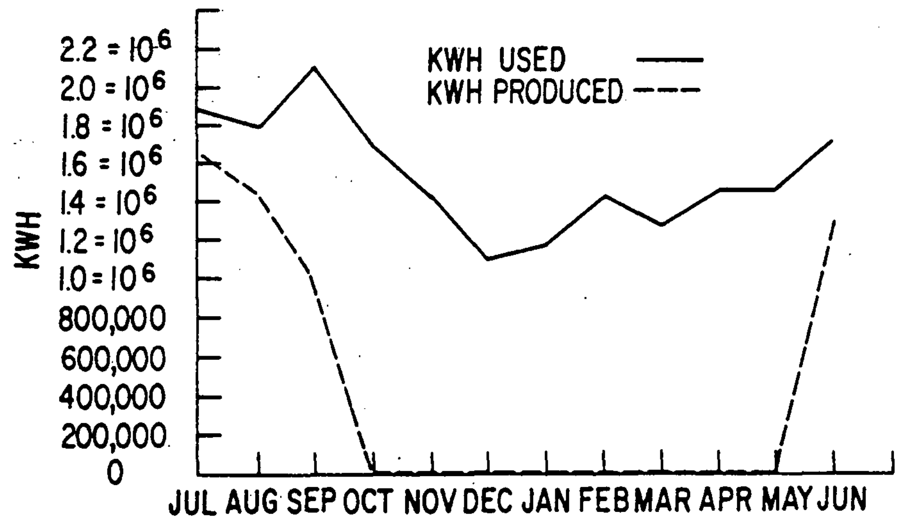


Fig. 6.6 Electric Generation and Use, 1975 - 1976

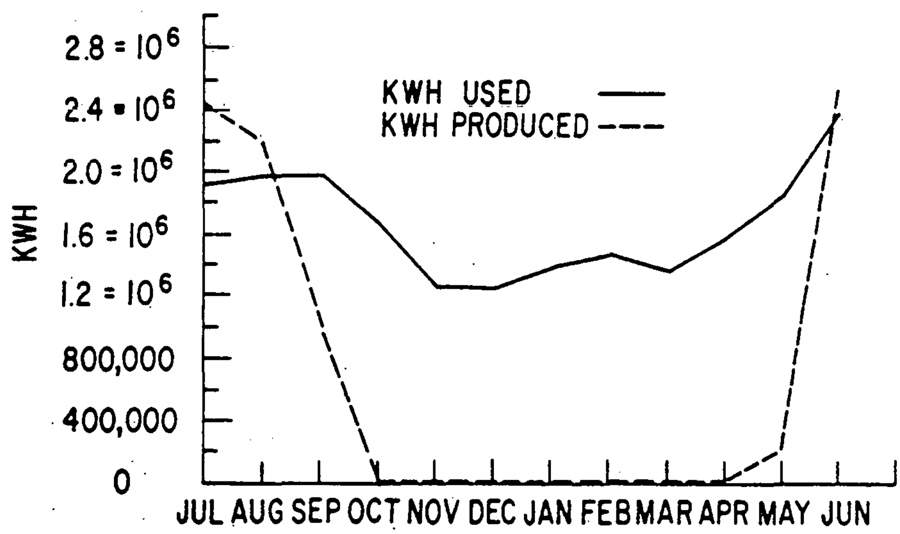


Fig. 6.7 Electric Generation and Use, 1976 - 1977

Detailed investigation of the plant steam loads shows some unexpected performance. Figure 6.8 represents the steam load on the power plant for two days when the weather was constant and there was no power generation.

The Sunday load, when no classes were in session and the average temperature was 41°, is about the same as Thursday, when classes were in session and the average temperature was 4° cooler. The Thursday profile shows a surge in load from 6:00 to 11:00 a.m.; otherwise, the load profiles seem to be random.

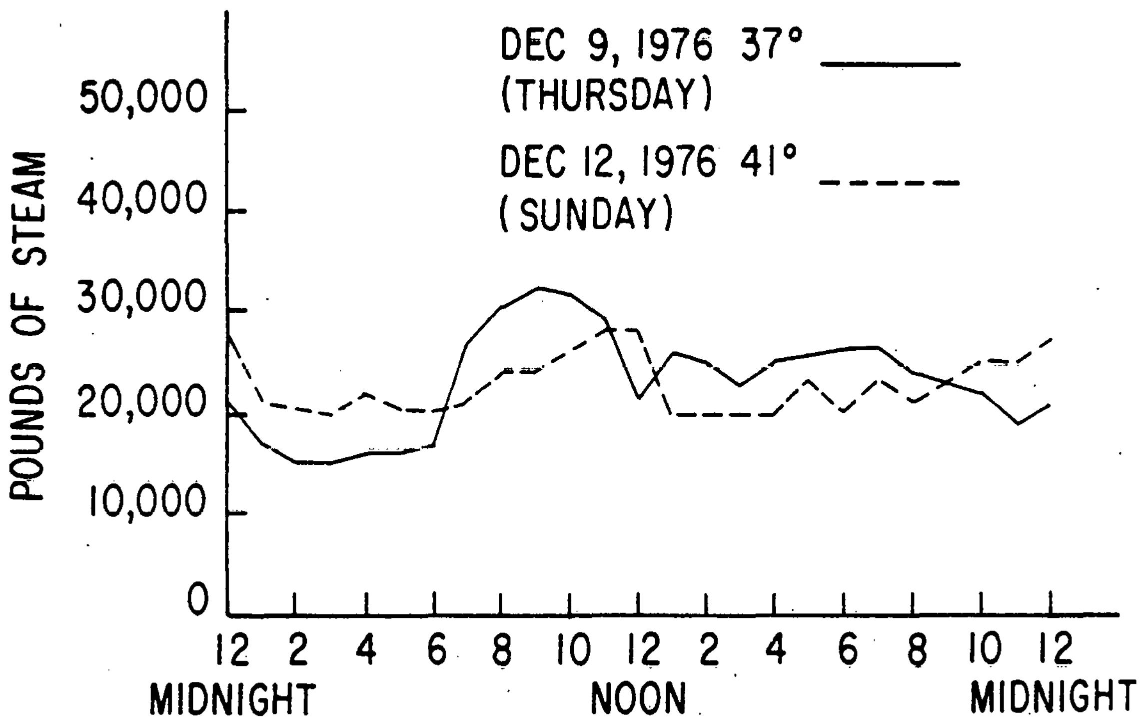


Fig. 6.8 24-Hour Steam Load Profile (No Electric Generation)

When the power generation system is in operation, the campus thermal requirements are of little significance as is shown in Fig. 6.9. The huge increase in steam use is coincident with delivery of electricity to the utility grid (Fig. 6.10). For the two Thursdays shown, the system was paralleled with the grid from 7:00 a.m. until 8:00 p.m. one evening and 10:00 p.m. the other, and the steam load increased to over 100,000 lb/h from the less than 60,000 lb/h needed to serve only the campus electrical and thermal needs.

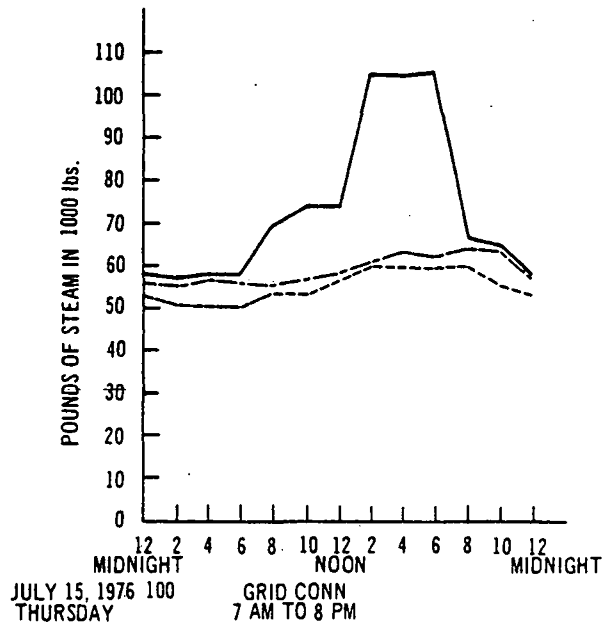


Fig. 6.9 24-Hour Steam Load Profile (with Electric Generation)

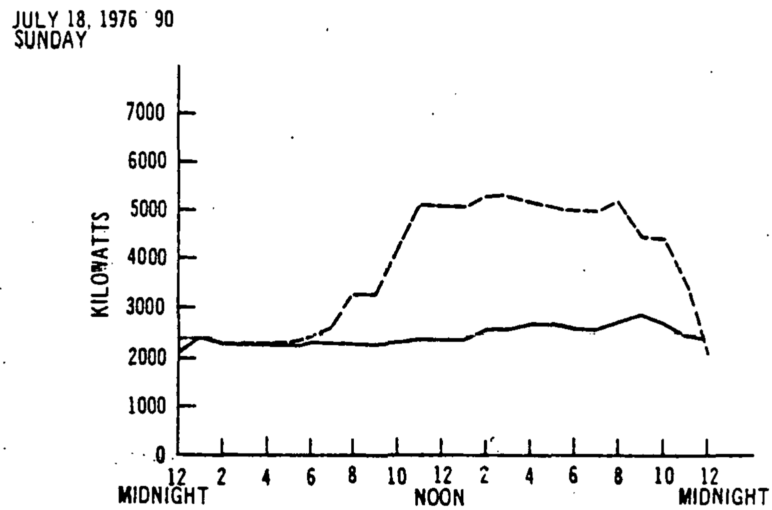


Fig. 6.10 24-Hour Electric Generation Profile

During December, 1976, the plant produced 15,700,000 lb of steam and served all the campus thermal needs (Fig. 6.11). During July, 1976, the plant had to produce 54,200,000 lb of steam to supply cogeneration needs as indicated in Fig. 6.12.

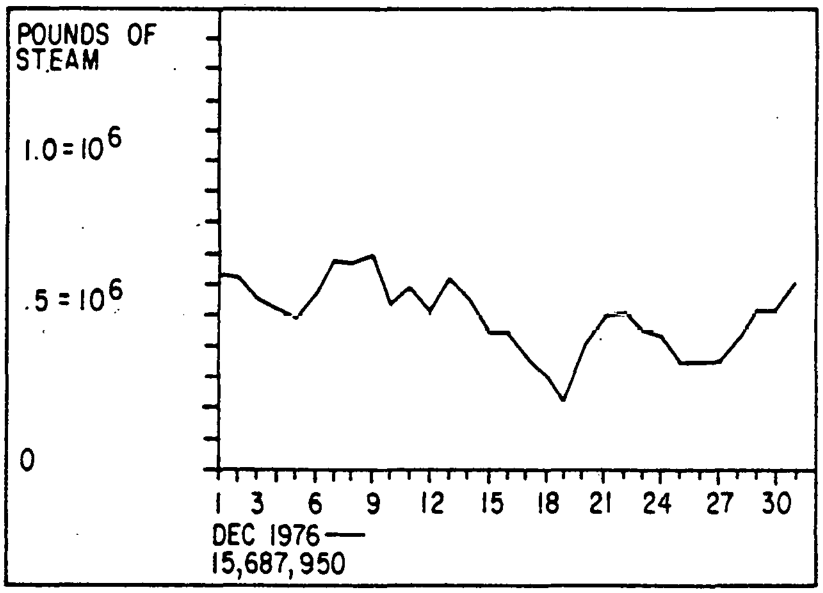


Fig. 6.11 One-month Steam Load Profile (No Electric Generation)*

*Average temperature = 32°F

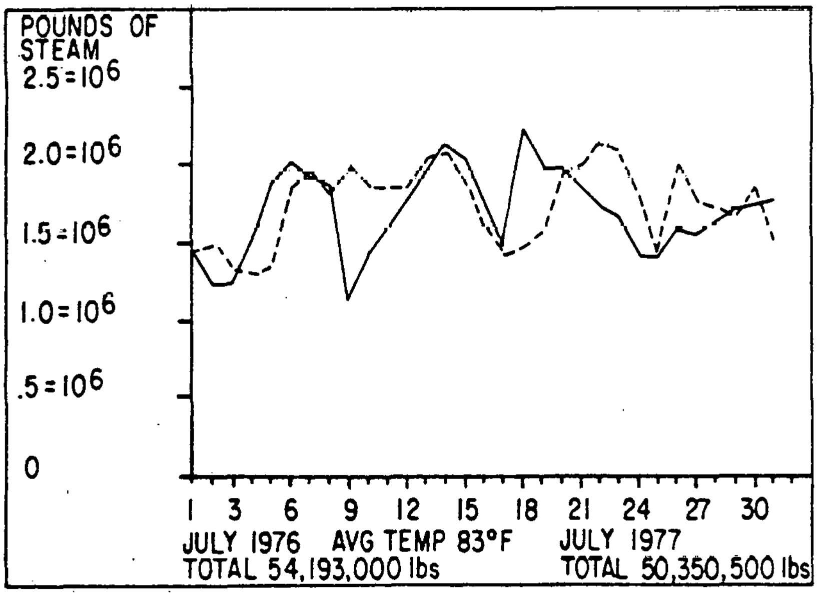


Fig. 6.12 One-month Steam Load Profile (with Electric Generation)*

*Average temperature = 83°F

7 INTERCONNECTION FEATURES

An agreement dated 10/19/72 and titled, *Coordinated Reserve Capacity Agreement* is the currently valid statement of the business relationship between the Missouri Utilities Company and Southeast Missouri State University. Some important features of this agreement are listed here:

1. Both participants expect to achieve economical utilization of existing equipment and provision of reserve capacity for emergency requirements.
2. The University's accredited capacity is that which can be produced continuously over three hours when the ambient temperature is above 90°F.
3. The University's accredited maximum demand is that one hour peak for the year including all power produced by the plant for university use plus any purchased simultaneously.
4. The Utility will provide capacity required by the University provided the Accredited Demand does not exceed 75% of the Accredited Capacity.
5. The University will make available to the Utility all excess capacity in the University's Power Plant during times of the utility's peak demand and during times of emergency. Anticipated hours of peak operation are estimated to be less than 500 h/yr.
6. Energy transfers are to be billed at the rate of $.009/kWh plus fuel adjustment. No demand charges are levied.
7. Term of the agreement was three years after which it could be terminated by 12 months' notice. Such notice was given by the Utility Company on 10/20/75. No adjustment in the contract has yet been made.

During the summers of 1976 and 1977, the utility requested use of all power that the University could provide during hot weather. The operating practice has been to parallel in the morning, about 10:00 a.m., and to run at peak capacity until evening, sometimes as late as 9:00 p.m. During 1977, the plant was operated at 7000 kW, and the delivery to the utility grid was 3750 kVa, the limitation of the 34.5-kV step-up transformer.

In June 1977, the plant delivered power to the grid on 21 days for a total of 130 hours; similar use was made in the summer of 1976.

Requests for information on rates that apply to the sale of electricity by Union Electric (UE) to Missouri Utilities Company were rebuffed by both utility company representatives. The Missouri Public Service Commission was most cooperative in reviewing files of data and provided copies of rates and other filings of the State-regulated utilities. Sales among utility companies are regulated by the Federal Power Commission, and the arrangement between UE and Missouri Utilities is apparently a unique contract which has not yet surfaced. Because transactions among regulated utilities are subject to public review, a copy of the June, 1977, bill for service furnished by UE to Missouri Utilities was obtained. The bill shows a charge of $3.56/kW demand charge, energy charge of .732¢/kWh plus fuel adjustment charge of .158¢/kWh. Review of other documents indicates that the demand charge is a rachet type and that the summer time peak establishes an effective 12-month plateau. The effect of this is that Missouri Utilities reduces its annual demand charge by 12 x $3.56, or $42.72 for each kW supplied by the University during the hot weather. University plant records indicate the delivered peak is 3100 kW; therefore, the annual cost avoidance to the utility company is $132,432.00. Since the fuel escalation cost is passed through, Missouri Utilities also keeps .9¢ - $.732 = .168¢/kWh for all energy sold to the University. For the past 12 months, this amounts to 12,216,000 kWh and $20,523. Considering the demand charge avoidance as revenue, the Missouri Utilities got 1.252¢/kWh for the power delivered to the University.

As shown later in Table 10.1, the University also benefited economically from this experience. Estimates of costs of the least expensive operating mode indicate the University paid out $63,849 less in 1976-77 by using cogeneration than if the alternative had been used.

An evaluation of the source energy effectiveness (Ee) of the University power plant is not accurate for comparison to other projects or even alternative systems for serving the University loads because those loads are insufficiently defined. In the University records, a set of calculations are used with available daily log data to develop a gross statement of campus steam load for each month. The uses made of the steam are not identified in the records, but it is known that absorption refrigeration uses a lot of steam in warm weather; warming outdoor air for ventilation uses a lot in cold weather. If electric driven chillers were used in lieu of absorption, there would be a different heat balance and a different source energy requirement.

A limited version of source energy use effectiveness has been developed. The 1976-77 annual campus thermal and electrical loads have been derived from available data and are considered to be:

Steam Load . . . . 212.7 x 10^9 Btu
Consisting of . . . . Heating 128 x 10^9 Btu (heating load)
. . . . Absorption Cooling 21.7 x 10^9 Btu (cooling load)

Electricity . . . . 20,191,065 kWh

On that basis, three cases of alternate power plant use are presented in Figs. 7.1, 7.2, and 7.3.

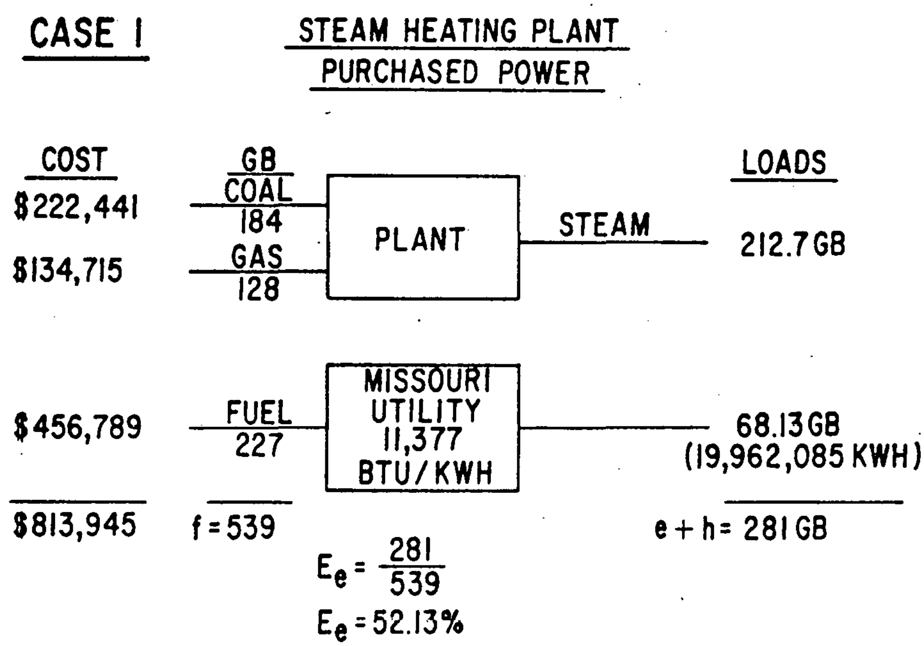


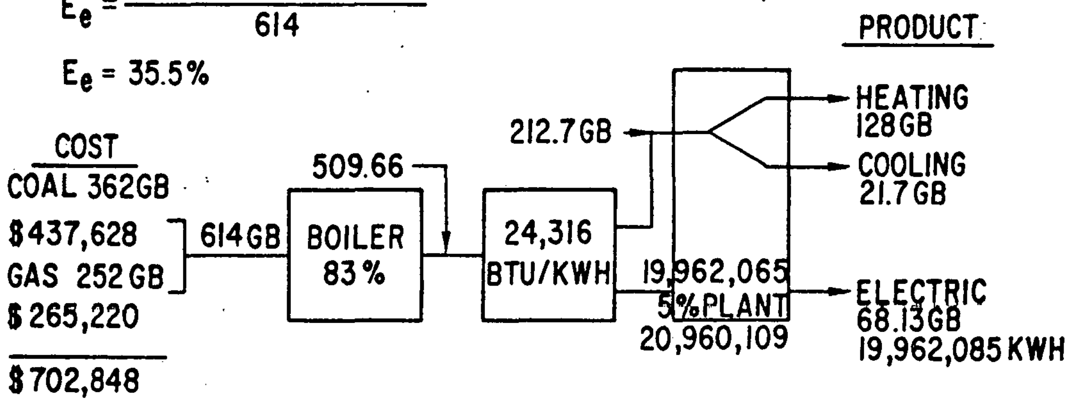
Fig. 7.1 Source Energy Use Effectiveness (Ee) Purchased Electricity with Steam Service Only from Power Plant

CASE 2 — STAND ALONE STEAM AND POWER

ASSUME 100% UTILIZATION

$$E_e = \frac{(128)+(21.7)+(68.13)}{614}$$

E_e = 35.5%

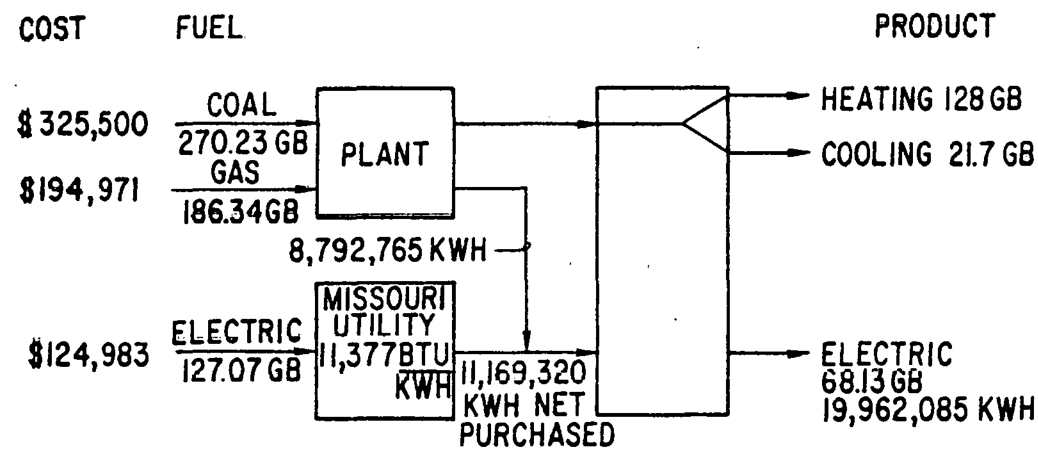


$$\text{STEAM / ELECTRIC RATIO } \frac{(212.7)(10^4)}{20,960,189} = 10,148 \text{ BTU / KWH}$$

Fig. 7.2 Source Energy Use Effectiveness (Ee) Isolated Power Plant for Electricity and Steam

CASE 3

1976 - 1977 CURRENT OPERATING MODE



$645,454 583.64 GB

$$E_e = \frac{217.83\text{GB}}{583.64\text{GB}}$$

E_e = 37.3%

217.83 GB

Fig. 7.3 Source Energy Use Effectiveness (Ee) Cogeneration as Operated in 1976 - 1977

8 LABOR AND STAFF

In 1975, the University administration created a position of Vice-President of Administrative Services. Among the areas of responsibility of this office is the administration of the department of physical plant.

The director of the physical plant working with and under the Vice-President is directly responsible for supervision of the generating plant. Operation policies and general procedures are established at the administrational level and effected by the engineers, operators, firemen, and repair and relief men.

The power plant operating staff includes a chief engineer whose duties take in overall supervision of plant operation, scheduling the operating personnel, scheduling and supervision of maintenance in the plant, supervision of water treatment, and instruction of operating personnel. The assistant engineer assumes the duties of the chief engineer in his absence, assists him in the performance of the engineering duties, and is responsible for plant records and logs.

Plant operators are responsible for operating the generating and steam production equipment and electric distribution equipment. They are also responsible for water treatment and logging of hourly production levels.

Firemen operate the steam generators, coal and ash handling equipment, and steam generator auxiliary equipment. Firemen also log hourly production levels of the steam generation, chemical water treatment tank levels, and operating status of the steam generating auxiliary equipment.

Repair and relief men are qualified to substitute for either operators or firemen and, when not acting in this capacity, accomplish service and repair of the plant equipment.

The plant is staffed 24 h/day and, in the generating mode, the working crew consists of an engineer (or assistant engineer), an operator, and a fireman. The engineers work the daytime 8-hour shift and are on call for emergencies. The operating staff of four and fireman staff of four rotate three 8-hour shifts. The repair and relief staff of three persons work the 8-hour day shift when not substituting for either operators or firemen.

In the non-generating mode, the staff is adjusted in that the four operators take over the firemen's three shifts. The firemen (4) and relief and repair personnel (3) become service and repair staff for plant projects or are assigned campus service and repair assignments as secondary priority.

The plant is exceptionally well kept and from observations made on the several visits to the plant, working conditions appear to be good. The staff is represented by stationary Local No. 2, International Union of Operating Engineers, AFL-CIO. Table 8.1 shows an abbreviated list of the most recent hourly wage scales.

Table 8.1 Hourly Wage Scales for Plant Personnel

Classification	Hourly Rates			
	Lead Man	Journeyman	Apprentice	Probation
Operators		$5.21		
Repair & Relief	$5.07	$4.88	$4.57	$4.44
Fireman		$4.53	$3.96	$3.68
Electrician	$5.28	$4.87	$4.56	$4.44

9 MAINTENANCE

From the initial on-site electric generation at Southeast Missouri State University until the early 1960s, maintenance of the plant equipment was on an informal basis. The plant felt a manpower pinch in the mid 1960s; yet the plant grew in size and complexity while maintenance was effectively reduced to repair at breakdown.

Plant visitation indicated good operation and equipment care. The facility is very clean. The plant personnel are apparently quite capable and almost all service and repairs are performed in house. However, the chief engineer felt that formal training in the area of service and operation of controls would upgrade the staff effectiveness.

The campus service and maintenance staff provides additional expertise available to the generating plant for special needs, affording a rather unique feature to the onsite service capability. Service work at the user buildings has been inadequately staffed, and much work needs to be done to ensure proper performance of all apparatus and controls.

During 1965 to 1970 an effort was made to organize maintenance. Equipment was inventoried and catalogued; maintenance manuals were organized; and a spare-parts inventory was begun. As the effort was expanded, service checklists, or maintenance procedures, were formulated. Records, however, were far from comprehensive, and a good portion of the maintenance still depended on memory, experience, and the staff knowledge and understanding of the equipment.

A change in chief engineers in 1971 saw the initiation of a formal maintenance program based on maintenance requirement cards. After a year or so of effort with no results, the program fell into disuse. A modification of the maintenance requirement cards in the form of a machinery history was tried in 1975, and, although it is effective to a degree, it is still not considered satisfactory.

Currently, the maintenance is accomplished with reasonable effectiveness. The plant personnel are all experienced, mature individuals and have been educated to the expected level of operation and maintenance by the engineer and his assistant. This educational process is a combination of accepted practice, manufacturers maintenance directives, and standards set by supervisory authority.

Admittedly, record-keeping is less than adequate; better program control is needed, especially where equipment comes on and off service seasonally.

Parts replacement records and equipment service life history are needed. A scheduling system is essential to make the maintenance program effective.

One area of operation and maintenance where record-keeping is effective and thorough is water treatment. Detailed records of test results, treatment procedures, costs of chemicals, etc., have been kept for some years.

10 FINANCIAL ANALYSIS

As previously indicated, cost analysis, production measurement, and value of services provided have not been important considerations for the University. Budget systems allocated all power plant expense as an overhead burden for general administrative purposes. Because there were no meters at the points of delivery, the plant production records were not related to the services provided and the records have been of minor interest until just recently when an increase in fuel costs of $300,000/yr focused the administration's attention on the problem quite dramatically. With the advent of cogeneration, the relative cost of producing electricity versus buying it has become a vital issue, and plant personnel have attempted to document their production data. As an example, steam used for ash removal (a rather significant load) can be estimated only by comparing the steam flow meter data when the ash system is shut off and when it is operated. However, this load may be only 8000 lb/h when total steam meter flow is 95,000 lb/h and the operator can only approximate the efficiency of this subsystem performance. Other plant supporting equipment loads are less apparent in existing plant production data, and there is no way to confirm the estimates made on plant burdens under various operating modes. Given these constraints, some hard data and some reasonable judgments based on prior experience, a comparative estimate of costs of production has been made on several alternative operating strategies.

10.1 COMPARATIVE OPERATING COSTS (See Table 10.1)

If the University so desired, it could permanently abandon the electric generation plant and purchase all power from the utility company under a large user rate. The power plant would continue to operate as a central heating plant. This is called Case 1.

In previous years the University generated all its power needs and bought virtually none from the utility, and this scheme could be reinstituted at any time. This is called Case 2.

For the most recent 12 months, July 1976 through June 1977, the University has operated its power plant as a generating station about 35% of the time, has delivered power to the utility company about 15% of the time and purchased power 65% of the year. This is called Case 3.

Table 10.1 Comparative Operating Costs, 1976-1977

Item	Central Heating Case 1	Stand Alone Case 2	Cogeneration Case 3
Fuel, Coal	$222,441.00	$437,628.00	$325,499.00
Fuel, Gas	134,274.00	265,220.00	194,971.00
Labor	71,661.00	155,266.00	129,261.00
Water	16,476.00	54,395.00	40,448.00
Chemicals & Supplies	12,619.00	41,513.00	30,980.00
Repair & Replacement	12,813.00	22,893.00	17,084.00
Electricity Purchases minus Sales	456,789.00		124,983.00
Total Cost	$927,073.00	$976,915.00	$863,226.00

Capital costs are not included in the above comparisons. The present plant could be used for any of these operating schemes, and debt service is a state responsibility not related to University operations. Because nearly all capital improvements for the power plant are funded by state appropriations, the identification of required expansion or improvement is related more to the social than to the economic impacts. The request for power plant improvements is listed along with the other building facilities needs. Occasionally, a member of the legislature has questioned the requested funds and asked for justification. The expansion of the plant, completed in 1971, required legislative approval of $2,725,000 funding and the consulting engineer's forecast of appreciable operating cost savings was questioned by a state senator, who expressed dissatisfaction with the following statement by the University's consultant.

> ". . . First, a detailed report on the Generation vs Purchase of Power at Cape Girardeau would require considerable time and detailed record analysis to prepare and we feel would be unjustified since the basic economics of institutional electrical generation at plants that have sizeable central station heating facilities are elementally and conclusively favorable to the generation of electricity.
>
> "As you are, of course, aware electrical energy for usage on the Southeast Missouri State Campus is, in reality, a by-product of

the heating steam requirements with electrical generation taking place in the reduction of temperature and pressure of the steam between the boiler and the heating distribution system to the campus buildings. The heat or energy taken from the steam and converted into electrical power represents a coal cost equivalent to approximately one mill per kilowatthour of electricity generated. Added to this are certain charges, such as additional capital investment required in electrical generation equipment, additional capital required in adaptation of boilers for specific generator usage, cooling tower capital investment and maintenance plus other factors which, if amortized over the approximately four million kilowatthours generated by the school in recent years, would increase the cost of electrical generation to an estimated two mills per kilowatthour."

There is a more precise analysis of energy conversion in Sect. 12.

For purposes of comparison, the 1976 costs for fuel used to generate electricity at the campus are calculated to be $.0214/kWh under the best conditions and averaged $.0225/kWh. Missouri Utilities normally buys power from its parent company, Union Electric Company, an efficient, coal-fueled power producer whose fuel cost in 1976 was reported to FPC as $.0074/kWh.

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11 REGULATORY AGENCIES

The University has enjoyed excellent community relations for decades; local municipal government agencies look to the University for guidance and do not attempt to inspect or administer physical facilities on campus. The State has no building code and makes only perfunctory inspections of the university buildings, and none of the power plant.

Recently, an agent of the Missouri Department of Natural Resources investigated a citizen complaint about stack effluents from the power plant coal-firing system. This has been the only source of an official citation of any sort, so the agency issued a letter on 3/3/75 advising the University that the power plant was operating in violation of Regulation S-VIII, Restriction of Emission of Visible Air Contaminants. In response to this citation, the University: (1) requested appropriations to increase the height of three boiler stacks; (2) instituted more careful operating techniques; and (3) imposed more stringent coal specifications. Each year the University has submitted an Emissions Inventory Questionaire to the Missouri Department of Natural Resources.

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12 PERFORMANCE EVALUATION

A detailed analysis of the 6250 kW turbine system indicates that it can be operated without extraction steam at a heat rate of 12,112 Btu/kWh output. Adding 5% for the steam plant auxiliaries incident to steam production, this unit will require 15,323 Btu fuel input to the boiler at 83% combustion efficiency. With coal at $27.50/ton, 11,000 Btu/lb, the fuel cost per kWh is 1.915¢ under the full condensing mode.

If the turbine steam extraction system serves the campus steam load with 30,000 lb/h of 100 psig steam, and the electrical load is more than 1800 kW (the reported minimum observed load in the past two years), then the turbine heat rate is 53,724 Btu for each kW produced in the extraction stages plus 12, 112 Btu for each kW produced by the condensing stages. The campus steam burden is met with 788 kW of turbine capacity; the cost of developing this electricity is the incremental cost of generating at 400 psig 750°F in lieu of 100 psig saturated, plus the plant auxiliaries burdens incident to power production. The higher steam pressure and temperature represent 19.79% more fuel input than 100 psig steam; the other auxiliaries and increased heat losses might total 5% additional fuel input. Thus, for that portion of the electric load produced incident to extraction steam load (not more than 788 kW under normal steam load conditions), the fuel cost per kW produced is 2.14¢. All other kW produced cost 1.915¢ according to the calculations given above. This unexpected increase in the cost of electricity produced in the extraction stage is a function of the increased fuel consumption required to attain 400 psig, 750°F steam when the campus steam load needs only 100 psig saturated steam.

By comparison, the 1000-kW diesel engine generator set recently installed for emergency and standby use is said to use about 13,000 Btu/kWh produced. With #2 fuel oil at $.37/gal, 138,000 Btu heat content, this unit produced a kWh for $.035 fuel cost/kWh.

The *average* cost of electricity, if purchased by the University of Missouri Utility Company Rate #GS-1, would be 2.29¢/kWh at current prices.

Because of the considerable fluctuation in the steam load for the campus, the condition used in the above example is not representative of coincident steam demands in every weather condition or degree of occupancy of the buildings. If a careful steam load management program were followed, the quantities of steam required probably would be lower, and the required extraction steam rate would be reduced.

The University power plant burns Illinois bituminous coal with a sulphur content of 2 to 3 1/2%, and the plant has no stack scrubber or fly ash collection system. Natural gas fuel is available on an interruptible basis, but future availability may be more severely curtailed. The delivery of power to Missouri Utility Co increases the fuel consumption appreciably; however, when gas fuel is used with coal, the environment is probably improved by the better combustion achieved by mixing coal and gas fuel in the boiler, rather than by burning only coal -- even at a reduced firing rate.

Any effort to substitute alternative power production or delivery systems to serve the University loads is subject to the restraints of the huge investment in plant and distribution systems already in place. Each alternative must start from the current status rather than an ideal, uncluttered future construction option.

The central steam plant has many desirable features for continued use. It concentrates the fuel conversion problem in one attended and specially constructed facility. It can accommodate all the available fuels. The distribution piping is in good condition, accessible for service and connection, and concealed from view. The control of steam heat is simple and reliable; the heat exchanger apparatus will continue to serve the desired functions for many years. Sufficient capacity exists to accommodate sizable increases in load with little change. By serving the absorption refrigeration machinery, the steam distribution system provides a desired function at no additional investment expense. Coal is available in the surrounding countryside and can be considered a permanent source of heat, immune from foreign influence, and usable only by plants such as those in the University or electric utility companies in the region.

The power distribution system on the campus is underground and suitably sized for present and future loads. The performance of this distribution system is much better than that of the local utility company. Central control of the main distribution feeders and delivery of power from a central point have provided a desirable degree of control over the distribution system.

Onsite power generation has evolved from a necessity to a convenience in the years since the institution was founded in 1873. Utility service is now a reliable alternative, although probably not as reliable as the cogeneration system has proven to be. Continuation of power generation would seem to be an economic decision with some other considerations for environmental pollution and the opportunity to be self reliant because of the ability to operate in isolation. In the present uncertainty of energy source availability, the University is best equipped to keep all the options open. Continuation of a mutually beneficial relationship with the utility would be advisable. Better cost controls would increase the accuracy of determing when interchange of power is beneficial and might dictate some operational modifications.

This plant has a common feature that has been observed in other onsite power plants in that superior skill and management efforts have been devoted to improving the efficiency of energy production. The major remaining opportunity for cost reduction is at the point of use -- the management of load. Decisions concerning ventilation rates, hours of use of conditioned spaces, levels of humidity and temperature control, efficient operation of refrigeration machinery, and use of the lighting and appliances in laboratories, shops, etc., are made without technical management supervision. Because these are the components of loads served by the central utility system, the Physical Plant Division should be equipped and staffed to conserve energy use on the campus.

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APPENDIX A

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LIST OF FIGURES
(For Appendix A)

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A.4	Southeast Missouri State Campus Steam System Site Plan	54

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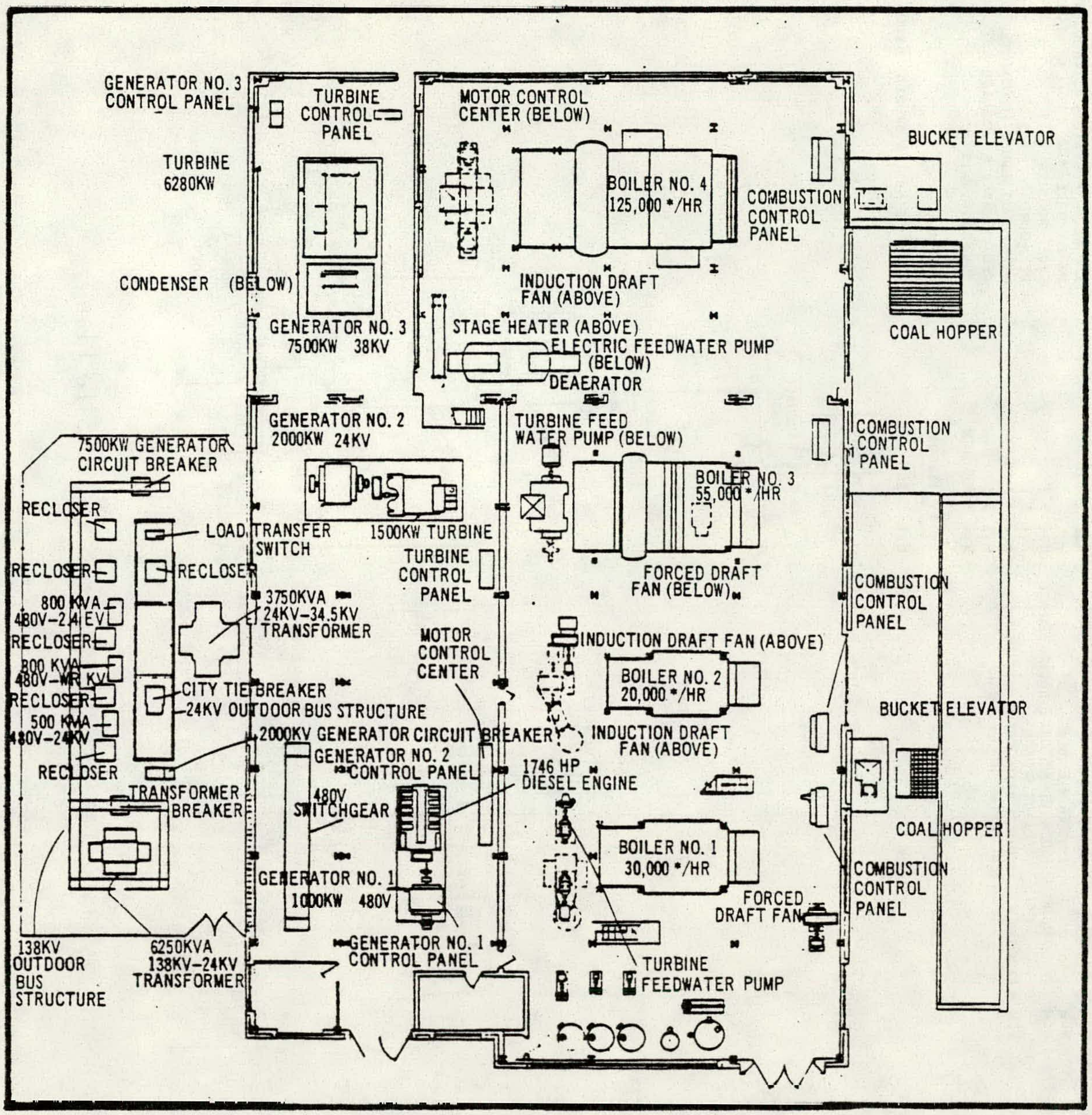

Fig. A.1 Southeast Missouri State Power Plant Floor Plan

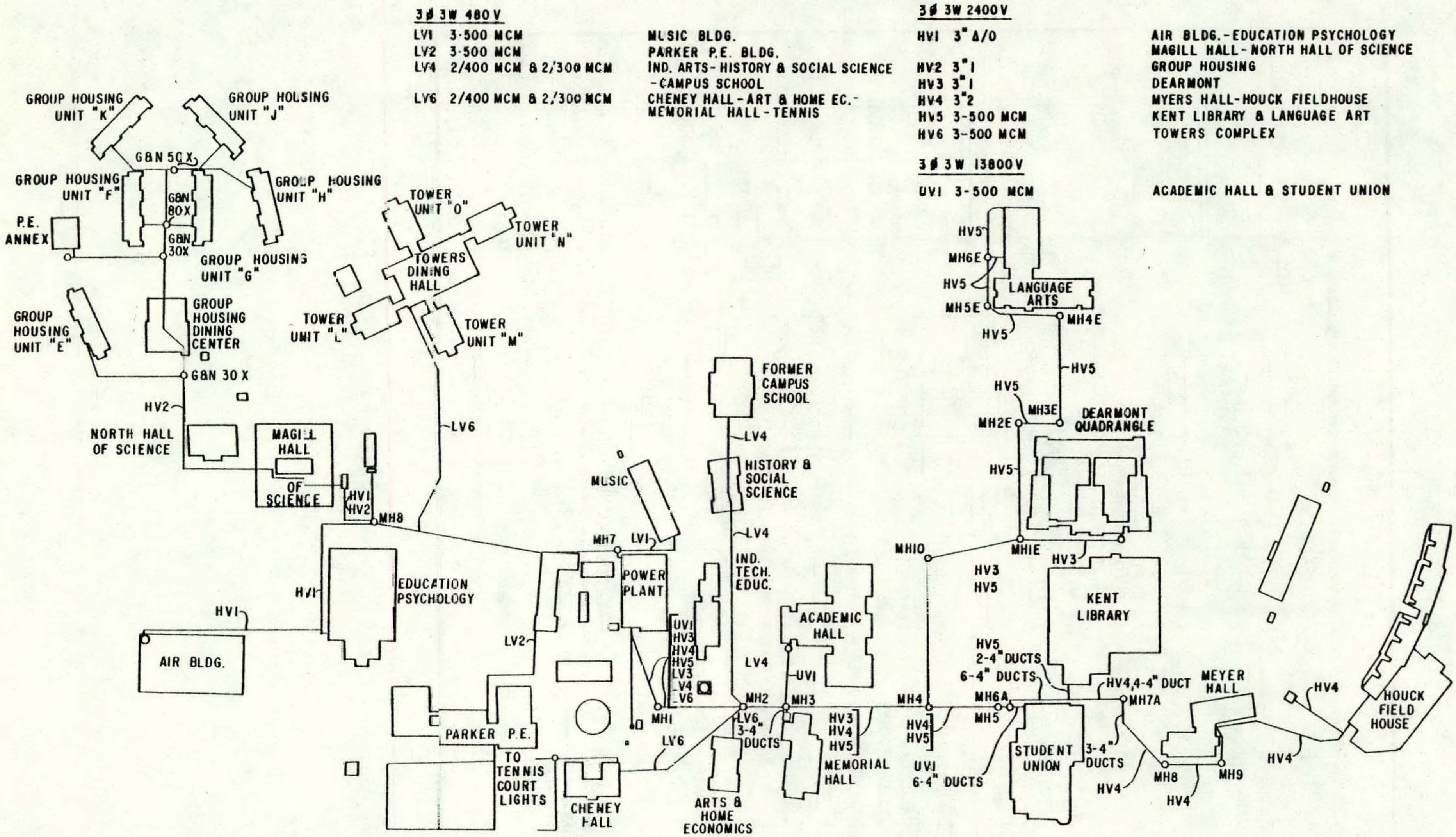

Fig. A.2 Southeast Missouri State Campus Electric System Site Plan

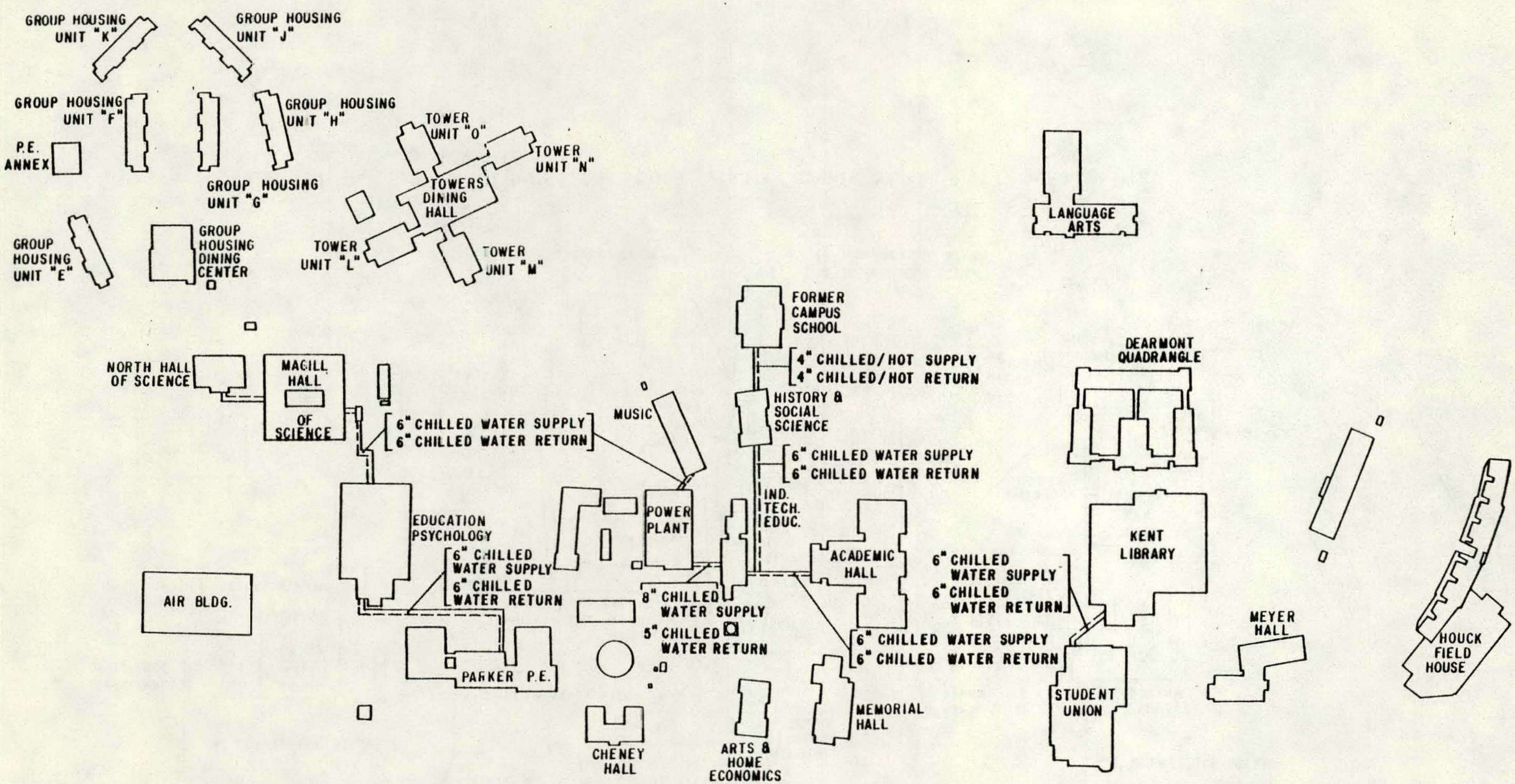

Fig. A.3 Southeast Missouri State Campus Chilled-water System Site Plan

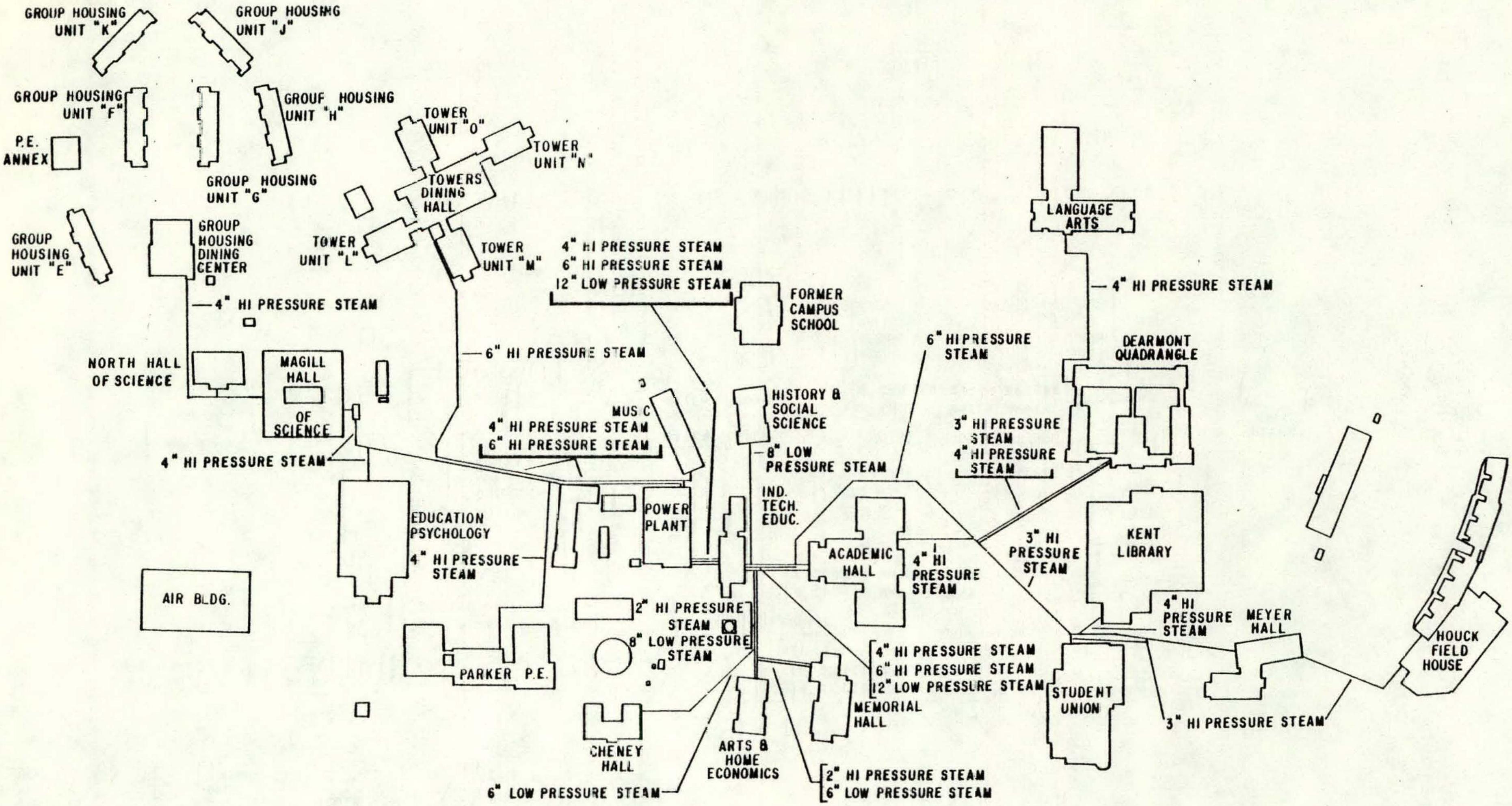

Fig. A.4 Southeast Missouri State Campus Steam System Site Plan