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**ENERGY AND ENVIRONMENTAL SYSTEMS
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PHILADELPHIA'S GALLERY II SHOPPING CENTER COMPLEX:
AN ANALYSIS FOR THE APPLICATION OF AN
INTEGRATED COMMUNITY ENERGY SYSTEM

Vol. 2: Complete Data Report

by

C. Lee, A. Davis, and R. Kron

Energy and Environmental Systems Division

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ABSTRACT

This report presents the detailed findings and calculations of Argonne's study of energy systems for the Gallery II commercial complex in Philadelphia. The presentation includes design demands, service demand profiles, and descriptions of the seven alternative energy systems considered for Gallery II. The energy system descriptions include schematics, equipment used, energy-use calculations, equipment costs, operation and maintenance costs, and energy costs.

1 INTRODUCTION

This document provides descriptive material designed to complement and further explain the conclusions provided in *Executive Summary; Philadelphia's Gallery II Shopping Center Complex: An Analysis for the Application of an Integrated Community Energy System* (ANL-CNSV-TM-19, Vol. 1, November 1979). The data provided in the Executive Summary and in this report are for a conceptual design of energy systems for Gallery II. Extensive work by an engineering firm will be required for preliminary and final designs of the system to be constructed.

2 EXECUTIVE SUMMARY

The Executive Summary summarizes results of Argonne's study on energy system alternatives. Based on economic and energy analyses, Argonne recommended the use of a water-to-water, double-bundle heat pumps that redistribute heat in the buildings. These heat pumps, along with electric auxiliary boilers, would provide all of Gallery II's heating and cooling needs. Electricity would be purchased from Philadelphia Electric Company. Although the initial capital cost would be about 1 million dollars more than a conventional, all-electric system, this higher investment could be paid back in about two years because of lower operating costs.

3 DESIGN LOADS AND LOAD PROFILES

3.1 THE GALLERY II DEVELOPMENT

The Gallery II commercial complex is still in the fairly early stages of design. Architectural details, such as building materials, exact building sizes and usage are not well defined. Preliminary design information has been used. The site plan and floor area are presented in the Executive Summary.

3.2 DESIGN LOADS

Because the architectural details of buildings in the Gallery II complex were not well-defined at the beginning of this study, typical design loads of services are assumed for the complex. Such services include space heating, space cooling, domestic hot water heating, lighting and power requirements. Table 3.1 shows the design loads per square foot of floor space of the buildings.

Table 3.1. Design Loads

	Offices	Gallery II Mall & J.C. Penney
Lighting (W/ft)	3	3
Power (W/ft)	3	4
Space heating (Btu/hft ²)	35	30
Space cooling (Btu/hft ²)	47	41
Domestic hot water heating (Btu/hft ²)	0.9	0.7

3.3 DEMAND PROFILES

For estimation of annual energy consumption of the development, the year was divided into six periods:

- (1) typical winter days,
- (2) typical spring days,
- (3) typical summer days,
- (4) typical fall days,
- (5) coldest winter days, and
- (6) hottest summer days.

Each type of day is further divided into weekdays and weekends. The number of weeks of each type of day is 12, 13, 12, 13, 1, and 1, respectively. Daily profiles of energy demands for each type of service and type of days are presented in Figs. 3.1 through 3.14. Domestic hot water heating requirement is small compared to other requirements and is assumed to be zero from 10 P.M. to 7 A.M. and 0.32 MW from 7 A.M. to 10 P.M. for weekdays and 0.20 MW during the same period on weekends.

Fig. 3.1. Lighting and Power Demands, Weekdays

Fig. 3.2. Lighting and Power Demands, Weekends

Fig. 3.3. Space Heating Demand, Coldest Winter Weekdays

Fig. 3.4. Space Heating Demand, Coldest Winter Weekends

Fig. 3.5. Space Heating Demand, Typical Winter Weekdays

Fig. 3.6. Space Heating Demand, Typical Winter Weekends

Fig. 3.7. Space Heating Demand, Typical Spring/Fall Weekdays

Fig. 3.8. Space Cooling Demand, Typical Spring/Fall Weekdays

Fig. 3.9. Space Heating Demand, Typical Spring/Fall Weekends

Fig. 3.10. Space Cooling Demand, Typical Spring/Fall Weekends

Fig. 3.11. Spacing Cooling Demand, Typical Summer Weekdays

Fig. 3.12. Spacing Cooling Demand, Typical Summer Weekends

Fig. 3.13. Space Cooling Demand, Hottest Summer Weekdays

Fig. 3.14. Space Cooling Demand, Hottest Summer Weekends

4 ENERGY SYSTEM DESCRIPTIONS

4.1 CANDIDATE ENERGY SYSTEMS

After a prescreening procedure, based on the environment of the Gallery II Complex, the following energy technologies were selected and analyzed.

- (1) all-electric, conventional system;
- (2) internal combustion engine total energy systems, including
 - (a) diesel engine,
 - (b) gas engine (Otto cycle), and
 - (c) dual-fuel engine;
- (3) gas turbine (Brayton cycle) total energy systems, including
 - (a) oil-fired, and
 - (b) gas-fired;
- (4) heat-pump-centered systems,
 - (a) without exterior heat source, and
 - (b) using Delaware River water as heat sink/source.

The following sections present a brief description, schematic, equipment list, energy consumption, equipment cost, and operation and maintenance cost for each system.

4.2 CONVENTIONAL SYSTEM

The conventional system is a decentralized system that supplies the energy demands of the complex by purchasing electricity from Philadelphia Electric Company. Each building has its own cooling plant that generates cooling power by means of compression chillers and delivers it to individual rooms in the building by air-handling devices. Heating is provided by electric resistance heaters installed in air ducts. An electric hot water heater is used for domestic hot-water heating. The COP of compression chillers is assumed to be 4.5.

Because the Gallery II system is the same as that of Gallery I; electrical, mechanical, and plumbing costs of Gallery II were estimated based on the cost record of Gallery I. All costs, provided by Market Street East Corporation, are in 1975 dollars; an annual escalation rate of 8% is assumed to bring the costs of the Gallery II Shopping Mall system to 1979 dollars. Costs for the office towers were obtained by adjusting the 1979 costs for the shopping mall according to *Mean's Mechanical & Electrical Cost Data* (1979) which provides square-foot building costs with respect to building types. Table 4.1

lists the in-building system cost for a conventional system. Operation and maintenance (O/M) is assumed to be under a service contract that provides staff and material for the operation and maintenance of the system. Personnel and material costs were estimated based on Gallery I figures of \$165,000 annually for 400,000 ft² of floor area. Table 4.2 lists the O/M cost of the system. The annual O/M cost presented includes property tax (2%) and insurance (1%) on the system. Table 4.3 shows the daily and annual electricity requirement of the system. With an average cost of electricity at 3¢/kWh, annual expenditure for energy is \$1.91 million.

Table 4.1. In-Building System Cost - Conventional System

<u>From Gallery I (400,000 ft²), 1975 Costs</u>			
Mechanical Systems	\$1,652,670	\$4.13/ft ²	
Plumbing	\$ 887,930	\$2.22/ft ²	
Electrical	\$1,622,855	\$4.06/ft ²	
<u>1979 Costs(a)</u>			
Mechanical	\$5.62/ft ²		
Plumbing	\$3.02/ft ²		
Electrical	\$5.52/ft ²		
<u>1979 Costs for Offices</u>			
Mechanical	\$7.03/ft ²		
Plumbing	\$2.48/ft ²		
Electrical	\$6.68/ft ²		
<u>Total Conventional System Costs(b)</u>			
	<u>Gallery II Mall</u>	<u>Offices</u>	<u>Total</u>
Mechanical(c)	\$1.10 x 10 ⁶	6.19 x 10 ⁶	7.29 x 10 ⁶
Plumbing	\$0.51 x 10 ⁶	2.18 x 10 ⁶	2.69 x 10 ⁶
Electrical(d)	\$1.01 x 10 ⁶	5.88 x 10 ⁶	6.89 x 10 ⁶
Total	\$4.64 x 10 ⁶	14.25 x 10 ⁶	16.87 x 10 ⁶

(a) An annual escalation of 8% is used.

(b) Excluding J.C. Penney except for distribution of electricity to the building.

(c) Chiller cost (1.01 x 10⁶) for J.C. Penney is included in Gallery II cost.

(d) Electrical cost for Gallery II includes distribution of electricity to J.C. Penney.

Table 4.2. Operation & Maintenance Costs - Conventional System

Item		\$/ft	Annual Cost \$(1979)
Personnel & Material	Gallery II	0.41	69,700
	Office	0.46	404,800
Property Tax			337,400
Insurance			168,700
Total			981,000

Table 4.3. Fuel Consumption - Conventional System

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (kWh)	Fuel Consumption Per Year (kWh)
Typical Winter Weekdays	60	2.38×10^5	1.43×10^7
Typical Winter Weekends	24	1.58×10^5	3.79×10^6
Coldest Winter Weekdays	5	3.13×10^6	1.56×10^6
Coldest Winter Weekends	2	2.02×10^5	4.04×10^5
Typical Spring/ Fall Weekdays	131	1.87×10^5	2.45×10^7
Typical Spring/ Fall Weekends	52	1.30×10^5	7.80×10^6
Typical Summer Weekdays	60	1.53×10^5	9.18×10^6
Typical Summer Weekends	24	9.75×10^4	2.34×10^6
Hottest Summer Weekdays	5	1.78×10^5	8.90×10^5
Hottest Summer Weekends	2	1.13×10^5	2.26×10^5
Totals	365	1.74×10^5 avg.	6.37×10^7

4.3 INTERNAL COMBUSTION ENGINE TOTAL ENERGY SYSTEMS

In this category, three kinds of internal combustion engines are used as prime movers, i.e., diesel engines (oil-fired), Otto cycle engines (gas-fired) and dual-fuel engines (oil- and gas-fired). In each case, the prime movers consume oil and/or gas to generate mechanical power that drives the electrical generators to produce electricity. The electricity is used to meet lighting and power demands of the complex and the central plant requirements, such as driving chillers, pumps, etc. Heat accompanying the production of mechanical power is recovered from the lube oil and by circulating water through the engine jacket. Considerable heat can be recovered from exhaust gas by feeding it to recovery steam boilers to generate steam. Steam thus generated can be used to run absorption chillers or to produce hot water for space heating and for domestic hot water heating. In general, the capacity of absorption chillers using steam heat recovered from exhaust gas is not sufficient to meet the cooling demand of the complex. Electrically-driven compression chillers would be necessary to top off the cooling load. An oil storage tank, capable of storing 75 days of peak daily oil consumption, is required if the system is oil-fired. The central plant is assumed to be located in the basement of the North Office Tower. Cooling towers, for both engines and chillers to dissipate undesirable heat, are to be installed atop the North Office Tower, and two 30-inch water pipes are required to pipe the cooling-tower water up and down the building. Figure 4.1 shows the schematics of the central plant for the diesel engine system, and Fig. 4.2 shows the layout of hot and chilled water distribution piping for all total energy systems. The distribution pipes are to be installed at the truck level.

Chilled water, pumped through the distribution pipe, enters the mechanical equipment room in each building and passes through cooling coils in air-handling units. Here it absorbs heat from the air and returns to chillers in the central plant. Hot water enters the building mechanical room and is pumped through the building and distributed to each branch duct where it passes through heating coils in the duct, gives up heat to the air, and returns to the central plant. Table 4.4 shows equipment used in the diesel engine system and Table 4.5 lists costs. In-building cost is shown in Table 4.6. The in-building cost is obtained by taking into account the differences in components between this system and the conventional system. These include the addition of: (1) heat exchangers for domestic hot water, (2) in-building hot water distribution, and (3) central plant cooling-tower-water piping. Some in-building components that can be omitted include: (1) compression chillers, (2) electric resistance heaters in air duct, (3) electric domestic hot water heaters, and (4) cooling towers for individual buildings. The size of the mechanical room in each building also would be reduced by about 50%. Table 4.7 shows the personnel and material needed to operate and maintain the diesel-engine system. Because the maintenance of in-building system is assumed to be performed by personnel dispatched from the central plant, the O/M cost of in-building systems would include only the insurance and property tax on the system. Fuel consumption for the diesel engine system is shown in Table 4.8. With the oil price at \$3.00/MMBtu, the annual fuel cost is \$1.37 million.

Fig. 4.1. Diesel Engine Total Energy System - Central Plant

Fig. 4.2. Distribution System for Total Energy Systems

Table 4.4. Equipment List - Diesel Engine Total Energy System

1. Diesel Engine

No. of Units	3
Unit Size	5 MW
Maximum Electricity Efficiency	32%
Heat Recovery at Maximum	
exhaust gas	33%
jacket water & lube oil	25%

2. Electric Generators

No. of Units	3
Unit Size	5 MW
Hz	60
Volt	480
Phase	3

3. Recovery Boilers

No. of Units	3
Gas Entering Temperature	1,600°F
Gas Leaving Temperature	325°F
Steam Pressure	30 psia
Steam Temperature	250°F
Steam Flow/Unit	2.02×10^4 lb/hr
Maximum Heat	1.76×10^7 Btu/hr or 5.16 MW

4. Oil Supply System

Oil Storage - #6 Oil	8.0×10^5 gal
#2 Oil	7.0×10^4 gal
Maximum Oil Flow	14.4 gpm = 864 gPh
Power Required	5 kW

5. Diesel Cooling Tower

Number of Units	3
Heat to be Dissipated at Maximum	1.33×10^7 Btu/hr per unit or 3.9 MW per unit
Water Temperature	150°F/176°F
Water Flowrate	1,023 gpm/unit
Pumps	
No. of Pumps Per Tower	2
Water Flow	512 gpm
Pressure Drop	80 ft H ₂ O
Power	11 kW pump

Table 4.4. Equipment List - Diesel Engine Total Energy System (contd.)

5. <u>Diesel Cooling Tower</u> (contd.)				
Fans				
No. of Unit Per Tower	1			
Air Flow	2.78 x 10 ⁵ CFM/unit			
Power	138 kW/unit			
6. <u>Water Treatment</u>				
Recovery Boiler	6 gpm			
Hot Water System	15 gpm			
Chilled Water System	80 gpm			
Engine Cooling Tower	60 gpm			
Chiller Cooling Tower	430 gpm			
7. <u>Heat Exchangers</u>				
No. of Units	3			
Steam Parameters	250°F/30 psia			
Heat Flow Maximum	5.16 MW/unit = 1.76 x 10 ⁷ Btu/hr			
Steam Flow	2.02 x 10 ⁴ lb/hr unit			
Water Temperature	176°F/210°F			
Water Flow	1,035 gpm/unit			
Condensate Pump	1/3 kW			
8. <u>Oil Supply Condensate Pump</u>				
No. of Units (totally)	2			
Power	1/3 HP			
gpm	2			
9. <u>Hot Water Supply System</u>				
No. of Units (pumps)	2	2	2	
Capacity (gpm)	263	263	215	
Heating Power (Btu/hr)	7.90 x 10 ⁶	7.90 x 10 ⁶	6.50 x 10 ⁶	
Temperature	210°/150°F			
Pressure Drop (ft H ₂ O)	50	80	80	
Power (HP)/unit	5	7.5	7.5	
10. <u>Chilled Water Supply System</u>				
No. of Pumps	4	4	4	
Capacity (gpm)	700	700	600	
Cooling Power/Pump (Btu/hr)	5.20 x 10 ⁶	5.20 x 10 ⁶	4.33 x 10 ⁶	
Temperature	57°F/42°F			
Pressure Heat (ft H ₂ O)	45	70	80	
Power (HP)/unit	15	20	20	
11. <u>Electric Hot Water Heater</u>				
No. of Units	2			
Power	840 kW/unit			

Table 4.4. Equipment List - Diesel Engine Total Energy System (contd.)

12. Absorption Chillers

No. of Units	3
Unit Size	1,150 tons/unit
Steam Pressure	30 psia
Temperature	250°F
Heat Consumption	1.85×10^4 Btu/hr ton
Water Temperature	42°F/57°F
Condensate Pump	
No. of Pumps Per Chiller	2
Water Flow	49 gpm/unit
Power	1.0 kW/unit

13. Compression Chillers

No. of Units	2
Unit Capacity	1,300 tons/unit
Temperature	42°F/57°F
Power	0.75 kW/ton

14. Absorption Chiller Cooling Towers

No. of Units	4
Capacity Per Unit	1,150 tons/unit
Water Temperature	95°F/85°F
Water Flow	3,450 gpm/unit
Pumps Per Unit	
No. of Pumps/Tower	4
Water Flow	860 gpm/pump
Δp	60 ft H ₂ O
Power	14 kW/unit
Fans	
No. of Fans/Tower	1
Power	135 kW/unit

15. Compression Chiller Cooling Towers

No. of Units	2
Unit Capacity	1,300 ton/unit
Water Temperature	95°F/85°F
Water Flow	3,900 gpm/unit
Pumps Per Unit	
No. of Pumps/Tower	4
Water Flow	1,000 gpm/pump
Δp	60 ft H ₂ O
Power	15 kW/pump
Fans	
No. of Fans/Tower	1
Power	153 kW/unit

16. Control and Metering Devices**17. Thermal Distribution System**

Table 4.5. Capital Cost - Diesel Engine Total Energy System

Equipment	Quantity	Unit Cost	Total Cost \$(1979)
1. Diesel Engines	3	1,650,000	4,950,000
2. Recovery Boilers	3	62,000	186,000
3. Oil Supply System		451,000	451,000
4. Diesel Cooling Towers	3	62,000	186,000
5. Water Treatment			150,000
6. Heat Exchangers	3	17,400	52,000
7. Hot Water Supply Pumps	6		10,000
8. Chilled Water Supply Pumps	12		27,000
9. Electric Hot Water Heaters	4	16,700	67,000
10. Absorption Chillers	2	345,000	690,000
11. Compression Chillers	2	312,000	624,000
12. Absorption Chiller Cooling Towers	4	80,500	322,000
13. Compression Chiller Cooling Towers	2	91,000	182,000
14. Condensate Pumps and Deaerators			62,000
15. Hot Water Distribution			53,000
16. Chilled Water Distribution			89,000
17. In-Plant Piping & Wiring			86,000
18. Control & Metering Devices			500,000
19. Plant Envelope			360,000
<u>Subtotal</u>			9,047,000
Contingency (15%)			1,357,000
<u>Equipment Total</u>			10,404,000
Design (6%)			624,000
<u>Total</u>			11,028,000

Table 4.6. In-Building Cost - IC Engine Total Energy System

In-Building Cost	=	Plumbing + Mechanical + Electrical
Plumbing Cost	=	Conventional System Cost - Domestic hot water heater cost + heat exchanger cost for domestic hot water $= 2.69 \times 10^6 - 1.24 \times 10^4 + 2.45 \times 10^3$ $= 2.68 \times 10^6$
Mechanical Cost	=	Conventional System Cost - Chiller cost - resistant heater cost in fan coil units + hot water distribution cost - chiller cooling tower cost + pipe cost for engine and plant chiller cooling tower water - mechanical room credit $= 7.29 \times 10^6 - 9.67 \times 10^5 - 4.84 \times 10^5 + 6.1 \times 10^4 - 2.82 \times 10^5 + 1.40 \times 10^5 - 0.25 \times 10^6$ $= \$5.51 \times 10^6$
Electrical Cost	=	\$6.89 million
Total Cost	=	\$15.08 million

Table 4.7. Operation & Maintenance Costs - Diesel Engine Total Energy System

Personnel	Salary/hr \$(1979)	Yearly \$(1979)
Manager (1)	20.00	41,700
HVAC (2)	15.30	63,800
Electrical (2)	17.10	71,300
Plumbing (2)	17.05	71,100
Engine (2)	17.60	73,400
Total		321,300
Salaries		321,300
Supply & Miscellaneous		130,000
Insurance (1%)		110,300
Property Tax (2%)		220,600
Total		782,200

Table 4.8. Fuel Consumption - Diesel Engine Total Energy System

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (Btu)	Fuel Consumption Per Year (Btu)
Typical Winter Weekdays	60	1.31×10^9	7.86×10^{10}
Typical Winter Weekends	24	8.36×10^8	2.01×10^{10}
Coldest Winter Weekdays	5	1.39×10^9	6.97×10^9
Coldest Winter Weekends	2	8.85×10^8	1.77×10^9
Typical Spring/ Fall Weekdays	131	1.39×10^9	1.80×10^{11}
Typical Spring/ Fall Weekends	52	9.00×10^8	4.68×10^{10}
Typical Summer Weekdays	60	1.48×10^9	8.85×10^{10}
Typical Summer Weekends	24	9.43×10^8	2.26×10^{10}
Hottest Summer Weekdays	5	1.71×10^9	8.52×10^9
Hottest Summer Weekends	2	1.08×10^9	2.16×10^9
Totals	365	1.25×10^9 avg.	4.56×10^{11}

Fig. 4.3. Otto Cycle Engine Total Energy System - Central Plant

For the Otto cycle system, which uses natural gas, a fuel oil supply system is not needed. Fig. 4.3 shows the Otto cycle schematic, and Tables 4.9 through 4.12 present the equipment used, its cost, O/M cost, and the fuel consumption of the system. Fuel cost is \$1.64 million for natural gas at \$0.26/100 scf. The dual-fuel engine system uses engines that burn both gas and oil and a smaller fuel supply system is required than for the diesel system. The schematics, equipment used, fuel consumption, and various costs are shown in Fig. 4.4 and Tables 4.13 through 4.16.

Table 4.9. Equipment List - Otto Cycle Total Energy System

1. Gas Engine

No. of Units	3
Unit Size	4 MW
Maximum Electrical Efficiency	23%
Heat Recovery at Maximum	
exhaust gas	37%
jacket water & lube oil	30%

2. Electric Generators

No. of Units	3
Unit Size	4 MW
Hz	60
Volt	480
Phase	3

3. Recovery Boilers

No. of Units	3
Gas Entering Temperature	1,200°F
Gas Leaving Temperature	325°F
Steam Pressure	30 psia
Steam Temperature	250°F
Steam Flow/Unit	2.53×10^4 lb/hr
Maximum Heat	6.44 MW or 2.20×10^7 Btu/hr

4. Engine Cooling Towers

No. of Units	3
Heat to be Dissipated/Unit	5.22 MW or 1.78×10^7 Btu/hr (1,200 tons)
Water Temperature	150°F/177°F
Water Flow Rate	1,320 gpm/unit
Pumps	
No. of Pumps Per Tower	2
Water Flow Per Pump	660 gpm
Pressure Drop	60 ft H ₂ O
Power/Pump	15 HP
Fans	
No. of Units Per Tower	1
Air Flow	4.04×10^5 CFM/tower
Power	260 HP/tower

Table 4.9. Equipment List - Otto Cycle Total Energy System (contd.)

<u>5. Water Treatment</u>				
Recovery Boiler	8 gpm			
Hot Water System	15 gpm			
Chilled Water System	80 gpm			
Engine Cooling Tower	80 gpm			
Chiller Cooling Tower	500 gpm			
<u>6. Heat Exchangers</u>				
No. of Units	3			
Steam Parameter	250°F/30 psia			
Heat Flow Maximum/Unit	6.44 MW or 2.2×10^7 Btu/hr			
Steam Flow	2.53×10^4 lb/hr unit			
Water Temperature	177°F/210°F			
Water Flow	1,340 gpm			
Condensate Pump	0.5 HP			
<u>7. Hot Water Supply System</u>				
No. of Units (pump)	2	2	2	
Capacity (gpm)	263	263	215	
Heating Power (Btu/hr)	7.9×10^6	7.9×10^6	6.45×10^6	
Temperature	210°F/150°F			
Pressure Drop (ft H ₂ O)	50	80	80	
Power (HP)	5	7.5	7.5	
<u>8. Chilled Water Supply System</u>				
No. of Units (pump)	4	4	4	
Capacity (gpm)	700	700	600	
Cooling Power/Pump (Btu/hr)	5.20×10^6	5.20×10^6	4.33×10^6	
Temperature	57°F/42°F			
Pressure Heat (ft H ₂ O)	45	70	80	
Power (HP)/Unit	15	20	20	
<u>9. Electric Hot Water Heater</u>				
No. of Units	2	1		
Unit Capacity	300 kW	150 kW		
<u>10. Absorption Chillers</u>				
No. of Units	3			
Unit Size	1,150 tons			
Steam Parameters	30 psia/250°F			
Heat Consumption	1.85×10^4 Btu/hr - ton or			
	21.3 lb/hr - ton			
Water Temperature	42°F/57°F			
Condensate Pumps				
No. of Pumps/Chiller	2			
Water Flow	24.5 gpm/pump			
Power	0.5 HP/pump			

Table 4.9. Equipment List - Otto Cycle Total Energy System (contd.)

11. Compression Chillers

No. of Units	1
Unit Size	1,380 tons
Temperature	42°F/57°F
Power	0.75 kW/ton

12. Absorption Chiller Cooling Towers

No. of Units	6
Unit Size	1,150 tons
Water Temperature	95°F/85°F
Water Flow	3,450 gpm/unit
Pumps	
No. of Pumps/Tower	4
Water Flow	860 gpm/pump
Δp	60 ft H ₂ O
Power	20 HP
Fans	
No. of Fan/Tower	1
Power	180 HP

13. Compression Chiller Cooling Tower

No. of Units	1
Capacity	1,380 tons
Water Temperature	95°F/85°F
Water Flow	4,140 gpm
Pumps	
No. of Pumps	4
Water Flow/Pump	1,040 gpm
Δp	60 ft H ₂ O
Power	25 HP
Fans	
No. of Fans	1
Power	200 HP

14. Condensate Pumps and Deaerators

Condensate Pumps	
No. of Units	6
gpm	50
Δp	20 ft H ₂ O
Power	0.5 HP/unit
Deaerator	
Flow	50 gpm/unit
No. of Units	3

15. Metering and Control Devices16. Hot Water Distribution Piping17. Chilled Water Distribution Piping

Table 4.10. Capital Cost - Otto Cycle Total Energy System

Equipment	Quantity	Unit Cost	Total Cost \$(1979)
1. Gas Engines	3	1,000,000	3,000,000
2. Recovery Boilers	3	77,300	232,000
3. Engine Cooling Towers	3	72,000	216,000
4. Water Treatment			160,000
5. Heat Exchangers	3	53,000	159,000
6. Hot Water Supply System			10,000
7. Chilled Water Supply			27,000
8. Electric Hot Water Heaters			31,000
9. Absorption Chillers	3	345,000	1,035,000
10. Compression Chillers	1	331,000	331,000
11. Absorption Chiller Cooling Towers	6	69,000	414,000
12. Compression Chiller Cooling Towers	1	83,000	83,000
13. Condensate Pumps & Deaerators			86,000
14. Hot Water Distribution			53,000
15. Chilled Water Distribution			89,000
16. In-Plant Piping & Wiring			85,000
17. Control & Metering Devices			500,000
18. Plant Envelope			360,000
<u>Subtotal</u>			6,547,000
Contingency (15%)			982,000
<u>Equipment Total</u>			7,529,000
Design (6%)			452,000
<u>Total</u>			7,981,000

Table 4.11. Operation & Maintenance Cost - Otto Cycle
Total Energy System

Item	Total Cost \$(1979)
Personnel	321,000
Supply & Miscellaneous	120,000
Insurance	80,000
Property Tax	160,000
Total	681,000

Table 4.12. Fuel Consumption - Otto Cycle Engine Total Energy System

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (Btu)	Fuel Consumption Per Year (Btu)
Typical Winter Weekdays	60	1.82×10^9	1.09×10^{11}
Typical Winter Weekends	24	1.18×10^9	2.83×10^{10}
Coldest Winter Weekdays	5	1.86×10^9	9.28×10^9
Coldest Winter Weekends	2	1.18×10^9	2.36×10^9
Typical Spring/ Fall Weekdays	131	1.96×10^9	2.55×10^{11}
Typical Spring/ Fall Weekends	52	1.26×10^9	6.55×10^{10}
Typical Summer Weekdays	60	2.04×10^9	1.22×10^{11}
Typical Summer Weekends	24	1.31×10^9	3.15×10^{10}
Hottest Summer Weekdays	5	2.31×10^9	1.16×10^{10}
Hottest Summer Weekends	2	1.46×10^9	2.93×10^9
Totals	365	1.75×10^9 avg.	6.38×10^{11}

Fig. 4.4. Dual-Fuel Engine Total Energy System - Central Plant

Table 4.13. Equipment List - Dual-Fuel-Engine Total Energy System.

1. Dual-Fuel Engines

No. of Units	3
Unit Size	5 MW
Maximum Electricity Efficiency	29%
Heat Recovery at Maximum	
exhaust gas	35%
jacket water & lube oil	26%

2. Electric Generators

No. of Units	3
Unit Size	5 MW
Hz	60
Volt	480
Phase	3

3. Recovery Boilers

No. of Units	3
Gas Entering Temperature	1,600°F
Gas Leaving Temperature	325°F
Steam Pressure	30 psia
Steam Temperature	250°F
Steam Flow/Unit	2.36×10^4 lb/hr
Maximum Heat	2.06×10^7 Btu/hr or 6.03 MW

4. Oil Supply System

Oil Storage - #2 Oil	7.8×10^4 gal
Maximum Oil Flow	15.9 gpm
Power Required	5.5 kW

5. Engine Cooling Tower

No. of Units	3
Heat to be Dissipated at Maximum	1.53×10^7 Btu/hr per unit or 4.5 MW per unit
Water Temperature	150°F/176°F
Water Flowrate	1,180 gpm/unit
Pumps	
No. of Pumps Per Tower	2
Water Flow	590 gpm
Pressure Drop	80 ft H ₂ O
Power	13 kW pump
Fans	
No. of Units Per Tower	1
Air Flow	3.20×10^5 CFM/unit
Power	160 kW/unit

Table 4.13. Equipment List - Dual-Fuel-Engine Total Energy System (contd.)

6. <u>Water Treatment</u>				
Recovery Boiler	6	gpm		
Hot Water System	15	gpm		
Chilled Water System	80	gpm		
Engine Cooling Tower	60	gpm		
Chiller Cooling Tower	430	gpm		
7. <u>Heat Exchangers</u>				
No. of Units	3			
Steam Parameters	250°F/30 psia			
Heat Flow Maximum	6.03 MW/unit = 2.06×10^7	Btu/hr		
Steam Flow	2.36×10^4	lb/hr unit		
Water Temperature	176°F/210°F			
Water Flow	1,210	gpm/unit		
Condensate Pump	1/3	kW		
8. <u>Oil Supply Condensate Pump</u>				
No. of Units	2			
Power	1/3	HP		
gpm	2			
9. <u>Hot Water Supply System</u>				
No. of Units (pump)	2	2	2	
Capacity (gpm)	263	263	215	
Heating Power (Btu/hr)	7.90×10^6	7.90×10^6	6.50×10^6	
Temperature	210°F/150°F			
Pressure Drop (ft H ₂ O)	50	80	80	
Power (HP)/Unit	5	7.5	7.5	
10. <u>Chilled Water Supply System</u>				
No. of Pumps	4	4	4	
Capacity (gpm)	700	700	600	
Cooling Power/Pump (Btu/hr)	5.20×10^6	5.20×10^6	4.33×10^6	
Temperature	57°F/42°F			
Pressure Heat (ft H ₂ O)	45	70	80	
Power (HP)/Unit	15	20	20	
11. <u>Electric Hot Water Heater</u>				
No. of Units	2			
Power	840	kW/unit		

Table 4.13. Equipment List - Dual-Fuel-Engine Total Energy System (contd.)

12. Absorption Chillers

No. of Units	2
Unit Size	1,150 tons/unit
Steam Pressure	30 psia
Temperature	250°F
Heat Consumption	1.85×10^4 Btu/hr - ton
Water Temperature	42°F/57°F
Condensate Pumps	
No. of Pumps Per Chiller	2
Water Flow	49 gpm/unit
Power	1.0 kW/unit

13 Compression Chillers

No. of Units	2
Unit Capacity	1,300 tons/unit
Temperature	42°F/57°F
Power	0.75 kW/ton

14. Absorption Chiller Cooling Towers

No. of Units	4
Capacity Per Unit	1,150 tons/unit
Water Temperature	95°F/85°F
Water Flow	3,450 gpm/unit
Pumps Per Unit	
No. of Pumps/Tower	4
Water Flow	860 gpm/pump
Δp	60 ft H ₂ O
Power	14 kW/unit
Fans	
No. of Fans/Tower	1
Power	135 kW/unit

15. Compression Chiller Cooling Towers

No. of Units	2
Unit Capacity	1,300 tons/unit
Water Temperature	95°F/85°F
Water Flow	3,900 gpm/unit
Pumps Per Unit	
No. of Pumps/Tower	4
Water Flow	1,000 gpm/pump
Δp	60 ft H ₂ O
Power	15 kW/pump
Fans	
No. of Fans/Tower	1
Power	153 kW/unit

16. Control and Metering Devices17. Thermal Distribution System

Table 4.14. Capital Cost - Dual-Fuel-Engine Total Energy System

Equipment	Quantity	Unit Cost \$(1979)	Total Cost \$(1979)
1. Dual-Fuel Engines	3	1,670,000	5,000,000
2. Recovery Boilers	3	62,000	186,000
3. Oil Supply System			50,000
4. Engine Cooling Towers	3	62,000	186,000
5. Water Treatment			150,000
6. Heat Exchangers	3	17,400	52,000
7. Hot Water Supply Pumps	6		10,000
8. Chilled Water Supply Pumps	12		27,000
9. Electric Hot Water Heaters	4	16,700	67,000
10. Absorption Chillers	2	345,000	690,000
11. Compression Chillers	2	312,000	624,000
12. Absorption Chiller Cooling Towers	4	80,500	322,000
13. Compression Chiller Cooling Towers	2	91,000	182,000
14. Condensate Pumps and Deaerators			62,000
15. Hot Water Distribution			53,000
16. Chilled Water Distribution			89,000
17. In-Plant Piping & Wiring			86,000
18. Control & Metering Devices			500,000
19. Plant Envelope			360,000
<u>Subtotal</u>			8,696,000
Contingency (15%)			1,304,000
<u>Equipment Total</u>			10,000,000
Design (6%)			600,000
<u>Total</u>			10,600,000

Table 4.15. Operation & Maintenance Cost - Dual-Fuel-Engine
Total Energy System

Item	Total Cost \$(1979)
Salaries	321,300
Supply & Miscellaneous	125,000
Insurance (1%)	106,000
Property Tax (2%)	212,000
Total	764,000

Table 4.16. Fuel Consumption - Dual-Fuel-Engine Total Energy System

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (Btu)	Fuel Consumption Per Year (Btu)
Typical Winter Weekdays	60	1.61×10^9	9.67×10^{10}
Typical Winter Weekends	24	1.03×10^9	2.47×10^{10}
Coldest Winter Weekdays	5	1.71×10^9	8.55×10^9
Coldest Winter Weekends	2	1.09×10^9	2.18×10^9
Typical Spring/ Fall Weekdays	131	1.71×10^9	2.22×10^{11}
Typical Spring/ Fall Weekends	52	1.11×10^9	5.76×10^{10}
Typical Summer Weekdays	60	1.82×10^9	1.09×10^{11}
Typical Summer Weekends	24	1.16×10^9	2.79×10^{10}
Hottest Summer Weekdays	5	2.11×10^9	1.05×10^{10}
Hottest Summer Weekends	2	1.33×10^9	2.66×10^9
Totals	365	1.54×10^9 avg.	5.61×10^{11}

4.4 GAS TURBINE TOTAL ENERGY SYSTEM

A gas turbine system employs gas- or oil-fired gas turbines, together with electrical generators to produce electricity. Resulting exhaust gas contains about 75% of the heating value of fuel input to the combustion chamber, of which about 65% can be recovered by steam boilers. Because, for the same electricity output, gas turbines can generate more steam from heat recovery compared to internal combustion engines, absorption chillers alone are almost adequate to meet the cooling demand of the community. A compression chiller of only about 100 tons capacity is needed to ensure adequate cooling. Figure 4.5 shows the schematics of the gas-fired system. Table 4.17 lists the equipment used. If oil-fired gas turbines are used, an oil supply system would be required, at an additional cost of \$485,000. Tables 4.18 through 4.21 list the central plant cost, O/M cost, in-building system cost, and fuel consumption for the system. The in-building system differs from the internal combustion engine systems by the pipes to carry cooling tower water. Smaller pipes are needed, because gas turbines do not need cooling towers and this decreases the in-building systems cost. The annual fuel cost for the gas-fired system is \$1.43 million with natural gas price at \$0.26/100 scf; that of the oil-fired system is \$1.67 million with #6 oil at \$3.00/MMBtu.

4.5 HEAT-PUMP-CENTERED SYSTEM

A schematic of a heat-pump-centered system with river water is shown in Fig. 4.6. Heat, extracted from water circulating in the cooling loop to the evaporator, is pumped to the condenser and then rejected to water in the heating loop. When simultaneous heating and cooling requirement just balance each other, no heat sink or heat source is necessary. However, this rarely happens. Therefore, a heat sink/source is required. The Gallery II complex is only one mile away from the Delaware River, and a subway tunnel stretches from the site to about 1,000 ft of the river; therefore, a feasible heat pump system using the river water as heat sink/source may result. The pipe to convey water from the river to the plant is sized by the summer heat sink requirement. The size is not adequate for winter heat source if the sole source of heat is from the river water. Internal generation of heat in the interior zones of buildings can be used as part of the heat source. The internal heat source available in winter, with respect to time, is shown in Figs. 4.7 through 4.10. The deficiency is supplied by electric boilers installed in parallel with the heating loop.

After use, the river water may be discharged through the storm sewer system of the city. If this cannot be done, a pump set and pipe should be installed to pipe the water back to the river.

Figure 4.11 shows the thermal distribution system of the heat-pump-centered system (with or without river water). Tables 4.22 through 4.26 show the equipment list, system cost, O/M cost, in-building cost and fuel consumption of the system. Assuming an electricity price of 3¢/kWh, the annual cost is \$1.45 million.

A heat-pump-centered system also has been analyzed without the use of river water. In this case, cooling towers are required. The operation and control of the system is described in the Executive Summary. Figure 4.12

shows the schematic of the system. Tables 4.27 through 4.31 present the equipment used, cost, O/M cost, in-building cost, and fuel consumption. The annual fuel cost is at \$1.56 million.

Table 4.17. Equipment List - Gas Turbine Total Energy System

1. Gas Turbines (Gas-Fired)

No. of Units	2
Unit Size	6 MW
Rated Electricity Efficiency	25%
Heat Recovered from Exhaust as Steam	65%

2. Electric Generators

No. of Units	2
Unit Size	6 MW
Hz	60
Volt	480
Phase	3

3. Recovery Boilers

No. of Units	2
Gas Entering Temperature	900°F
Gas Leaving Temperature	325°F
Steam Pressure	30 psia
Temperature	250°F
Steam Flow/Unit	6.12×10^4 lb/hr
Maximum Heat	15.6 MW = 5.32×10^7 Btu/hr

4. Heat Exchangers

No. of Units	2
Steam Parameters	250°F/30 psia
Heat Flow Maximum/Unit	15.6 MW = 5.32×10^7 Btu/hr
Steam Flow/Unit	6.12×10^4 lb/hr
Water Temperature	150°F/210°F
Water Flow	1,770 gpm/unit
Condensate Pump	1.5 HP/unit

5. Water Treatment

Recovery Boiler	12 gpm
Hot Water System	15 gpm
Chilled Water System	80 gpm
Chiller Cooling Tower	635 gpm

6. Hot Water System

No. of Units (pumps)	2	2	2
Capacity, gpm/Unit	263	263	215
Heating Power/Unit, Btu/hr	7.90×10^6	7.90×10^6	6.45×10^6
Temperature	210°F/150°F		
Pressure Drops (ft H ₂ O)	50	80	80
Power (HP/Unit)	5	7.5	7.5

Table 4.17. Equipment List - Gas Turbine Total Energy System (contd.)

<u>7. Chilled Water Supply System</u>				
No. of Units (pumps)	4	4	4	
Capacity/Unit (gpm)	700	700	600	
Cooling Power/Unit, Btu/hr	5.20×10^6	5.20×10^6	4.33×10^6	
Temperature	57°F/42°F			
Pressure Head (ft H ₂ O)	45	70	80	
Power (HP)/Unit	15	20	20	
<u>8. Electric Hot Water Heater</u>				
No. of Units	3			
Power	240 kW/unit			
<u>9. Absorption Chillers</u>				
No. of Units	4			
Unit Size	1,210 tons/unit			
Steam Pressure	30 psia			
Temperature	250°F			
Heat Consumption	1.85×10^4 Btu/hr - ton			
Water Temperature	42°F/57°F			
Condensate Pumps				
No. of Pumps Per Chiller	2			
Water Flow	23 gpm/pump			
Power	0.5 HP/pump			
<u>10. Compression Chillers</u>				
No. of Units	1			
Capacity	95 tons			
Water Temperature	42°F/57°F			
Power	0.75 kW/ton			
<u>11. Absorption Chiller Cooling Towers</u>				
No. of Units	8			
Capacity Per Unit	1,210 tons			
Water Temperature	95°F/85°F			
Water Flow	3,630 gpm/tower			
Pumps Per Tower				
No. of Pumps/Tower	4			
Water Flow	910 gpm			
Δp	60 ft H ₂ O			
Power	20 HP/pump			
Fans				
No. of Fans/Tower	1			
Power	140 kW/fan or 200 HP			

Table 4.17. Equipment List - Gas Turbine Total Energy System (contd.)

12. Compression Chiller Cooling Towers

No. of Units	1
Unit Capacity	950 tons
Water Temperature	95°F/85°F
Water Flow	2,850 gpm
Pumps Per Tower	
No. of Pumps	4
Water Flow	720 gpm
Δp	60 ft H ₂ O
Power	.5 HP/pump
Fans	
No. of Fans/Tower	1
Power	110 kW
	150 HP

13. Thermal Distribution System14. Control and Metering15. Condensate Pump

No. of Units	2	2
Unit Capacity (gpm)	62	165
Δp (ft H ₂ O)	20	20
Power (HP)	1/2	1-1/2

Table 4.18. Capital Cost - Gas Turbine Total Energy System

Equipment	Quantity	Unit Cost \$(1979)	Total Cost \$(1979)
1. Gas Turbine	2	1,920,000	3,840,000
2. Recovery Boiler	2	187,000	374,000
3. Heat Exchangers	2	90,000	180,000
4. Water Treatment			150,000
5. Hot Water Supply			10,000
6. Chilled Water Supply			27,000
7. Electric Hot Water Heater	2	10,200	31,000
8. Absorption Chillers	4	363,000	1,452,000
9. Compression Chillers	1	23,000	23,000
10. Absorption Chiller			
Cooling Tower	8	72,600	581,000
11. Compression Chiller			
Cooling Tower	1	57,000	57,000
12. Hot Water Distribution			53,000
13. Chiller Water Distribution			89,000
14. In-Plant Piping & Wiring			80,000
15. Control & Metering Devices			450,000
16. Plant Envelope			320,000
17. Condensate Pump & Deaerators			83,000
<u>Subtotal</u>			7,800,000
Contingency (15%)			1,170,000
<u>Equipment Total</u>			8,970,000
Design (6%)			538,000
<u>Total</u>			9,508,000

Table 4.19. Operation & Maintenance Cost - Gas Turbine
Total Energy System

Item	Total Cost \$(1979)
Personnel	321,000
Supply & Miscellaneous	110,000
Insurance	95,000
Property Tax	190,000
Total	716,000

Table 4.20. In-Building Cost - Gas Turbine
Total Energy System

In-Building Cost	=	Plumbing + Mechanical + Electrical
Plumbing Cost	=	Conventional System Cost - Domestic hot water heater cost + heat exchang- er cost for domestic hot water = $2.69 \times 10^6 - 1.24 \times 10^4 + 2/45 \times 10^3$ = 2.68×10^6
Mechanical Cost	=	Conventional System Cost - Chiller cost - resistant heater cost in fan coil units + hot water distribution cost - chiller cooling tower cost + pipe cost for plant chiller cooling tower water - mechanical room credit = $7.29 \times 10^6 - 9.67 \times 10^5 - 4.84 \times 10^5$ + $6.1 \times 10^4 - 2.82 \times 10^5 + 8.4 \times 10^4$ - 0.25×10^6 = 5.45×10^6
Electrical Cost	=	\$6.89 million
Total Cost	=	\$15.02 million

Table 4.21. Fuel Consumption - Gas Turbine Total Energy System

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (Btu)	Fuel Consumption Per Year (Btu)
Typical Winter Weekdays	60	1.62×10^9	9.73×10^{10}
Typical Winter Weekends	24	1.04×10^9	2.50×10^{10}
Coldest Winter Weekdays	5	1.67×10^9	8.34×10^9
Coldest Winter Weekends	2	1.07×10^9	2.13×10^9
Typical Spring/ Fall Weekdays	131	1.71×10^9	2.22×10^{11}
Typical Spring/ Fall Weekends	52	1.11×10^9	5.75×10^{10}
Typical Summer Weekdays	60	1.77×10^9	1.06×10^{11}
Typical Summer Weekends	24	1.14×10^9	2.73×10^{10}
Hottest Summer Weekdays	5	1.91×10^9	9.57×10^9
Hottest Summer Weekends	2	1.23×10^9	2.45×10^9
Totals	365	1.52×10^9 avg.	5.57×10^{11}

Fig. 4.6. Heat-Pump-Centered System with River Water

Fig. 4.7. Interior Cooling Demand, Typical Winter Weekdays

Fig. 4.8. Interior Cooling Demand, Typical Winter Weekends

Fig. 4.9. Interior Cooling Demand, Coldest Winter Weekdays

Fig. 4.10. Interior Cooling Demand, Coldest Winter Weekends

Fig. 4.11. Distribution System for Heat Pump Systems

Table 4.22. Equipment List - Heat-Pump-Centered
System with River Water

1. Heat Pumps

No. of Units	2
Unit Cooling Capacity	800 tons
Condenser Water Temperature	75°F/115°F
Chilled Water Temperature	55°F/40°F
Heating Capacity	11,100 MBtu/hr
Hot Water Temperature	85°F/115°F
Evaporator Water Temperature	41°F/37°F
Power	625 kW

2. Centrifugal Chillers

No. of Units	3
Unit Capacity	1,100 tons
Condenser Water Temperature	75°F/115°F
Chilled Water Temperature	55°F/40°F
Power	860 kW

3. Pumps at River (to pump water to Gallery II)

No. of Units	4
Capacity	800 gpm/unit
Pressure Head	306 ft H ₂ O
Power	125 HP

4. Pumps at River (to pump water from river)

No. of Units	4
Capacity	800 gpm/unit
Pressure Head	30 ft H ₂ O
Power	7.5 HP

5. Hot Water Distribution Pump

No. of Pumps	2	2	2
Capacity/Pump (gpm)	525	525	430
Heating Power (Btu/hr)	7.9×10^6	7.9×10^6	6.45×10^6
Temperature	85°F/115°F		
Pressure Drop (ft H ₂ O)	80	95	75
Power (HP)	15	20	15

6. Chilled Water Distribution Pump

No. of Pumps	4	4	4
Capacity/Pumps (gpm)	700	700	580
Cooling Power/Pump (Btu/hr)	5.20×10^6	5.20×10^6	4.33×10^6
Pressure Head (ft H ₂ O)	45	70	80
Power/Unit (HP)	15	20	20

Table 4.22. Equipment List - Heat-Pump-Centered
System with River Water (contd.)

7.	<u>Pipe from River to Plant</u>	
	Size, Diameter	10 in.
	Length	5,500 ft (or 11,000 ft)
8.	<u>Water Treatment</u>	
	Capacity	3,200 gpm
	Filtration Tank	
	ph Adjustor	
9.	<u>Hot Water Distribution Pipes</u>	
10.	<u>Chilled Water Distribution Pipes</u>	
11.	<u>Auxiliary Boilers</u>	
	No. of Units	3
	Capacity	2,970 kW/unit
12.	<u>Control & Metering Devices</u>	

Table 4.23. Equipment Cost - Heat-Pump-Centered System with River Water

	Without River Water Return	With River Water Return
1. Heat Pumps	480,000	480,000
2. Centrifugal Chillers	660,000	660,000
3. Pumps at River	11,000	11,000
4. Pumps to Pump Water from River	40,000	80,000
5. River to Plant Piping	770,000	1,540,000
6. Auxiliary Boiler	128,000	128,000
7. Hot Water Distribu- tion Pump	12,000	12,000
8. Chilled Water Dis- tribution Pump	27,000	27,000
9. Hot Water Distribu- tion Pipe	71,000	71,000
10. Chilled Water Dis- tribution Pipe	88,000	88,000
11. Water Treatment	400,000	400,000
12. Control and Metering	200,000	200,000
13. Plant Envelope	200,000	200,000
14. In-Plant Piping & Wiring	30,000	30,000
15. Water Treatment & Pump House	44,000	44,000
<u>Subtotal</u>	<u>3,161,000</u>	<u>3,971,000</u>
Contingency (15%)	474,000	596,000
<u>Equipment Total</u>	<u>3,635,000</u>	<u>4,567,000</u>
Design (6%)	218,000	274,000
<u>Total</u>	<u>3,853,000</u>	<u>4,841,000</u>

Table 4.24. Operation & Maintenance Cost -
Heat-Pump-Centered System with River Water

	Without River Water Return	With River Water Return
Salary	248,000	248,000
Supply & Miscellaneous	90,000	90,000
Insurance	39,000	48,000
Property Tax	77,000	96,000
<u>Total</u>	<u>454,000</u>	<u>482,000</u>

Table 4.25. In-Building System Cost -
Heat-Pump-Centered-System with River Water

In-Building Cost	=	Plumbing + Mechanical + Electrical
Plumbing Cost	=	Conventional System Cost = 2.69×10^6
Mechanical Cost	=	Conventional System Cost - Chiller cost - resistant heater cost in fan coil units + hot water distribution cost - chiller cooling tower cost - mechanical room credit $= 7.29 \times 10^6 - 9.67 \times 10^5 - 4.84 \times 10^5$ $+ 6.60 \times 10^4 - 2.82 \times 10^5 - 0.25 \times$ 10^6 $= 5.35 \times 10^6$
Electrical Cost	=	\$6.89 million
Total Cost	=	\$14.93 million

Table 4.26. Fuel Consumption - Heat-Pump-Centered System with River Water

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (kWh)	Fuel Consumption Per Year (kWh)
Typical Winter Weekdays	60	1.53×10^5	9.18×10^6
Typical Winter Weekends	24	9.62×10^4	2.31×10^6
Coldest Winter Weekdays	5	2.36×10^5	1.18×10^6
Coldest Winter Weekends	2	1.41×10^5	2.82×10^5
Typical Spring/ Fall Weekdays	131	1.39×10^5	1.82×10^7
Typical Spring/ Fall Weekends	52	8.93×10^4	4.64×10^6
Typical Summer Weekdays	60	1.49×10^5	8.94×10^6
Typical Summer Weekends	24	9.67×10^4	2.32×10^6
Hottest Summer Weekdays	5	1.76×10^5	8.80×10^5
Hottest Summer Weekends	2	1.11×10^5	2.22×10^5
Totals	365	1.52×10^5 avg.	4.82×10^7
With River Water Return			4.91×10^7

Fig. 4.12. Heat-Pump-Centered ICES

Table 4.27. Equipment List - Heat-Pump-Centered System

1. Heat Pumps

No. of Units	2
Unit Cooling Capacity	710 tons
Condensate Water Temperature	85°F/95°F
Chilled Water Temperature	57°F/42°F
Heating Capacity	9,845 MBtu/hr
Hot Water Temperature	85°F/115°F
Evaporator Water Temperature	57°F/42°F
Power	550 kW

2. Centrifugal Chillers

No. of Units	3
Unit Capacity	1,160 tons
Condenser Water Temperature	85°F/95°F
Chilled Water Temperature	57°F/42°F
Power	960 kW

3. Auxiliary Boilers

No. of Units	4
Unit Capacity	2,790 kW

4. Chiller Cooling Towers

No. of Units	2	3
Capacity	710	1,160
Water Temperature	85°F/95°F	
Water Flow (gpm)	2,130	3,480
Pumps		
No. of Pumps/Tower	3	4
Water Flow (gpm)	710	870
Δp	60 ft H ₂ O	
Power	20 HP	20 HP
Fans		
No. of Fans/Tower	1	
Power	85 kW	

5. Hot Water Distribution Pumps

No. of Pumps	2	2	2
Capacity/Pump (gpm)	525	525	430
Heating Power (Btu/hr)	7.9×10^6	7.9×10^6	6.45×10^6
Temperature	85°F/115°F		
Pressure Drop (ft H ₂ O)	80	95	75
Power/Unit (HP)	15	20	15

Table 4.27. Equipment List - Heat-Pump-Centered System (contd.)

6. <u>Chilled Water Distribution Pumps</u>				
No. of Pumps	4	4	4	
Capacity/Pump (gpm)	700	700	580	
Cooling Power/Pump (Btu/hr)	5.2×10^6	5.2×10^6	4.33×10^6	
Pressure Drop (ft H ₂ O)	45	70	80	
Power/Unit (HP)	15	20	20	
7. <u>Water Treatment</u>				
Hot Water	30 gpm			
Chilled Water	80 gpm			
Cooling Tower	300 gpm			
8. <u>Hot Water Distribution Pipes</u>				
9. <u>Chilled Water Distribution Pipes</u>				
10. <u>Control & Metering Devices</u>				

Table 4.28. Equipment Cost - Heat-Pump-Centered System

Equipment	Total Cost \$(1979)
1. Heat Pumps	426,000
2. Centrifugal Chillers	696,000
3. Auxiliary Boilers	171,000
4. Chiller Cooling Towers	245,000
5. Hot Water Distribution Pumps	12,000
6. Chilled Water Distribution Pumps	27,000
7. Water Treatment	150,000
8. Hot Water Distribution Pipes	71,000
9. Chilled Water Distribution Pipes	88,000
10. Control & Metering Devices	200,000
11. Plant Envelope	200,000
12. In-Plant Piping & Wiring	40,000
<u>Subtotal</u>	2,326,000
Contingency (15%)	349,000
<u>Equipment Total</u>	2,675,000
Design (6%)	161,000
<u>Total</u>	2,836,000

Table 4.29. Operation & Maintenance Cost -
Heat-Pump-Centered System

Item	Total Cost \$(1979)
Salary	248,000
Supply & Material	90,000
Insurance	57,000
Property Tax	28,000
<u>Total</u>	423,000

Table 4.30. In-Building System Cost - Heat-Pump-Centered System

In-Building Cost	=	Plumbing + Mechanical + Electrical
Plumbing Cost	=	Conventional System Cost = 2.69×10^6
Mechanical Cost	=	Conventional System Cost - Chiller cost - resistant heater cost in fan coil units + hot water distribution cost - chiller cooling tower cost + pipe cost for plant chiller cooling tower water - mechanical room credit $= 7.29 \times 10^6 - 9.67 \times 10^5 - 4.84 \times 10^5$ $+ 6.60 \times 10^4 - 2.82 \times 10^5 + 8.4 \times 10^4$ $- 0.25 \times 10^6$ $= 5.43 \times 10^6$
Electrical Cost	=	\$6.89 million
Total Cost	=	\$15.01 million

Table 4.31. Fuel Consumption - Heat-Pump-Centered System

Type of Day	No. of Days/Year of This Type	Fuel Consumption Per Day (kWh)	Fuel Consumption Per Year (kWh)
Typical Winter Weekdays	60	2.00×10^5	1.20×10^7
Typical Winter Weekends	24	1.22×10^5	2.93×10^6
Coldest Winter Weekdays	5	2.84×10^5	1.42×10^6
Coldest Winter Weekends	2	1.78×10^5	3.56×10^5
Typical Spring/ Fall Weekdays	131	1.40×10^5	1.83×10^7
Typical Spring/ Fall Weekends	52	9.02×10^4	4.69×10^6
Typical Summer Weekdays	60	1.48×10^5	8.88×10^6
Typical Summer Weekends	24	9.60×10^4	2.30×10^6
Hottest Summer Weekdays	5	1.74×10^5	8.70×10^5
Hottest Summer Weekends	2	1.10×10^5	2.20×10^5
Totals	365	1.42×10^5 avg.	5.19×10^7

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