MASTER

WATER RESOURCES RESEARCH PROGRAM

**DISTRICT HEATING AND COOLING UTILIZING
TEMPERATURE DIFFERENCES OF LOCAL WATERS**

**Preliminary Feasibility Study for the
Chicago 21, South Loop New Town Project**

by

**W. Harrison, A. A. Frigo, G. T. Kartsounes,
D. J. Santini, S. J. LaBelle, and F. H. Davis**

Great Lakes Project

ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

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ABSTRACT

This report examines the feasibility of cooling and heating buildings of Chicago's South Loop New Town (SLNT) project by using cool Lake Michigan water and warm water from Commonwealth Edison Company's Fisk Generating Station. Three systems are considered for the heating/cooling requirements of the SLNT project: conventional, conventional with lake-water cooling, and modular heat-pump systems. Characteristics of the source waters and institutional constraints to their use are also considered. The modular heat-pump system, using water-to-water heat pumps, is the most attractive type of system for the SLNT project both from an economic and an energy-savings point of view. The modular heat-pump system offers an initial reduction in both the required capital investment for the heating, ventilating, and air-conditioning (HVAC) system when compared to a conventional system and also a significant reduction in annual operating expenses. The heat-pump system, however, requires a significant additional capital investment for the water supply and return system. Even with this investment, the heat-pump system savings in annual operating expenses and reduced capital investment for the HVAC system could pay for the cost of the water supply and return system in less than five years. Added to the economic savings would be an energy savings equivalent of about 450,000 barrels of fuel oil per year when the modular heat-pump system is compared to a conventional system.

1 INTRODUCTION

1.1 CHICAGO 21 PLAN'S SOUTH LOOP NEW TOWN DEVELOPMENT

The South Loop New Town (SLNT) project, which has been named "Dearborn Park," is a general concept for community development that involves a tract of land adjacent to the southern end of Chicago's central business district. The area covered by the project tract (Fig. 1.1) includes 335 acres generally bounded by Congress Parkway on the north, the Chicago River on the west, State

Fig. 1.1. Location of South Loop New Town Development and Features Referred to in Text.

Street on the east, and Cermak Road and Archer Avenue on the south. Plans as of 1976 call for 13,150 dwelling units to be built, housing 30,000-35,000 people. The first phase of the development, currently in the design stage, is to contain 3000 dwelling units. The eventual date of completion of all 13,150 is to be before the year 2000, consistent with the Chicago 21 plan.

The integrated planning effort being applied to this project makes it amenable for study as a possible location for innovative energy-supply systems. The planners involved in this project are among the leaders in their field and are consequently relatively receptive to the use of new technology.

A positive attitude toward energy conservation for SLNT is indicated in the City of Chicago Department of Development and Planning's publication on the SLNT Guidelines for Development. A specific commitment is made to energy conservation in the publication's fourth "basic policy" which is to:

"insure that all environmental concerns are addressed in all aspects of the South Loop development."

This basic policy includes energy conservation because of its context. On a previous page, under a paragraph headed "environmental concerns," the question is asked, "What energy conserving features can be built into new residential development?"

1.2 SCOPE OF STUDY

The study presented in this report considers several methods of district heating and cooling utilizing temperature differences of local bodies of water. The SLNT site is attractive because of its potential generic applications to the urban residential use of local bodies of water as heat sources and sinks. This study should provide useful information applicable to many major U.S. urban centers located on rivers, lakes, or oceans.

As indicated in Fig. 1.1, the SLNT site is close to a large body of water, Lake Michigan; a river, Chicago River South Branch; and a power plant, Commonwealth Edison Company's Fisk generating station. Figure 1.1 shows the location of abandoned tunnels that pass through or near the lake, river, and power plant in the vicinity of the SLNT project. These tunnels make it possible to transfer warm condenser discharge water from the Fisk station and cool water from Lake Michigan to the site. The Chicago River can be used as a sink for discharge water from the project.

This report examines the costs and benefits of several district-heating and -cooling schemes in terms of both cost and energy consumption. The following schemes are considered.

1. Conventional heating and conventional cooling using chillers with cooling towers.
2. Conventional heating and heat exchangers using 40°F lake water.
3. Conventional heating and chillers using 50°F lake water.
4. Modular heat-pump system.

The first system is used as a reference for the study. The modular heat-pump system uses lake water when the load is predominantly cooling, discharge water from the power plant when heating is predominant, and a combination of water sources when the needs of cooling and heating are nearly in balance.

The use of power-plant waste heat in conjunction with heat pumps to provide urban heating and cooling was proposed many years ago by Eibling and Landry.¹ More recently Miller *et al.*² and Illeri *et al.*³ have proposed similar concepts for use of the waste heat from nuclear power plants. However, these works are theoretical treatments. The study of the modular heat pump system presented in this report is unique with respect to its examination of specific details and its proposal for the joint use of power-plant waste heat for winter heating and a natural body of water for summer cooling.

2 EXPLOITATION OF COOL-WATER SOURCE

2.1 NATURE OF COOL-WATER SOURCE

The temperature of Lake Michigan bottom water was measured at three stations (Fig. 2.1) from July through October, 1976. The precise location, water depth, and thermistor position above the lake bottom for each station are shown in Table 2.1. Appendix A gives a complete listing of water-temperature and lake-current data for several depths over the test period.

The thermistor at Station T6 recorded water temperatures that fluctuated between about 50-65°F for July. In August, there was an extended period when the temperature never dropped below 66°F. The warm temperatures extended into September and finally began to decline in October. Similar data were obtained at Station VI and V. For these two locations, additional data were recorded in late May and June. For this period, water temperatures were less than 50°F.

Summer water temperatures at the Park Row Pumping Station, for water drawn from the Four-Mile Crib, are presented in Table 2.2. They range from 59 to 70°F for the period June 17 - August 30, 1963.

2.2 CONSTRUCTION OF A LAKE-CONDUIT EXTENSION

To use Lake Michigan water for direct space cooling within the SLNT project would require water at a temperature less than 50°F. It is estimated that this water could be obtained about 11 miles from the Four-Mile Crib, at

Table 2.1. Location of Current Meter and Thermograph Installations in Lake Michigan during 1976, Water Depth, and Elevation of Bottom Thermistors

Station number	Station Location (Lat.) (Long.)		Water Depth* (ft)	Current meter (present)	Elevation of bottom thermistor above lake floor (ft)
T6	41° 52.0'	87° 30.5'	46	No	4.9
VI	41° 51.5'	87° 28.0'	72	Yes	3.3
V	41° 50.7'	87° 22.8'	53	Yes	3.3

*Referenced to International Great Lakes Datum (1955)

Fig. 2.1. Location of the Three Current-meter and Thermograph Stations Referred to in Table 2.1 and Appendix A.

Table 2.2. Temperatures (°F) of Raw Water from the
Four-Mile Crib as Measured at the Park
Row Pumping Station

(Daily Averages: June 17 - August 30, 1963)					
June 17	61°F	July 12	68°F	Aug 6	59°F
18	62	13	67	7	59
19	62	14	68	8	59
20	62	15	67	9	59
21	62	16	68	10	62
22	62	17	68	11	62
23	63	18	69	12	61
24	63	19	68	13	61
25	63	20	69	14	64
26	63	21	70	15	66
27	63	22	69	16	65
28	62	23	68	17	65
29	64	24	70	18	67
30	66	25	70	19	67
July 1	66	26	69	20	67
2	66	27	68	21	67
3	66	28	65	22	67
4	68	29	59	23	67
5	67	30	61	24	67
6	67	31	59	25	68
7	67	Aug 1	58	26	68
8	67	2	61	27	68
9	68	3	61	28	69
10	67	4	58	29	69
11	67	5	59	30	68

water depths of 95-100 ft. The estimated cost for constructing only a 2-mile extension to the Four-Mile Crib (Table 2.3) is about \$8,000,000. Thus, an 11-mile extension would be prohibitively high in cost.

2.3 FOUR-MILE AND POLK STREET TUNNELS

The Four-Mile Tunnel used for water intake begins to the east of the immediate project area, near Michigan Avenue and Roosevelt Road. This 21,000-ft brick conduit was abandoned for use as a water source by the City of Chicago in 1974. It is located about 25-60 ft beneath the bottom of Lake Michigan. It terminates at the Four-Mile Crib and shaft, located due east of the immediate project area. The first 12,500 ft of the tunnel consists of two six-foot-diameter conduits; the remaining length is taken up by one eight-foot-diameter conduit.

The cooling water would flow west through the Four-Mile Tunnel to the Park Row Shaft (Fig. 1.1). At this point, the water would flow north on the east side of Michigan Avenue until it comes to the 8th Street Shaft. It would then flow west again through the Polk Street Tunnel along Polk Street.

At the intersection of Dearborn and Polk Streets, a pumping station and shaft would be constructed to deliver the water from the Polk Street Tunnel to the SLNT cooling system. The only major refurbishing to the existing tunnel system would be the removal of a bulkhead in the Four-Mile Tunnel just east of the Park Row Shaft. To prevent a potential cross connection between the raw lake Michigan cooling water and the treated Lake Michigan potable water that is pumped at the Cermak Pumping Station, a new bulkhead would be constructed in the Polk Street Tunnel (Fig. 1.1).

To remove the bulkhead near the Park Row Shaft and construct a new bulkhead in the Polk Street Tunnel, both the Four-Mile Tunnel and the on-shore tunnels would need to be dewatered so that the work could be done in a dry conduit. About three weeks would be required to dewater the tunnels and remove the concrete bulkhead with pneumatic tools.

As shown in Table 2.4, the total cost for removing the bulkhead near the Park Row Shaft and constructing a new bulkhead in the Polk Street Tunnel is estimated at \$125,000: \$85,000 for bulkhead removal, \$15,000 for installing a new concrete bulkhead in the seven-ft-diameter Polk Street Tunnel, and

Table 2.3. Estimated Construction Cost of a Two-mile Lake-conduit Extension

Item	Quantity	Unit Cost	Cost
8'-diameter reinforced concrete pipe	10,560 ft	\$ 200/ft	\$2,112,000
Installation of pipe	10,560 ft		
Backfill excavation		275/ft	
Bedding		13/ft	
Disposal of excess material		29/ft	
		\$ 317/ft	\$3,347,520
Intake Structure			
Tees	4	\$17,600 each	\$ 70,400
Els	9	12,400 each	111,600
Reducers	9	9,200 each	82,800
Installation	9	300,000	300,000
Crib Connection			
Concrete for special precast boxes	38 yd ³ *	\$ 125/yd ³	\$ 4,750
72"-diameter RCP	40 ft	150/yd ³	6,000
Y 96" diameter x 72" diameter	1	3,000 each	3,000
1/16 bend, 72" diameter	2	1,500 each	3,000
Cofferdam		60,000	60,000
Excavation	2500 yd ³	4.50/yd ³	11,250
Bedding	89 yd ³	20/yd ³	1,780
Labor for placement and grouting			
Divers	10 day	300/day	3,000
Barge and equipment	10 day	2500/day	25,000
Subtotal			\$6,142,000
		Say	\$6,140,000
Contingencies* @ 25%			\$1,535,000
Engineering and Administration @ 10%			615,000
TOTAL COST FOR LAKE CONDUIT EXTENSION			\$8,290,000

*This relatively high figure is necessary due to such problems as inclement weather and other unforeseen difficulties that could arise during construction on the lake.

Table 2.4. Estimated Cost for Bulkhead Removal and Replacement

Item	Quantity	Unit Cost	Cost
Dewatering intake tunnel	22 days	\$1,540/day	\$ 33,880
Dewatering shore tunnel	14 days	1,540/day	21,560
Demolition of bulkhead	109 yd ³	71/yd ³	7,739
Disposal of bulkhead	132 yd ³	25/yd ³	3,300
Equipment	14 days	405/day	5,670
Access to Park Row Shaft		10,000	10,000
Ventilation		3,000	3,000
Subtotal			\$ 85,149
		Say	85,000
<u>Bulkhead Replacement</u>			
Concrete	63 yd ³	\$ 150/yd ³	\$ 9,450
Modification to existing tunnel (for bulkhead ring placement)		5,000	5,000
Subtotal			\$ 14,450
		Say	15,000
Subtotal Bulkhead Removal and Replacement Costs			\$100,000
Engineering and Contingencies @ 25%			25,000
TOTAL COST FOR BULKHEAD REMOVAL AND REPLACEMENT			\$125,000

\$25,000 for engineering and contingencies. Dewatering costs are not included in the \$15,000 estimate since it is assumed that such dewatering would take place in conjunction with the bulkhead removal project.

2.4 NEW PUMP STATION

The total cost for the cooling-water pump station at Polk and Dearborn Streets is estimated at \$1,125,000. As shown in Table 2.5, this cost includes construction of a 20-ft-diameter shaft which would house the pumping facility. The shaft would be constructed to a depth of 75 ft below the ground surface to connect to the Polk Street Tunnel.

The capacity of the proposed pumping station is 60,000 gpm (134 cfs), based on the peak cooling-water demands for the entire South Loop New Town Development. The total power requirement is 2,500 HP, based on a total dynamic head of 140 feet (50 psig in the main line of the cooling system and a 25-ft static head).

Table 2.5. Estimated Cost of Cooling-water Pump Station

Item	Quantity	Unit Cost	Cost
<u>Shaft</u>			
Concrete	204 yd ³	\$150/yd ³	\$ 30,600
Excavation	1170 yd ³	9.50/yd ³	11,115
Sheeting and Bracing	5500 ft ²	20/ft ²	110,000
Subtotal			\$ 151,715
Pumps, Motors, Controls & Installation			\$ 750,000
Subtotal			\$ 901,715
		Say	\$ 900,000
Engineering & Contingencies @ 25%			\$ 225,000
TOTAL COST FOR PUMP STATION			\$1,125,000

2.5 COOL-WATER DISCHARGE SYSTEM

Two alternative systems have been investigated for discharge of the spent cooling water from the study area. Alternative No. 1 would involve the construction of a sewer outfall to the South Branch Chicago River. As shown on Fig. 1.1, the sewer would be constructed from Dearborn Street and Roosevelt Road to its outfall at the river along Roosevelt Road. This alternative would constitute a diversion of Lake Michigan water.

Alternative No. 2, which would not divert Lake Michigan water, consists of tunneling east from the study area under the Illinois Central railroad tracks and constructing an outfall at the north end of Burnham Park Harbor.

As shown in Table 2.6, the cost of constructing an outfall to the South Branch Chicago River (Alternative No. 1) to discharge spent cooling water is estimated at \$655,000. The outfall would be constructed in the same manner as a typical storm sewer and would start at Dearborn and Roosevelt Road.

Costs for discharge to a Lake Michigan outfall (Alternative No. 2) total an estimated \$4,315,000, as shown in Table 2.7. This alternative would require two shafts and a tunnel extending under the Illinois Central Railroad tracks. A shaft and outfall structure would be constructed adjacent to Burnham Park Harbor to discharge the spent cooling water.

Table 2.8 summarizes the costs associated with the two alternative plans for providing cool water to the project. This table indicates that the alternatives differ in cost by a factor of about three.

Table 2.6. Estimated Cost of Chicago River Outfall (Alternative No. 1)

Item	Quantity	Unit Cost	Cost
7'-diameter RC pipe	1500 ft	\$150/ft	\$225,000
Installation and Restoration	1500 ft	\$100/ft	150,000
Outfall Structure	L.S.	150,000	150,000
Subtotal			<u>\$525,000</u>
Engineering and Contingencies @ 25%			<u>131,250</u>
TOTAL COST FOR CHICAGO RIVER OUTFALL			\$656,250
		Say	\$655,000

Table 2.7. Estimated Cost of Lake Michigan Outfall (Alternative No. 2)

Item	Quantity	Unit Cost	Cost
15'-diameter shaft at Roosevelt and Dearborn	1	\$151,715	\$ 151,715
7'-diameter tunnel to the lake	5000/ft	600/ft	3,000,000
10'-diameter shaft at Burnham Park Harbor	1	99,500	99,500
Outfall Structure	1	200,000	200,000
Subtotal			<u>\$3,451,215</u>
Engineering and Contingencies @ 25%			<u>862,804</u>
TOTAL COST FOR LAKE MICHIGAN OUTFALL			\$4,314,019
		Say	\$4,315,000

Table 2.8. Cost Summary of Alternative Plans

Cost Item	Alternative No. 1 Four-Mile Crib Intake Discharge to Chicago River	Alternative No. 2 Four-Mile Crib Intake Discharge to Lake Michigan
Bulkhead	125,000	125,000
Renovation of Four-Mile Crib	10,000	10,000
Pumping Station	1,125,000	1,125,000
Discharge Alt. 1	655,000	-
Discharge Alt. 2	-	<u>4,315,000</u>
	<u>1,915,000</u>	5,575,000

2.6 COOL-WATER INSTITUTIONAL CONSTRAINTS

As indicated in Table 2.8, a significant cost savings can be realized by discharging water to the Chicago River. The maximum expected cooling-water flow for the SLNT project is about 150 cfs. However, to supply this water constitutes a diversion of Lake Michigan water.

The State of Illinois is limited by a U.S. Supreme Court decision to an annual average diversion of 3200 cfs, including the diversion of storm runoff from the lake made necessary when the flow of the Chicago River was reversed. Recently, however, a temporary, 5-year increase to 10,000 cfs was signed into law. On the average, the 3200-cfs diversion from Lake Michigan encompasses the runoff allowance from the Lake Michigan watershed (20%), lockage and leakage flows (8%), navigational make-up water (2%), potable water use (55%) and discretionary diversion (15%). The discretionary diversion flows are utilized by the Metropolitan Sanitary District to meet the water-quality standards set for the Chicago River system. These flows are diverted from Lake Michigan at Wilmette Harbor, Chicago Harbor, and the O'Brien Locks. It is estimated that discretionary diversion flows will range from 25 cfs during the winter to 490 cfs during the summer months.

If the outfall were to be located in Burnham Park Harbor, there would be no diversion of Lake Michigan water. Although the construction cost associated with this alternative is significantly greater, the discharge of cooling water in the harbor could yield the benefit of increased circulation of the stagnant harbor water. There also would be no adverse thermal effects on discharge to the lake if the temperature of the cooling water were increased only to that of the shoreline water.

In addition to the diversion issue, certain other institutional constraints must be considered relevant to the use of lake water for cooling. Among these are:

- 1) The City of Chicago has an ordinance prohibiting use of lake water for once-through air conditioning. (This ordinance may need interpretation to see if it applies to the proposed project and to determine if a variance could be obtained, if one is needed.)
- 2) State of Illinois standards limit new sources of cooling-water discharges to no more than 0.1×10^9 Btu/hr. (An exemption would probably not be required for the proposed system.)

- 3) The State has a policy of no new cooling-water discharges along the Chicago shoreline. The Federal EPA would abide by this policy. (A USEPA 316a exemption would probably be required if the SLNT cooling water were discharged to Burnham Park Harbor.)

3 EXPLOITATION OF WARM-WATER SOURCE

3.1 NATURE OF WARM-WATER SOURCE

Commonwealth Edison Company's Fisk Generating Station (Fig. 1.1) is located on the Chicago River (South Branch) 1.3 miles downstream from the SLNT site. There are two units at Fisk: a 320- and a 150-MW unit. This fossil-fuel-fired plant uses a once-through cooling system which discharges into the Chicago River. Average seasonal river flows, plant condenser-water discharge flow rates, heat-rejection rates, and discharge-water temperatures are presented in Table 3.1. The condenser-water discharges are greater than the river flow in some cases, indicating that condenser water may recirculate.

The Fisk Generating Station is a reliable source of warm water all year. The Fisk plant is an important part of the Commonwealth Edison system; each generating unit is in operation 65-86% of the year with generally noncoincident downtime spread throughout the year (as based on data from 1975 and part of 1976).

Typical intake and discharge condenser-water temperatures are presented in Table 3.2. Based on 1975 data, the discharge temperature exceeds 60°F during 63% of the time. Occurrences of discharge temperatures falling below 60°F are limited mainly to December, January, February, and March, when the river is very cold (40-48°F) and the flow is low. At such times, because of the low flow, recirculation of the water occurs; that is, the plant's discharge

Table 3.1. Characteristics of Fisk Station Cooling-water Discharge

Season	Average River Flow (cfs)	Average Fisk Condenser Flow ^a (cfs)	Average Heat Rejection Rate ^a (10 ⁸ Btu/hr)	Average Discharge Temperature ^a (°F)
Winter	575	607.6	12.65	50.0
Spring	950	642.6	11.71	71.9
Summer	1890	662.1	11.30	82.0
Fall	735	636.0	10.59	67.3

^a Commonwealth Edison data for 1975; condenser flows can be larger than river flows because of recirculation.

Table 3.2. Typical Intake and Discharge Temperatures at Fisk Station^a

Month	Intake Temperature (°F)	Discharge Temperature (°F)
January	40	50
February	40	50
March	48	60
April	50	64
May	63	70
June	72	82
July	76	84
August	78	87
September	71	80
October	67	76
November	60	68
December	48	58

^aSource: Commonwealth Edison

water flows upstream to its intake, as the plant requires more cooling water than the river can supply by flow past the plant. If the rate of recirculation were increased, the discharge temperature could be raised without a large effect on the plant's operating efficiency. The main constraint on discharge temperature is the effect on water quality of a large increase in the discharge temperature relative to the temperature of the river water. If the discharge water were used for heating the SLNT project, however, the rise in temperature due to recirculation would be partially offset by the introduction of the cooler water back into the river at the site.

3.2 WARM-WATER SUPPLY SYSTEM

The distance between the SLNT site and the power station can be traversed by constructing two new tunnels to connect to the existing abandoned Blue-Island Tunnel (Fig. 1.1). New tunnels totaling 5000 ft in length -- 3000 ft for the section from the Fisk Station to the Blue-Island Tunnel, and 2000 ft for the section from the west end of the Polk Street Tunnel to Halsted Street and north to the Blue Island Tunnel -- are required. The cost would be between \$4,000,000 and \$4,500,000. This is a conservative estimate and includes the cost of 8-ft-diameter tunnels (at \$300/ft), a construction shaft

for each tunnel, dewatering and repairing the Blue Island Tunnel, a gate at the Polk Street Pumping Station, bulkheads (at Polk and Jefferson Streets, Blue Island Avenue at Harrison Street, and in the Blue Island Tunnel leading to the old 22nd Street Pumping Station), the connection to the Fisk plant, and engineering and contingency fees. The cost of making the abandoned tunnel usable is a small portion of the total cost, amounting to only \$450,000 for dewatering, bulkhead construction, and repairs.

3.3 WARM-WATER DISCHARGE SYSTEM

Regardless of how the warm water arrives at SLNT from the Fisk Station, it would be discharged from the site to the Chicago River near Roosevelt Road. The cost for this outfall, assuming it begins at Dearborn Street and Roosevelt Road, is estimated at \$655,000. The same discharge system is used for the warm water as for the cool water from Lake Michigan (discussed in Section 2.5). The discharge system does not constitute a diversion of Lake Michigan water; instead, it is a reuse of river water.

3.4 WARM-WATER INSTITUTIONAL CONSTRAINTS

The use of waste-heat water from the Fisk Generating Station is limited by (1) continued operation of Fisk by Commonwealth Edison and (2) water-quality laws of the State of Illinois regarding secondary-contact waters and indigenous aquatic life. The planned retirement date for Fisk is 1994. It is assumed that Commonwealth Edison Company will build new units at the Fisk site at that time. The retirement of old units and construction of new ones at the same site are common utility practice.

An examination of the State of Illinois water-quality laws indicates that the SLNT warm-water discharge would not violate water-temperature or effluent-concentration standards. The water-quality regulations of prime concern are Sections 205 and 401 of Chapter 3 of the Illinois Pollution Control Board's Rules and Regulations.⁴ Section 205(f) states that water temperatures in the Chicago River (South Branch) cannot exceed 93°F more than 50% of the time, or 100°F at any time. Since the river water would be cooled by the intended use in SLNT, this is not likely to be a problem.

The only other possible problem is a potential increase in the concentration of solids due to evaporation. Section 401(b) of the Water Pollution

Control Board's regulations states, however, that "compliance with the numerical effluent standards is, therefore, not required when effluent concentrations in excess of the standards result entirely from influent contamination, evaporation, and/or the incidental addition of traces of materials not utilized or produced in the activity that is the source of the waste."

From the foregoing, institutional constraints do not appear to be a problem in the case of use of power-plant waste-heat water to heat the SLNT development.

4 DISTRICT HEATING AND COOLING SYSTEMS

Three systems were considered for providing the heating, ventilating, and air-conditioning (HVAC) requirements for the SLNT development. This chapter discusses the technical and economic characteristics of the HVAC systems evaluated.

To contrast the various HVAC schemes, design parameters such as living-space floor area, heating and cooling loads, and water flows are required. The proposed planning framework for SLNT is summarized in Table 4.1. The initial development comprises parts of Regions A and B as indicated in Fig. 1.1. For all systems considered, it was assumed that adequate electric power at proper electric characteristics would be available throughout the development.

4.1 THE CONVENTIONAL SYSTEM

A valid analysis of the economic feasibility of the several systems considered in this report requires the selection of a proper "conventional" system. An all-electric system using resistance heating has been selected for this purpose. For this system, the heating/cooling needs of both the initial and ultimate developments would be supplied from a system of six central stations strategically located throughout the site. Cooling towers located

Table 4.1. Maximum Refrigeration, Heating, and Cooling-water Demands for the SLNT Project

	Dwellings	Business	Community facilities	Total
		<u>Initial Development</u>		
Floor area, ft ²	3,041,000	97,500	119,750	3,258,250
Refrigeration, tons	5,068	218	241	5,527
Heating, W	24,300	975	1,238	26,513
Cooling water, gpm	14,200	520	792	15,512
		<u>Ultimate Development</u>		
Floor area, ft ²	14,514,000	450,000	600,000	15,564,000
Refrigeration, tons	24,190	1,001	1,308	26,499
Heating, W	116,000	4,500	6,000	126,500
Cooling water, gpm	62,500	2,550	3,510	68,560

at ground level near the central stations would be used as a heat sink for the cooling system. It is estimated that cooling towers would require considerable site work to satisfy esthetic and environmental conditions. Such costs are not included in the cost estimates presented below. Conventional heating with high-voltage electrode boilers would be used for supplying all space-heating requirements for this system.

A combination of factors gives credence to the selection of an electrical system as the likely conventional HVAC method. One of the biggest factors is the strong shift to electrical heating in the residential sector resulting from current and anticipated shortages of natural gas. In the North-Central region, electric space-heating systems were installed in 49% of new multi-family units constructed in 1975, a 10% increase over 1974 (Ref. 5). In the first place, these trends are likely to continue, and second, these figures understate the proportion of electrical systems installed in high-rise dwelling units such as found on the SLNT site. In Chicago, current gas-utility policy is to require individual metering of dwelling units. This requirement eliminates decentralized gas-fired systems from high rises. Economics and engineering eliminate decentralized gas-fired systems from high rises. Political considerations and uncertainty rule out oil. A coal ban in Chicago rules out coal. Thus, an all-electric conventional system is a reasonable choice for comparison in the case of the SLNT development. Capital and operating costs for the conventional system are estimated in Table 4.2.

4.2 SYSTEM USING CONVENTIONAL HEATING AND LAKE-WATER COOLING

For this system, space heating is accomplished using high-voltage electrode boilers, and cooling is accomplished by using lake water with or without auxiliary water chillers. A schematic diagram of this system is presented in Fig. 4.1.

For the cooling mode of operation, water is pumped from the lake via existing tunnels and collected in a reservoir. The reservoir would be an integral part of the new pumping station near Roosevelt and Dearborn Streets. Lake water is screened or otherwise adequately treated at the pumping station to prevent blocking of heat exchangers or condenser tubes by debris or dirt. Lake water is then pumped from the reservoir to six central stations

S- SUPPLY RESERVOIR, LOW HEAD PUMPING STATION AND
SCREENING PLANT

R- RETURN WATER RESERVOIR FOR DISCHARGE INTO
CHICAGO RIVER OR LAKE MICHIGAN

C- CONDITIONED-WATER PUMPING STATIONS

Fig. 4.1. Flow Diagram for a System Using Conventional Heating and Lake-water Cooling.

Table 4.2. Cost Estimate for the Conventional System

	Initial development	Ultimate development
<u>Capital Investment</u>		
Cooling Towers	\$ 553,000	\$ 2,650,000
Central Stations	1,744,000	7,321,000
Chilled Water Distribution	538,000	1,520,000
Hot Water Distribution	589,000	1,750,000
Ventilation and Exhaust	1,254,000	5,700,000
Space Air Conditioning	3,160,000	13,850,000
Engineering	451,000	1,886,000
Misc. and Contingencies	1,176,000	4,919,000
Total	9,465,000	39,596,000
<u>Annual Operating Expenses</u>		
Cooling (Electrical Power)	197,000	845,000
Heating (Electrical Power)	1,320,000	6,495,000
Operating Labor	20,000	120,000
Maintenance	90,000	350,000
Misc. (Supplies, Refrigerant Chemicals, Lubricants, Water, etc.	8,000	60,000
Total	\$1,635,000	\$ 7,870,000

(designated as C in Fig. 4.1) strategically located throughout the site. These stations contain electrode boilers for heating, water chillers for cooling (if necessary), and booster pumps to distribute the water to the buildings. Water leaving the buildings returns to the central stations and then is discharged to the lake or river. The individual apartments in each building are cooled using individual water-to-air heat exchangers with a ventilation system to distribute the conditioned air.

For space-heating operation, the new pumping station is inoperative and water is merely circulated in a closed loop between the pumping stations and the buildings. The boilers are used to continually heat the water, and makeup water is provided at each station as needed. The apartments in each building are space-heated using baseboard heaters.

There will be times when some of the apartments of a building require heating while others require cooling. Because of this possibility, a two-pipe system must be installed between the central stations and the individual buildings; one pipe would carry cool water (or chilled water) and the other hot water.

For operation of this HVAC scheme, two lake-water temperatures have been considered: 40 and 50°F. Using 50°F water requires an auxiliary chiller in each pumping station to reduce the water temperature to 40°F for direct use in the individual water-to-air heat exchangers. Table 4.3 presents cost estimates for the HVAC, using either 40 or 50°F lake water for cooling.

4.3 THE MODULAR HEAT-PUMP SYSTEM

As discussed in Chapter 3, warm discharge water from the Fisk Generating Station can be transported to the SLNT site via existing tunnels. Together with cool water from Lake Michigan, it would be possible to operate a heat-pump system on the SLNT site for the required HVAC. Using each source separately, or by combining sources, a relatively constant water temperature of 55-65°F could be maintained. For this temperature range, a water-to-water heat pump can operate at a Coefficient of Performance (COP) of 3.2-3.5, year-round. Conventional cooling systems operate at a COP of about 1.9-2.1, whereas resistance heating has a COP slightly less than 1.0. Thus, the proposed heat pump would be about 1.7 times as efficient for cooling and about 3.4 times as efficient for heating. This improved efficiency corresponds to an energy savings equivalence of about 450,000 bbls of fuel oil per year.

Table 4.3. Cost Estimate for Conventional Heating and Lake-water Cooling for HVAC

	Initial Development		Ultimate Development	
	Conv'tl. Htg. & Heat Exchgrs. using 40°F Lake Water	Conv'tl. Htg. & Chillers using 50°F Lake Water	Conv'tl. Htg. & Heat Exchgrs. using 40°F Lake Water	Conv'tl. Htg. & Chillers using 50°F Lake Water
<u>Capital Investment</u>				
Lake-water Distribution	\$ 231,000	\$ 231,000	\$ 693,000	\$ 693,000
Central Stations	616,000	1,744,000	2,302,000	7,321,000
Chilled-water Distribution	538,000	538,000	1,520,000	1,520,000
Hot-water Distribution	589,000	589,000	1,750,000	1,750,000
Ventilation and Exhaust	1,254,000	1,254,000	5,700,000	5,700,000
Space Air Conditioning	3,160,000	3,160,000	13,850,000	13,850,000
Engineering	367,000	432,000	1,485,000	1,773,000
Misc. & Contingencies	958,000	1,127,000	3,873,000	4,625,000
Total	7,713,000	9,075,000	31,173,000	37,232,000
<u>Annual Operating Expenses</u>				
Cooling (Electrical Power)	90,000	150,000	355,000	638,000
Heating (Electrical Power)	1,250,000	1,305,000	6,165,000	6,455,000
Operating Labor	20,000	20,000	120,000	120,000
Maintenance	80,000	100,000	300,000	375,000
Misc. (Supplies, Refrigerant & Chemicals, Lubricants, etc.)	6,000	8,000	25,000	40,000
Total	\$1,446,000	\$1,583,000	\$ 6,965,000	\$ 7,628,000

The system configuration utilizing heat pumps is similar to that illustrated in Fig. 4.1. The supply reservoir (S) receives water from the Fisk plant and/or Lake Michigan. The six central stations (C) now contain only booster pumps. Space conditioning of each apartment is achieved using individual or "modular" heat pumps. A single water line between the central stations and buildings is required, thus eliminating the two-pipe network necessary for the conventional system (Section 4.2). This scheme permits each apartment to have individual and independent temperature selectivity. An additional feature of the modular heat pump is that the superheat in the discharge gas from the individual compressors can be used to provide part of the domestic hot-water needs of each apartment.

Table 4.4 presents a cost estimate for the HVAC using the modular-heat-pump concept. The performance of the heat pump in the cooling mode has been assumed to be about the same as a conventional water chiller (Table 4.2) with 55-70°F cooling water available. This is a conservative estimate since there will be times, such as early spring, when lake water is available at temperatures as low as 40°F. Modular heat pumps are more complex than cooling units equipped with electric heat and, therefore, cost about 50% more. Offsetting this cost would be the simplified piping system, to and within the buildings, and the gain in equipment operating efficiency.

4.4 SUMMARY OF COSTS FOR VARIOUS SYSTEM ALTERNATIVES

The estimated costs for the various system alternatives are summarized in Table 4.5. Based on this table, a system using conventional heating and lake water at either 40 or 50°F for cooling is not economically competitive for SLNT, due to the prohibitively high capital cost of the intake-pipe extension. However, if water could be obtained from the lake at a reasonable cost, this system would be very attractive. Using 40°F water would result in the lowest capital investment for the various system alternatives. For example, for the ultimate development, a savings of about \$8,400,000 (about 21%) compared to the conventional system could be achieved.

Based on the cost estimates presented in this report, the modular (water-to-water) heat-pump system is economically attractive. It offers a reduction of about \$2,800,000 (about 7%) in the required capital investment for the HVAC for the ultimate development, when compared to the conventional

Table 4.4. Cost Estimate for HVAC for Modular Heat-pump System

	Initial development	Ultimate development
	<u>Capital Investment</u>	
Lake- & River-water Distribution	\$ 231,000	\$ 693,000
Central Stations	616,000	2,302,000
Water Distribution	600,000	1,783,000
Ventilation & Exhaust	1,254,000	5,700,000
Space Air Conditioning	4,563,000	20,000,000
Engineering	418,000	1,752,000
Misc. & Contingencies	1,089,000	4,570,000
Total	8,771,000	36,800,000
	<u>Annual Operating Expenses</u>	
Cooling (Electrical Power)	197,000	845,000
Heating (Electrical Power)	423,000	2,084,000
Operating Labor	20,000	120,000
Maintenance	90,000	350,000
Misc. (Supplies, Refrigerant, Chemicals, Lubricants, Water, etc.)	8,000	60,000
Total	\$ 738,000	\$ 3,459,000

Table 4.5. Summary of System Cost Estimates

System	HVAC Cost Estimates				Water Supply and Return ^a
	Initial Development		Ultimate Development		
	Capital Investment	Annual Operating Expenses	Capital Investment	Annual Operating Expenses	
Conv'tl. Htg. & Conv'tl. Cooling using Chillers with Cooling Towers	\$9,465,000	\$1,635,000	\$39,596,000	\$7,870,000	0
Conv'tl. Htg. & Heat Exchgrs. using 40°F Lake Water	7,713,000	1,446,000	31,173,000	6,965,000	>>8,290,000 ^b
Conv'tl. Htg. & Chillers using 50°F Lake Water	9,075,000	1,583,000	37,232,000	7,628,000	>8,290,000 ^c
Modular Heat-pump System	8,771,000	738,000	36,800,000	3,459,000	6,415,000 or 10,075,000 ^d

^a Bulkhead, renovation of Four-Mile Crib, pumping station, discharge system, etc.

^b Depending on length of lake-water pipeline extension necessary to obtain 40°F water, costs could be much greater than \$8,290,000.

^c Depending on length of lake-water pipeline extension necessary to obtain 50°F water, costs could be greater than \$8,290,000.

^d The lower cost is for discharge to Chicago River; the higher cost is for discharge to Lake Michigan.

system. Even more important are the substantial reductions in annual operating expenses. Due to the reduced power consumption in the heating season, for example, the annual operating expenses are reduced by about \$4,400,000 (about 56%) compared to the conventional system.

The heat-pump system requires a significant capital investment for the water (i.e., lake water or river water) -supply and -return system. If the water leaving the individual heat pumps can be returned to the Chicago River, the capital investment is about \$6,400,000. If the water must be returned to Lake Michigan, this investment is increased to about \$10,000,000.

Considering the ultimate development, the savings in annual operating expenses and the reduced capital investment for the HVAC would pay for the cost of the water-supply and -return system within one to two years. However, plans for SLNT call for phased development with completion of the project before the year 2000. For the initial development, the savings in capital investment for the HVAC is about \$700,000, compared to the conventional system. About \$900,000 per year will be saved in operating expenses. Based on the proposed development plan, the capital investment for the water-supply and -return system would not be recovered for several years.

4.5 ECONOMIC FEASIBILITY OF THE MODULAR HEAT-PUMP SYSTEM

Among the three innovative HVAC systems considered in this study, only the modular heat-pump system has been demonstrated to be technically feasible for the SLNT project. This section will demonstrate that the modular heat-pump system is also economically feasible when compared to the conventional system.

Table 4.6 presents the costs and differences in costs of the conventional system and the modular heat-pump system. These figures are developed directly from Table 4.5. Table 4.6 distinguishes between the initial development, remaining development, and ultimate development. This table illustrates that, after the initial increase in capital expenditures caused by the water-supply and -return system, the modular heat-pump system is estimated to require less capital costs than the conventional system. Table 4.6 illustrates also that, although annual operating costs for the initial development's modular heat-pump system are \$897,000 less than the conventional system, the use of the modular heat-pump system in the full development results in an

Table 4.6. Calculation of Incremental Costs (Thousands of Dollars) of Adopting the Modular Heat-Pump System Instead of the Conventional System

	<u>Initial Development</u>		<u>Remaining Development</u>		<u>Ultimate Development</u>	
	Capital Investment	Annual Operating Expenses	Capital Investment	Annual Operating Expenses	Capital Investment	Annual Operating Expenses
Conventional System	9,465	1,635	30,131	6,235	39,596	7,870
Modular Heat-Pump System						
On Site	8,771	738	28,029	2,721	36,800	3,459
Water Supply and Return	6,415 ¹ or 10,075 ²		Previously Completed		6,415 ¹ or 10,075 ²	
Difference	-5,721 ¹ or -9,381 ²	+897	+2,102	+3,514	-3,619 ¹ or -7,279 ²	+4,411

¹Alternative No. 1

²Alternative No. 2

annual savings of \$4,411,000. Thus, if the full development were built in conjunction with the water-supply and -return system, the modular heat-pump system would quickly pay for itself. Unfortunately, as previously mentioned, the full development will be built over a period of years or may not be built at all. It is therefore important to know what effects different development patterns will have on the economic feasibility of the modular heat-pump scheme.

To test for these effects, different construction schedules have been assumed for the SLNT development. The estimates of schedules of incremental costs of adopting the modular heat-pump system instead of the conventional system are shown in Table 4.7. This table presents a 20-year and a 10-year construction schedule for the remaining development after completion of the initial development. The first two rows of Table 4.7 show the incremental capital costs of the two alternative water-supply and -return schemes. These figures are obtained from the first column of the difference row in Table 4.6. Since full annual operating savings cannot be realized until one year after completion of the water-supply and -return system, the initial development operating savings are not shown until the end of year one of development operation. This assumes that the water-supply and -return system and the initial development are in operation for a year by 1980. The annual operating savings presented in the third (1980) row of Table 4.7 are those from the second column of the difference row of Table 4.6.

After construction of the initial development, uniform annual construction of the remaining development is assumed to take place over the 20-year (or 10-year) construction period. Thus, the capital savings for the remaining development, as presented in column three of the difference row of Table 4.6, are divided by 20 (or 10) years to obtain the annual savings in construction costs presented in Table 4.7.

As more and more of the development is constructed, the annual operating savings realized (by the choice of the modular heat-pump system instead of the conventional system) increase each year until the maximum annual operating savings are realized. These savings are equal to the \$4,411,000 figure presented in the final column of the difference row of Table 4.6. Obviously, with a 10-year instead of 20-year construction schedule, the full operating savings can be realized sooner and for a larger portion of the supply and return system lifetime.

Table 4.7. Assumed Schedules of Incremental Costs of Adopting the Modular Heat-pump System Instead of the Conventional System

Year	Initial Development Complete in 1979: 20 Years Construction to Ultimate Development			Initial Development Complete in 1979: 10 Years Construction to Ultimate Development		
	Incremental Capital (1)	Incremental Operating (2)	Total Incremental (3)	Incremental Capital (4)	Incremental Operating (5)	Total Incremental (6)
1979 Alt. 1	-5,721,000 ^a	0	-5,721,000 ^a	-5,721,000 ^a	0	-5,721,000 ^a
1979 Alt. 2	-9,381,000 ^a	0	-9,381,000 ^a	-9,381,000 ^a	0	-9,381,000 ^a
1980 1	105,100 ^b	897,000 ^a	1,002,100	210,200 ^c	897,000 ^a	1,107,200
1981 2	105,100 ^b	1,072,700	1,177,800	210,200 ^c	1,248,400	1,458,600
1982 3	105,100 ^b	1,248,400	1,353,500	210,200 ^c	1,599,800	1,810,000
1983 4	105,100 ^b	1,424,100	1,529,200	210,200 ^c	1,951,200	2,161,400
1984 5	105,100 ^b	1,599,800	1,704,900	210,200 ^c	2,302,600	2,512,800
1985 6	105,100 ^b	1,775,500	1,880,600	210,200 ^c	2,654,000	2,864,200
1986 7	105,100 ^b	1,951,200	2,056,300	210,200 ^c	3,005,400	3,215,600
1987 8	105,100 ^b	2,126,900	2,232,000	210,200 ^c	3,356,800	3,567,000
1988 9	105,100 ^b	2,302,600	2,407,700	210,200 ^c	3,708,200	3,918,400
1989 10	105,100 ^b	2,478,300	2,583,400	210,200 ^c	4,059,600	4,269,800
1990 11	105,100 ^b	2,654,000	2,759,100	0	4,411,000 ^a	4,411,000 ^a
1991 12	105,100 ^b	2,829,700	2,934,800	0	4,411,000 ^a	4,411,000 ^a
1992 13	105,100 ^b	3,005,400	3,110,500	0	4,411,000 ^a	4,411,000 ^a
1993 14	105,100 ^b	3,181,100	3,286,200	0	4,411,000 ^a	4,411,000 ^a
1994 15	105,100 ^b	3,356,800	3,461,900	0	4,411,000 ^a	4,411,000 ^a
1995 16	105,100 ^b	3,532,500	3,637,600	0	4,411,000 ^a	4,411,000 ^a
1996 17	105,100 ^b	3,708,200	3,813,300	0	4,411,000 ^a	4,411,000 ^a
1997 18	105,100 ^b	3,883,900	3,989,000	0	4,411,000 ^a	4,411,000 ^a
1998 19	105,100 ^b	4,059,600	4,164,700	0	4,411,000 ^a	4,411,000 ^a
1999 20	105,000 ^b	4,235,300	4,340,400	0	4,411,000 ^a	4,411,000 ^a
2000 21	0	4,411,000 ^a	4,411,000 ^a	0	4,411,000 ^a	4,411,000 ^a

^aFigure obtained from difference row of Fig. 4.6.

^bFrom difference row of Fig. 4.6 incremental capital investment of remaining development is spread over 20 yrs ($=2102000 \div 20$).

^cFrom difference row of Fig. 4.6 incremental capital investment of remaining development is spread over 10 yrs ($=2102000 \div 10$).

Although the water-supply and -return system would undoubtedly last longer, it is given a 21-year lifetime in this analysis for the purpose of simplifying computation. Since rates of return necessary to justify a project such as the one demonstrated here are relatively high, the effect of ignoring operating savings after 21 years is not substantial and, in any case, tends to favor the conventional system.

The assumptions discussed above result in the Table 4.7 streams of incremental capital and operating costs involved in selecting the modular heat-pump system. Column 1 presents the schedule of incremental capital costs (savings) assuming a 20-year construction schedule. For the same construction schedule, column 2 represents incremental annual operating savings. Column 3 is merely the sum of columns 1 and 2. To determine the rate of return earned on the 1979 incremental capital costs of the modular heat-pump system, it is necessary to find the rate of interest for which the sum of the present (1979) values of annual savings figures in column 3 is equal to the 1979 cost value in column 3. For alternative No. 1 (1979 incremental costs equal \$9,381,000), this rate of return is 19.2%. For alternative No. 2, the rate of return would be 28.0%. These estimates of project rate of return appear in the first two rows of the third column of Table 4.8.

Column 4 of Table 4.7 represents incremental capital costs (savings) assuming a 10-year construction schedule. Column 5 of the same table illustrates annual operating savings with the 10-year schedule, and the final column is the sum of these two. As shown in the fifth column of Table 4.8, the rates of return with a 10-year construction schedule are substantially increased. For alternative No. 1, the rate of return is 24.6% and for alternative No. 2, it is a substantial 35.6%.

The prudent investor, however, looks not only at his best possible return, but also at his worst likely rate of return. The remaining possibilities presented in Table 4.8 are intended to make this examination. One damaging possibility is that the SLNT project will not be a market success and will not be completed as planned. The first column of Table 4.8 takes this possibility into account by estimating rates of return if only the initial development is completed. For alternative No. 1, the rate of return for this case drops to an undesirable 7.5%. For alternative No. 2, the rate of return is a reasonable 14.8%.

Table 4.3. Rate of Return and Payback Period for Various Levels of Additional 1979 Investment to Install Modular Heat-pump System

Alternative	No Construction After Initial Development		20-yr Construction Schedule to Complete Ultimate Development		10-yr Construction Schedule to Complete Ultimate Development	
	Before-tax rate of return, % (1)	Crude payback period, yr (2)	Before-tax rate of return, % (3)	Crude payback period, yr (4)	Before-tax rate of return, % (5)	Crude payback period, yr (6)
No. 1	14.8	6.4	28.0	4.4	35.6	3.6
No. 2	7.5	10.5	19.2	7.0	24.6	5.1
No. 1 with 100% 1979 cost overrun	5.1	12.7	16.3	7.3	21.4	5.8
No. 1 with 200% 1979 cost overrun	<1.0	19.1	11.3	9.7	14.9	7.6
No. 2 with 100% 1979 cost overrun	<1.0	20.9	10.1	10.3	13.9	8.0

A second possibility that would damage the attractiveness of the modular heat-pump system is the chance of underestimating costs. To test for this possible problem, the 1979 incremental costs were increased from 100 to 200%, and rates of return were computed. The effects of these computations are illustrated in the last three rows of the table. In effect, if only the initial development were built, cost overruns would clearly kill the desirability of the modular heat-pump system. However, if the entire project were completed as planned, substantial cost overruns for the water-supply and -return system could be sustained without killing the economic viability of the heat-pump system.

Table 4.8 also presents a second tool of investment analysis, the payback period. The crude payback period presented in this table merely indicates how long it will take a future stream of benefits to equal a present cash-flow expenditure, without discounting the future. Ceteris paribus, the shorter the payback period the more desirable the project. The payback periods presented in the table complement the rate-of-return figures. They illustrate that some very attractive payback periods are possible if the modular heat-pump system is adopted.

In summary, this table clearly illustrates the desirability of applying the modular heat-pump system for a broad range of alternative events. The absolute desirability of the system can only be defined by those who decide on a reasonable rate of return. However, there is clearly a broad range of possible rates of return which would be attractive to private industry, quasi-public (regulated) industry such as utilities, or government agencies. (See note for additional discussion on project economics.)

Note: Some factors not yet discussed could affect project feasibility. These are (1) variation from the kW/ft² figures used in this study, (2) electricity-cost escalation, (3) water-temperature variability, and (4) power-plant retirement.

The heating-demand figures used in the cost calculations could be up to 30% higher compared to demands in well-insulated buildings. Such a possibility would clearly reduce the economic attractiveness of the modular heat-pump system. However, on the other side of the economic-feasibility issue is the fact that likely escalation in electricity costs has not been taken into account in the cost calculations. Reasonable electricity cost-escalation rates would positively affect the economic

feasibility of the modular heat-pump system and would far outweigh the possible effects of a reduced figure.

While the project costs are computed on a constant-water-temperature assumption, there would be some episodes when water temperature could not be held at 60°F. Compensation for this problem would involve the addition of capacity to the modular heat pumps. Since the economic feasibility of the system is dominated by the capital costs for water supply and return, the added capital costs for capacity of heat pumps would probably not alter any rates of return presented in Table 4.8 by as much as 1%.

Finally, there is the possibility that the Fisk power plant could be shut down by 1994, if Commonwealth Edison's plans are to be believed. There are good reasons to assume that this plant (perhaps with new generating units) will continue to operate indefinitely. A history of Fisk plant decommissioning plans since its construction can be cited. Yet, the plant still exists. Environmental regulations now prevent the modification of Fisk, primarily because of high scrubber costs. By 1994, however, environmental-control technology may be well developed and costs reasonable. Also, the decommissioning of Fisk would require substantial investment in new transmission facilities in Chicago's central area. Continued operation of Fisk will allow existing transmission facilities and rights of way to be used. On the whole, then, it is reasonable to assume continued operation of Fisk. Further, even if Fisk were shut down in 1994, the investment in the water-supply and -return system could have been paid off. In such a case, a central heating facility could be constructed at the Fisk site for the SLNT project.

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5 SUMMARY AND CONCLUSIONS

5.1 CHARACTERISTICS OF WATER VS. ELECTRICITY FOR ENERGY SUPPLY

In this report, three innovative water-based district heating-and cooling systems were examined and compared to a conventional all-electric system for application to the SLNT site. To make general comparisons between system options requires considering such attributes as efficiency, marketability, dependability, and degree of utilization. For the SLNT site, the modular heat-pump system scores better than the conventional electric system on enough of these attributes to be the most attractive system for consideration. If similar applications are to be found on a national level, candidate projects will need to be selected on the basis of their satisfaction of these four attributes in ways similar to the SLNT project. A discussion of each attribute with respect to water-based and electric-based energy supply follows.

5.1.1 Efficiency

One attribute of the efficiency of water-based energy-supply systems is deliverability of the energy resource per dollar invested or per unit distance delivered. This study illustrates the fact that capital costs of a water-distribution system for heating/cooling can be very substantial. In general, the distribution of energy via water in a pipe network is much less efficient and more costly per unit energy delivered per unit distance than is distribution via a conventional electric-cable grid system. On a percentage basis, energy losses per unit distance are substantially greater for a water-distribution network than for an electricity-distribution grid. As a consequence of these properties, the economic viability of a water-based community energy system will be strongly influenced by proximity of the community and the water energy resource (see References 1 and 3).

In the case of the SLNT project, an economical and efficient water-distribution system can be constructed. There is the opportunity to combine power-plant waste heat and residential heating demand with a comparatively low-capital-cost distribution system whose distance of distribution does not result in substantial energy losses before consumption of the energy. The relatively low capital costs illustrated earlier are possible because of the existing network of tunnels which can be used for water distribution.

Additional tunneling required to complete the system is about 5000 ft, not including discharge tunneling to Burnham Park Harbor. This is important to the SLNT application because of the high costs of new tunnels in an urbanized area. Near more rural power plants, much lower tunnel costs could be expected.

Estimates of uninsulated piping heat loss over the distance from the Fisk Generating Station to the SLNT site indicate less than 1°F drop in temperature. On the SLNT site itself, distribution costs are less than for residences in general, since the development is one of relatively high density. The low mean unit-to-unit distance in a high-density residential area lends itself to shorter runs of pipe and to higher average diameter of piping. Both of these piping properties reduce heat losses by reducing the surface area of pipe per unit volume of water distributed.

5.1.2 Marketability

A problem related to a pipe distribution system is the inability of marketing a water-energy resource via existing grids supplying other customers. Electricity, gas, and oil energy supplies all have the advantage of being marketable through a distribution grid of one sort or another (electricity by wire, gas by pipe, oil by highway). Consequently, a supplier of electric, gas, or oil energy to a community under development can easily market excess supplies to customers outside the community, recovering capital costs invested in providing a given supply capacity. Such an opportunity is not available to suppliers of energy stored in water.

If the power-plant water is to be used to provide heat to the SLNT, one problem to be faced is the lack of a fully developed market at the time the supply system is completed. A major portion of initial tunneling costs from the Fisk plant to the Blue Island Tunnel (see Fig. 1.1) would be labor costs and permit-approval time costs. To go through such costs only once, it would be less costly initially to provide full capacity to serve the eventual SLNT site rather than to reconstruct the tunnel system as the size of the SLNT increases. However, as Table 4.8 shows, the recovery of the cost of initial excess capacity depends greatly on the rate at which the SLNT is completed. More rapid completion shortens the payback period and increases the rate of return. However, even with rapid completion, a single SLNT project-

development corporation suffers some adverse cash-flow effects. Consequently, the construction of a water-supply system and the sale of heated water would best be accomplished by a public utility for which the capital expenditures of this project are only a minor element. For existing public utilities to enter this field of endeavor, legislation might be required. Water utilities are typically not in the business of selling energy, while electric utilities are seldom involved in selling water.

5.1.3 Dependability

Dependability is a third factor of concern. It is also ultimately related to the availability of a marketing grid. Electric utilities take advantage of regional and national grids to purchase power from one another and distribute it over their local networks in periods when local capacity cannot meet local demand. Similarly, a customer for oil may purchase from another supplier if his customary supplier cannot supply his needs. Only suppliers of natural gas are currently not dependable. As discussed, the effect of this potential lack of continued supply of natural gas is illustrative of the potential importance of a dependable energy supply. Current gas prices arising from regulation dictate the use of gas instead of electricity if gas supplies are assured. However, supplies of gas at current prices are not sufficient to meet demand. As a result, fewer and fewer new customers are installing gas-based energy systems.

In fact, as a result of supply curtailments, some existing gas users are converting to alternative energy systems in spite of higher costs of alternative fuels. It is apparent that energy customers will pay substantial penalties to avoid interruption in service. This fact makes it necessary to provide highly dependable water-based community energy systems if they are to replace conventional systems. For systems using heated water from power plants, this raises the problem of energy supply during power-plant maintenance or during unforeseen shutdowns. A single power-generating unit linked to a single community would not provide adequate system dependability.

This dependability consideration may favor fossil-fuel-fired power plants, such as Fisk, over nuclear plants for heated-water supply. In Fisk and other fossil-fuel-fired plants, electricity is generated by multiple units. With multiple units of similar generating capacity, such a power

plant can be in continuous operation even though individual units may shut down for maintenance or by operating problems. For such a plant, two approaches for provision of dependability are possible. A community might be designed to utilize waste heat from only that fraction of the plant capacity expected to be in continuous operation, or the community could be designed to utilize full-capacity waste heat generated from the plant and accept efficiency losses due to reductions in waste heat available during generating-unit shutdowns. The minimum waste-heat flow expected from the Fisk plant with only the smaller of the two units operating is more than sufficient to provide heating for the SLNT project.

Failure to provide the design level of system performance is clearly not as costly as complete failure of the system. Winter failures are those that must be avoided since prolonged lack of heat not only causes physical damage to buildings but also affects the health of human beings. If winter "failures" are confined to short periods, and to temperatures well above freezing, then the cost of this type of failure may be acceptable when compared to overall efficiency benefits of the system.

In a recent paper (1976), Illeri et al.³ compare schemes for waste-heat utilization in which communities utilized power-plant waste heat for heating and cooling. Three different climates, two community sizes, two systems, and four power-plant types were examined in various levels of detail. The two waste-heat utilization schemes were 1) a steam bleed-off system using 300°F water from the power plant and 2) a heat-pump system using power-plant condenser-outlet temperatures varying from 46 to 120°F depending on location and time of year. The steam bleed-off system was slightly more economical than the heat-pump system. However, operation of the systems during power-plant shut down was not considered. The steam bleed-off system would be inoperative, but the heat-pump system could still be operated (though at a loss of efficiency) if it were linked on a standby basis to the power-plant cooling-water supply. Such an opportunity is an attractive option for a heat-pump system as long as the power-plant cooling-water supply is sufficiently above freezing in coldest periods.

The Chicago River adjacent to the Fisk Generating Station meets this criterion. Water temperature rarely falls below 40°F in winter months. Water-to-water heat pumps, selected for the SLNT project, can be run at 35°F,

although at a substantial loss in efficiency. However, the point is that, even in the unlikely event of a complete failure of the Fisk plant, SLNT residents would have heat. (If failure included failure to provide power locally from other stations on the grid, the SLNT residents would be no worse off than other electrically heated residences in the area.)

The use of numerous smaller heat pumps throughout the SLNT site also has the effect of increasing system dependability in worst periods. If two heat pumps rather than one serve a building, then if one pump fails to operate, the building will not completely lose heat (or cooling). Those zones heated by the failed pump will still receive heat from other zones of the building. Thus, the possibility of "catastrophic" local-building-system failure is mitigated.

5.1.4 Utilization

In the trade-off between capital costs and operating costs, the effect on operating costs (savings) of the degree of utilization have not been mentioned. One aspect of utilization is illustrated by the present problems of northern U.S. electrical utilities with respect to air-conditioning demand. Many of these utilities are concerned with the need to build plant capacity to meet peak electrical demand which occurs only on a very few hot days in the summer. At present, most utilities, by regulation, must charge for electricity on the basis of the average cost of providing the electricity. Unfortunately, this charging procedure does not allow the utility to recover the actual cost of constructing additional facilities to serve consumers for only a few days per year. In northern areas, consumers with air conditioning are subsidized by those without air conditioning. If utilities did, in fact, charge the actual cost of providing the final increment in capacity, the costs to consumers for peak electricity would be substantially greater than at present. In Northern Illinois such a peak (or marginal) pricing scheme would increase costs of air conditioning substantially.

An attractive attribute of the heat pump is that its capital costs are utilized throughout most of the year. It is one piece of capital equipment which can provide both heating and air conditioning and save fuel at the same time. As fuel costs in general increase, and if utilities begin to adopt peak-pricing policies, these attributes of the heat pump will make it more

attractive relative to current two-system, heating/cooling methods in residences.

While summer peak pricing by some utilities may cause people to abandon air conditioning as a consumer good, there is reason to doubt that this will be the case in multifamily construction such as that to be built in the SLNT. In 1975 the rate of installation of air conditioning in multifamily units in the North Central U.S. was 88% compared to 35% in single-family housing.⁵ Further, the typical multifamily building does not present the opportunity for cross-ventilation in moderately hot days. The variation of heating and cooling loads from southern to northern exposures can be substantial. On occasion, both heating and cooling can be required in the same building. Thus, the market and the technical need for air conditioning in multifamily housing is far greater than in single-family housing. As a result, heat pumps are more attractive than if only heating were needed.

Still another aspect of the heat-pump system proposed here, which might easily be overlooked, is its effect on present and future electricity demand. Currently, Commonwealth Edison experiences a summer peak in demand due largely to residential customers. The systems proposed here for the SLNT would reduce the magnitude of SLNT's contribution to this peak. In the future, as more and more new homes install electrical heating systems the Commonwealth Edison peak will shift to winter months. The proposed modular heat-pump system will substantially reduce the SLNT's contribution to this peak. This is not a trivial point, because it depends on the use of water-to-water heat pumps running from constant-temperature water. Conventional air-to-air heat pumps, if installed in the future in Chicago area homes, may save fuel, but they can contribute to a substantial winter peaking problem for Commonwealth Edison. In coldest periods, air-to-air heat pumps have freezing problems and become less efficient than resistive heating. Unless backed up by resistive heating, they increase peak demand above that for resistance heating only. Even if air-to-air heat pumps are backed up by resistive heating, such a mixed system would be much less efficient than the (constant-temperature) water-to-water system proposed here.

Finally, as indicated above, the cold-weather dependability of the water-to-water heat-pump system proposed for the SLNT site obviates the need for a seldom-utilized, resistive back-up heating system. Thus, the effect of

using Fisk warm water and Lake Michigan cool water is to allow a single heat-pump system to meet both heating and cooling needs with adequate dependability. Multiple systems, and system redundancy, so common in most current HVAC installations are eliminated.

5.2 SUMMARY AND RECOMMENDATIONS FOR FURTHER WORK

This report has demonstrated that the modular heat-pump system is both technically and economically feasible for application to the SLNT site. The system is attractive from the point of view of efficiency, dependability, and rate of utilization of capital equipment. As a result, it is economically superior to its logical competitor, a conventional all-electric system. It would appear even more economically attractive in the presence of increasing fuel prices and rapid SLNT construction. Remaining problems to be overcome are primarily institutional. In view of economic and fuel-conservation possibilities, the institutional impediments to this project should be studied with attention to their removal.

The scheme proposed here for heating and cooling the SLNT project derives its viability from several factors. These are:

1. the existence of an abandoned water-intake crib and associated abandoned water tunnels,
2. demand for cooling in multifamily dwellings,
3. proximity of cool- and warm-water resources to the site,
4. linkage to a multiple-generating-unit power plant, and
5. large savings in fuel cost due to large fuel demands in the Chicago climate.

If the approach taken here is to have an impact on the national energy picture, it will be necessary to demonstrate the economical use of power plant or industrial waste heat and/or cool-water resources in other situations. A much broader range of possibilities should be examined. The results of this study give reason to believe that numerous economically desirable applications can be found. It is proposed, therefore, that the present project be continued and that it address the following three areas:

- (1) complete analysis of the remaining impediments to implementation of the ANL scheme for the South Loop New Town HVAC system,

- (2) development of a nationwide inventory of sites where the ANL concepts can be economically applied, and
- (3) development of information on the potential energy savings to be gained by implementation of such systems at the several potential sites nationwide.

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APPENDIX A. LAKE MICHIGAN WATER TEMPERATURES AND CURRENTS
OFFSHORE OF CHICAGO'S FOUR-MILE CRIB,
MAY-OCTOBER, 1976

Lake-water temperatures and currents were measured almost continuously from May 20 through October 29, 1976, at two stations (Fig. A.1) located 4.2 and 8.8 mi offshore from the City of Chicago's abandoned Four-Mile Crib. In addition, lake-water temperatures at four different depths were measured at a thermograph station located 2.1 mi offshore from the Four-Mile Crib from July 1 through October 29, 1976.

The current meters used for this study had Bendix Q-15R current-meter heads. The current data, along with data from several thermistors, were recorded with in-situ electronic instrumentation developed by Argonne National Laboratory. Only water temperatures were recorded at the nearshore station. A more detailed description of the current meters and instrumentation packages, along with equipment and data-handling techniques, is contained in an Argonne National Laboratory report (Saunders and Van Loon, 1976).

Temperature data from thermograph Station T6 (Fig. A.1) are presented in Figs. A.2-A.5. Temperatures were recorded at 1-1/2, 2-1/2, 5, and 10 meters above the lake bottom. Although it is difficult to distinguish the four curves in the figures, water temperature generally decreased with depth. The lowermost thermistor probe at Station T6 recorded water temperatures that fluctuated between about 10 and 18°C (50 and 65°F) for July. In August, there was an extended period when the lake-water temperature near the bottom never dropped below 19°C (66°F). The warm temperatures extended into September and finally began to drop in early October. Similar bottom temperature behavior was noted also at Stations VI and V (Figs. A.6-A.17). Data were also available for late May and June at the two offshore stations. For this period, bottom-water temperatures were less than 10°C (50°F).

Lake-current data measured at Stations VI and V are presented in Figs. A.18-A.29. Currents at the two stations were dominantly shore-parallel with speeds generally less than 100 mm/s (0.3 ft/s). However, some episodes occurred when current speeds were as high as 310 mm/s (0.9 ft/s).

Fig. A.1. Location of Thermograph and Current-meter Stations.

Fig. A.2. Lake-water Temperature at Station T6 for July, 1976.

Fig. A.3. Lake-water Temperature at Station T6 for August, 1976.

Fig. A.4. Lake-water Temperature at Station T6 for September, 1976.

Fig. A.5. Lake-water Temperature at Station T6 for October, 1976.

Fig. A.6. Lake-water Temperature at Station VI for May, 1976.

Fig. A.7. Lake-water Temperature at Station VI for June, 1976.

Fig. A.8. Lake-water Temperature at Station VI for July, 1976.

Fig. A.9. Lake-water Temperature at Station VI for August, 1976.

Fig. A.10. Lake-water Temperature at Station VI for September, 1976.

Fig. A.11. Lake-water Temperature at Station VI for October, 1976.

Fig. A.12. Lake-water Temperature at Station V for May, 1976.

Fig. A.13. Lake-water Temperature at Station V for June, 1976.

Fig. A.14. Lake-water Temperature at Station V for July, 1976.

Fig. A.15. Lake-water Temperature at Station V for August, 1976.

Fig. A.16. Lake-water Temperature at Station V for September, 1976.

Fig. A.17. Lake-water Temperature at Station V for October, 1976.

Fig. A.18. Lake-current Speed and Direction at Station VI for May, 1977.

Fig. A.19. Lake-current Speed and Direction at Station VI for June, 1977.

Fig. A.20. Lake-current Speed and Direction at Station VI for July, 1977.

Fig. A.21. Lake-current Speed and Direction at Station VI for August, 1977.

Fig. A.22. Lake-current Speed and Direction at Station VI for September, 1977.

Fig. A.23. Lake-current Speed and Direction at Station VI for October, 1977.

Fig. A.24. Lake-current Speed and Direction at Station V for March, 1977.

Fig. A.25. Lake-current Speed and Direction at Station V for June, 1977.

Fig. A.26. Lake-current Speed and Direction at Station V for July, 1977.

Fig. A.27. Lake-current Speed and Direction at Station V for August, 1977.

Fig. A.28. Lake-current Speed and Direction at Station V for September, 1977.

Fig. A.29. Lake-current Speed and Direction at Station V for October, 1977.

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