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FEASIBILITY OF A DISTRICT COOLING SYSTEM USING NATURAL COLD WATER

SUMMARY REPORT

by

Tracor JITCO

ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

Prepared for U. S. Department of Energy

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**FEASIBILITY OF A DISTRICT COOLING SYSTEM
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by
Tracor JITCO

prepared for

Energy and Environmental Systems Division
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PREFACE

NATURAL COLD WATER DISTRICT COOLING

CONCEPT REVIEW

Cold water can be used to directly cool buildings. Studies indicate that when a sufficient quantity of natural cold water is available close to areas of high air conditioning demand, 70 to 80 percent of the electrical energy used for air conditioning can be saved by converting to this technique.

The electricity saved in this manner smoothes the hot weather electrical demand peaks, reducing the need for expensive peaking equipment and the possibility of brownouts.

A PROVEN CONCEPT

Direct natural cold water cooling is a proven concept. Air-conditioning handbooks printed as late as the 1950's suggest the use of local water supplies for direct cooling. Many installations were made in the mid-west using city water. This concept fell into disuse in more recent years because the availability of unlimited cheap electricity made the search for large cold water bodies, and the means to exploit them, unnecessary.

- (A) Land distribution system. Each outlet represents a large building or complex.
- (B) Closed loop chilled water circulating pump.
- (C) Discharge of used water locally, or into discharge system for re-use or reservoir recharge.

SCHEMATIC OF DISTRICT COOLING SYSTEM

HOW WILL IT WORK?

A Cooling District is formed (Cold Water Utility Company) and cold water (salt or fresh) is delivered at a contracted rate to heat exchangers on the users' properties, much the way electricity is delivered to the transformer on the pole. The user circulates fresh water through the other side of the heat exchanger to one or more coil/fan units in his building. (This is the chilled water air-conditioning system in common use today.) Refrigeration compressors, cooling towers and much auxiliary air-conditioning equipment are thus replaced by a heat exchanger. The entire concept makes use of existing technology.

COLD WATER SOURCES

Initial research in this program was directed at determining the feasibility of using cold seawater for direct cooling in areas where it is available close to shore near areas of large cooling demand (e.g., South Florida, South California, and Honolulu and Puerto Rico). Results from the preliminary work show technical feasibility as well as economic and energy-saving benefits. These have been impressive enough to warrant extending the program to major fresh water sources so that inland cities could also utilize the concept. This has great promise, since deep lakes in areas where the air temperature drops below 39°F in the winter (temperature zone) have year-round bottom temperatures of about 40°F. This water occurs at depths much more accessible than the cold seawater. Ground water in the northern-most U.S. is also suitable for use.

OTHER USES

The cold water, once used for air conditioning, is returned to the sea, lake, or aquifer from which it was removed. Depending on local needs, the used water can be re-used for:

- Supplemental fire systems
- Pools and sanitary systems
- Industrial process water
- Industrial cooling (it will still be cooler than ambient)
- Irrigation (fresh water)
- Flushing of local water bodies
- Supplemental fresh water supply (after treatment) or anywhere that cheap non-potable water can be used.

RENEWED INTEREST

Cheap electricity and unlimited energy are things of the past. Alternate energy sources are being sought while conservation efforts are intensified (the electrical equivalent of a barrel of oil saved is worth three barrels delivered).

- Advances in marine and aquatic sciences and offshore pipeline technology make hitherto unknown or unavailable cold water sources accessible.
- The concept of heating and cooling districts, proven elsewhere in the world, permits the economic benefits of large, centralized cold water intakes and distribution systems. Preliminary analyses for the Miami area indicate that, in addition to great electrical savings, the cold water system is cost competitive with conventional air-conditioning systems over time.

CONCEPTUALIZED VIEW OF SEAWATER COOLING SYSTEM

(A) Sea bottom (B) Deep seawater intake (C) Offshore pipeline (buried in shallow water) (D) Wet well and pumps (E) Land distribution system.

ABSTRACT

This report outlines the findings of investigations into the use of natural cold water district cooling systems. Concepts involving the use of natural cold water for cooling commercial and residential buildings have been examined and found to be economically sound and technically feasible. Studies indicate that naturally occurring cold water sources exist in proximity to certain municipal areas that have large cooling demands. Savings in energy resources, long term cost benefits, and environmental safety are the most attractive features of natural cold water cooling.

ENERGY SAVINGS

As a result of in-depth studies of the various aspects of natural cold water cooling, it has been concluded that at present technology levels, such a system could conserve as much as 70 to 80 percent of the electrical energy now being used in conventional air-conditioning systems. This energy saving is the result of the elimination of compressors and condensing units which are the largest energy users in conventional systems. In a natural cold water district cooling system, energy is used to pump the water from its source and circulate it through the system, and for air circulation. Energy savings for a Miami Beach Cooling District should be 30 to 40 percent of total energy use. Peak energy savings of 16 MW are predicted for a single district.

COST BENEFITS

Although the initial cost of developing a natural cold water district cooling system using natural cold water would be greater than the cost of an equivalent amount of conventional air-conditioning equipment, cost benefits over the life of the system would more than offset these initial costs. Savings from reduced energy use would pay back the initial investment, including the cost of the invested money at the probable interest rates, within the first five years of the equipment life cycle. The study of a Miami Beach site shows that over a 20 year equipment life cycle, the net cost saving for that site (after payback) should average 30 to 40 percent.

ENVIRONMENTAL SAFETY

The implementation of a natural cold water district cooling system should have no negative impact on the environment. The reduction in energy use would indirectly reduce air pollution and fossil fuel depletion. System discharge water, which would be clean and unaltered, would be near or slightly below ambient temperature. This water could be applied to other useful purposes such as crop irrigation, flushing rivers and streams, etc.

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INTRODUCTION

Direct natural cold water district cooling involves the use of natural cold water circulated through a heat exchanger, which eliminates the need for vapor compression system such as that used in conventional air-conditioning systems. A simplified diagram of a typical conventional air-conditioning system is shown in figure 1. A compressor forces compressed vapor through a water cooled condenser which removes heat from it as it is compressed into liquid form. This liquid is released into a heat exchanger where it expands into a gas, cooling the water in the chilled water loop. This chilled water is circulated through cooling coils that are used to cool the air in the room.

FIGURE 1. CONVENTIONAL AIR-CONDITIONING PLANT

Figure 2 shows the individual building portion of a natural cold water district cooling system as it would be designed to replace the system shown in figure 1. The direct cold water cooling system would use the existing chilled water loop and air handling equipment in each building, and the natural cold water system would be a utility servicing the entire district. Specific data cited in this report is extracted from the results of an in-depth study of a proposed cooling district which would comprise the newer hotel area of Miami Beach, Florida. These values would vary depending on specific site conditions and the cost versus efficiency trade-off decisions must be made separately for each site.

FIGURE 2. INDIVIDUAL USER EQUIPMENT FOR THE NATURAL COLD WATER DISTRICT COOLING SYSTEM

COLD WATER SOURCE

Direct cold water cooling when used without further moisture removal generally requires a cold water source that is 50°F or colder. Usable natural cold water occurs near land in some offshore ocean sites and in many large lakes. The location and depth of the natural cold water is unique for each geographical area. An area study of each prospective district cooling location must be made to determine the distance from shore and the depth at which usable cold water sources exist. These and other factors will determine whether natural cold water district cooling would be technically feasible at a particular location.

A feasibility study conducted recently resulted in the confirmation that several sites could benefit by converting to natural cold water district cooling. One such site is the hotel area of Miami Beach, Florida (see figure 3). A usable source of natural cold water is located about four miles off-shore at a depth of 700 feet. For that site, converting to a district direct cold water cooling system would represent a sound investment because more than 50 percent of the electrical energy consumed by the area is used for air-conditioning. The proposed cooling district would consist of 38 buildings presently using 20,000 tons of chilled water system air-conditioning.

PUMPING AND PIPING

The primary technical problems and a major portion of the costs for the development of natural cold water district cooling systems result from the requirement for long runs of large diameter off-shore pipe from the natural cold water source to the cooling site. A pumping station on land would pump the natural cold water into the district circulation system which distributes it to the individual users.

FIGURE 3. AERIAL VIEW OF MIAMI BEACH

INDIVIDUAL BUILDING COOLING SYSTEMS

The conversion of individual building cooling systems would involve the installation of pipelines to the buildings from the central pumping station and modification of the existing air-conditioning system. The chilled water circulating system and the air handling equipment of the existing system could be retained and the natural cold water would replace the vapor compression system, eliminating the need for compressors and condensing units. With the installation of a switching/bypass system, the existing air-conditioning equipment could be retained as an alternate system.

SYSTEM IMPLEMENTATION

The implementation of a natural cold water district cooling system generally requires a permanent source of natural cold water below 50°F. Some other factors affecting the feasibility of such a system are:

- Depth of the cold water source and distance from shore
- Total cooling demand
- Density of buildings
- Seasonal and transient water temperature fluctuations
- Elevation of the cooling district
- Waves and currents (normal and storm conditions)
- Condition of the ocean or lake bottom at the cold water source and along the pipeline route
- Site construction conditions

Bathymetric and temperature studies are necessary to determine the location and extent of a usable cold water source. Time series tests must be made throughout at least a full year to determine the stability and reliability of the natural cold water source. The depth and distance from shore of the cold water source are of primary importance in determining the cost of installing the off-shore pipeline which will bring the cold water from the source to the pumping and distribution equipment. Underwater currents and storm waves would necessitate anchoring the pipeline, even if it is buried in the ocean or lake bottom, and these forces will determine the type of or extent to which such anchoring is required. Bathymetry and sub-bottom geology are used to select the pipeline route, the method of anchoring, and other construction techniques.

A variety of techniques for the installation of large diameter offshore pipelines is presently available. The specific technique used in any installation is dependent on site conditions. In the Miami Beach area, variation of the swamp method (bottom pull) is the most satisfactory method. Because of the congestion in the area, a temporary offshore assembly/launching would be required. Even with this added cost, a direct cold water cooling system at the Miami Beach site would still result in substantial savings over the life of the equipment. This is largely due to the high population density and high cooling demands in the area.

The population density in the cooling district and its distance from and elevation above the cold water source are important considerations in determining the feasibility of direct cold water cooling. There is obviously a point where the energy used for distributing the cold water overcomes the basic economies of the system if the district buildings are too widespread, too far from the source, or too high above sea or lake level.

The pumping system selected for Miami Beach is a variable flow system based on the necessity of reducing electrical use during periods of low demand. Figure 4 illustrates the heat gains in the system at different flow rates. The lowest permissible flow for this system was 10,000 gpm. Below this flow rate heat gains become unacceptable.

SUMMARY OF HEAT GAINS IN SYSTEM (MIAMI BEACH)

	$\Delta T @$ 50,000 GPM °F	$\Delta T @$ 10,000 GPM °F	$\Delta T @$ 5,000 GPM °F
1. INFLUENT PIPE CONDUCTION GAIN			
A. EXPOSED PIPE SECTION	.123	.615	1.230
B. BURIED PIPE SECTION	.072	.360	.720
2. INFLUENT PIPE FRICTION GAIN	.062	.003	-
3. WET WELL GAIN			
A. CONDUCTION	.014	.070	.140
B. PUMP BOWL INEFFICIENCY	.042	.021	.021
4. INFLUENT -- SUBTOTAL	.313	1.069	2.111
5. NORTH LEG FRICTION GAIN (@ 60% OF TOTAL FLOW RATE - INCLUDES PUMP COLUMN GAIN)	.030	.001	-
6. NORTH LEG CONDUCTION GAIN	.492	.994*	1.621*
7. NORTH LEG GAIN -- SUBTOTAL	.522	.995	1.621
8. PLUS INFLUENT -- SUBTOTAL	.313	1.069	2.111
9. NORTH LEG -- TOTAL ΔT	.835	2.064	3.732
10. EXPECTED DISCHARGE TEMP. WITH 45.5°F INLET TEMPERATURE	46.335	47.564	49.232
5A.) SOUTH LEG FRICTION GAIN (@ 40% OF TOTAL FLOW RATE - INCLUDES PUMP COLUMN GAIN)	.016	.001	-
6A.) SOUTH LEG CONDUCTION GAIN	.460	1.496**	2.736**
7A.) SOUTH LEG GAIN -- SUBTOTAL	.476	1.497	2.736
8A.) PLUS INFLUENT -- SUBTOTAL	.313	1.069	2.111
9A.) SOUTH LEG TOTAL ΔT	.789	2.566	4.847
10A.) EXPECTED DISCHARGE TEMP. WITH 45.5°F INLET TEMPERATURE	46.289	48.066	50.347

*ASSUMED A MINIMUM THROWAWAY DISCHARGE OF 600 GPM.

**ASSUMED A MINIMUM THROWAWAY DISCHARGE OF 438 GPM.

NOTE: SEE FIGURE AT RIGHT FOR ΔT LOCATIONS

SEAWATER COOLING SYSTEM SCHEMATIC

FIGURE 4. SUMMARY OF HEAT GAINS

The cost of the distribution system and the energy required for pumping as compared to the cost of operating an equivalent conventional system is the measure of whether a particular site is suitable for conversion. Energy costs are currently increasing at a faster rate than construction costs, so some sites that may not be suitable for conversion at today's costs may become viable candidates if, as predicted, fuels become scarcer and more costly in the future.

LOCATING THE COLD WATER SOURCE

Extensive bathymetric and temperature studies are necessary to determine the depth, the distance from shore, and the reliability of the natural cold water source.

Bathymetric and Temperature Studies

Bathymetric studies provide bottom profile data and are used in this case to determine bottom depths at various distances from shore. Bathymetric data aids in planning pipeline routes.

Ocean Sites. Figure 5 shows the general bathymetry of the Florida Straits. Temperature studies provide water temperature data as they relate to the bathymetry, as shown in figure 6. Figure 6 is a temperature profile of the same area for which bathymetry data are shown in figure 5. These studies facilitate the location of the usable water source by showing the temperature of the water in relation to depth and distance from shore.

Bathymetry and temperature profiles of other ocean sites are shown in figures 7 through 14. These sites are:

- Los Angeles, California
- San Diego, California
- San Juan, Puerto Rico
- Honolulu, Hawaii

Los Angeles and San Diego (figures 7 through 10) are not particularly suitable cooling districts because the cooling demand is low and the potential natural cold water cooling district is farther inland.

At San Juan, Puerto Rico (figures 11 and 12), the usable cold water source occurs about four miles off shore at a depth of over 2,000 feet. Although the cooling demand is high and the buildings are close to the shore, the depth of the cold water source makes this location unattractive as a cooling district site at current technology levels and construction costs.

The Waikiki Beach area of Honolulu (figures 13 and 14) has a high cooling demand and its buildings are located close to the shore. A usable cold water source is located about two miles offshore at a depth of 1,440 feet. A district cold water cooling system using seawater would be feasible at this site. Although the cold water supply pipeline for the Honolulu system would be shorter than the pipeline for the Miami Beach system, construction and maintenance for the Honolulu pipeline would be more difficult because of the depth of the cold water at the Honolulu site.

FIGURE 5. BATHYMETRY - SOUTH FLORIDA

FIGURE 6. TEMPERATURE PROFILE - MIAMI

FIGURE 7. BATHYMETRY - LOS ANGELES

FIGURE 8. TEMPERATURE PROFILE - LOS ANGELES

FIGURE 9. BATHYMETRY - SAN DIEGO

FIGURE 10. TEMPERATURE PROFILE - SAN DIEGO

FIGURE 11. BATHYMETRY - SAN JUAN

FIGURE 12. TEMPERATURE PROFILE - SAN JUAN

FIGURE 13. BATHYMETRY - HONOLULU

FIGURE 14. TEMPERATURE PROFILE - HONOLULU

THE ANNUAL TEMPERATURE CYCLE IN TYPICAL DEEP LAKES OF THE TEMPERATE ZONE. IN THE DEEP PART OF A LAKE BASIN THE WATER TEMPERATURE REMAINS CLOSE TO 39°F. THROUGHOUT THE YEAR. (AFTER HOUGH)

FIGURE 15. TYPICAL TEMPERATURE CYCLE IN DEEP LAKES

Lakes. The waters of deep lakes in the temperate zone tend to stratify into three thermal layers during the summer months:

- The epilimnion — the sun-heated, wind-mixed upper layer
- The thermocline — the transition layer between the warm and cold water
- The hypolimnion — the dense cold bottom layer

The epilimnion is usually at or near the average daily temperature of the air and extends deeper in warmer than cooler climates. The warmer the climate, the deeper a lake must be to be useful for cooling. Shallow lakes (less than 100 feet deep) are not well stratified, because wind action tends to mix the waters more uniformly, making them unsuitable for cooling purposes. This mixing action also occurs in deeper lakes, but as a result of the stratification in summer, only the upper layer (epilimnion) is mixed, as shown in figure 15. The denser hypolimnion, or bottom layer, remains stable and tends to maintain a temperature near 39.2°F in temperate climates where water temperature drops to freezing or near freezing in the winter. Water reaches its maximum density at 39.2°F, so in climates where temperatures fall below that level, the hypolimnion consists of dense water at 39.2°F. In winter, the surface water is colder than the hypolimnion, so in spring the hypolimnion is replenished as the surface water is warmed to 39.2°F. In larger lakes the hypolimnion is seldom deeper than 100 feet which makes this usable source readily accessible. Unfortunately, few large cities are located near large deep lakes. Onondaga Lake, near Syracuse, New York; Coeur d'Alene Lake, near Spokane, Washington; Lake Champlain, near Burlington, Vermont; and Lake Tahoe with many hotels and resort facilities on its shores are examples of suitable cold water sources. Temperature profiles for these lakes are presented in figures 16 through 19.

FIGURE 16. TEMPERATURE PROFILE - ONONDAGA LAKE

FIGURE 17. TEMPERATURE PROFILE - COEUR D'ALENE LAKE

FIGURE 18. TEMPERATURE PROFILE - LAKE CHAMPLAIN

FIGURE 19. TEMPERATURE PROFILE - LAKE TAHOE

The Great Lakes. With the exception of shallow Lake Erie, the Great Lakes have excellent potential as direct cold water cooling resources. The Great Lakes turn over in late fall and spring and exhibit strong stratification in summer, with a very cold deep water layer and a warm surface layer. The surface layer reaches its maximum depth in September and October, during which time the depth to the hypolimnion can reach 100 feet, which is about the maximum for most locations.

A number of large cities and many large industrial centers are located on the shores of the Great Lakes and are potential users of this resource for cooling. Each site should be examined separately in terms of its cooling demand, cold water availability, and construction factors at the site. Figures 20 through 23 show the depths of the Great Lakes and the cities located along their shores. These charts show the distance from the shore to points at which the lakes are more than 100 feet deep. Cities or industrial centers closest to such deep water would be the most likely candidates for natural cold water district cooling. Lake Erie has been omitted because it has poor potential as a cold water source.

FIGURE 20. BATHYMETRY - LAKE MICHIGAN

FIGURE 21. BATHYMETRY - LAKE ONTARIO

FIGURE 22. BATHYMETRY - LAKE HURON

FIGURE 23. BATHYMETRY - LAKE SUPERIOR

Seasonal and Transient Climatic Temperature Changes

Some changes may occur in the water temperature at a particular location as a result of seasonal and short-term climatic fluctuations. Temperature studies must be conducted all year to monitor such seasonal fluctuations in the water temperature at the selected site. With this information, a site can be selected which will provide usable cooling water through the cooling season. In the studies conducted at the Miami Beach site, it was determined that the nearest offshore location at which usable cold water can be found all year is about 18,000 feet (approximately 4 miles) from shore at a depth of about 700 feet.

Many deep, large lakes have a usable bottom layer of cold water, but in shallow lakes, mixing under varying climatic and weather conditions make them unreliable as cooling water sources. Ground water sources in the northernmost U.S. could be used, but are not as suitable as surface water. Rivers and streams are not reliable cooling water sources because their temperatures tend to closely follow average daily air temperatures.

Defining the Cooling District

Once the cold water source has been defined, the cooling district must be sized to determine the amount of seawater required to cool the district. Direct cooling systems generally require an average flow of 2.5 gallons per minute for one ton of air-conditioning. Analysis of the specific air-conditioning systems in all the buildings would generate a more valid number. In new construction, coil/fan units which operate more efficiently at warmer temperatures can be specified, thus reducing the amount of cold water required.

Maps of the district showing building locations and other site specific information are required prior to design of the land distribution system.

Cold Water Pipeline and Pumping Station Construction

Once the cold water demand has been determined, the intake pipeline and pumping system can be sized. A number of cost/energy trade-offs can be made when pipeline diameter versus energy required to overcome friction losses is considered.

In the Miami Beach design, energy savings were given first priority. An intake pipeline, with a large diameter, that operates under suction (pumps on the shore) was selected. The intake pipeline, which is brought ashore below sea level, feeds into a deep wet well (figure 24.) Pumps lift the cold water from the wet well and distribute the water under positive pressure throughout the land system. Because the intake pipeline is below sea level, water from the source flows into the wet well as the pumping pulls down the water level in the well. Maximum flow is determined by the amount of positive head (depth below sea level) and siphon head obtainable. The Miami Beach design requires 47 feet of head to overcome friction losses for a 50,000 gpm flow through a four foot internal diameter pipeline.

Pipeline Construction

Such factors as weather conditions, water movement at the site, the condition of the ocean or lake bottom and the sub-surface geology influence the pipeline installation procedure and the type of pipe used. The Miami offshore area is subject to mild storm conditions, occasional hurricanes and strong surface currents. Strong surface currents would preclude the use of surface pipelaying techniques for that site; the bottom pull method is recommended.

The weather conditions at the cooling site must be considered in terms of design factors and construction factors. The pipeline must be designed to withstand any conditions that may occur at the site, including hurricanes. Thus hurricane wave and current forces on the pipeline are calculated, and become the controlling factors in the offshore pipeline design.

The possibility of such conditions occurring during construction of the pipeline must be considered and included in construction plans as a risk factor. For example, in the Miami Beach site studies it was determined any construction technique used must allow for underwater currents of the Gulf Stream which are always present at the time; but, if a hurricane occurred during construction, the project would be delayed and serious damage to equipment could be expected. For this reason a \$6 million risk factor is added to the cost planning for this project.

The bottom pull method of pipeline construction involves assembling sections of the pipeline ashore and pulling these to sea while more sections are added. Three or four long sections are then moved along the ocean bottom to the installation site, where they are coupled together underwater. The forward end of each pipeline section rides on a reusable pulling sled which serves as a harness and a stabilizer. The pulling sled on the first pipe section is permanently attached to the forward end of the pipeline and can serve as the intake structure.

FIGURE 24. CONCEPTUAL VIEW OF CONSTRUCTION SITE

The bottom pull method of pipeline construction requires a long assembly corridor on land. In areas of high population density such as Miami Beach, assembly space is not available on shore. For this site, an 800-foot ramp or peninsula would be built as an assembly area and removed after completion of the pipeline installation (see figure 24). Storm wave and current conditions at different depths and the condition of the bottom determine whether the pipeline must be buried or if it can rest on the bottom. Securing of the pipeline by means of additional weight or embedment anchors is required where predicted storm forces could shift the pipeline and cause damage.

Wet Well Construction

The recommended size of the wet well for the Miami Beach site is 50 X 40 feet and 60 feet deep. Since most of the equipment at the pumping station is at or below ground level, it can be easily housed in an attractive structure. Five constant speed or three variable speed pumps would be used to lift the cooling water into the distribution system which supplies it to the individual buildings (see figure 25). The entire cooling water distribution system would be installed underground to take advantage of the added insulation and for aesthetic reasons. The distribution system will be designed to provide adequate water pressure along the entire system.

FIGURE 25. WET WELL AND LIFT PUMPS

COOLING SYSTEM

The cooling system consists of a central cold water distribution pipeline and individual building cooling equipment, as shown in figure 25.

Water Distribution

The land water distribution pipeline will be sized to meet the maximum cooling demand of the district. A basic value of 2.5 gallons per minute is required to provide a ton of air-conditioning. In the absence of detailed building plans, this formula is used in computing individual building requirements. Temperature controlled valves at each heat exchanger determine the total system demand. Variable flow pumps are controlled by microprocessors to provide the necessary flow at the proper pressure. During periods of extremely low cooling demand, water may travel so slowly in the pipeline that its temperature can rise above the maximum allowable level. Proportional control servo valves installed throughout the water distribution pipeline would be programmed to spill the proper amount of water to maintain the minimum flow required to maintain the proper cold water temperatures.

FIGURE 26. SCHEMATIC OF SEAWATER DISTRIBUTION SYSTEM

Individual Building Cooling Systems

The natural cold water district cooling system will replace the vapor compression system in the building's conventional air-conditioning system. A heat exchanger in each individual building would transfer the cooling energy to the existing chilled water cooling loop, as shown in figure 26. The existing cooling coils, cooling fans, and temperature control equipment could be retained with minor modification. Plate type heat exchangers are recommended because they transfer heat more efficiently than tube or shell type. The plate type heat exchanger is also easier to clean. This is an important factor since the natural cold water circuit may be subject to some biofouling and ingestion of foreign matter.

The objective within the user's building is to retain and utilize as much of the existing air-conditioning equipment as possible. To this end, studies of existing fan/coil sizes in a typical hotel and condominium building show that these units are suitable for use with the cold water system. The entire existing chilled water system is retained, and the flow is redirected to the new natural cold water/chilled water heat exchanger where heat from the chilled water passes into the cold natural water and is eliminated from the building.

Special System Requirements

In special cases, such as highly congested public areas (restaurants, auditoriums, etc.) of hotels or apartments, the moisture content in the air increases more rapidly than the natural water cooling system can remove it. In such cases, additional dehumidification may be necessary. Dehumidification can be achieved by operating small conventional air-conditioning systems in addition to the natural cold water district cooling system in these public areas, or by installing desiccant drying or other economical dehumidification systems suitable for the special area. In any case, evaluation of installed equipment and determination of functional design and operational conditions are again essential in planning solutions of special cooling problems of this type.

Systems using seawater must be designed to withstand the corrosive effects of saltwater. The heat exchanger, the land distribution pipeline, and the code water landing and pumping system components must be capable of handling seawater. Corrosive resistant components should be chosen when available, and epoxy coatings should be used where possible.

BENEFITS OF SYSTEM

Conversion to a natural cold water district cooling system using natural cold water would result in immediate and sustained energy savings, long term cost benefits, and both direct and indirect environmental benefits.

ENERGY BENEFITS

The elimination of the compressors and condensing units in conventional vapor compression air-conditioning systems provides a substantial energy saving as shown in Table 1. Table 1 shows a comparison between a conventional 100-ton air-conditioning system and a typical district cooling system using natural cold water. Studies show that a natural cold water flow of 250 gpm would be required to produce 100 tons of air-conditioning.

TABLE 1. ELECTRICAL ENERGY CONSUMPTION FOR CONVENTIONAL AIR-CONDITIONING SYSTEM VS DISTRICT COOLING USING NATURAL COLD WATER

FUNCTION	ELECTRICITY CONSUMPTION (kW)	
	CONVENTIONAL SYSTEM	NATURAL COLD WATER SYSTEM
NATURAL COLD WATER PUMPING	--	7.5*
CHILLED WATER PUMPING	8	8
COOLING COIL FANS	17	17
COMPRESSORS	82	--
CONDENSING UNITS	6	--
TOTAL POWER	113 kW	32.5 kW

*MIAMI BEACH

As Table 1 shows, the natural cold water system would require 32.5 kW of electrical energy to produce the same amount of cooling capacity as a conventional system consuming 113 kW. This is a reduction of 70 percent in the total energy consumption.

The total energy savings would vary in each individual natural cold water district cooling system, but substantial savings can be expected in every case. When the cooling demand decreases toward minimum levels, the cold water system still saves more energy than the conventional system because its operation can be cut back to a greater degree than can air-conditioning compressors. Additionally, the cold water system energy requirements do not vary as drastically between nominal and peak demand periods as conventional air-conditioning systems do. Because of this and the inherently lower electrical demand, the system would tend to smooth the peak energy demand curve.

COST BENEFITS

The initial cost of installing natural cold water district cooling air-conditioning is considerable. Estimates including cost of user's equipment for Miami Beach range from \$20 to \$23 million. A system costing \$20,460,000 has been used in this analysis (see Table 2). Total economic life of the system is set at 20 years.

TABLE 2. ECONOMIC ELEMENT SUMMARY (MIAMI BEACH)

	SW SYSTEM FIBERGLASS (RISK EXCLUDED)	SW SYSTEM FIBERGLASS (RISK INCLUDED)	CONVENTIONAL A/C SYSTEM
1. CONSTRUCTION COSTS (INCL. 10% CONTINGENCY)			
a. SW SUPPLY SYSTEM	\$ 16,031,895	\$ 16,031,895	
b. HEAT EXCHANGERS	4,040,000	4,040,000	
c. A/C BUILDING MODS.	390,500	390,500	
d. RISK FACTOR	--	6,127,000	
TOTAL	\$ 20,462,395	\$ 26,589,395	\$ 3,700,000
2. O&M COSTS (ANNUAL)			
a. LABOR AND OVERHEAD	340,000	340,000	
b. PARTS, SUPPLIES AND OUTSIDE MAINTENANCE	185,000	185,000	
c. G&A	250,000	250,000	
TOTAL	\$ 775,000	775,000	\$ 370,000
3. ENERGY USE (ANNUAL)	29.4 X 10 ⁶ KWH	29.4 X 10 ⁶ KWH	90.4 X 10 ⁶ KWH
4. ENERGY SAVINGS 61.2 X 10 ⁶ KWH/YEAR			
5. ENERGY RATE	1976 = .0300¢ /KWH (ACTUAL) 1981 = .0543¢ /KWH k/WH (PROJECTED AT 16% ESCALATION RATE - SHORT TERM)		
6. TOTAL ANNUAL ENERGY COST SEAWATER SYSTEM (1981) \$1,568,000			
7. TOTAL ANNUAL ENERGY COST CONVENTIONAL A/C (1981) \$4,910,000			

The method of economic analysis used is to discount all costs to their net present value for comparison.

Though the initial cost may appear to be high, the cold water system is nonetheless attractive because of the difference between escalation of energy costs and escalation of all other costs. Standard calculations with discount/inflation rate of 10 percent and energy cost escalation at 7 percent above this show that the total investment in the system can be paid back after 5 years of operation (see Table 3). This represents a discounted cash savings of 30 to 40 percent after operating and investment costs are paid off and after a reasonable return on invested money is realized. These savings could be returned to the user in the form of lower cold water rates over the entire life of the system. Even if energy costs do not escalate more rapidly than other costs, a considerable energy savings would be realized, and the investment returned within the life span of the system.

TABLE 3. ECONOMIC SENSITIVITY ANALYSIS

*DISCOUNT/ INFLATION RATE	DIFFERENTIAL ENERGY COST ESCALATION RATE	NET PRESENT VALUE DISCOUNT/COST OF SYSTEM OVER 20 YEARS		NET PRESENT VALUE ACCUMULATED ENERGY SAVINGS	DISCOUNTED PAY BACK PERIOD	NET DISCOUNTED ENERGY SAVINGS
		NCWDCS ¹	CONVENTIONAL A/C			
10%	0%	\$ 32,318,000	\$ 38,323,000	\$ 22,466,000	9TH YEAR	\$ 6,005,000
* 10%	0%			22,466,000	16TH YEAR	430,000
** 10%	7%	43,396,000	73,414,000	47,395,000	5TH YEAR	30,018,000
* 10%	7%	48,971,000	73,414,000	47,395,000	7TH YEAR	24,443,000
10%	10%	53,026,000	103,599,000	67,032,000	END OF 4TH YEAR	50,533,000
* 10%	10%			67,032,000	6TH YEAR	44,958,000
* RISK INCLUDED						
** NOMINAL CASE						
1 NCWDCS - NATURAL COLD WATER DISTRICT COOLING SYSTEM						

The actual return on the investment and the pay-off period would vary from site to site. However, as in Miami, other cooling sites may expect economic benefits from the natural cold water district cooling system.

Figure 27 shows a net present value comparison between the costs of conventional air-conditioning at the Miami Beach site and a comparable natural cold water district cooling system. The cost of the existing air-conditioning equipment is not included, but the cost of new conventional equipment (\$3,700,000) is added in the 10th year (the normal life cycle for conventional equipment). The life cycle for the natural cold water district cooling system equipment is 20 years. Two cases are shown in figure 27: in one case, the natural cold water district cooling system cost includes a risk factor because of the possibility of severe storms and hurricanes in the Miami area; in the other case, only actual costs are shown. Without the risk factor the energy savings resulting from use of the natural cold water district cooling system would pay back the \$16,656,000 discounted initial investment in five years after start of operation. With the risk factor included, the discounted initial investment would be \$21,199,000, which would be paid back in energy savings in seven years under the conditions shown in figure 27. Discounted annual operating costs for the conventional air-conditioning equipment would be \$4,723,570, compared to \$1,970,711 for the natural cold water district cooling system in 1978.

LEGEND:

NCWDCS = NATURAL COLD WATER DISTRICT COOLING SYSTEM

* = DISCOUNTED TOTAL INVESTMENT COST

*1 = \$16,656,000 -- RISK EXCLUDED

*2 = \$21,199,000 -- RISK INCLUDED

AES = ACCUMULATED ENERGY SAVINGS

DISCOUNT/INFLATION RATE -- 10%

DIFFERENTIAL ENERGY

ESCALATION RATE -- 7%

YEAR 0 = 1976

YEAR 23 = 2000

FIGURE 27. COMPARISON BETWEEN CONVENTIONAL AIR-CONDITIONING AND NATURAL COLD WATER DISTRICT COOLING SYSTEMS

ENVIRONMENTAL BENEFITS

The cold water which has passed through the system remains clean and generally oxygenated. This discharge is relatively cool and can be used for additional cooling purposes. It can also be used for aesthetic purposes such as pools, fountains, etc. In tropical ocean areas the deep cold water is nutrient rich, and can be used in large aquaculture enterprises. If no convenient use can be found, the water must be discharged directly into a nearby body of water. The temperature difference between the discharge water and ambient water must be considered if the discharge constitutes a significant addition to the volume of the body of water. A nearly negligible local temperature modification would result from a diffused discharge into a large body of water. The general characteristics of the discharge make it a desirable addition to stagnant or poorly circulating water bodies because oxygen levels and flushing would be increased.

Additional energy benefits are derived by reduction of the adverse effects of conventional power plants in proportion to the energy saved.

CONCLUSIONS

Feasibility studies conducted on the natural cold water district cooling system show that such a system can be developed using existing technology, and would result in substantial savings in energy resources, resulting in long-term cost benefits. The following conclusions are the result of extensive studies of natural cold water cooling and an in-depth study of a specific site.

- The system is technically feasible and can be developed in the immediate future
- The concept can conserve up to 70 percent of the electrical energy currently being used in conventional air-conditioning systems
- Areas such as South Florida where more than 50 percent of the electricity used is used for air-conditioning — 30 to 40 percent of the total energy used in the cooling district is conserved
- Electricity savings occur during peak demand periods and can significantly smooth demand curves (16 MW in Miami Beach District studied)
- The net cost saving should average 30 to 40 percent over conventional air conditioning
- The initial investment in the system will be returned well within the life span of the system
- The system will not harm the environment, and in many cases will be beneficial

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