# SEAWATER DISTRICT COOLING
# AND LAKE SOURCE DISTRICT COOLING

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## ABSTRACT

Seawater District Cooling (SDC), and the similar Lake Source District Cooling (LSDC), is a technology which is beginning to make a significant impact on energy conservation as a viable alternative to conventional central air conditioning systems. The principles of SDC can be implemented in any region of the world with a sufficient cold water resource located in close proximity to a dense central air conditioning load. SDC systems have been developed in all climates and locales ranging from Stockholm, Sweden, to Kona, Hawaii. Implementation of SDC principles in the design, development, or conversion of central air conditioning systems has proven to save in excess of 85% of the energy typically required for conventional air conditioning. With escalating and volatile energy prices, SDC systems provide a sustainable and reliable means of stabilizing energy costs for the air conditioning component of a building or facility’s energy budget.

## INTRODUCTION

Throughout the world’s tropical oceans, seawater temperatures decrease with depth. The existence of the deep-water ocean heat sink results from natural climatic processes where water is cooled at the poles, becomes dense, and sinks into the deep ocean. Temperatures of 8°C or colder can be reached at 700 m depth within the tropical zone, 4°C or colder at 1000 m, as shown in Figure 1. The deep portion of this profile changes little seasonally and therefore cold water is available on a year-round basis. At depths exceeding 700 meters, these temperatures are equivalent to chill water temperatures required for space cooling.

In many regions of the tropical and sub-tropical zones, the combination of year-round space cooling demand, high electricity rates, and high-load air conditioning district locations near steep coastal bathymetries provide a good opportunity for SDC. Similarly, in many temporal regions, large, dense air conditioning loads are located in close proximity to cold water lakes capable of providing the necessary chill water resource temperatures for an LSDC system.

An SDC or LSDC utility is a demand-side management technology with the potential to avoid up to 90% of the energy consumption and carbon emissions typical for conventional air conditioning systems. The cold water resources suitable for these applications are abundant and sustainable. Their proper use does not produce environmental harm and often can be shown to have an environmental benefit. The development of such a system can provide significant cost savings to the end consumer, such as military bases, barracks, hotels and adjacent commercial buildings, and a significant reduction in electricity utilization for air conditioning and associated greenhouse gas emissions over currently employed conventional air conditioning systems.

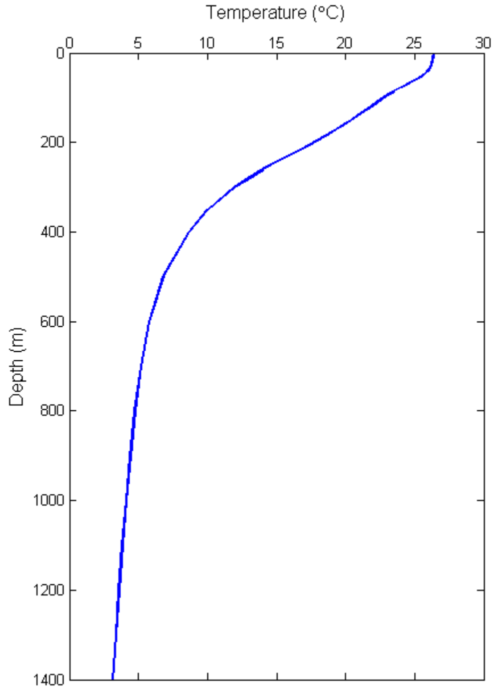

FIGURE 1. TYPICAL TEMPERATURE PROFILE IN HAWAII.

Large-scale implementation of SDC potential to tropical and sub-tropical military bases in suitable geographical locations can provide an economical alternative to conventional air conditioning systems while exemplifying the end-consumer's commitment to sustainable energy development and compliance with Executive Order #13123.

## SEAWATER DISTRICT COOLING BASICS

An SDC system consists of a seawater supply system, a heat exchange facility, a chilled freshwater loop, and an end-user air conditioning load (Figure 2). Offshore pipelines supply deep, cold ocean water to the land-based heat exchange facility, where it is used to cool freshwater by passing the two fluids through a counter-flow heat exchanger. The seawater and freshwater never mix. The chilled water is sent through a distribution network to buildings requiring space cooling and the warmer cooling water is either returned to the ocean or lake or utilized for ancillary system applications in the interim. Buildings on the distribution loop no longer require a conventional chiller; they simply connect to the district supply of cold water.

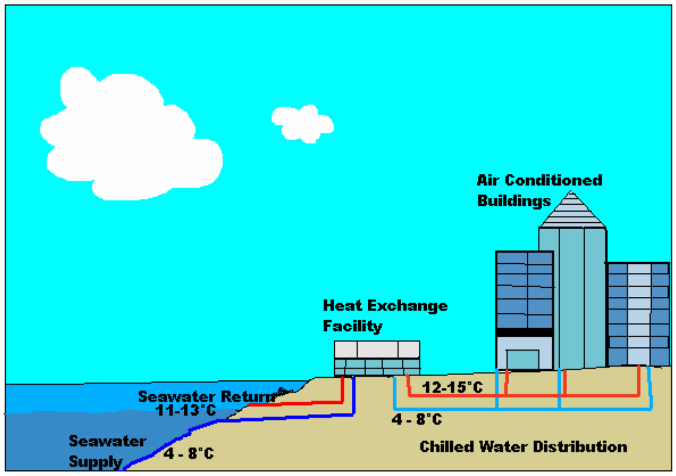

FIGURE 2. SEAWATER DISTRICT COOLING

In a conventional system, each building has its own chilled water loop and chiller. Chillers are expensive to both purchase and maintain, and require on average between 0.8 and 0.9 kilowatts of electricity per ton of air conditioning. Approximately 30 to 45 percent of a large commercial building's electrical bill is spent chilling water for air conditioning. In an SDC scenario, the chillers from all buildings in the district are replaced by a centralized heat exchanger and pumps. The district chilled water loop provides the cooling for the building's internal chilled water loop in an environmentally-friendly, sustainable way.

## ECONOMIC VIABILITY OF SDC

SDC is suitable in general for coastal communities with air conditioning demand. The factors that influence the economics of an SDC project are:

- Distance offshore to deep, cold water
- Total air conditioning load
- Size of the onshore distribution network
- Local cost of electricity

The seawater intake pipeline is one of the most critical components and the most expensive. Reasonable access to 4°C to 8°C seawater is essential. Generally this is found at depths between 700 and 1000 meters. Steep offshore terrain translates to nearer access to cold water and a shorter offshore pipeline.

Larger systems are more economical than small systems. As a general rule, the total load of a system must be greater than 1000 tons, although the individual buildings in a system may have loads as low as 50 to 100 tons depending on the spread of the distribution network.

## SEAWATER DISTRICT COOLING COSTS

The infrastructure costs for an SDC system can be broken down into three main parts. The biggest cost is for the seawater supply system, which is composed of the cold seawater intake and discharge pipes. The seawater intake pipe is the single largest cost in the system; as such, the seawater supply system represents approximately 50% of the cost. Figure 3 below shows the actual deployment of a 55” High Density Polyethylene pipeline in Kona, Hawaii.[8]

**FIGURE 3: COLD WATER PIPE DURING DEPLOYMENT[8]**

The second major component is the chilled water distribution network, which connects the air conditioning systems to the cold sea water. The cost is a function of pipe length and labor, where a condensed air conditioning load is most economical. On average, the chilled water distribution network represents about 35% of the cost.

The heat exchanger, generally plate and frame which is the interface that allows the cold seawater to chill the fresh water, is the third main component of the SDC System, costing about 15% of the system budget. The heat exchanger facility at Cornell University is shown in Figure 4.

**FIGURE 4: CORNELL UNIVERSITY LSDC HEAT EXCHANGE FACILITY[4]**

Project costs are minimized for locations that have quick access to the cold water source, reducing the length of the cold water pipe, and locations that have condensed air conditioning loads, where the distribution network is small. An additional factor in the economics of an SDC system is the cost of electricity. The higher the local cost of electricity, the greater the savings realized from SDC.

The implementation of an SDC system greatly reduces the electricity consumed by air conditioning. A reasonable estimate of the average electrical requirements for conventional air conditioning systems is 0.85 kW/ton of air conditioning. SDC uses only 0.12 kW/ton of air conditioning, thus offering savings of about 85% over conventional air conditioning.

Additional operating costs may be incurred in certain cases. Some SDC systems do not have access to cold enough water to be able to completely eliminate electric chillers. In such situations, auxiliary chillers are used to augment the work done by the heat exchangers. This lessens the positive results of using a natural resource to provide cooling, but can still be environmentally and economically beneficial. If water of about 50°F can be reached, a significant reduction in electricity usage may still be achieved. Monetary savings are dependant on the local electricity rate and the size of the load to be serviced.

## EXISTING APPLICATIONS

SDC is neither a new concept nor unproven technology. In the United States, the concept of District Cooling using conventional air conditioning has been realized in 40 districts distributed among 16 states. Cornell University in Ithaca, New York, was the first institution in the United States to construct and operate a District Cooling system that utilizes its local cold water resource, Cayuga Lake, in place of conventional air conditioning systems. Cornell has been servicing 20,000 tons of air conditioning using their LSDC system saving 85% of the energy previously required for the serviced AC load since 2001. Recently in 2004, Toronto, Canada began operation of a 50,000 ton LSDC system utilizing Lake Ontario water to cool several districts in downtown Toronto saving 90% of the electricity previously required to service the same air conditioning load.

The feasibility of using cold seawater to directly cool buildings has been studied and analyzed for many years. Successful installation and operation has occurred at a number of locations.

## ANCILLARY USES

Economically and environmentally beneficial uses of the exhaust seawater may also be possible, as the seawater is still relatively cold at 12°C to 14°C (the actual temperature depends on the local humidity). Realizing secondary uses for the exhaust seawater reduces the total capital required for an SDC system. In general, the effluent water can be used to support a marine biotechnical or commercial marine life demonstration facility such as a world-class aquarium, as auxiliary cooling water for conventional power plants or industrial processes, or for cooling of grounds, e.g., parks and golf courses. Furthermore, the effluent may also be discharged into brackish bodies of water, estuaries, canals, and harbors to provide flushing and improve water quality.

## CASE STUDY - DIEGO GARCIA

Diego Garcia, an atoll in the Indian Ocean, is home to a U.S. Navy Support Facility. The atoll is located at 7° 20' S latitude. The tropical location makes air conditioning a necessity for the welfare of electronic equipment and the comfort of base personnel.

Air Conditioning at Diego Garcia is currently being provided through a variety of systems. The total air conditioning load on base for all units of three tons in size or greater is 3,440 tons. This load is composed of direct exchange units, as well as chilled water systems. 2,265 tons of the air conditioning is supplied by chilled water systems. Of the capacity generated by these systems, approximately 1,555 tons could initially be serviced by an SDC system. The 1,555-ton chilled water air conditioning load consumes nearly 13.3 million kWh of electricity per year based on an average efficiency of 1.4 kWh per ton for each chilled water system and a utilization rate of 70%.

The air conditioning load at Diego Garcia is relatively small and comprises many small loads ranging in size from 25 to 110 tons. The chilled water air conditioning systems are spread throughout the Cantonment area of the base. However, the island is small and the inhabited Cantonment covers a modest area. This provides for a distribution system that is economically viable under certain conditions. Several aspects of Diego Garcia make it appealing for the implementation of SDC.

1. High electricity price (greater than $0.30 / kWh and rising)

The cost per kWh of electricity was $0.3029 for FY05 and the cost of the JP-5 fuel oil used to generate that electricity was $1.79 / gal. Since the establishment of those rates, the cost of JP-5 has increased by more than 42% and electricity rates are sure to follow, as the two rates are directly related.

2. Good bathymetry for access to cold water

The bathymetry off the coast of Diego Garcia allows access to 6°C water within three miles of the heat exchange facility site. Additionally, the horizontal distance to the reef edge from shore is less than 0.5 miles. This is within the range of operability for horizontal directional drilling and enables the seawater supply and return pipes to be brought to shore without damage to the coral reef surrounding the island.

3. High temperatures and humidity throughout the year

Located near the equator, Diego Garcia is hot and humid throughout the year. This causes the need for a high utilization rate of air conditioning to maintain human comfort and a suitable environment for electronics equipment both day and night.

4. Relatively compact distribution system

The distribution system at Diego Garcia is confined to an area of approximately one square mile. This minimizes the capital cost of the distribution system as well as the head loss that must be overcome by the freshwater pumps.

Relevant costs for both conventional air conditioning and SDC are shown in Table 1. Costs are based on a 30-year project life with a 7.5% interest rate.

## TABLE 1: COST COMPARISON OF CONVENTIONAL AIR CONDITIONING AND SDC

| Air Conditioning Costs | Conventional | Seawater District Cooling |
|---|---|---|
| Capital Cost | $ 9,646,300 | $ 26,420,500 |
| Annual Capital Payment | $ 816,800 | $ 2,483,500 |
| Annual Operational Cost | $ 4,082,400 | $ 720,200 |
| **Total Annual Cost** | **$ 4,899,200** | **$ 3,203,700** |

The SDC system capital cost includes a 20% contingency and is broken down by component as shown in Table 2. The costs are based on direct quotes from manufacturers and suppliers of the components. Installed chiller costs for conventional systems at Diego Garcia were taken as approximately $1,600 per ton with the average chiller size being between 40 and 50 tons.

## TABLE 2: SDC COMPONENT COSTS

| Component | Capital Cost |
|---|---|
| Seawater Supply Pipe | $ 15,888,505 |
| Discharge Pipe | $ 1,381,419 |
| Heat Exchangers (and facility) | $ 1,700,909 |
| Seawater Pumps | $ 915,693 |
| Freshwater Pumps | $ 390,541 |
| Distribution System | $ 3,983,502 |
| Building Connections | $ 2,160,000 |
| **Total** | **$ 26,420,569** |

Results of a life cycle cost analysis comparing conventional air conditioning and SDC are favorable towards SDC. An analysis performed by OCEES International, Inc. in accordance with Department of Energy guidelines yielded a payback period of 8.7 years and a Savings-to-Investment Ratio (SIR) of 2.71. The adjusted Internal Rate of Return (IRR) calculated in the life cycle cost analysis is just over 8%. With a discount rate including inflation of 4.6%, all of these metrics indicate that SDC would be economically viable. More importantly, there is a life cycle savings of over $30 million.

In addition to the economic gains presented by SDC, there are also environmental and logistical benefits to be considered. The implementation of SDC would eliminate the use of 11,100 MWh of electricity per year, translating into a savings of over 19,000 barrels of oil and a reduction in carbon emissions of 9,000 tons per year. The reduced electricity usage also means the power production equipment will last longer and require less maintenance. There will also be less of a burden on the utility system overall.

## SUMMARY

SDC and LSDC are methods of meeting air conditioning and process cooling needs through the use of natural resources. It is a simple thermal process that reduces or eliminates the need for electric chillers and cuts electricity consumption by as much as 90%. SDC systems can be implemented in any area with nearby access to large sources of cold water. The process begins when seawater of 4°C to 8°C is drawn in through a pipeline from typical depths of 700 to 1,000 meters. The cold seawater (or lake water) is delivered to a heat exchange facility where it is used as a heat sink for cooling water. The cooling water is freshwater that is chilled when heat is transferred from the freshwater to the cold seawater via plate and frame heat exchangers. After passing through the heat exchangers, the seawater may then be used for secondary purposes, such as desalination, additional cooling or returned to the ocean. The freshwater is sent to various points of use via the closed loop distribution piping and then returns to the heat exchange facility to repeat the process.

SDC provides many benefits for both the owners and customers of the system.

- Stable and predictable costs less than that of conventional cooling technologies
- Electricity usage reduced by up to 90%
- Reduced $CO_2$, $NO_x$, and $SO_x$ emissions
- Lowered strain on electricity infrastructure
- Reduction of ozone depleting refrigerants (CFCs and HCFCs)
- Reduced maintenance requirements
- Increased reliability - current systems operate at over 99% reliability rate

SDC works best when the cooling loads to be serviced are nearby and densely positioned. This helps keep operation costs down and reduces the capital cost of the distribution loop. Operation costs for the SDC system consist primarily of the electricity used to pump the seawater to the heat exchange facility and the freshwater through the distribution loop. Servicing densely populated cooling loads means less head loss through the distribution piping and, therefore, less pumping power required.

Table 3 displays the energy savings estimated for developing projects as well as the energy savings realized by existing projects (i.e., Cornell and Toronto).

## TABLE 3: SDC AND LSDC ANNUAL ENERGY SAVINGS

| Location | Energy Consumed (MWh) | Energy Saved (MWh) | Oil Replaced (bbl) | $CO_2$ Replaced (tons) |
|---|---|---|---|---|
| **Diego Garcia** | 2,250 | 11,000 | 19,400 | 9,000 |
| **Pearl Harbor** | 4,140 | 36,600 | 64,100 | 30,600 |
| **Bahamas** | 4,900 | 52,000 | 91,100 | 43,500 |
| **Aruba** | 50,380 | 71,300 | 124,800 | 59,600 |
| **Cabo San Lucas** | 4,670 | 14,100 | 24,700 | 11,800 |
| **Cornell University**[4] | 4,070 | 25,000 | 43,800 | 11,000 |
| **Toronto**[2] | 105,000 | 94,500 | 165,400 | 79,000 |

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