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1. Seawater cooling system 2. Sea/lake water air conditioning I. Z0840-01-001

Seawater cooling was found to be economically feasible for a trial Naval facility in San Diego, Calif. and an operational test was recommended for the Naval Security Group Activity (NSGA), Winter Harbor, Maine. A preliminary design and environmental impact assessment were performed for a seawater cooling system at NSGA. This work was supplemented with seawater temperature measurements in the adjoining bay, a study of biofouling and its prevention in this system, and land and offshore surveys at NSGA. A separate study found that the life cycle cost of this seawater cooling system was less than that of the existing conventional air conditioning system. It was concluded that a seawater cooling system for NSGA would cost about $150K, and annually save over 200 MWh of energy and $9,000. Also, a study of the Navywide potential of sea/lake water cooling found that if such cooling were installed at 25 Navy sites, 59×10^3 MWh and $3 million could be saved annually. This report recommends that: (1) a final design and installation of an operational test seawater cooling system for NSGA, Winter Harbor be made; (2) seawater temperatures be measured at Apra Harbor, Pearl Harbor, Chicago, and Point Mugu as potential sites; and (3) a parametric model be developed for estimating the capital and energy costs of sea/lake water cooling systems.

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INTRODUCTION

While the demand for air conditioning (AC) at Naval facilities has stabilized, the cost of power has grown tremendously in recent years and the availability of power plant fuel from the traditional domestic sources has declined sharply. Therefore, alternatives to the high power consuming AC systems are being sought. The alternative that this report addresses is the use of sea or lake water as a cooling and dehumidification medium at Naval facilities.

Objective

The objectives of the study reported herein were (1) to determine if sea or lake water AC is a technically and economically feasible alternative to conventional AC at Naval facilities and (2) to determine at which Naval facilities, sea/lake water AC can be best applied.

Scope

In this report, the feasibility of seawater cooling is assessed for a trial Naval facility, the Fleet Combat Direction Systems Training Center (FCDSTC) in San Diego, California. The results of a preliminary design of a seawater cooling system for the NSGA, in Winter Harbor, Maine, are given. The Navywide applicability of seawater cooling is determined, and 25 potential Navy sites for this application are given with the economic characteristics of each.

Background

The potential utility of cold sea or lake water as a medium for air conditioning has been occasionally mentioned in the literature of the past 50 years; however, not until recently has serious attention been paid to this old idea. Reference 1 concluded that seawater cooling* is technically feasible and can result in a 70% to 80% savings in the power consumed for air conditioning in areas where there is a concentrated demand like the rows of hotels in Miami Beach, Fla. or Honolulu, Hawaii. This reference determined that water for cooling from natural water bodies must be no warmer than 50°F (10°C).

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*The use of the term "seawater (or lake water) cooling" here and elsewhere in this report implies "seawater (or lake water) air conditioning" because both cooling and dehumidification are included.

The work of reference 1 was continued with a detailed study and preliminary d-sign of a Miami Beach seawater cooling system (Ref 2). It was estimated that for this 20,000-ton seawater cooling system the total cost would range from \$20.4 to \$23.4 million, and the offshore pipeline length would be 22,000 feet.

This reference also assessed the use of naturally cold freshwater in the United States as an AC medium. The Great Lakes were considered an excellent source of cold water for direct AC. In addition, other large lakes in the northern two-thirds of the country and ground water in the northern one-third were considered good sources, but rivers and streams were considered essentially useless for direct AC because the water is not cold enough.

The Civil Engineering Laboratory (CEL) conducted a study of seawater cooling as an alternative to conventional AC for Naval facilities (Ref 3). This study, part of which is included in this report, concluded that the potential of seawater cooling for saving energy and money at Naval facilities is great and warrants further attention, and that a good site for an operational test of seawater cooling for Naval facilities would be the Naval Security Group Activity (NSGA), Winter Harbor, Maine.

The Winter Harbor facility was the subject of a preliminary design and analysis of a seawater cooling system conducted for CEL by Tracor Marine (Ref 4). A summary of the results of this work is included in this report.

A study, performed for CEL under a contract through the Northern Division of the Naval Facilities Engineering Command, compared alternative modifications to the air conditioning system at NSGA, Winter Harbor, Maine (Ref 5). This study found that the 20-year life cycle cost of energy for AC at the facility using the existing system is 50% greater than that of a seawater cooling system and that the 20-year total life-cycle cost of energy plus first cost of the existing system (replacement cost) is 20% greater than that of a seawater cooling system. Furthermore, seawater cooling was found to be the most economical of the six modifications that were considered, but none of these are economically justified at this time. Conclusions of the report (Ref 5) are that (1) the seawater cooling system uses less energy than the existing system with any of the other modifications and (2) seawater cooling could be added to the existing system with no internal modifications to the existing system except the replacement of a 25-hp fan motor with one of 30 hp.

FEASIBILITY STUDY

A study was performed in FY76 to determine if seawater AC for Naval facilities is feasible and whether a development program was warranted (Ref 3). This study produced useful guidance in the early stages of the seawater cooling work at CEL using preliminary estimates of performance and costs at a trial site.

Seawater Cooling

Air Conditioning Potential. The major question concerning a seawater cooling system is? How cold must the supply water be to meet the AC requirements? The answer to this question depends on the answers to several other questions. Does the seawater directly cool the air or does it cool an intermediate fluid? Is the seawater supposed to meet the total latent heat load, or will it be aided by a dehumidification system? Finally, is the AC for comfort only, or is it required for electronics such as in a computer facility?

A design using seawater which directly cools the air can use warmer seawater than a design requiring an intermediate fluid. A general rule-of-thumb is that the temperature of the cooling fluid entering a heat exchanger must be at least 5° to 10°F cooler than the temperature of the air leaving it. Chilled water heat exchangers vary widely, however, and designs using them are generally based on actual experimental data of existing equipment. Another rule-of-thumb is that the temperature of the primary fluid entering a water-to-water heat exchanger should be 3° to 5°F cooler than the temperature of the secondary fluid leaving the exchanger.

A design required to meet the total heat load (latent and sensible) of a building must use colder seawater than a design which meets only the latent heat load. The latent heat load is that part of the heat load responsible for condensing the moisture in the air. The other part of the load - the sensible heat load - is the amount of heat which must be removed from air to reduce its temperature. Thus, if the latent heat load can be reduced by a dehumidification system the seawater cooling system can use warmer water.

The AC requirements for a computer facility are much more stringent than the requirements for comfort according to ASHRAE (Ref 6); the more stringent requirements are imposed by a computer facility because humidity levels must be more strictly controlled to prevent computer papers and cards from curling and sticking. This contrasts greatly with the wide range of humidity level that is acceptable for comfort cooling.

Taking into account these factors and design alternatives, it appears that to meet the sensible cooling requirements of Reference 6 for comfort cooling, the seawater need only be cooler than 65°F. If latent heat must also be removed, the water must be colder, ranging down to 50°F. To meet the requirements of a computer facility that has a low latent heat load and requires very little ventilation, a seawater temperature of 45° to 50°F would be required unless auxiliary dehumidification were used.

Pump Work and Pipe Size. Other questions which must be answered to evaluate this system are: What size pipe should be used and how much pump work will be required? Here again, several alternatives are available. The pump can be located at the pipe inlet, and its outlet, or somewhere along the pipe. To illustrate the relationship between pump work and pipe size it was assumed that the pump is placed on shore at the pipe outlet. Thus, to prevent cavitation in the pump, the suction head must be limited to 30 feet of water. This criteria essentially limits the flow rate by setting an upper limit on the friction losses that can be allowed. The diameter and length of the pipe can be related given a flow rate and an allowable friction loss. Calculations were performed to illustrate this point. In these calculations the load was fixed at 100 tons refrigeration (TR), and the pipe friction was allowed to be no greater than 30 feet of water. This caused the pump work required to get the water to shore to vary as shown by the top four curves of Figure 1.

Another variable is the elevation above sea level of the facility to be air conditioned. This elevation can be a very important consideration if the facility is located very far above sea level as is evidenced by the bottom four curves of Figure 1. These curves were calculated assuming that the point of use of the seawater is 300 feet above sea level and that 80% of the pump work is recovered by a turbine on the beach. This situation is equivalent to pumping the water up 60 feet with no pump work recovery. Without the turbine energy recovery stage, a 300-foot altitude increase would provide a coefficient of performance of about 12.

Selection of the Trial Site

Based on the installed AC and seawater temperatures of Naval facilities in the continental United States, the Fleet Combat Direction Systems Training Center (FCDSTC), San Diego was selected for a trial analysis of the technical and economic feasibility of seawater cooling for Naval facilities. A seawater cooling system for this facility would include many of the elements of a system of this type at any facility. In addition, FCDSTC is at a site where cold seawater can be found near the shoreline rather than several miles away. This reduces the energy consumed in overcoming the head lost to friction in the intake pipeline and makes the technical and economic feasibility more a function of the basic differences between seawater cooling and conventional AC.

Another consideration in the selection of FCDSTC as a trial facility was its concentrated AC demand. This facility, which requires only computer cooling, was chosen rather than one requiring comfort cooling because the total cooling load for this facility is localized in one building and not scattered among several. Limiting the cooling load to one building minimizes, for the purposes of this preliminary economic analysis, the effect of the cost of land distribution on the total cost. Figure 2 shows the seawater temperature/depth/distance from shore profiles for the San Diego site. Also shown are the bathymetry and topography of the site.

Seawater Cooling For FCDSTC

A calculation was performed for FCDSTC to provide information for an economic analysis. This facility is located 300 feet above sea level. Extra-heavy 12-inch pipe was assumed to be laid 1.3 nautical miles out to 55°F seawater, and a turbine energy recovery stage was included to maximize the coefficient of performance of the system. The results of the calculation indicate that a 120-hp pump that would pump 1,250 gal/min from the ocean bottom to the point of use would be required. Accounting for the energy recovered by the turbine, 31 hp (23 kW) must be supplied to the pump. If the water is heated from 55° to 65°F at the facility, 500 TR can be furnished by the system. Thus, the system would have a coefficient of performance of 75.

Heat Transfer Considerations. The foregoing calculation makes the seawater system appear quite favorable; there are problems, however. One major concern is whether the cold seawater can be pumped to the surface without being excessively heated by the surrounding water. If the pipe is a good heat conductor, the temperature of the deep seawater will rise too much. A calculation run with the steel pipe of the example indicates that the water temperature will approach that of the surface water, whereas a calculation for a pipe insulated with an inch of rubber indicates that a temperature rise of 1.5°F will be experienced. The latter is an acceptable level but the former indicates that the pipeline should either be made of an insulating material or insulated in some manner.

Alternative Designs. The results of this study indicate that a seawater cooling system for FCDSTC, San Diego is technically feasible. Several alternatives are available to reduce the length of the offshore pipeline or the requirement for insulation. One alternative is to use the seawater for sensible cooling and employ alternative systems (i.e., desiccant, vapor compression) for humidity control. Another alternative is the use of seawater for condenser cooling or brine precooling. Thus, the seawater systems could be used to improve the performance of conventional systems. Finally, alternative pipe materials could be used to reduce the cost of the system. For example, fiberglass pipe might eliminate the need for insulation, but it would pose a more severe anchoring problem than steel pipe.

Costs

Installation. As indicated in Reference 1, the total capital cost of a seawater cooling system includes the cost of the: (1) offshore pipeline, (2) pumping station/wet well, (3) land distribution system, and (4) user equipment.

From the preliminary figures given in Reference 1, it is seen that the major portion (nominally 85%) of the installation costs are for the offshore pipeline. The authors of References 1 and 3 found that offshore contractors are reluctant to make estimates of pipe-laying costs. However, it was clear from discussions with these contractors, that the laying of 12-inch pipe to depths up to 300 feet was well within the state-of-the-art. The estimated cost of laying pipelines (including welding, but not burial on shore) was $9 per foot for standard 12-inch pipe. Offshore, the pipe-laying costs increase rapidly with depth. The costs (without burial) for standard 12-inch pipe varied from $15/ft for depths less than 50 feet to $27/ft for depths to 300 feet. Laying extra-heavy pipe would be somewhat more expensive because of the additional welding time. For this preliminary estimate, $30/ft was selected as a reasonable estimate for laying extra-heavy 12-inch pipe to 100-foot water depths.

These pipe-laying costs do not include the cost of the pipe, which is $27 per foot for extra-heavy steel pipe. To these pipe and pipe-laying costs must be added the cost of pipe coating, cathodic protection, anchoring, and burial. For the purposes of making a preliminary estimate of seawater cooling for the trial Naval facility, it was assumed that coating, cathodic protection, and anchoring would not be required if extra-heavy pipe is used. Although burial may be required to protect the pipeline from wave forces or fishing trawlers or to prevent damage to the trawlers, the cost of pipe burial was not included in this preliminary estimate of the installation cost of the seawater cooling pipeline. The additional cost of extra-heavy pipe, which is almost three times that of standard pipe, should provide some contingency in this cost estimate to account for protection against these environmental hazards that were not specifically addressed.

The installation cost of a seawater cooling system at FCDSTC is estimated below. These are based on the characteristics of the site and the air-conditioning analysis given in previous sections and on the subsystem costs given above. These figures do not include provisions for burial or insulation of the offshore pipeline.

Item Description	Item Cost	Length (ft)	Total Cost ($K)
(1) Offshore pipeline			
pipe	$30/ft	x 7,900 =	474
installation	$30/ft		
(2) Pumping station/wet well			
pump 1250 GPM, 150 HP		=	15
turbine 300 ft head		=	15
(3) Land pipeline (with return)			
pipe	$11/ft	x 1,500 =	30
installation	$ 9/ft		
			$534

Operation. The power demand of the 500-TR seawater cooling system includes:

Item	Power (kW)
Seawater pumping (with partial recovery	23
Additional pumping (in facility)	20
Cooling coil fans	85
Total	128

If it is assumed that this electronics cooling system must operate continuously with a 50% load factor, 1,536 kWh will be used per day, which, at 4¢/kWh, equals $61/day.

The cost of labor and materials for operating and maintaining a 500-TR seawater cooling system for FCDSTC is estimated as $52 per day, based on the estimate made in Reference 1. The total operational cost of the seawater cooling system for FCDSTC is $113 per day. This includes the cost of power ($61) and the cost of labor and materials for operating and maintaining the system ($52). Not included in these costs are the cost of a small amount of additional dehumidification that is required to supplement the humidity control provided by the seawater system.

Economic Feasibility. The power requirement of a conventional, large building AC system for comfort cooling was estimated in Reference 1 to be 113 kW/100 TR of maximum AC load. With the assumption that this estimate can be used to estimate the power required for a 500-TR electronics cooling load at San Diego, 565 kW are required. For continuous 24 hr/day operation with a load factor of 50%, the power consumption is, therefore, 6,780 kWh. The cost of this power at 4¢/kWh is then $271/day for conventional AC at FCDSTC, San Diego. Recall that the power required for seawater cooling at this facility was estimated in the previous section to be 128 kW compared to the 565-kW estimate for conventional AC - an energy saving of 77%.

The following is a comparison of the cost per day for operational expense of conventional versus seawater AC at the San Diego facility. This comparison is intended to give an estimate of the cost saving that may be accrued from using seawater to air-condition FCDSTC. For a conservative estimate, it is assumed that conventional AC systems required only half as much labor and supplies for operating and maintaining the equipment.

Item	Conventional ($)	Seawater ($)
Power	271	61
Labor and Supplies	26	52
Total	297	113

Therefore, a saving of $184/day or $67K/year may be realized by using seawater cooling rather than conventional AC.

A capital investment of $534,000 is required for seawater cooling at FCDSTC, San Diego. This new type of air conditioning will result in an annual savings of $67,000. If it is assumed that 10% is the interest rate for capital to finance the construction of this seawater cooling system, the payback period is 16½ years.

Findings, Conclusions and Recommendations

Seawater cooling was found to be economically feasible for FCDSTC, San Diego, based on preliminary estimates of performance and cost. However, this facility is not a suitable site for an operational test of a complete seawater cooling system because the capital cost of such a system would be over $500K. Such a large investment for an operational test of a complete system at FCDSTC is not prudent, but this facility might be a good site for the development of equipment to improve the effectiveness of seawater cooling, particularly equipment which can use warmer seawater (65°F rather than 55°F) for AC. Because costs of offshore pipeline installation are such a high portion of the total seawater cooling system investment, a Naval facility that does not require a long offshore pipeline should be used for an operational test. NSGA at Winter Harbor, Maine, is such a facility.

It was recommended in the FY76 study that:

1. An operational test of seawater cooling be performed at the Naval Security Group Activity (NSGA) in Winter Harbor, Maine.

2. Alternative designs for seawater cooling be investigated, particularly desiccant systems, for improving the efficiency of seawater cooling.

3. The environmental impact of seawater cooling be investigated.

WINTER HARBOR DESIGN AND ANALYSIS

A preliminary design, economic and energy analysis, and environmental impact assessment of a seawater AC system for a building in Corea, Maine, which is part of NSGA Winter Harbor, was conducted in early FY77 for CEL by Tracor Maine (Reference 4). This work was performed for a 100 TR system with 100% seawater AC backup. The energy and system costs used did not include the air-handling system costs or energy requirements.

Subsequent to the above work, seawater temperature measurements in the bay that adjoins Corea (Prospect Harbor) were obtained and the biofouling potential of the seawater AC system and prevention devices was assessed. The results of these two efforts were published as supplements to Reference 4, which is summarized below. In addition, surveys of the land and seafloor topography and geology along potential pipeline routes were made and will be used if the final design, fabrication, and installation are done.

Site

The Winter Harbor site, shown in Figures 3 and 4, was chosen because the building requiring continuous AC is located less than 2,600 feet (1,300 feet to the shoreline and 1,300 feet from the shoreline to the seawater intake) from a source of seawater estimated as 50°F the year-round.

Design

Two major design options were examined: the first, to use seawater for the entire cooling load (100 TR); the second, to use additional cooling and dehumidification if and when the seawater temperature exceeds

$50^{o}F$. Subsequent seawater temperature measurements revealed that enhancement is required during 3 months of the year. A number of alternate enhancement methods were examined, and preliminary designs developed, including one for a solar/disiccant drying system. A simply packaged, air-cooled, direct-exchange (DX) system of 40 TR was selected for the enhancement. The use of the existing AC system for an enhancement was considered. These design considerations led to these three potential seawater AC systems with: (1) no enhancement, (2) enhancement by new DX units, and (3) enhancement by the existing AC system.

Energy and Economic Analysis

These three seawater AC systems with 100% backup were compared with each other and with a conventional AC system of the same capacity (100 TR) and 10-year life-cycle cost (LCC) as follows (Reference 4):

	Annual Energy Use (MWh)	10-yr LCC ($K)
Seawater AC	111	305
Seawater AC with new DX enhancement	250	380
Seawater AC with existing AC enhancement	322	397
Conventional AC	861	404

The existing AC system at Winter Harbor and a seawater cooling system without enhancement are compared in Table 1. It was concluded from these comparisons that significant savings in both energy and money are possible with seawater AC at Winter Harbor (Reference 5).

Environmental Impact

An environmental impact assessment (EIA) was performed in the early stages of this work on a much larger sea-water air conditioning system than was finally settled upon in the preliminary design. The EIA was made for a 3,000-gpm system, which led to a very conservative (high) estimate of the impact because the system was finally envisioned to be less than 400 gpm. Another difference between the preliminary criteria for the EIA and the final system design was the solution to the biofouling problem. The subsequent biofouling study recommended systems which do not require chlorination; this approach considerably reduced the impact of seawater cooling on the environment.

The EIA judged that no significant adverse environmental impacts are foreseen. The long-term local environmental impact will take the form of minor adverse disturbance to plankton and fish in the water and plant life on land. Short-term temporary local disturbance along the pipeline construction route is unavoidable.

SEA/LAKE WATER AIR CONDITIONING NAVYWIDE

The energy saving and economic potential of sea or lake water AC of facilities throughout the Navy were determined. First, the individual AC demands of Naval facilities adjoining major water bodies were determined; then the water temperatures in these water bodies were found. Ten facility sites with high potential for the application of sea/lake water AC were selected. Then the economic potential of these ten was determined. Finally, 15 other sites, which also have potential (but not as high as the ten) for sea/lake water AC, were identified, and the potential energy saving of these was determined.

Air Conditioning Demands

The present energy demands of AC at facilities throughout the Navy were determined using the output of the Defense Energy Information System-Utilities (DEIS-2). For 241 of these 514 facilities, reasonable estimates could be made of the electrical energy consumption for each month of FY76. These monthly estimates were used to determine the amount of electrical energy consumed each year at each facility for AC (Ref 7).

Sea/Lake Water Temperatures

To make the collection of water temperature data tractable, limits were placed on the desired temperature; this 50°F selection was based on prior work discussed in the following.

The maximum water temperature feasible for direct cooling of buildings in Miami Beach, Fla. was determined in Reference 2 to be 50°F. During the work described in Reference 4, it was found that the cooling efficiency of available coils and particularly their ability to remove moisture falls off rapidly at 50°F. Therefore, 50°F was selected as the maximum yearly bottom water temperature to be sought in this data collection.

As shown in Figure 5, water with a year-round temperature of under 50°F can be found all around the continental United States. The distance from shore to this sufficiently cold sea or lake water varies from a minimum of 0 nautical mile (adjacent to the coast) in the extreme Northeast to up to 150 nautical miles in the Southeast. The sources of this water temperature data were (1) National Oceanographic Data Center for facilities near the ocean, (2) W. Harrison of Argonne Laboratories for Lake Michigan near the Great Lakes Training Center, Chicago, Ill., (3) Reference 2 for Miami Beach, Fla., and (4) Reference 4 for Winter Harbor, Maine.

Ten Selected Navy Sites

The selection of the ten sites with high potential for sea or lake water AC was based on the water temperature criteria (50°F) discussed above and on the following criteria for distance from shore and minimum annual AC energy usage.

A limit of 3.5 nautical mines (nmi) was placed on the distance from shore to reach 50°F water for selection of these ten sites. This distance limit was based on the previous studies, discussed below. Reference 2 considered seawater cooling for Miami Beach, Fla., where 50°F water can be obtained 3.6 nmi offshore, and a preliminary design of a high capacity (20,000 TR) seawater cooling system for this site was discussed. A comparatively low capacity (100 TR) seawater cooling system was preliminarily designed for Winter Harbor, Maine, where 50°F water can be obtained 1,300 feet offshore (Ref 4). Therefore, 0 to 3.5 nmi was selected as the range of distances to 50°F water for the selection of these ten sites, and the costs of the Miami Beach and Winter Harbor seawater AC systems were used as starting points for the economic comparison, which follows in the section entitled "Economic Comparison."

The third criteria used in the selection of these ten sites was a 1000-MWh/yr lower limit of energy use for AC. This amount of annual energy consumption for AC is about that of a continuously operating 130-TR AC system, or a 250-TR system that only operates in the summer, or a 500-TR system that neither continuously operates nor is used for summer cooling. These ten facility sites are listed in Table 2 in order of potential energy dollar savings.

Economic Comparison

For comparing sea/lake water AC with conventional AC at these ten sites, the energy and economic characteristics of each site are also given in Table 2. The electrical energy costs and capital investment costs of sea/lake water AC and conventional AC systems were estimated using the techniques described below for each site.

The electrical energy costs were assumed to be the same per unit of energy for either sea/lake water AC or conventional AC. These costs at Naval facilities were determined using the DEIS-2 output. The costs per megawatt hour (MWh) were found from this output for FY76; these were extrapolated to FY80 using a 16%/yr electrical energy escalation rate. The electrical energy costs for these two years are shown in Table 3.

The capital investment costs (first costs including design) of both sea/lake water AC and conventional AC were determined assuming a situation in which an AC system of some type is required at a Naval facility to replace an existing conventional AC system. Therefore, the first cost estimates of both sea/lake water AC and conventional AC did not include the costs of the portions of the AC systems which can be used in either type of system. Thus, the material and labor costs of the fans and ductwork were not included in the capital costs of either type of system, but the costs of modifications to make a sea/lake water AC system usable in a formerly conventional AC system are included in the first costs of sea/lake water AC systems. These criteria were used in estimating first costs in References 2, 4 and 5 so the first costs estimated in these references were used in the following capital investment cost estimates.

The capital cost in FY77 of the 100-TR seawater AC system at NSGA, Winter Harbor with full backup was estimated to be $229K (Reference 4). This cost included two offshore pipelines, one for the primary system and one for the backup system, each of which is 1,300 feet long. The capital cost of a 100-TR system without backup (the additional pipeline and accessories) was estimated to be $173K (Ref 8). Reference 5 indicates that only 81.4 TR are required at this NSGA. Therefore, the above cost for a 100-TR system was reduced to account for this lower tonnage. This led to an estimate of $148K for a seawater AC system of 81.4 TR without backup at Winter Harbor. For the purpose of capital cost estimating, it was assumed that the above seawater AC system cost could be used to make estimates, albeit cruide, of low capacity (under 1,000 TR) sea/lake water AC systems. It was assumed further, because the cost of the offshore pipeline is such a major portion of the total cost of sea/lake water cooling systems, that the total cost is a function of the offshore pipeline length. Therefore, the factor, $700K/nmi ($148K/0.21 nmi) was used to estimate the first cost of low capacity sea/lake water AC systems. The capital cost of a seawater AC system of 20,000 TR for Miami Beach was estimated in Ref 2 to range up to $23.4 million and require a pipeline 3.6 nmi long or about $6,500K/nmi. Five of the selected sites require AC systems of less than 20,000 TR ($6,500K/nmi) but more than 2,000 TR ($700K/nmi.) These extremes of seawater AC costs are plotted in Figure 6(a). The costs of seawater AC at all ten sites were estimated using this figure. The resulting estimates are admittedly very crude, but presently there are no more precise methods of estimating the cost of sea/lake water AC systems short of performing a preliminary design like that done for NSGA Winter Harbor (Ref 4). A better means of estimating the cost of sea/lake water AC systems is needed which will allow the rapid evaluation of sea/lake water AC at Naval facilities.

Estimates of the first cost of conventional AC systems were based on approximate costs per TR in FY77. Reference 5 estimated that the first cost of a conventional system like that at NSGA, Winter Harbor (81.4 TR) would cost $160.8K or about $2,000/TR. For large systems of about 10,000 TR, current practice calls for an estimating factor of $1,000/TR. These extremes of conventional AC costs are plotted in Figure 6(b), and this plot was used to estimate the first costs of conventional AC at the ten selected sites.

Fifteen Other Navy Sites

The total energy saving potential (in terms of MWh and dollars per year) is needed for all sites of Naval facilities which can use sea/lake water AC. Therefore, others of the 241 (of 514) Naval facilities at which reasonable estimates of AC energy requirements could be made were selected considering the minimum water temperature criteria (50°F) described above, but not considering the criteria of 3.5 nmi maximum distance from shore or of 1,000 MWh/yr minimum AC energy requirement. The fifteen other sites thus selected are listed in Table 4 with the total energy saving potential of these fifteen plus the saving potential of the previous ten. It must be noted that these fifteen sites may not be found to be economically feasible if the capital costs are considered as they were with the ten selected sites. However, it must also be pointed out that these 25 Naval facility sites may not include all of the sites which may have potential for sea/lake water AC because all of these sites were selected from only 241 Naval facilities from the total number of over 500.

FINDINGS AND CONCLUSIONS

It was found that:

1. The capital cost of a seawater AC system without new backup or enhancement at NSGA Winter Harbor is $148K (FY77). This system will conserve 213 MWh of electrical energy and save $9K per year.

2. Naval facilities in the United States (particularly in Maine, near Chicago, on the West Coast, and in Hawaii) can profit from installing sea or lake water AC in lieu of conventional AC when there is a need to replace existing AC systems. In Guam and Puerto Rico Naval facilities can also profit from the same type of installation.

3. Twenty-five sites of Naval facilities were identified, from 241 facilities which were investigated, as having potential for sea/lake water AC. If sea/lake water AC were used at these 25 sites, the sum of the energy savings would be 59×10^3 MWh and a corresponding dollar savings of $3 million per year.

4. Ten of these sites of Naval facilities have high potential for economically using sea/lake water AC; the sum of the energy savings at these ten is 23×10^3 MWh and a corresponding saving of $1.3 million per year.

5. Naval facilities at Apra Harbor, Guam; Pt Mugu Calif; Chicago Ill.; and Pearl Harbor, Hawaii have the highest potential of the 25; sea/lake water AC at these four sites can have energy savings of 19×10^3 MWh and a corresponding saving of $1 million/yr.

It was concluded that:

1. An operational test of sea/lake water AC is needed.

2. Seawater temperature measurements at the sites of Naval facilities with the highest potential savings in energy and money are needed.

3. A means of estimating the cost of sea/lake water AC, short of doing a preliminary design, is needed.

RECOMMENDATIONS

It is recommended that:

1. A parametric model be developed for estimating the capital and energy costs of sea/lake water AC systems at Naval facilities.

2. Seawater temperatures be measured at Apra Harbor, Guam; Pearl Harbor Hawaii; Chicago Ill; and Point Mugu, Calif.

3. A final design, fabrication, instrumentation, and installation of a seawater AC system for NSGA Winter Harbor be made.

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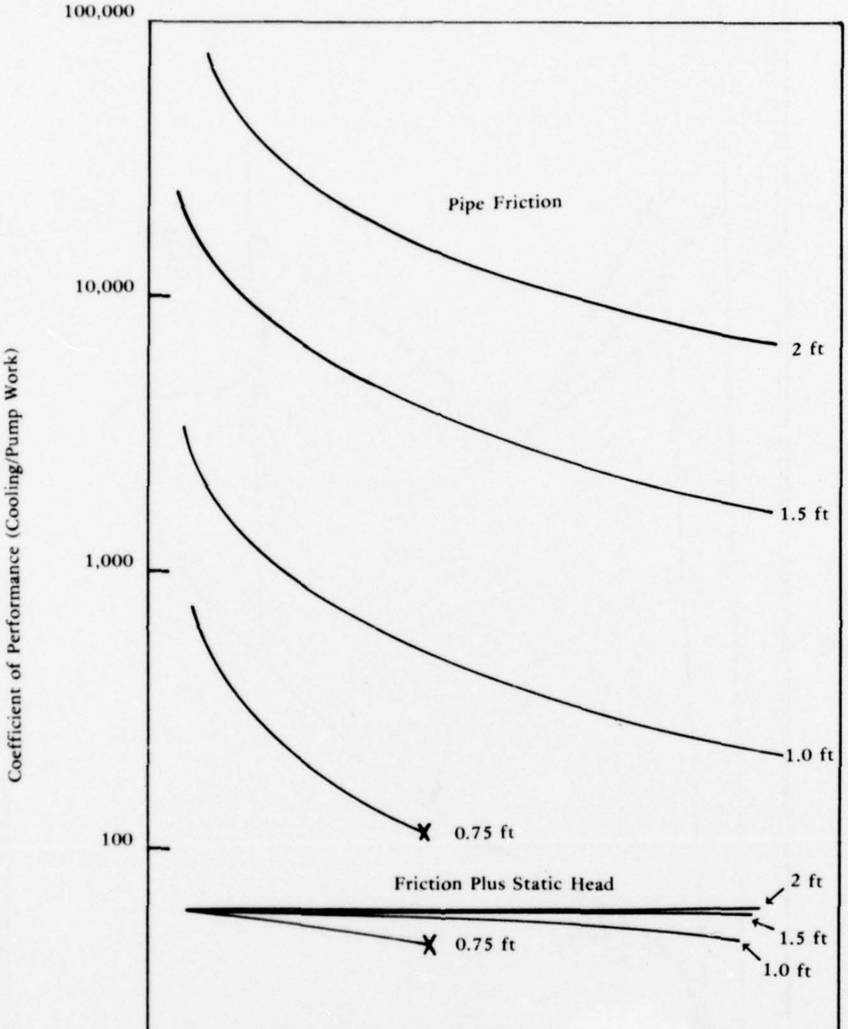
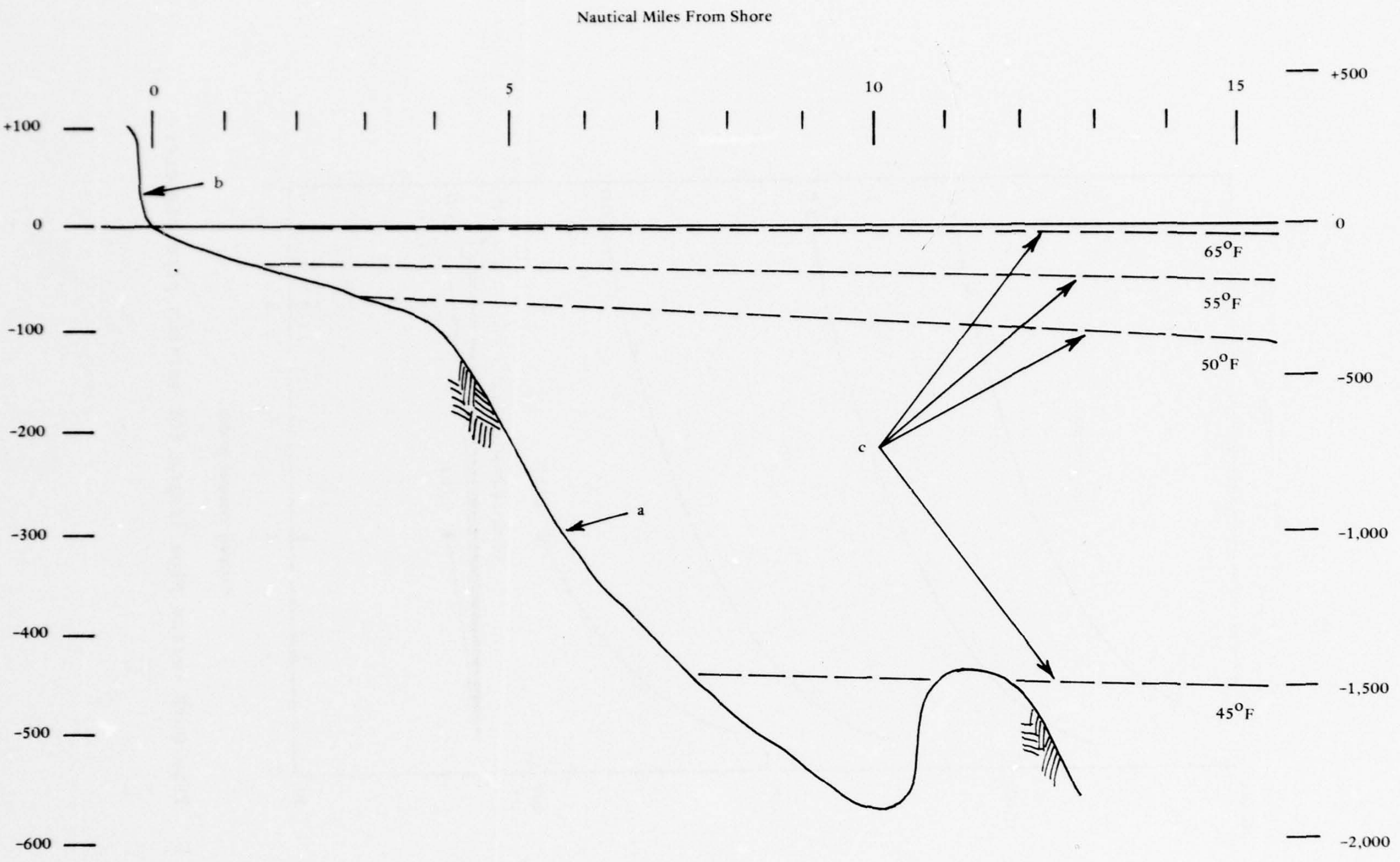


Figure 1. Pump work versus pipe length for various pipe diameters.



a – Bathymetry from National Ocean Survey, Chart 18349
b – Land Topography from Geological Survey Chart, Point Loma Quadrant
c – Temperature data from Oceanic Observations of the Pacific (University of California)

Figure 2. Seawater temperatures at San Diego in August (latitude 32°42'30").

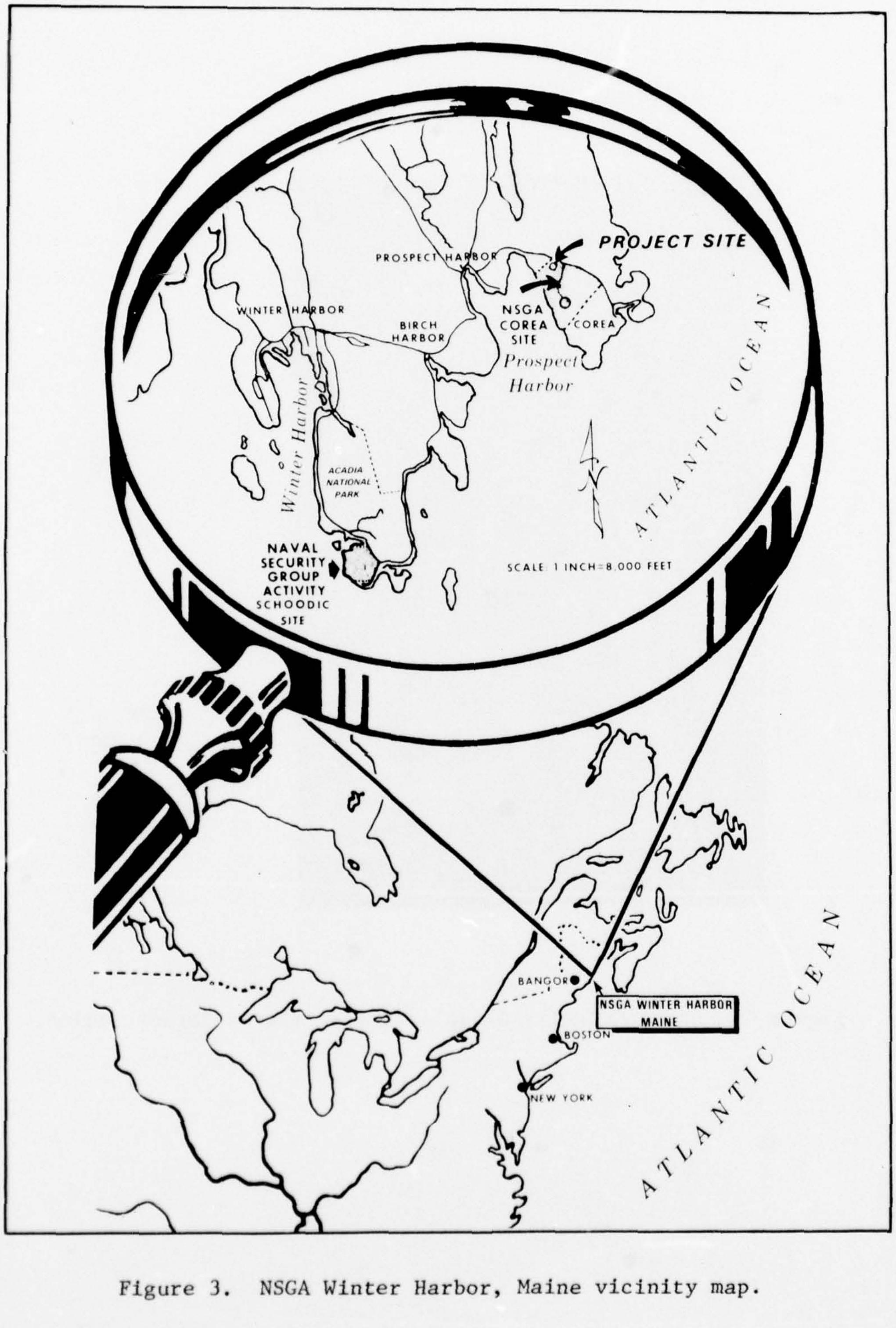


Figure 3. NSGA Winter Harbor, Maine vicinity map.

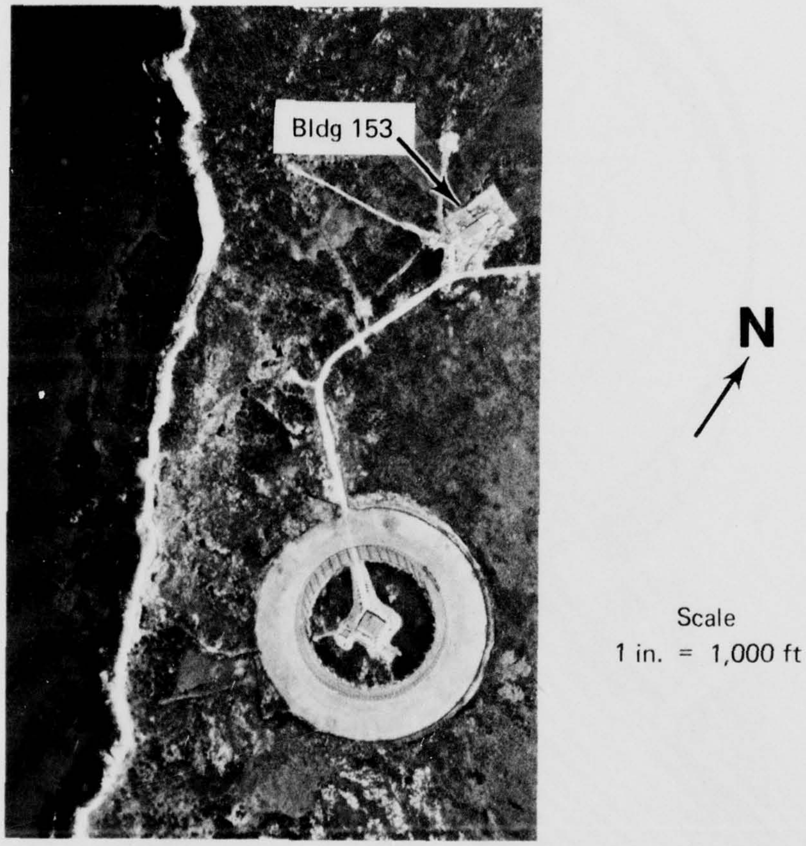
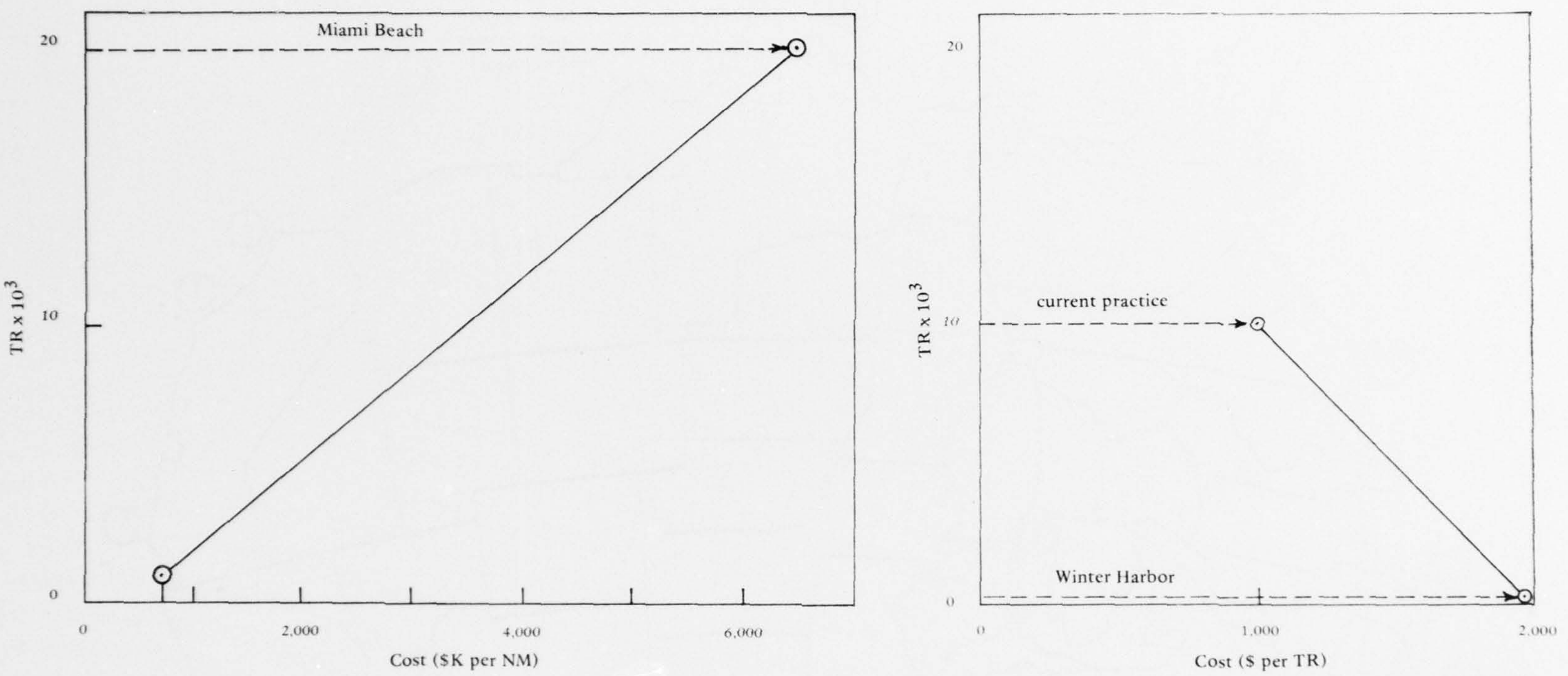


Figure 4. Naval Security Group Activity, Winter Harbor, Maine.

Figure 5. Distance to cold sea/lake water around the continental United States.



(a) Sea/lake water AC costs.

(b) Conventional AC costs.

Figure 6. Capital costs of air conditioning systems.

Table 1. Energy and Economic Analysis for Winter Harbor Seawater Air Conditioning System

Analysis Factors	Air Conditioning Only	Total[a]
Annual Electric Energy Consumption[b]		
Existing AC System MWh	399	659
Seawater Cooling System, MWh	117	446
Annual Electric Energy Savings, MWh[c]	282	213
Percentage of Present Consumption, %	71	32[d]
Fuel Oil Savings, barrels[e]	584	441
FY80 Dollar Savings, $	11,400	8,600

[a] Air Conditioning + Distribution + Humidity Control

[b] From Ref 5.

[c] Existing AC System - Seawater Cooling System.

[d] Also used in Tables 2 and 4 to estimate potential savings at the 10 selected sites and 15 other sites, respectively.

[e] Assuming 35% power plant efficiency: 1 MWh = 2.07 barrels of oil.

[f] Assuming electrical energy cost in FY77 = $0.0259/kWh (averaged from Ref 5) with 15%/yr short-term escalation to FY80; when the seawater cooling system becomes operational, electrical energy cost = $0.0404/kWh.

Table 2. Ten Selected Navy Sites for Sea/Lake Water Air Conditioning

	Site (Naval Facilities)	Annual AC Energy Requirement			Potential Annual Savings			Proximity to $50^{O}F$ Seawater		Capital Costs in FY77 ($ million)			Payback Period of Differential Cost, yr	E Annual Energy Savings $\left(\frac{MBTU}{yr} x10^3\right)$	$\frac{E}{C}$ $\left(\frac{MBTU}{\$K}\right)$
		MWh $x10^3$	Barrels of Oil Equivalent $x10^3$	Tons Refrig. $x10^3$	Energy (32% of AC Energy Reqm't), MWh	Dollars (FY80) $K	Distance (nmi)	Depth, ft	Offshore Pipeline Length, (nmi)	Sea/Lake water Cooling $(x10^3)$	Conventional AC	Differential Cost (SW-Conv)			
1.	Apra Harbor, Guam (Public Work Center)	22.8	47.0	5.7	7300	515	1.6	1080	1.6	3.5	8.0	-4.5	0	84.4	24
2.	Pearl Harbor, Hawaii (10 facilities)	26.7	55.0	6.7	8540	439	3.4	1310	3.4	8.5	8.7	-0.2	0	99.1	12
3.	Chicago, Ill. (5 facilities)	8.4	17.3	2.1	2700	93	2.6	80	2.6	2.9	3.8	-0.9	0	31.2	11
4.	Barking Sands, Hawaii (Pac Mis Range Fac)	1.9	3.9	0.5	610	76	3.3	980	3.3	2.3	1.0	1.3	24	7.0	3
5.	Point Loma, Calif. (NUC)	2.9	6.0	1.5	930	45	3.3	230	3.3	2.8	2.7	0.1	3	10.8	4
6.	Barbers Point, (Hawaii (2 facilities)	2.6	5.4	0.7	830	43	2.7	1150	2.7	1.9	1.3	0.6	18	9.3	5
7.	Point Loma, Calif. (FCDSTC)	2.1	4.3	0.3	670	38	2.6	260	2.6	1.8	0.6	1.2	>30	7.8	4
8.	Point Mugu, Calif. (Pacific Missile Test Center)	2.1	4.3	1.1	670	30	1.0	200	1.0	0.8	2.1	-1.3	0	7.8	10
9.	Sabana Seca, P.R. (Security Group Act)	1.0	2.1	0.1	320	26	0.9	1970	1.0	0.7	0.2	0.5	28	3.5	5
10.	Cutler, Maine (Radio Station)	1.1	2.3	0.1	350	15	1.0	160	1.0	0.7	0.2	0.5	>30	4.1	6
				TOTALS	22920	1320									
	Winter Harbor, Maine (Security Group Act)	0.7	1.4	0.1	220	9	0.2	50	0.21	0.15	0.16	0	0	2.5	13

Table 3. Electrical Energy Costs at Naval Facilities at Ten Selected Sites

Site	Electrical Energy Cost, ($/MWh)	
	FY76	FY80
Apra Harbor, Guam	39.00	70.59
Pearl Harbor, Hawaii	28.38	51.37
Chicago, Ill.	19.00	34.39
Barking Sands, Hawaii	68.79	124.51
Point Loma, Calif. (Naval Undersea Center)	26.46	47.89
Barbers Point, Hawaii	28.38	51.37
Point Loma, Calif. (FCDSTC)	31.39	56.82
Point Mugu, Calif.	24.89	45.05
Sabana Seca, PR	44.20	80.00
Cutler, ME	24.26	43.91

Table 4. Fifteen Other Navy Sites for Sea/Lake Water Air Conditioning

Site (Naval Facilities)	Annual AC Energy Requirement, ($MWhX10^3$)	Annual Potential Savings		Offshore Pipeline Length (nmi)			
		Energy (32% of AC Energy Requirement), MWh	$ (Energy Savings X46.43* $\frac{\$}{MWh}$) $K	0-5	5-10	10-15	15-20
11 Subic Bay, Philippine Islands (NSRF)	23.3	7460	346			X	
12 San Diego, Calif. (11 Facilities)	20.4	6530	303		X		
13 Key West, Fla. (4 Facilities)	19.0	6080	282				X
14 North Island, Calif. (Air Station)	15.3	4900	228		X		
15 Yokosua, Japan (5 Facilities)	14.6	4670	217			X	
16 Okinawa, Japan (Flt Act)	6.6	2110	98			X	
17 Balboa, Panama (Com. Station)	5.3	1700	79				X
18 Long Beach, Calif. (Shipyard)	3.0	960	45		X		
19 Sasebo, Japan (Flt Act)	2.5	800	37			X	
20 Coronado, Calif. (Phib Base)	2.2	700	33		X		
21 Winter Harbor, Maine (Security Grp Act)	0.7	220	10	X			
22 Ferndale, Calif. (Naval Facility)	0.5	160	7	X			
23 Seal Beach, Calif. (Weapons Station)	0.3	100	5	X			
24 Antigua, Bahamas (Naval Facility)	0.2	60	3	X			
25 Whidbey Island, Wash. (Air Station)	0.1	30	1		X		
TOTALS		36480	1694				
Sites 11-25		$36.5X10^3$	1.7 million				
Sites 1-10 (Table 2)		$22.9X10^3$	1.3 million				
Total Potential Savings		$59.4X10^3$	3.0 million				

*Average cost of electrical energy to the Navy in FY80.

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NCBU 405 OIC, San Diego, CA

NCBC CEL (CAPT N. W. Petersen), Port Hueneme, CA; CEL AOIC Port Hueneme CA; Code 10 Davisville, RI; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 400, Gulfport MS; NESO Code 251 P.R. Winter Port Hueneme, CA; PW Engrg, Gulfport MS; PWO (Code 80) Port Hueneme, CA; PWO, Davisville RI

NCBU 411 OIC, Norfolk VA

NCR 20, Commander

NCSO BAHRAIN Security Offr, Bahrain

NMCB 133 (ENS T.W. Nielsen); 5, Operations Dept.; Forty, CO; THREE, Operations Off.

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NSC Code 54.1 (Wynne), Norfolk VA

NSD SCE, Subic Bay, R.P.

NTC Code 54 (ENS P. G. Jackel), Orlando FL; Commander Orlando, FL; OICC, CBU-401, Great Lakes IL

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PMTC Code 3331 (S. Opatowsky) Point Mugu, CA; EOD Mobile Unit, Point Mugu, CA; Pat. Counsel, Point Mugu CA

PWC ACE Office (LTJG St. Germain) Norfolk VA; CO Norfolk, VA; CO, Great Lakes IL; Code 116 (LTJG. A. Eckhart) Great Lakes, IL; Code 120, Oakland CA; Code 120C (Library) San Diego, CA; Code 128, Guam; Code 200, Great Lakes IL; Code 200, Guam; Code 200, Oakland CA; Code 220 Oakland, CA; Code 220.1, Norfolk VA; Code 30C (Boettcher) San Diego, CA; Code 40 (C. Kolton) Pensacola, FL; Code 400, Pearl Harbor, HI; Code 42B (R. Pascua), Pearl Harbor HI; Code 505A (H. Wheeler); Code 680, San Diego CA; OIC CBU-405, San Diego CA; XO Oakland, CA

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