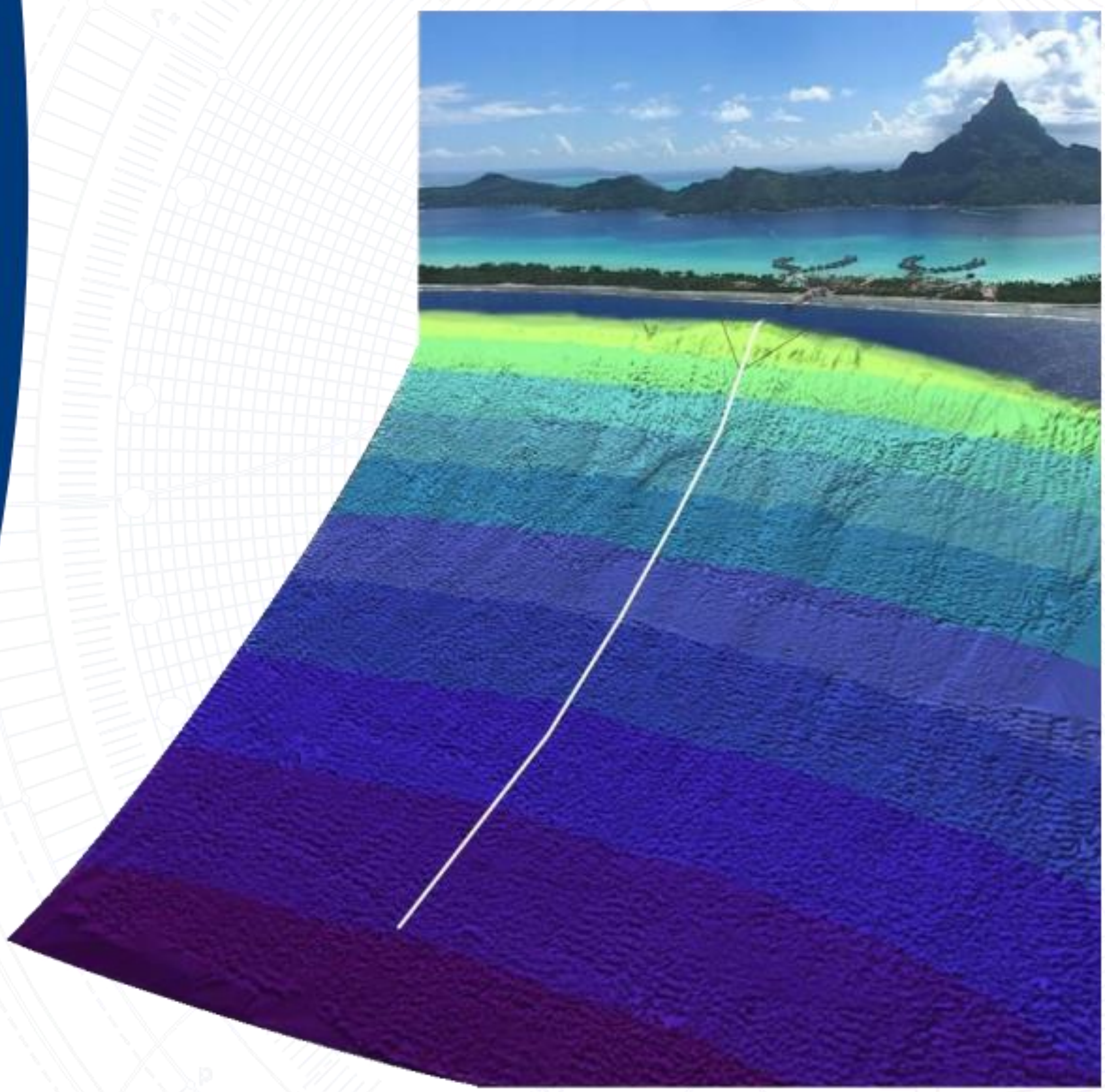
Makai Ocean Engineering

SWAC

An Introduction to Seawater Air Conditioning

Harnessing a valuable, renewable energy
for predictable, economical cooling



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Seawater Air Conditioning: A Basic Understanding

Introduction

Seawater Air Conditioning (SWAC) is an alternate-energy system that uses the cold water from the deep ocean (and in some cases a deep lake) to cool buildings. In some areas it is possible to reduce dramatically the power consumed by air conditioning (AC) systems; SWAC can be a cost-effective and attractive investment. It is an alternate energy for air conditioning.

This paper is an introduction to Seawater Air Conditioning; it describes the benefits, the technology, the areas best suited for this form of energy, some example projects, the economics and the key components of the systems.

Benefits of a SWAC System

The Seawater Air Condition Systems taps into a significant and highly valuable natural energy resource that is available at some coastal locations. The benefits of a seawater air conditioning system include:

- Large energy savings approaching 90%
- Proven technology
- Short economic payback period
- Environmentally friendly
- Costs are nearly independent of future energy price increases.
- No evaporative water consumption.
- Cold seawater availability for secondary applications.

Conventional Air Conditioning Basics

The schematic to the right illustrates a conventional air conditioning system for a large building. A constant flow of cold fresh water is circulated throughout the building (sometimes multiple buildings) for heat removal. As this chilled water moves throughout the building and absorbs heat, its temperature rises from an incoming value of approximately 7-8ºC to an outflow value approximately 5ºC higher. This warmer water then enters the chiller.

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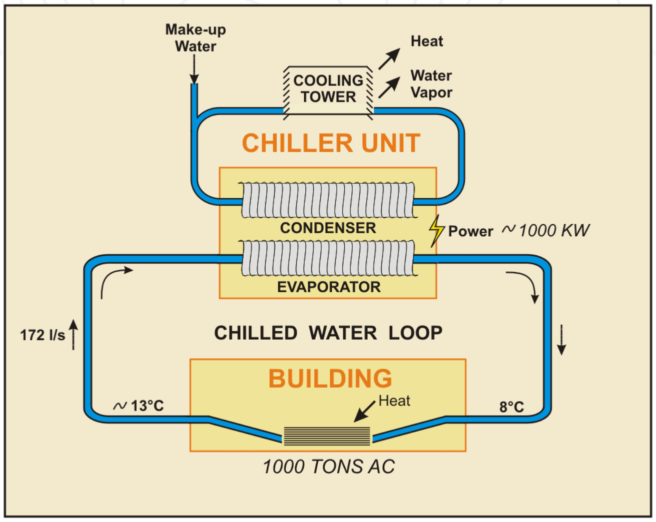
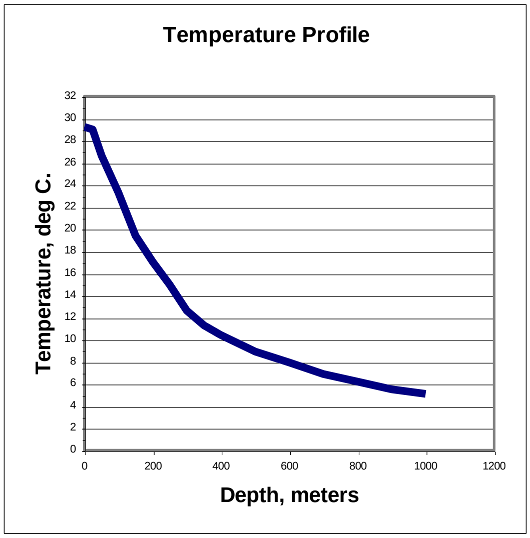
The chiller is a refrigeration system that cools the recirculation water. Water enters the chiller at a nominal 12-13°C and exits at 7-8°C. The chiller consumes electricity as it "pumps" heat from a cold source to a warmer source. The total heat removed from the building and the electrical power consumed by the chiller passes through the chiller's condenser to a heat sink. The most conventional means of eliminating this excess heat is to use a cooling tower that dumps the heat into the atmosphere primarily through evaporative cooling. Cooling towers consume fresh water; some chillers are air cooled if fresh water is not economically available.



The energy requirements for a large building's air conditioning system are significant and, depending upon the location, may be the dominant electrical load of the building. The electrical requirement for conventional chiller operation and cooling is 0.9 to 1.3 kW/ton depending upon the location, cooling system, and age of the system.

Seawater Air Conditioning Concepts

Along many ocean coastlines and lake shorelines, there is reasonable access to naturally cold water that is as cold or colder than the water used in conventional air conditioning systems. If this water can be tapped, then the significant power for operating mechanical chillers to keep the chilled water cold can be eliminated.



The adjacent temperature profile illustrates the temperature vs depth that is typical for the world's tropical deep oceans in the summertime: 7°C or below can be reached at 700m depth, 5°C. or below at 1000m. The deep-water portion of this profile changes little seasonally and therefore cold water is available on a year round basis. In more northern climates, very cold water can be

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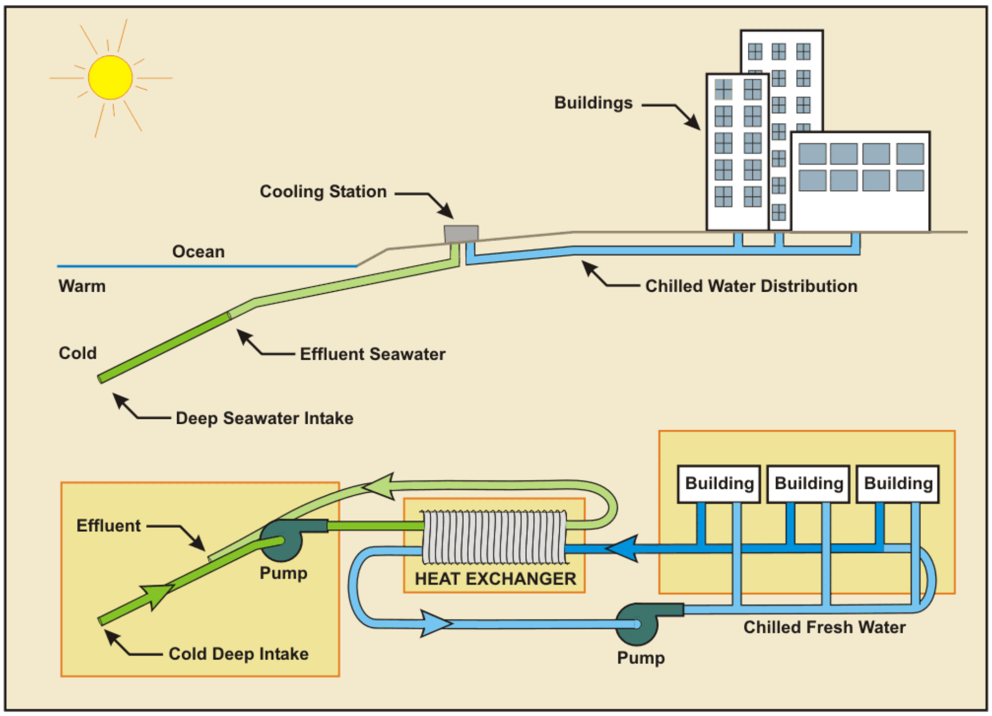
reached at shallower depths during the summer – in both oceans and in deep water lakes.

The basic concept of seawater air conditioning is to take advantage of available deep cold seawater to cool the chilled water in one or more buildings as opposed to using more energy intensive refrigeration systems.

A seawater air conditioning system is illustrated below. The buildings to the far right are identical internally to buildings cooled with conventional A/C. Chilled fresh water moves through these buildings with the same temperatures and flows of conventional systems. The seawater and chilled water pumps and heat exchangers would typically be located at the shoreline in a cooling station.



The main components of a seawater air conditioning system are the seawater supply system, the heat exchanger or cooling station and the fresh water distribution system. These basic components can be optimized for each specific location, climate and building.

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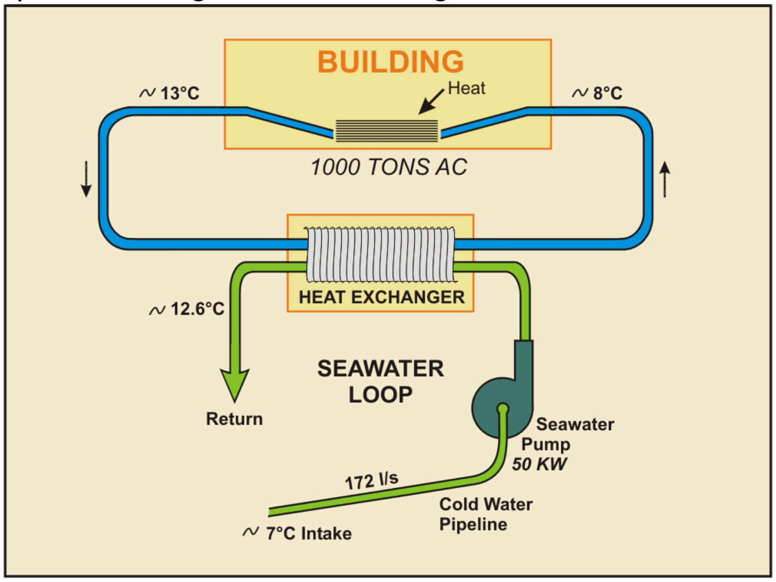
This schematic is an alternate view of a basic centralized seawater air conditioning system. The chilled water loop is fresh water and operating at the same temperatures as with conventional AC. The interior of the building is unchanged with SWAC systems. The chilled water is kept cool through a heat exchanger with a counter flow of deep cold seawater. The heat exchanger is titanium to eliminate corrosion and fouling does not occur because of the purity of the deep seawater. Seawater is brought to the site through a deep-water polyethylene pipeline. These pipelines reach out several kilometers offshore and have a nominal intake depth of 700 m. The effluent seawater is discharged though a second pipe at a depth of approximately 40 m.



Seawater air conditioning is not technically complex nor is it a high technical risk. It is established technology being applied in an innovative way. All the components necessary exist and have been operated under the conditions required.

In some cases, it is either too costly or impractical to supply seawater at the necessary low temperatures to maintain the required temperatures in the chilled water loop for direct cooling with deep seawater. The distance offshore to reach sufficiently cold water might be prohibitive or the ocean depth may simply not be available. In such cases, there are two other methods to use seawater to reduce the energy costs associated with air conditioning.

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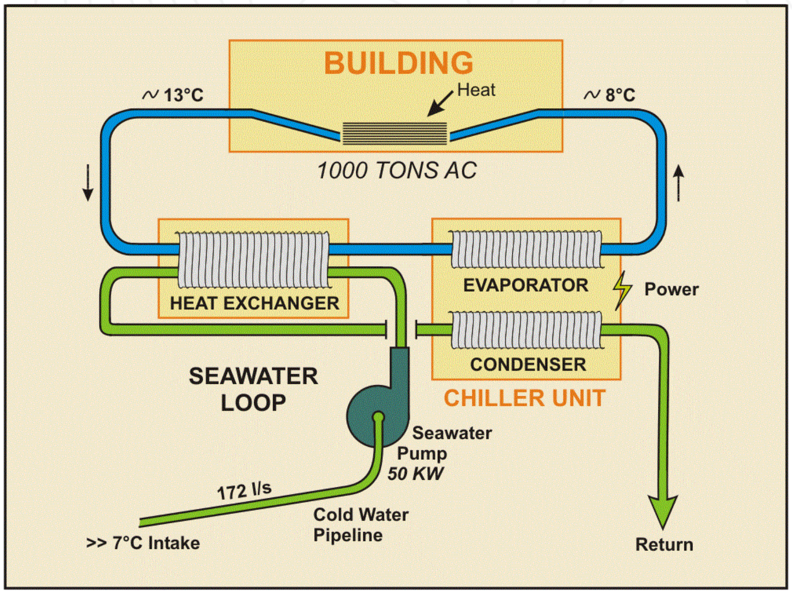
Use of an Auxiliary Chiller: It is sometimes economically possible to use auxiliary chillers to supplement the cooling provided by the seawater exposure. This is illustrated at right. The fresh chilled water is first cooled by seawater through a heat exchanger and then is secondarily cooled with an auxiliary chiller. The auxiliary chiller is basically a refrigeration system with its condenser cooled by the returning flow of cool seawater. Alternatively, the chiller's condenser can be cooled by the return flow from the chilled water loop (not shown). In either case, with a reduction in the condenser water temperature, the auxiliary chiller can operate at higher efficiency – as high as double that of an air-cooled conventional chiller.



Seawater Cooled Chiller: If a site with high air conditioning costs has no access to cold seawater, near shore seawater can also be used to reduce air conditioning costs. This is done by replacing an air-cooled or evaporative cooling tower cooled condenser with seawater cooling. If the condensing temperature of a conventional chiller unit can be reduced, energy savings will result. The amount of energy saved will depend upon the change in condensing temperature. Shallow surface seawater will typically be much cooler than the air, especially during the hottest time of year. Thus, an air-cooled condenser can be replaced by seawater cooling and obtain 25% or more energy savings. If the chiller uses an evaporative cooling tower for condenser cooling, usually shallow seawater can both improve chiller performance and can eliminate the noise, water demand and sewage fees associated with the evaporative cooling tower. The figure below shows a schematic of a conventional chiller with its condenser cooled with shallow surface seawater.

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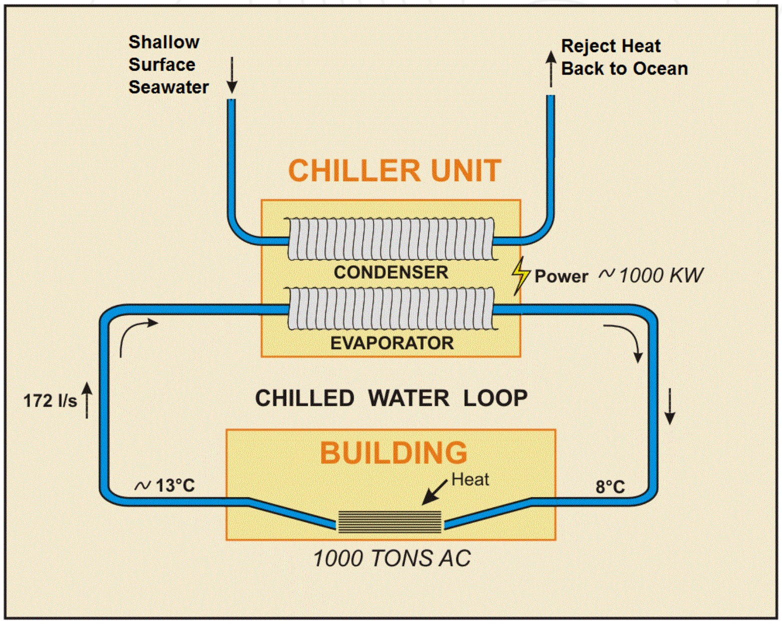

Cold Storage: A SWAC system has a high capital cost and a low operating cost. The peak capacity of the system must match the peak demand of the buildings that it serves. These demands are not constant throughout the day or throughout the year, and the total system is frequently not being used to its maximum capacity. Therefore, capital dollars are spent on a system that may not always be used to its maximum potential. A means of minimizing the capital cost is to use cold-water storage. Such a system allows a smaller seawater air conditioning system to be installed and operated 100 percent of the time. When the building A/C demand is low, the excess capacity is directed into a storage system of cold fresh water. When A/C demand is at its peak, the cold water is drained from its storage to meet the demand.

Insulated cold water storage tanks are commercially available; the warm water remains at the top and the coldest water remains at the bottom. These tanks are now used in conjunction with conventional A/C systems to take advantage of low, off-peak electrical rates.

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Environmental Aspects

A SWAC system has significant environmental benefits: These include drastic reductions in electricity consumption which reduces air pollution and greenhouse gas production, and substitution of simple heat exchangers for chiller machinery which often use ozone-depleting chlorofluorocarbons (CFCs).

The existence of the deep ocean heat sink results from natural climatic processes where water is cooled at the poles, becomes dense and sinks to deeper water and slowly moves toward the equator. The cold ocean is therefore both immense and renewable.

Return water from a SWAC system can be handled in a number of ways. Typically it is returned to the ocean at a location where the return water temperature nearly matches the ambient water.

There are significant secondary applications for this seawater. Secondary cooling, aquaculture, desalination and even agriculture can benefit from the cold seawater. Aquaculturists value the water because it is clean and disease free. When used in conjunction with a warm source of water, they can have any temperature seawater their product needs. Secondary cooling can be used in greenhouses and other locations where humidity control is not a major factor. Finally, research in Hawaii has shown that even an arid land can be made highly productive with low fresh water consumption by cooling the soil and the roots of many tropical and non-tropical plants. Deep seawater is also desalinated and sold as a premium drinking water in Asian markets.

Economic Viability

The economic viability of a SWAC system is site specific. Each location has unique opportunities as well as problems. The main factors influencing the economic viability of a specific location include:

- *The distance offshore to cold water*: shorter pipelines are more economical than long pipelines.
- *The size of the air conditioning load:* there is an economy of scale associated with SWAC – systems less than 2000 tons are more difficult to justify economically,
- *The percent utilization of the air conditioning system:* The higher the utilization throughout the year, the higher the direct benefits.

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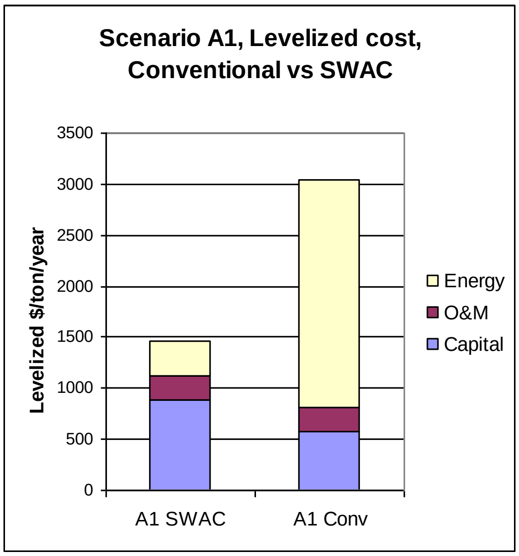
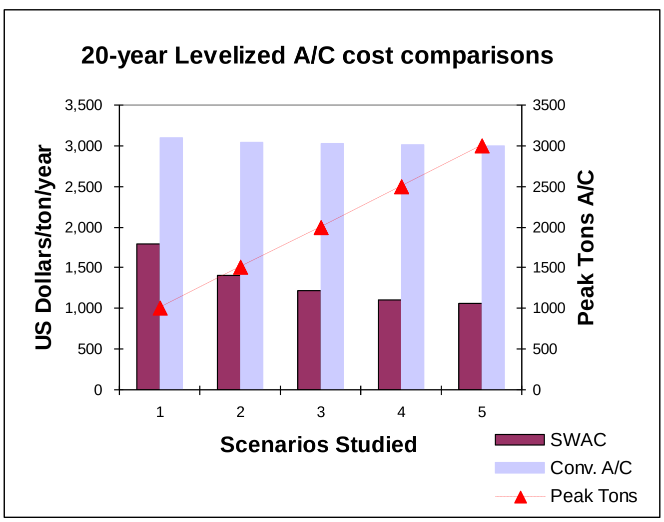
- *The local cost of electricity*: A high cost of electricity makes conventional AC more costly and SWAC, in comparison, more attractive. Any cost analysis should include current and future costs of electricity.
- *The complexity of the distribution system on shore:* SWAC works best with a district cooling arrangement, where many buildings are cooled taking advantage of the economy of scale. SWAC is even more economical if this distribution system is compact.
- *The marine construction infrastructure:* if marine contractors are available locally, this will reduce offshore construction and mobilization costs.



The adjacent figure illustrates the difference in lifetime costs for a conventional AC system and a typical SWAC system. The costs are broken down into capital, operating (energy) and maintenance. The primary cost of a SWAC system is in the initial capital cost. The operating and maintenance costs are small. For a conventional AC system, the primary cost is in the power consumed over its lifetime. Hence, SWAC systems are ideal for base load AC that has high utilization and conventional AC may be better for situations of infrequent use.



It's important to note that there is a dramatic economy of scale as the size of the pipeline increases. The reason is that the cold water pipe costs per liter of water delivered decreases as the pipeline size increases and temperature rise via large pipelines is practically negligible. The figure to the right illustrates five SWAC scenarios of varying overall size; the two bars compare the lifetime cost difference between conventional AC and SWAC.

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Makai has performed SWAC feasibility studies of a variety of sites. Typical results are that electrical consumption is reduced by 80 to 90 percent. Simple payback can be from three to seven years, and long term costs can be half that of a conventional air conditioning system. Not all locations, however, are ideal. Some have poor access to deep cold-water sources or the overall size is too small to be economical. Each site is unique.

Makai's SWAC model (METHOD™)

For over 25 years, Makai has continuously developed custom software for modeling the hydraulic and thermal aspects of fluid networks. The cost algorithms were recently upgraded and now account for 160 various costs applied across a dozen of the key construction steps for district cooling systems. This software have been used to model, analyze, and design district cooling networks, and especially SWAC district cooling systems. The model, called the Makai Economic, Thermal, and Hydraulic Optimization and Design software, or METHOD™ software, takes into account all of the major capital and operational costs for both systems and the complex interplay between the sub-system designs and operational costs. This enables an "apples-to-apples" economic comparison of district cooling versus an equivalent conventional A/C system. Other financial metrics, such as payback period and rate of return of the district cooling system, are also computed. The METHOD™ software consists of two components: an engineering and an economic model. It considers the primary engineering and economic parameters associated with a particular SWAC site, produces a conceptual design, and provides a fair comparison of the cost of cooling provided by SWAC versus conventional air conditioning.

In order to reduce the costs of a district cooling system, METHOD™ is used to design and optimize components to minimize the overall levelized cost of cooling. The software is particularly useful for providing quick and cost-effective "what if" analyses to help the developer decide between possible design variations early in the project, such as evaluating whether or not to add a nearby A/C customer to the network. Users can instantly see the effect on levelized cost due to a change in the network. In the case of a SWAC system, METHOD™ includes accurate costs for the offshore seawater pipes that are derived from real construction projects – these are necessary to get an accurate project cost, and are something only a firm with significant offshore pipeline construction experience can offer. More than 25 years ago, Makai created the original SWAC model, and our engineers have been improving its functionality ever since.

Engineering model: Starting from a few client-provided inputs, this software determines a very basic conceptual design for a SWAC system that includes the following components:

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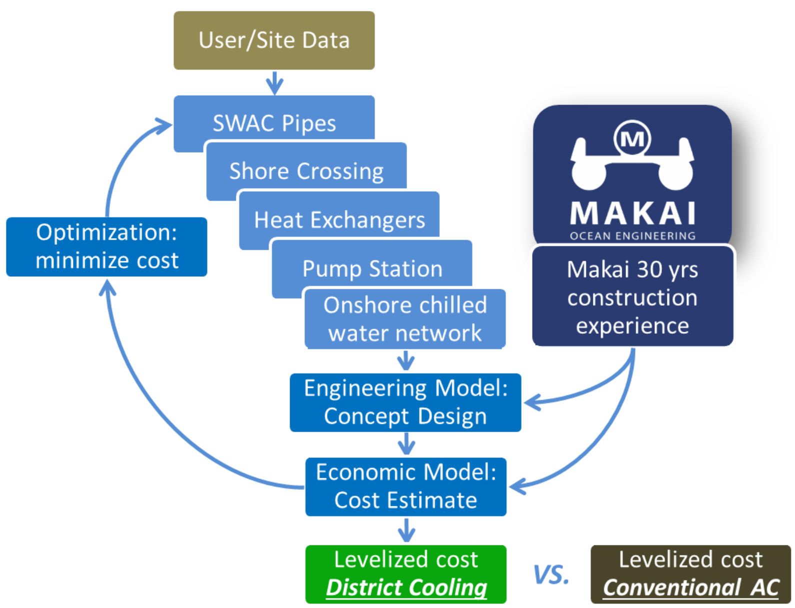
- Offshore pipes (intake and return water)
- Pipeline Shore Crossing
- Seawater Pumping/Heat Exchanger Station
- Onshore Chilled Water Pump Station
- Onshore Chilled Water Distribution System

The software defines the parameters (e.g. sizes, lengths, flow rates, power requirements, etc) for each of these major components.

Economic model: Once an initial conceptual design is complete, Makai uses the software to assign a cost for the design, construction, operation and maintenance to each component in the SWAC system. The model then runs an optimization algorithm to minimize for the levelized cost of cooling. The optimized design then produces a cost estimate that allows a fair economic comparison between SWAC and conventional air conditioning, using a levelized cost analysis. Usually a SWAC system must look significantly better than a conventional AC system solution before Makai will recommend it.



Makai's economic model is based on an analytical procedure developed by the Electric Power Research Institute (EPRI) in their Technical Assessment Guide [TAG]. The TAG model is an economic analysis method of comparing two alternate energy systems with different capital and operating costs.

One of the most important inputs to the economic model is the cost of the large and unique offshore pipelines. Makai's strength is our extensive experience and knowledge of costs associated with constructing and installing large marine pipelines, as will be discussed below. No other firm has such an intimate knowledge of the costs of these unique submarine pipelines.

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SWAC History Highlights

The feasibility of using cold seawater to directly cool buildings has been studied and analyzed for many years. At certain locations, successful installation and operation has occurred. The following is a brief partial history of seawater air conditioning systems around the world:

In **1975**, the US Department of Energy funded a program entitled "Feasibility of a District Cooling System Utilizing Cold Seawater." [Hirshman et al] Several locations were studied and the two most favorable sites were Miami/Ft. Lauderdale and Honolulu. The study, however, noted that one of the limiting technical factors was the inability to deploy large diameter pipelines to depths of 1500' and more. This technical challenge has since been addressed and demonstrated with Makai-designed deep-water pipelines at the Natural Energy Laboratory of Hawaii, Keahole Point, Hawaii.

In **1980**, the Naval Material Command at Port Hueneme, California, conducted a study entitled: "Sea/Lake Water Air Conditioning at Naval Facilities." [Ciani]. Computer models were developed which provided reasonable estimates of the capital cost and energy use of seawater air conditioning systems at Point Mugu, California and Pearl Harbor, Hawaii. The study concluded that: at a hypothetical typical Navy facility, a SWAC system will use 80% less energy than conventional A/C, but the capital costs of SWAC systems are 60% greater. The Life Cycle Cost of SWAC at a typical naval facility would be 25% lower than the life cycle cost of conventional A/C.

In **1986**, a joint project between the Canadian government and Purdy's Wharf Development, Ltd. demonstrated the use of ocean water as a source for building cooling to a 350,000 square ft. office complex along the waterfront in Halifax, Nova Scotia. Due to the geographic conditions and annual low water temperatures, a small diameter pipeline was deployed to a depth of less than 100' ft. This was a major factor in limiting the overall expense of installing the cooling system. Total investment for this project was $200,000. The project was very successful and savings were identified in the following areas: a saving of $50-60,000 per year in avoided electrical cost, fewer maintenance staff, reduction in fresh water, savings in water treatment, and savings in cooling tower maintenance and replacement. The financial result in terms of a simple payback period was two years. [Building Cooling] Today, Purdy's Wharf continues to utilize successfully an expanded seawater air conditioning system for their waterfront properties.

In **1986**, the Natural Energy Laboratory of Hawaii Authority, Keahole Point, Hawaii began the successful utilization of SWAC in their main laboratory building. Deep-water pipelines were already installed to provide cold, nutrient rich, seawater for research purposes in alternate energy and aquaculture. Since a cold water supply was already

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incorporated into the infrastructure, it was decided to utilize the cold water for cooling. This proved to be a very sound economic decision that resulted in monthly electric savings of $400. Today, the use of SWAC has been expanded to a new administration building and a second laboratory. Estimated monthly saving in electricity is $2000.

In **1990**, the US Department of Energy funded a study entitled: "Waikiki District Cooling Utility." The purpose of this brief study was to evaluate whether it was economically and technically feasible to utilize seawater air conditioning as a means to provide cooling to the hotels in Waikiki and to create a Waikiki Cooling Utility. Waikiki was targeted because of the high density of hotels, high electrical consumption and a large demand for air conditioning. It was estimated by Hawaiian Electric Company that of the 107 Megawatts consumed in Waikiki, 51.4 Megawatts were used for air conditioning. This study concluded that economically and technically, Waikiki could be cooled by utilizing seawater air conditioning.

In **1995**, Stockholm Energy started supplying properties in central Stockholm with cooling from its new district cooling system. Most of the cooling is produced by using cold water from the Baltic Sea. The temperature of the cooling water leaving the plant is 6°C or lower and the return temperature from the distribution grid is 16°C at high load and a few degrees lower at low load. The district cooling system is designed for a maximum load of 60 MW.

In **1999**, the Cornell Lake Source Cooling Project installed a 63” diameter pipeline into nearby Lake Cayuga. This Makai-designed pipeline was 10,000 feet in length and installed to a depth of 250’. Cold water from this pipeline, at approximately 4°, provides air conditioning for the Cornell University Campus. This system is capable of providing in excess of 20,000 tons of cooling; the system started operation in mid-2000.

In **2004**, the Deep Water Cooling Project for Toronto, Canada, commenced cooling of downtown Toronto with a peak capacity of 58,000 tons. Three 63” pipelines reach far into Lake Ontario for both potable and cooling water for the city. Makai assisted in the engineering of the deep water aspects of the pipeline designs for this project.

In **2004**, Makai completed the design for a 450 ton SWAC system in French Polynesia for a major hotel. Construction has been completed and the system has been in operation since May 2006.

In **2006**, a SWAC system design and planning is underway in the Caribbean for 3000 tons AC for a complex of hotels, meeting centers and university. This SWAC system design was completed in 2008.

In **2008**, a SWAC system design started for a very large SWAC systems to service a district cooling system in downtown Honolulu, Hawaii. The design is completed, and it is scheduled for construction in 2015.

In **2011**, Makai became a member of the International District Energy Association. This organization promotes energy efficiency and environmental quality through the advancement of district heating, district cooling and cogeneration.

INTERNATIONAL DISTRICT ENERGY ASSOCIATION
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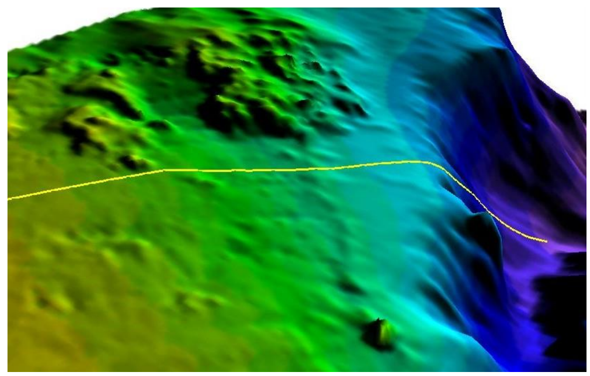
Offshore Pipelines



The key cost and risk component of any SWAC system is the offshore pipeline. The lack of a low-cost methodology for the installation of these pipelines prevented SWAC development in the 1970’s and 80’s. Today, the technology for the successful installation of pipelines to depths of 3000’ and greater is available. Numerous deep water intake pipelines have been installed – nearly all of the world’s successful pipes have been Makai designs.

All of the deep seawater intake pipelines designed by Makai have used polyethylene as the pipeline material. Polyethylene has significant advantages for these pipelines in that it is inert and will neither corrode nor contaminate the water. Polyethylene lengths are heat fused together to form a long, continuous pipeline with joints that are as strong as the pipeline itself. Polyethylene has excellent strength and flexibility and is buoyant in water. These characteristics allow a great deal of design flexibility and deployment ease. The wall thickness can be varied depending on strength requirements for deployment and operating suction over the lifetime of the pipe.

Makai's approach for a deep water pipe deployment is to minimize the time at-sea. The pipeline is basically designed for the deployment process since this represents the

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major cost and risk of the installation. The pipeline is assembled complete on shore, launched floating using the pipeline to support all anchors and fastenings, towed to the site, and controllably submerged while carefully monitoring pipe tensions and pressures. The procedure is stable and reversible.

The major risk to the pipeline is during deployment. These are standard marine construction risks and would be covered by the installer's insurance. Once deployed, the likelihood of deep-water failure is very remote.

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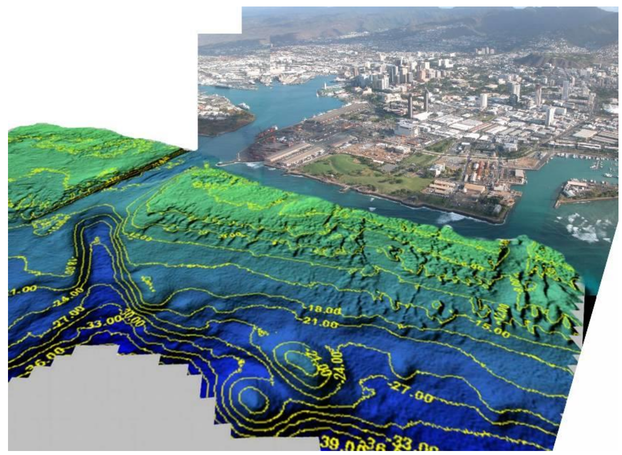
SWAC and Offshore Pipeline Experience

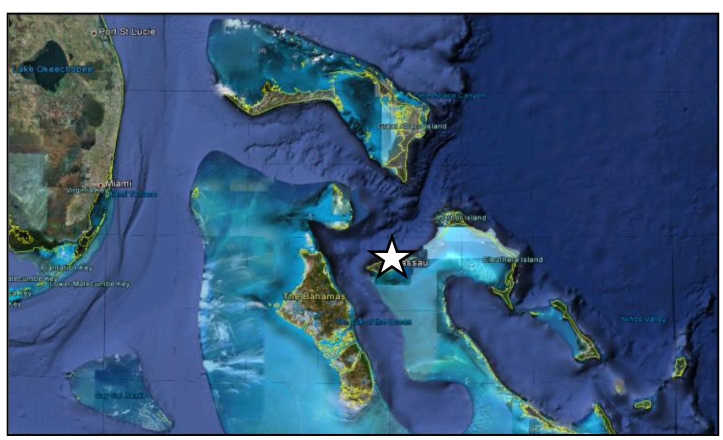
A summary of some of Makai's previous experience in pipeline design, analysis and deployment is listed below. Many of these pipelines have been for Seawater Air Conditioning (SWAC) systems. More details and illustrations of key pipeline Makai projects may be found on Makai's webpage at www.makai.com, or upon request. A complete list of SWAC studies performed by Makai is provided below.

1. Honolulu, Hawaii – SWAC, Active



Makai has completed the 80% final design for Honolulu Seawater Air Conditioning LLC, (HSWAC) a subsidiary of Ever-Green Energy of St. Paul, Minnesota. The overall goal of this ambitious project is to provide over 20,000 tons of air conditioning to downtown Honolulu commercial and government buildings. Makai is responsible for the design of the 63" (1.6m) diameter deep water intake pipeline from 43' (13m) depth to the intake depth at 1750' (534m) stretching over a length of approximately 4.7mi (7.6km). Makai's design includes a companion shallow water return water discharge pipe. This project is currently on hold until HSWAC is able to obtain 59% of the overall cooling load signed to binding contractual agreements. This is the key element to the release of construction funds.

2. Bahamas – SWAC, Active

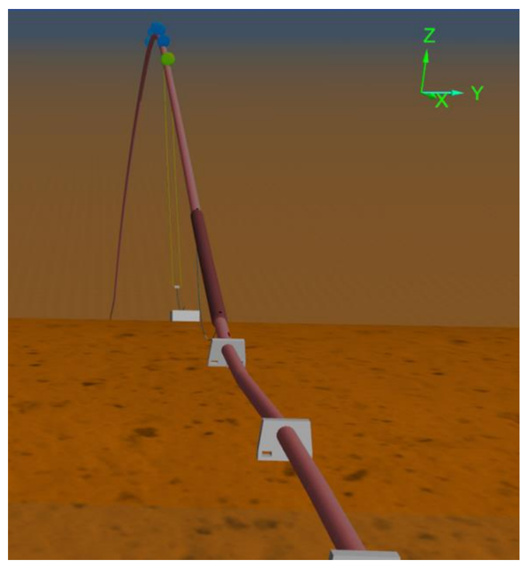


Makai has completed the initial pipeline engineering and a very detailed offshore survey and route selection for a pending SWAC intake for the Bahamar Hotel. This work was performed in 2011-12 for OTE Corporation. This route survey and route selection was the most challenging ever performed by Makai. The bottom terrain is extremely rough with a vertical cliff, steep slopes, sunken vessels, crisscrossing telecommunications cables, and no direct straight path. Makai selected and analyzed an acceptable path for the 63” (1.6m) diameter HDPE pipeline down to 3,600’ (1100m) depth. This project is currently on hold pending a final engineering contract with the system developer – OTE Corporation.

3. La Reunion – SWAC, Active

Since 2009 Makai has been working with GDF Suez Energy Services at La Reunion Island in the Indian Ocean. This pipeline is for a 40 MW cooling load with a 63” (1.6m) HDPE intake, a 1.4m discharge, 3,600’ (1100m) intake depth, and 5.5 km pipe length. In 2011 Makai assisted with a detailed bathymetric survey which used an ROV. This project is in the preliminary design phase and is moving forward a step at a time as funds become available from the European Union and France; the operational date is 2016.

4. Hawaii – 1 meter pipe repair, 2013



In 2011, Makai was contracted by the State of Hawaii to perform final design and construction oversight services for the repair of a deep water 40” (1.0m) diameter HDPE pipe at the Natural Energy Laboratory of Hawaii (NELHA) located in Kona, HI. The pipe, originally built for ten year design life, has been in place for over 25 years. The pipe design involves a 915m long floating catenary section from 150m to 670m depth, and several of the chain bridles restraining the pipe had worn from corrosion and continuous motion over the years. Makai simulated the current pipe conditions using Orcaflex 3-dimensional finite element software, simulated repair solutions, and provided final design drawings and specifications. In July 2013, repairs were conducted and Makai provided on-site representation for our client, the State of Hawaii. The repairs were successful, and post-repair measurements showed excellent agreement with Makai’s model predictions and design specifications.

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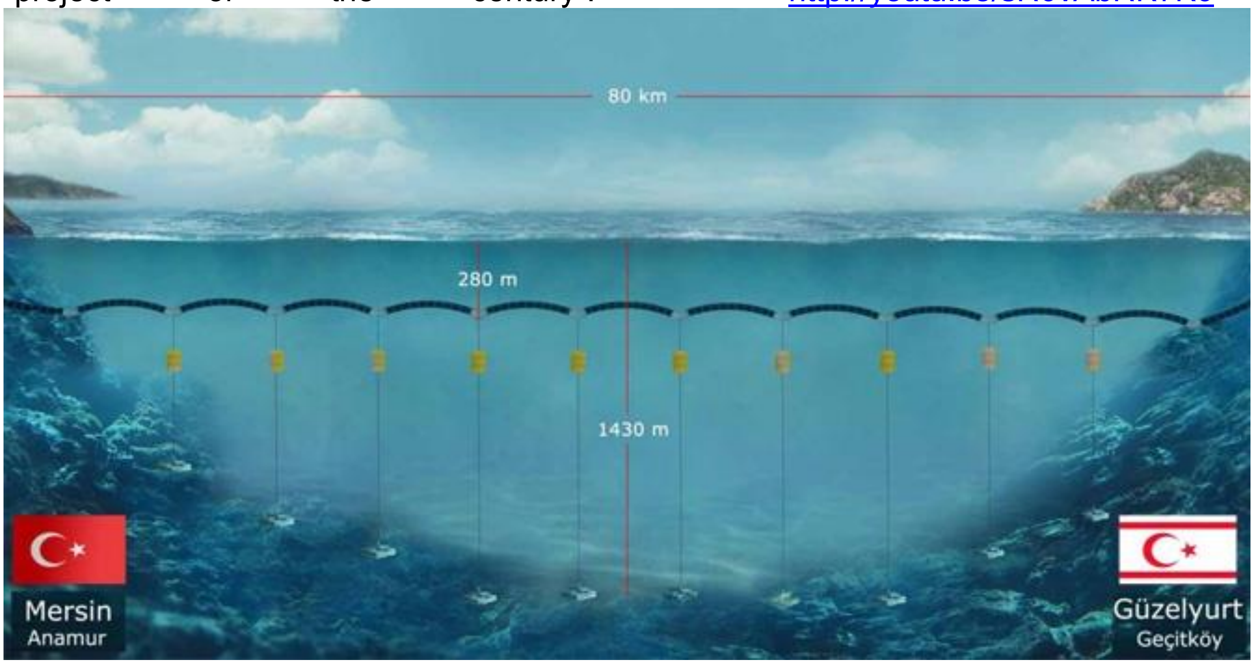
5. TRNC Drinking Water Supply – 1.6 meter Pipe, 2013

In late 2013, Makai was contracted by a joint venture between Sigur Ros and Kalyon Group to perform deployment analysis for the on-bottom portion of a 63" (1.6m) diameter, 66 mile (107 km) long HDPE pipeline to transmit drinking water from the Turkish mainland to the island of Cyprus (Turkish Republic of Northern Cyprus). Makai performed pipe stress analysis, design of the holdfasts, pipe weights, and bridle system, and final deployment analysis and guidelines. Here is a video of the "project of the century": http://youtu.be/sR0vAbRK7K0



6. Maldives, Hulhumale – SWAC, 2012

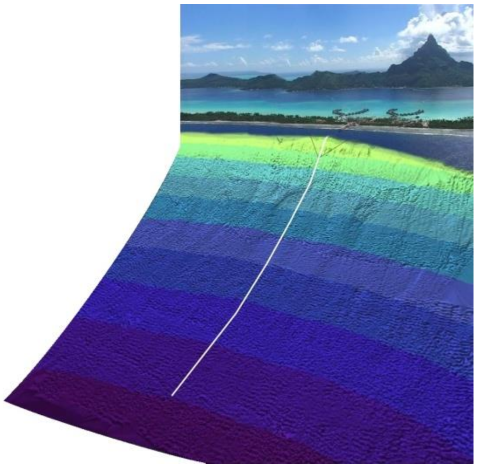
In 2011, Makai was contacted by Hitachi Plant Technologies, Ltd to investigate a SWAC system on the island of Hulhumale in the Republic of the Maldives. The purpose of this study was a conceptual level engineering assessment of the potential and feasibility of building a deep water intake pipeline, pump station, and discharge pipe system to support a SWAC system defined by Hitachi PT. Makai's analysis and conceptual design, completed in 2012, suggested that a SWAC system with 900mm diameter intake pipeline would be an economically desirable system. Makai recommended that Hitachi PT pursue development. However, Hitachi PT informed Maki in 2012 that, due to government complications, the project was stalled, and they were putting it on hold.

7. Curacao Piscadera - SWAC, 2008

In March of 2008, Makai completed the final design for the deep seawater intake pipeline, the return water pipeline and the pump station mechanical plant for a seawater air conditioning system to be built in the Piscadera region on the Caribbean Island of Curacao. This 3000 ton air conditioning system will supply cooling to 4 hotels and a power plant. A 36” (915mm), 3.7mi (6km) long intake pipeline extending to an intake depth of 2790’ (850m) has been designed; the construction of this project was disrupted by the financial crisis of 2008, and to date has not been assumed by another developer.

8. French Polynesia – SWAC, 2006

Makai has engineered a complete SWAC system for a resort in French Polynesia, supplying 450 tons of AC. This demanding project involved a 6600’ (2000m) long deep seawater intake pipeline extending to 2950’ (900m) depth on a seabed with extremely steep slopes up to 60 degrees. The design has a portion of the pipeline suspended off of the seabed. This project was completed in 2006, and has been in operation since May of that year. See http://www.boraboraspa.interconti.com/



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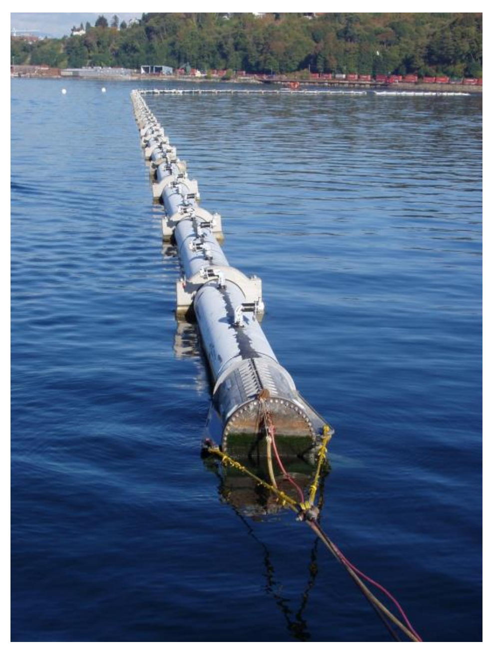
9. Bahrain – Cooling Project, 2005

In 2005, Makai designed intake and discharge pipelines to provide seawater to the Bahrain Diplomatic Area District Cooling Project's air conditioning plant for condenser cooling. Seawater drawn from the Arabian Gulf is slightly warmed and then returned into near shore waters. The system, owned by Tabreed Bahrain, features a 63" (1.6 meter) diameter by 2240' (683 meter) long intake pipeline, and a 55" (1.4 meter) diameter by 5104' (1556 meter) long outfall pipeline with a 20 port diffuser, operating at a flow rate of 60,000 gallons per minute (3.79 m^3/sec).

10. Everett, Washington – Outfall Pipeline, 2004



Makai designed the deep water portion of a 63" (1600mm) diameter outfall pipeline for Kimberly-Clark Paper Company and the City of Everett, Washington. This pipeline delivered 70 MGD of treated municipal and industrial wastewater to a depth of 350 feet (107m) in Puget Sound. The total length of the deep water outfall was 2741' (836m) and included a 1550' (472m) diffuser section with 80 ports. The alignment included a 40 degree bend right at toe of a steep submarine slope. Makai devised a unique diffuser port plug design that allowed this outfall to be installed using standard controlled submergence techniques for deep water HDPE pipes, and then allowed the diffuser ports to be quickly opened using an inexpensive remotely operated vehicle. The pipeline was installed in late 2003 and has been in service since the spring of 2004.

11. Toronto – Deep Lake Water Cooling, 2003

Makai performed significant design aspects for the three deep water intakes for ENWAVE's Deep Lake Water Cooling Project in Lake Ontario, installed in 2003. The deep intake pipes provide cold water for a district cooling system that provides a max of 75,000 tons (264 megawatts) of air conditioning load for downtown Toronto. The new system will provide water of higher purity than is provided by the old intakes that obtained water from shallower depths. Each HDPE pipeline is 5km long and 63” (1.6m) in diameter downtown Toronto as well as the municipal drinking water system.

12. Hawaii – 1.4 M Intake Pipeline Design and Installation, 2001

Makai engineered the main seawater supply source for the Hawaii Ocean Science Technology Park (HOST Park) at Keahole Point, Hawaii This supply system consists of a cold-water pipeline that is 55” (1.4m) diameter, 3000’ (915m) deep, and 2 miles (3 km) long, a 55” (1.4m) diameter warm water intake pipe, a tunneled shoreline crossing and a shore-based pumping station. The system will provide 27,000 gpm (1.7 m3/s) of 4-degree Celsius water and over 40,000 gpm (2.5m3/s) of warm water to the technology park. Two micro-tunnels extend from shore to a breakout point offshore at approximately 85’ (26m) depth. The largest and deepest seawater intake in the world, this pipeline earned a major national award from the American Society of Civil Engineers

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13. Cornell University – Lake Source Cooling, 1999

Makai was selected by Gryphon International Engineering Services and Cornell University to design a 63” (1.6m) diameter HDPE intake and a 48” (1.21m) diameter outfall pipeline in Cayuga Lake, NY to provide 20,000 tons of centralized cooling for the university. The intake pipeline is two miles long with an intake at 250’ (76m) depth. The pipeline provides 32,000 gpm (2.0m^3/s) of cold water and has a 75-year lifetime. Deep pipe construction was completed in 1999 and the operation of the air-conditioning system started in 2000. As the pioneer large SWAC-type system, Lake Source Cooling has earned a trophy case full of engineering and environmental awards.

Autumn tow of 63” (1.6m) pipeline for an air-conditioning intake at Cornell University

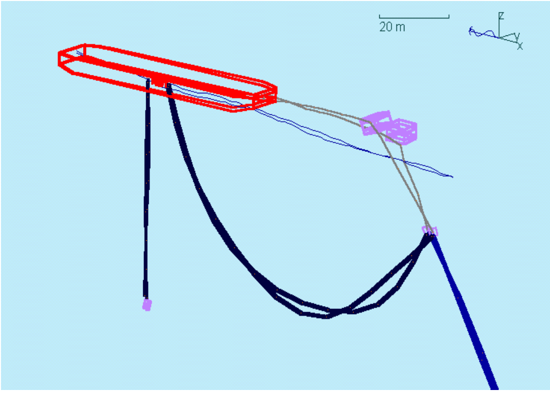
14. Hawaii – 1 meter Intake Pipeline Design and Installation, 1987

In a project with R.M. Towill Corporation, funded by the State of Hawaii and the U.S. Department of Energy, Makai was tasked with the design of a 40" polyethylene cold water pipe to be used jointly by the Natural Energy Laboratory and the Hawaii Ocean Science and Technology (HOST) Park sites on the Big Island. It is the largest deep-water intake pipeline in the world. This pipe is a larger and more rugged version of the previous Makai 12" pipe design at NELH and includes a 3000' long buoyant section. Makai assisted in the deployment of this pipe to a depth of 2200' in August 1987. It was the main source of water for the Natural Energy Laboratory until 2005.

15. Hawaii – 460 mm Intake Pipeline Design and Installation, 1987

Makai designed and provided construction management for an 18" (0.46m) down-the-slope cold-water intake at the Natural Energy Laboratory of Hawaii. The goal to install a reliable, minimal cost, deep-water intake system to 2200' (670m). This polyethylene design differs from previous NELH pipelines in that the deep water pipe is buoyed approximately 40' (1.0m) off the bottom on a series of pendants, the deployment was accomplished without major offshore equipment. This pipeline was successfully deployed in October, 1987, and is still operational.

16. India – OTEC Pipeline, 1988



In 1988, Makai provided conceptual designs and design guidance to the National Institute of Ocean Technology (NIOT) in Madras, India, for in OTEC intake pipeline and mooring system for a floating OTEC research barge in the Indian Ocean. This pipeline was 3.3' (1m) in diameter and was designed to provide water from a 3,300' (1000m) depth.

17. Hawaii – 300 mm Intake Pipeline Design / Installation, 1981

Makai conceived, designed and managed the construction of an experimental, down the slope polyethylene OTEC pipeline, 12" (0.30m) in diameter, for the State of Hawaii. This one mile long pipeline has an intake at 2200' (670m) and utilizes a unique 3000' (915m) long free floating catenary section to avoid contact with the steep, rocky bottom. The pipeline was installed in 1981 off Keahole Point, Hawaii. In spite of its

"temporary" design life of 2 years, it has survived many major storms including a hurricane and was operational for over twelve years. This pipe was recovered in November 2012 and will be reused as a seawater distribution pipe by the Natural Energy Laboratory of Hawaii Authority.

18. Hawaii Mini-OTEC – vertically Suspended OTEC Pipeline, 1979

Makai engineered several portions of the Mini-OTEC project under contract to Dillingham Corp. This project was a full demonstration of Ocean Thermal Energy Conversion (OTEC) and jointly funded by the State of Hawaii, Lockheed, Dillingham and Alfa Laval. Makai designed a 2' (610mm) diameter polyethylene pipe that served not only as an intake pipe from a 2000' (610m) depth, but also as the "mooring line" for the 120' x 35' (37m x 11m) barge. The initial design for the barge layout, seawater intakes (cold and warm), effluent lines, and pumps was also done by Makai. Makai developed and planned the deployment scheme and participated in the at-sea deployment. On August 2, l979, Mini-OTEC developed 50 kW of power and consumed 40 kW, for a net positive output of l0 kW. This was the first time that a positive output had been achieved from any OTEC facility.

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Awards

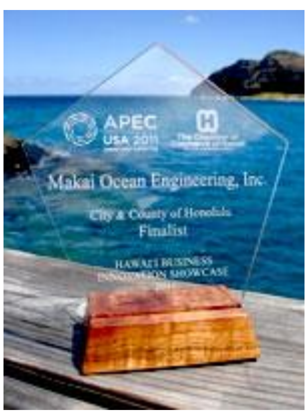
2014, Leaders in Sustainability Finalist

Makai was nominated for Pacific Business News' 2014 Business Leadership Hawaii Awards – Hawaii's premier business recognition event of the year. Based on our outstanding work during the year, PBN selected Makai as a finalist in the *Leaders in Sustainability* award, recognizing a company that has made significant strides in reducing energy use or conserving natural resources for itself or other businesses.

ISO 9001:2008 Certification

Makai Ocean Engineering, Inc. has achieved ISO 9001:2008 certification, an internationally recognized standard for quality management systems. The Certificate is only awarded to companies that can demonstrate their ability to consistently provide products and services that meet customer requirements, placing customer satisfaction as a key component of those requirements.

APEC 2011 Hawaii Business Innovation Finalist



Makai was chosen as one of the 30 finalist among 2000 local companies that competed to represent Hawaii at the 2011 Asia Pacific Economic Cooperative (APEC) Summit. The criteria for the award included business services or products that are attractive to markets outside Hawaii, having developed unique, leading and cutting-edge innovations in product development, technology, marketing or delivery; having positively impacted Hawaii's business environment, having growth and investment potential; and having adopted environmentally sound programs and practices.

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Aon Grand Build America Award

Advanced American Construction, Inc. received the 2011 Aon Build America Award from the Associated General Contractors of America for their work constructing an innovative buoyant HDPE sewage interceptor pipeline submerged in Lake Oswego, Oregon. Makai assisted in the design and engineering analysis of the pipeline.

2010 SBA Prime Contractor of the Year for Hawaii and Region IX

The Small Business Administration honored Makai Ocean Engineering for their work in the Federal government contracting arena. Makai was nominated for their "outstanding performance, innovative solutions, professionalism, cost effectiveness and on-time delivery by the federal agencies that contracted their services.

2005 Compass Industrial Award

The Marine Technology Society awarded Makai with the Compass Industrial Award for outstanding contributions to advancement of the science and engineering of oceanography and marine technology.

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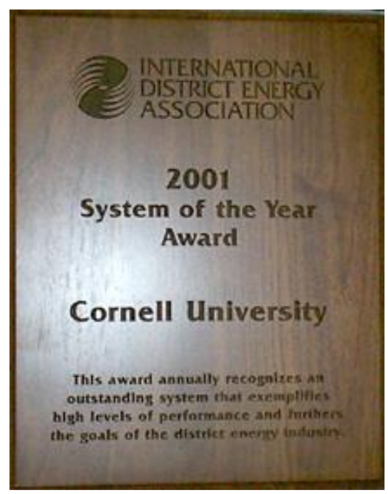
American Society of Civil Engineers

The American Society of Civil Engineers selected the HOST Park Seawater Supply Pipeline, the world's deepest large-diameter seawater intake pipeline, as one of six finalists for the 2003 Outstanding Civil Engineering Achievement (OCEA) Award. The survey, conceptual and final design, and construction observation for this project was performed by Makai Ocean Engineering.

Cornell's Lake Source Cooling

The success of Cornell's Lake Source Cooling Project has won three awards: the New York State Society of Engineers, the Associated General Contractors of America, and the International District Energy Association. Makai was responsible for the design engineering of the two-mile long 63-inch cold-water intake pipe and the 48-inch discharge pipe.



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Contact Makai to discuss your SWAC Project

Makai has been working on SWAC projects consistently for more than 20 years. Our database of worldwide site information and experience with successful SWAC projects enables us to assess a site rapidly for its viability.

For those interested in developing SWAC systems, Makai provides a preliminary opinion of viability free of charge. If the site looks promising, Makai will propose one or more options for a SWAC feasibility study for your particular site that fits within your budget.

Please contact us at the phone, email, or mailing address listed below.

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