SEA WATER DISTRICT COOLING FEASIBILITY ANALYSIS

FOR THE STATE OF HAWAII

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Executive Summary

This study is an evaluation of the potential for using cold seawater to provide air conditioning for areas in Hawaii that have high demand concentrations. Presently air conditioning (A/C) is provided in these areas by conventional cooling systems (CCSs) that use electric power to chill water that is distributed throughout the building to pick up heat and transfer it to the outside air. The conventional A/C system consumes around 40% of the total electrical power used in such buildings. A seawater A/C district cooling system (SDC) consists of a cold seawater supply line, a heat exchanger (at the shoreline), and a closed cycle fresh water distribution system, all with appropriate pumps. The electrical energy required by an SDC system is only to run the pumps. This amounts to about 10%, or less, of what is needed for the conventional A/C system.

The costs associated with an SDC system are primarily related to the initial capital expenditure. This, in turn, is related to the distance to cold water, to the temperature of that water, to the extent and location of the on shore distribution loop, and to the sizes of all pipelines. Operating costs are related to amount of pumping power required. This is related to the amount of water to be pumped and to the size and length of the pipelines.

An SDC system can be evaluated and optimized on the basis of overall minimum cost or on minimum energy. Both of these methods were used in this study.

Evaluations were conducted for six areas on Oahu, and four on the neighbor islands using a common set of economic parameters (base case analyses). On Oahu the primary demand areas are along the shores of Mamala Bay where it is difficult to get to the 3,300 foot (1,000 meter) depth required for 39^{o}F (4^{o}C) water. However, the

1,600-foot (500 meter) depth contour is within reach and consequently 45°F (7°C) water is available.

Each of the six case study SDC systems was further analyzed to determine the impact of changes in various parameters involved the economics of SDC systems and CCSs. The impact of combinations of changes in two, or more, of these parameters was also investigated. Summaries of the results for sensitivity analyses for each of the six case studies are also presented in this report, as is a summary of the benefits of SDC systems.

The results of these sensitivity analyses show that SDC systems in the Waikiki, Kakaako, and Honolulu Waterfront areas are very cost effective, even in the base case analyses. On a weighted average basis, case study systems (West Waikiki, Kakaako, and Honolulu Waterfront) have base case levelized costs that are 18.4% less than CCSs. Best case scenarios show potential levelized cost savings greater than 58%. Even for some of the other non-Oahu case studies, various incentives would make them cost effective when compared to CCSs.

Savings of these magnitudes could justify a significant reduction in cooling costs to SDC system customers, while still providing developers with a good return on investment. In fact, any incentives provided may have to be limited in order to prevent developers from receiving "windfall" profits. This may have to be decided on a case-by-case basis.

SDC systems save more than 90% of the energy used for CCSs. On a weighted average basis, the West Waikiki, Honolulu Waterfront, and Kakaako case studies saved 92.5% of the energy typically used in CCSs. (Similar reductions in future utility electricity generation capacity are also provided.) This is equivalent to 4,526 kWh/rated ton-yr, or 8.43 Bbl of imported crude oil/rated ton-yr.

The Waikiki, downtown Honolulu, and Kakaako areas have the potential for a total capacity of more than 50,000 tons of cooling provided by SDC systems. Based on this potential, more than 226,000 MWh, and 420,000 Bbl of imported crude oil can be saved each year (4,530,000 MWh, and 8,420,000 Bbl of imported crude oil over the 20-year life of these systems). And, this does not include electricity transmission and distribution losses.

Other benefits of such a large reduction in imported fossil fuels use include significant greenhouse gas reduction and other air and water pollution benefits. An SDC system also does not use potentially harmful working fluids (such as the ones used in many CCSs) and greatly reduces the water and toxic chemical use and disposal associated with cooling towers.

The method of evaluation used in this study is conservative in that it does not consider site specific characteristics, the possible use of off peak ice production (or other thermal storage), or such economic factors as tax credits or carbon trading. An example of the use of some site specific information and the inclusion of thermal storage is included in this report for Kakaako. A follow-up project to evaluate the "Integration of Energy Storage With Seawater Air Conditioning (SWAC) Systems" is currently underway.

Another consideration for federal facilities (and more recently for state facilities) is the requirement to reduce the dependence on fossil fuel by 30%. An SDC system for such facilities would go a long way to meeting this requirement.

The next phase of an evaluation of the possible use of SDC systems in Hawaii is to conduct site-specific evaluations for each of the positive and marginal sites identified in this study. Such "Phase II" evaluations would essentially be business plans with preliminary designs and economic evaluations that consider site specific information as well as timely economic factors and legal requirements.

Section 1 of this report discusses the background and objectives of this study. Areas in with potential for seawater air conditioning are also identified. Operational considerations and conditions required for a cost effective (SDC) system are also discussed.

Section 2 describes the technical process involved in this study. Of particular interest are the costs (capital and operation and maintenance [O&M]) of the: (1) seawater supply and effluent disposal system; (2) heat exchanger and district cooling systems; and (3) conventional cooling systems (CCSs). The Electric Power Research Institute Technology Assessment Guide (EPRI TAG) method was used for economic analyses.

Section 3 identifies six large-scale SDC systems and uses them as case studies to evaluate the economics of SDC systems in Hawaii.

Section 4 provides the results of a number of sensitivity analyses to determine the impacts of changes in various parameters on the economics of SDC systems and CCSs. These parameters include: (1) system lifetimes; (2) estimated percent replacement for competing CCSs; (3) real interest rates; (4) contingency costs; (5) changes in electricity costs; (6) changes in real annual escalation rates for electricity; (7) combined State and federal income tax rates; (8) federal investment tax credits;

(9) various depreciation methods; (10) utility rebates; (11) State of Hawaii Energy Conservation Income Tax Credits; (12) various production incentives; and (13) combined property tax and insurance rates. Summaries of the results for sensitivity analyses for each of the six case studies are also presented.

Section 5 provides a preliminary marketing plan for such systems.

Finally, Section 6 provides a number of conclusions and recommendations regarding the potential for development of SDC systems in Hawaii, and for technology export to other areas.

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List of abbreviations and symbols

A	Area
α	Heating time constant, day-night district cooling ratio
AC	Air conditioning
β	Coefficient of Performance
c	Heat capacity
C	Hazen-Williams coefficient, Celsius, Cost
C_A	Conventional air conditioning cost
C_D	Drag coefficient
C_L	CWP section cost
C_C	Chilled water distribution system cost
C_S	Seawater supply system cost
CWP	Cold water pipe
C / B	Cost-Benefit ratio
D	Diameter
δ	Wall thickness
Δ	Difference between quantities
DC	Darcy-Colebrook equation
e	Roughness
er	Electricity rate
E	Modulus of elasticity

E_A	Cooling expense of equivalent conventional system
E_C	Pumping expense of chilled water system
E_S	Pumping expense of Seawater system
fps	Feet per second
ft	Foot
F	Force
F_D	Drag force
F_L	Lifting force
F_W	Anchoring force
FW	Chilled water
FV	Future Value
g	Gravitational acceleration
h	Hour
$\dot{h}$	Specific heat generation
H	Heat or Thermal Energy, Wave height
$\dot{H}$	Heat transfer rate
$HDPE$	High Density Polyethylene
HW	Hazen-Williams equation
HX	Heat Exchanger
ir	Interest rate
k	Thermal conductivity coefficient, breaker depth coefficient

kg	Kilogram
$\ln$	Natural logarithm
L	Length
$LMTD$	Log mean temperature difference
L_{S-S}	Distance between stiffening rings
m	Mass, meter
$\dot{m}$	Mass flow rate
n	Number, quantity
np	Number of Payments
$NELHA$	Natural Energy Laboratory of Hawai‘i Authority
η	Efficiency
ν	Poisson’s ratio
p	Pressure
P_A	Power demand of conventional air conditioning system
P_C	Power demand of chilled water system
PMT	Periodic Payment
P_S	Power demand of seawater system
PV	Present Value, Loan Amount
p_{vm}	Von Misen buckling pressure
π	3.14
Q	Volumetric flow rate
R	Radius (inner radius of pipe)

Re	Reynolds's Number
R_h	Hydraulic radius
ρ	Density
s	Second
S	Safety factor
SDC	Seawater District Cooling
t	Time
T	Temperature
T_{corr}	Temperature correction coefficient
TES	Thermal energy storage
TFA	Total floor area
τ	Period, life cycle
u	Utilization fraction, horizontal water particle velocity
U	Flow velocity
USEPA	United States Environmental Protection Agency
V	Volume
w	Vertical water particle velocity
x	Displacement
z	Elevation/depth
z_b	Wave breaking depth
ζ	Hydraulic head

Notation

$\bar{x}$	Mean of x, any parameter
$\langle x \rangle_y$	Time averaged value of x over y period

Subscripts

C	Capacity
D	Day
f	Flow friction
i, j	Index
INS	Insulation
n	Node
N	Night
o	Initial
p	Pump
T	Total, tank
S	Storage
w	Weight

1. Background and Objectives

Over the past decade, a growing number of scientists and engineers have become concerned about global climate change. This phenomenon shows a strong correlation to human use of fossil fuels. A century's exponential growth in the build-up of combustion products trapped within Earth's atmosphere is implicated as the primary cause of the "Greenhouse effect" (Marland, 2001). Furthermore, one of the main fossil fuels, petroleum, is a finite resource and has been a focus of international conflict for nearly the same period. The other significant greenhouse gas producer is the burning of coal. While there is an abundant supply of coal, its contribution to global warming is the most intense of all fossil fuels per unit energy generated (USDOE, 2000).

Recently, the official viewpoint of the United States on "global warming as fostered by human activity" has shifted from unknown to confirmed. As a national member of the "Climate Change Partner" program initiated by the U.S. Environmental Protection Agency, Hawaii is expected to: "…..take an active and immediate role in addressing greenhouse gas emissions." (Alber, 2000).

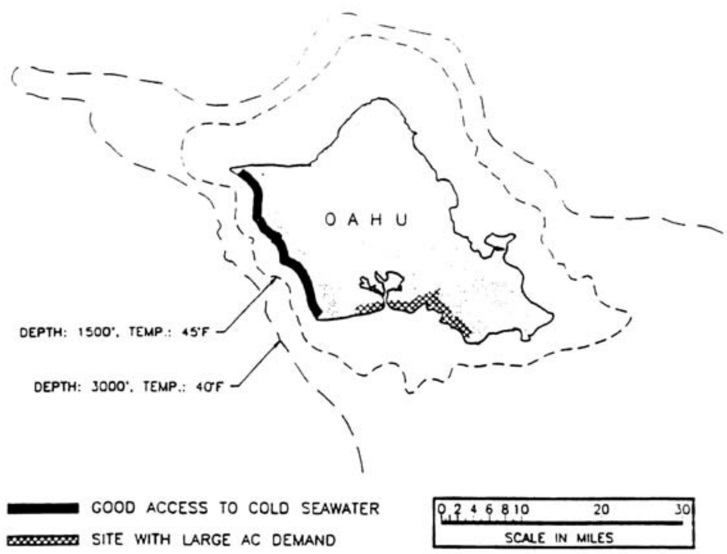
Moreover, Hawaii's economy is "overly dependent on oil" (Alber, 2000). The State's energy needs are more than 90% dependent on imported fossil fuels (Rezachek, 2002). Sudden surges in the oil price result in significant economic damage, while no economical by-products result from expenditure money for imported fuels (Alber 2000). Hawaii's dependence on imported fossils fuels can be reduced by utilizing the nearby cold ocean waters for district cooling.

Out of the research and experimentation that has been conducted on ocean thermal energy conversion (OTEC), one easily implemented and economically viable technology has emerged: seawater air conditioning (SWAC). It is both technically and economically feasible today, and, once installed, the energy supply is inexhaustible, renewable, and without adverse environmental impacts.

SWAC is identical in all aspects, save one, to any other air conditioning system used in a modern major building. That one aspect is that instead of providing the cooling effect with a mechanical/chemical system, it is provided rather through a heat exchanger with the typical chilled water system on one side and cold sea water on the other. The seawater is supplied either from an OTEC or from dedicated piping and pumps.

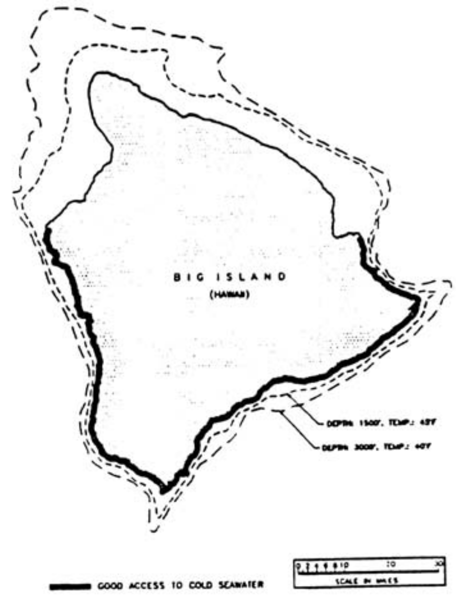
Throughout the world's oceans, seawater temperatures decrease with depth. At depths exceeding 1,500 feet, these temperatures are equivalent to chilled water temperatures required for space cooling. In Hawaii, the coupling of year-round space cooling demand, high electricity rates and district locations near steep coastal bathymetries provides one of most opportune circumstances for seawater district cooling in the world. A seawater district cooling utility is a demand-side management technology with the potential to avoid more than 90% of the energy consumption and carbon emissions typical for conventional air-conditioning systems. The cold-water resources surrounding the island-chain are abundant and sustainable, and their proper use does not produce environmental harm and often can be shown to have an environmental benefit.

All islands in Hawaii have some shorelines that have good access to deep, cold seawater. Figures 1, 2, 3, and 4 show the proximity of deep, cold water to each of the major Hawaiian islands. All islands have some shorelines that have good access to deep cold seawater. Notable areas are southern Kauai, west Oahu and the southern 60% or more of the Big Island. Other sites, such as Honolulu, already have huge A/C requirements but significant distribution challenges and relatively long distances to cold water offshore. The large size and resulting economy-of-scale in Honolulu can probably overcome the obstacles associated with longer pipelines and onshore distribution (Rezachek, et al., 2000).



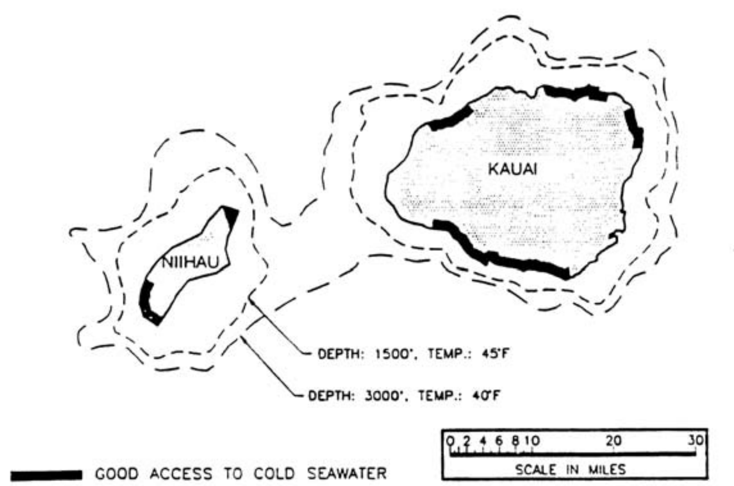
Source: Makai Ocean Engineering, Inc.

Figure 1 Optimum SWAC Sites for the Island of Oahu



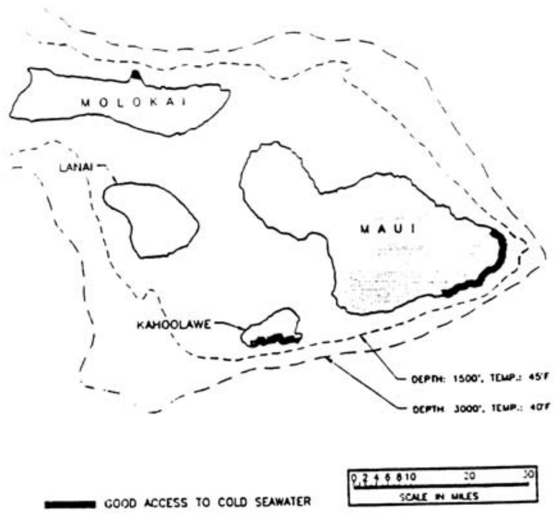
Source: Makai Ocean Engineering, Inc.

Figure 2 Optimum SWAC Sites for the Island of Hawaii



Source: Makai Ocean Engineering, Inc.

Figure 3 Optimum SWAC Sites for the Islands of Kauai and Niihau



Source: Makai Ocean Engineering, Inc.

Figure 4 Optimum SWAC Sites for the Islands of Maui, Molokai, Lanai, and Kahoolawe

Essentially, an SDC system pumps up cold ocean water from below 1,500 feet to cool a freshwater loop supplying chilled water equivalent to that produced by a building's centralized air-conditioning plant. On average, the pumping of the cold liquids is far less energy intensive than producing the equivalent cold liquids by conventional refrigeration. A seawater district cooling system in Hawaii consists of the following main components:

- large diameter cold-water supply pipe of several miles length;
- heat exchanger resistant to corrosion by seawater for chilling the freshwater distribution medium;
- network of distribution pipes within the district to supply chilled water to centralized air-conditioning systems; and
- possible secondary utilization of cold seawater and/or a seawater return line.

A simplified schematic is illustrated in figure 5.

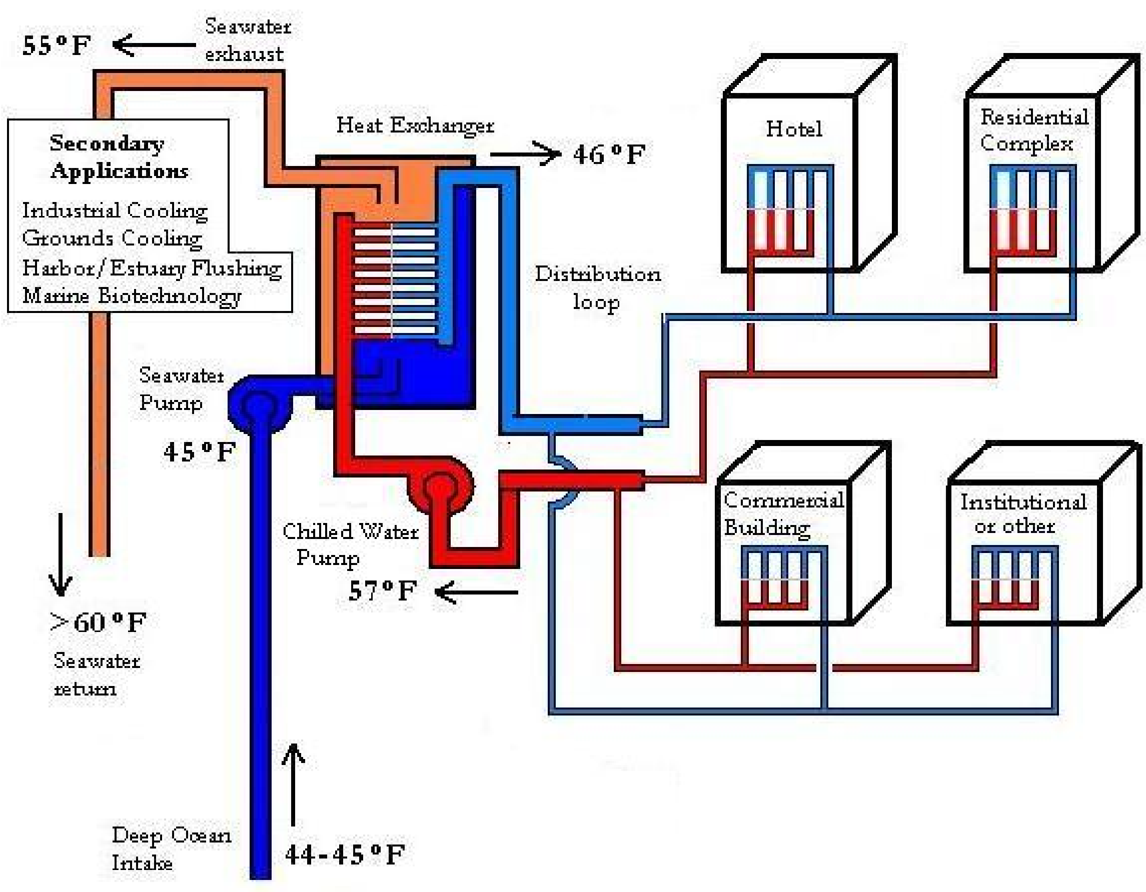


Figure 5 SDC system schematic

In the United States, the concept of district cooling using conventional air-conditioning has been cost-effectively demonstrated in 40 districts distributed among 16 states. Cornell University (Ithaca, New York) has become the first institution in the United States to construct and operate a district cooling system that utilizes its local deep cold water resource in place of conventional air-conditioning systems (Pierce, 2002). Large-scale implementation of SDC system's potential in Hawaii can provide an economical solution for meeting state, national and international requirements for local action on reducing climatic impact due to energy consumption.

As an initial step in this local development and future technology export, this project will:

- Identify potential areas for SWAC applications (such areas include the downtown Honolulu area, Waikiki, Ala Moana Center, and large hotels or hotel clusters on each of the islands with good access to cold deep seawater);
- Update previous feasibility studies for SWAC (e.g., West Beach, Waikiki);
- Conduct preliminary technical and economic feasibility analyses for other promising locations in Hawaii;
- Prioritize these locations for further technical and economic analysis;
- Develop a marketing plan to allow private sector development of one, or more, of these Hawaii projects; and
- Identify types of assistance that can be provided by the State of Hawaii (e.g., Special Purpose Revenue Bonds) and other government sources.

This study investigates Hawaii's potential use of the surrounding deep cold oceans for seawater district cooling (SDC) applications ranging from resorts on the neighbor islands to the central business district of downtown Honolulu, as well as federal and state facilities. Economic summaries and marketing methods for each district demonstrating technical viability are presented.

The evaluation of potential districts within Hawaii began with constructing a generic district model and its associated seawater supply system. Based on geographical information system (GIS) databases and facility surveys, real district values parameterized the models to determine economic outcome. Economic viability was measured by the difference in levelized cost of cooling using conventional mechanical methods versus the proposed cold seawater utilization alternative. The following major variables determine system economics:

- Financing methods (type of ownership, interest rates);
- Local bathymetry (district location);
- District Characteristics (size and demand density);
- Electricity rates (consumer costs); and
- Seawater system utilization (secondary utilization).
- The effects of each variable are briefly discussed below.

1.1 Financing Methods

The financing method will have a significant impact on the economics of an SDC system (see Section 4.3 for a further discussion of this impact). The two competing parameters between an SDC utility and the complementary set of air-conditioning plants are the differences in capitalization and operating costs. Higher electricity rates favor an SDC system; however, the capitalization costs are greater for the SDC system. Since the cost of the cold water pipe and the installation of the district chilled water distribution system are so significant with regard to the total capitalization cost of an SDC utility system, it is important to recognize that these components have a significantly longer life than the average facility air-conditioning plant. The longer life cycles are attributed to the fact that most of the capital is invested in high-density polyethylene plastic (HDPE) pipe and its deployment. A minimum of 50 years of service is expected from this pipe. The cost of SDC system operation is an order of magnitude less than the sum of the individual facilities' air-conditioning plants. The competitive advantage of an SDC utility depends on this and the financing and ownership of the SDC system. Additionally, SDC system is an undeveloped but promising demand-side management technology could justifiably be a candidate for an investment tax credit or other type of support. It also is an indigenous renewable energy technology that uses abundant deep cold seawater.

1.2 Local Bathymetry

The most critical physical variable is the local bathymetry near the district of interest. The local bathymetry determines the length, and thus the cost and capacity of the cold-water pipe (CWP). Gradual bathymetric changes require longer pipes and demand more pumping power for equivalent cooling capacity. Only high cooling density and large districts may attain economic success near gradual bathymetries. Ultimately, a maximum CWP length limitation exists that economically and/or technically prohibits SDC system development using conventional economic analysis. This economic limit can be expanded if various incentives are provided that recognize the demand reduction, energy savings, renewable energy use, and environmental benefits of this technology.

1.3 District Characteristics

District characterization encompasses cooling demand, chilled water supply temperature, demand density, and construction cost rates. These variables must be considered separately and in detail. However, due to significant inter-dependency, the characterizing variables can be summarized in concert. Total district demand affects the CWP construction and operational costs in an inverse manner. As district demand increases, the cold water flow rate in the CWP must increase for a fixed temperature change through the seawater-side of the heat-exchanger. This relationship is compounded by a decreasing in buckling resistance of larger pipes, thus the tendency is towards greater unit expense for the CWP as the demand increases. This effect is somewhat compensated by relatively lower operational (pumping) costs. In conjunction with relatively lower operational costs, some scale-invariant aspects of the CWP capitalization costs produce an economy of scale tending to favor larger district demands. As the district size/demand is varied, a minimum levelized cost of cooling is achieved representing an optimum district size.

The installation of a chilled water distribution system is also a major cost of an SDC system. The tendency towards favoring denser districts is tempered by significantly higher unit construction costs in urban scenarios. This implies that dense districts must also have large demands (tall buildings), which is usually, but not necessarily correlated. Some districts can have urban-like traffic/streets, yet lack volume in air-conditioning demand due to a predominance of low-rise buildings. Furthermore, this also implies that relatively small resort scenarios in rural settings may have good prospects. The material cost of the distribution piping itself tends to be less significant than the installation costs (Valentine, 2001).

1.4 Electricity Rates

The cost of electricity provided to facilities with a demand greater than 300 kW, principally involves two variables, *demand charge* and *energy charge*. The demand charge is determined from the highest *15-minute average of demand* experienced by a facility in the billing month, and often constitutes one quarter of a building's electricity bill. This demand is called the *billing demand*, and very large users will experience a discount for volume of demand. Additionally, billing demand also affects the energy charge. The energy charge accumulates over the billing month, and experiences a volume discount that is proportional to the ratio of average demand over the billing demand. Thus, the billing demand can affect the total electric bill by as much as 10% due to increased energy charges. This type of billing structure approximates first degree price discrimination, which is an idealized concept of being able to charge every customer at exactly the unit price that they would be willing to pay (demand price). Price discrimination occurs when a supplier is not restricted by competition; the supplier is free to charge as if it were a monopoly. In the situation of a public utility, the demand price is set by the public utility commission.

Two sample tables (tables 1 and 2) of electricity rate determination are shown prior to SDC system implementation, and following the loss of A/C load to the SDC system provider when metering on secondary voltage. In all cases, the facility energy rates increase as the customer's purchase quantity shifts lower resulting increased unit pricing due to price discrimination.

The price discrimination schedule can be idealized in two steps, an “industrial” rate yielding an average electricity rate of \$0.0986/kWh, or a “commercial” rate yielding an average electricity rate of \$0.1040/kWh. The classification depends on how the voltage is transmitted to the customer (secondary, primary, or transmission). The University of Hawaii Ocean & Resources Engineering (UH-ORE) program (developed by Ennis Patterson) determined the electricity rates for each district per schedule under the assumption of single point metering. An “industrial” rate of \$0.105/kWh and a “commercial” rate of \$0.112/kWh was provided to Makai Ocean Engineering by UH-ORE, representing fair rates to apply to both system due to demand-price shifts.

Table 1 Electricity bill and load profile prior to an SDC system

time	Facility	A/C	total
23:00	168	137	305
0:00	168	137	305
1:00	168	137	305
2:00	201	165	366
3:00	243	199	442
4:00	344	281	625
5:00	453	370	823
6:00	461	377	838
7:00	469	384	854
8:00	469	384	854
9:00	478	391	869
10:00	478	391	869
11:00	486	398	884
12:00	520	425	945
13:00	562	460	1021
14:00	562	460	1021
15:00	562	460	1021
16:00	562	460	1021
17:00	562	460	1021
18:00	486	398	884
19:00	411	336	747
20:00	344	281	625
21:00	268	219	488
22:00	201	165	366
		328	

PS schedule	factors	Charges
Peak Demand (kW)	1021	
Daily energy consumption (kWh)	17498	
Customer		$320
1st Demand ($10*kWmax)	500	$5,000
2nd Demand ($9.5*kWmax)	521	$4,952
over Demand ($8.5*kWmax)	0	$0
1st level ($0.072087/kWh)	204244	$14,723
2nd level ($0.064104/kWh)	204244	$13,093
3rd level ($0.06101/kWh)	125198	$7,638
Energy cost adjustment ($/kWh)	0.0178	$9,500
Power factor adjustment (80%)		$182
Monthly energy consumption (kWh)		533686
Total		$55,407
average $/kWh		$0.1038

Table 2 Electricity bill and load profile after an SDC system

time	total
23:00	168
0:00	168
1:00	168
2:00	201
3:00	243
4:00	344
5:00	453
6:00	461
7:00	469
8:00	469
9:00	478
10:00	478
11:00	486
12:00	520
13:00	562
14:00	562
15:00	562
16:00	562
17:00	562
18:00	486
19:00	411
20:00	344
21:00	268
22:00	201

PS schedule present	factors	Charges
Peak Demand (kW)	562	
Daily energy consumption (kWh)	9624	
Customer		$320
1st Demand ($10*kWmax)	500	$5,000
2nd Demand ($9.5*kWmax)	62	$586
over Demand ($8.5*kWmax)	0	$0
1st level ($0.072087/kWh)	112334	$8,098
2nd level ($0.064104/kWh)	112334	$7,201
3rd level ($0.06101/kWh)	68859	$4,201
Energy cost adjustment ($/kWh)	0.0178	$5,225
Power factor adjustment (80%)		$100
Monthly energy consumption (kWh)		293527
Total		$30,731
average $/kWh		$0.1047

1.5 Seawater System Utilization

The utilization of an air-conditioning system is directly related to the daily and seasonal variations of cooling required. In Hawaii, a typical air-conditioning system would experience an annual average utilization of 60% (MOE, 1994), mostly due to daily demand variation (day and night). The utility of the cold-water delivery system can be improved by diverting excess flow potential at night to storage tanks (space permitting), then allowing the stored cold-water to augment daytime flow. Otherwise, the excess night flow can be used as a heat-sink for an ice-making process, where the ice is used during the day to reduce the chilled water temperature (increase the temperature differential). Either method can accomplish the same results; the choice of method is dependent on space availability among other factors. Other factors that determine this choice could be related to energy savings incentive. In such cases where space-availability is not a decision factor, stored cold-water could be the better option as it would be less energy intensive.

Use of a TES system in conjunction with an SDC system would allow greater utilization of the SDC system by increasing its capacity factor. The viability of a thermal energy storage (TES) system is determined by a levelized cost comparison between a larger-diameter CWP and the proposed TES system. Otherwise, a TES system could be used to expand the network of SDC system customers.

Economically and environmentally beneficial uses of the exhausted seawater may also be possible, as the seawater is still relatively cold at 55° F to 57° F. Realizing secondary uses for the exhausted seawater reduces the total capital required for an SDC system as by-product utilization reduces the cost of an effluent pipe (and, in some cases, may provide additional income). Without secondary use, isothermal return of the seawater would require an effluent pipe that extends to the 800-foot contour; the effluent pipe would cost approximately half the amount of the supply pipe. However, a shorter seawater return pipe and shallower (150 feet) discharge depth can often be justified because of environmental conditions related to the vertical excursion of the thermocline in an active internal wave field. A minimum of 150 feet is suggested to bring discharge below standard scuba diving depths to avoid impact on recreational diving.

In general, the effluent water can be used at a marine biotechnical industrial park/facility, as auxiliary cooling water for conventional power plants or industrial processes, for cooling of grounds, e.g. parks and golf courses. In ground cooling, the cold pipes (effluent) are buried a couple feet underground. The condensation of humid air occurs through the ground, thus watering the grounds. Furthermore, the effluent may also be discharged into brackish bodies of water, estuaries, canals and harbors to provide flushing and improvement in water quality (Krock, 1997).

The full environmental impact of such applications varies with the site considered. The opportunity for each site requires detailed inspection and in some cases may be unique. For example, if Pearl Harbor Naval Shipyard used an SDC system, the seawater exhaust has potential use as a preservation medium for the *USS Arizona* memorial. This method of preservation is used on the *HL Hunley*, a civil war submersible located in Charleston, South Carolina (Murphy, 2001).

The *HL Hunley* is actually contained in a tank where the aqueous medium is carefully controlled. Providing a cold and oxygen poor aqueous environment for the

USS Arizona might be accomplished by a bottom-mounted encircling pipe outfitted with numerous vertical discharge spouts (a diffuser). The continuous flow and distribution of the exhausted heat-exchanger seawater would create a protective shroud around the memorial that may be more effective than the oxygen consumption attributed to local microbial action. On average, the seawater would have a half-day residence time, and would ultimately have negligible impact on the entire Pearl Harbor water body. The chemical properties of surface and deep ocean water are compared in table 3.

Table 3 Chemical properties of surface and deep ocean water

Components	**Surface**	**Deep**
Salinity (‰)	34.8	34.2
pH	8.2	7.5
Nitrate & Nitrite (mg/L)	0.2	39
Phosphate (mg/L)	0.16	3
Silica (mg/L)	3.09	75
Ammonia (mg/L)	0.36	0.2
Organic Nitrogen (mg/L)	4.3	1.8
Organic Phosphor (mg/L)	0.24	0.1
Oxygen (ml/L)	7	1.2
Carbon (mg/L)	0.77	0.36
Solids (mg/L)	0.6	0.25

2. Technical Process

The SDC system technical evaluation method begins by outlining coastal regions where the 1,600-foot bathymetric contour lies less than 5 miles from shore. For this purpose, bathymetry maps were obtained from the University of Hawaii's Mapping Group. Given outlined regions, each area is inspected for air-conditioning demand by either determining the total floor area (sum of all buildings' floor spaces) or directly contacting building managers to obtain air-conditioning data. The first method was utilized for approximately 50% of Honolulu's region, while the second method was exclusively used for neighbor island investigations.

Once a region is chosen as a scenario of study, a piping schematic is constructed connecting the district loads and the cold-water supply pipe via a heat exchanger. Computer programs are used to optimize the piping network for best ratios of capital expenditure versus displaced electricity, which is the driving variable. The displaced electricity is determined by the difference between electricity consumption of the district using conventional centralized building cooling and district supplied chilled water. The programs require many empirically derived inputs and coefficients. The details of the generation of these inputs and coefficients are discussed next.

2.1 Cost of Seawater Supply System

The seawater supply system consists of the cold-water pipe (HDPE pipe) and associated ballast and anchoring, the sump facility, and the seawater pump. The effective life-cycle of the seawater supply system depends largely on the life-cycle of HDPE pipe, which is a function of accumulation of stresses. Manufacturers of HDPE pipe give a 50-year life for low impact vacuum conditions (KWH, 2001). However, the pipe could last hundreds of years since it is shielded from ultra-violet radiation by the overlying seawater. There are presently no data on the expected maximum life. By design, the flow rates would be limited to reduce stresses and achieve maximum pipe life.

The capital cost of the seawater supply system varies predominately with the capital cost of the CWP, which depends on its length and diameter. The strategy for optimizing the cost of the seawater supply system for a particular scenario is to minimize its material and construction costs against the minimization of operational costs. Decreasing the CWP diameter will reduce its capital cost, but increase pumping power and sump depth (ζ_T), thus increasing those components of the total cost of the seawater supply system. Equation 1 contains model costs of material, fabrication, mobilization, deployment, sump construction, pump cost, and route inspection and insurance. The equation is valid for pipes from 16 to 63-inch diameters with wall-thickness in the 3-inch range (DR=17). Wall thicknesses range from 2.4 inches to 3.3 inches; a small amount of error occurs about the 3-inch mean, which becomes negligible in the final analysis. The power requirements for the seawater supply are determined by the sum of the pumping heads:

Sump depth $\equiv \zeta_T$
Land crossing loss $\equiv \zeta_L$
Seaside Heat exchanger loss $\equiv \zeta_{HX}$

and determine the pump's cost given by Equation 2 (units are in meters).

$$C_L = 134\exp[0.03038 * D]L$$
$$L(ft) \equiv \text{Length in feet} \qquad \textit{Equation 1}$$
$$D(in.) \equiv \text{Diameter in inches}$$

$$\text{Cost of pump and sump} = \frac{[\$6466]}{kW}\frac{Q\rho g(\zeta_T + \zeta_L + \zeta_{HX})}{\eta} + \frac{\$12{,}200}{ft}\zeta \qquad \textit{Equation 2}$$

In most cases unstiffened pipes suffice, as the tendency of the program is to minimize diameter, which strengthens the pipe. Only loads in excess of 11,000 tons required stiffening rings for the larger pipes or digging deeper sumps for smaller and stronger pipes; such loading is available in Waikiki and downtown Honolulu. Equation 3 expresses the allowable length for a particular section of CWP as a function of radius, wall thickness, and demanded flowrate (metric units).

$$L_i = \frac{E}{\rho g}\left(\frac{\delta}{2(R_i + \delta)}\right)^3 \left(\frac{0.5486\pi C R_i^{2.63}}{Q_T}\right)^{1.851} T_{CORR} \qquad \textit{Equation 3}$$

where the modulus of elasticity E is 32,000 psi (223MPa) at 73 degrees Fahrenheit. The temperature correction factor can be used when ambient conditions are different. In the case of cold water flow originating from 1,600-foot depths, the material will be approximately 12% to 18% stronger. The CWP is composed by summing all lengths of CWP sections required to cover the entire length for intake to sump, see equation 4 (in S.I. units):

$$L = \sum_i \left[\frac{E}{\rho g}\left(\frac{\delta}{2(R_i + \delta)}\right)^3 \left(\frac{0.5486\pi C R_i^{2.63}}{Q_T}\right)^{1.851} T_{CORR}\right]_i \qquad \textit{Equation 4}$$

The systematic approach begins at the source with all pipe diameters made available; the program sequentially reduces the pipe diameters availability until one of four thresholds is met:

- minimum levelized cost is found;
- maximum sump depth is reached;
- sum of pipe lengths equals total length; or
- seawater temperature at input of heat exchanger equals maximum allowable per district characteristics.

In the program illustrated in figure 2, the pipe dimensions are given in inches. However, in the program execution, all dimensions are first converted to mks system (S.I.).

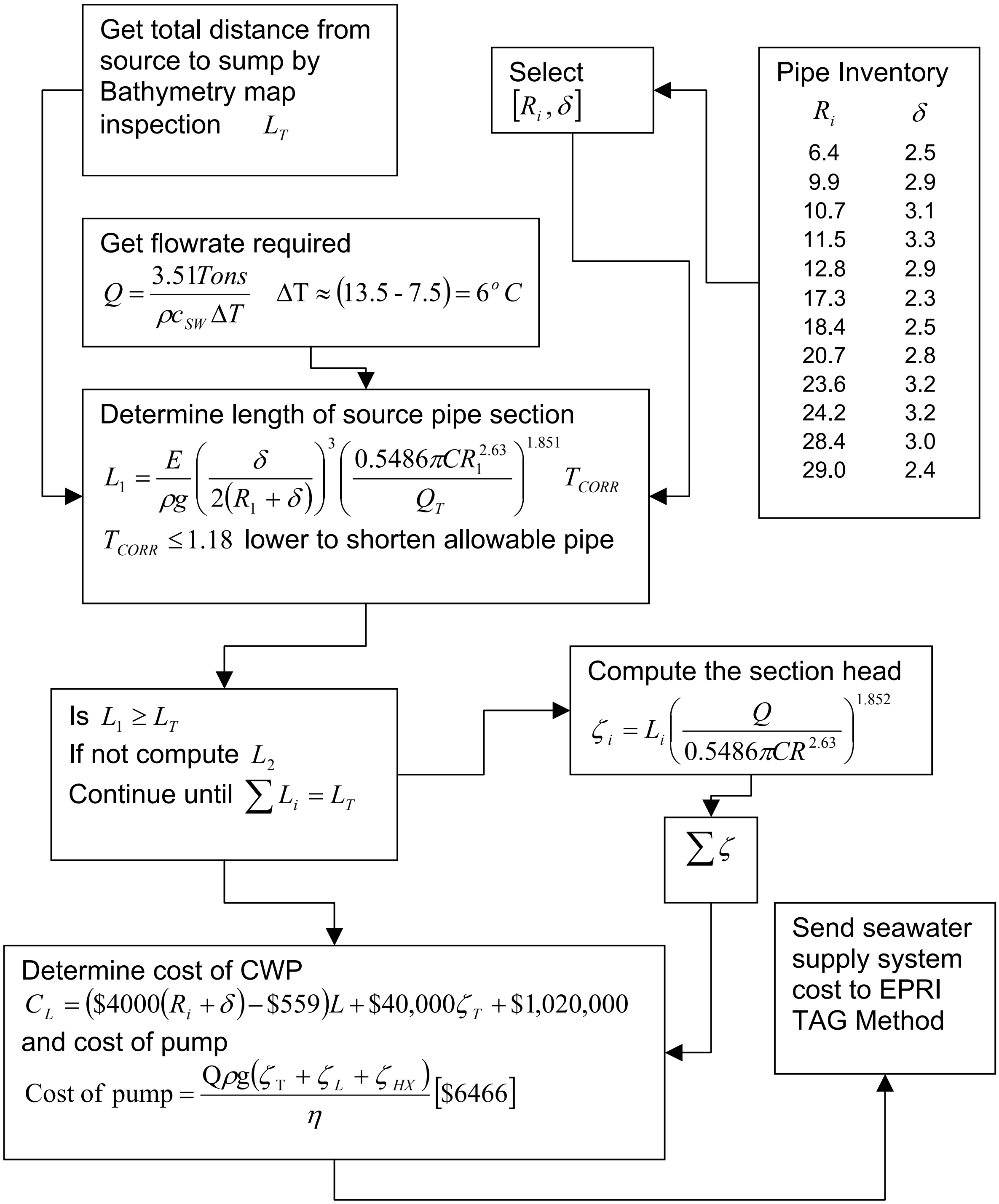


Figure 6 Cold-water pipe optimization method

2.2 *Cost of Operating the Seawater Supply System*

Equation 5 is used to determine the electric cost of operations of the system over a year at a specified utilization percentage determined by the district average (48 to 60%).

$$\text{Cost of pumping} = 8760\,\frac{Q\rho g\left(\zeta_T + \zeta_L + \zeta_{HX}\right)}{\eta}\cdot er \cdot u \qquad \textit{Equation 5}$$

Additionally, maintenance costs are included, see equation 6:

Cost of Maintenance= ($4 per ton)(total tonnage)+$60,000

Equation 6

2.3 *Cost of Heat Exchanger and District Cooling Loop*

The total capital for a chilled water distribution system is dominated by the cost of the piping system installation, rather than the cost of the material itself (~10% of total in urban areas). In urban areas, trenching costs are necessarily high due to the additional planning and management required in reducing effects on daytime traffic. The low traffic in suburban and rural areas reduces these costs significantly (cost of piping ~45% of total).

Micro-tunneling can mitigate traffic disruption during business hours. However, micro-tunneling has other requirements that restrict its application in congested urban areas. For example, prior to the horizontal drilling phase, the drill bit must travel at a slant that covers a significant distance. Additionally, the pipe is installed as a completed unit in one continuous motion, to prevent hydraulic lock with the soil. This implies that a roadway of length equal to the total pipe to be inserted must be clear prior to insertion (Fawner, 2001).

The high costs of trenching or the impracticalities of micro-tunneling have resulted in negative economic analyses of potential district cooling systems for downtown Honolulu in the past, particularly with regard to the use of large pipe (Valentine, 2001). Installing supply and return lines of 24-inch pipe within the same trench prohibits the use of steel plates to cover work in progress due to trench breadth, thereby significantly increasing the total district distribution system cost (Valentine, 2001). Smaller pipes transmitting equivalent volumes at higher velocities can be installed in the same trench.

The principal competing costs are installation (capital) versus operation (O&M). Decreasing the radius in distribution pipes reduces installation costs, while increasing pumping costs (both materially and energetically). For all cases of flow variation, an optimum radius exists. The major concern in high flow rate systems is sudden demand changes or surges that lead to “water hammer” and its possible effects must be considered in high velocity applications (KWH, 2001). This can always be overcome by requiring valve designs and pump controllers that limit the rate of transition. Equations 7 and 8 describe the in-place cost for pipes with 3-inch wall thickness from 16 to 42-inch diameters; the derivation is presented in appendix B:

Urban

$$C_C = 716 \exp[0.0162(R + \delta_{INS})]L$$
$L \equiv$ length in feet
$R \equiv$ radius in inches
$\delta \equiv$ insulation thickness in inches

Equation 7

Rural

$$C_C = 88 \exp[0.0572(R + \delta_{INS})]L$$
$L \equiv$ length in feet
$R \equiv$ radius in inches
$\delta \equiv$ insulation thickness in inches

Equation 8

The cost of the heat exchanger, its housing facility and associated chilled water pump are determined as follows by equations 9 and 10 respectively:

$$\text{Cost of Heat exchanger and facility} \equiv \$513 \cdot \text{Tons} + \$59{,}600 \qquad \textit{Equation 9}$$

$$\text{Cost of chilled water pump} \equiv \$465 \cdot \text{Power}[\text{kW}] + \$57{,}900 \qquad \textit{Equation 10}$$

In a programmatic approach, the pipe lengths and flowrates are determined by the district layout and demand, respectively. The objective is to find the lowest cost-to-benefit ratio, where benefit is evaluated in terms of electricity displaced by chilled water flow and cost is evaluated in terms of the capital and operational expenditures required. Obtaining the lowest ratio guarantees the lowest levelized cost. The simplest method is to test individual sections of pipe for a given flowrate. While varying the radius, a minimum can be found for that length and flow. Upon collecting a set of pipe radii as a function of length and flow, a function is generated that is applied to each section of pipe (where length and flow is specified).

2.4 Cost of Operating the District Cooling Loop

The chilled water loop pumping costs are determined by the same equations as were used for the seawater pump. The total pumping power of the loop is the sum of pumping powers required for each section, which were determined in the previous section (benefit-to-cost ratio), plus the pumping power required to flow through all heat exchangers (supply and load). Once the total pumping power for the loop is determined, the equation for pumping cost for the seawater pump can be applied to the chilled water pump. The maintenance costs of the heat exchanger and distribution system can be estimated by equation 11 given the total demand (tons):

$$\text{Cost of district maintenance} = (\$22 \text{ per ton})(\text{total rated tonnage}) + \$150{,}000 \qquad \textit{Equation 11}$$

2.5 Cost of Conventional Cooling Equipment

The capitalization of the conventional air conditioning system is taken as $1,700 per ton over a twenty-five year life cycle as determined from a sampling survey (appendix B). The actual capitalization cost for a specific building can vary from this unit cost by 50% due to building work required to replace the conventional unit (DeSmit, 2002).

Additionally, an assumed value of only 30% of the district's total capital for conventional cooling equipment is used. This value is a conservative estimate of the number of customers that are ready to change out their systems based on willingness to convert within 4 years of an SDC system start-up (i.e., an 8-year span) due to an average 25-year conventional cooling life cycle. If the capital required for a 100% conventional cooling systems replacement cost were used, then the evaluation would ignore the fact that these systems are already in place, partially or completely amortized, and with significant remaining life. This method of capital cost evaluation for the status quo technology presents a real competitive barrier to the “disruptive” technology.

Equivalently, the customer base can be determined by assuming Gaussian probability densities function given a 15.7 year mean life and a dispersion of 9 years about this mean. Approximately 30% of the conventional systems will be greater than 20 years of life based on those statistical values derived in appendix (under conventional cooling data).

2.6 Cost of Operating Conventional Cooling Equipment

The electrical demand required per ton of air-conditioning is assumed to be 0.9 kW, which includes chillers and condensers that would be replaced in the SDC system scenarios. The electricity cost per building can be determined by the product of rated demand in kW and total actual operating hours in a year.

2.7 Programmatic Approach Using EPRI TAG method

All the costs and cost rates collected are passed to the EPRI TAG method illustrated in figure 3. Additionally, inflation rates for money and electricity can be adjusted in the program. All scenarios were evaluated at constant dollar and 1% real inflation per year in the electricity rate, and an interest rate of 7%.

Furthermore, a 20% contingency cost is added to the total capitalization costs based on the sum of the costs of all components.

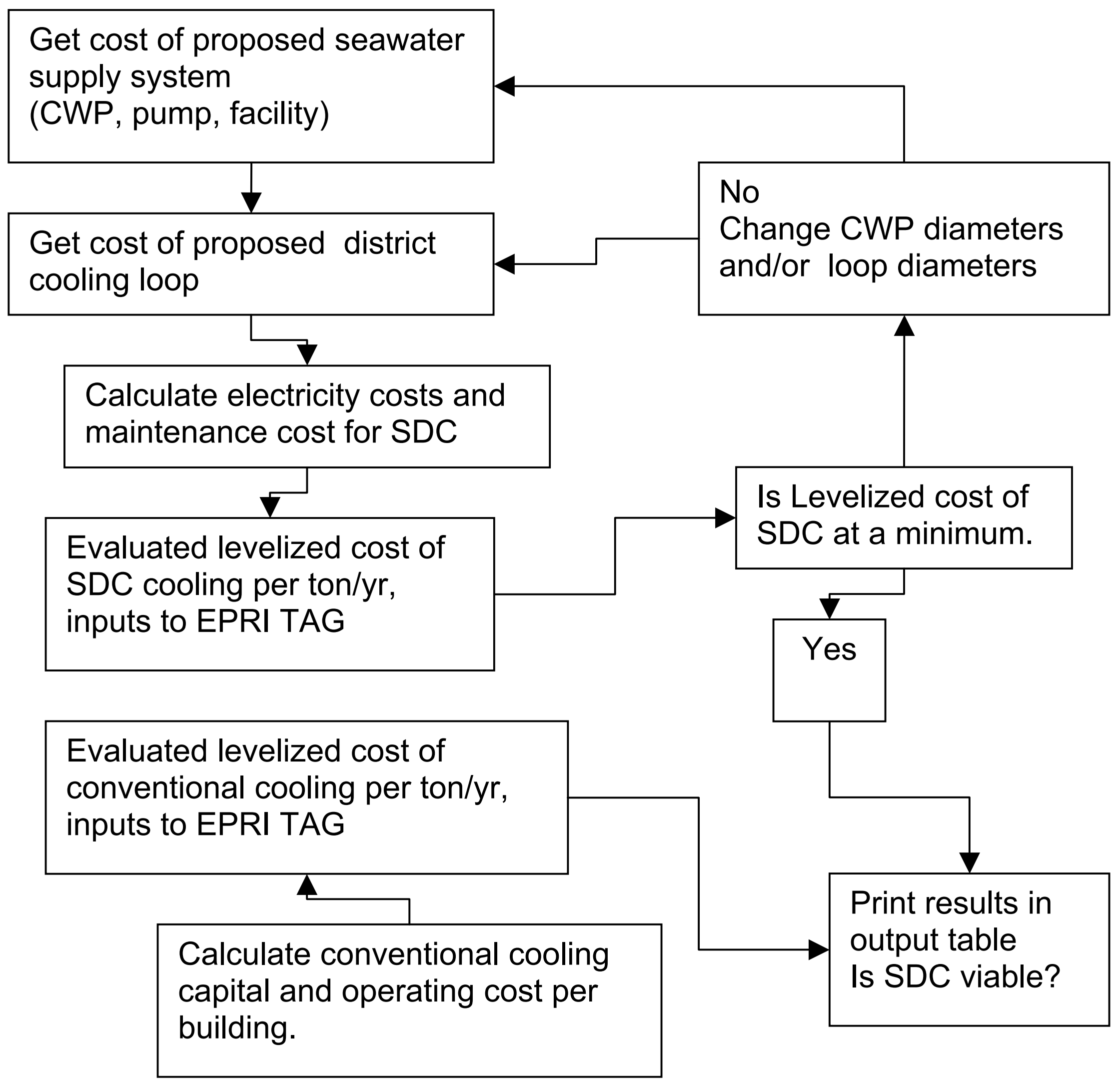


Figure 7 Economic evaluation method

3. Case Studies

All islands were investigated, however, based on the assumptions used in this analysis, only Oahu has good potential for SDC system application. For Kauai, Hawaii and Maui, only 4 to 5 districts are technically feasible, representing 5-6% of the State's total potential. However, in general, these sites would require financing plans spanning the SDC system life-cycle, expected to be in excess of 40 years and/or financial incentives to make them costeffective. A cost-weighted life-cycle age is given for each SDC system scenario. The cost-weighted life (CWL) of an SDC system is the sum of the individual component cost and expected life products divided by total cost. On average (over 20 year book life) their levelized costs were twice that of conventional systems. Only Oahu's summaries are covered in detail here (Kauai's scenarios can be found in Appendix C). The order of appearance of case studies generally coincides with the potential order of success or priority.

Additionally, the levelized cost analysis is based on competing against conventional cooling systems on a "30% ready for replacement" basis; this reduces the viability of a proposed SDC system. Finally, none of these case studies consider the financial impacts of utility rebates or other incentives that might be provided to such systems. The impacts of such incentives on SDC systems are discussed in detail in Section 4.

For Oahu, potential SDC system application is restricted to the southern side of Oahu and Kaneohe Marine Corps Base Hawaii on the eastern side. The southern region runs from Pearl Harbor to Waikiki, and may extend inland, for example, as far as the University of Hawaii at Manoa. The electricity rates for Oahu are the lowest in the state, while construction costs in its urban areas are the highest. These unfavorable attributes are offset by the typically dense districts, which reduce construction costs by requiring relatively smaller distribution networks. Additionally, the Oahu candidates typically present a wide diversity of secondary (seawater effluent use) applications.

Kauai's high electricity rates coupled with low construction costs, and occurrences of clustered resorts in Poipu, Wailua, and Princeville with good access to cold-water defined the island as a candidate for small scenarios. Additionally, Kauai is considered a good island for an NELHA-type facility, though the best site for such a facility does not occur within the resort areas (OH, 2000). However, book-lives spanning 40 years would be required in order to achieve economic success.

Bathymetry maps for each area investigated show the minimum and maximum distances to waters that support the typical district supply temperatures, marked by a red 1,600-foot (500-meter) contour and a blue 3,200-foot (1000-meter) contour, respectively. At depths of less than 1,600 feet the waters are too warm for direct use of deep seawater, and at depths greater than 3,200 feet the waters have reached their ultimate minimum temperature.

For all case study summaries, two sets of levelized costs are given, 20-year and 30-year book lives. Two sets of summaries are presented. The first set was generated by University of Hawaii's Ocean and Resources Engineering graduate student Ennis E. Patterson (UH-ORE). This data represents a student effort to develop a program and a design philosophy in the field. Costing data for the UH-ORE programs for the various systems were either provided from Makai Ocean Engineering data tables or from

Honolulu Board of Water supply (district cooling loop construction costs). The other set was generated by a Makai Ocean Engineering (MOE), a world-leader in seawater supply systems design and engineering.

Makai Ocean Engineering has several decades of experience in the design of CWP systems. MOE was intimately involved in the design of Cornell University's Deep Lake source cooling project, which represent the first operational large-scale deep cold water district cooling system in the U.S. Presently, MOE is designing a CWP system for the city of Toronto. The UH-ORE program attempts to reduce capital by favoring smaller thick-walled pipes, thus higher velocities. The MOE program favors relatively larger pipes yielding lower energy costs. Detailed MOE program results are presented in the appendix. Three UH-ORE scenarios are detailed in Appendix D.

The key values in the summary tables are 20-year and 30-year levelized costs. They represent the average cost per year of operating the mean load in tons; the mean load is the utilized tonnage, while the rated tonnage is the value required to meet peak demands.

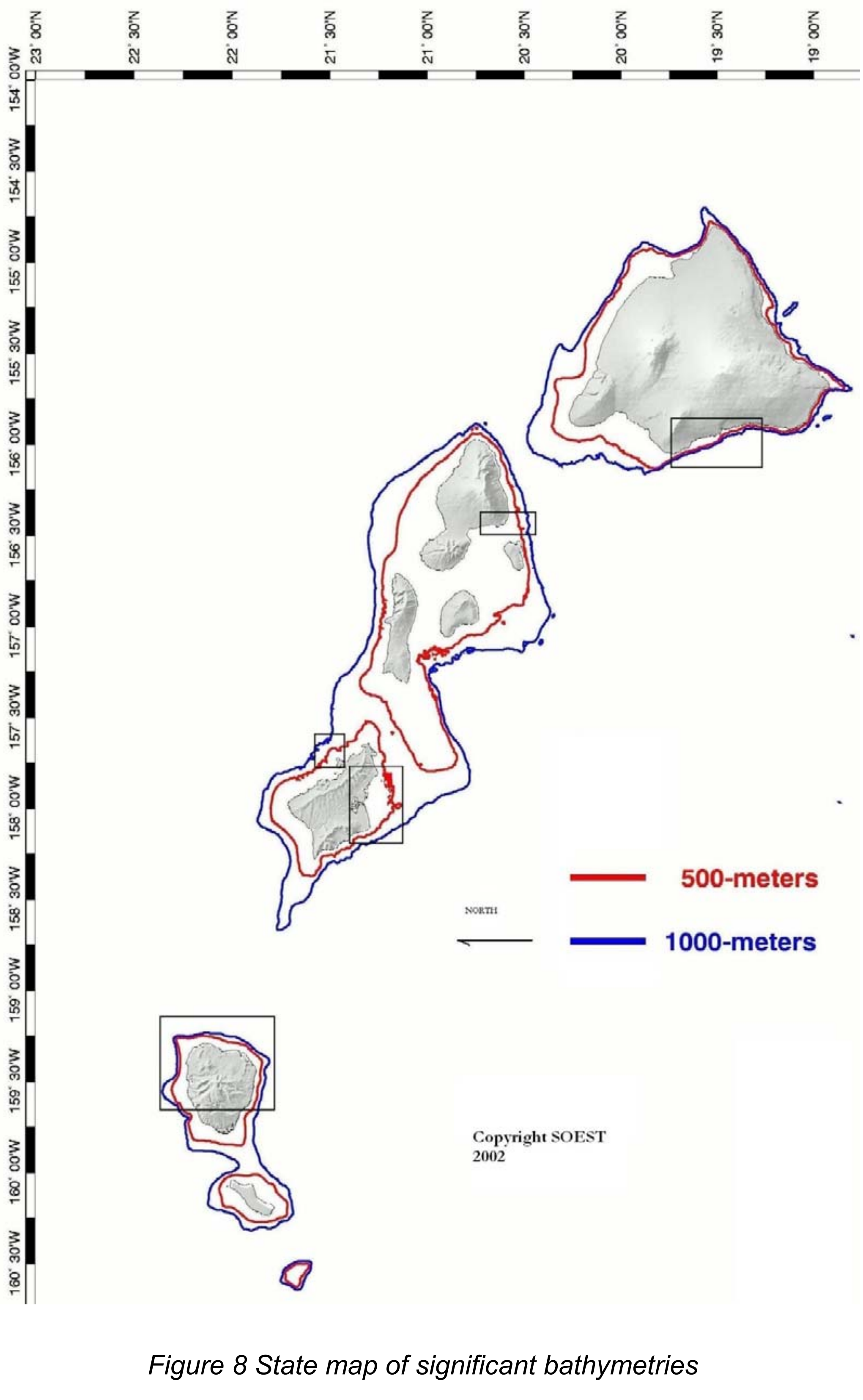


Figure 8 State map of significant bathymetries

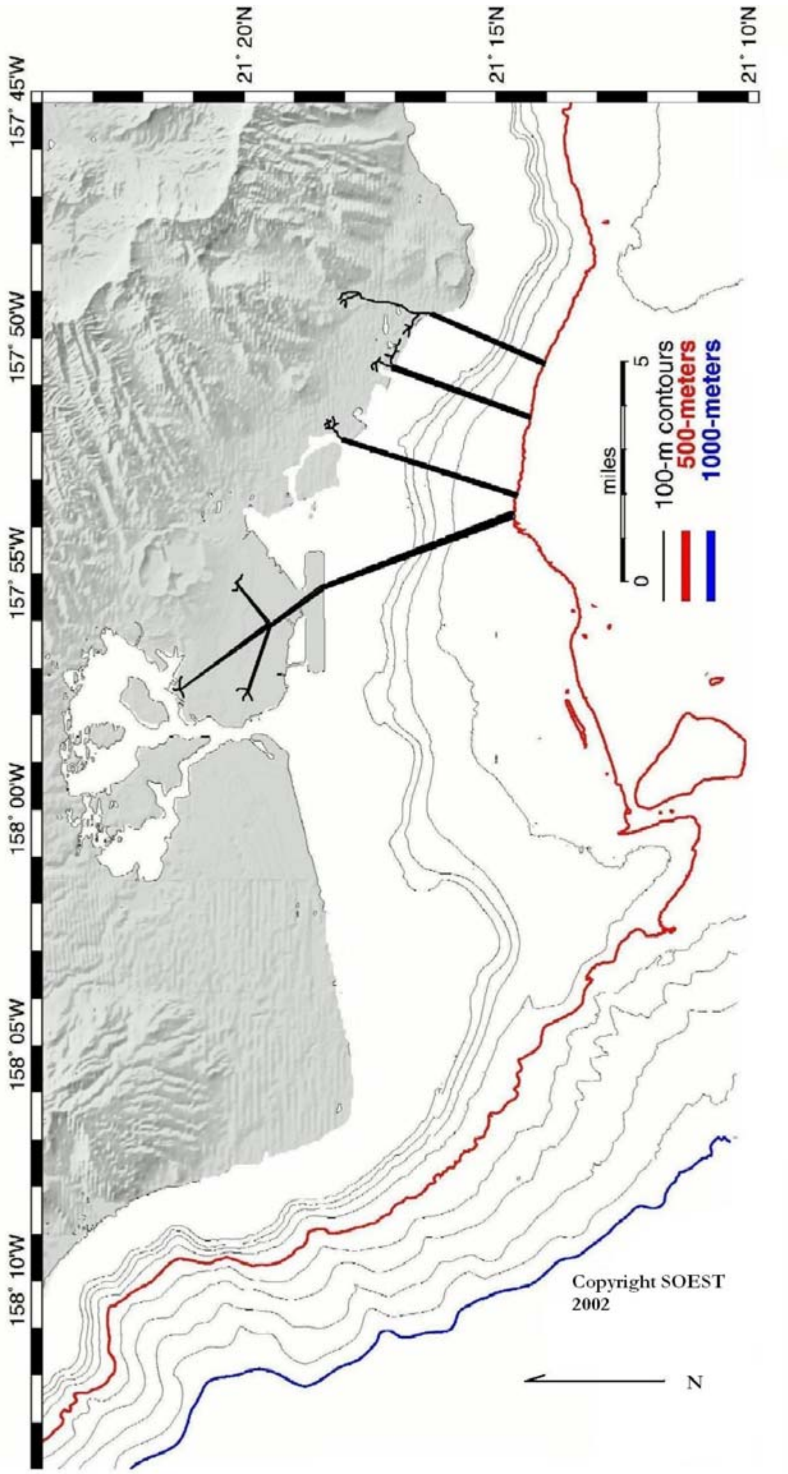


Figure 9 Southern Oahu map of significant bathymetries

3.1 Waikiki

Waikiki presents a premier SDC system opportunity, with the exception of finding space to set-up a SDC system heat exchanger and pumping facility. A survey of hotels was conducted to determine the potential load of Waikiki. Fifteen samples were used to correlate total floor area data of unknown facilities to a probabilistic air-conditioning demand. A tax map key database was used to determine a “total floor area” threshold for consideration in a district cooling network. The objective was to focus on the densest region. A map (figure 10) of Waikiki shows about 23,000 tons of rated demand when accounting all facilities with greater than 100,000 square feet of total floor area; this load is distributed over 60 facilities.

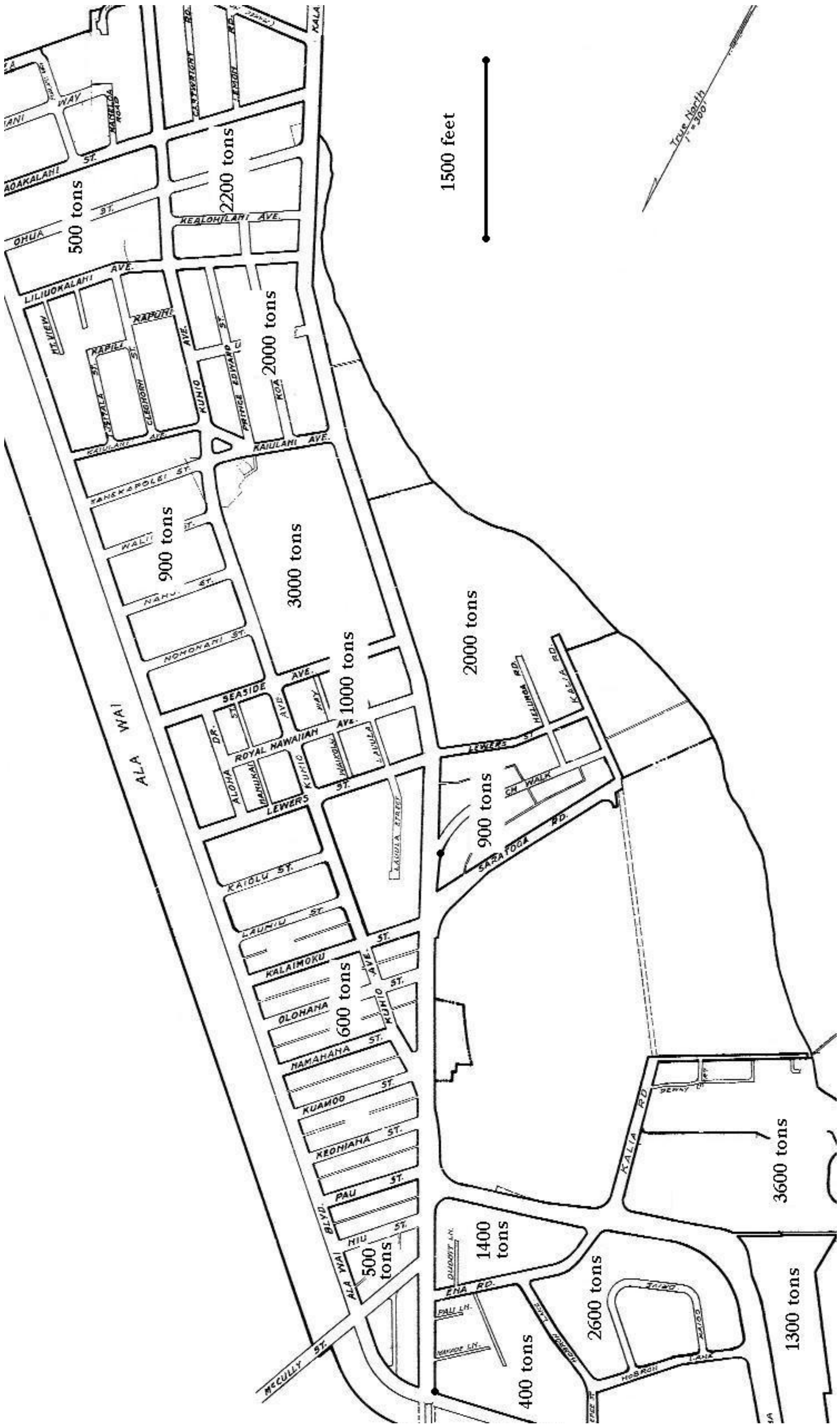


Figure 10 Waikiki A/C load map

The CWP intake was located at the 1,500-foot contour and cold water was brought to shore via a 47-inch pipe (10,360 feet) and an inshore section of 42-inch pipe (8,320 feet) where the velocity reached 4.9 feet per second. Seawater pumping required 353 kW. The chilled water side distribution was supplied by 6,035 feet of 18-inch pipe (weighted average). Chilled water pumping required 531 kW. Secondary usage of the exhausted seawater for Waikiki applications is limited to ground cooling and flushing of the Ala Wai. There are no power plants or industries in the vicinity, and high real estate costs prohibit any marine biotechnology park. However, flushing of the Ala Wai following ground cooling of the Ala Wai golf course (or the proposed conversion to a park) appears to be an attractive opportunity for the City & County of Honolulu. Tables 4 and 5, and figures 11 and 12 summarize the Waikiki scenario.

Table 4 West Waikiki SDC system summary UH-ORE

	West Waikiki SDC against 30% conventional cooling capital	
Mean Load (tons)	5,152	Interest rate
Utilization	62%	7.00%
	Conventional Cooling system	**SDC system**
Electricity Rate ($/kWh)	$0.104	$0.113
Annual energy consumption (MW-hr)	40,614	4,805
Annual electricity cost	$4,223,880	$543,612
CO_2 emissions - annual (tons)	406,142	48,052
Cost Weighted life (CWL)	25	42
Capitalization cost	$5,173,800	$41,436,835
20-year levelized book value ($/ton/yr)	$1,265	$1,139
30-year levelized book value ($/ton/yr)	$1,312	$1,073
SWAC system breakdown		
CWP	$12,046,202	
EWP	$4,578,493	
SWPump	$2,544,865	
Heat exchanger	$4,323,030	
Loop pump	$304,812	
Distribution	$10,364,357	
Back up Generator	$368,936	
20% Contingency	$6,906,139	

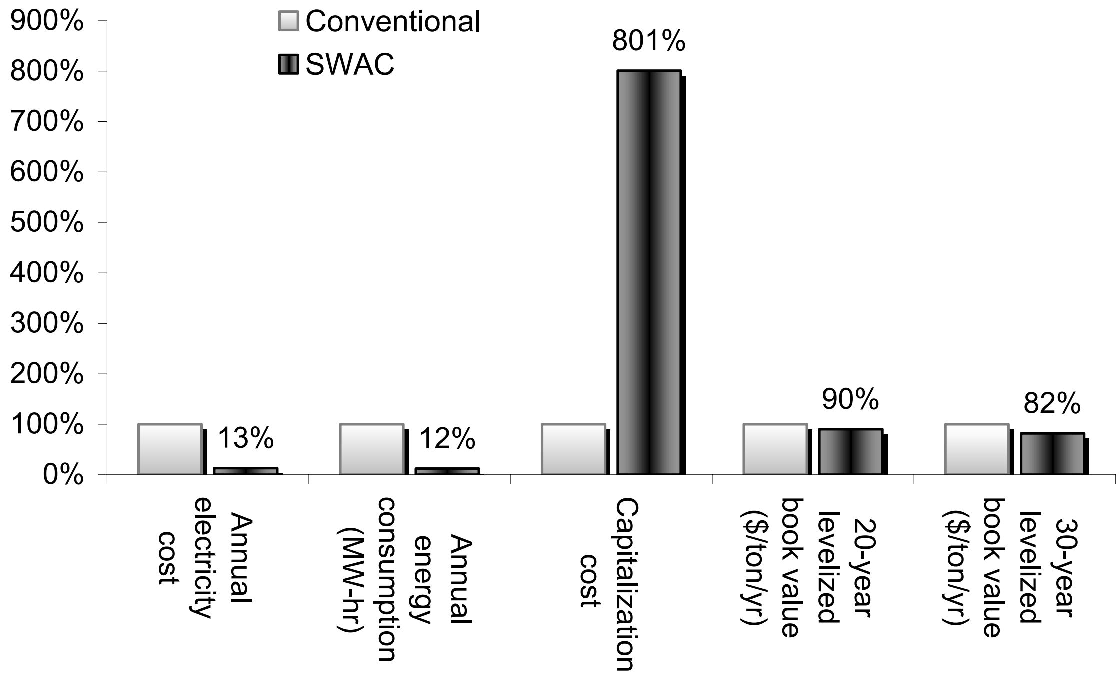


Figure 11 West Waikiki SDC system summary graph

Table 5 West Waikiki SDC system summary: MOE

West Waikiki SDC		
District Characteristics		
Mean Load (tons)	5,152	
Utilization	62%	
	Conventional Cooling system	**SDC system**
Capital costs	$5,173,800	$39,567,600
Operational and Maintenance costs	$5,473,558	$856,000
20-year levelized book value ($/ton/yr)	$1,342	$1,067
SWAC system breakdown		
Seawater supply system	$16,830,000	
Centralized cooling station	$4,299,000	
Chilled water distribution system	$11,698,000	
Backup Power	$146,000	
Contingency	$6,594,600	

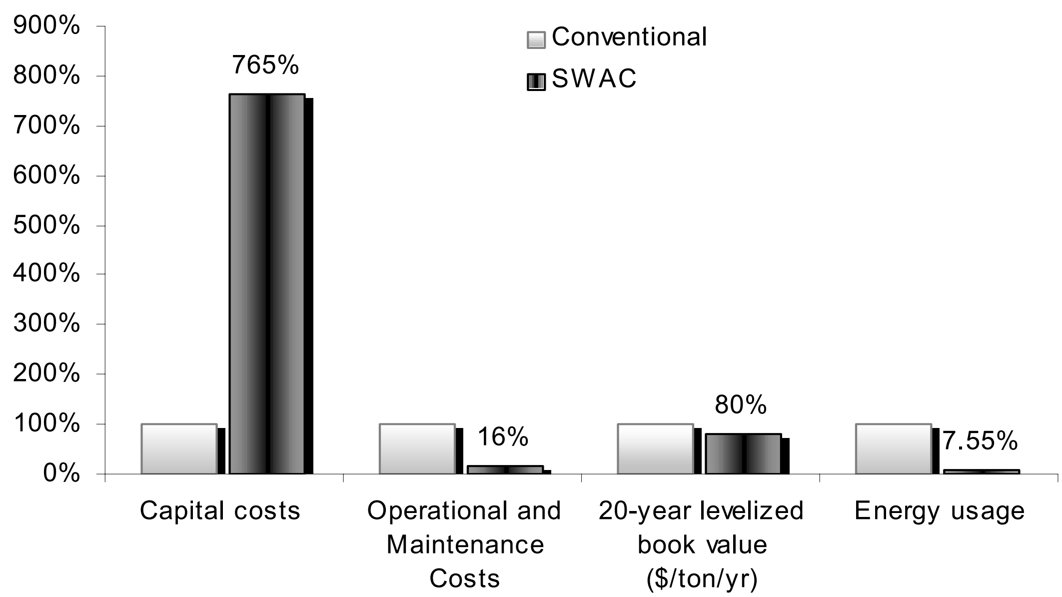


Figure 12 West Waikiki summary graph: MOE

3.2 Downtown Honolulu (Waterfront)

Along the waterfront of downtown Honolulu, the demand density is the greatest. This district has been evaluated for a district cooling system using a conventional thermal energy (ice) storage system serving approximately 12,000 tons (Valentine, 2001). Despite the intensity of the demand, that form was not economically feasible due to the high costs associated with installing pipe. An illustration in figure 13 of the loads in the downtown district contains a 20,000-ton demand over a 150 acres region. This scenario was weighted against 30% conventional cooling capital (a value derived by UH-ORE).

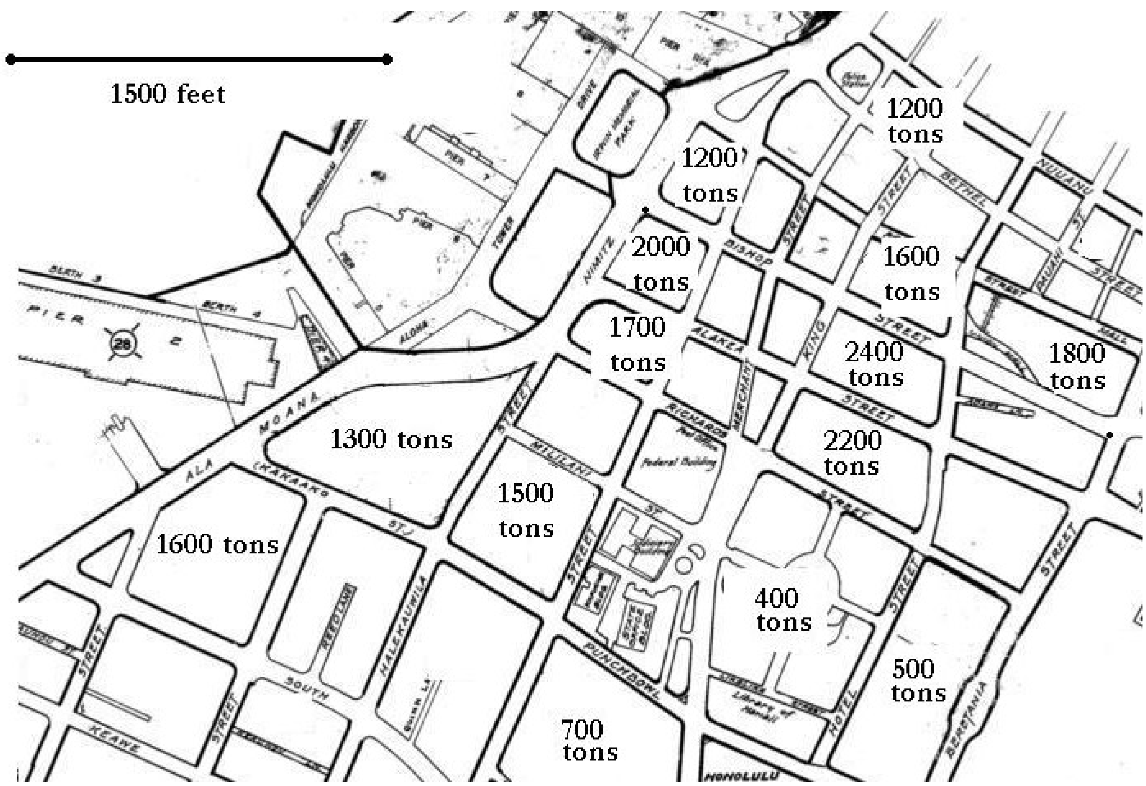


Figure 13 Downtown AC load map

The CWP intake was located in 1,600 feet and cold water was brought to shore via a 47-inch pipe (12,230 feet) and an inshore section of 42-inch pipe (6,793 feet) where the velocity reached 4.9 feet per second. The seawater supply pumping required 359 kW. The chilled water side distribution was supplied by 3,723 feet of 18-inch pipe (weighted average). Chilled water pumping required 394 kW.

The downtown power station presents an excellent opportunity to utilize the exhausted heat exchanger seawater. The power station presently takes harbor water as condenser cooling water. The value of taking the exhaust water from the heat exchanger at 59°F (15°C) and discharging at 77°F (25°C) has multiple effects. For the same condenser flow rate, and assuming a saturated steam generator enthalpy of 1,288 Btu/lb (at 500°F), an extra 8% of power can be extracted from the turbines for the portion of steam condensed by the SDC system exhaust. Only 4% extra heat has to be added to the cooler feedwater. Assuming an 80% isentropic efficiency for the turbine, an extra 2.0 megawatts per 10,000 tons of SDC system seawater flow can be gained. Sold at $53 per megawatt-hour above floor cost, and at a power plant capacity factor of 60%, this exhausted heat exchanger water has an application value of $482,000 per year. The 8,650-ton SDC system only requires 34% of this power. Furthermore, the power plant would have reduced thermal impact on the harbor, while providing a flushing potential to the harbor. Tables 6 and 7, and figures 14 and 15 summarize the Honolulu Waterfront scenario.

Table 6 Honolulu Waterfront SDC system summary: UH-ORE

Honolulu Waterfront SDC against 30% conventional cooling capital

Mean Load (tons)	5,248	Interest rate
Utilization	62%	7.00%
	Conventional Cooling system	**SDC system**
Electricity Rate ($/kWh)	$0.104	$0.114
Annual energy consumption (MW-hr)	40,316	4,102
Annual electricity cost	$4,188,792	$467,187
CO_2 emissions - annual (tons)	403,156	41,021
Cost Weighted life (CWL)	25	41
Capitalization cost	$5,270,250	$37,444,898
20-year levelized book value ($/ton/yr)	$1,239	$1,013
30-year levelized book value ($/ton/yr)	$1,285	$955

SWAC system breakdown	
CWP	$12,470,858
EWP	$4,578,493
SWPump	$2,588,917
Heat exchanger	$4,403,058
Loop pump	$241,419
Distribution	$6,606,384
Back up Power	$314,953
20% Contingency	$6,240,816

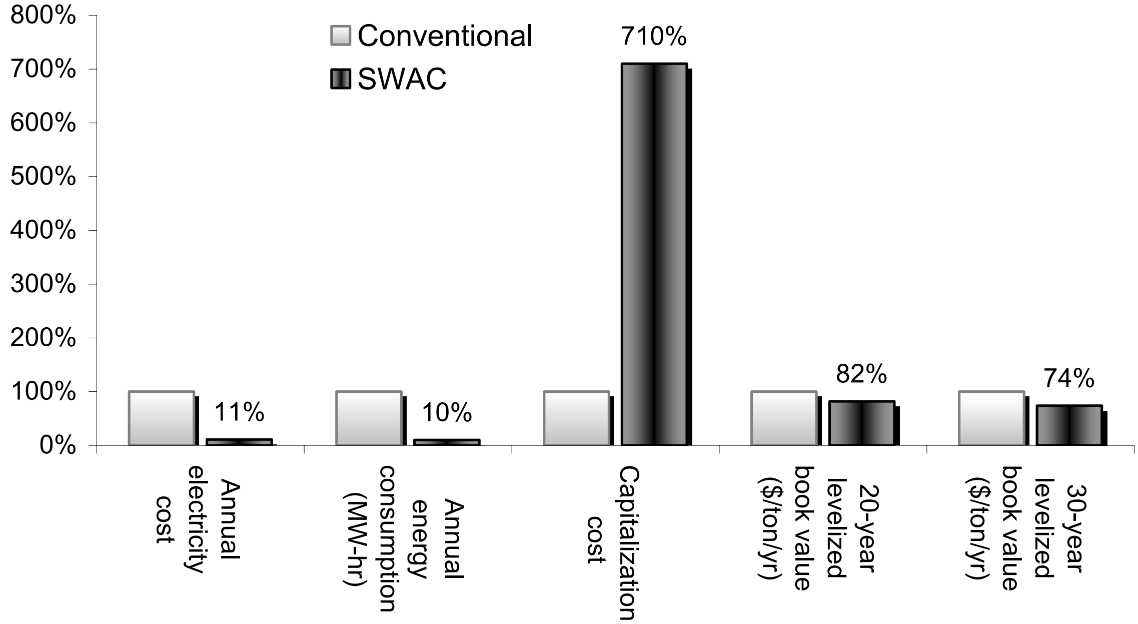


Figure 14 Honolulu Waterfront SDC system summary graph: UH-ORE

Table 7 Honolulu Waterfront SDC system summary: MOE

Honolulu Waterfront SDC		
District Characteristics		
Mean Load (tons)	5,248	
Utilization	62%	
	Conventional Cooling system	**SDC system**
Capital costs	$5,270,250	$41,166,000
Operational and Maintenance costs	$5,118,784	$792,000
20-year levelized book value ($/ton/yr)	$1,342	$1,071
SWAC system breakdown		
Seawater supply system	$25,202,000	
Centralized cooling station	$4,373,000	
Chilled water distribution system	$4,583,000	
Backup Power	$147,000	
Contingency	$6,861,000	

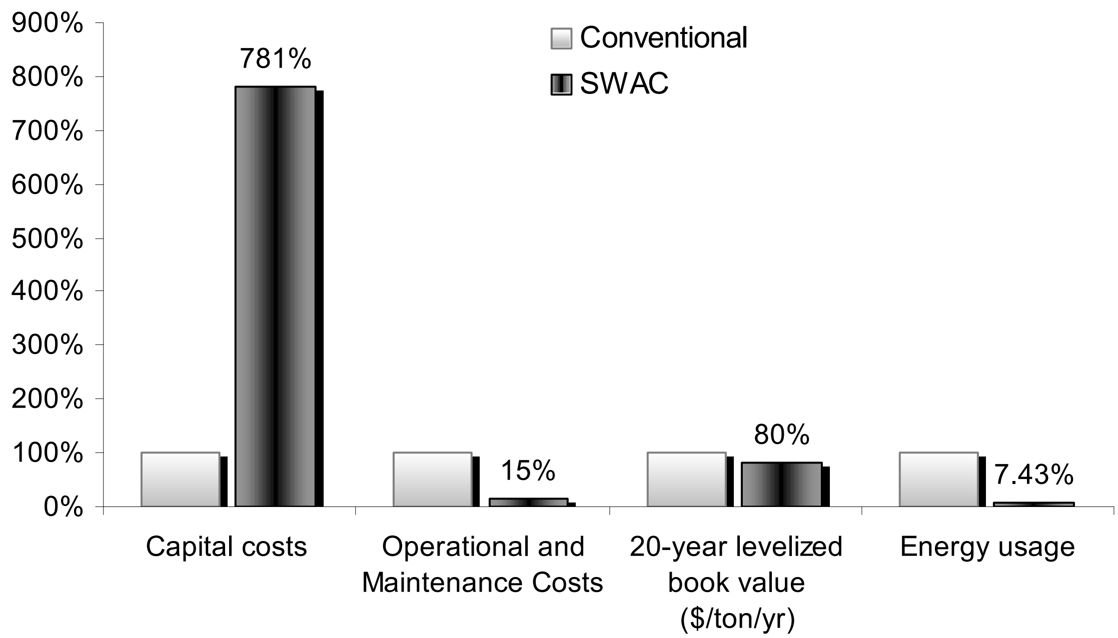


Figure 15 Honolulu Waterfront SDC system summary graph: MOE

3.3 Kakaako

The Kakaako region is defined to contain the Ward shopping area and the proposed University of Hawaii Medical Research Center and Ala Moana Shopping Center. Secondary usage of the exhausted seawater has the same potential as Downtown, except that the facility would be located at Kakaako Park. The cost of sending the exhausted seawater to the downtown power plant is equivalent to the cost of the effluent pipe (within 10%). Alternatively, this system could support a University Research Facility to explore the uses of the cold seawater supply in OTEC system optimization, hydrogen production and liquefaction, and bioproducts development.

The CWP intake was located in 1,600 feet and cold water was brought to shore via a 42-inch pipe (15,275 feet), a 36-inch pipe (1,555 feet) and an inshore section of 26-inch pipe (2,198 feet) where the velocity reached 11.1 feet per second. The seawater supply pumping required 414 kW. The chilled water side distribution was supplied by 5,580 feet of 18-inch pipe (weighted average). Chilled water pumping required 384 kW. This scenario would require a 30 year book life. Tables 8 and 9, and figures 16 and 17 summarize the Kakaako scenario.

Table 8 Kakaako SDC system summary: UH-ORE

Kakaako SDC against 30% conventional cooling capital

District Characteristics		Interest rate
Mean Load (tons)	4,495	7.00%
Ulitization	62%	
	Conventional Cooling system	**SDC system**
Electricity Rate ($/kWh)	$0.104	$0.115
Annual energy consumption (MW-hr)	34,551	4,067
Annual electricity cost	$3,593,342	$466,185
CO_2 emissions - annual (tons)	345,514	40,672
Cost Weighted life (CWL)	25	42
Capital cost	$4,513,800	$37,242,451
20-year levelized book value ($/ton/yr)	$1,246	$1,091
30-year levelized book value ($/ton/yr)	$1,292	$1,028
SDC system breakdown		
CWP	$10,732,754	
EWP	$3,804,347	
SWPump	$2,616,069	
Heat exchanger	$3,779,250	
Loop pump	$236,462	
Distribution	$9,554,218	
Back-up Generator	$312,276	
20% Contingency	$6,207,075	

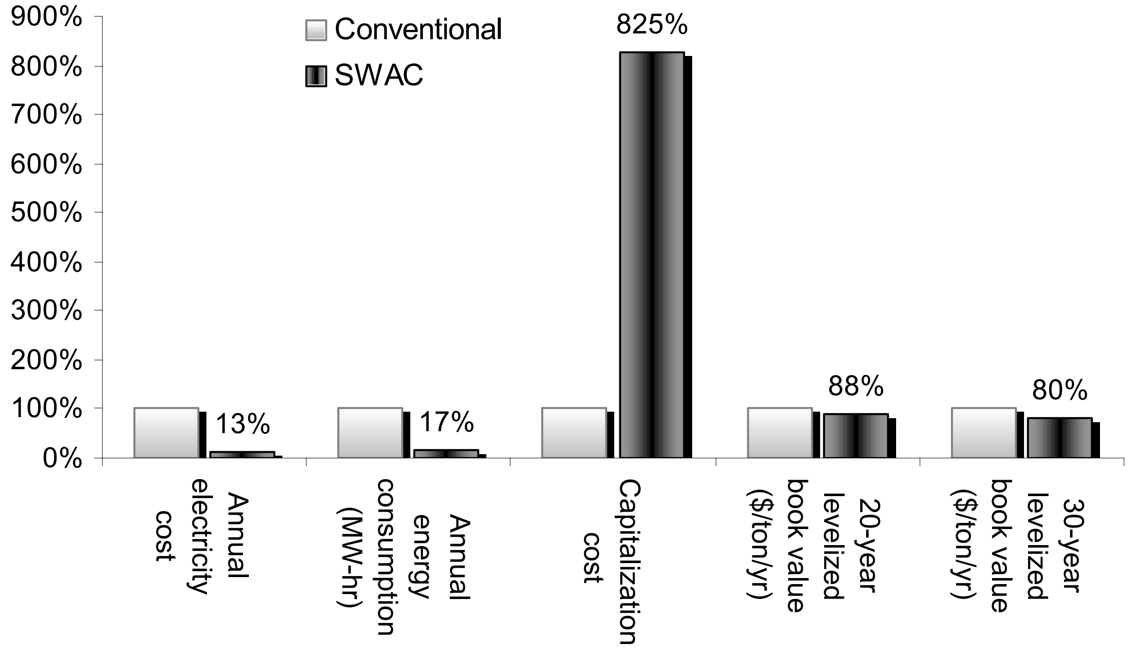


Figure 16 Kakaako SDC system summary graph: UH-ORE

Table 9 Kakaako SDC system summary: MOE

Kakaako SDC		
District Characteristics		
Mean Load (tons)	4,495	
Utilization	62%	
	Conventional Cooling system	**SDC system**
Capital costs	$4,513,800	$38,982,000
Operational and Maintenance costs	$4,789,121	$643,800
20-year levelized book value ($/ton/yr)	$1,345	$1,159
SWAC system breakdown		
Seawater supply system	$23,566,000	
Centralized cooling station	$3,764,000	
Chilled water distribution system	$5,027,000	
Backup Power	$128,000	
Contingency	$6,497,000	

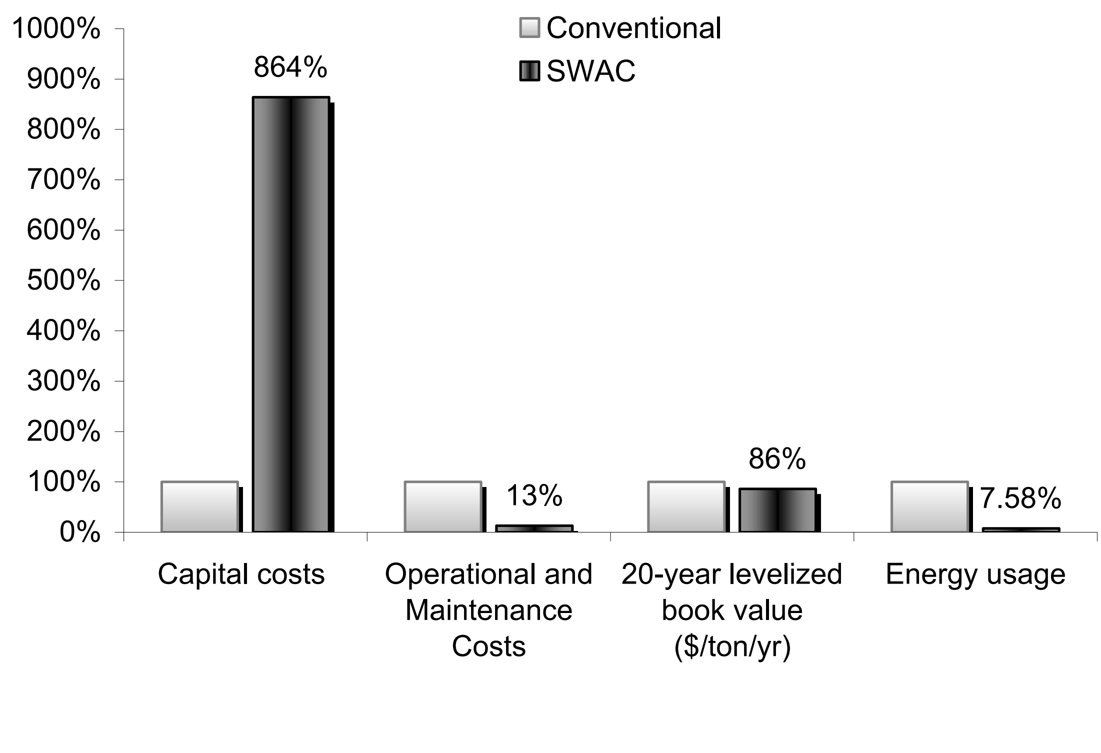


Figure 17 Kakaako SDC system summary graph: MOE

3.4 East Waikiki with University of Hawaii at Manoa

The challenges of installing an SDC system on the University of Hawaii at Manoa (UHM) campus are relatively the same as for Cornell University in Upstate New York, except that UHM has a year round cooling load suggesting higher benefits for the UHM system.

The use of a TES system allowed for a reduction in the CWP's mean diameter. The CWP intake was located in 1,600 feet and cold water was brought to shore via a 47-inch pipe (19,024 feet) at a velocity reached 3.6 feet per second. The seawater supply pumping required 311 kW. Chilled water pumping required 660 kW.

The required TES storage volume was determined to be 1.5 million gallons. The in-place cost of such water storage tanks was estimated at $1.1 Million (based on the U.S. Naval Pacific Facility Engineering Command costing book). A UHM TES-assisted system would reduce levelized costs for East Waikiki by 0.5% and reduced total carbon emissions by 24 %. Potential secondary usage of the exhausted heat exchanger seawater is identical to a Waikiki scenario, flushing of Ala Wai canal and grounds cooling at Ala Wai golf course/park. Tables 10 and 11, and figures 18 and 19 summarize the East Waikiki-UHM scenario.

It should be noted that the relatively large differences between UH-ORE and MOE for chilled water system distribution costs are based on different assumptions used regarding allowable flow rates and pipe installation. A more detailed study may be required to resolve these differences.

It should also be noted that most of the higher cost for this system is due to the cost of chilled water distribution loop that supplies the UH campus. It is anticipated that costs for just the East Waikiki portion of this case study would be similar to those for the rest of Waikiki (West Waikiki), Kakaako, and the Honolulu Waterfront case studies

Table 10 East Waikiki-UHM SDC system summary: UH-ORE

East Waikiki-UHM SDC against 30% conventional cooling capital

Mean Load (tons)	4,836	Interest rate
Ulitization	62%	7.00%
	Conventional Cooling system	**SDC system**
Electricity Rate ($/kWh)	$0.105	$0.112
Annual energy consumption (MW-hr)	36,882	5,312
Annual electricity cost	$3,866,872	$594,387
CO_2 emissions - annual (tons)	368,825	53,120
Cost Weighted life (CWL)	25	43
Capitalization cost	$4,953,780	$45,215,693
20-year levelized book value ($/ton/yr)	$1,246	$1,391
30-year levelized book value ($/ton/yr)	$1,292	$1,310

SWAC system breakdown	
CWP	$11,813,032
EWP	$1,666,959
SWPump	$2,396,182
Heat exchanger	$4,061,400
Loop pump	$177,165
Distribution	$17,157,161
Back up Power	$407,846
20% Contingency	$7,535,949

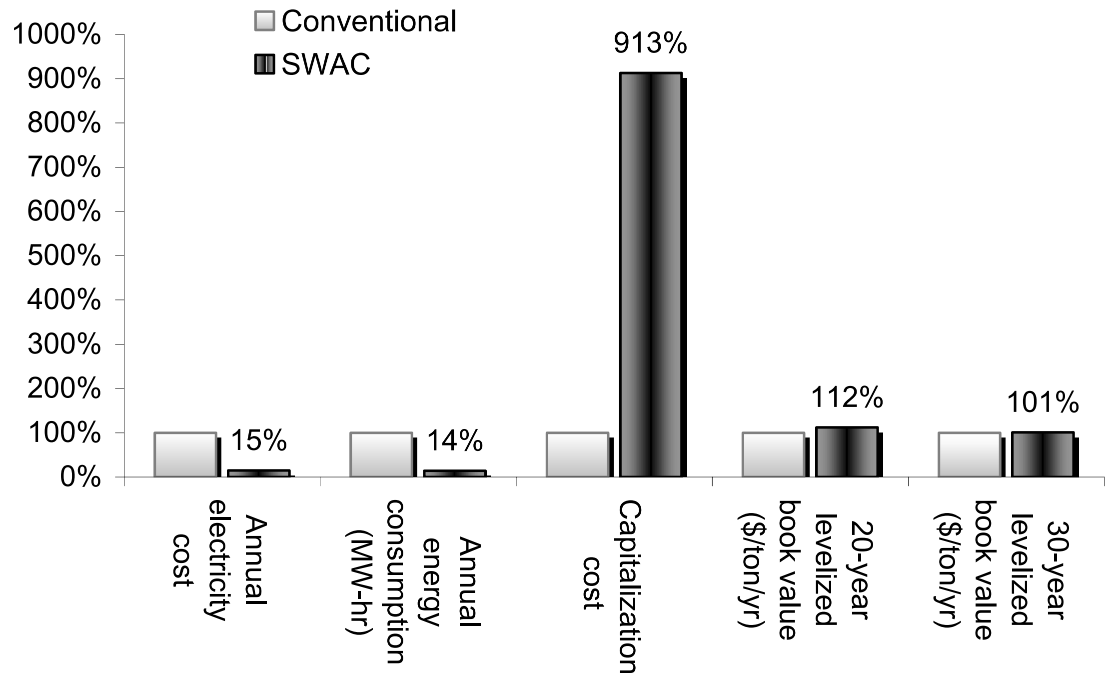


Figure 18 East Waikiki-UHM SDC system summary graph: UH-ORE

Table 11 East Waikiki-UHM SDC system summary: MOE

East Waikiki and UHM SDC		
District Characteristics		
Mean Load (tons)	4,836	
Utilization	62%	
	Conventional Cooling system	**SDC system**
Capital costs	$4,856,200	$77,505,600
Operational and Maintenance costs	$5,147,852	$1,192,000
20-year levelized book value ($/ton/yr)	$1,344	$2,114
SWAC system breakdown		
Seawater supply system	$19,102,000	
Centralized cooling station	$4,063,000	
Chilled water distribution system	$41,252,000	
Backup Power	$171,000	
Contingency	$12,917,600	

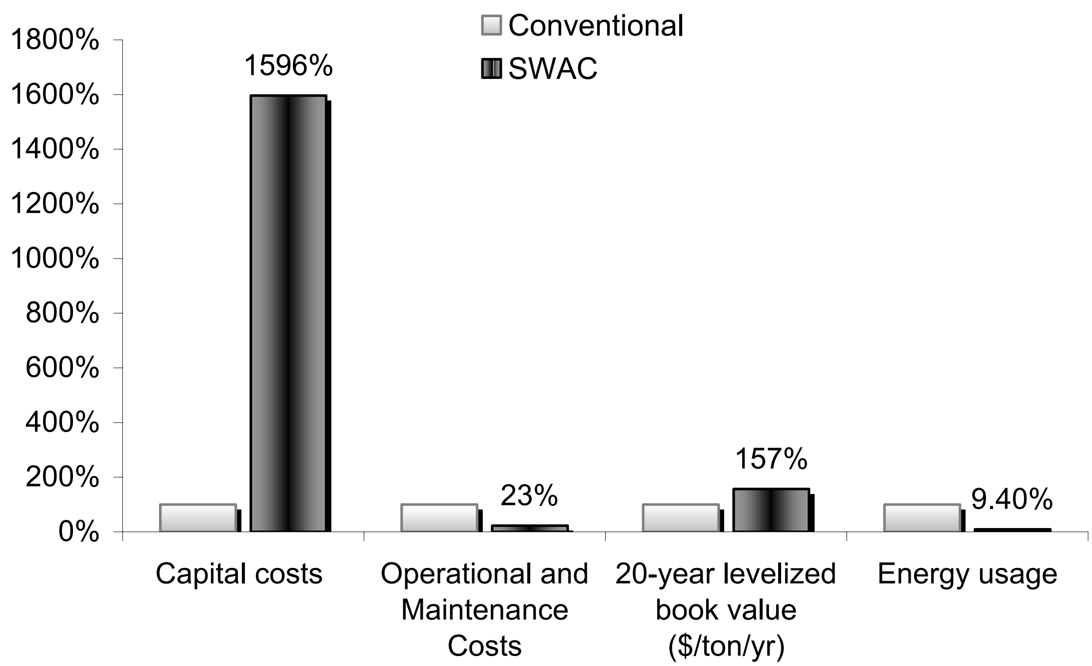


Figure 19 East Waikiki-UHM SDC system summary graph: MOE

3.5 Pearl Harbor Naval Shipyard

The Pearl Harbor Naval Shipyard is considered as a potential district, although this scenario approaches both technical and economic limits. The actual district layout is not known due to security issues; hence, a hypothetical SDC system layout was used for the analysis. The greatest challenge is the distance from landfall to the district, and the length of the CWP. The most economical method requires the use of Reef Runway as a point to locate the seawater supply system and a thermal energy storage (TES) system (night-time ice-making).

As with the UHM scenario, a TES would improve the economic outlook of the proposed SDC system. The CWP intake was located at 1,600 feet. The cold water was brought to shore via a 42-inch pipe (28,400 feet) at a velocity of 3.3 feet per second. Further technical details are provided in appendix C.

A number of secondary uses of the effluent seawater can be identified in the Pearl Harbor area. The region is not rainy; hence, ground cooling is a favorable means of secondary use. Additionally, the reduced oxygen concentration and lower pH in the exhaust seawater could reduce the corrosion rate of the *USS Arizona*, and flush the region to increase the scope of the viewable memorial. Tables 12 and 13, and figures 20 and 21 summarize the Pearl Harbor Naval Shipyard scenario. This scenario could be expanded to include Hickham Air Force Base, this could add another 2,500 tons and reduces the levelized costs stated for the present scenario due to economy of scale.

Table 12 Pearl Harbor NSY SDC system summary: UH-ORE

PHNSY SDC against 30% conventional cooling capital

	3,410	Interest rate
Utilization	62%	7.00%
	Conventional Cooling system	**SDC system**
Electricity Rate ($/kWh)	$0.099	$0.105
Annual energy consumption (MW-hr)	26,142	5,766
Annual electricity cost	$2,574,954	$607,397
CO_2 emissions - annual (tons)	261,417	57,661
Cost Weighted life (CWL)	25	45
Capitalization cost	$3,424,400	$39,353,228
20-year levelized book value ($/ton/yr)	$1,205	$1,650
30-year levelized book value ($/ton/yr)	$1,250	$1,554

SWAC system breakdown	
CWP	$14,963,917
EWP	$734,972
SWPump	$2,001,152
Heat exchanger	$1,784,250
Loop pump	$397,521
Distribution	$12,469,834
Back up Generator	$442,711
20% Contingency	$6,558,871

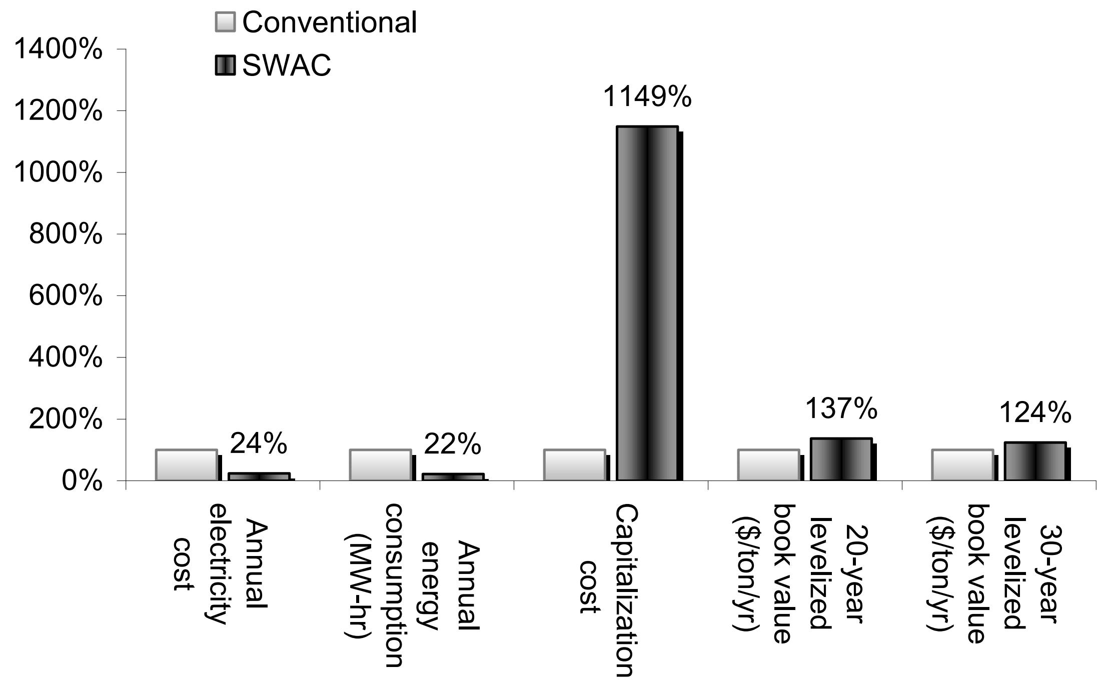


Figure 20 Pearl Harbor NSY SDC system summary graph: UH-ORE

Table 13 Pearl Harbor NSY SDC system summary: MOE

PHNSY SDC		
District Characteristics		
Mean Load (tons)	3,410	
Utilization	62%	
	Conventional Cooling system	**SDC system**
Capital costs	$3,424,200	$42,619,200
Operational and Maintenance costs	$3,672,057	$681,533
20-year levelized book value ($/ton/yr)	$1,356	$1,663
SWAC system breakdown		
Seawater supply system	$24,157,000	
Centralized cooling station	$2,888,000	
Chilled water distribution system	$8,331,000	
Backup Power	$140,000	
Contingency	$7,103,200	

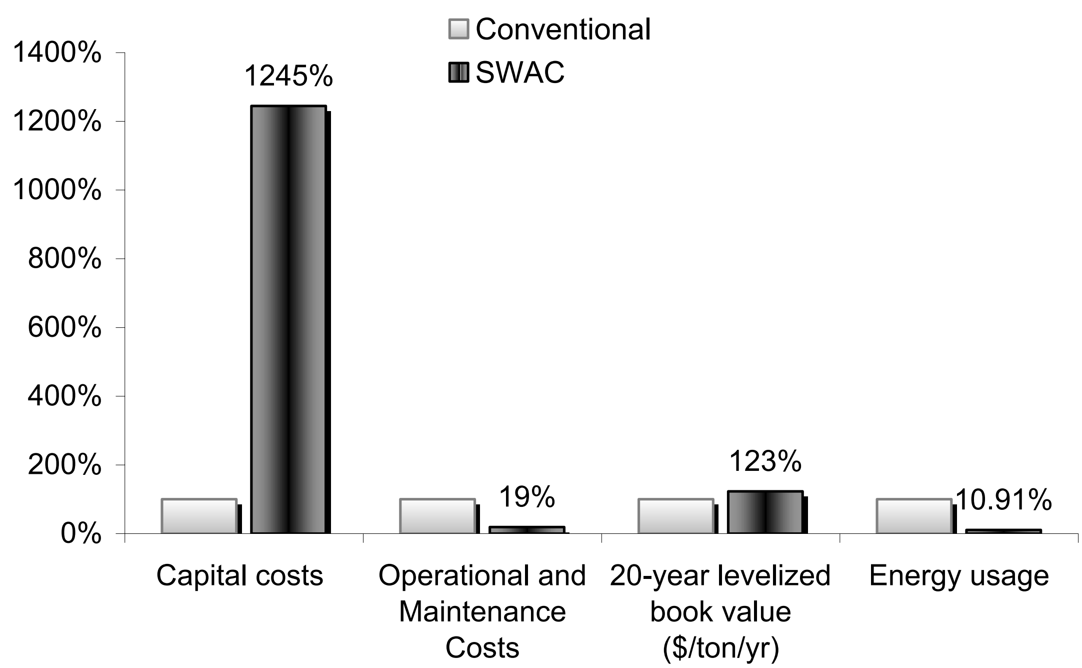


Figure 21 Pearl Harbor NSY SDC system summary graph: MOE

3.6 Kaneohe Marine Corps Base Hawaii

The scenario for Kaneohe Marine Corps Base Hawaii did not need to be hypothetical, as the base loads did not involve security issues. The CWP intake was located in 1,500 feet and cold water was brought to shore via a 26-inch pipe (14,294 feet) at a velocity of 6.6 feet per second. The base can probably utilize the effluent seawater in grounds cooling application, otherwise secondary uses were not apparent. The map in figure 22 shows the layout.

For non-institutional SDC system, a book value over life-cycle would not be considered. However, including evaluation over life-cycle shows the dramatic improvement, giving the system merit from an institutional perspective. Tables 14 and 15, and figures 19 and 20 summarize the Kaneohe MCBH scenario with respect to a potential expansion in base air-conditioning demand.

It should be noted that the air conditioning demand is expected to increase significantly at Kaneohe MCBH. A number of non-air-conditioned spaces have been proposed for the installation of air conditioning and additional new facilities are being constructed.

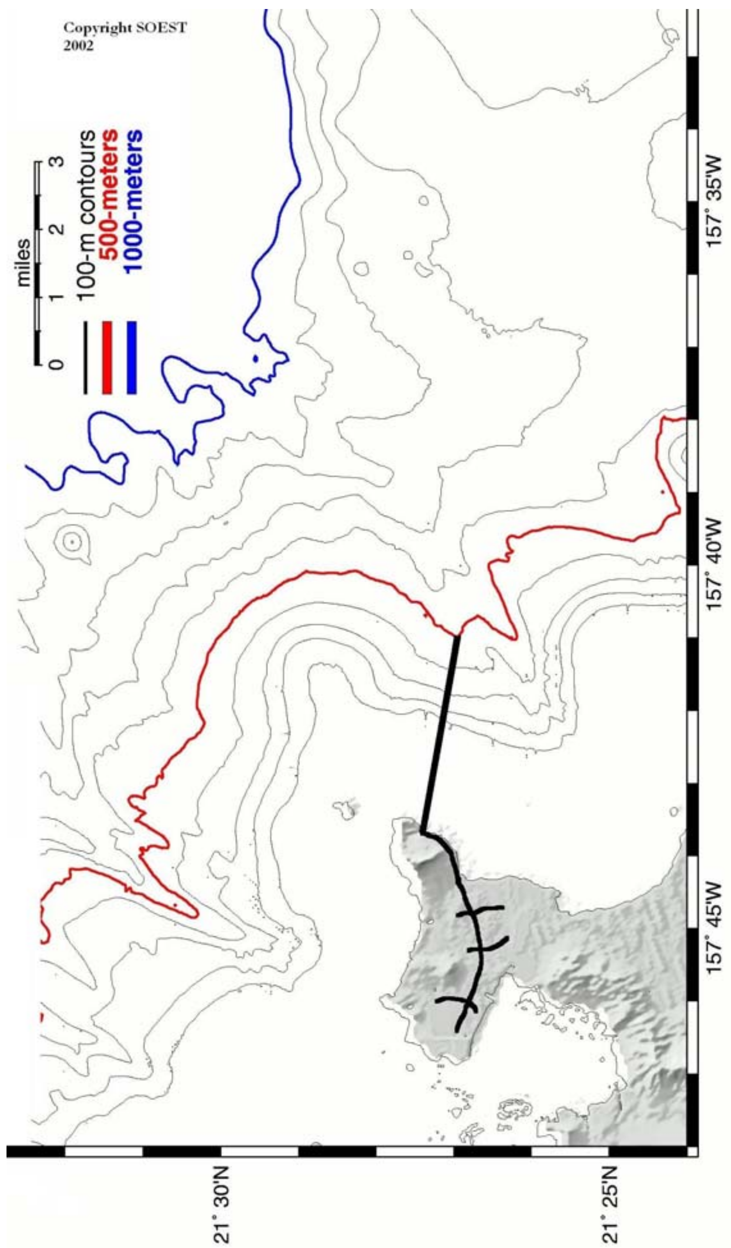


Figure 22 Kaneohe Bay map of significant bathymetries

Table 14 Kaneohe MCBH SDC system summary: UH-ORE

Kaneohe MCBH SDC against 30% conventional cooling capital

Mean Load (tons)	2,604	Interest rate
Utilization	62%	7.00%
	Conventional Cooling system	**SDC system**
Electricity Rate ($/kWh)	$0.099	$0.107
Annual energy consumption (MW-hr)	20,023	4,442
Annual electricity cost	$1,974,296	$474,219
CO_2 emissions - annual (tons)	200,233	44,423
Cost Weighted life (CWL)	25	44
Capitalization cost	$2,614,800	$31,102,887
20-year levelized book value ($/ton/yr)	$1,223	$1,722
30-year levelized book value ($/ton/yr)	$1,268	$1,622
SWAC system breakdown		
CWP	$6,085,903	
EWP	$2,822,498	
SWPump	$1,617,532	
Heat exchanger	$2,214,600	
Loop pump	$340,084	
Distribution	$12,498,311	
Back up Generator	$340,144	
20% Contingency	$5,183,814	

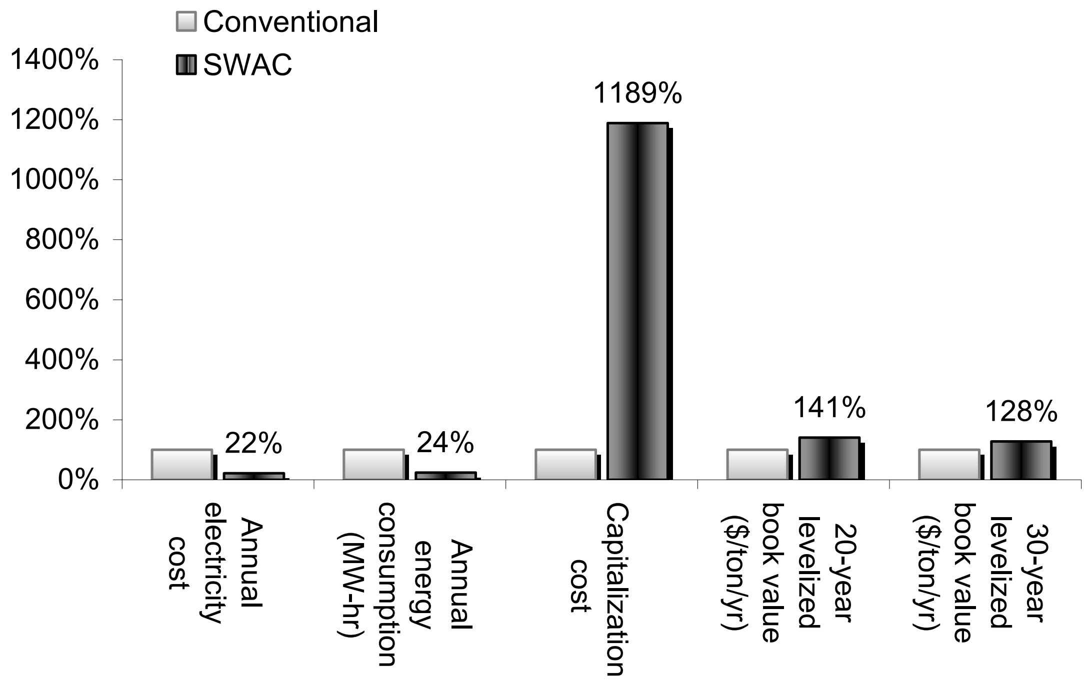


Figure 23 Kaneohe MCBH SDC system summary graph: UH-ORE

Table 15 Kaneohe MCBH SDC system summary: MOE

Kaneohe MCBH SDC		
District Characteristics		
Mean Load (tons)	2,604	
Utilization	62%	
	Conventional Cooling system	**SDC system**
Capital costs	$2,614,800	$35,114,400
Operational and Maintenance costs	$2,841,353	$539,247
20-year levelized book value ($/ton/yr)	$1,371	$1,783
SWAC system breakdown		
Seawater supply system	$20,349,000	
Centralized cooling station	$2,211,000	
Chilled water distribution system	$6,605,000	
Backup Power	$97,000	
Contingency	$5,852,400	

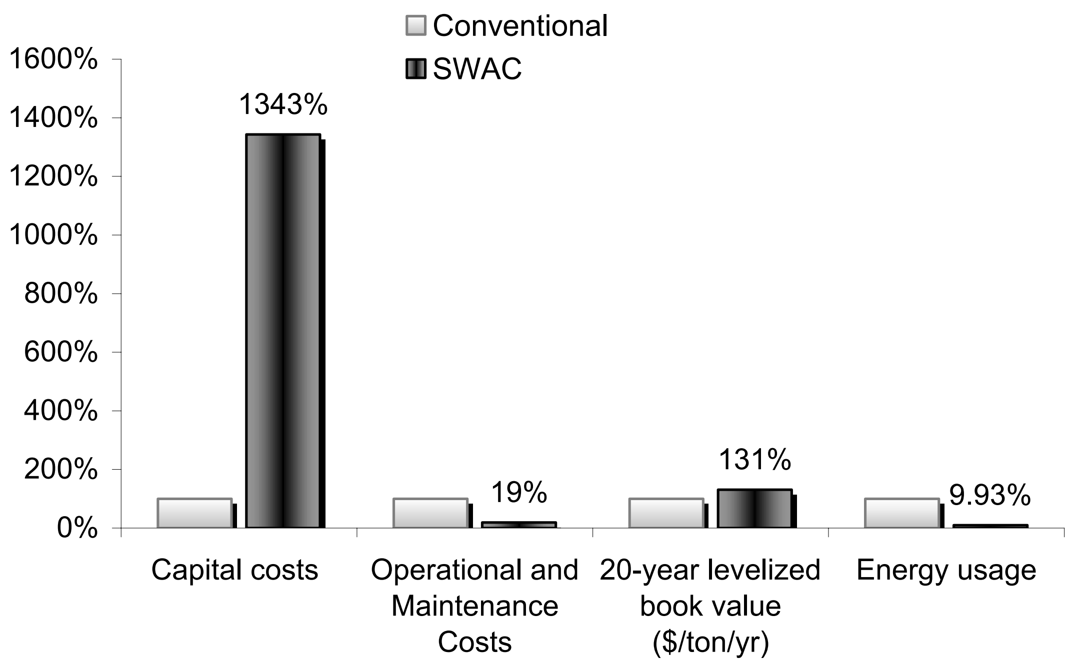


Figure 24 Kaneohe MCAS SDC system summary graph: MOE

3.7 *Scenario Summary and Ranking*

The case studies presented have been combined into summary figures (25 and 26) for comparisons. Figure 25 summarizes Makai Ocean Engineering's analysis, while figure 26 summarizes UH-ORE analysis. As can be seen from these summaries, the best areas for SDC systems are Waikiki, Honolulu Waterfront, and Kakaako.

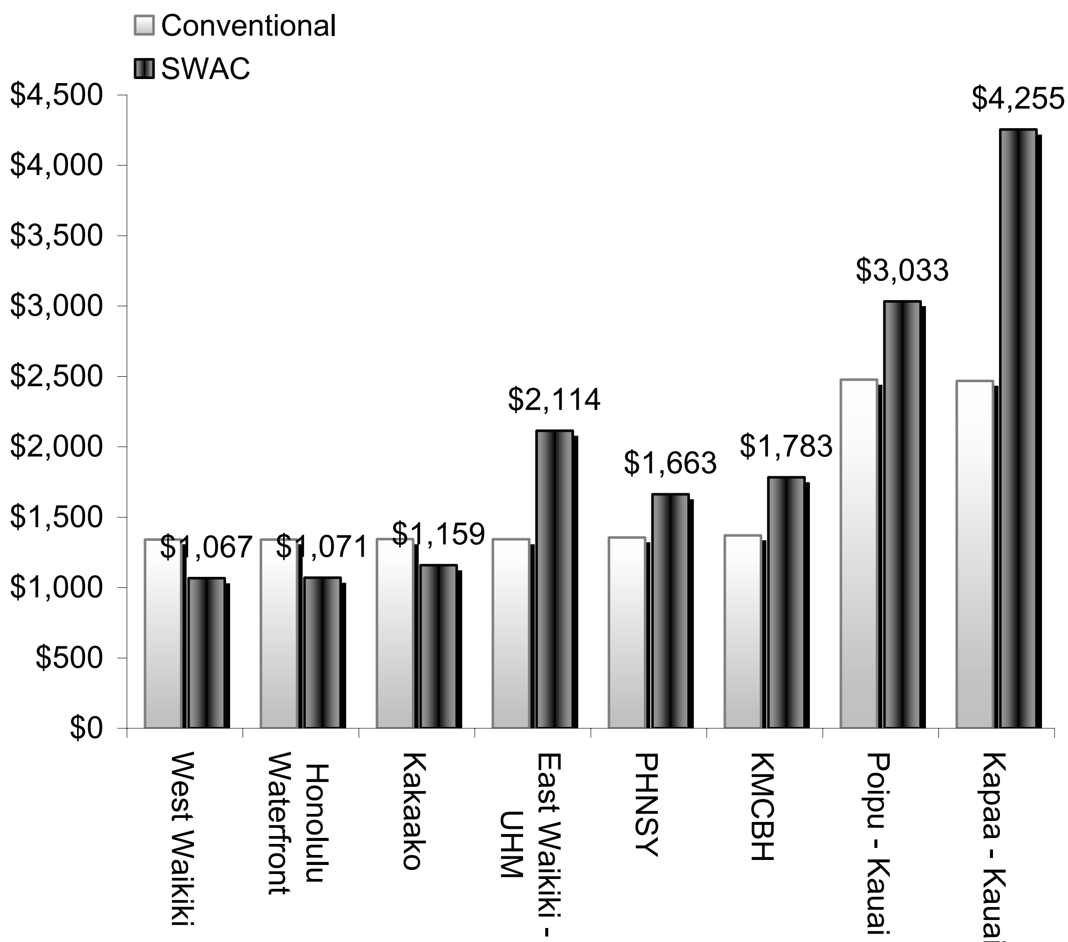


Figure 25 MOE scenario summary

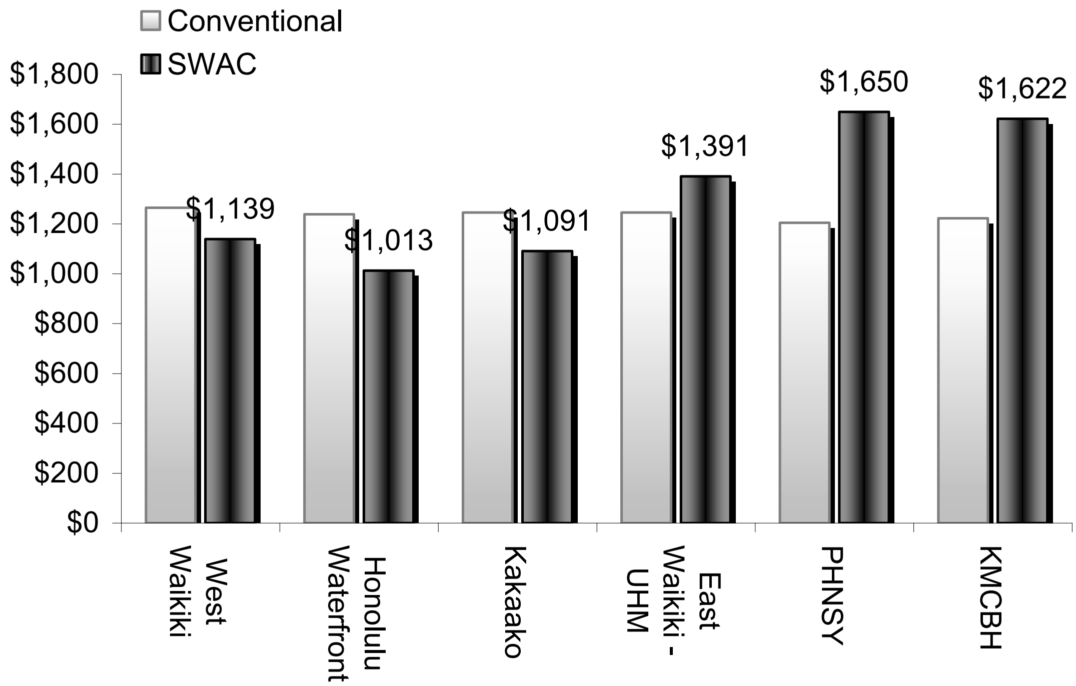


Figure 26 UH-ORE scenario summary

4. Sensitivity Analyses

The comparative cost of SDC systems and CCSs are a function of a number of parameters. These parameters are summarized in table 16.

Table 16 Economic analysis parameters

Parameter	Used	
	CCS	SDC
FINANCING		
Constant dollar	Yes	Yes
Straight line depreciation	Yes	Yes
Debt ratio (%)	100.0	100.0
Preferred ratio (%)	0.0	0.0
Common ration (%)	0.0	0.0
COST OF MONEY		
Real cost of debt (%)	7.00	7.00
Real cost of preferred stock (%)	N/A	N/A
Real cost of common stock (%)	N/A	N/A
Annual inflation rate (0 if constant dollars) (%)	0.00	0.00
Real annual escalation rate (Non-electric) (%)	0.00	0.00
Real annual escalation rate (Electric) (%)	2.00	2.00
Computed discount rate (After tax) (%)	7.00	7.00
Computed discount rate (Before tax) (%)	7.00	7.00
TAXES		
Combined federal & state income tax (%)	0.00	0.00
Combined property tax & insurance rate (%)	2.00	2.00
INITIAL CONSTRUCTION COST		
Total plant construction (TPC)	Varies	Varies
% of TPC expended in construction year 1	5	15
% of TPC expended in construction year 2	95	85
Startup costs (Land, Inventory, Startup)	0	0
OPERATING COSTS	Varies	Varies
Cost of electricity ($/kWh)	0.112	0.112
Annual energy cost	Varies	Varies
Annual non-energy O&M costs	Varies	Varies
OPERATION		
Total rated cooling capacity	Varies	Varies
Capacity factor of cooling system	0.62	0.62
REPAIR & REPLACEMENT COSTS	Varies	Varies
CONTINGENY (%)	0	20

The six case studies selected for more detailed analysis were reanalyzed by the DBEDT-Energy Resources and Technology Division using a common set of input parameters as shown in table 17. The results of these analyses are presented in table 18. The ratio of conventional cooling system (CCS) costs to seawater air conditioning district cooling (SDC) system costs is also provided.

Table 17 Common set of input parameters

Parameter	Used	
	CCS	SDC
FINANCING		
Constant dollar	Yes	Yes
Straight line depreciation	Yes	Yes
Debt ratio (%)	100.0	100.0
COST OF MONEY		
Real cost of debt (%)	7.00	7.00
Annual inflation rate (0 if constant dollars) (%)	0.00	0.00
Real annual escalation rate (Non-electric) (%)	0.00	0.00
Real annual escalation rate (Electric) (%)	2.00	2.00
Computed discount rate (After tax) (%)	7.00	7.00
Computed discount rate (Before tax) (%)	7.00	7.00
TAXES		
Combined federal & state income tax (%)	0.00	0.00
Combined property tax & insurance rate (%)	2.00	2.00
INITIAL CONSTRUCTION COST		
% of TPC expended in construction year 1	5	15
% of TPC expended in construction year 2	95	85
Startup costs (Land, Inventory, Startup)	0	0
OPERATING COSTS	Varies	Varies
Cost of electricity ($/kWh)	0.112	0.112
OPERATION		
Capacity factor of cooling system	0.62	0.62
CONTINGENY (%)	0	20

Table 18 Summary of comparative case study cooling costs

Case Study	CCS Cost ($/ton-yr)	SDC Cost ($/ton-yr)	SDC Cost/ CCS Cost
West Waikiki	$1,342.27	$1,067.37	0.7952
Honolulu Waterfront	$1,341.66	$1,071.01	0.7983
Kakaako	$1,345.04	$1,159.22	0.8618
East Waikiki – UH Manoa	$1,344.38	$2,114.08	1.5698
Pearl Harbor Naval Shipyard	$1,356.45	$1,663.27	1.2262
Kaneohe Marine Corps Base Hawaii	$1,370.75	$1,782.54	1.3004

These six case studies were then reanalyzed to determine the impact of changes in various input parameters. These data are presented and discussed in the following sections.

4.1 Impact of System Lifetimes on Cooling Costs

SDC systems can have lifetimes in excess of 40 years, and CCSs are assumed to last up to 25 years (with periodic maintenance and replacement of some components). Preliminary analyses conducted in this study used a conservative lifetime of 20 years for both types of systems. In order to determine the affect of system lifetime on cooling costs, system lifetimes (for both CCSs and SDC systems) were varied over the range of 5 years to 40 years using the Honolulu Waterfront case study. Figure 27 shows these results.

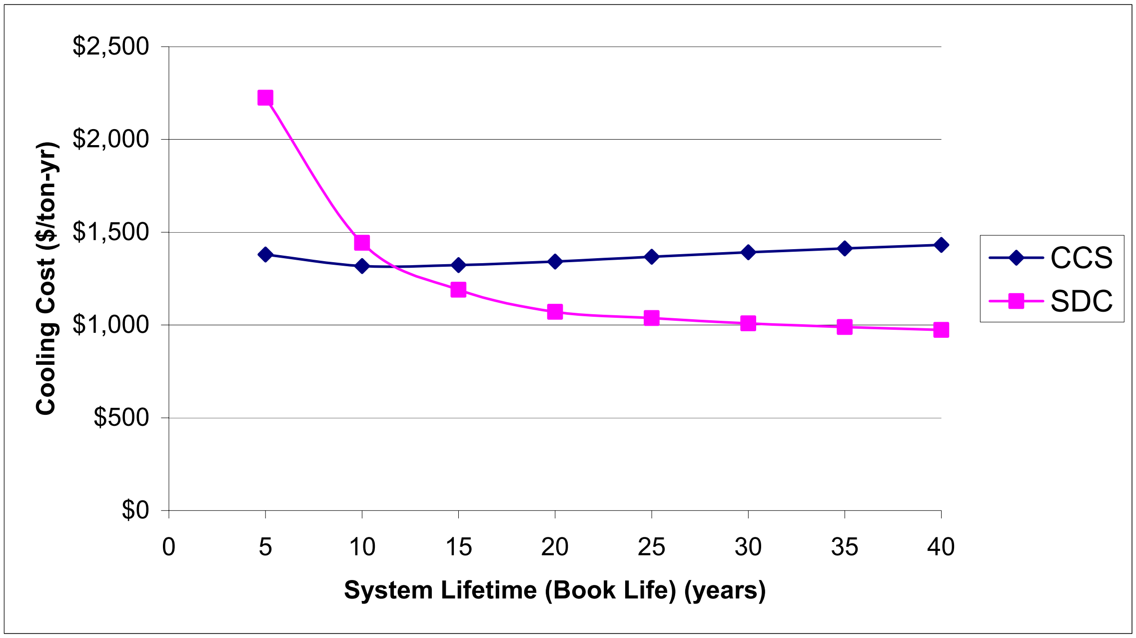


Figure 27 Impact of system lifetime on cooling costs

For very short lifetimes (i.e., 12.4 years, or less), the base case Honolulu Waterfront SDC system would cost more than conventional air conditioning. After this time, the SDC system has a steadily increasing cost advantage. After this point the CCS cooling costs increase by ~0.3%/yr of additional lifetime and the SDC system cooling costs decrease by ~1.0%/yr of additional life. Using a 20-year lifetime provides a conservative estimate of the cost differences between CCS and an SDC system. This 20-year lifetime was used in all subsequent analyses.

4.2 Impact of Estimated Percent Replacement on CCS Capital Costs

The original economic analyses for CCSs used a "30% ready for replacement" basis. This was based on a statistical analysis of the lifetimes using a limited number of conventional cooling systems. This estimated value did not include additional systems that would reach their useful lives and would have to be replaced during the lifetime of the SDC system. It also did not take into account the impact of systems that were near the end of their useful lives, had already been substantially amortized and depreciated, and/or had increasing O&M costs due to their increased life. This provided a very conservative estimate of the capital costs for such systems (as used in the comparison with SDC systems).

More representative capital costs for CCSs were determined by evaluating four different scenarios for replacement. These are:

- Uniform annual replacement at 5% per year for 20 years;
- 10% replacement in year 1, with annual replacement at 5% per year for years 2-19;
- 20% replacement in year 1, with annual replacement at 5% per year for years 2-17; and
- 40% replacement in year 1, with annual replacement at 5% per year for years 2-13

These scenarios recognize that potential SDC customers may elect to replace their CCSs before the end of the CCSs' useful life for a variety of reasons. Each of these scenarios gave significantly higher estimates of initial capital costs for competing CCSs. These data are presented in Table 19.

Table 19 Impact of estimated percent replacement on CCS capital costs

Scenario	Equivalent Fraction of 100% Replacement	CCS Capital Cost Relative to Base Case
Base Case	30.00%	1.000
Uniform annual replacement at 5% per year for 20 years	41.02%	1.367
10% replacement in year 1, w/ annual replacement at 5% per year for years 2-19	45.94%	1.531
20% replacement in year 1, w/ annual replacement at 5% per year for years 2-17	55.56%	1.852
40% replacement in year 1, w/ annual replacement at 5% per year for years 2-13	74.30%	2.477

4.3 Impact of Real Interest Rates

The interest rate used also has a significant impact on the economics of a cooling system, particularly for capital-intensive SDC systems. A 7.00% real interest rate (nominal interest rate corrected for inflation) was used. Sensitivity analyses were performed to determine the impacts of real interest rates in the range of 4.00 to 10.00%. These data are presented in table 20.

Table 20 Impact of real interest rates

Real interest rate (%)	Type of System	
	CCS	SDC
	Relative to Base Case*	
4.00	-0.15%	-15.46%
5.50	-0.12%	-7.98%
7.00*	-	-
8.50	+0.20%	+8.44%
10.00	+0.47%	+17.29%

The impacts of real interest rates on levelized costs for CCSs are insignificant. CCS costs are dominated by O&M costs (particularly energy costs). However, the impacts of real interest rates on levelized costs for SDC systems are relatively much larger owing their capital-intensive nature. Favorable interest rates will greatly enhance the cost competitiveness of SDC systems.

The State of Hawaii frequently provides Special Purpose Revenue Bond (SPRB) financing for various innovative, renewable energy projects. SPRB interest rates are typically 1-2 points below the rates for conventional financing. At a real interest rate for SPRBs (1.5 points lower than the conventional base case interest rate of 7.00%), the Honolulu Waterfront SDC system would provide cooling at 7.98% less than the Base Case.

4.4 Impact of Contingency Costs

There are no existing district cooling or large-scale seawater air conditioning systems in Hawaii. While the costs of heat exchangers and installing large pipes are fairly well known, there is considerably more uncertainty about the costs of installing chilled water distribution piping in Hawaii, particularly in well-developed urban areas in Honolulu. As a result, a 20% cost contingency factor was used for SDC systems (SDC Base Case). This has a significant impact on the economic of capital-intensive SDC systems.

No contingency was used for CCSs in the original analyses in this report (CCS Base Case). However, for consistency, and considering that there may be wide variations in CCS costs under different situations, a 20% contingency was also added to

CCSs for subsequent analyses. The impact of this contingency is relatively less for CCSs than for SDC systems (~1/8). These data are summarized in table 21.

Table 21 Impact of contingency costs

Contingency cost (%)	Type of System	
	CCS	SDC
	Relative to Base Case	
0 (CCS Base Case)	-	-14.08%
10	+0.86%	-7.04%
20 (SDC Base Case)	+1.72%	-

4.5 Impact of Changes in Electricity Costs

Changes in electric rates can have a significant impact on the levelized costs of cooling, especially for energy-intensive CCSs. A sensitivity analysis was conducted using electric rates in the range of ± 20% of the base case value ($0.1120/kWh). The Honolulu Waterfront case study was used for this analysis. These data are shown in table 22. This table shows that levelized cooling costs for CCSs vary by ± 15.6% over this range in electricity costs, while those for SDC systems vary by only ± 1.5% over the same electricity price range. SDC systems are more cost effective than CCSs down to a cost of $0.0808/kWh (a price that is unlikely to occur in Honolulu again).

Table 22 Impact of changes in electricity costs

Electricity Cost ($/kWh)	Cost Relative to Base Case	CCS	SDC	SDC/CCS
0.1344	+20%	$1,551,54	$1,086.61	0.7003
0.1232	+10%	$1,446.61	$1,078.81	0.7458
0.1120	Base Case	$1,341.48	$1,071.01	0.7984
0.1008	-10%	$1,236.83	$1,063.22	0.8597
0.0896	-20%	$1,131.83	$1,055.42	0.9325

4.6 Impact of Changes in Real Annual Escalation Rate (Electricity)

The previous analyses assumed a real annual escalation rate for electricity of 2.00%. A sensitivity analysis was used to determine the effects of changes in this assumed real annual escalation rate for electricity. Cooling costs are dominated by energy costs in CCSs, whereas energy costs represent a much smaller proportion of total costs for SDC systems. The Honolulu Waterfront case study was used as the base case for this sensitivity analysis. Real annual escalation rates for electricity were varied from 0.00 to 2.00%.

Electricity prices increased by 4.11% per year over the period of 1990 to 2000. During the same time the Honolulu CPI increased by 2.47% per year (Shah, 2001 and DBEDT, 2000). This means that electricity prices in Hawaii increased by a real inflation rate of 1.60% per cent per year over this same period. This value was used for comparison in table 23, and is used in future analyses. The results for an SDC system are also shown in table 23.

Table 23 Impact of changes in real annual escalation rate (electricity)

Real annual escalation rate for electricity (%/yr)	Type of System	
	CCS	SDC
	Relative to Base Case*	
0.00	-12.27%	-1.12%
0.40	-10.03%	-0.93%
0.80	-7.69%	-0.72%
1.20	-5.24%	-0.49%
1.60	-2.68%	-0.25%
2.00*	-	-

The cost of a CCS is reduced by 2.68% at a real annual escalation rate for electricity of 1.60% (vs. 2.00%). The impacts of real annual escalation rate for electricity are relatively greater for CCSs than for SDC systems (~11 times as great).

4.7 Impact of Combined State & Federal Income Taxes

Owing to the fact that effective State and federal income tax rates can vary greatly depending on the facility owner, a combined tax rate of 0.00% was assumed for initial analyses. In order to determine the impacts of combined State and federal taxes on project economics, a sensitivity analysis was conducted for combined State and federal tax rates over the range of 0% to 40%. The Honolulu Waterfront case study was used for this analysis. The results of this tax rate sensitivity analysis are presented in figure 28. In order to better visualize the changes, the y-axis has been expanded and uses an initial point of $1,000/ton-yr.

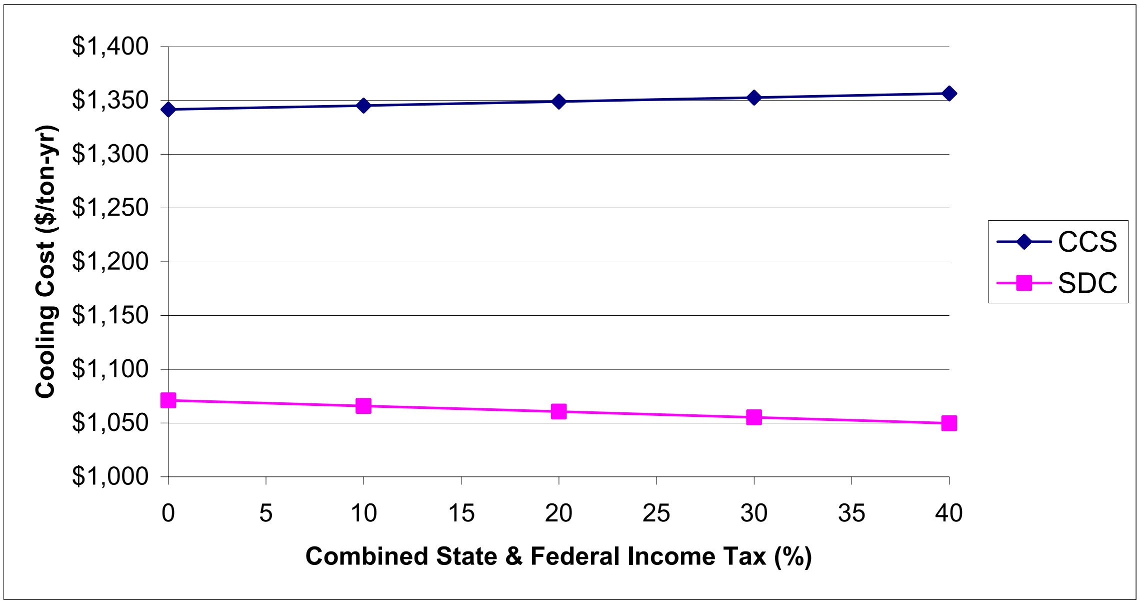


Figure 28 Effect of combined state & federal income tax

on the Honolulu Waterfront SDC System

As can be seen from figure 28, CCS costs increase slightly (~1.1%), and SDC system costs decrease slightly (~2.0%), over the range of 0% to 40% for combined State and federal income tax rates. A proxy value of 39.9% was used for subsequent analyses. This is the rate used by HECO in a recent PUC docket (HECO, 2000).

4.8 Impact of Federal Investment Tax Credit

The federal government provides a 10% investment tax credit to various commercial photovoltaics and solar thermal systems. An SDC system may qualify as a solar thermal system (it is an application of Ocean Thermal Energy Conversion [OTEC]). If this same 10% investment tax credit is applied to SDC systems, a significant reduction in cooling costs is possible. For the Honolulu Waterfront case study this 10% federal investment tax credit results in a 6.98% cost reduction. Similar cost reductions also occur for other case studies.

4.9 *Impact of Various Depreciation Methods*

The base case analysis uses straight line depreciation over the assumed 20-year booklife of SDC systems and CCSs. Commerical solar thermal and photovoltaic (PV) systems meeting federal eligibility requirements qualify for accelerated five-year tax depreciation instead of the normal 20-year depreciation. Going to a five-year depreciation schedule reduces a PV system's life cycle cost by approximately 12.5% (WisconSun, 2002). A similar reduction was assumed for SDC systems. This reduces SDC system levelized cooling costs by ~10.6%.

4.10 *Impact of Utility Rebates*

As part of their demand side management (DSM) programs, utilities often provide incentives in the form of rebates for energy systems that reduce energy use and reduce or delay the need for new generation capacity. SDC systems do both.

Air conditioning is a significant contributor to building energy (kWh) and power demand (kW). The impact of air appears to be increasing as more and more of Hawaii's buildings and residences install air conditioning. This was demonstrated recently when HECO reached a record peak demand during a recent heat spell. This demand reduction follows the cooling load profile and reaches its maximum during the peak cooling period. This peak cooling period appears to be approaching the peak utility demand period.

On a weighted average, SDC systems reduce the energy required for space cooling by 91.25% (or, 4,470 kWh/rated ton-yr). SDC systems produce a similar reduction in power demand. This is estimated to be 0.927 kW/rated ton (=0.9 kW/ton * 0.9145/0.888). Table 24 shows the value of avoided future utility capacity (HECO, 2000). Using these data, a real interest rate (discount rate) of 7.00%, and the Honolulu Waterfront case study, the calculated appropriate utility rebate should be $612.66/rated ton. This rebate amount is applied to subsequent analyses for all cases. For the Honolulu Waterfront case study, this rebate is equivalent to a decrease in capital costs of 12.6% and provides a cooling cost reduction of 10.65%.

Table 24 Avoided capital cost for avoided utility capacity

Year	Avoided capital cost ($/kW)
2005	$0.00
2006	$0.00
2007	$0.00
2008	$0.00
2009	$0.00
2010	-$195.81
2011	-$218.84
2012	-$204.65
2013	-$194.71
2014	-$260.61
2015	-$66.54
2016	-$97.86
2017	-$108.74
2018	-$163.43
2019	$0.00
2020	$0.00
2021	$0.00
2022	$0.00
2023	$0.00
2024	$0.00

4.11 Impact of a State of Hawaii Energy Conservation Income Tax Credit

The State of Hawaii currently provides Energy Conservation Income Tax Credits (ECITC)to various renewable and energy efficiency technologies. For example, wind energy systems and heat pumps receive a 20% ECITC; solar systems receive 35%; and ice storage systems, 50%. These ECITCs are scheduled to expire on July 1, 2003. However, efforts are currently underway to extend them with some modifications. The ECITC has been instrumental in the success of solar water heating systems, and the local solar water heating industry has repeatedly demonstrated that the benefits of this ECITC significantly exceed the costs, i.e., the ECITC does not cost – its pays.

A similar incentive may be appropriate for SDC systems. The impact of four scenarios, using various levels of ECITCs corresponding to those provided to existing technologies, were analyzed. The results of these analyses are presented in table 25.

Table 25 Impact of a State of Hawaii Energy Conservation Income Tax Credit

Scenario	Equivalent ECITC	Savings Relative to Base Case
No ECITC (Base Case)	-	-
20% ECITC (Similar to that provided for wind energy systems and heat pumps)	20.0%	-16.9%
35% ECITC (Similar to that provided for commercial solar thermal and photovoltaic systems	35.0%	-29.6%
50% ECITC for everything but chilled water distribution system (Similar to Rickmar's proposed Downtown Honolulu Ice Storage/District Cooling Project)	43.3%	-36.6%
50% ECITC for entire SDC system (Similar to ice storage system)	50.0%	-42.3%

4.12 Impact of Various Production Incentives

The federal government provides a renewable energy production incentive (REPI) for various types of technologies (e.g., wind and dedicated biomass plantations). The amount of this production incentive is 1.5 cents per kWh generated. If an analogous production incentive was provided for SDC systems (i.e., 1.5 cents per KWh saved [displaced]), this would have a significant impact on SDC systems. On a weighted average, the six SDC system case studies analyzed save 91.45% of the electricity currently used for conventional cooling. For the Honolulu Waterfront system alone, this would amount to nearly 38,400 MWh/yr (38,400,000 kWh/yr).

HECO's transmission and distribution system also experiences significant losses, especially far from the main electricity generation source (such as is the case for the downtown Honolulu/Kakaako/Waikiki areas). HECO estimates these losses to be 11.2% (HECO, 2000). The production incentive that would correspond to a 1.5 cents per kWh production incentive at the source (i.e., Kahe Point) would then correspond to 1.69 cents per kWh (1.5/0.888) at the end use.

Other production incentives are provided to other energy sources in Hawaii. For example, the State's ethanol mandate provides a $0.30/gallon incentive to ethanol producers. On a lower heating value, Btu-equivalent basis (76,100 Btu/gal), this ethanol energy incentive (EEI) amounts to 4.16 cents per kWh (based on HECO's heat rate of 10,550 Btu/kWh). And, once again, when adjusted for transmission and distribution losses, this is equivalent to 4.68 cents per kWh.

The impact of these various production incentives on the economics of the Honolulu Waterfront case study was also analyzed. These results are presented in table 26.

Table 26 Impact of various production incentives on SDC system costs

Production Incentive	Savings Relative to No Incentive	Equivalent ECITC (%)
REPI = 1.50 cents per kWh (w/o T&D losses)	-11.38%	13.47%
REPI = 1.69 cents per kWh (w/ T&D losses)	-12.67%	15.00%
EEI = 4.16 cents per kWh (w/o T&D losses)	-29.53%	34.95%
EEI = 4.68 cents per kWh (w/ T&D losses)	-33.31%	39.43%

4.13 Impact of Changes in Combined Property Tax & Insurance Rates

Property tax and insurance rates can have a significant impact on the costs of SDC systems owing to the high capital cost of such systems. The effect of property tax and insurance rates on less capital-intensive CCSs is proportionately less (~1/9 of SDC systems). A base case value of 2.00% was used for previous analyses. These data are shown in table 27.

Table 27 Impact of changes in combined property tax and insurance rates

Combined property tax and insurance rates (%/yr)	Type of System	
	CCS	SDC
	Relative to Base Case*	
0.00	-1.50%	-14.21%
0.50	-1.12%	-10.65%
1.00	-0.75%	-7.10%
1.50	-0.37%	-3.55%
2.00*	-	-

The relatively large impact of property taxes on the economics of SDC systems suggests the possibility of a property tax reduction as an incentive for SDC systems. The City and County of Honolulu has relatively low property taxes (0.888% of assessed value). Reducing this rate by 50% would reduce SDC system cost by 3.25% (vs. only 0.33% for a CCS).

4.14 Summary of Case Study Analyses

Each of the six case study SDC systems was analyzed using changes in various parameters invloved the economics of SDC systems and CCSs. These parameters include: (1) estimated percent replacement for competing CCSs; (2) real interest rates; (3) contingency costs; (4) changes in real annual escalation rates for electricity; (5) combined State and federal income tax rates; (6) federal investment tax credits; (7) various depreciation methods; (8) utility rebates; (9) State of Hawaii Energy Conservation Income Tax Credits; (10) various production incentives; and (11) combined property tax and insurance rates. The impact of combinations of changes in two, or more, of these parameters was also investigated. Summaries of the results for sensitivity analyses for each of the six case studies are also presented in tables 28 through 39. Table 40 provides a summary of the benefits of SDC systems.

The results of these sensitivity analyses show that SDC systems in the Waikiki, Kakaako, and Honolulu Waterfront areas are very cost effective, even in the base case analyses. On a weighted average basis, case study systems (West Waikiki, Kakaako, and Honolulu Waterfront) have base case levelized costs that are 18.4% less than CCSs. Best case scenarios (last entry in tables 29, 31, and 33) show potential levelized cost savings greater than 58%. Even for some of the other case studies, various incentives would make them cost effective when compared to CCSs (see tables .

Savings of these magnitudes could justify a significant reduction in cooling costs to SDC system customers, while still providing developers with a good return on investment. Any incentives provided may have to be limited in order to prevent developers from receiving “windfall” profits. This may have to be decided on a case-by-case basis.

SDC systems also save more than 90% of the energy used for CCSs. On a weighted average basis, these three case studies saved 92.5% of the energy used in CCSs. This is equivalent to 4,526 kWh/rated ton-yr, or 8.43 Bbl of imported crude oil/rated ton-yr.

The Waikiki, downtown Honolulu, and Kakaako areas have the potential for a total capacity of more than 50,000 tons of cooling provided by SDC systems. Based on this potential, more than 226,000 MWh, and 420,000 Bbl of imported crude oil can be saved each year (4,530,000 MWh, and 8,420,000 Bbl of imported crude oil over the 20-

year life of these systems). And, this does not include electricity transmission and distribution losses.

Other benefits of such a large reduction in imported fossil fuels use include significant greenhouse gas reduction and other air and water pollution benefits. SDC also does not use potentially harmful working fluids (such as the ones used in many CCSs) and greatly reduces the water useful and toxic chemical use and disposal associated with cooling towers.

Table 28 Final case study - West Waikiki - Conventional financing (7%)

	Cost ($/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,342.27	
Using 5%/year New Construction	$1,384.59	
+ 20% Contingency	$1,416.10	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,380.15	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,388.76**	
SDC Base Case w/ Conventional Financing @ 7.00%	$1,067.37	-23.1
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,064.65	-23.3
+ @ 38.9097% Combined State and Federal Income Tax	**$1,046.38**	-24.7
w/ 10% Federal Investment Tax Credit (FITC)	$950.61	-31.5
w/ Utility Rebate = $612.66/rated ton (UR)	$954.95	-31.2
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$957.56	-31.0
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$975.32	-29.8
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$904.26	-34.9
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$797.67	-42.6
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$691.08	-50.2
w/ 50% Reduction in Local Property Tax (RiPT)	$1,012.28	-27.1
w/ 100% Reduction in Local Property Tax (RiPT)	$978.18	-29.6
w/ 10% FITC + MACRS	$873.75	-37.1
w/ 10% FITC + MACRS + UR	$804.53	-42.1
w/ 10% FITC + MACRS + UR +35% ECITC	$640.47	-53.9
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$606.37	-56.3

Table 29 Final case study - West Waikiki - Special Purpose Revenue Bond financing (5.5%)

	Cost ($/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,342.27	
Using 5%/year New Construction	$1,384.59	
+ 20% Contingency	$1,416.10	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,380.15	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,388.76**	
SDC Base Case w/ Conventional Financing @ 5.50%	$983.75	-29.2
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$980.88	-29.4
+ @ 38.9097% Combined State and Federal Income Tax	**$970.40**	-30.1
w/ 10% Federal Investment Tax Credit (FITC)	$882.35	-36.5
w/ Utility Rebate = $612.66/rated ton (UR)	$888.83	-36.0
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$887.07	-36.1
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$903.76	-34.9
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$836.94	-39.7
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$736.21	-47.0
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$634.41	-54.3
w/ 50% Reduction in Local Property Tax (RiPT)	$936.31	-32.6
w/ 100% Reduction in Local Property Tax (RiPT)	$902.21	-35.0
w/ 10% FITC + MACRS	$810.47	-41.6
w/ 10% FITC + MACRS + UR	$752.65	-45.8
w/ 10% FITC + MACRS + UR +35% ECITC	$606.97	-56.3
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$572.88	-58.7

Table 30 Final case study - Honolulu Waterfront - Conventional financing (7%)

	Cost ($/ton-yr)	**% Diff. from CCS Base Case**
CCS Base Case w/ Conventional Financing @ 7.00%	$1,341.68	
Using 5%/year New Construction	$1,384.68	
+ 20% Contingency	$1,415.51	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,379.56	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,388.17**	
SDC Base Case w/ Conventional Financing @ 7.00%	$1,071.01	-22.8
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,068.34	-23.0
+ @ 38.9097% Combined State and Federal Income Tax	**$1,049.56**	-24.4
w/ 10% Federal Investment Tax Credit (FITC)	$951.74	-31.4
w/ Utility Rebate = $612.66/rated ton (UR)	$958.14	-31.0
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$958.84	-30.9
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$976.98	-29.6
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$904.40	-34.8
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$795.54	-42.7
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$686.67	-50.5
w/ 50% Reduction in Local Property Tax (RiPT)	$1,014.73	-26.9
w/ 100% Reduction in Local Property Tax (RiPT)	$979.84	-29.4
w/ 10% FITC + MACRS	$873.24	-37.1
w/ 10% FITC + MACRS + UR	$804.02	-42.1
w/ 10% FITC + MACRS + UR +35% ECITC	$635.94	-54.2
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$601.12	-56.7

Table 31 Final case study - Honolulu Waterfront - Special Purpose Revenue Bond financing (5.5%)

	Cost ($/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,341.68	
Using 5%/year New Construction	$1,384.68	
+ 20% Contingency	$1,415.51	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,379.56	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,388.17**	
SDC Base Case w/ Conventional Financing @ 5.50%	$958.58	-30.9
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$982.75	-29.2
+ @ 38.9097% Combined State and Federal Income Tax	**$971.93**	-30.0
w/ 10% Federal Investment Tax Credit (FITC)	$882.00	-36.5
w/ Utility Rebate = $612.66/rated ton (UR)	$890.36	-35.9
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$891.00	-35.8
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$907.18	-34.6
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$842.43	-39.3
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$745.31	-46.3
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$648.18	-53.3
w/ 50% Reduction in Local Property Tax (RiPT)	$937.11	-32.5
w/ 100% Reduction in Local Property Tax (RiPT)	$902.28	-35.0
w/ 10% FITC + MACRS	$811.38	-41.6
w/ 10% FITC + MACRS + UR	$750.57	-45.9
w/ 10% FITC + MACRS + UR +35% ECITC	$601.60	-56.7
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$566.77	-59.2

Table 32 Final case study - Kakaako - Conventional financing (7%)

	Cost ($/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,345.04	
Using 5%/year New Construction	$1,387.36	
+ 20% Contingency	$1,418.86	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,382.98	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,391.56**	
SDC Base Case w/ Conventional Financing @ 7.00%	$1,159.22	-16.7
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,156.51	-16.9
+ @ 38.9097% Combined State and Federal Income Tax	**$1,135.43**	-18.4
w/ 10% Federal Investment Tax Credit (FITC)	$1,027.28	-26.2
w/ Utility Rebate = $612.66/rated ton (UR)	$1,044.00	-25.0
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$1,035.12	-25.6
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$1,055.18	-24.2
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$974.94	-29.9
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$854.58	-38.6
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$734.21	-47.2
w/ 50% Reduction in Local Property Tax (RiPT)	$1,096.92	-21.2
w/ 100% Reduction in Local Property Tax (RiPT)	$1,058.42	-23.9
w/ 10% FITC + MACRS	$940.49	-32.4
w/ 10% FITC + MACRS + UR	$871.27	-37.4
w/ 10% FITC + MACRS + UR +35% ECITC	$682.87	-50.9
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$644.37	-53.7

Table 33 Final case study - Kakaako - Special Purpose Revenue Bond financing (5.5%)

	Cost ($/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,345.04	
Using 5%/year New Construction	$1,387.36	
+ 20% Contingency	$1,415.51	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,379.56	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,388.17**	
SDC Base Case w/ Conventional Financing @ 5.50%	$958.58	-30.9
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$982.75	-29.2
+ @ 38.9097% Combined State and Federal Income Tax	**$971.93**	-30.0
w/ 10% Federal Investment Tax Credit (FITC)	$882.00	-36.5
w/ Utility Rebate = $612.66/rated ton (UR)	$890.36	-35.9
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$891.00	-35.8
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$907.18	-34.6
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$842.43	-39.3
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$745.31	-46.3
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$648.18	-53.3
w/ 50% Reduction in Local Property Tax (RiPT)	$937.11	-32.5
w/ 100% Reduction in Local Property Tax (RiPT)	$902.28	-35.0
w/ 10% FITC + MACRS	$811.38	-41.6
w/ 10% FITC + MACRS + UR	$750.57	-45.9
w/ 10% FITC + MACRS + UR +35% ECITC	$601.60	-56.7
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$566.77	-59.2

Table 34 Final case study - East Waikiki - UHM - Conventional financing (7%)

	Cost ($/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,344.38	
Using 5%/year New Construction	$1,386.70	
+ 20% Contingency	$1,418.21	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,382.26	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,380.69**	
SDC Base Case w/ Conventional Financing @ 7.00%	$2,117.08	+52.2
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$2,110.70	+51.8
+ @ 38.9097% Combined State and Federal Income Tax	**$2,068.85**	+48.7
w/ 10% Federal Investment Tax Credit (FITC)	$1,868.49	+34.3
w/ Utility Rebate = $612.66/rated ton (UR)	$1,977.42	+42.2
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$1,883.48	+35.4
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$1,920.56	+38.1
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$1,772.34	+27.4
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$1,549.82	+11.4
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$1,327.38	-4.6
w/ 50% Reduction in Local Property Tax (RiPT)	$1,997.69	+43.6
w/ 100% Reduction in Local Property Tax (RiPT)	$1,926.53	+38.5
w/ 10% FITC + MACRS	$1,708.60	+22.8
w/ 10% FITC + MACRS + UR	$1,639.38	+17.9
w/ 10% FITC + MACRS + UR +35% ECITC	$1,270.66	-8.6
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$1,199.51	-13.8

Table 35 Final case study - East Waikiki - UHM - Special Purpose Revenue Bond financing (5.5%)

	Cost **($/ton-yr)**	**% Diff. from CCS Base Case**
CCS Base Case w/ Conventional Financing @ 7.00%	$1,345.04	
Using 5%/year New Construction	$1,387.36	
+ 20% Contingency	$1,418.86	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,382.98	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,391.56**	
SDC Base Case w/ Conventional Financing @ 5.50%	$1,064.69	-23.5
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,061.80	-23.7
+ @ 38.9097% Combined State and Federal Income Tax	**$1,049.55**	-24.6
w/ 10% Federal Investment Tax Credit (FITC)	$950.12	-31.7
w/ Utility Rebate = $612.66/rated ton (UR)	$967.98	-30.4
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$960.06	-31.0
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$977.96	-29.7
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$906.37	-34.9
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$798.79	-42.6
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$691.60	-50.3
w/ 50% Reduction in Local Property Tax (RiPT)	$1,011.05	-27.3
w/ 100% Reduction in Local Property Tax (RiPT)	$972.54	-30.1
w/ 10% FITC + MACRS	$873.06	-37.3
w/ 10% FITC + MACRS + UR	$811.59	-41.7
w/ 10% FITC + MACRS + UR +35% ECITC	$644.31	-53.7
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$605.81	-56.5

Table 36 Final case study – Pearl Harbor Naval Shipyard - Conventional financing (7%)

	Cost (\$/ton-yr)	% Diff. from CCS Base Case
CCS Base Case w/ Conventional Financing @ 7.00%	$1,356.45	
Using 5%/year New Construction	$1,398.77	
+ 20% Contingency	$1,430.27	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,394.40	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,402.97**	
SDC Base Case w/ Conventional Financing @ 7.00%	$1,663.27	+18.6
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,659.35	+18.3
+ @ 38.9097% Combined State and Federal Income Tax	**$1,628.22**	+16.1
w/ 10% Federal Investment Tax Credit (FITC)	$1,472.36	+4.9
w/ Utility Rebate = $612.66/rated ton (UR)	$1,536.79	+9.5
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$1,483.67	+5.8
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$1,512.58	+7.8
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$1,396.93	-0.4
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$1,223.46	-12.8
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$1,050.00	-25.2
w/ 50% Reduction in Local Property Tax (RiPT)	$1,572.73	+12.1
w/ 100% Reduction in Local Property Tax (RiPT)	$1,517.24	+8.1
w/ 10% FITC + MACRS	$1,347.28	-4.0
w/ 10% FITC + MACRS + UR	$1,278.06	-8.9
w/ 10% FITC + MACRS + UR +35% ECITC	$995.86	-29.0
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$940.37	-33.0

Table 37 Final case study – Pearl Harbor Naval Shipyard - Special Purpose Revenue Bond financing (5.5%)

	Cost **($/ton-yr)**	**% Diff. from CCS Base Case**
CCS Base Case w/ Conventional Financing @ 7.00%	$1,356.45	
Using 5%/year New Construction	$1,398.77	
+ 20% Contingency	$1,430.27	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,394.40	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,402.97**	
SDC Base Case w/ Conventional Financing @ 5.50%	$1,526.94	+8.8
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,522.79	+8.5
+ @ 38.9097% Combined State and Federal Income Tax	**$1,504.37**	+7.2
w/ 10% Federal Investment Tax Credit (FITC)	$1,361.07	-3.0
w/ Utility Rebate = $612.66/rated ton (UR)	$1,422.80	+1.4
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$1,375.41	-2.0
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$1,401.20	-0.1
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$1,298.03	-7.5
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$1,143.26	-18.5
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$988.51	-29.5
w/ 50% Reduction in Local Property Tax (RiPT)	$1,448.88	+3.3
w/ 100% Reduction in Local Property Tax (RiPT)	$1,393.39	-0.7
w/ 10% FITC + MACRS	$1,250.02	-10.9
w/ 10% FITC + MACRS + UR	$1,188.55	-15.3
w/ 10% FITC + MACRS + UR +35% ECITC	$937.98	-33.1
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$882.49	-37.1

Table 38 Final case study - Kaneohe Marine Corps Base Hawaii - Conventional financing (7%)

	Cost **($/ton-yr)**	**% Diff. from CCS Base Case**
CCS Base Case w/ Conventional Financing @ 7.00%	$1,370.75	
Using 5%/year New Construction	$1,413.07	
+ 20% Contingency	$1,444.57	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,408.69	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,417.27**	
SDC Base Case w/ Conventional Financing @ 7.00%	$1,782.54	+25.8
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,778.97	+25.5
+ @ 38.9097% Combined State and Federal Income Tax	**$1,748.69**	+23.4
w/ 10% Federal Investment Tax Credit (FITC)	$1,580.53	+11.5
w/ Utility Rebate = $612.66/rated ton (UR)	$1,657.26	+16.9
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$1,592.73	+12.4
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$1,623.92	+14.6
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$1,499.15	+5.8
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$1,311.99	-7.4
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$1,124.83	-20.6
w/ 50% Reduction in Local Property Tax (RiPT)	$1,688.82	+19.2
w/ 100% Reduction in Local Property Tax (RiPT)	$1,628.95	+14.9
w/ 10% FITC + MACRS	$1,445.58	+2.0
w/ 10% FITC + MACRS + UR	$1,376.36	-2.9
w/ 10% FITC + MACRS + UR +35% ECITC	$1,069.97	-24.5
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$1,010.10	-28.7

Table 39 Final case study - Kaneohe Marine Corps Base Hawaii - Special Purpose Revenue Bond financing (5.5%)

	Cost **($/ton-yr)**	**% Diff. from CCS Base Case**
CCS Base Case w/ Conventional Financing @ 7.00%	$1,370.75	
Using 5%/year New Construction	$1,413.07	
+ 20% Contingency	$1,444.57	
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,408.69	
+ @ 38.9097% Combined State and Federal Income Tax	**$1,417.27**	
SDC Base Case w/ Conventional Financing @ 5.50%	$1,635.23	+15.4
+ @ 1.6% Real Annual Escalation Cost (Electricity)	$1,631.46	+15.1
+ @ 38.9097% Combined State and Federal Income Tax	**$1,615.08**	+14.0
w/ 10% Federal Investment Tax Credit (FITC)	$1,460.47	+3.0
w/ Utility Rebate = $612.66/rated ton (UR)	$1,533.51	+8.2
w/ Federal Modified Accelerated Cost Recovery System (MACRS)	$1,475.93	+4.1
w/ 10% Energy Conservation Income Tax Credit (ECITC)	$1,503.76	+6.1
w/ 20% Energy Conservation Income Tax Credit (ECITC)	$1,392.45	-1.8
w/ 35% Energy Conservation Income Tax Credit (ECITC)	$1,225.47	-13.5
w/ 50% Energy Conservation Income Tax Credit (ECITC)	$1,058.49	-25.3
w/ 50% Reduction in Local Property Tax (RiPT)	$1,555.21	+9.7
w/ 100% Reduction in Local Property Tax (RiPT)	$1,495.34	+5.5
w/ 10% FITC + MACRS	$1,340.65	-5.4
w/ 10% FITC + MACRS + UR	$1,279.18	-9.7
w/ 10% FITC + MACRS + UR +35% ECITC	$1,007.14	-28.9
w/ 10% FITC + MACRS + UR +35% ECITC + 50% RiPT	$947.26	-33.2

Table 40 Summary of the benefits of SDC systems

	Total or Weighted Average	**HWF**	**EWUHM**	**WW**	**KK**	**PHNS**	**KMCBH**
Capital Cost ($1,000s)	$274,955	$41,166	$77,506	$39,568	$38,982	$42,619	$35,114
Rated Capacity (tons)	41,525	8,465	7,800	8,310	7,250	5,500	4,200
Annual Energy Saving (MWh/yr)	185,794	38,371	34,606	37,621	32,753	23,951	18,492
Annual Energy Saving (%)	91.45	92.57	90.60	92.45	92.42	89.09	90.07
Annual LSRFO Savings (Bbl/yr)	311,734	64,381	58,063	63,123	54,954	40,186	31,027
Per Rated Ton	7.51	7.61	7.44	7.60	7.58	7.31	7.39
Lifetime LSRFO Savings (Bbl)	6,234,684	1,287,622	1,161,262	1,262,451	1,099,089	803,728	620,532
Per Rated Ton	150.14	152.11	148.88	151.92	151.60	146.13	147.75
Annual Crude Oil Sav's (Bbl/yr)	337,909	69,787	62,938	68,423	59,569	43,561	33,632
Per Rated Ton	8.14	8.24	8.07	8.23	8.22	7.92	8.01
Lifetime Crude Oil Sav's (Bbl)	6,758,183	1,395,737	1,258,768	1,368,454	1,191,375	871,214	672,635
Per Rated Ton	162.75	164.88	161.38	164.68	164.33	158.40	160.15
Equivalent SWH System (energy)	66,402	13,536	12,473	13,288	11,593	8,795	6,716
Equivalent SWH System (capac.)	52,089	10,618	9,784	10,424	9,094	6,899	5,268

Notes: HWF = Honolulu Waterfront
EWUHM = East Waikiki – UHM
WW = West Waikiki
KK = Kakaako
PHNS = Pear Harbor Naval Shipyard
KMCBH = Kaneohe Marine Corps Base Hawaii
LSRFO = Low Sulfur Residual Fuel Oil

5. Marketing Plan

5.1 Market Analysis

The target market is confined to a relatively small number of decision makers for facilities that will already have central air-conditioning, and are located within a physical district technically defined as a viable candidate for SDC system application. Thus, successful solicitation of each customer is very critical. For example, the most promising district contains less than 20 significant customers. By comparison, the conventional cooling systems market is not strictly limited by geography or density, as their systems are discrete and stand-alone.

5.2 Competition

As an SDC system in Hawaii would represent a new product, no direct district cooling competition presently exists (SDC systems must compete with a relatively large number of smaller independent systems). However, ice (or thermal energy) storage district cooling without the deep seawater component is potential competitor. Presently, cooling services exclusively provided by manufacturers and suppliers of central air-conditioning systems such as Trane and Carrier.

5.3 Promotion and Service Analysis

The service provided to the customers begins before agreements are made by performing facility analyses that are beneficial to supplier and customers. This analysis provides detailed information on how an SDC system might be of value to the customers. Analysis would include the following:

- electric load profile (over minimum of one month), to be used to evaluate; changes in the electricity rate and facility power grid due to shifting to an SDC system;
- heating and cooling map in various spaces;
- noise level checks in and around the cooling system space;
- maintenance and service records and bills for the cooling systems;
- cooling system space evaluation and alternate uses, and salvage value of cooling system; and
- educate customers on tax credits due to using energy efficient services

Once this information has been gathered for all prospective customers, a business plan can be developed, and the detailed costs, merits and risks of an SDC system can be discussed with customers on the basis of confidence in this plan. Upon agreement and construction of an SDC system, the provider will perform service monitoring, routine equipment interface inspections, and operate and maintain the SDC system.

5.4 Marketing Strategy

A SDC system can provide numerous economic and technical advantages to its customers over the conventional individualized systems. A SDC system can produce capital and operating cost savings to its customers. Given the proper financing assistance for this innovative technology, the supplier can provide overall savings in excess of 10%. Capital costs for possible upgrades or necessary replacements are eliminated and more facility space is made available by conventional equipment removal (chillers, cooling towers and evaporators). Furthermore, economic risks associated with local energy supply fluctuations and costs are significantly reduced by the more efficient SDC system. Finally, the heat and noise generated by conventional cooling systems within a facility are removed.

Additionally, the marketing strategy of the privatized SDC system supplier should emphasize the strength of the proposed SDC system to supply space cooling in the most socially responsible and environmentally friendly manner. Total energy consumption and environmental pollution (noise, thermal, and chemical) are consistently and significantly reduced by a SDC system.

5.5 Economics

The focus of this marketing plan is on reducing the levelized cost of the unit space cooling by considering all advantages gained. As carbon emissions penalties are not currently assessed, rewards for reducing carbon emissions mostly rely on moral and ethical value system of the individual business. A carbon emissions reduction incentive would provide additional economic incentives for SDC system use.

All case studies were most sensitive to changes in the period of the financing plan. Longer plans always favor SDC systems, due to longer life-cycles and lower operating costs. Within a possible interest rate range of 4% to 10% (low end demonstrated in California energy programs), the average levelized costs between 20-year and 30-year book-life's varied 6.2%.

5.6 Risk

Most of the invested capital can not be recovered if the system fails to be profitable; the piping systems (seawater supply and distribution) do not have any salvage value as it would be too costly to recover. For example, a 63-inch CWP of 19,000 feet would have an initial material value of $1 Million. However, the high-density polyethylene material can not be reused to produce more pipe (per code); at best an attempt could be made to find a buyer for the used HDPE pipe, but would likely cost more in recovery than its used resale value (Grandelli, 2002). The same is true for the HDPE pipe used in the distribution system; its in-place value materially is only about 10% of the total financial effort to install, thus it can not be profitably removed.

6. Conclusions and Recommendations

6.1 Conclusions

- A typical SDC system is quite simple and is suitable for coastal developments with large air conditioning demand and reasonable access to deep, cold seawater.
- SDC systems are both technically and economically feasible today and, once installed, the energy supply is inexhaustible, renewable, and with minimal environmental impacts.
- SDC systems have great potential in Hawaii. All islands have some shorelines that have good access to deep cold seawater and Hawaii has a year-round, relatively uniform need for air conditioning. Hawaii has an estimated SWAC potential of more than 100,000 tons, with more than 50,000 tons of this potential in the Waikiki/Kakaako/downtown Honolulu area. Based on this potential, more than 226,000 MWh, and 420,000 Bbl of imported crude oil can be saved each year (4,530,000 MWh, and 8,420,000 Bbl of imported crude oil over the 20-year life of these systems). And, this does not include electricity transmission and distribution losses.
- The results of sensitivity analyses conducted show that SDC systems in the Waikiki, Kakaako, and Honolulu Waterfront areas are very cost effective, even in the base case analyses. On a weighted average basis, case study systems (West Waikiki, Kakaako, and Honolulu Waterfront) have base case levelized costs that are 18.4% less than CCSs. Best case scenarios show potential

levelized cost savings greater than 58%. Even for some of the other non-Oahu case studies, various incentives would make them cost effective when compared to CCSs.

- Savings of these magnitudes could justify a significant reduction in cooling costs to SDC system customers, while still providing developers with a good return on investment. In fact, any incentives provided may have to be limited in order to prevent developers from receiving "windfall" profits. This may have to be decided on a case-by-case basis.
- Other benefits of such a large reduction in imported fossil fuels use include significant greenhouse gas reduction and other air and water pollution benefits. An SDC system also does not use potentially harmful working fluids (such as the ones used in many CCSs) and greatly reduces the water useful and toxic chemical use and disposal associated with cooling towers.
- Economically and environmentally beneficial uses of the exhausted seawater may also be possible, as the seawater is still relatively cold at 55° F to 57° F. Realizing secondary uses for the exhausted seawater reduces the total capital required for an SDC system as by-product utilization reduces the cost of an effluent pipe (and, in some cases, may provide additional income). Without secondary use, isothermal return of the seawater would require an effluent pipe that extends to the 800-foot contour; the effluent pipe would cost approximately half the amount of the supply pipe. However, a shorter seawater return pipe and shallower (150 feet) discharge depth can often be justified because of environmental conditions related to the vertical excursion of the thermocline in an

active internal wave field. A minimum of 150 feet is suggested to bring discharge below standard scuba diving depths to avoid impact on recreational diving.

- The best system for Hawaii (and possibly other areas where the technology might be marketed) might be a hybrid SDCC/Energy Storage system. Use of a thermal energy storage (TES) system in conjunction with an SDC system would allow greater utilization of the SDC system by increasing its capacity factor. This would be accomplished by allowing the SDC system to supply a much larger base load cooling demand (for a given pipe size and cost), and for the TES system to supply the peak demand. A smaller TES system would also be able to provide peaking capabilities for a much larger district cooling system. Utility demand during peak demand periods would be reduced significantly and energy use would be reduced by 80 - 90%.

6.2 Recommendations

- A follow-up study should be conducted to evaluate the potential for integrating SDC systems with energy storage systems. (This study is currently underway.)
- There is also a need to conduct site-specific evaluations for each of the positive and marginal sites identified in this study. Such "Phase II" evaluations would essentially be business plans with preliminary designs and economic evaluations that consider site specific information as well as timely economic factors and legal requirements.

- The ultimate objective should be to commercialize one, or more, SDC or SDC/Energy Storage Hybrid Systems in Hawaii, with the potential for technology export to other areas.

Appendix A Engineering Derivations

A1 Thermal and Density Properties of Seawater as Function of Depth

The ocean's temperature varies with depth and somewhat with time. In the evaluation of a potential district cooling system, the length of the CWP is determined by the *significant district chilled water supply temperature* and the local bathymetry. The temperature at depth can be described statistically. A temperature and density profile was established as a function of depth to allow continuous variability in the optimization procedure. Several sources were gathered to construct the graph shown in figure 29 and 30 and determine the best-fit equations.

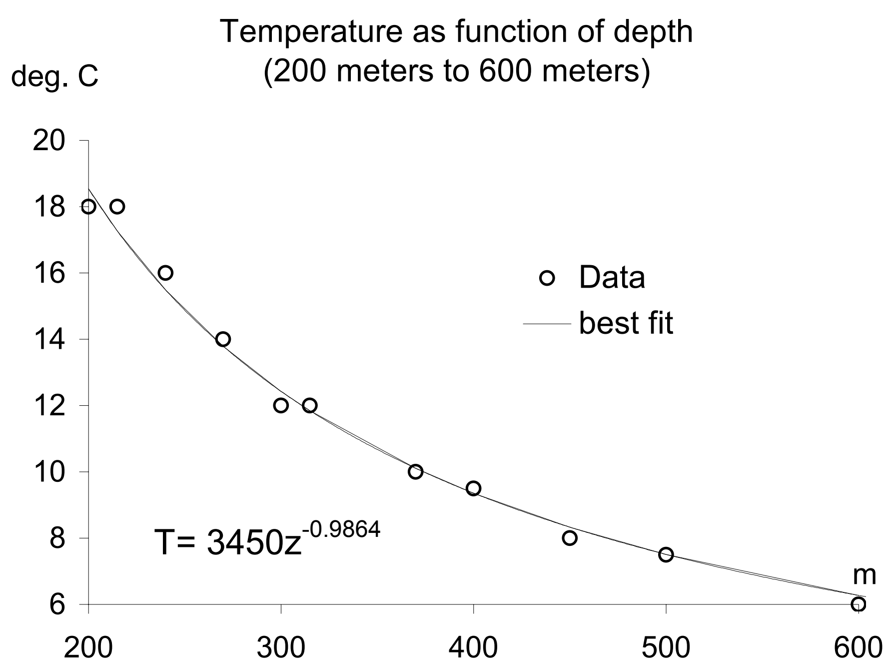


Figure 29 Temperature as function of depth from 200 to 600 meters

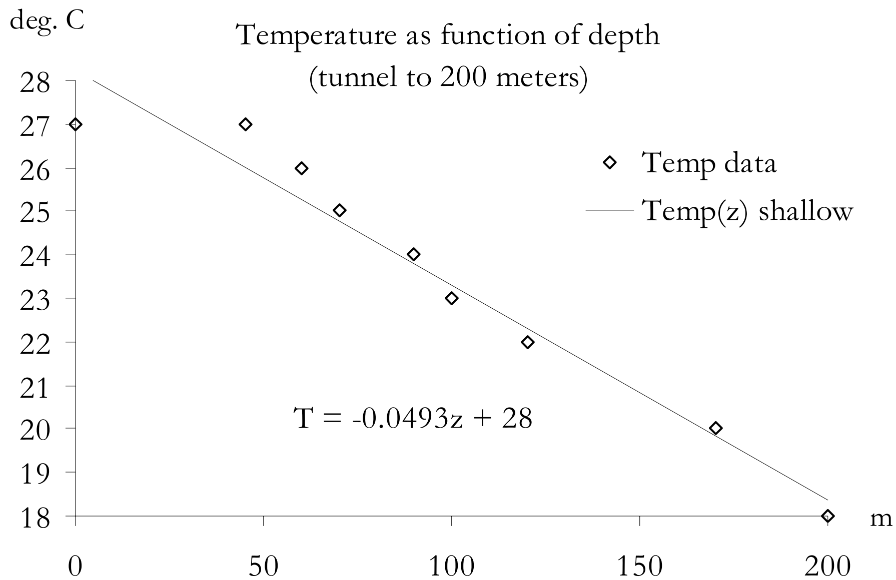


Figure 30 Temperature as function of depth from surface to 200 meters

Additionally, a static head function was developed for a range of intake depths. The static head occurs due to differences in the mean densities between waters internal and external to the CWP. The water level within the CWP would come to rest below sea level upon allowing a cessation in flow. The density within the CWP is essentially that of the water at the intake depth. This static head reduces the applied head in a flowing condition, and is determined by the equation for hydrostatic equilibrium (equation 12).

$$\sum F_z(\rho_0) = \sum F_z(\bar{\rho}) \rightarrow \rho_0 gz = \bar{\rho} gz \qquad \textit{Equation 12}$$

where $$\bar{\rho} = \frac{\frac{1}{2}\int_0^z \rho^2(z)dz}{\int_0^z \rho(z)dz}$$

The sump water level depression ζ_ρ below sea level, is then expressed per equation 13 in absolute terms,

$$\zeta_\rho = \left| z\frac{\bar{\rho}}{\rho_0} - z \right| \qquad \textit{Equation 13}$$

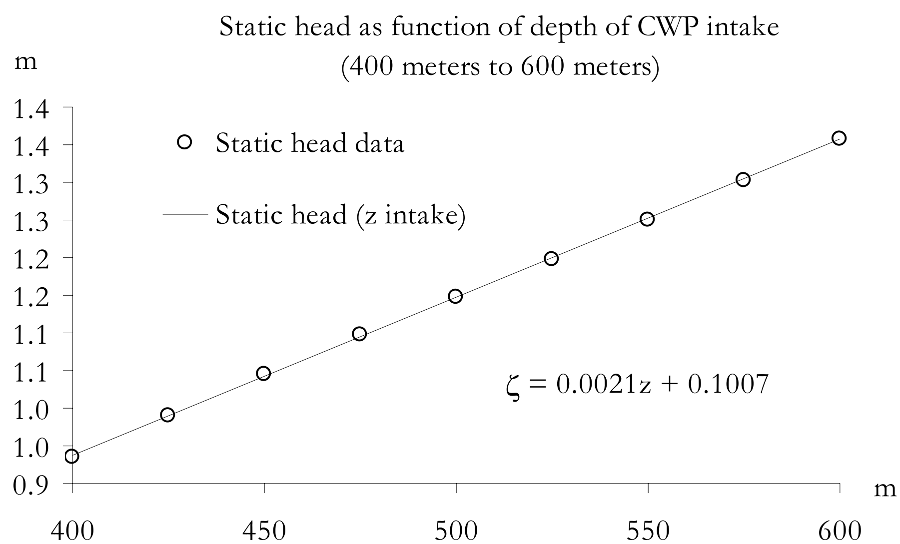


Figure 31 Static head as function of depth of CWP intake

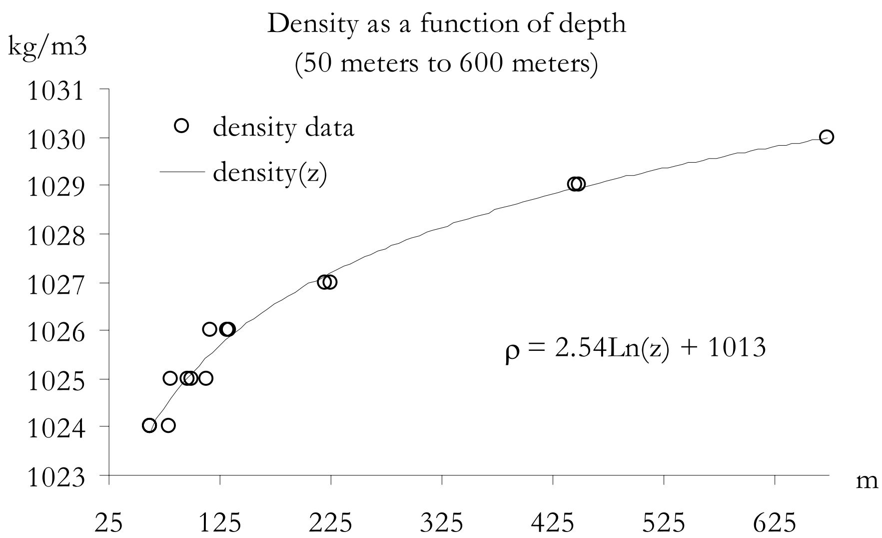


Figure 32 Density as a function of depth

From the graph shown in figure 31, a linear relationship in the range of depth of intake for static head is determined. The temporal variations of deep seawater temperatures at the Natural Energy Laboratory Hawai‘i Authority's (NELHA) intake have been report to vary ±1.71°C (±0.95°C) (Fast, 1988). The variation is largely due to internal waves (Fast, 1988). For the purpose of this effort, the spatial variations of these internal waves can be neglected. Otherwise, temperature variations of 0.32 to 0.36 °C (0.18 to 0.2 °C) for a several different Hawaiian locations have been reported at the typical SDC system intake depth (Fast, 1988). These variations would need to be measured for each specific site.

A2 Pipe Buckling Stress Due to Internal Flow

Typically, internal flow is established by providing a positive pressure at the source relative to the drain. The internal friction due to liquid-wall and liquid-liquid interaction produces a counter-pressure that is a function of flowrate. For a range of applied heads, there exists an equilibrium range of flowrates. In the case of a seawater supply system, the concept of a positive source is reversed, as a pump installed offshore at depth is presently considered an unnecessary challenge. Instead, flow is induced by either drawing a “vacuum” on the line (by pump’s impeller) or by lowering the outlet below sealevel (subsequently, the sump is pumped out). Either way, an inwardly directed radial stress on the pipe is created that must not exceed the buckling/collapse pressure rating (Avery, 1994).

HDPE is not a strong material in comparison to traditional pipe material (e.g., concrete or steel), leading to low buckling strengths (Watkins, 2000). The equation for allowable buckling pressure for an unstiffened pipe was determined from manufacturer’s data and is given in equation 14 (KWH, 2001):

$$p_{MAX} = E\left(\frac{\delta}{2R_o}\right)^3 T_{corr} \qquad \textit{Equation 14}$$

$E \equiv$ Modulus of Elasticity
$R_o \equiv$ outer radius
$\delta \equiv$ Pipe wall thickness
$p_{MAX} \equiv$ Maximum allowable buckling pressure
$T_{corr} \equiv$ Temperature correction factor (1.15 for pipe material at $10^o C$)

The modulus of elasticity is a function of temperature, which in CWP application strengthens the HDPE (Menard, 1999). The maximum allowable vacuum head is simply the maximum allowable external pressure divided by the density-gravity product as shown in equation 15,

$$\zeta_{MAX} = \frac{E}{\rho g}\left(\frac{\delta}{2R_o}\right)^3 T_{corr} \qquad \textit{Equation 15}$$

Equation 14 can be modified to express maximum allowable buckling pressure for pipes with stiffening rings, upon which failure is called Von Misen buckling (lobar buckling) as indicated in equation 16 (Allmendinger, 1990):

$$p = 2.42E\left(1-\nu^2\right)^{-0.75}\left(\frac{\delta}{D_o}\right)^{2.5}\left(\frac{L_{S-S}}{D_o} - 0.45\sqrt{\frac{\delta}{D_o}}\right)^{-1}[S]T_{corr} \qquad \textit{Equation 16}$$

L_{S-S} ≡ Pipe length between stiffener rings
S ≡ Safety factor (0.5)
T_{corr} ≡ Temperature correction factor (1.15 for pipe material at $10^{o}C$)
ν ≡ Poisson's ratio (0.30 - 0.42, depending on Manufacturer)
P_{VM} ≡ Von Misen buckling pressure

These equations can be substituted into the hydrostatic pressure equation to express total head as a function of the lobar buckling limit as shown in equation 17,

$$\zeta_{MAX} = \frac{2.42E}{\rho g}\left(1-\nu^2\right)^{-0.75}\left(\frac{\delta}{D_o}\right)^{2.5}\left(\frac{L_{S-S}}{D_o} - 0.45\sqrt{\frac{\delta}{D_o}}\right)^{-1} \qquad \textit{Equation 17}$$

Two methods are commonly employed to calculate liquid flow rates in pipes. The more generalized method of flow rate evaluation is by use of the Moody diagram and the Colebrook and Darcy equations. These equations are more versatile as they allow for viscosity variation in the liquid under investigation. Civil engineering applications use the Hazen-Williams equation, since water is the principal liquid being studied. The Hazen-Williams equation is simpler to use than the Colebrook-Darcy method, which requires iterative computer methods to solve.

This study uses the Hazen-Williams equation, as it is sufficiently accurate and more efficient. Moreover, use of this equation conforms to HDPE pipe manufacturer's literature, which omits the other method. The Hazen-Williams coefficient C must be determined empirically, and is supplied by the manufacturer (Liou, 1998). Equation 18 is the standard published Hazen-Williams equation in S.I (Liou, 1998):

$$U = 0.849 C R_h^{0.63} \left(\frac{\zeta}{L}\right)^{0.54} \qquad \textit{Equation 18}$$

$C \equiv$ Hazen Williams Coefficient (HPDE = 150, cast iron = 120 - 145)
$L \equiv$ length of pipe
$R_h = \dfrac{2\pi R}{\pi R^2} = \dfrac{R}{2} \equiv$ hydraulic radius
$U \equiv$ flow velocity
$\zeta \equiv$ total head

Substituting for hydraulic radius in a circular pipe with inner radius, the volumetric flow rate is expressed as shown in equation 19:

$$Q = UA = 0.5486 \pi C R^{2.63} \left(\frac{\zeta}{L}\right)^{0.54} \qquad \textit{Equation 19}$$

$A \equiv$ Cross - sectional area of pipe
$Q \equiv$ Volumetric flow rate
$R \equiv$ inner radius

The graph shown in figure 33 provides maximum attainable flowrates as functions of length and hydraulic diameter at limiting heads and low temperature 59°F (15°C). The vacuum heads are limited by the pipe's collapse pressure considering 50 years of creep, or by sump depths of 33 feet (10 meters). The sump depth limit only affects unstiffened pipes with internal diameters less than 25 ½ inches 65 centimeters (0.65 meters).

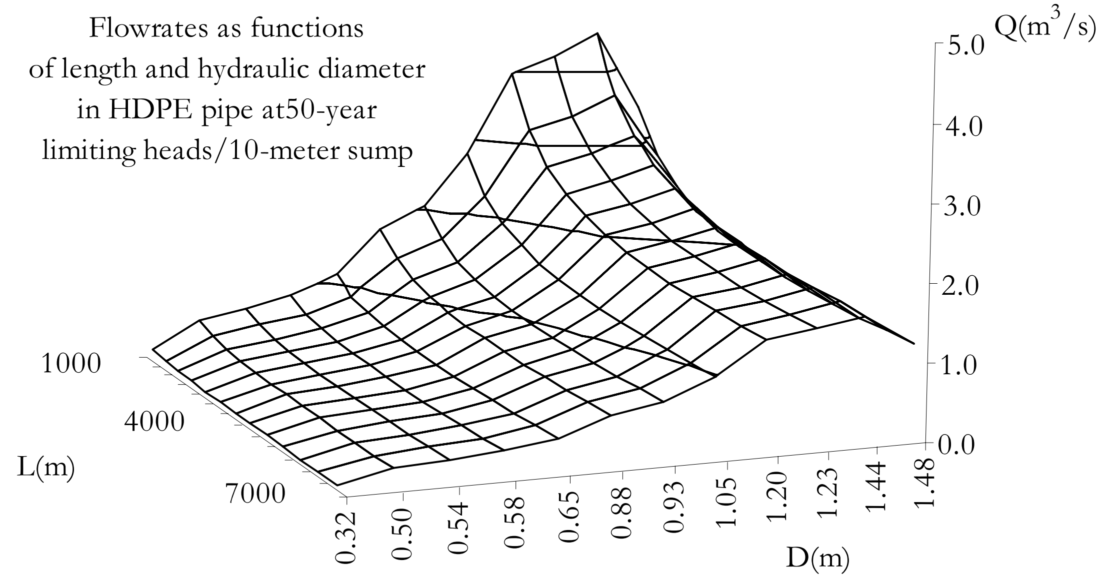


Figure 33 Flowrates as functions of length and diameter in HDPE pipe

When computing the flow rates for the CWP, it is important to recognize the static density head. As the CWP is filled with cold water, it statically comes to rest below sealevel, as its column is denser than the external equivalent column. The static head depends on the pipe's radius, flow rate, and depth of intake. Radius and flowrate affect heating of the liquid within the pipe, and depth of intake determines the mean density of the water column within the CWP.

The isentropic power required to generate the flows is computed from the rate of change of potential energy, where the change in potential energy is given by the sum of heads to lift the water to sealevel and overcome internal friction, equation 20 expresses the pumping power (Fox, 1998).

$$P_S = 0.5486 \pi C R^{2.63} \left(\frac{\zeta_f}{L} \right)^{0.54} \rho g \left(\zeta_f + \zeta_\rho \right) \qquad \textit{Equation 20}$$

The following derivation shows the extreme inverse relationship between pumping power and radius.

$$Q_i = Q_j \rightarrow 0.5486\pi C R_i^{2.63}\left(\frac{\zeta_i}{L}\right)^{0.54} = 0.5486\pi C R_j^{2.63}\left(\frac{\zeta_j}{L}\right)^{0.54} \rightarrow$$

$$R_i^{2.63}\left(\frac{\zeta_i}{L}\right)^{0.54} = R_j^{2.63}\left(\frac{\zeta_j}{L}\right)^{0.54} \rightarrow R_i^{2.63}\zeta_i^{0.54} = R_j^{2.63}\zeta_j^{0.54}$$

$$\frac{\zeta_i}{\zeta_j} = \left(\frac{R_j}{R_i}\right)^{4.87}$$ *Equation 21*

Equation 21 shows that pumping power increases at nearly the fifth power of ratio of radii. Despite this adverse relationship, it will be shown that reducing the pipe's diameter reduces the levelized cost. The thermal advantage of smaller diameter pipe for constant wall thickness will be demonstrated shortly. The economic advantage will be demonstrated in the last part of this section.

HDPE pipe exhibits hydrophobia, meaning it repels water (KWH, 2001). One pipe manufacturer pragmatically claims that marine fouling of the flow surfaces is unlikely, and if present during stagnant periods, would easily flush at higher flow rates. It has also been observed at NELHA, that the cold-water side of the heat exchanger was not fouled due to low biological activity extending back to the source (Fast, 1988).

A3 External Heating of Pipe Flow

Fourier's heat diffusion law is expressed in cylindrical coordinates in equation 22.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \phi}\left(k\frac{\partial T}{\partial \phi}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + \dot{h} = \rho c\frac{\partial T}{\partial t}$$ *Equation 22*

CWP heat diffusion is symmetrical along z and ϕ and no internal heat generation

$$\frac{\partial T}{\partial z} = \frac{\partial T}{\partial \phi} = \dot{h} = 0 \qquad \textit{Equation 23}$$

One dimensional heat diffusion resulting in internal temperature rise

$$\frac{1}{r}\frac{d}{dr}\left(kr\frac{dT}{dr}\right) = \rho c\frac{dT}{dt} \qquad \textit{Equation 24}$$

Once integrated yields the temperature gradient.

$$\int d\left(kr\frac{dT}{dr}\right) = \rho c\frac{dT}{dt}\int rdr$$

$$kr\frac{dT}{dr} = r^2\frac{\rho c dT}{2dt} + a$$

$$\frac{dT}{dr} = r\frac{\rho c dT}{2kdt} + \frac{a}{kr}$$

Integrated again yields the temperature at the interface

$$\int dT = \frac{\rho c dT}{2kdt}\int rdr + \frac{a}{k}\int\frac{dr}{r}$$

$$T = r^2\frac{\rho c dT}{4kdt} + \frac{a}{k}\ln r + b$$

Applying the boundary conditions and arranging the difference in temperature allows for an expression of a first order linear differential equation with respect to time.

$$\left(r_2^2 - r_1^2\right)\frac{\rho c dT}{4kdt} + T_1 = T_2 - T_1 - \frac{a}{k}\ln\frac{r_2}{r_1}$$

$$\alpha^{-1} = \left(r_2^2 - r_1^2\right)\frac{\rho c}{4k}$$

$$\frac{dT}{dt} + \alpha T = \alpha T_\infty - \alpha\frac{a}{k}\ln\frac{r_2}{r_1}$$

The first order DE is solved with a constant external temperature to determine the unknown constant by the initial condition

$$\frac{dT}{dt} + \alpha T = \alpha T_\infty - \alpha \frac{a}{k} \ln \frac{r_2}{r_1}$$

$$e^{\alpha t} \frac{dT}{dt} + \alpha e^{\alpha t} T(t) = \alpha e^{\alpha t} T_\infty + \frac{\alpha a}{k} e^{\alpha t} \ln \frac{r_2}{r_1}$$

$$\frac{de^{\alpha t} T}{dt} = \alpha e^{\alpha t} T_\infty + \frac{\alpha a}{k} e^{\alpha t} \ln \frac{r_2}{r_1}$$

$$T = T_\infty \left(1 - e^{-\alpha t}\right) + \frac{a}{k} \ln \frac{r_2}{r_1} \left(1 - e^{-\alpha t}\right) + e^{-\alpha t} T_0$$ *Equation 25*

$$t \to \infty \qquad T \to T_\infty \;\therefore a = 0$$

Once the value of the constant of integration is known for the constant external temperature case, the DE is re-evaluated for a time-varying external temperature.

$$\frac{dT}{dt} + \alpha T(t) = \alpha T_\infty(t)$$

$$e^{\alpha t} \frac{dT}{dt} + \alpha e^{\alpha t} T(t) = \alpha e^{\alpha t} T_\infty(t)$$

The external depth varying temperature function is transformed to a time varying function, where the depth variable has an empirical coefficient that yields a dimensionless product.

$$T_\infty(t) = 25e^{-0.0021z} \qquad z = \beta L = \frac{z}{L} Ut \qquad T_\infty(t) = 25e^{-\frac{0.0021zUt}{L}}$$

$$e^{\alpha t} T(t)\Big|_0^\tau = \int \alpha e^{\alpha t} 25e^{-\frac{0.0021zUt}{L}} dt = 25\alpha \int e^{\left(\alpha - \frac{0.0021zU}{L}\right)t} dt$$

$$e^{\alpha t}T(t)\Big|_0^{\tau} = \frac{25\alpha}{\left(\alpha - \frac{0.0021zU}{L}\right)} e^{\left(\alpha - \frac{0.0021zU}{L}\right)t}\Bigg|_0^{\tau}$$

$$e^{\alpha t}T(t)\Big|_0^{\tau} = \frac{25\alpha}{\left(\alpha - \frac{0.0021zU}{L}\right)} \left(e^{\left(\alpha - \frac{0.0021zU}{L}\right)t} - 1 \right)$$

$$T(t) = \frac{25\alpha e^{-\alpha t}}{\left(\alpha - \frac{0.0021zU}{L}\right)} \left(e^{\left(\alpha - \frac{0.0021zU}{L}\right)t} - 1 \right) + e^{-\alpha t}T_0 \qquad \textit{Equation 26}$$

The time-valued function can be transformed into a residence-valued function based on the length-velocity ratio.

A4 Offshore Pipe Protection Calculations

In considering pipe protection, the following methodology is presented. First, a determination of breaker depth for design wave is made using equation 27. The beach slope is assumed flat for the most limiting condition/greatest depth (Dean, 1991).

$$z_b = \frac{1}{k^{0.8} g^{0.2}} \left(\frac{H_0^2 \tau g \cos\theta_0}{4\pi} \right)^{0.4} \qquad \textit{Equation 27}$$

where $k \to 0.78 \text{ as beach slope} \to 0$ yielding the deepest breaker depth of 49 feet (15 meters) for the design wave of 39 feet (12 meters) and 14 seconds. The minimum length of the micro-tunnel is determined by this depth.

This implies that the anchoring weight is approximately half of the water displacement for the fully submerged and air-filled pipe (the weight of the CWP can be neglected in this model). Equation 28 is used for the anchoring weight.

$$F_W = \frac{\pi D^2 g\rho}{8} \qquad \textit{Equation 28}$$

The water particle velocities and accelerations must be determined at depth and imposed on the pipe through Morison's equation. The velocity potentials are determined by the governing equation for progressive waves (equation 29) that rest on conservation of periodicity,

$$\phi = -\frac{H_0 g\tau \cosh\frac{2\pi}{L}(z_b - z)}{4\pi \cosh\frac{2\pi}{L} z_b}\sin\left(\frac{2\pi x}{L} - \frac{2\pi t}{\tau}\right) \qquad \textit{Equation 29}$$

The wavelength L can be solved for intermediate depths, $0.05 < \frac{z_b}{L} < 0.5$, by the approximating equation 30 (Dean, 1991),

$$L = \frac{g\tau^2}{2\pi}\sqrt{\tanh\left(\frac{4\pi^2 z_b}{g\tau^2}\right)} = 302\ \text{feet}\ \ (92m) \qquad \textit{Equation 30}$$

The partial derivatives of equation 19 in horizontal and vertical directions solve the respective particle velocities, while taking the partial time derivatives of the particle velocities yield the respective accelerations. Equation 29 is considered at the maximum potential just deeper than the breaker depth, which are the horizontal components near the seafloor (Dean, 1991).

$$u = 2.2\, m/s \qquad \frac{\partial \mathrm{u}}{\partial \mathrm{t}} = 1.0\, m/s^2$$

$$w = 0.15\, m/s \qquad \frac{\partial \mathrm{u}}{\partial \mathrm{t}} < 0.067\, m/s^2$$

Two limiting conditions are drag and lift forces. The total drag force per unit length on a circular pipe is expressed by Morison's equation (equation 31) for the maximum force at a 45° angle of incidence (Dean, 1991).

$$\frac{F}{L}(D = 1m) \cong \left(\frac{\rho D \left| \frac{\partial \phi}{\partial x} \right| \frac{\partial \phi}{\partial x}}{2} C_D + \frac{\partial}{\partial t}\left(\frac{\partial \phi}{\partial x} \right) \frac{\rho \pi D^2}{2} \right) 0.707 \qquad \textit{Equation 31}$$

The maximum lift force on a pipe for a pipe resting on the seafloor at 45° incidence is given by equation 32 when the water particle excursions are greater than the CWP's diameter (Dean, 1991).

$$F_L \cong 3.2 \frac{\rho D \left(\frac{\partial \phi}{\partial x} \right)^2}{2} \qquad \textit{Equation 32}$$

Assuming the CWP is designed to rest a pipe diameter above seafloor, then the goal is to find the depth at design wave condition where

$$F_W > F_L \text{ or } F_D$$

and the coefficient of static friction is taken to be 0.6 (OH, 2000).

A5 Distribution Pipe Optimization Calculations

This section describes an alternate, but equally effective way of computing distribution system dimensions (pipe radii). The simplest distribution system consists of one node with a finite number of branches. It is described by the continuity equation (33) and can be expanded using the Hazen-Williams equation as shown in equation 34:

$$Q_0 = \sum_{i=1}^{N} Q_i = Q_1 + Q_2 + \ldots + Q_N \qquad \textit{Equation 33}$$

$$0.5486\pi C R_0^{2.63} \frac{\left(\zeta_p - \zeta_n\right)}{L_0} = 0.5486\pi C \sum_{i=1}^{N} R_i^{2.63} \frac{\left(\zeta_n - \zeta_i\right)}{L_i} = Q_T \qquad \textit{Equation 34}$$

Either side of equations 33 and 34 is known as the total demand. Given that the entire system is made of circular pipe of the same material, the equation further reduces as shown in equation 35,

$$R_0^{2.63} \frac{\left(\zeta_p - \zeta_n\right)_0}{L_0} = \sum_{i=1}^{N} R_i^{2.63} \frac{\left(\zeta_n - \zeta_i\right)}{L_i} \qquad \textit{Equation 35}$$

In the distribution system model, the lengths, flowrates, and backpressures at the loads are always known from the district characteristics. It remains to solve the radii and pumping pressures for each branch. The economics of the system depend on these parameters, where the radii determine capitalization (construction and pump size) and pumping pressures, which in turn determine operational costs.

Furthermore, both parameters affect the heat gain of the chilled water in the loop. Ideally, equation 35 is reduced to one unknown, either pumping pressure or main pipe radius. Thus, varying one of the variables provides full economic knowledge of the system. This is accomplished by rationalizing a relationship between the main radius and the load branches radii that is proportional to the respective flowrates. A function of dynamic similitude is chosen (equation 36), where velocity can be substituted for the known required flowrate. Additionally, the order of the function can be adjusted, as exact dynamic similitude may not determine an economic optimum (equation 37).

$$\mathrm{Re} \equiv \frac{UD\rho}{\mu} \Rightarrow [RU]_0 = [RU]_i \rightarrow \left[\frac{Q}{R}\right]_0 = \left[\frac{Q}{R}\right]_i \qquad \textit{Equation 36}$$

$$R_i = R_0 \left(\frac{Q_i}{Q_0}\right)^n \qquad \textit{Equation 37}$$

A series of nodes (fig. 34) is solved by initially guessing a main pumping pressure and radius, and solving the leading node pressure (equation 38),

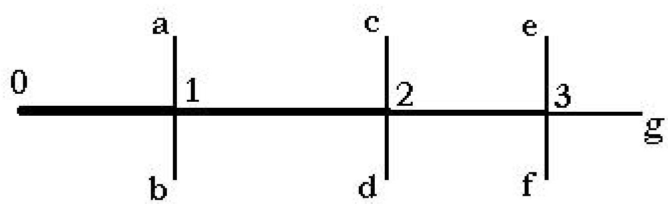


Figure 34 Simple distribution pipe network

$$\zeta_n = \zeta_P - L\left(\frac{Q_0}{0.5486\pi C R_0^{2.63}}\right)^{1.\overline{851}} \qquad \textit{Equation 38}$$

This node pressure is substituted into the individual expressions for branch radii (equation 39). The subsequent node pressure is solved using the equation 38, while letting the previously solved node pressure substitute as the pumping pressure, and applying the dynamic similitude expression to solve the radius of the interconnecting branch.

$$R_i \equiv R(\zeta_n, \zeta_i) = \left(\frac{Q_i}{0.5486\pi C} \left(\frac{L_i}{\zeta_n - \zeta_i} \right)^{0.54} \right)^{0.3802}$$

Equation 39

Again, the individual branch radii are expressed by equation 39. Upon completing construction of the entire system, the main radius and pressure only need to be varied to ensure real solutions throughout the network.

In the model, the supply lines and return lines are symmetric. Thus, the pumping pressure required to complete the entire closed circuit is twice the main pressure in equation 30 (algebraically rearranged) plus the pressure drop across the supply heat exchanger (equation 40).

$$\zeta_{FW} = 2\left(L\left(\frac{Q_0}{0.5486\pi C R_0^{2.63}} \right)^{1.\overline{851}} + \zeta_n \right) + \zeta_{HX}$$

Equation 40

It is desirable to use a relationship between the main radius and the pumping pressure, minimizing the solution time geometrically. The pumping pressure can be adjusted from a previous pressure-radius combination by use of equation 37 (over a limited range).

A *solver* program varies R_0 to determine the lowest levelized cost. The solution does not always converge requiring a new initial guess. Upon optimizing with the dynamic similitude order set at unity, the order of the function described in equation 37 may be varied to seek further minimizations in the levelized cost. Essentially, the distribution system is optimized using a multi-variate non-linear root-finding algorithm such as the Newton-Raphson method (Gerald, 1994). Several attempts are usually required to due divergence of solution.

A6 Heat Exchanger

There are many types of heat exchangers, and a specific class of heat exchangers, called recuperators, performs the essential function of maintaining separation between the physical and/or chemical properties of the working fluids, while allowing them to be in state of accelerated thermal communication (Moran, 1992). This is first accomplished by bringing the fluids separately to each side of a material with high thermal conductivity properties. Secondly, thermal communication is accelerated by confining the interaction to a turbulent space that is “capillary” in size with respect to the input. Inspection of any flow equation shows that creating turbulent flow in capillary-like channels requires significant force or pressure. Furthermore, heat transfer by conduction varies with the magnitude of the temperature gradient across the material and inversely with its thickness (Hewitt, 1994). Adequate transfer rates are maintained by minimizing the intervening material thickness as the temperature gradient is minimized.

Another design consideration in heat exchangers is the flow patterns the two working fluids exhibit with respect to each other (Hewitt, 1994). Depending on application, the flow patterns may be co-current, counter or cross with respect to temperature relationship (cross-flow is not considered). In a co-current flow, two streams meet with extreme temperature difference and exit upon optimum minimization. In counter-flow, the temperature difference is maintained constant by introducing one flow to the exit condition of the other. Given the low temperature gradient in SDC system applications, counter-flow is chosen. In co-current flow, the low temperature gradient would force prohibitively long residence times or unit sizes to achieve efficiencies equal to counter-current flow (Hewitt, 1994). Heat exchange with seawater presents a challenge in minimizing corrosion potential of the heat transfer surfaces (Krock, 1997). All of these factors place severe restrictions on the type of material that can be used in SDC system applications.

A modular design with elastic gaskets separating the heat exchange plates, allows for routine maintenance shutdowns of sections while the entire unit remains operational. The best choice of heat exchanger is a modular titanium plate heat exchanger with gasket joints in a counter-flow configuration (MOE, 1994). The key parameters then become the head loss and the logarithmic mean temperature difference at the cold-end of the heat exchanger. The head loss is set at 46 feet (14 meters), and the LMTD is 0.9°F (0.5°C) (Grandelli).

A7 Average District Cooling System Chilled Water Supply Temperature

Each facility within the district has its own independent chilled water temperature range. Only by coincidence would all facilities have the same chilled water supply temperature range. As was outlined earlier, a lower chilled water supply temperature necessarily means a longer CWP. However, the existence of a few facilities within the district with significantly lower chilled water temperature requirements should not prompt extending CWP to meet their specific demand; instead, further cooling of the district chilled water supply at their facilities could be more economical.

Given an alternative to meeting the temperature needs of a few facilities, the CWP length is determined by the *significant district-averaged chilled water supply temperature*. The district average would be determined by a demand-weighted average per facility. Furthermore, the cost of individual heat pumping stations (capitalization and operation) would be balanced against the cost of lengthening the CWP (capitalization and operation). The heat-pumping concept can be extended to the entire supply temperature; this alternative effectively raises the district-averaged chilled water supply temperature with respect to CWP length. This option is not explored here, as this tends towards a conventional district cooling concept.

Another means of artificially raising the district-averaged chilled water supply temperature is by a conventional refrigerant-driven TES system, implying further cooling of stored nighttime flow. This presents a very favorable economic solution, when the refrigerated TES system is separately metered qualifying it for reduced off-peak rates. However, this method does not increase energy efficiency or reduce carbon dioxide emissions (Wang, 2000).

From a sampling of facilities, the average chiller out temperature was 45.4ºF (7.4ºC) with a standard deviation of 1.4ºF (0.8ºC). It appears that a facility could operate anywhere between 44ºF (6.7ºC) to 47ºF (8.3ºC). Higher chilled water temperatures require increased chilled water flow rates. For SDC utilities challenged to reach optimal district requirements, it may be necessary to incorporate forced cooling as described by conventional TES methods.

A8 Thermal Energy Storage Systems

Refrigerant-driven TES systems produce and store very cold fluids, or even solid ice, during off-peak electricity generation hours, and release this heat sink during peak rate hours to reduce the cost of air-conditioning (Wang, 2000). A refrigerant-driven TES system does not necessarily save electricity, but they are cost-effective because of off-peak rates.

The CWP's flow capacity is not fully utilized over a 24-hour period; its nighttime demand is significantly reduced. Full utilization over the 24-hour period could be realized if the night excess capacity is stored and released during the day increasing the district's size or reducing the CWP's diameter. The economic viability of a seawater TES system is achieved when its levelized total cost per ton-hr is less than the CWP's. A logic flow diagram of SDC system with a TES is illustrated in figure 35. The following definitions are used in the formula for determining economic viability of a TES.

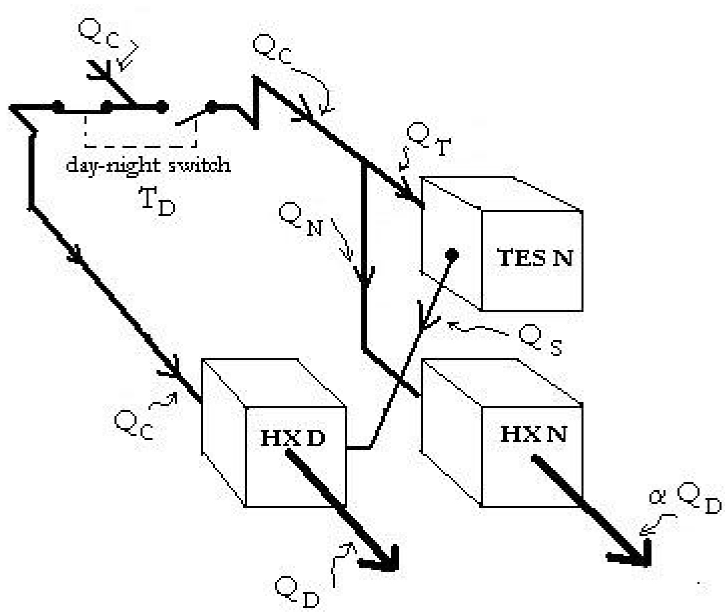


Figure 35 Logic diagram for TES flow balance

$Q_C \equiv$ CWP flow capacity
$Q_S \equiv$ Flow from storage to day operation
$Q_T \equiv$ Flow from night operation to storage
$Q_D \equiv$ Day flow
$Q_N \equiv$ Night flow
$T_D \equiv$ period of day operation
$\alpha \equiv$ night to day ratio

The expansion capacity by thermal storage is determined by knowledge of the day-night ratio and the period of day operation. Equations 41, 42 and 43 describe these relationships, which are readily derived by inspection of figure 34.

$$Q_D = Q_C \frac{\left(1+\frac{(24-T_D)}{T_D}\right)}{\left(1+\alpha\frac{(24-T_D)}{T_D}\right)}$$ *Equation 41*

$$Q_S = (Q_C - Q_N)\frac{(24-T_D)}{T_D}$$ *Equation 42*

$$\frac{(Q_C - Q_N)(24-T_D)}{C_{SWTES} T_D} < \frac{Q_C}{C_{CWP}}$$ *Equation 43*

The following is list of institutions using or considering large Chiiled water storage systems, sizes and locations are listed as well (Pierce, 2002):

- University of Iowa - 7,000 ton-hours buried beneath a football practice field
- Georgetown University - 2 million-gallon tank underneath a parking garage
- Arizona State University - 54,000 ton-hours located beneath athletic fields
- Youngstown State University - 1 million-gallon tank under parking garage
- New Mexico State University - 3 million-gallon tank below parking lot on campus
- Yale University - 3 million-gallon tank buried under a parking lot, tennis court and green space
- Fort Huachuca, Arizona - 0.5 million-gallon stratified chilled water underground system
- U.S. Naval Academy - system currently under design
- University of Cincinnati - 3 million-gallon system currently under design

Appendix B Data

B1 Cold-water Pipe Costs

Table 41 Cold-water pipe costing data (source: MOE)

length (ft)	Diameter (in.)	Perform. bonds & liability ins.	CWPRoute inspection	CWPipe materials	CWP Mobilization
17000	**28**	$83,900	$200,000	$1,308,800	$134,000
24000	**30**	$109,400	$200,000	$2,098,000	$202,400
38000	**42**	$191,500	$200,000	$6,170,500	$509,700
16200	**48**	$169,200	$200,000	$3,520,900	$284,300
20800	**55**	$262,900	$200,000	$5,624,300	$429,900
19700	**63**	$299,500	$200,000	$6,880,700	$505,000
22000	**63**	$222,600	$200,000	$7,682,700	$562,100
21300	**63**	$218,500	$200,000	$7,428,500	$544,000
length (ft)	**Diameter (in.)**	**SWP sump Construction & materials**	**CWPPipe fabrication**	**CWPipe deployment**	**CWP Contractors markup**
17000	**28**	$389,200	$827,000	$343,700	$764,800
24000	**30**	$392,300	$1,252,600	$497,000	$950,300
38000	**42**	$496,800	$2,770,900	$1,053,200	$1,256,000
16200	**48**	$730,100	$1,397,200	$568,600	$1,417,000
20800	**55**	$932,400	$1,982,900	$791,400	$2,194,000
19700	**63**	$1,050,300	$2,149,100	$869,400	$2,407,700
22000	**63**	$1,064,600	$2,399,600	$959,600	$1,320,200
21300	**63**	$1,159,900	$2,320,200	$931,000	$1,314,800
length (ft)	**Diameter (in.)**	**CWP Project management**	**CWP Engineering design**	**CWP Construction management & Inspect.**	**CWP Local Engineering Supervision & Coord.**
17000	**28**	$131,500	$432,800	$161,200	$253,925
24000	**30**	$159,400	$535,000	$198,400	$312,480
38000	**42**	$244,400	$846,900	$311,800	$491,085
16200	**48**	$225,200	$776,500	$286,200	$450,765
20800	**55**	$329,100	$1,157,300	$424,700	$668,885
19700	**63**	$368,200	$1,300,600	$476,800	$750,960
22000	**63**	$275,900	$962,100	$353,700	$557,095
21300	**63**	$271,800	$947,100	$348,300	$548,520

The data in table 40 are used to generate the graph in figure 36.

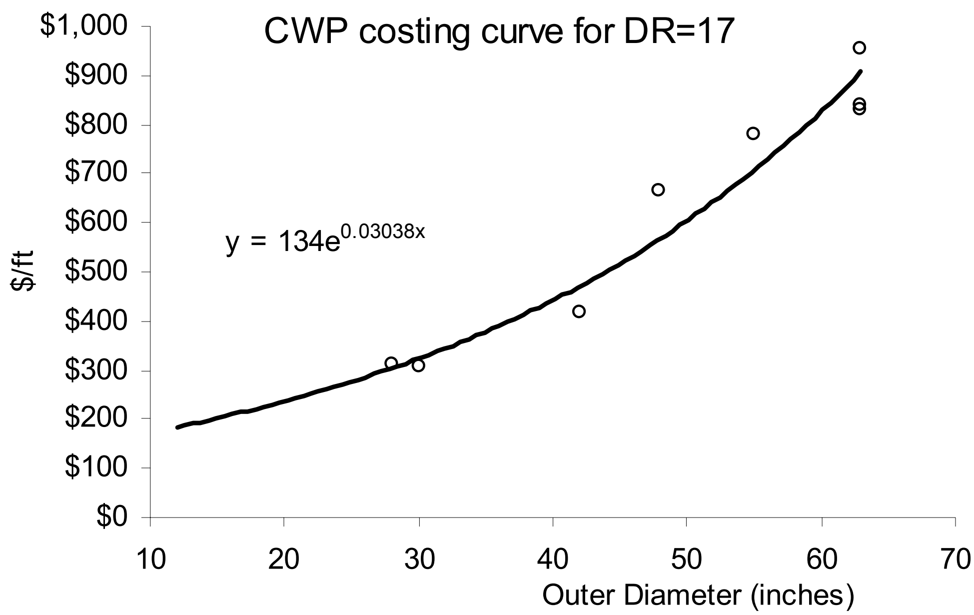


Figure 36 Cold-water pipe costing graph

B2 Heat Exchanger costs

Table 42 Heat Exchanger costing data (source: MOE)

A/C load (tons)	Building structure	Heat exchangers	Installation	Engineering design
897	$40,000	$399,000	$40,000	$40,000
928	$40,000	$415,000	$42,000	$40,000
1944	$51,000	$862,000	$86,000	$52,000
4200	$76,000	$1,871,000	$187,000	$77,000
5500	$91,000	$2,460,000	$246,000	$92,000
7250	$110,000	$3,222,000	$322,000	$111,000
7388	$112,000	$3,326,000	$333,000	$113,000
8310	$121,000	$3,687,000	$369,000	$122,000

The data in table 41 are used to generate the graph in figure 37.

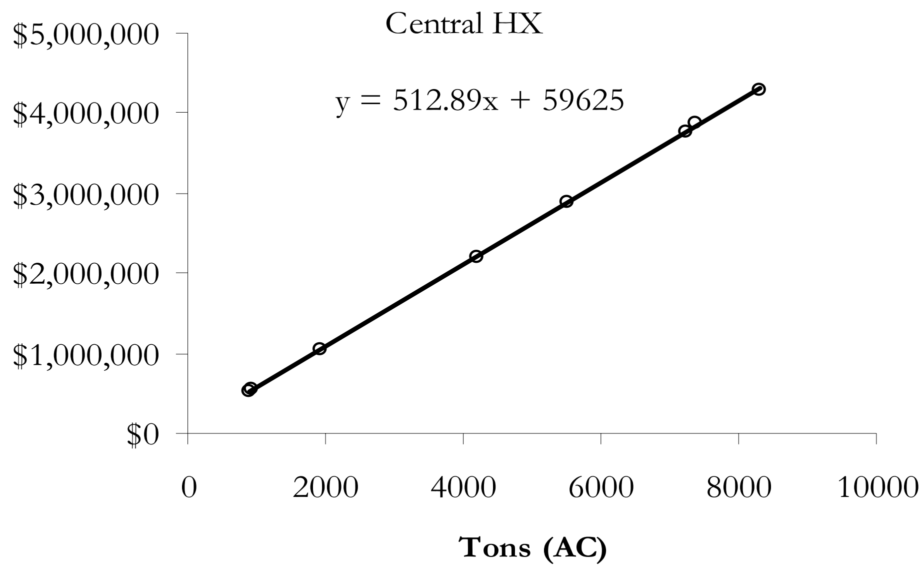


Figure 37 Heat exchanger costing graph

B3 Seawater and chilled Water Pumping Capital Costs

Table 43 Sea- and Chilled water pump costing data (source: MOE)

kW	Total SWP	kW	Total FWP
21	$429,200	18	$61,000
21	$433,600	37	$65,000
42	$579,900	36	$73,000
110	$904,700	123	$112,000
151	$1,179,900	183	$142,000
161	$1,343,900	146	$142,000
157	$1,363,800	299	$181,000
181	$1,496,500	167	$156,000

The data in table 42 are used to generate the graphs in figure 34.

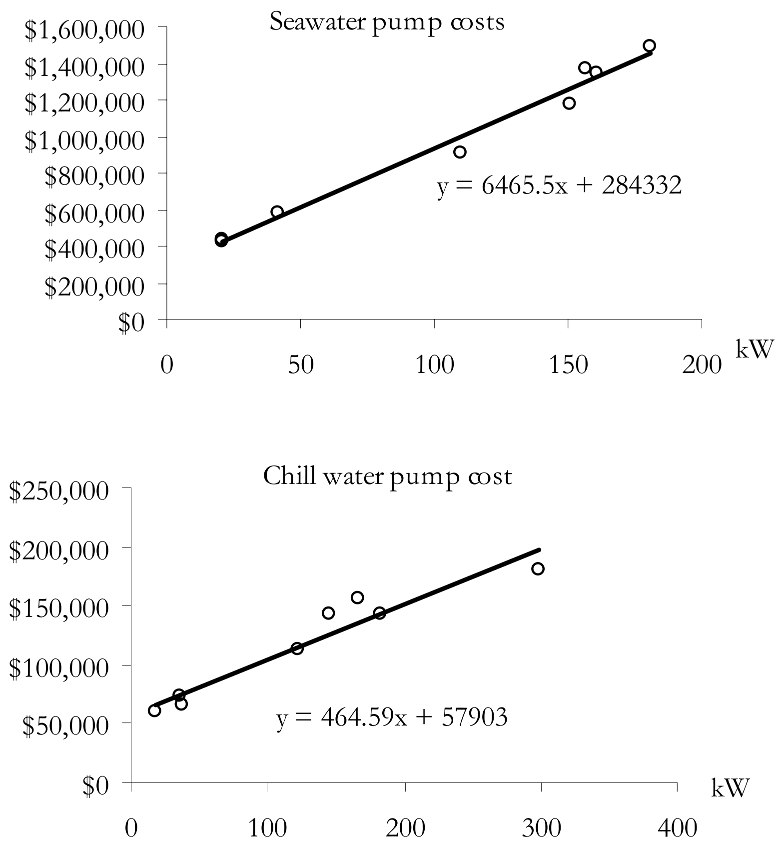


Figure 38 Sea- and chilled water pump costing graph

B4 District Cooling Loop Capital Costs

Table 44 Distribution loop costing data (source: HBWS)

Diameter (in.)	Urban	Diameter (in.)	sub/rural
10	$800	12	$170
16	$900	16	$225
24	$1,200	20	$235
42	$2,100	36	$1,250
42	$900	42	$625

The data in table 43 are used to generate the graph in figure 39.

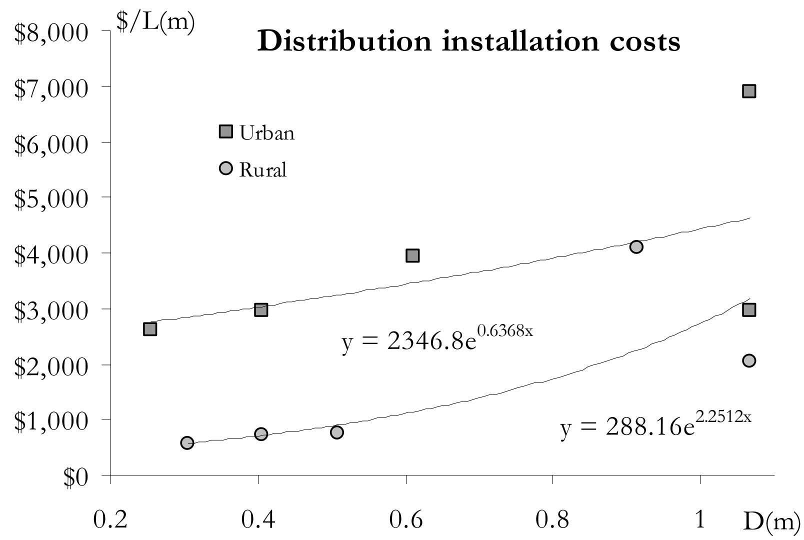


Figure 39 Distribution loop costing graph

B5 Conventional Cooling Data

Table 45 Chiller age and replacement costs (source: Outrigger Hotels, DAGS)

	Chiller age	tons	replacement cost ($k/ton)	
	8	450	2.8	
	10	500	0.9	
	9	175	1.45	
	4	200	1.8	
	24	**ave**	**1.7**	
	25			
	30			
	9			
	15			
	23			
	35			35-year age not in statistical values
ave	**15.7**			
std	**9**			
upper	**25**			

Appendix C Makai Ocean Engineering Detailed Program Output

C1 West Waikiki, Honolulu Waterfront, Kakaako

TECHNICAL INFORMATION: DISTRIBUTION SYSTEM	**Scenarios**	**West Waik**	**Hon Wfrnt**	**Kakaako**	
	AIR CONDITIONING LOAD	8310	8465	7250	Ton
	Length of main branch	4220	3710	5250	ft
(U<4 fps)	Pipe size (nom.)	48	48	48	in (max)
	Flow rate	19900	20271	17362	gpm
	LMTD in Heat Exchanger:	0.90	0.90	0.90	F
	Network Supply Temperature	46.3	46.5	46.5	F
	Network Return Temperature	56.7	56.9	56.9	F
CAPITAL COST	Carrier pipe (supply and return)	$637,000	$316,000	$1,146,000	$
	Insulation of carrier pipe	$155,000	$88,000	$279,000	$
	Pipe installation and testing	$10,121,000	$3,477,000	$3,148,000	$
	Valve stations & piping	$60,000	$60,000	$60,000	$
	Chilled water pumps	$156,000	$153,000	$142,000	$
	Design & management	$569,000	$489,000	$252,000	$
	TOTAL CAPITAL	$11,698,000	$4,583,000	$5,027,000	
REPLACEMENT ITEMS	Chilled water pumps	$101,000	$99,000	$92,000	
	Estimated lifetime	10	10	10	years
OPERATION AND MAINTENANCE COST					
Non-energy costs					
	Maintenance and service matls.	$114,000	$98,000	$51,000	$/year
	Personnel	$120,000	$120,000	$60,000	$/year
	Total	$234,000	$218,000	$111,000	/year
Energy operating cost					
	Mean power (- Building losses)	168	151	146	kW
	Cost of electricity	0.112	0.112	0.112	$/kWhr
	Total	$165,100	$148,100	$149,333	/year
	TOTAL O&M	$399,100	$366,100	$260,333	/year

TECHNICAL INFORMATION: CENTRAL COOLING STATION	Scenarios	West Waik	Hon Wfrnt	Kakaako	
	AIR CONDITIONING LOAD	8310	8465	7250	Tons
SEAWATER	Flow rate	20275	20653	17689	gpm
	Supply temperature	45.38	45.59	45.58	F
	Effluent temperature, peak hour	55.76	55.96	55.97	F
CHILLED WATER	Flow rate	19900	20271	17362	gpm
	Network supply temperature	46.28	46.49	46.48	F
	Return temperature, peak hour	56.66	56.86	56.87	F
	Head losses in H.E. and Chiller	46	46	46	ft
	Pump & motor efficiency	0.76	0.76	0.76	
SEAWATER-CHILLWATER HEAT EXCHANGERS	Heat transfer, peak hour	30330	30870	26510	kW
	Fraction of cooling station load	100%	100%	100%	
	Area of heat exchanger plates	165350	168310	144510	ft2
	Coefficient of heat transfer (U)	204	204	204	W/ft2F
In:	Chilled water temp.	56.66	56.86	56.87	F
Out:		46.28	46.49	46.48	F
In:	Seawater temp.	45.38	45.59	45.58	F
Out:		55.76	55.96	55.97	F
CAPITAL COST	Building structure	$121,000	$123,000	$110,000	
	Heat exchangers	$3,687,000	$3,753,000	$3,222,000	
	Installation	$369,000	$375,000	$322,000	
	Engineering design	$122,000	$124,000	$111,000	
	TOTAL CAPITAL	$4,299,000	$4,373,000	$3,764,000	U.S.$
REPLACEMENT ITEMS					
	Heat exchangers	$4,055,000	$4,128,000	$3,544,000	
	estimated lifetime	20	20	20	years
OPERATIONAL AND MAINTENANCE COST					
Non-energy cost					
	Maintenance heat exchanger	$92,000	$94,000	$81,000	$/year
	Personnel	$152,000	$60,000	$60,000	$/year
	TOTAL O&M	$152,000	$154,000	$141,000	/year

TECHNICAL SUMMARY: SEAWATER LAND CROSSING	Scenarios	West Waik	Hon Wfrnt	Kakaako	
	AIR CONDITIONING LOAD	8310	8465	7250	Tons
FLOWS					
	Seawater Flow	20275	20653	17689	gpm
	Land Crossing Distance, one way	98	449	131	ft
	Supply Pipe OD	63	63	63	in
	Return Pipe OD	63	63	63	in
	Supply head loss	0.0	0.1	0.0	ft
	Return head loss	0.0	0.1	0.0	ft
	Heat Exchanger Head Loss	45.9	45.9	45.9	ft
	Total Head Loss	46.0	46.2	46.0	ft
TEMPERATURES					
	Supply Shore Temp	45.40	45.60	45.60	F
	Supply Temp Rise	0.00	0.01	0.00	F
	Supply Temp at HX	45.40	45.60	45.60	F
	Return Temp at HX	55.80	56.00	56.00	F
	Return Temp Rise	0.00	0.01	0.00	F
	Return Shore Temp	55.80	56.00	56.00	F
COST: SEAWATER LAND CROSSING					
	Pipes	$ 51,000	$ 211,300	$ 61,700	$
	Install	$ 208,200	$ 1,078,500	$ 78,700	$
	Total Cross Land:	$ 259,200	$ 1,289,800	$ 140,400	$

TECHNICAL INFORMATION: SEAWATER SUPPLY SYSTEM	Scenarios	West Waik	Hon Wfrnt	Kakaako	
	AIR CONDITIONING LOAD	8310	8465	7250	Ton
INTAKE PIPE (Suction pipe)					
	Diameter (Outer)	63	63	63	in
	Length	21310	20450	19740	ft
	Depth at intake	1744	1709	1652	ft
	D.R. at shoreline	21	21	21	(OD/t)
	D.R. at intake	26	26	26	(OD/t)
EFFLUENT PIPE					
	Diameter (Outer)	63	63	63	in
	Length	0	12070	10930	ft
	Depth at outlet	330	330	330	ft
OPERATING CONDITIONS					
	Flow rate	20275	20653	17689	gpm
	Temperature at deep intake	44.71	44.94	44.85	F
	Thermal Ocean losses	0.67	0.65	0.72	F
	Thermal Land losses	0	0.01	0	F
	Supply temperature	45.38	45.58	45.58	F
	Effluent temperature	55.8	56	56	F
HEAD LOSSES AND PUMPING ENERGY					
	Suction pipe	8.4	8.4	6.7	ft
	Land Crossing	0.1	0.3	0.1	m
	Cooling station losses	26.2	26.2	26.2	ft
	Effluent pipe	0.0	3.5	2.4	ft
	Total head	34.7	38.4	35.4	ft
	Pump and Motor efficiency	0.75	0.75	0.75	
	Electric pumping power	182	204	161	kW

COST: SEAWATER SUPPLY	Scenarios	West Waik	Hon Wfrnt	Kakaako	
CAPITAL COST	AIR CONDITIONING LOAD	8310	8465	7250	Ton
Contractors cost					
	Perform.bonds & liability ins.	$218,500	$318,500	$299,500	
Cold water pipe (CWP)					
	Route inspection	$200,000	$200,000	$200,000	$
	Pipe materials	$7,428,500	$7,128,500	$6,880,700	$
	Mobilization	$544,000	$522,600	$505,000	$
	Pipe fabrication	$2,320,200	$2,226,500	$2,149,100	$
	Pipe deployment	$931,000	$897,300	$869,400	$
	Total capital cost	$11,423,700	$10,974,900	$10,604,200	
Effluent pipe (EP)		0%	59%	55%	of CWP
	Route inspection	$0	$118,100	$110,800	$
	Pipe materials	$1,100	$4,208,700	$3,810,900	$
	Mobilization	$100	$308,600	$279,700	$
	Pipe fabrication	$400	$1,314,500	$1,190,300	$
	Pipe deployment	$100	$529,800	$481,500	$
	Total	$1,700	$6,479,700	$5,873,200	
Pumping station	Pumps & motors	336,600	342,900	293,600	$
	Construction & materials	1,159,900	1,175,900	1,050,300	$
	Total	$1,496,500	$1,518,800	$1,343,900	
Contractors markup	Rate (20% less CWP)	$1,314,800	$2,598,100	$2,407,700	
	Project management	271,800	389,800	368,200	$
	Engineering design	947,100	1,379,800	1,300,600	$
	Constr.management & Inspect.	348,300	505,600	476,800	$
	Local Eng. Supervision & Coord.	548,520	796,320	750,960	$
Onshore SW Pipe Crossings	Separate Contract, 2 pipes	259,200	1,289,800	140,400	
TOTAL CAPITAL COST		$16,830,100	$26,251,300	$23,565,500	
REPLACEMENT ITEMS					
	Seawater pumps	$337,000	$343,000	$294,000	
	Estimated lifetime	10	10	10	years
OPERATING AND MAINTENANCE COST					
Non-energy costs	Inspection & maintenance	$44,000	$45,000	$42,000	$/year

	Personnel	$60,000	$60,000	$30,000	$/year
	Total	$104,000	$105,000	$72,000	/year
Energy operating cost	Mean pumping power	182	204	161	kW
	Cost of electricity	0.112	0.112	0.105	$/kW hr.
	Total	$179,000	$201,000	$157,867	/year
	TOTAL O&M	$283,000	$306,000	$229,867	/year

TOTAL COST: SDC	**Scenarios**	**West Waik**	**Hon Wfrnt**	**Kakaako**	
CAPITAL COST	AIR CONDITIONING LOAD	8310	8465	7250	Ton
	Seawater supply system	$16,830,000	$25,202,000	$23,566,000	$
	Centralized cooling station	$4,299,000	$4,373,000	$3,764,000	$
	Chilled water distribution system	$11,698,000	$4,583,000	$5,027,000	$
	Backup Power ($417/kW)	$146,000	$147,000	$128,000	$
	Contingency (20%)	$6,594,600	$8,157,600	$6,497,000	$
	TOTAL CAPITAL	$39,567,600	$41,166,000	$38,982,000	
Replacement costs	Seawater pumps (10 years)	$337,000	$342,000	$294,000	
	Chilled water pumps (10 years)	$101,000	$99,000	$92,000	
	Plate heat exchangers (20 years)	$4,055,000	$4,128,000	$3,544,000	
SDC - OPERATING AND MAINTENANCE COST					
Non-energy operating cost					
	Seawater supply system	$104,000	$105,000	$72,000	$/yr
	Cooling station	$152,000	$154,000	$141,000	$/yr
	Chilled water distribution system	$234,000	$218,000	$111,000	$/yr
	Back-up power sys ($61/kW/yr)	$21,000	$22,000	$19,000	$/yr
	Total	$511,000	$447,000	$343,000	
Energy operating cost					
	Seawater supply system (pumps)	$179,000	$201,000	$157,867	$/yr
	Chilled water pumping	$165,000	$148,000	$149,333	$/yr
	Total	$344,000	$349,000	$300,800	
Total operating cost	TOTAL O&M	$856,000	$792,000	$643,800	

CONVENTIONAL A/C - TOTAL COST	Scenarios	West Waik	Hon Wfrnt	Kakaako	
CAPITAL COST	AIR CONDITIONING LOAD	8310	8465	7250	Ton
	Number of buildings (parcels)	4	4	4	
	Installed A/C Ton:	8310	8465	7250	Ton
	% New Construction:	30%	30%	30%	
	Chillers:	$ 4,238,100	$ 4,317,150	$ 3,697,500	
	Backup Power ($417/kW):	$ 935,700	$ 953,100	$ 816,300	
	Total Conv Capital	$ 5,173,800	$ 5,270,250	$ 4,513,800	
REPLACEMENT ITEMS					
	Chillers (20 years):	$ 14,127,000	$ 14,390,500	$ 12,325,000	
	Backup Power (20 years):	$ 3,119,000	$ 3,529,910	$ 2,721,000	
Non-energy operating cost					
	Maintenance ($30/ton-rated)	$249,000	$254,000	$218,000	$/yr
	Back-up power sys ($61/kW/yr)	$507,000	$516,000	$442,000	$/yr
	Personnel ($40k/buildg./yr)	$160,000	$160,000	$160,000	$/yr
	Total	$916,000	$930,000	$820,000	
Energy operating cost					
	Chiller & Condsr (0.9kW/ton):	7479	7619	6525	kW
	Annual utilization ratio	62.0%	62.0%	62.0%	
	Mean power requirement	4637	4723	4046	kW
	Electricity cost	0.112	0.112	0.112	$/kWhr
	Total	$4,557,558	$4,642,566	$3,969,121	/year
	TOTAL O&M	$5,473,558	$5,572,566	$4,789,121	/year

ECONOMIC EVALUATION OF SDC		West Waik	Hon Wfrnt	Kakaako	
	AIR CONDITIONING LOAD	8310	8465	7250	Ton
CAPITAL COST	SDC	$39,567,600	$41,166,000	$38,982,000	$
	Conventional A/C	$5,173,800	$5,270,250	$4,513,800	$
	Capital cost difference (dCAP)	$34,393,800	$35,895,750	$34,468,200	
ANNUAL OPERATING COST	SDC	$856,000	$792,000	$643,800	$/year
	Conventional A/C	$5,473,558	$5,572,566	$4,789,121	$/year
	Annual O&M cost savings (dOM)	$4,617,558	$4,780,566	$4,145,321	/year
SIMPLE PAYBACK (ignoring replacement items)	SDC capital cost / annual savings	8.6	8.6	9.4	Years
	dCAP/dOM (Credit for chillers)	7.4	7.5	8.3	Years
ELECTRIC POWER SAVINGS	Conventional A/C	100%	100%	100%	
	Seawater pumping, constant flow	3.9%	3.1%	4.0%	
	Chilled water pumping, peak flow	3.6%	2.3%	3.6%	
	SDC power savings (avg.)	92.5%	94.6%	92.4%	
SDC	Mean output:	5,152	5,248	4,495	tons
	Cumulative PV of cooling over Book Life	$565	$567	$614	$/ton/yr
	Levelized cost of cooling over book life:	$1,067	$1,071	$1,159	$/ton/yr
CONVENTIONAL A/C	Mean output:	5,152	5,248	4,495	tons
	Cumulative PV of cooling over Book Life	$711	$711	$715	$/ton/yr
	Levelized cost of cooling over book life:	$1,342	$1,342	$1,345	$/ton/yr
LEVELIZED ANNUAL COST SAVINGS		$1,416,855	$1,420,557	$835,261	/year

C2 East Waikiki and UHM, Pearl Harbor NSY, Kaneohe MCAS

TECHNICAL INFORMATION: DISTRIBUTION SYSTEM	Scenarios	E.Waik&UHM	PHNSY	KMCBH	
	AIR CONDITIONING LOAD	7800	5500	4200	Ton
	Length of main branch	17280	10080	8360	ft
(U<4 fps)	Pipe size (nom.)	48	42	36	in (max)
	Flow rate	17980	14634	10058	gpm
	LMTD in Heat Exchanger:	0.90	0.90	0.90	F
	Network Supply Temperature	45.96	48.94	40.02	F
	Network Return Temperature	56.81	58.36	56.85	F
CAPITAL COST	Carrier pipe (supply and return)	$2,895,000	$1,297,000	$831,000	$
	Insulation of carrier pipe	$782,000	$374,000	$258,000	$
	Pipe installation and testing	$35,371,000	$6,049,000	$5,016,000	$
	Valve stations & piping	$60,000	$60,000	$60,000	$
	Chilled water pumps	$169,000	$142,000	$112,000	$
	Design & management	$1,975,000	$409,000	$328,000	$
	TOTAL CAPITAL	$41,252,000	$8,331,000	$6,605,000	
REPLACEMENT ITEMS	Chilled water pumps	$109,000	$92,000	$72,000	
	Estimated lifetime	10	10	10	years
OPERATION AND MAINTENANCE COST					
Non-energy costs					
	Maintenance and service matls.	$396,000	$82,000	$65,000	$/year
	Personnel	$120,000	$60,000	$60,000	$/year
	Total	$516,000	$142,000	$125,000	/year
Energy operating cost					
	Mean power (- Building losses)	245	183	123	kW
	Cost of electricity	0.112	0.112	0.112	$/kWhr
	Total	$241,200	$180,267	$120,853	/year
	TOTAL O&M	$757,200	$322,267	$245,853	/year

TECHNICAL INFORMATION: CENTRAL COOLING STATION	**Scenarios**	**E.Waik&U HM**	**PHNSY**	**KMCBH**	
	AIR CONDITIONING LOAD	7800	5500	4200	Tons
SEAWATER	Flow rate	18319	14910	10247	gpm
	Supply temperature	45.06	48.04	45.53	F
	Effluent temperature, peak hour	55.91	57.46	55.95	F
CHILLED WATER	Flow rate	17980	14634	10058	gpm
	Network supply temperature	45.96	48.94	46.43	F
	Return temperature, peak hour	56.81	58.36	56.85	F
	Head losses in H.E. and Chiller	46	46	46	ft
	Pump & motor efficiency	0.76	0.76	0.76	
SEAWATER-CHILLWATER HEAT EXCHANGERS	Heat transfer, peak hour	28640	20240	15390	kW
	Fraction of cooling station load	100%	100%	100%	
	Area of heat exchanger plates	156160	110340	83900	ft2
	Coefficient of heat transfer (U)	204	204	204	W/ft2F
In:	Chilled water temp.	56.81	58.36	56.85	F
Out:		45.96	48.94	46.43	F
In:	Seawater temp.	45.06	48.04	45.53	F
Out:		55.91	57.46	55.95	F
CAPITAL COST	Building structure	$116,000	$91,000	$76,000	
	Heat exchangers	$3,482,000	$2,460,000	$1,871,000	
	Installation	$348,000	$246,000	$187,000	
	Engineering design	$117,000	$92,000	$77,000	
	TOTAL CAPITAL	$4,063,000	$2,888,000	$2,211,000	U.S.$
REPLACEMENT ITEMS					
	Heat exchangers	$3,830,000	$2,706,000	$2,058,000	
	estimated lifetime	20	20	20	years
OPERATIONAL AND MAINTENANCE COST					
Non-energy cost					
	Maintenance heat exchanger	$87,000	$62,000	$47,000	$/year
	Personnel	$60,000	$60,000	$60,000	$/year
	TOTAL O&M	$147,000	$122,000	$107,000	/year

TECHNICAL SUMMARY: SEAWATER LAND CROSSING	**Scenarios**	**E.Waik&UHM**	**PHNSY**	**KMCBH**	
	AIR CONDITIONING LOAD	7800	5500	4200	Tons
FLOWS					
	Seawater Flow	18319	14910	10247	gpm
	Land Crossing Distance, one way	98	3279	8197	ft
	Supply Pipe OD	63	63	47	in
	Return Pipe OD	63	63	47	in
	Supply head loss	0.0	0.5	2.7	ft
	Return head loss	0.0	0.5	2.5	ft
	Heat Exchanger Head Loss	45.9	45.9	45.9	ft
	Total Head Loss	45.9	46.9	51.1	ft
TEMPERATURES					
	Supply Shore Temp	45.10	48.00	45.20	F
	Supply Temp Rise	0.00	0.07	0.29	F
	Supply Temp at HX	45.10	48.00	45.50	F
	Return Temp at HX	55.90	57.50	56.00	F
	Return Temp Rise	0.00	0.06	0.22	F
	Return Shore Temp	55.90	57.50	56.20	F
COST: SEAWATER LAND CROSSING					
	Pipes	$ 51,000	$ 1,542,300	$ 2,166,600	$
	Install	$ 208,200	$ 1,968,000	$ 4,920,000	$
	Total Cross Land:	$ 259,200	$ 3,510,300	$ 7,086,600	$

TECHNICAL INFORMATION: SEAWATER SUPPLY SYSTEM	**Scenarios**	**E.Waik&U HM**	**PHNSY**	**KMCBH**	
	AIR CONDITIONING LOAD	7800	5500	4200	Ton
INTAKE PIPE (Suction pipe)					
	Diameter (Outer)	63	55	48	in
	Length	25050	20810	16730	ft
	Depth at intake	1786	1364	1820	ft
	D.R. at shoreline	21	21	21	(OD/t)
	D.R. at intake	26	26	26	(OD/t)
EFFLUENT PIPE					
	Diameter (Outer)	63	55	48	in
	Length	0	12450	8580	ft
	Depth at outlet	330	330	330	ft
OPERATING CONDITIONS					
	Flow rate	18319	14910	10247	gpm
	Temperature at deep intake	44.45	47.22	44.29	F
	Thermal Ocean losses	0.61	0.75	0.96	F
	Thermal Land losses	0	0.07	0.29	F
	Supply temperature	45.06	47.97	45.24	F
	Effluent temperature	55.9	57.5	56	F
HEAD LOSSES AND PUMPING ENERGY					
	Suction pipe	8.4	8.3	7.8	ft
	Land Crossing	0.0	1.0	5.2	m
	Cooling station losses	26.2	26.2	26.2	ft
	Effluent pipe	0.0	3.8	2.5	ft
	Total head	34.6	39.4	41.7	ft
	Pump and Motor efficiency	0.75	0.75	0.75	
	Electric pumping power	164	151	110	kW

COST: SEAWATER SUPPLY	**Scenarios**	**E.Waik&UHM**	**PHNSY**	**KMCBH**	
CAPITAL COST	AIR CONDITIONING LOAD	7800	5500	4200	Ton
Contractors cost					
	Perform.bonds & liability ins.	$248,900	$262,900	$169,200	
Cold water pipe (CWP)					
	Route inspection	$200,000	$200,000	$200,000	$
	Pipe materials	$8,735,000	$5,624,300	$3,520,900	$
	Mobilization	$637,100	$429,900	$284,300	$
	Pipe fabrication	$2,728,300	$1,982,900	$1,397,200	$
	Pipe deployment	$1,078,000	$791,400	$568,600	$
	Total capital cost	$13,378,400	$9,028,500	$5,971,000	
Effluent pipe (EP)		0%	60%	51%	of CWP
	Route inspection	$0	$119,600	$102,500	$
	Pipe materials	$1,100	$3,364,600	$1,805,200	$
	Mobilization	$100	$257,200	$145,800	$
	Pipe fabrication	$400	$1,186,200	$716,400	$
	Pipe deployment	$100	$473,400	$291,500	$
	Total	$1,700	$5,401,000	$3,061,400	
Pumping station	Pumps & motors	304,100	247,500	174,600	$
	Construction & materials	1,077,000	932,400	730,100	$
	Total	$1,381,100	$1,179,900	$904,700	
Contractors markup	Rate (20% less CWP)	$1,457,700	$2,194,000	$1,417,000	
	Project management	303,700	329,100	225,200	$
	Engineering design	1,064,300	1,157,300	776,500	$
	Constr.management & Inspect.	390,900	424,700	286,200	$
	Local Eng. Supervision & Coord.	615,615	668,885	450,765	$
Onshore SW Pipe Crossings	Separate Contract, 2 pipes	259,200	3,510,300	7,086,600	
TOTAL CAPITAL COST		$19,101,500	$24,156,700	$20,348,600	
REPLACEMENT ITEMS					
	Seawater pumps	$304,000	$248,000	$175,000	
	Estimated lifetime	10	10	10	years
OPERATING AND MAINTENANCE COST					
Non-energy costs	Inspection &	$42,000	$39,000	$35,000	$/year

	maintenance				
	Personnel	$60,000	$30,000	$30,000	$/year
	Total	$102,000	$69,000	$65,000	/year
Energy operating cost	Mean pumping power	164	151	110	kW
	Cost of electricity	0.112	0.112	0.112	$/kW hr.
	Total	$161,000	$148,267	$107,733	/year
	TOTAL O&M	$263,000	$217,267	$172,733	/year

TOTAL COST: SDC	Scenarios	E.Waik&UHM	PHNSY	KMCBH	
CAPITAL COST	AIR CONDITIONING LOAD	7800	5500	4200	Ton
	Seawater supply system	$19,102,000	$24,157,000	$20,349,000	$
	Centralized cooling station	$4,063,000	$2,888,000	$2,211,000	$
	Chilled water distribution system	$41,252,000	$8,331,000	$6,605,000	$
	Backup Power ($417/kW)	$171,000	$140,000	$97,000	$
	Contingency (20%)	$12,917,600	$7,103,200	$5,852,400	$
	TOTAL CAPITAL	$77,505,600	$42,619,200	$35,114,400	
Replacement costs	Seawater pumps (10 years)	$304,000	$248,000	$175,000	
	Chilled water pumps (10 years)	$109,000	$92,000	$72,000	
	Plate heat exchangers (20 years)	$3,830,000	$2,706,000	$2,058,000	
SDC - OPERATING AND MAINTENANCE COST					
Non-energy operating cost					
	Seawater supply system	$102,000	$69,000	$65,000	$/yr
	Cooling station	$147,000	$122,000	$107,000	$/yr
	Chilled water distribution system	$516,000	$142,000	$125,000	$/yr
	Back-up power sys ($61/kW/yr)	$25,000	$20,000	$14,000	$/yr
	Total	$790,000	$353,000	$311,000	
Energy operating cost					
	Seawater supply system (pumps)	$161,000	$148,267	$107,733	$/yr
	Chilled water pumping	$241,000	$180,266	$120,533	$/yr
	Total	$402,000	$328,533	$228,267	
Total operating cost	TOTAL O&M	$1,192,000	$681,533	$539,267	

CONVENTIONAL A/C - TOTAL COST	Scenarios	E.Waik&UHM	PHNSY	KMCBH	
CAPITAL COST	AIR CONDITIONING LOAD	7800	5500	4200	Ton
	Number of buildings (parcels)	4	4	4	
	Installed A/C Ton:	7800	5500	4200	Ton
	% New Construction:	30%	30%	30%	
	Chillers:	$ 3,978,000	$ 2,805,000	$ 2,142,000	
	Backup Power ($417/kW):	$ 878,100	$ 619,200	$ 472,800	
	Total Conv Capital	$ 4,856,100	$ 3,424,200	$ 2,614,800	
REPLACEMENT ITEMS					
	Chillers (20 years):	$ 13,260,000	$ 9,350,000	$ 7,140,000	
	Backup Power (20 years):	$ 2,927,000	$ 2,064,000	$ 1,576,000	
Non-energy operating cost					
	Maintenance ($30/ton-rated)	$234,000	$165,000	$126,000	$/yr
	Back-up power sys ($61/kW/yr)	$476,000	$336,000	$256,000	$/yr
	Personnel ($40k/buildg./yr)	$160,000	$160,000	$160,000	$/yr
	Total	$870,000	$661,000	$542,000	
Energy operating cost					
	Chiller & Condsr (0.9kW/ton):	7020	4950	3780	kW
	Annual utilization ratio	62.0%	62.0%	62.0%	
	Mean power requirement	4352	3069	2344	kW
	Electricity cost	0.112	0.112	0.112	$/kWhr
	Total	$4,277,852	$3,011,057	$2,299,353	/year
	TOTAL O&M	$5,147,852	$3,672,057	$2,841,353	/year

ECONOMIC EVALUATION OF SDC		E.Waik&UHM	PHNSY	KMCBH	
	AIR CONDITIONING LOAD	7800	5500	4200	Ton
CAPITAL COST	SDC	$77,505,600	$42,619,200	$35,114,400	$
	Conventional A/C	$4,856,200	$3,424,200	$2,614,800	$
	Capital cost difference (dCAP)	$72,649,400	$39,195,000	$32,499,600	
ANNUAL OPERATING COST	SDC	$1,192,000	$681,533	$539,247	$/year
	Conventional A/C	$5,147,852	$3,672,057	$2,941,353	$/year
	Annual O&M cost savings (dOM)	$3,955,852	$2,990,524	$2,302,106	/year
SIMPLE PAYBACK (ignoring replacement items)	SDC capital cost / annual savings	19.6	14.3	15.3	Years
	dCAP/dOM (Credit for chillers)	18.4	13.1	14.1	Years
ELECTRIC POWER SAVINGS	Conventional A/C	100%	100%	100%	
	Seawater pumping, constant flow	3.8%	4.9%	4.7%	
	Chilled water pumping, peak flow	5.6%	6.0%	5.3%	
	SDC power savings (avg.)	90.6%	89.1%	90.0%	
SDC	Mean output:	4,836	3,410	2,604	tons
	Cumulative PV of cooling over Book Life	$1,120	$881	$944	$/ton/yr
	Levelized cost of cooling over book life:	$2,114	$1,663	$1,783	$/ton/yr
CONVENTIONAL A/C	Mean output:	4,836	3,410	2,604	tons
	Cumulative PV of cooling over Book Life	$712	$719	$726	$/ton/yr
	Levelized cost of cooling over book life:	$1,344	$1,356	$1,371	$/ton/yr
LEVELIZED ANNUAL COST SAVINGS		($3,722,269)	($1,046,256)	($1,072,275)	/year

C3 Poipu, Kapaa

CHILLED WATER DISTRIBUTION SYSTEM						
TECHNICAL INFORMATION, Scenario:				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
KEY DATA FOR DISTRIBUTION NETWORK						
	Length of main branch			1930	6440	ft
	Pipe size (nom.)	(U<4 fps)		16	16	in (max)
	Number of Valve stations			4	4	
DESIGN OPERATING CONDITIONS						
	Flow rate			2148	2222	gpm
	Network Supply Temperature			46.5	46.4	F
	Max Building Input Temperature supplied			46.5	46.5	F
	Min Building Input Temperature supplied			46.5	46.4	F
	Max Building Input Temperature required			46.5	46.5	F
	Temperature rise, main supply branch			0.0	0.1	F
	Max d-T required of one or more buildings			10.0	10.0	F
	Min d-T required of one or more buildings			10.0	10.0	F
	Max Bld'g Exit Temp, inc 0.2C add loss			56.9	56.9	F
	Network Return Temperature			56.9	56.9	F
COST, DISTRIBUTION SYSTEM				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
CAPITAL COST						
	Carrier pipe (supply and return)			$71,000	$255,000	$
	Insulation of carrier pipe			$29,000	$102,000	$
	Trench excavation and backfill			$0	$0	$
	Pipe installation and testing			$1,161,000	$3,866,000	$
	Valve stations & piping			$265,000	$60,000	$
	Chilled water pumps			$61,000	$65,000	$
	Design & management			$96,000	$234,000	$
	TOTAL CAPITAL...			$1,683,000	$4,582,000	
REPLACEMENT ITEMS						
	Chilled water pumps			$39,000	$42,000	
	Estimated lifetime			10	10	years
OPERATION AND MAINTENANCE COST (Piping,valves,Pumps)						
Non-energy costs						
	Maintenance and service matls.			$17,000	$45,000	$/year
	Personnel			$60,000	$60,000	$/year
	Total...			$77,000	$105,000	/year

				85.841695	113.1465 52	
Energy operating cost (Pumping)						
	Mean power (- Building losses)			19	38	kW
	Cost of electricity			0.203	0.203	$/kWh r
	Total..			$33,700	$67,500	/year
	TOTAL O&M...			$110,700	$172,500	/year

CENTRAL COOLING STATION						
TECHNICAL INFORMATION, Scenario:				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Tons
SEAWATER (Heat sink)						
	Flow rate			2188.5	2264	gpm
	Supply temperature			45.56	45.48	F
	Effluent temperature, peak hour			55.95	55.95	F
CHILLED WATER (Heat source)						
	Flow rate			2148	2222	gpm
	Network supply temperature			46.46	46.38	F
	Return temperature, peak hour			56.85	56.85	F
	Head losses in H.E. and Chiller			46	46	ft
	Pump & motor efficiency			0.756	0.756	
HEAT EXCHANGERS (Between incoming seawater & chilled water)						
	Heat transfer, peak hour			3280	3420	kW
	Fraction of cooling station load			1	1	
	Area of heat exchanger plates			17870	18630	ft2
	Coefficient of heat transfer (U)			204	204	W/ft2F
	Approach temp. peak hr.(LMTD)			0.9	0.9	F
	Chilled water temp.		In:	56.85	56.85	F
			Out:	46.46	46.38	F
	Seawater temp.		In:	45.56	45.48	F
			Out:	55.95	55.95	F

COST, CENTRAL COOLING STATION				Poipu	Kapaa	
	AIRCONDITIONING LOAD			897	928	Ton
CAPITAL COST						
	Building structure			$40,000	$40,000	
	Heat exchangers			$399,000	$415,000	
	Installation			$40,000	$42,000	
	Engineering design			$40,000	$40,000	
	TOTAL CAPITAL..			$519,000	$537,000	U.S.$
REPLACEMENT ITEMS						
	....estimated lifetime			20	20	years
	Heat exchangers			$438,000	$457,000	
	....estimated lifetime			20	20	years
OPERATIONAL AND MAINTENANCE COST (Annual)						
Non-energy cost						
	Maintenance heat exchanger			$10,000	$10,000	$/year
	Personnel			$60,000	$60,000	$/year
	Total...			$70,000	$70,000	
Energy operating cost (auxiliary chiller)						
	Mean auxiliary chiller power			0	0	kW
	Cost of electricity			0.203	0.203	$/kWhr
	Total...(24hr x 365 days)..			0	0	/year
	TOTAL O&M..			$70,000	$70,000	/year

SEAWATER LAND CROSSING						
TECHNICAL SUMMARY				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Tons
FLOWS						
	Seawater Flow			2189	2264	gpm
	Land Crossing Distance, one way			984	656	ft
	Supply Pipe OD			22	24	in
	Return Pipe OD			22	22	in
	Supply head loss			0.8	0.4	ft
	Return head loss			0.7	0.5	ft
	Heat Exchanger Head Loss			45.9	45.9	ft
	Total Head Loss			47.4	46.8	ft
TEMPERATURES						
	Supply Insulation			0	0	in
	Supply Shore Temp			45.4	45.4	F
	Supply Temp Rise			0.16	0.11	F
	Supply Temp at HX			45.6	45.5	F
	Return Insulation			0	0	in
	Return Temp at HX			56	56	F
	Return Temp Rise			0.12	0.08	F
	Return Shore Temp			56.1	56	F
SEAWATER LAND CROSSING						
COST SUMMARY				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Tons
COSTS						
	Pipes			$56,100	$41,300	$
	Insulation			$0	$0	$
	Trench & backfill			$0	$0	$
	Install			$590,400	$393,600	$
	Total Cross Land:			$646,500	$434,900	$

SEAWATER SUPPLY SYSTEM						CWP
TECHNICAL INFORMATION, Scenario:				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
	Future expansion CWP Capacity:			0	0	Ton
INTAKE PIPE (Suction pipe)						
	Diameter (Outer)			28	30	in
	Length			17020	24070	ft
	Depth at intake			2936	2896	ft
	D.R. at shoreline			21	21	(OD/t)
	D.R. at intake			26	26	(OD/t)
EFFLUENT PIPE						
	Diameter (Outer)			28	30	in
	Length			9240	9240	ft
	Depth at outlet			330	330	ft
OPERATING CONDITIONS						
	Flow rate			2189	2264	gpm
	Temperature at deep intake			39.72	39.83	F
	Thermal Ocean losses (Incr.temp.)			5.68	5.55	F
	Thermal Land losses (Incr. Temp.)			0.16	0.11	F
	=Supply temperature			45.4	45.38	F
	Effluent temperature			56	56	F
HEAD LOSSES AND PUMPING ENERGY						
	+Suction pipe			7.8	8.1	ft
	+Land Crossing			1.5	0.9	m
	+ Cooling station losses			26.2	26.2	ft
	+ Effluent pipe			2.2	1.7	ft
	= Total head			37.7	36.9	ft
	Pump and Motor efficiency			0.75	0.75	
	Electric pumping power			21.3	21.5	kW

SEAWATER SUPPLY SYSTEM						
ITEMIZED CAPITAL COST, SEAWATER SUPPLY				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
	Future expansion CWP Capacity:			0	0	Ton
Contractors cost						
	Perform.bonds & liability ins.			$83,900	$109,400	
Cold water pipe (CWP)						
	Route inspection			$200,000	$200,000	$
	Pipe materials			$1,308,800	$2,098,000	$
	Mobilization			$134,000	$202,400	$
	Pipe fabrication			$827,000	$1,252,600	$
	Pipe deployment			$343,700	$497,000	$
	Total capital cost........................			$2,813,500	$4,250,000	
Effluent pipe (EP)			L-factor>>>	0.5428229	0.38374924	of CWP
	Route inspection		1	$108,600	$76,700	$
	Pipe materials		1	$710,500	$805,100	$
	Mobilization		1	$72,700	$77,700	$
	Pipe fabrication		1	$448,900	$480,700	$
	Pipe deployment		1	$186,500	$190,700	$
	Total...............................			$1,527,200	$1,630,900	
Pumping station						
	Pumps & motors			$40,000	$41,300	$
	Construction & materials			$389,200	$392,300	$
	Total................................			$429,200	$433,600	
Contractors markup			Less CWP			
	Rate		0.2	$764,800	$950,300	
Project design & management						
	Project management			$131,500	$159,400	$
	Engineering design			$432,800	$535,000	$
	Constr.management & Inspect.			$161,200	$198,400	$
	Local Eng. Supervision & Coord.			$253,925	$312,480	$
				$979,425	$1,205,280	
Onshore SW Pipe Crossings						
	Separate Contract, 2 pipes			$646,500	$434,900	

TOTAL CAPITAL COST....				$7,244,500	$9,014,400	
Capital cost breakdown (w/o markup)						
	Contractors cost			1%	1%	
	Cold water pipeline			43%	53%	
	Effluent pipe			24%	20%	
	Pump station			7%	5%	
	On shore piping			10%	5%	
	Engineering & management			15%	15%	
	TOTAL..................................			100%	100%	

TOTAL COST, SEAWATER SUPPLY SYSTEM				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
	Future expansion CWP Capacity:			0	0	Ton
CAPITAL COST						
	Contractors cost			$84,000	$109,000	$
	Cold water pipe			$2,814,000	$4,250,000	$
	Effluent pipe			$1,527,000	$1,631,000	$
	Pumping station			$429,000	$434,000	$
	On-shore crossing			$646,500	$434,900	$
	Contractors markup			$765,000	$950,000	$
	Project design & management			$979,000	$1,205,000	$
	TOTAL CAPITAL.................................			$7,244,500	$9,013,900	
REPLACEMENT ITEMS						
	Seawater pumps			$40,000	$41,000	
	....Estimated lifetime			10	10	years
OPERATING AND MAINTENANCE COST						
Non-energy costs						
	Inspection & maintenance			$27,000	$27,000	$/year
	Personnel			$30,000	$30,000	$/year
	Total..			$57,000	$57,000	/year
				63.545151	61.4224138	
Energy operating cost (pumping)						
	Mean pumping power			21	22	kW
	Cost of electricity			0.203	0.203	$/kW hr.
	Total....................................			$38,000	$38,000	/year
	TOTAL O&M..................................			$95,000	$95,000	/year

SUMMARY, SEAWATER AIR CONDITIONING						
TECHNICAL INFORMATION				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Tons
	Average A/C load utilization			0.62	0.62	
	Future expansion CWP Capacity:			0	0	Ton
SEAWATER SYSTEM						
	Flow rate			138	143	l/s
	Pipe size			28.013	30.02	in
	Pipe length			17020	24070	ft
	Head Loss			37.7	36.9	ft
	Depth of intake			2940	2900	ft
	Temperature of seawater at intake			39.72	39.83	F
	Temp rise in the ocean			5.68	5.55	F
	Temp rise crossing land			0.16	0.11	F
	Delivery temperature to Heat Ex			45.56	45.48	F
	Discharge temperature			56.07	56.03	F
CHILLED WATER SYSTEM						
	Flow rate			2148	2222	gpm
	Length of main branch			1930	6440	ft
	LMTD in Heat Exchanger:			0.9	0.9	F
	Max. supply temperature - building			46.5	46.5	F
	Max. temperature rise - building			10	10	F
	Max Bld'g Exit Temp, inc 0.2C add loss			56.85	56.85	F
	Temperature rise through network			10.39	10.47	F
COOLING STATION - LOAD SHARING						
	Heat exchanger			1	1	of total
	Auxillary chiller			0	0	of total
	Utilization of chiller (average)			0	0	
	LMTD Heat exchanger			0.9	0.9	F
POWER REQUIREMENTS SWACS VS. CONVENTIONAL AC						
	Conventional AC power (average)................			501	518	kW
	Seawater pumps at design flow			21	22	kW
	+Average power auxillary chiller			0	0	kW
	+Chilled water pumps (8m HX)			19	38	kW
	=Total SWACS power (average)..............			40	60	kW
	Power ratio SWACS/Conv.A/C			0.08	0.11	

COST, TOTAL SWACS				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
	Future expansion CWP Capacity:			0	0	Ton
SWACS - CAPITAL COST						
	Seawater supply system			$7,245,000	$9,014,000	$
	Centralized cooling station			$518,000	$537,000	$
	Chilled water distribution system			$1,683,000	$4,582,000	$
	Backup Power	417	/KW	$17,000	$25,000	$
	Contingency	0.2		$1,892,600	$2,831,600	$
	TOTAL CAPITAL..			$11,355,600	$16,989,600	
TOTAL CAPITAL COST...			Life, yrs			
	Seawater pumps		10	$40,000	$41,000	
	Chilled water pumps		10	$39,000	$42,000	
	Plate heat exchangers		20	$438,000	$457,000	
	Auxiliary chillers		20	$0	$0	
SWACS - OPERATING AND MAINTENANCE COST						
Non-energy operating cost						
	Seawater supply system			$57,000	$57,000	$/yr
	Cooling station			$70,000	$70,000	$/yr
	Chilled water distribution system			$77,000	$105,000	$/yr
	Back-up power sys	61	/KW/yr	$2,000	$4,000	$/yr
	Total..			$206,000	$236,000	
Energy operating cost (pumps & auxiliary chiller)						
	Seawater supply system (pumps)			$38,000	$38,000	$/yr
	Cooling station (auxiliary chiller)			$0	$0	$/yr
	Chilled water pumping			$34,000	$68,000	$/yr
	Total..			$72,000	$106,000	
Total operating cost						
	Seawater supply system			$95,000	$96,000	$/yr
	Back-up Power sys			$2,000	$4,000	$/yr
	Cooling station			$70,000	$70,000	$/yr
	Chilled water distribution system			$111,000	$172,000	$/yr
	TOTAL O&M......................................			$278,000	$342,000	

CONVENTIONAL A/C, Scenario				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
	Future expansion CWP Capacity:			0	0	Ton
CONVENTIONAL A/C - CAPITAL COST						
	Number of buildings (parcels)			4	4	
	Installed A/C Ton:	1	of load	897	928	Ton
	% New Construction:			0.3	0.3	
	Chillers:	1700	/Ton	$457,500	$473,400	
	Backup Power:	417	/KW	$101,100	$104,400	
	Total Conv Capital			$558,600	$577,800	
REPLACEMENT ITEMS			Life, yrs			
	Chillers:		20	$1,525,000	$1,578,00 0	
	Backup Power:		20	$337,000	$348,000	
CONVENTIONAL A/C - OPERATING COST OF CHILLERS & COOLING TOWERS						
Non-energy operating cost						
	Maintenance	30	/inst. Ton	$27,000	$28,000	$/yr
	Back-up power sys	61	/kw/yr	$55,000	$57,000	$/yr
	Personnel	40000	/build/y r.	$160,000	$160,000	$/yr
	Total..			$242,000	$245,000	
+ Energy operating cost (chiller & cooling tower. No chilled water pumping cost included)						
	Chiller:	0.9	kW/Ton	807	835	kW
	Cooling tower:	0	kW/Ton	0	0	kW
	Total power req.	0.9	kW/Ton	807	835	kW
	Overall COP	3.907616	kW/kW			
	Annual utilization ratio			0.62	0.62	
	Mean power requirement			501	518	kW
	Electricity cost			0.203	0.203	$/kWh r
	Total................................			$890,075	$920,836	/year
	TOTAL O&M.................................			$1,132,075	$1,165,83 6	/year

ECONOMIC EVALUATION OF SWACS				Poipu	Kapaa	
	AIR CONDITIONING LOAD			897	928	Ton
CAPITAL COST						
	SWACS			$11,355,600	$16,989,600	$
	Conventional A/C			$558,600	$577,800	$
	Capital cost difference (dCAP)			$10,797,000	$16,411,800	
				$100	$100	
ANNUAL OPERATING COST						
	SWACS			$278,000	$342,000	$/year
	Conventional A/C			$1,132,075	$1,165,836	$/year
	Annual O&M cost savings (dOM)			$854,075	$823,836	/year
SIMPLE PAYBACK (ignoring replacement items)						
	SWACS capital cost / annual savings			13.3	20.6	Years
	dCAP/dOM (Credit for chillers)			12.6	19.9	Years
ELECTRIC POWER SAVINGS (percentage of conventional A/C)						
	Conventional A/C			1.0000	1.0000	
	Seawater pumping, constant flow			0.0425	0.0416	
	Chilled water pumping, peak flow			0.0379	0.0733	
	Heat transfer (HE & HP) at (U.R.%)			0.0000	0.0000	
	SWACS power savings (avg.)			0.9196	0.8850	
LEVELIZED COST (Annual cost of capital and O&M over 20 years) per EPRI TAG						
SWACS				Poipu	Kapaa	
	Mean output:			556	575	tons
	Cumulative PV of cooling over Book Life			$1,852	$2,597	$/ton/yr
	Levelized cost of cooling over book life:			$3,033	$4,255	$/ton/yr
CONVENTIONAL A/C						
	Mean output:			556	575	tons
	Cumulative PV of cooling over Book Life			$1,512	$1,506	$/ton/yr
	Levelized cost of cooling over book life:			$2,477	$2,468	$/ton/yr
LEVELIZED COST SAVINGS						
	Levelized cost savings			-$309,390	-$1,028,500	/year

Appendix D Technical details of selected cases by UH-ORE

D1 Honolulu Waterfront

Length from shore (ft)	Depth (ft)	Sea temperature (Fahrenheit)	Radius (inches)	Velocity (fps)	Wall thickness (inches)	Internal Water temperature (Fahrenheit)
0	0	82.4	24	5.2	2.8	45.7
6256	164	77.9	24	5.2	2.8	45.7
9579	328	73.4	24	3.6	2.8	45.6
10361	656	65.4	26	3.6	2.8	45.6
11534	984	54.4	26	3.6	2.8	45.5
13293	1312	48.8	26	3.6	2.8	45.5
19024	1640	45.5	26	3.6	2.8	45.5

Honolulu Waterfront conventional cooling schedule	kW	kW	kW
time	**Facility**	**A/C**	**total**
23:00	168	137	305
0:00	168	137	305
1:00	168	137	305
2:00	201	165	366
3:00	243	199	442
4:00	344	281	625
5:00	453	370	823
6:00	461	377	838
7:00	469	384	854
8:00	469	384	854
9:00	478	391	869
10:00	478	391	869
11:00	486	398	884
12:00	520	425	945
13:00	562	460	1021
14:00	562	460	1021
15:00	562	460	1021
16:00	562	460	1021
17:00	562	460	1021
18:00	486	398	884
19:00	411	336	747
20:00	344	281	625
21:00	268	219	488
22:00	201	165	366
		328	

PS schedule	factors	Charges
Peak Demand (kW)	1021	
Daily energy consumption (kWh)	17498	
Customer		$320
1st Demand ($10*kWmax)	500	$5,000
2nd Demand ($9.5*kWmax)	521	$4,952
over Demand ($8.5*kWmax)	0	$0
1st level ($0.072087/kWh)	204244	$14,723
2nd level ($0.064104/kWh)	204244	$13,093
3rd level ($0.06101/kWh)	125198	$7,638
Energy cost adjustment ($/kWh)	0.0178	$9,500
Power factor adjustment (80%)		$182
Monthly energy consumption (kWh)		533686
Total		$55,407
average $/kWh		$0.1038

Downtown Waterfront SDC

time	SDC(kW)
23:00	196
0:00	196
1:00	196
2:00	235
3:00	284
4:00	401
5:00	529
6:00	538
7:00	548
8:00	548
9:00	558
10:00	558
11:00	568
12:00	607
13:00	656
14:00	656
15:00	656
16:00	656
17:00	656
18:00	568
19:00	480
20:00	401
21:00	313
22:00	235

PS schedule	factors	Charges
Peak Demand (kW)	656	
Daily energy consumption (kWh)	11239	
Customer		$320
1st Demand ($8.5*kWmax)	500	$5,000
2nd Demand ($8*kWmax)	156	$1,481
over Demand ($8*kWmax)	0	$0
1st level ($0.072087/kWh)	131182	$9,457
2nd level ($0.064104/kWh)	131182	$8,409
3rd level ($0.06101/kWh)	80413	$4,906
Energy cost adjustment ($/kWh)	0.0178	$6,101
Power factor adjustment (80%)		$117
Monthly energy consumption (kWh)		342777
Subtotal		$35,791
District charge adjustment		($3,597)
Total		$39,389
average $/kWh		$0.1149

Downtown Waterfront other loads

time	total
23:00	168
0:00	168
1:00	168
2:00	201
3:00	243
4:00	344
5:00	453
6:00	461
7:00	469
8:00	469
9:00	478
10:00	478
11:00	486
12:00	520
13:00	562
14:00	562
15:00	562
16:00	562
17:00	562
18:00	486
19:00	411
20:00	344
21:00	268
22:00	201

PS schedule present	factors	Charges
Peak Demand (kW)	562	
Daily energy consumption (kWh)	9624	
Customer		$320
1st Demand ($10*kWmax)	500	$5,000
2nd Demand ($9.5*kWmax)	62	$586
over Demand ($8.5*kWmax)	0	$0
1st level ($0.072087/kWh)	112334	$8,098
2nd level ($0.064104/kWh)	112334	$7,201
3rd level ($0.06101/kWh)	68859	$4,201
Energy cost adjustment ($/kWh)	0.0178	$5,225
Power factor adjustment (80%)		$100
Monthly energy consumption (kWh)		293527
Total		$30,731
average $/kWh		$0.1047

	Total	Section	Section
Wall thickness (inches)		2.8	3.2
Internal Diameter (inches)		41.5	47.3
D/R		16.9	16.9
friction slope		0.00128	0.00068
section length		2071	3729
Velocity (fps)		1.5	1.2
CWP Cost	$12,470,858	$3,804,710	$8,366,148
Sump depth (ft)	7.2		
Length of CWP (ft)	19024		
District Load (tons)	8465		
Flow rate (GPM)	20750		
CWP headloss (ft)	20.3		
Total headloss (ft)	66		
Length of EWP (ft)	6255		
Pump power (kW)	359		

Load	Flowrate (GPM)	Length of branch (ft)	Inner Radius (inches)	Velocity (fps)	Pumping power of branch (kW)	Cost
Interconnect	20744	377	14	4.3	185	$892,994
1200	2941	131	8	4.7	10	$152,258
1420	3480	131	8	5.1	11	$155,039
Interconnect	14324	164	12	9.8	7	$372,301
1100	2696	918	8	4.6	12	$1,056,220
850	2083	623	7	4.0	8	$698,637
Interconnect	9545	623	11	8.1	15	$1,357,377
1050	2573	492	8	4.5	10	$563,154
1425	3492	131	8	5.1	11	$155,099
1420	3480	131	8	5.1	11	$155,039
Land Length	20744	787	16			$1,048,265

D2 Kakaako

Length from shore (ft)	Depth (ft)	Sea temperature (Fahrenheit)	Radius (inches)	Velocity (fps)	Wall thickness (inches)	Internal Water temperature (Fahrenheit)
0	0	82	13	11.2	2.8	46.0
6256	164	78	13	11.2	2.8	45.9
9579	328	73	21	4.2	2.8	45.8
10361	656	65	21	4.2	2.8	45.6
11534	984	54	21	4.2	2.8	45.6
13293	1312	49	21	4.2	2.8	45.6
19024	1640	46	21	4.2	2.8	45.5

Kakaako conventional cooling schedule			
time	**Facility**	**A/C**	**total**
23:00	144	117	261
0:00	144	117	261
1:00	144	117	261
2:00	172	141	313
3:00	208	170	379
4:00	294	241	535
5:00	388	317	705
6:00	395	323	718
7:00	402	329	731
8:00	402	329	731
9:00	409	335	744
10:00	409	335	744
11:00	416	341	757
12:00	445	364	809
13:00	481	394	875
14:00	481	394	875
15:00	481	394	875
16:00	481	394	875
17:00	481	394	875
18:00	416	341	757
19:00	352	288	640
20:00	294	241	535
21:00	230	188	418
22:00	172	141	313
		281	
PS schedule present	factors	Charges	
Peak Demand (kW)	875		
Daily energy consumption (kWh)	14985		
Customer		$320	
1st Demand ($10*kWmax)	500	$5,000	
2nd Demand ($9.5*kWmax)	375	$3,558	
over Demand ($8.5*kWmax)	0	$0	
1st level ($0.072087/kWh)	174907	$12,609	
2nd level ($0.064104/kWh)	174907	$11,212	
3rd level ($0.06101/kWh)	107216	$6,541	
Energy cost adjustment ($/kWh)	0.0178	$8,135	
Power factor adjustment (80%)		$156	
Monthly energy consumption (kWh)		457031	
Total		$47,531	
average $/kWh		$0.1040	

SWAC		
time	**SWAC**	
23:00	212	
0:00	212	
1:00	212	
2:00	255	
3:00	308	
4:00	435	
5:00	573	
6:00	584	
7:00	594	
8:00	594	
9:00	605	
10:00	605	
11:00	616	
12:00	658	
13:00	711	
14:00	711	
15:00	711	
16:00	711	
17:00	711	
18:00	616	
19:00	520	
20:00	435	
21:00	340	
22:00	255	
PS schedule	factors	Charges
Peak Demand (kW)	650	
Daily energy consumption (kWh)	11143	
Customer		$320
1st Demand ($10*kWmax)	500	$5,000
2nd Demand ($9.5*kWmax)	150	$1,428
over Demand ($8.5*kWmax)	0	$0
1st level ($0.072087/kWh)	130067	$9,376
2nd level ($0.064104/kWh)	130067	$8,338
3rd level ($0.06101/kWh)	79729	$4,864
Energy cost adjustment ($/kWh)	0.0178	$6,050
Power factor adjustment (80%)		$116
Monthly energy consumption (kWh)		339864
Subtotal		$35,492
Customer charge adjustment		($3,464)
Total		$38,956
average $/kWh		$0.1146

Kakaako other loads with SDC		
time	Facility	
23:00	144	
0:00	144	
1:00	144	
2:00	172	
3:00	208	
4:00	294	
5:00	388	
6:00	395	
7:00	402	
8:00	402	
9:00	409	
10:00	409	
11:00	416	
12:00	445	
13:00	481	
14:00	481	
15:00	481	
16:00	481	
17:00	481	
18:00	416	
19:00	352	
20:00	294	
21:00	230	
22:00	172	
PS schedule present	**factors**	**Charges**
Peak Demand (kW)	**481**	
Daily energy consumption (kWh)	**8242**	
Customer		**$320**
1st Demand ($10*kWmax)	**481**	**$4,810**
2nd Demand ($9.5*kWmax)	**0**	**$0**
over Demand ($8.5*kWmax)	**0**	**$0**
1st level ($0.072087/kWh)	**96199**	**$6,935**
2nd level ($0.064104/kWh)	**96199**	**$6,167**
3rd level ($0.06101/kWh)	**58969**	**$3,598**
Energy cost adjustment ($/kWh)	**0.0178**	**$4,474**
Power factor adjustment (80%)		**$86**
Monthly energy consumption (kWh)		**251367**
Total		**$26,389**
average $/kWh		**$0.1050**

	Total	Section	Section	Section
Wall thickness (inches)		2.9	2.5	2.8
Internal Diameter (inches)		25.5	36.8	41.5
D/R		10.9	16.9	16.9
friction slope		0.01021	0.00173	0.00096
section length		2196	1554	15274
Velocity (fps)		11.2	5.4	4.2
CWP Cost	$10,443,541	$761,367	$739,833	$8,556,442
Sump depth (ft)	29.8			
Length of CWP (ft)	19025			
District Load (tons)	7250			
Flow rate (GPM)	17773			
CWP headloss (ft)	43.0			
Total headloss (ft)	89			
Length of EWP (ft)	6255			
Pump power (kW)	414			

Load	Flowrate (GPM)	Length of branch (ft)	Inner Radius (inches)	Velocity (fps)	Temperature (Fahrenheit)	Pumping power of branch (kW)	Cost
Interconnect	17767	131	13	10.8	46.8	162.3	$127,505
700	1715	66	7	3.7	46.8	5.4	$26,298
540	1323	656	6	3.3	46.8	4.9	$242,666
Interconnect	14728	328	12	9.9	46.8	15.4	$746,847
350	858	131	6	2.7	46.8	2.7	$136,393
3000	7352	2626	10	7.2	46.8	65.5	$5,577,994
Interconnect	6519	656	10	6.8	46.8	8.9	$1,379,748
860	2108	328	7	4.1	46.8	7.3	$368,116
850	2083	328	7	4.1	46.8	7.2	$140,177
950	2328	328	7	4.3	46.8	8.1	$371,698
Land crossing		328	16				$436,777

D3 Pearl Harbor Naval Shipyard

Length from shore (ft)	Depth (ft)	Sea temperature (Fahrenheit)	Radius (inches)	Velocity (fps)	Wall thickness (inches)	Internal Water temperature (Fahrenheit)
0	0	82.4	21	3.2	2.76	46.2
4476	164	77.9	21	3.2	2.76	46.2
8206	328	73.4	21	3.2	2.76	46.1
8952	656	65.4	21	3.2	2.76	45.9
11190	985	54.4	21	3.2	2.76	45.7
20119	1313	48.8	21	3.2	2.76	45.6
28416	1641	45.5	21	3.2	2.76	45.6

PHNSY			
time	Facility	A/C	total
23:00	1525	1248	2773
0:00	1525	1248	2773
1:00	1525	1248	2773
2:00	1830	1497	3327
3:00	2211	1809	4020
4:00	3126	2558	5684
5:00	4117	3369	7486
6:00	4194	3431	7625
7:00	4270	3493	7763
8:00	4270	3493	7763
9:00	4346	3556	7902
10:00	4346	3556	7902
11:00	4422	3618	8041
12:00	4727	3868	8595
13:00	5109	4180	9288
14:00	5109	4180	9288
15:00	5109	4180	9288
16:00	5109	4180	9288
17:00	5109	4180	9288
18:00	4422	3618	8041
19:00	3736	3057	6793
20:00	3126	2558	5684
21:00	2440	1996	4436
22:00	1830	1497	3327
PT schedule present	factors	Charges	
Peak Demand (kW)	9288		
Daily energy consumption (kWh)	159147		
Customer		$320	
1st Demand ($9.67*kWmax)	500	$4,835	
2nd Demand ($9.19*kWmax)	1000	$9,190	
over Demand ($8.22*kWmax)	7788	$64,019	
1st level ($0.069708/kWh)	1857638	$129,492	
2nd level ($0.061989/kWh)	1857638	$115,153	
3rd level ($0.058997/kWh)	1138704	$67,180	
Energy cost adjustment ($/kWh)	0.0178	$86,401	
Power factor adjustment (80%)		$1,559	
Monthly energy consumption (kWh)		4853980	
Total		$478,150	
average $/kWh		$0.0985	

PHNSY SDC system		
time	**SWAC**	
23:00	247	
0:00	247	
1:00	247	
2:00	297	
3:00	359	
4:00	507	
5:00	668	
6:00	681	
7:00	693	
8:00	693	
9:00	705	
10:00	705	
11:00	773	
12:00	811	
13:00	859	
14:00	859	
15:00	859	
16:00	859	
17:00	859	
18:00	773	
19:00	688	
20:00	612	
21:00	527	
22:00	452	
PS schedule		Charges
Peak Demand (kW)	903	
Daily energy consumption (kWh)	15797	
Customer		$320
1st Demand ($10*kWmax)	500	$5,000
2nd Demand ($9.5*kWmax)	403	$3,829
over Demand ($8.5*kWmax)	0	$0
1st level ($0.072087/kWh)	180614	$13,020
2nd level ($0.064104/kWh)	180614	$11,578
3rd level ($0.06101/kWh)	120593	$7,357
Energy cost adjustment ($/kWh)	0.0178	$8,576
Power factor adjustment (80%)		$163
Monthly energy consumption (kWh)		481822
Sub total		$49,844
District charge adjustment		($910)
Total		$50,754
average $/kWh		$0.1053

PHNSY other loads with SDC system		
time	**total**	
23:00	1525	
0:00	1525	
1:00	1525	
2:00	1830	
3:00	2211	
4:00	3126	
5:00	4117	
6:00	4194	
7:00	4270	
8:00	4270	
9:00	4346	
10:00	4346	
11:00	4422	
12:00	4727	
13:00	5109	
14:00	5109	
15:00	5109	
16:00	5109	
17:00	5109	
18:00	4422	
19:00	3736	
20:00	3126	
21:00	2440	
22:00	1830	
PS schedule present	factors	Charges
Peak Demand (kW)	5109	
Daily energy consumption (kWh)	87531	
Customer		$320
1st Demand ($9.7*kWmax)	500	$4,835
2nd Demand ($9.2*kWmax)	1000	$9,190
over Demand ($8.2*kWmax)	3609	$29,662
1st level ($0.069708/kWh)	1021701	$71,221
2nd level ($0.061989/kWh)	1021701	$63,334
3rd level ($0.058997/kWh)	626287	$36,949
Energy cost adjustment ($/kWh)	0.0178	$47,520
Power factor adjustment (80%)		$861
Monthly energy consumption (kWh)		2669689
Total		$263,892
average $/kWh		$0.0988

Sump depth (ft)	51.1
Length of CWP (ft)	28398.24
District Load (tons)	5500.00
Wall thickness (inches)	2.8
Internal Diameter (inches)	41.5
D/R	16.9
Flow rate (GPM)	13480
friction slope	0.00057
Velocity (fps)	3.3
CWP Cost	$16,252,798
CWP headloss (ft)	18.4
Total headloss (ft)	66
Length of EWP (ft)	1313
Pump power (kW)	227

Load	Flowrate (GPM)	Length of branch (ft)	Inner Radius (inches)	Velocity (fps)	Temperature (Fahrenheit)	Pumping power of branch (kW)	Cost
Interconnect	13478	33	12	9.50	47.31	118.2	$31,913
786	1926	246	7	3.91	47.31	6.5	$102,414
786	1926	246	7	3.91	47.31	6.5	$102,414
Interconnect	9626	2626	11	8.15	47.34	64.5	$2,130,962
786	1926	246	7	3.91	47.35	6.5	$102,414
786	1926	246	7	3.91	47.35	6.5	$102,414
Interconnect	5774	2626	10	6.45	47.39	29.5	$1,668,463
786	1926	246	7	3.91	47.40	6.5	$102,414
786	1926	246	7	3.91	47.40	6.5	$102,414
784	1921	246	7	3.90	47.40	6.5	$102,328
Land crossing	13478	17066	13				$7,921,684

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