CODE CHANGE PROPOSAL FOR

Cooling Towers

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Overview

This proposal contains three provisions to enhance the performance of chilled water plants, and their treatment under Title 24.

Description

Limitation on the Application of Air-Cooled Chillers

Our first measure is a limitation on the use of air-cooled chillers in chilled water plants. Above 300t plant capacities we propose to require water-cooled chillers with cooling towers. Water-cooled plants cost more but are far more efficient than air-cooled plants. This proposed requirement is based on a life-cycle cost analysis.

At present, Title 24 has a mandatory requirement for the efficiency of cooling towers (gpm/hp at Cooling Tower Institute Acceptance Test Code 105 (CTI ATC 105) test conditions, §112, Table 1-C7) and a prescriptive requirement for the unloading capabilities of cooling tower fans (§144h). These measures were adopted in the AB970 emergency standard based on analysis performed for ASHRAE/IES Standard 90.1-1999. The effect of these measures is an increase in both the size and cost of cooling towers and water-cooled systems. To prevent a shift in the market to less efficient and less expensive air-cooled equipment we propose a companion requirement for a limitation on air-cooled chillers.

This proposal is based on a life cycle cost analysis and comparison of air- vs. water-cooled chilled water plants as a function of plant size (installed tonnage) and climate (dry, intermediate or humid). This analysis is based on similar analysis that we have performed for a number of commercial building clients in the greater San Francisco Bay Area. As detailed below, we have found that water-cooled plants are cost effective above 200t. The analysis includes the increased installed cost, the cost of the utilities (electricity and water) and the maintenance costs.

Our analysis was based on a real design of a 200t plant. That plant design is quite typical of dozens of other plants that we have either designed or reviewed in the field. The comparison of the cost effectiveness of that plant included maintenance cost estimates from a service contractor, installed cost estimates from a mechanical contractor and detailed energy and water usage from eQuest simulations with water estimates based on post simulation analysis. We scaled this plant to represent a small, medium and large facility in each of the three climates (dry, intermediate and humid). Each design was analyzed for its energy and water usage as well as the installed and maintenance costs.

Cooling Tower Flow Turndown

Our second proposed measure addresses the design of cooling towers to accommodate variations in flow as chillers are staged on or off in multiple chiller plants. When staging chillers in a multiple chiller plant, you must either design the tower cells to accommodate a range of flows or provide multiple tower cells with isolation valves so that one cell is designed for the flow of each chiller. Varying water flow through a tower that is not designed for it can cause premature scaling of the fill and drastic loss of capacity. Cooling towers can be designed to provide flow turndown on the order of 3:1 (i.e. they can accommodate between design flow and 1/3 of design flow with no loss of performance). This is accomplished by selection of flow nozzles and weirs (for basin type towers).

With two-speed or variable speed motors (a present Prescriptive requirement, Section 144(h)), it is far more efficient to run tower water through multiple cells due to the near cube law efficiency of the fans; running two fans at ½ speed uses approximately ¼ of the energy of running one fan at full speed for the same heat rejection. On the design side, it is less expensive to design the tower for variable flow than it is to provide automatic isolation valves on the tower cells; nozzles and weirs cost approximately $300 to $500 per cell while automatic isolation valves cost $1,500 to $2,000 per cell.

Cooling Tower Limitation for Centrifugal Fan Application

Our final proposed measure addresses the application of cooling towers with centrifugal fans. Towers with centrifugal fans use approximately twice the energy of towers with propeller fans for the same heat rejection. The rated conditions in Section 112 of the AB970 Standards (Section 112, Table 1-C7) reflect this: 38.2 gpm/hp for propeller and axial fans and 20.0 gpm/hp for centrifugal fans. There are three applications where centrifugal fans may be required:

1. For low profile applications, centrifugal blow-through towers can be built lower than draw-through towers with propeller fans.

2. For applications with high static pressure like towers that are sited in a well and require ducted inlet or outlet air.

3. For noise sensitive applications.

The first application is completely aesthetic and can usually be accommodated through careful location of the tower or the application of architectural screens. The second application (high static pressure) is legitimate and should be accommodated through the standard. The third issue can generally be accommodated through application of low-noise propeller blades (a relatively new product), careful siting of the tower and the application of variable speed controls on the tower fans.

Since there are no cost premiums for propeller towers and they save ½ the energy this measure is immediately cost effective.

Benefits

As shown below, the restriction on air-cooled chillers will drastically reduce both energy and demand. Even with the pumping energy included our study indicates that water-cooled plants use less than half the energy in all three climates that we simulated.

The requirement for tower flow turndown will save both energy and first cost of chilled water plants.

The requirement for propeller or axial fans will save both energy and demand with no little or no addition of first cost.

Environmental Impact

The limitation on air-cooled chillers will increase both water consumption and the use of chemicals (biocides) for water treatment but these impacts will be offset by a significant reduction in both electrical energy and demand.

The requirements for tower flow turndown and limitation on centrifugal fans offers savings in energy and demand with no adverse environmental impacts.

Type of Change

We propose three new prescriptive requirements:

1. A limitation on the capacity of air-cooled chillers in central chilled water plants

2. A requirement for design of cooling towers to accommodate variable flow

3. A limitation on the application of centrifugal fans for cooling towers

No changes are anticipated for the ACM Manual. Changes will be required for the Non-Residential Users manual and compliance forms.

Technology Measures

Measure Availability and Cost

Both cooling towers and water-cooled chillers are readily available from multiple providers. The principal manufacturers of cooling towers are Marley, Evapco and BAC. The principal manufacturers of chillers are Carrier, York, Trane and McQuay. All of these manufacturers distribute their products through district and regional sales offices. It is anticipated that the manufacturing base can easily adjust to changes as a result of the proposed measure.

All three manufacturers of cooling towers have product lines with centrifugal and propeller fans. They also all have the ability to provide tower flow turndown through application of nozzles and weirs using existing parts.

Our first cost estimates are detailed in Table 1 and Table 2 below. Table 1 presents the cost estimates for the water-cooled plants and Table 2 details the cost estimates for the air-cooled plants and summarizes the incremental costs for the water-cooled plant. Costs are developed for three plant sizes; 200, 400 and 600 tons. As noted in the table, both first- and annual-cost data were collected from a wide variety of sources, including vendors, a water treatment company, a mechanical contractor, a service company, and RS Means Mechanical Cost Data Book. Costs not specifically listed in the tables are assumed to be equal in both cases. For example, installation and maintenance costs are not listed for the water or air-cooled chillers as they are roughly equal.

Table 1

Equipment Selections and Cost Data				
Water Cooled Chillers				
chiller first cost	**200 ton Plant**	**400 ton Plant**	**600 ton Plant**	**Data Source**
num chillers	2	2	2	
tons/chiller	100	200	300	
chiller type	screw	screw	centrifugal	
chiller cost ($/ton)	$ 323	$ 244	$ 299	Average of costs from Trane, Carrier, York
chiller cost (includes tax, freight)	$ 64,667	$ 97,779	$ 179,133	
chiller penthouse cost ($/sf)	$30	$30	$30	estimate
incremental penthouse area (sf)	600	800	1000	based on Electronic Arts penthse.
incr. Penthouse cost	$ 18,000	$ 24,000	$ 30,000	
CW pump head	40	40	40	from EA and other designs
CW pump GPM	163.3	304.2	493	from the CoolTools optimization
Num CW pumps	2	2	2	based on pump vendor data +
CW pump first costs (incl installation)	$ 3,591	$ 4,388	$ 5,456	Means labor costs. See Figure 6
chiller room exhaust fan CFM	1400	2000	2500	per UMC (based on lbs of refrigerant)
chiller room fan cost ($/cfm)(fan+labor)	$ 2.48	$ 2.48	$ 2.48	Southland (mech. contractor)
chiller room fan cost ($) (fan+labor)	$ 3,472	$ 4,960	$ 6,200	
refrig monitoring system cost	$ 7,500	$ 7,500	$ 7,500	Southland (mech. contractor)
Tower cost in San Francisco (65 wb)	$ 13,080	$ 18,520	$ 31,000	tower manufacturer (includes tax, freight)
Tower cost in Long Beach (70 wb)	$ 10,820	$ 17,540	$ 25,300	does not include VSD, contractor markup, installation
Tower cost in Fresno (73 wb)	$ 10,380	$ 16,520	$ 25,300	
Tower installation cost	$ 6,700	$ 8,000	$ 10,000	MEANS 2002 p. 469
Tower HP (per cell)	7.5	10.0	15.0	
Tower VSD $/HP	250	250	250	
Tower VSD Cost	$ 3,750	$ 5,000	$ 7,500	
CW treatment installed cost	$ 3,128	$ 4,061	$ 5,399	Chem Aqua
Tower/Chem. Maintenance ($/yr)	$ 4,000	$ 4,000	$ 4,000	Southland, tower vendor, Linford Service
Water Rate ($/100 ft3)	$ 1.98	$ 1.98	$ 1.98	EBMUD website
Cycles of Concentration	4	4	4	Chem Aqua - statewide average
SF Tower Load (Mbtu)	1,492	2,985	4,477	
gallons evaporated	192,328	384,657	576,985	970 btu/lb water
gallons bled	48,082	96,164	144,246	
SF Water Cost/yr	$ 636	$ 1,273	$ 1,909	
Fresno Tower Load (Mbtu)	2,986	5,973	8,959	
Fresno water cost/yr	$ 1,273	$ 2,547	$ 3,820	
Long Beach Tower Load (Mbtu)	3,731	7,462	11,194	
Long Beach water cost/yr	$ 1,591	$ 3,182	$ 4,773	
Piping/Fitting/Valve Costs	$ 9,000	$ 12,000	$ 17,000	Means, Southland (see Figure 5)
Contractor Markup	25%	25%	25%	estimate
First cost - San Francisco	$ 157,722	$ 222,380	$ 360,587	
First cost - Long Beach	$ 154,897	$ 221,155	$ 353,462	
First cost - Fresno	$ 154,347	$ 219,880	$ 353,462	
Annual Cost - San Francisco	$ 4,636	$ 5,273	$ 5,909	
Annual Cost - Fresno	$ 5,273	$ 6,547	$ 7,820	
Annual Cost - Long Beach	$ 5,591	$ 7,182	$ 8,773	

Table 2

Air Cooled Assumptions	200 ton Plant	400 ton Plant	600 ton Plant	
num chillers	2	2	2	
cost/chiller	$ 37,668	$ 70,313	$ 100,286	data from Trane, Carrier, York
chiller cost	$ 75,336	$ 140,625	$ 200,572	
incremental screen wall length (ft)	30	40	50	estimate
screen wall cost ($/ft)	5	5	5	estimate
screen cost	$ 150	$ 200	$ 250	
Air cooled first cost	$ 75,486	$ 140,825	$ 200,822	
Incremental Cost (Water Minus Air)				
Incr. First cost - San Francisco	$ 82,236	$ 81,555	$ 159,765	
Incr. First cost - Long Beach	$ 79,411	$ 80,330	$ 152,640	
Incr. First cost - Fresno	$ 78,861	$ 79,055	$ 152,640	
Avg	$ 80,169	$ 80,313	$ 155,015	
Incr. Annual Cost	see Annual Cost above			

Flow Turndown

Costs for tower nozzles/weirs were collected from two of the major cooling tower manufacturers: Marley and Baltimore Air Coil. The incremental cost to add the nozzles/weirs necessary for a 3:1 turndown ratio on a typical 200 – 600 ton tower is about $300 to $500. A controls contractor, Siemens Controls, provided an estimate to automate an isolation valve on a tower in this size range ($2,000). This price includes the actuator and all controls, but not the actual valve itself since a manual isolation valve would still be required in the base-case scenario.

Centrifugal Fans

No costs were collected in support of this measure. Our experience is that there is no significant cost difference between towers with centrifugal and propeller fans in the larger plant applications (300 tons and above).

Useful Life, Persistence and Maintenance

Both air and water-cooled chiller plants require maintenance but water-cooled plants require more maintenance due because of the cooling tower and associated water treatment.

Cooling tower performance degrades over time from the following effects:

- Fouling of the fill from debris and precipitation of dissolved solids
- Slippage of fan belts and dirt or wear of the bearings
- Dirt in the fan wheels (centrifugal tower fans)
- Fouling in the nozzles

All of these items can be addressed with routine maintenance and automatic water treatment. In extreme cases nozzles and fill will need to be replaced.

Air-cooled chillers degrade in time from:

- Fouling of the condenser coil
- Rusting of the condenser coil fins
- Slippage of fan belts and dirt or wear of the bearings

Unfortunately air-cooled condensing coils are much harder to clean than tower fill. Fouled or rusted condensers usually leads to replacement of the entire chiller.

The compressors in air-cooled chillers are more susceptible to early failure than the compressors in water-cooled chillers due to the expanded range of condensing temperatures that they experience. Our experience is that the service life of an air-cooled chiller is ~ 15years. Water-cooled chillers and towers are closer to 20 years. (The 1999 ASHRAE Applications Handbook lists service lives of 20 years for air-cooled chillers, 20-23 years for water-cooled chillers and 20-34 years for cooling towers.)

As a conservative assumption we assumed that the maintenance costs of air and water-cooled chillers are equal (and therefore not included in the tables above) and the only incremental maintenance is for the cooling tower. Incremental maintenance costs are included in the tables above.

An additional conservative assumption that we made is that both air and water-cooled plants have an expected life of 15 years.

Performance Verification

It is very difficult to measure the performance of cooling towers in the field. CTI/ATC has a field performance test procedure that costs in practice $5,000 to $10,000 to implement. We have NEVER heard of this test performed on a commercial building (it is routinely applied to towers connected to power plants). Key factors that make this difficult include the need for water flow measurements, outdoor air wet-bulb measurements and assessment of tower air recirculation (entrainment of discharge air).

We do not recommend any new performance verification measures for these requirements. Standard start-up procedures are adequate to ensure performance of the system and new measures are unlikely to be either practical or cost-effective.

Relationship to Other Measures

No other measures are affected by this change.

Methodology

The following section describes our methodology for the analysis of the air-cooled chiller limitation. As described below we simulated three sizes of chilled water plants in three climate zones. The three plant sizes correspond to the break points in minimum water-cooled chiller efficiencies in Section 112 of the Standard. The three climates were chosen to represent the full range of design wet-bulb temperatures in California.

There is no analysis performed to support the flow turndown requirement; this requirement is immediately cost effective because it saves both energy and first cost. As previously stated, it is far more efficient to run tower water through multiple cells due to the near cube law efficiency of the fans; running two fans at ½ speed uses approximately ¼ of the energy of running one fan at full speed for the same heat rejection. On the design side, it is less expensive to design the tower for variable flow than it is to provide automatic isolation valves on the tower cells; nozzles and weirs cost approximately $300 to $500 per cell while automatic isolation valves cost $1,500 to $2,000 per cell.

There is also no analysis performed to support the limitation on centrifugal fan cooling towers. As previously stated propeller or axial fan towers provide the same heat rejection at the same cost but use approximately ½ of the energy. This measure is also immediately cost effective as it provides energy cost savings with little or no cost premium.

Simulation Using DOE2 Office in California

We simulated a generic 10 story, 100,000 sf building with Title-24 non-residential defaults for occupancy, building envelope, etc. We ran 12 parametric runs: 4 models in 3 climate zones.

- 3 climate zones:

- San Francisco (Mild) - 84/65 dry-bulb/wet-bulb design conditions
- Long Beach (Intermediate) – 97/70 dry-bulb/wet-bulb design conditions
- Fresno (Extreme) – 104/73 dry-bulb/wet-bulb design conditions

- One air-cooled model.
- 3 water-cooled models because the T-24 minimum efficiencies are different for the 3 sizes of chillers used for the different plant sizes. (Air-cooled minimum efficiencies did not change). The energy results for each run were scaled as required to model different installed plant capacities. In each case we assumed that the scaled peak load was equal to 90% of the installed plant capacity.

Modeling Assumptions

Our modeling assumptions are summarized in Table 3, Table 4 and Table 5 below. Table 3 details the general economic and modeling assumptions that were used in both the air- and water-cooled plant models. Table 4 details the modeling parameters particular to water-cooled plants. Table 5 details the modeling parameters particular to water-cooled plants.

Table 3 – General Modeling Assumptions for All Plants.

General Assumptions (both Cases)		
economic criteria	CEC avg annual PV (1.02, 7.04)	
climate zones (1% data)	CZ3: SF CO (84/65) CZ6: Long Beach CO (97/70) CZ12: Fresno AP (104/73)	These represent a large percentage of population and range of climates. If we are to propose a rule, we should run all climate zones
plant sizes	200, 400, 600 ton	little chance of success mandating WC below 200 t
peak load sizes	180, 360, 540 ton	90% of plant capacity
bldg size	100 x 100 ft square, 10 stories	
simulation runs	4 runs per CZ: (3) WC+(1) AC	since 200, 400, and 600 ton WC plants have different efficiencies and curves.
window wall ratio	50%	typical
envelope/internal load assumptions	per ACM	
All chilled water pipe costs are same for both cases		
CHW setpoint	44	per ACM
CHW delta T	10	per ACM
CHWST control	44 fixed	
zone min air flow ratio	0.4	
zone min outside air	0.15 cfm/sf	
AHU suppply air temperature (SAT)	55F when OAT >= 60F	
SAT control	reset to 60F when OAT <=55	
economizer	drybulb	
drybulb hi limit	75F	

Table 4 - Modeling Assumptions for Water-Cooled Plants

Water Cooled Modeling Assumptions		
chiller type and T-24 min efficiencies	200t = (2) 100t screw (4.45 COP = 0.2247 EIR, 4.50 IPLV)	
	400t = (2) 200t screw (4.90 COP = 0.204 EIR, 4.95 IPLV)	
	600t = (2) 300t centrif (6.10 COP = 0.1639 EIR, 6.10 IPLV)	
chiller curves	DOE-2 defaults for W.C. screw, centrif	
CW pump selection	GPMs from the CoolTools optimization, Head from EA and other designs	
chiller min unloading	0%	DOE-2 does not do a good job modeling start/stop losses
chiller HGB	15%	ACM min unload default is 10% centrif, Screw 15%
chiller staging	max out 1st before bringing on second	
Tower efficiency (EIR)	0.01	based on manufacturer's cost/performance data
CW approach	7 degree F	common practice
CW delta T	18	based on CoolTools optimization
CWST setpoint	fixed at design wb	

Table 5 – Modeling Assumptions for Air-Cooled Plants

Air Cooled Modeling Assumptions		
chiller type	200t = (2) 100t screw	
	400t = (2) 200t screw	
	600t = (2) 300t screw	
chiller efficiency	T-24 min = 2.8 COP (0.357 EIR), 2.8 IPLV	
chiller compressor vs fan power split	93% compressor, 7% fan	Carrier catalog
compressor EIR	0.3333	
fan EIR	0.0245	
chiller curves	DOE-2 defaults	
Min Air temp	70	default
	Below this, control action is initiated to maintain this min temp.	
chiller min unloading	0%	DOE-2 does not do a good job modeling start/stop losses
chiller HGB	15%	ACM min unload default is 10% centrif, Screw 15%

Economic Criteria

Assumptions:

- 15 year expected life of equipment
- 3% discount rate used to calculate present value of annual maintenance and water costs.
- Water utility rates were taken from the East Bay Municipal Utility District website (see water rate sensitivity analysis below).
- We used two sets of electricity cost criteria:
    - CEC PV - $1.37 as the present value of a kilowatt-hour saved over a 15 year life (This is the CEC standard value.)
    - CPUC TOU - The California Public Utility Commission Time Of Use rate has different value for the present value of a KWH saved based on time of use bins (Summer-Peak, Summer-Off-Peak, Winter-Mid-Peak, etc.)

Due to time and budgetary constraints, we did not apply the TDV cost methodology. As it was, the threshold justified using the flat rate electric cost is as low as we would recommend for a new requirement; this requirement will cause changes in both standard practice of engineers and in the balance of sales between vendors in the market place. Refer to the Life Cycle Cost Methodology Report by Eley Associates for further information on these electricity rates.

Results

Simulation and LCC Results

Figure 1 illustrates the relative amount of energy used for the two plant types and for the three climate zones. (The water-cooled results in this figure are using the 600 ton plant minimum efficiencies. The 200 and 400 ton water-cooled results are very similar.)

Figure 1

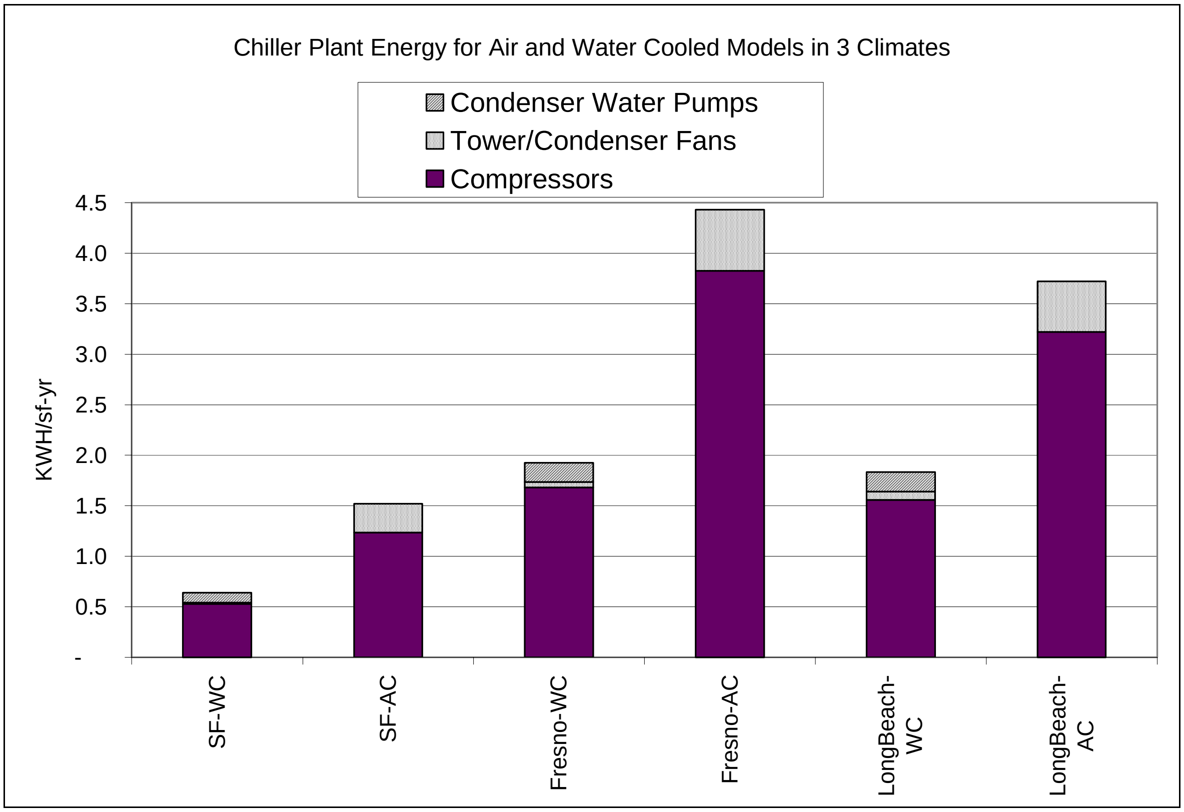
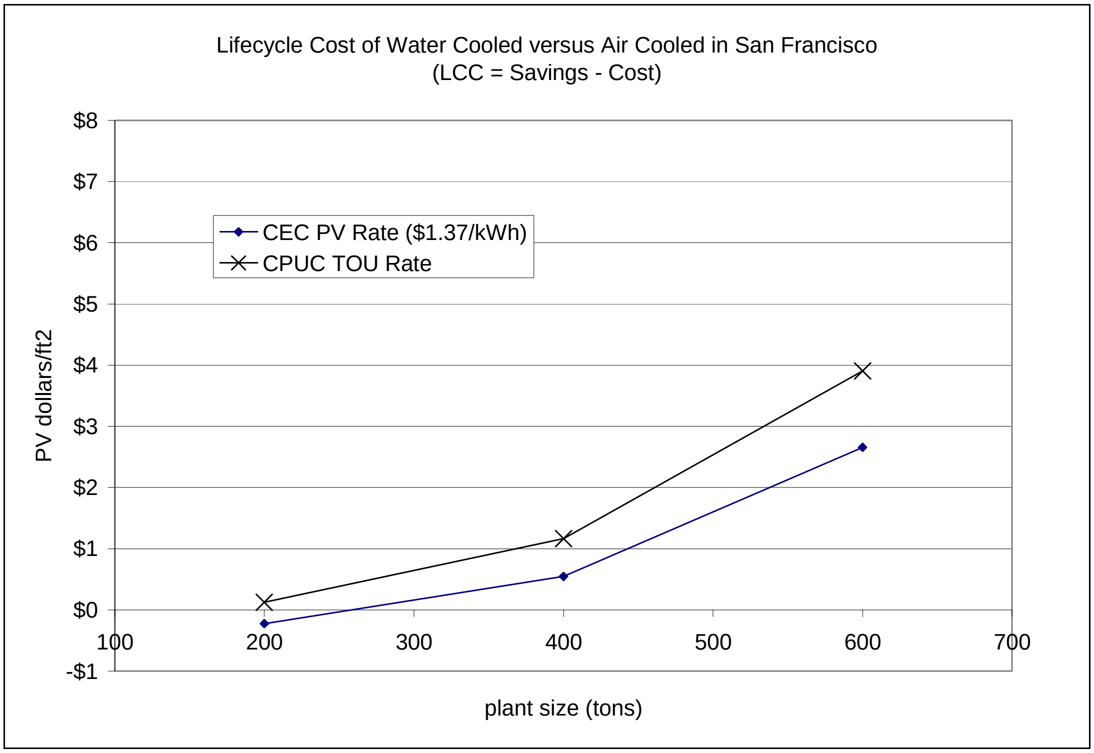


Figure 2, Figure 3, and Figure 4 show the lifecycle cost for San Francisco, Long Beach and Fresno, respectively. In each of these figures the present value of the life-cycle cost savings from a water-cooled plant is depicted on the y-axis as a function of the plant size (x-axis). Two sets of results are presented on these graphs: electricity costs using the CEC fixed present value equation and using the CPUC time of use rates. In each case the TOU rate structure justifies a more aggressive limitation of air-cooled plants. Lifecycle cost includes energy cost savings as well as incremental first costs and maintenance costs. These figures indicate that water-cooled is cost effective above 200 tons in all climate zones using the CPUC TOU rates and is cost effective above 250 tons in all climates using the CEC PV rate.

Figure 2



Lifecycle Cost of Water Cooled versus Air Cooled in San Francisco
(LCC = Savings - Cost)
CEC PV Rate ($1.37/kWh)
CPUC TOU Rate
PV dollars/ft2
$8
$7
$6
$5
$4
$3
$2
$1
$0
-$1
100
200
300
400
500
600
700
plant size (tons)

Figure 3

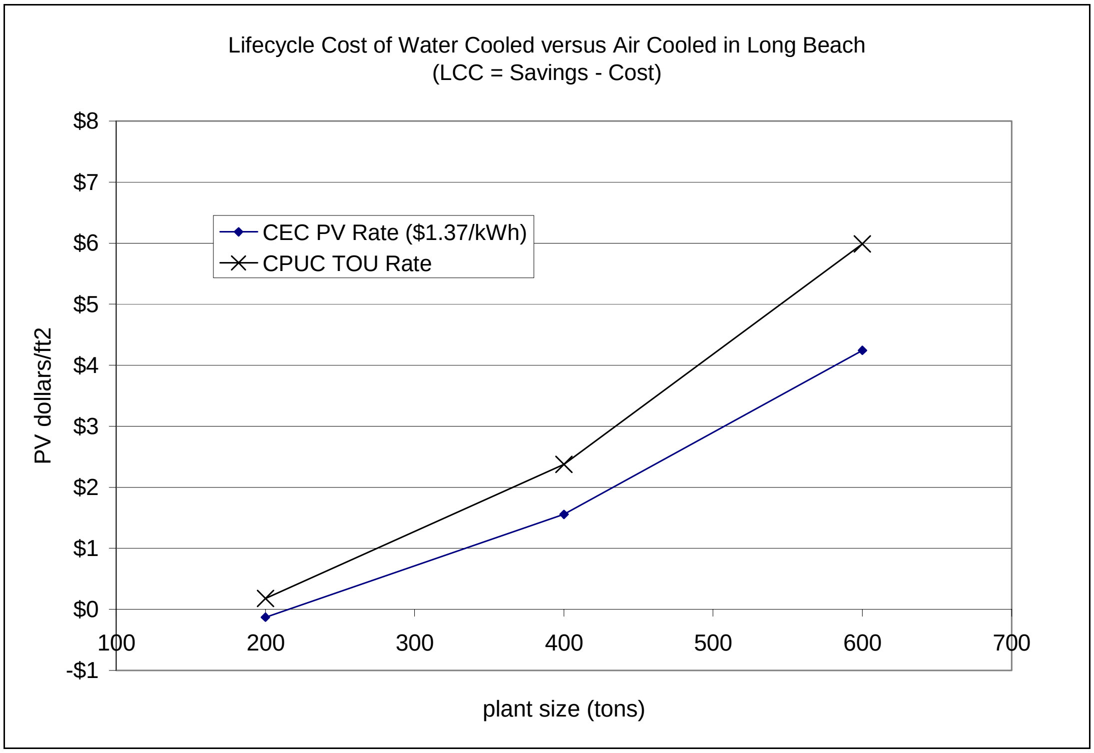
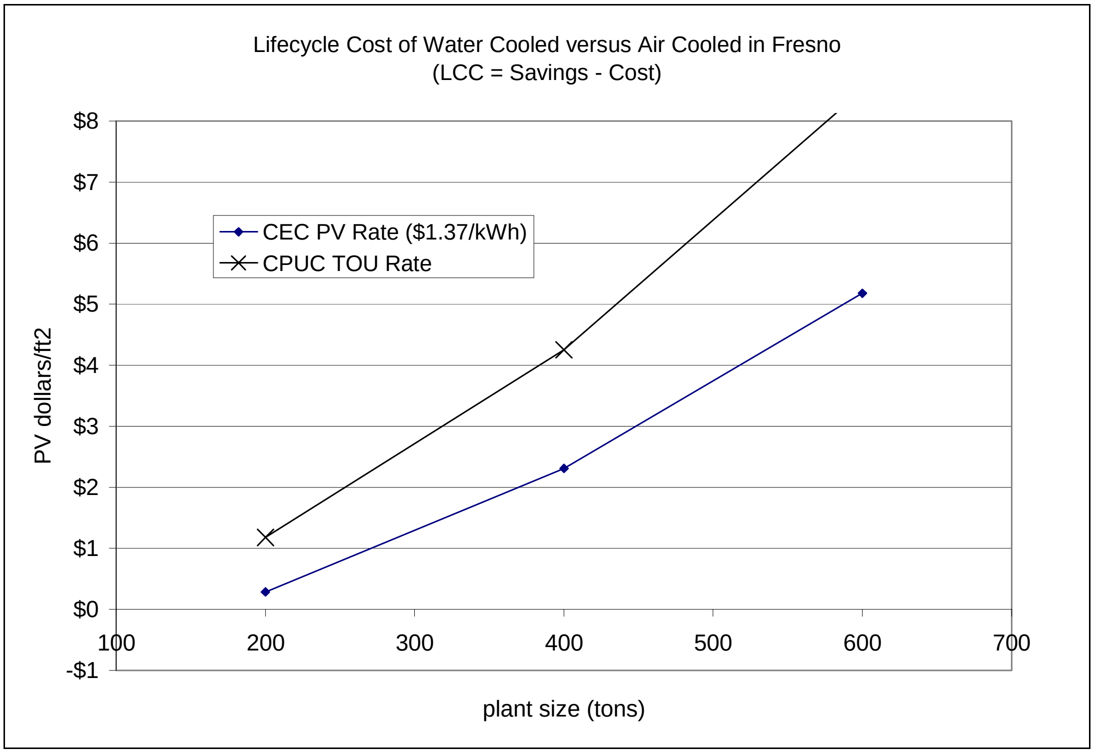


Figure 4



Cost Multiplier

Given the many different elements that are included in first cost and the various sources of cost data, there is a significant amount of uncertainty in the costs. Also, many of the costs that are assumed to be equal in both cases may in fact not be equal. In order to test the sensitivity to the cost assumptions we included a cost multiplier of 120% on all water-cooled plant first costs and incremental maintenance costs. The results of this sensitivity analysis are shown in the Appendices. With a 120% cost multiplier, the breakpoint moves up to about 300-400 tons for San Francisco, 250-300 tons for Long Beach and 200-250 tons for Fresno.

Water Rates

We used the current East Bay Municipal Utility District's commercial water rate. It turns out that the cost of the water used in the water-cooled scenario is only about 10% of the total present value cost. We ran a sensitivity analysis on water rate by more than doubling the water rate to $4.00 per 100 ft3. Doubling the cost of water has little impact on the results. The results of this sensitivity analysis are shown in the Appendices.

Recommendations

We recommend that chilled water plants over 300 tons be required to use water-cooled chillers rather than air-cooled chillers. Of course, air-cooled chillers are allowed if the Performance method of compliance is used.

We recommend that water-cooled plants with more than one chiller be required to have a flow turndown ratio of at least 2.5:1 on all cooling towers.

We also recommend a limitation on centrifugal fan cooling towers in plants over 300t of capacity.

Proposed Standards Language

Proposed New Prescriptive Requirement for Water-Cooled Plants

Chilled water plants shall employ water-cooled chillers.

Exceptions:

1. *Air-cooled chillers may be installed up to a maximum total installed capacity of 300t*

2. *Where it can be demonstrated to the authority having jurisdiction that the water quality prohibits the use of water-cooled equipment.*

Proposed New Prescriptive Requirement for Tower Flow Turndown

Heat rejection units configured with multiple condenser water pumps shall be designed so that all cells can be run in parallel with the larger of the flow that's produced by the smallest pump or 33% the design flow.

Proposed New Prescriptive Requirement for Limitation on Centrifugal Fan Cooling Towers

Heat rejection units serving cooling loads 300t and greater shall use propeller fans in lieu of centrifugal blowers.

Exceptions:

1. *If heat rejection units is located indoors and requires external static pressure capability*
2. *If an acoustical engineer certifies that acceptable noise levels cannot be achieved with a propeller fan tower.*
3. *If the heat rejection unis meets the energy efficiency requirement for propeller fan towers in Section 112, Table 1-C7.*

Proposed ACM Language

No changes are anticipated for the ACM manual.

Bibliography and Other Research

CTI ATC 105, Acceptance Test Code for Water-Cooling Towers. 1997. Houston TX.

CTI STD 201, Standard for the Certification of Water-Cooling Tower Thermal Performance. 1996. Houston TX.

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AB 970 Impact Analysis

Acknowledgments

PG&E sponsored this proposal under direction of Pat Eilert. The contractor for this project is the Heschong Mahone Group The analysis for this measure was performed by Jeff Stein, Mark Hydeman and Steve Taylor of Taylor Engineering. Incremental cost and estimated incremental labor data were provided by Bob Levi and Jon Malkovich of Carrier Corporation, Kurt Wessels of Trane Company, Bill Bates of York International, and Ben Clark of Norman Wright Company.

Appendices

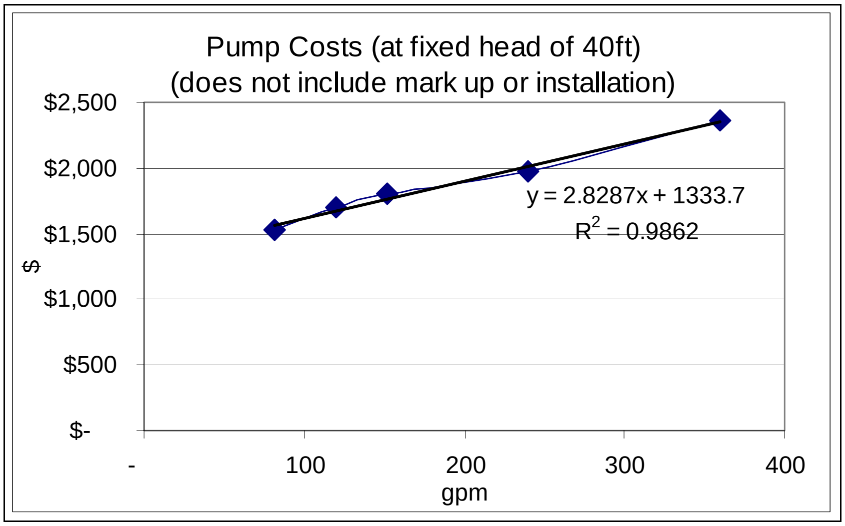
Piping Unit Prices and Takeoffs

Figure 5

Condenser Water Piping System Unit Prices and Material Takeoffs					
Includes prices for labor+materials to install the following:					
Fitting Allowance for Means		1.50			
	Local Contractor	**MEANS/Cooltools**	Count - No Aux load		
	Unit Prices ($/ft)		200t Plant	400t Plant	600t Plant
3" pipe length (incl. fittings)	41.2	31.38	169		
4" pipe length (incl. fittings)	49.92	38.46	4	188	
5" pipe length (incl. fittings)	58.32	52.19		4	208
6" pipe length (incl. fittings)	76.42	69.52			4
8" pipe length (incl. fittings)	87.86	90.34			
valves:	Unit Prices ($/item)				
1" shut off (ball)	50.24	38.11	3	3	3
2" shut off (ball)	99.29	83.12	2	2	2
3" shut off (bfly)	271.25	243.01	8		
4" shut off (bfly)	354.65	401.49		8	
5" shut off (bfly)	488.75	474.75			8
8" shut off (bfly)	538.75	707.19			
3" check valve	367.89	483.20	2		
4" check valve	461.96	411.36		2	
5" check valve	543.95	536.73			2
3" strainer	372.88	339.51	2		
4" strainer	394.56	605.06		2	
5" strainer	587.12	1,959.57			2
3" flex connection	278.36	170.92	4		
4" flex connection	366.25	242.94		4	
5" flex connection	468.24	375.28			4
peet's plugs	38.98		8	8	8
pump pressure gages with tubing	103.89		2	2	2
thermometers	108.29		4	4	4
Refrigerant monitoring equip	7500		1	1	1
Exhaust Fan installation Cost	2.48 per cfm		includes fan		
CW Chemical Treatment System	10 per gal				
Tower Maint Cost ($/yr)	4000		per year		

Pump Costs

Figure 6



Sensitivity Analysis: 120% Cost Multiplier

Figure 7

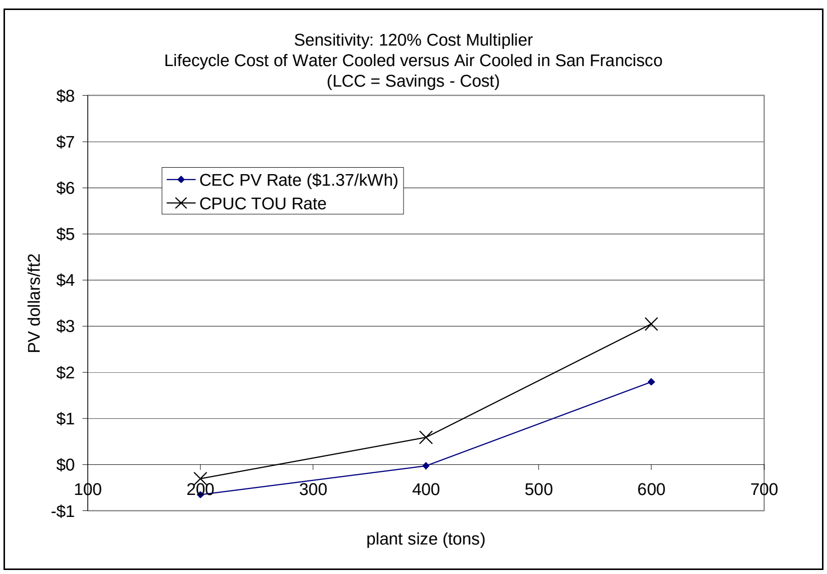


Figure 8

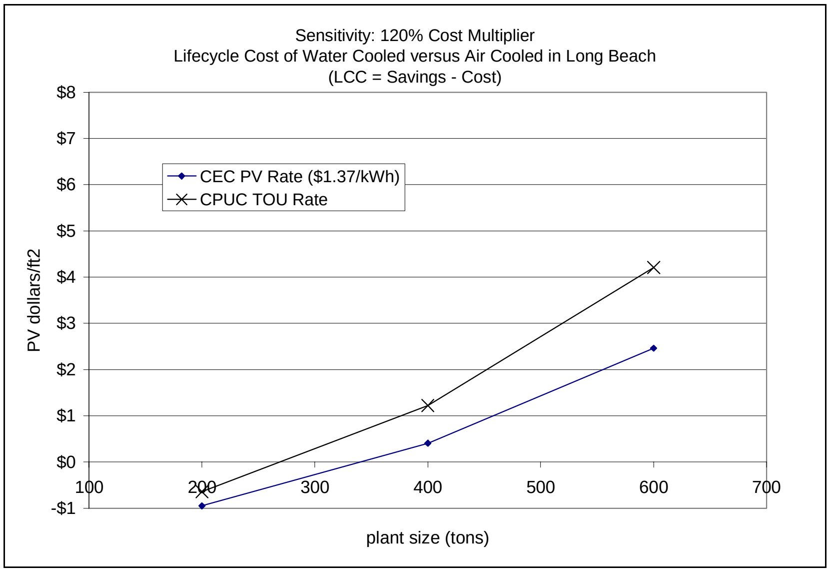
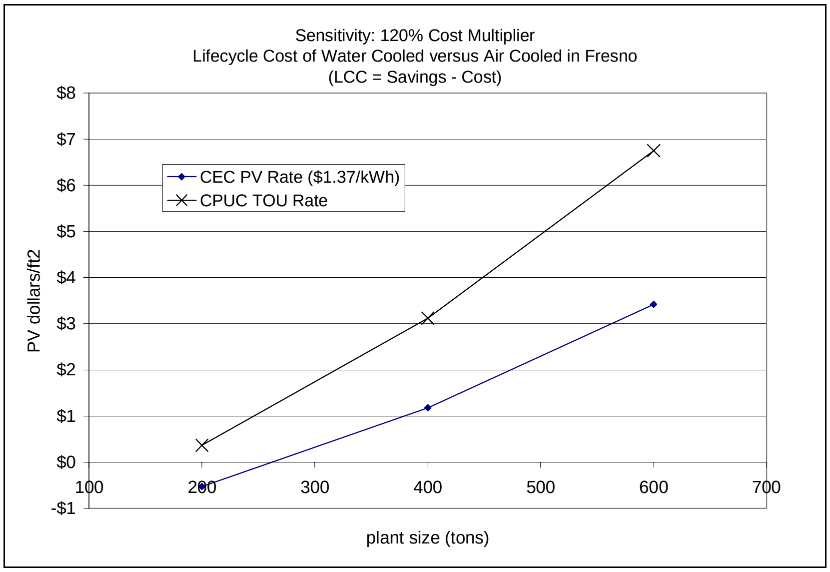


Figure 9



Sensitivity Analysis: Double Water Rates

Figure 10

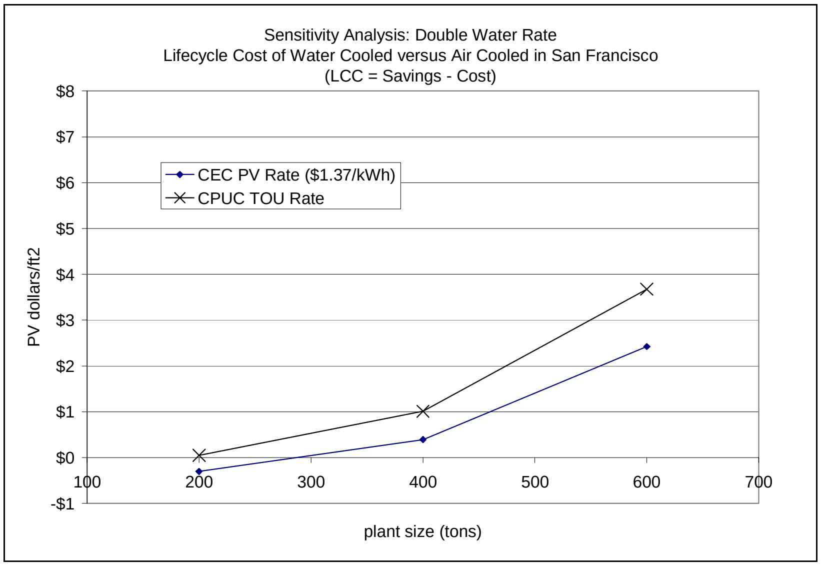


Figure 11

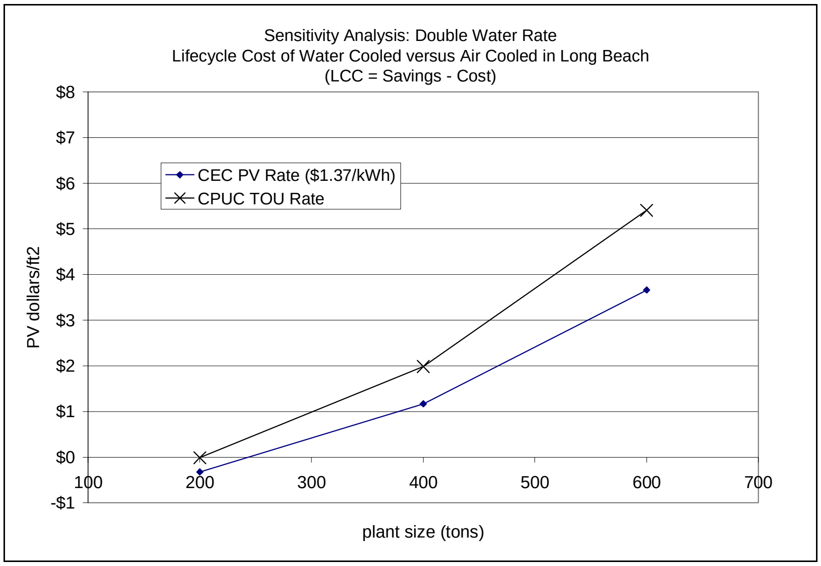
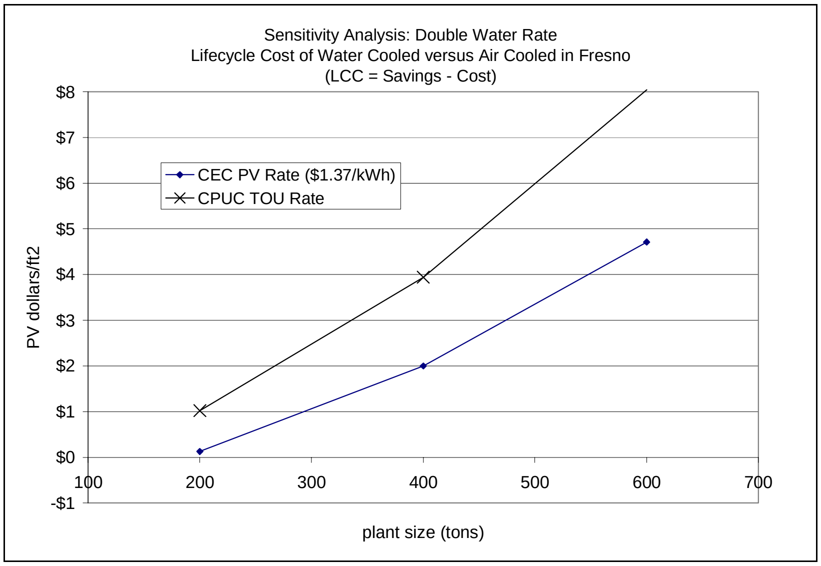


Figure 12



Sensitivity Analysis: Double Water Rate
Lifecycle Cost of Water Cooled versus Air Cooled in Fresno
(LCC = Savings - Cost)
CEC PV Rate ($1.37/kWh)
CPUC TOU Rate
PV dollars/ft2
$8
$7
$6
$5
$4
$3
$2
$1
$0
-$1
100
200
300
400
500
600
700
plant size (tons)