HVAC&R ENGINEERING
update

Chiller-Plant Design in a Deregulated Electric Environment

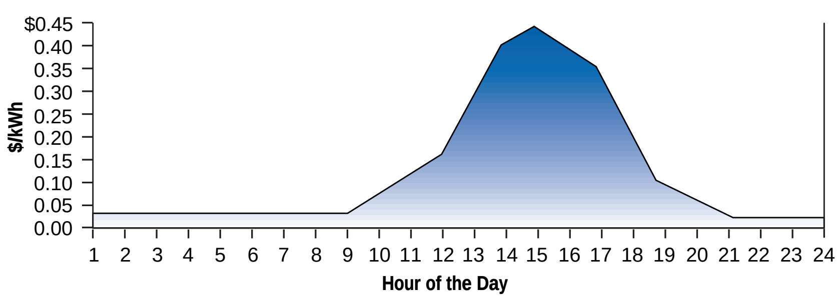
Electric deregulation means that the generation and distribution markets will be regulated solely by supply-and-demand economics. Current expectations are that deregulation will force the electric industry to slash costs, become more competitive, and ultimately provide lower average electric prices. This will be accomplished using two principal concepts: retail wheeling and real-time pricing (RTP).

- Retail wheeling, which has received the most attention thus far, allows low-cost producers in one area of the country to deliver electricity to customers in another area.
- RTP has received less attention, but may have greater impact on chiller-plant economics. RTP reflects the real cost of producing and delivering electricity at a given point in time. RTP prices are developed from daily cost information and can vary hourly, depending on conditions such as weather and demand.

‘Peak’-ing Ahead

On the surface, deregulation sounds like a great idea. Everyone is interested in less expensive power. However, blindly accepting the generally predicted results of lower electricity prices may be a mistake for chiller-plant owners and designers. With RTP, you will be paying a variety of prices to operate your electric chillers — some lower than present, but also some higher. The overall price of electricity may decrease if you evaluate total dollars spent on all electrical uses in relation to total kilowatt-hours (kWh) purchased, but the cost of electricity during high-demand periods also may increase.

Figure 1: Sample RTP Schedule – Summer



This demand usually occurs at the same time as the peak electric-cooling load. Supply-and-demand economics tell us that during peak electric-demand periods, we will experience peak prices, as shown in the sample RTP schedule in Figure 1.

As bad as rates look in Figure 1, they could get even worse. During critical periods of demand, the marginal cost of supplying power may escalate by a factor of 20, or even 50. That could mean that a customer paying $.05 per kWh during low-demand periods may pay as high as $2.50 per kWh when electricity is in high demand.

Could rates really get that high? The answer is: they already have. In Southern California, utilities who are spearheading the move to RTP have issued rate structures with on-peak rates as high as $3.50/kWh. Such rates can have a major impact on chiller-plant design.

In this Update, you will see how RTP impacts the energy bill of an all-electric chiller plant. Then, we will compare this cost to the expense of operating various hybrid plants utilizing a combination of electric and alternative-drive (non-electric) chillers. You’ll see how employing a mix of chiller technologies can help you exploit RTP to substantially cut your overall energy bill.

A ‘Cool’ Forecast

To understand the impact of RTP on chiller plants, we must examine building loads, electric rates and their relationship to weather data. Although a straight-line relationship

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between building loads and weather data is not always accurate for industrial and commercial cooling applications, it is suitable for the purposes of the illustrations in this paper. Plus,some suppliers are basing their RTP schedules on the ASHRAE temperature bins.

ASHRAE has organized hours into five-degree temperature bins. Chiller operating costs can be analyzed by estimating the load in each of the bins, and assigning a cost to the power sold during each hour in that bin.

The first step in this type of analysis is shown in Figure 2. Harrisburg, PA weather data is used for this example. In addition to the annual hours spent in each temperature bin, the graph also shows the typical entering-condenser-water temperature (ECWT) available for that bin. For this analysis, it is assumed that the chillers are turned off below 55°F outdoor temperature.

Highs and Lows

When using electric chillers in conjunction with the sample RTP schedule, it's vital to understand how this pricing structure will affect electricity bills. Figure 3 combines the RTP data from Figure 1 with the weather data from Figure 2 to show the RTP for each of the temperature bins.

This RTP schedule has a low electric price ($.03/kWh) during low electric-demand hours (which corresponds to low building-load hours) and a high price ($.45/kWh) during high electric-demand hours (high building-load hours). Although the vast majority of operating hours are at lower loads, when electricity costs less, there are significant hours of operation when electric prices are high.

This leads us to the following hypothesis: For facilities to benefit economically in a deregulated environment, electric chillers should operate primarily during low-load, low-cost hours of operation, while alternative-drive (non-electric) chillers run during high-load, high-cost hours. This is the key to lowest life-cycle cost.

One strategy is to design chiller plants containing both electric-drive and alternative-drive (hot water, steam or gas) chillers. These are known as hybrid systems. Hybrid systems offer the flexibility to operate with the energy source that provides the greatest operating economics. Staging chillers in a hybrid plant can be accomplished by determining the lowest cost-per-hour of each chiller at a given utility price.

Figure 2: Temperature Bins, Hours, and Entering-Condenser-Water Temperatures

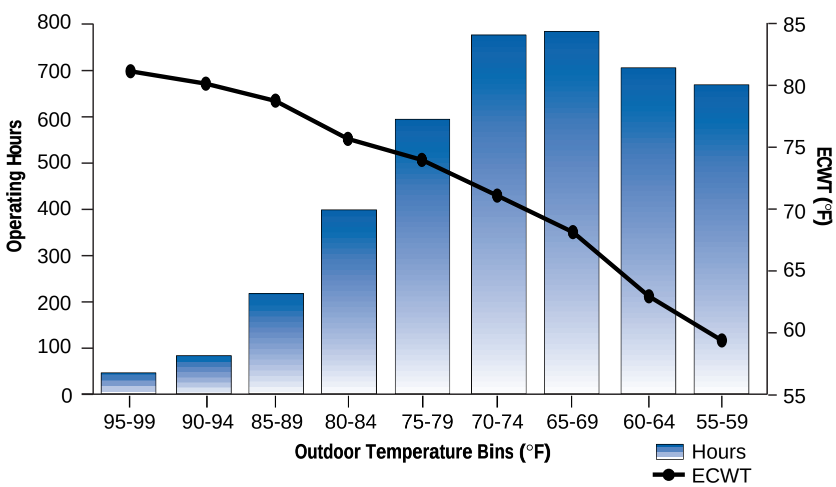
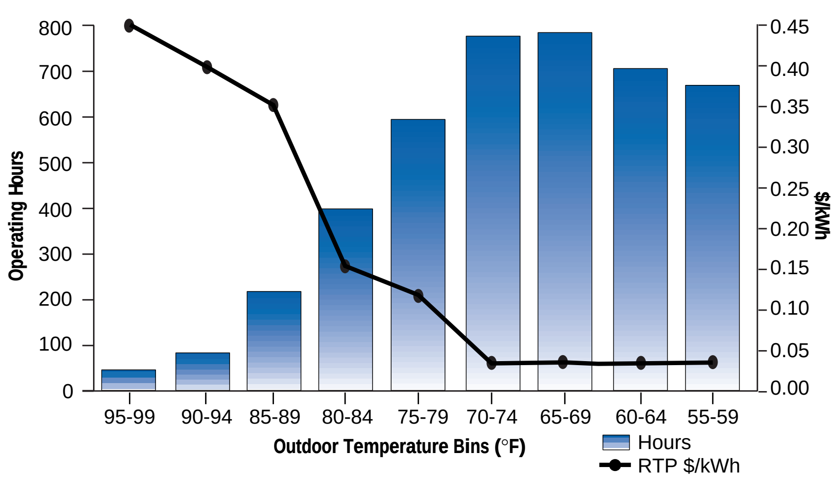


Figure 3: Temperatures, Hours, and Electric Costs



Testing 1, 2, 3 ...

Let's test the above hypothesis. We will analyze a chiller-plant example comparing a base plant of all electric chillers with a variety of hybrid plants. Each plant will serve a maximum load of 800 tons, with 2.4 GPM/ton of chilled water from 54°F to 44°F, and 3.0 GPM/ton of condenser water from 85°F to 95°F.

Electricity costs will be based on the RTP schedule in Figure 1, and a gas price of $.35 per therm will be assumed. Where steam is used, it will be created in a gas boiler. We'll compare operating costs and equipment costs. Data will be generated from actual equipment ratings using YorkCalc™ Energy Analysis Program.

The first-cost differential of the hybrid plants will be compared to the operating-cost differential to determine a simple payback as compared to the base plant.

First, a note on equipment costs: a complete evaluation would require examining the total installed costs rather than simply equipment costs. While electric chillers require electrical service and switchgear, alternative-drive units may require exhaust systems, steam piping or larger cooling towers. Due to these variables, equipment first-cost is used for this example. However, a maintenance premium was included in the operating cost of the gas-engine-drive centrifugal units.

The base chiller plant (Figure 4) consists of two 500-ton electric centrifugal chillers. This plant has an annual operating cost of $95,799 and equipment cost of $252,000. Next, we'll look at a variety of hybrid plants to see how they compare to the base plant's performance.

Figure 4: All-Electric Plant
Two 500-Ton Electric Centrifugal Chillers

TEMP BIN	HRS	TONS LOAD	ECWT	kW/TON	kW DRAW	kWh	RTP $/kWh	COST OF OPERATION
95-99	20	800	82	0.527	422	8,432	$0.45	$ 3,794
90-94	84	742	81	0.517	384	32,224	0.40	12,889
85-89	216	687	79	0.504	346	74,790	0.35	26,176
80-84	393	632	76	0.487	308	120,959	0.15	18,144
75-79	585	577	74	0.479	276	161,684	0.10	16,168
70-74	775	522	72	0.476	248	192,566	0.03	5,777
65-69	784	467	68	0.468	219	171,348	0.03	5,140
60-64	706	412	63	0.475	196	138,164	0.03	4,145
55-59	670	357	59	0.497	177	118,877	0.03	3,566
								$95,799

	Equipment Cost	Operating Cost
CH-1	**$126,000**	
CH-2	**126,000**	
Total	**$252,000**	**$95,799**

Hybrid-Plant Operating Strategy

The traditional operating strategy for hybrid plants is to avoid peak electric charges by operating alternative-drive chillers during a defined on-peak period. The on-peak period is defined by the electric utility, and penalties such as demand or ratchet charges are applied to customers that operate electric chillers during peak periods.

RTP replaces the demand/non-demand schedule. Facility owners can now operate alternative-drive chillers during hours when electricity cost is high, and operate electric chillers when electricity cost is low. RTP provides many hours of operation with very low electric rates, typically when low ECWTs also are available.

The hybrid-plant operating strategy takes advantage of the relationship between load and hourly utility rates. The operating schedule may change daily in response to the electric rates. The strategy, however, remains the same — operate the chiller that has the lowest operating costs. An automation system that can monitor electric rates and determine the most cost-effective operating sequence will provide the lowest possible operating costs.

Traditional Hybrid Systems

A traditional hybrid plant incorporates two equally-sized chillers, an electric unit and an alternative-drive unit. The operating scheme for this plant requires the alternative-drive chiller to be base-loaded during hours of high electric costs. The electric chiller then handles the remaining load. This operating scheme is analyzed in Figures 5, 6, and 7 for a variety of hybrid plants. The simple payback is calculated against the base all-electric plant.

Figure 5 shows the performance of a hybrid plant consisting of a single-stage steam absorption chiller and an electric centrifugal chiller. Its operating cost is $6,053 less than the all-electric plant, while the equipment-cost premium is only $3,000, resulting in an almost immediate payback.

Figure 5: Hybrid Plant
Chiller #1: 500-Ton Single-Stage Steam Absorption Chiller
Chiller #2: 500-Ton Electric Centrifugal Chiller

TEMP BIN	HRS	TONS LOAD	ECWT	STEAM TONS	STEAM #/TON-HR	THERMS /HR	THERMS	GAS PRICE $/THERM	COST OF STEAM OPERATION	ELECTRIC TONS	kW/ TON	kW DRAW	kWh	RTP $/kWh	COST OF ELECTRIC OPERATION	TOTAL OPERATING COSTS
95-99	20	800	82	500	18.00	108.00	2,160	$0.35	$ 826	300	0.560	168	3,360	$0.45	$1,512	$ 2,338
90-94	84	742	81	500	17.60	105.60	8,870	0.35	3,399	242	0.540	131	10,977	0.40	4,391	7,789
85-89	216	687	79	500	16.90	101.40	21,902	0.35	8,422	187	0.590	110	23,831	0.35	8,341	16,763
80-84	393	632	76	500	16.50	99.00	38,907	0.35	14,993	132	0.620	82	32,163	0.15	4,824	19,817
75-79	585	577	74	500	16.10	96.60	56,511	0.35	21,826	77	0.690	53	31,081	0.10	3,108	24,934
70-74	775	522	72	0	0.00	0.00	0	0.35	0	522	0.475	248	192,161	0.03	5,765	5,765
65-69	784	467	68	0	0.00	0.00	0	0.35	0	467	0.464	217	169,883	0.03	5,097	5,097
60-64	706	412	63	0	0.00	0.00	0	0.35	0	412	0.455	187	132,347	0.03	3,970	3,970
55-59	670	357	59	0	0.00	0.00	0	0.35	0	357	0.456	163	109,071	0.03	3,272	3,272
																$89,745

	Equipment Cost	Operating Cost	
CH-1	**$129,000**		
CH-2	**126,000**		
Total	**255,000**	**$89,745**	
Base Plant	**252,000**	**95,799**	**Simple Payback**
Delta	**$3,000**	**($6,054)**	**0.50 Years**

Figure 6 shows the performance of a hybrid plant consisting of a two-stage direct-fired absorption chiller and an electric centrifugal chiller. Its annual operating cost is $35,627 less than the all-electric plant, resulting in a simple payback of 2.5 years.

The hybrid plant analyzed in Figure 7 consists of a gas-engine-drive centrifugal chiller and an electric centrifugal chiller. The operating cost of $57,247 is the lowest of the three hybrid plants, resulting in a very reasonable payback of 3.6 years.

All three hybrid plants fully load the alternative-drive chiller during periods of high electric costs, while the electric chiller is only partially loaded. The resulting operating-cost savings offer some very reasonable paybacks that are well worth considering. But can we do better? Let's consider a non-traditional hybrid plant.

Non-traditional Hybrid Schemes

A non-traditional hybrid design sizes the alternative-drive chiller to service the ***entire*** load during high-cost electric hours, while an electric chiller sized for off-design conditions operates only during hours of low-cost electricity. The idea is to completely eliminate the use of an electric chiller during periods of high electric cost.

Figure 6: Hybrid Plant
Chiller #1: 500-Ton Two-Stage Direct-Fired Absorption Chiller
Chiller #2: 500-Ton Electric Centrifugal Chiller

TEMP BIN	HRS	TONS LOAD	ECWT	GAS TONS	MBTU/ HR	THERMS/ HR	THERMS	GAS PRICE $/THERM	COST OF GAS OPERATION	ELECTRIC TONS	kW/ TON	kW DRAW	kWh	RTP $/kWh	COST OF ELECTRIC OPERATION	TOTAL OPERATING COSTS
95-99	20	800	82	500	5,000	50.00	1,000	$0.35	$ 350	300	0.560	168	3,360	$0.45	$1,512	$1,862
90-94	84	742	81	500	4,800	48.00	4,032	0.35	1,411	242	0.540	131	10,977	0.40	4,391	5,802
85-89	216	687	79	500	4,600	46.00	9,936	0.35	3,478	187	0.590	110	23,831	0.35	8,341	11,819
80-84	393	632	76	500	4,400	44.00	17,292	0.35	6,052	132	0.620	82	32,163	0.15	4,824	10,877
75-79	585	577	74	500	4,200	42.00	24,570	0.35	8,600	77	0.690	53	31,081	0.10	3,108	11,708
70-74	775	522	72	0	0	0.00	0	0.35	0	522	0.475	248	192,161	0.03	5,765	5,765
65-69	784	467	68	0	0	0.00	0	0.35	0	467	0.464	217	169,883	0.03	5,097	5,097
60-64	706	412	63	0	0	0.00	0	0.35	0	412	0.455	187	132,347	0.03	3,970	3,970
55-59	670	357	59	0	0	0.00	0	0.35	0	357	0.456	163	109,071	0.03	3,272	3,272
																$60,172

	Equipment Cost	Operating Cost	
CH-1	**$214,500**		
CH-2	**126,000**		
Total	**340,500**	**$60,172**	
Base Plant	**252,000**	**95,799**	**Simple Payback**
Delta	**$88,500**	**($35,627)**	**2.48 Years**

Figure 7: Hybrid Plant
Chiller #1: 500-Ton Gas-Engine-Drive Centrifugal Chiller
Chiller #2: 500-Ton Electric Centrifugal Chiller

TEMP BIN	HRS	TONS LOAD	ECWT	GAS TONS	MBTU/ HR	THERMS/ HR	THERMS	GAS PRICE $/THERM	COST OF GAS OPERATION*	ELECTRIC TONS	kW/ TON	kW DRAW	kWh	RTP $/kWh	COST OF ELECTRIC OPERATION	TOTAL OPERATING COSTS
95-99	20	800	82	500	3,250	32.50	650	$0.35	$ 298	300	0.560	168	3,360	$0.45	$1,512	$ 1,810
90-94	84	742	81	500	3,100	31.00	2,604	0.35	1,205	242	0.540	131	10,977	0.40	4,391	5,598
85-89	216	687	79	500	2,925	29.25	6,318	0.35	2,967	187	0.590	110	23,831	0.35	8,341	11,308
80-84	393	632	76	500	2,725	27.25	10,709	0.35	5,124	132	0.620	82	32,163	0.15	4,824	9,948
75-79	585	577	74	500	2,600	26.00	15,210	0.35	7,371	77	0.690	53	31,081	0.10	3,108	10,479
70-74	775	522	72	0	0	0.00	0	0.35	0	522	0.475	248	192,161	0.03	5,765	5,765
65-69	784	467	68	0	0	0.00	0	0.35	0	467	0.464	217	169,883	0.03	5,097	5,097
60-64	706	412	63	0	0	0.00	0	0.35	0	412	0.455	187	132,347	0.03	3,970	3,970
55-59	670	357	59	0	0	0.00	0	0.35	0	357	0.456	163	109,071	0.03	3,272	3,272
																$57,247

	Equipment Cost	Operating Cost	
CH-1	**$265,000**		
CH-2	**126,000**		
Total	**391,000**	**$57,247**	
Base Plant	**252,000**	**95,799**	**Simple Payback**
Delta	**$139,000**	**($38,552)**	**3.61 Years**

*** Includes Maintenance Premium**

Figure 8 analyzes the performance of such a plant. The 850-ton single-stage steam absorption chiller handles the entire load above 79°F outdoor temperature, when electric costs are highest. Then a 650-ton electric centrifugal chiller takes over below 79°F. The operating cost is $27,019 less than the all-electric plant, and the payback is a very attractive 1.5 years.

An interesting point to note about this plant, and all the non-traditional hybrid plants, is that the 650-ton electric centrifugal chiller has a lower first cost than the 500-ton electric centrifugal chiller used in the traditional hybrid and all-electric plants. How can this be so? It is because the 650-ton chiller is selected for the off-design ECWT of 74°F maximum rather than the 85°F maximum required in the other types of plants. This means that a smaller chiller can handle more tons. As a result, a non-traditional hybrid plant is not only cheaper to operate, it also has more redundancy because of its higher installed capacity.

The plant analyzed in Figure 9 consists of an 850-ton two-stage direct-fired absorption chiller and a 650-ton electric centrifugal chiller. The operating cost of $52,765 results in a payback of 5.2 years.

Figure 8: Non-Traditional Hybrid Plant
Chiller #1: 850-Ton Single-Stage Steam Absorption Chiller
Chiller #2: 650-Ton Electric Centrifugal Chiller

TEMP BIN	HRS	TONS LOAD	ECWT	STEAM TONS	STEAM #/TON-HR	THERMS /HR	THERMS	GAS PRICE $/THERM	COST OF STEAM OPERATION	ELECTRIC TONS	kW/ TON	kW DRAW	kWh	RTP $/kWh	COST OF ELECTRIC OPERATION	TOTAL OPERATING COSTS
95-99	20	800	82	800	18.1	173.76	3,475	$0.35	$ 1,276	0	0.0	0	0	$0.45	$ 0	$ 1,216
90-94	84	742	81	742	17.8	158.49	13,313	0.35	4,660	0	0.0	0	0	0.40	0	4,660
85-89	216	687	79	687	17.4	143.45	30,984	0.35	10,844	0	0.0	0	0	0.35	0	10,844
80-84	393	632	76	632	16.9	128.17	50,371	0.35	17,630	0	0.0	0	0	0.15	0	17,630
75-79	585	577	74	0	0.0	00.00	0	0.35	0	577	0.486	280	164,047	0.10	16,405	16,405
70-74	775	522	72	0	0.0	00.00	0	0.35	0	522	0.475	248	192,161	0.03	5,765	5,765
65-69	784	467	68	0	0.0	00.00	0	0.35	0	467	0.464	217	169,883	0.03	5,097	5,097
60-64	706	412	63	0	0.0	00.00	0	0.35	0	412	0.455	187	132,347	0.03	3,970	3,970
55-59	670	357	59	0	0.0	00.00	0	0.35	0	357	0.445	159	106,440	0.03	3,193	3,193
																$68,780

	Equipment Cost	Operating Cost	
CH-1	**$176,000**		
CH-2	**117,000**		
Total	**293,000**	**$68,780**	
Base Plant	**252,000**	**95,799**	**Simple Payback**
Delta	**$41,000**	**($27,019)**	**1.52 Years**

Figure 9: Non-Traditional Hybrid Plant
Chiller #1: 850-Ton Two-Stage Direct-Fired Absorption Chiller
Chiller #2: 650-Ton Electric Centrifugal Chiller

TEMP BIN	HRS	TONS LOAD	ECWT	GAS TONS	MBTU/ HR	THERMS/ HR	THERMS	GAS PRICE $/THERM	COST OF GAS OPERATION	ELECTRIC TONS	kW/ TON	kW DRAW	kWh	RTP $/kWh	COST OF ELECTRIC OPERATION	TOTAL OPERATING COSTS
95-99	20	800	82	800	9,400	94.00	1,880	$0.35	$ 658	0	0.0	0	0	$0.45	$ 0	$ 658
90-94	84	742	81	742	8,485	84.85	7,127	0.35	2,495	0	0.0	0	0	0.40	0	2,495
85-89	216	687	79	687	7,659	76.59	16,543	0.35	5,790	0	0.0	0	0	0.35	0	5,790
80-84	393	632	76	632	6,828	68.28	26,834	0.35	9,392	0	0.0	0	0	0.15	0	9,392
75-79	585	577	74	0	0	0.00	0	0.35	0	577	0.486	280	164,047	0.10	16,405	16,405
70-74	775	522	72	0	0	0.00	0	0.35	0	522	0.475	248	192,161	0.03	5,765	5,765
65-69	784	467	68	0	0	0.00	0	0.35	0	467	0.464	217	169,883	0.03	5,097	5,097
60-64	706	412	63	0	0	0.00	0	0.35	0	412	0.455	187	132,347	0.03	3,970	3,970
55-59	670	357	59	0	0	0.00	0	0.35	0	357	0.445	159	106,440	0.03	3,193	3,193
																$52,765

	Equipment Cost	Operating Cost	
CH-1	**$359,000**		
CH-2	**117,000**		
Total	**476,000**	**$52,765**	
Base Plant	**252,000**	**95,799**	**Simple Payback**
Delta	**$224,000**	**($43,034)**	**5.20 Years**

Figure 10 analyzes the performance of a plant using an 850-ton gas-engine-drive centrifugal chiller and a 650-ton electric centrifugal chiller. The operating cost is $43,297, which is 55 percent less than the all-electric plant, and the payback is only 4.8 years, which is worth considering given the large operating-cost savings that would be available for the other 20 years of the chillers' lives.

By maximizing the use of alternative-drive chillers during periods of high electricity costs, the non-traditional hybrid plants generate the greatest operating cost savings, and the added equipment costs are not so large as to result in unreasonable paybacks.

Making 'Cents'

With electricity deregulation imminent, assuming that all-electric chiller plants are best in a deregulated environment may be costly. Chiller-plant owners and designers should consider adopting a hybrid chiller-plant design for selected operations. It will cut operating costs by reducing or eliminating the use of expensive electricity to operate the chiller plant during high-demand periods.

There is another significant benefit of a hybrid system. Because it has a lower on-peak demand and a flat load profile, the facility becomes a more attractive customer for the electric utility. This may well result in lower off-peak electric rates, reducing the cost to operate electric base-loads, such as lights.

When dealing with deregulation, combining the benefits of electric and alternative-drive chillers simply makes good 'cents.'

Figure 10: Non-Traditional Hybrid Plant
Chiller #1: 850-Ton Gas-Engine-Drive Centrifugal Chiller
Chiller #2: 650-Ton Electric Centrifugal Chiller

TEMP BIN	HRS	TONS LOAD	ECWT	GAS TONS	MBTU/ HR	THERMS/ HR	THERMS	GAS PRICE $/THERM	COST OF GAS OPERATION*	ELECTRIC TONS	kW/ TON	kW DRAW	kWh	RTP $/kWh	COST OF ELECTRIC OPERATION	TOTAL OPERATING COSTS
95-99	20	800	82	800	4,985	49.85	997	$0.35	$ 349	0	0.0	0	0	$0.45	$ 0	$ 349
90-94	84	742	81	742	4,342	43.42	3,647	0.35	1,277	0	0.0	0	0	0.40	0	1,277
85-89	216	687	72	687	3,710	37.10	8,014	0.35	2,805	0	0.0	0	0	0.35	0	2,805
80-84	393	632	76	632	3,225	32.25	12,674	0.35	4,436	0	0.0	0	0	0.15	0	4,436
75-79	585	577	74	0	0	0.00	0	0.35	0	577	0.486	280	164,047	0.10	16,405	16,405
70-74	775	522	72	0	0	0.00	0	0.35	0	522	0.475	248	192,161	0.03	5,765	5,765
65-69	784	467	68	0	0	0.00	0	0.35	0	467	0.464	217	169,883	0.03	5,097	5,097
60-64	706	412	63	0	0	0.00	0	0.35	0	412	0.455	187	132,347	0.03	3,970	3,970
55-59	670	357	59	0	0	0.00	0	0.35	0	357	0.445	159	106,440	0.03	3,193	3,193
																$43,297

	Equipment Cost	Operating Cost	
CH-1	**$385,000**		
CH-2	**117,000**		
Total	**502,000**	**$43,297**	
Base Plant	**252,000**	**95,799**	**Simple Payback**
Delta	**$250,000**	**($52,502)**	**4.76 Years**

*** Includes Maintenance Premium**