“LOOP” Chiller Plant Dramatically Lowers Chilled Water Costs

by

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Introduction

I would like first to thank all those who have worked very hard to make this conference the success that it is, and also those attending. As we gather here to discuss the development of more environmentally friendly technologies to meet the responsibilities and challenges, but also the opportunities of a new Millennium, I am certain it will be a valuable experience for all of us, and I offer my encouragement and welcome to all!

This morning, I will be introducing you to a new but effective and very straightforward technology that applies to any chiller plant being constructed, or already operating. This presentation will focus particularly on the plant itself. In a later session, I will discuss how the technology can also be applied to chilled and heating water distribution systems. In order to facilitate this discussion, I will try to limit my remarks to about twenty minutes to leave adequate time for your questions and comments. I would also like to let you know that my colleagues and I have organized several evening discussions this week, each focused on different aspects of this new technology and how it can be implemented most effectively. If you would like to participate in any of these discussions, you are certainly invited to do so. Please see me after this or any other session, or leave a message for me with the hotel.

This “LOOP” technology I will be discussing this morning has the capability to make a significant impact on energy use throughout the world. In broad terms, the LOOP technology can reduce total chiller plant energy use by about twenty to forty-five percent (depending on climate and application), below the most efficient chiller plant technologies now in use. Lawrence Berkeley Laboratories estimates that in North America, well over twenty percent of all electricity generated is consumed by chiller plants, so a widespread application of the LOOP technology promises a significant impact on electrical energy use.

What is most inviting about the LOOP technology, is that LOOP chiller plants can be designed to cost no more, and often less than conventional chiller plants. The implementation of LOOP technology does not require any new products or processes. It requires primarily that we rethink the way a system such as a chiller plant operates most efficiently.

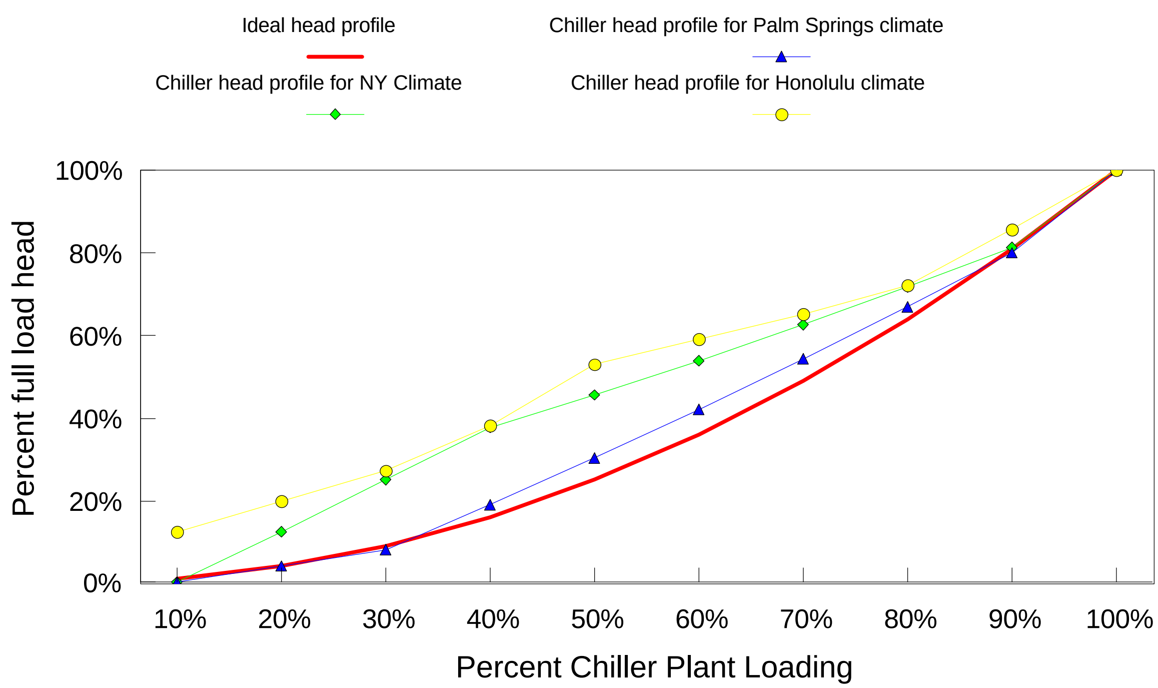
How LOOP Technology Works

To explain the LOOP technology, I will use a simple analogy of a window fan. Imagine you are using a fan to cool your bedroom at night. You have a window fan unit that consists of two side by side fans. Now imagine that tonight is not as warm as usual, so you know you will be satisfied with just one-half the maximum airflow from the unit. The question the Loop technology poses is "Using today's available technologies, how can I achieve 50% of the maximum airflow (capacity) from this unit using the least amount of energy?"

A first reaction may be to shut off one fan. This is analogous to how virtually all chiller plants are designed to operate today. The idea is to supply the load with the least amount of equipment operating. By turning off one fan, the remaining fan will provide 50% of the total airflow with 50% of the power. The same full load efficiency is achieved at this part load condition.

However, let us imagine that these window fans are equipped with variable speed drives so their speed can be varied instead of just being turned "on" and "off". Using the fan and pump laws, we know that slowing both fans to 50% speed will result in 50% of the maximum airflow, but require only 12.5% (0.5 cubed) of the power. This means that by slowing both fans rather than stopping one to meet a 50% load condition, the operating efficiency is improved by 400%! This is a simple picture of the thesis behind the LOOP technology.

Because all equipment in a centrifugal chiller plant is subject to the same fan and pump laws as the window fan unit, slowing an all-variable speed chiller plant instead of shedding chillers as the load falls also provides an opportunity for energy savings. However, a chiller plant is a complex system, and actual chiller compressor head does not usually follow the "ideal" curve required by the fan an pump laws to result in the efficiency improvement cited in the window fan analogy. The percent of full load chiller compressor head pressure for several climates at various loads is shown in the "Percent Chiller Plant Loading" graph below:

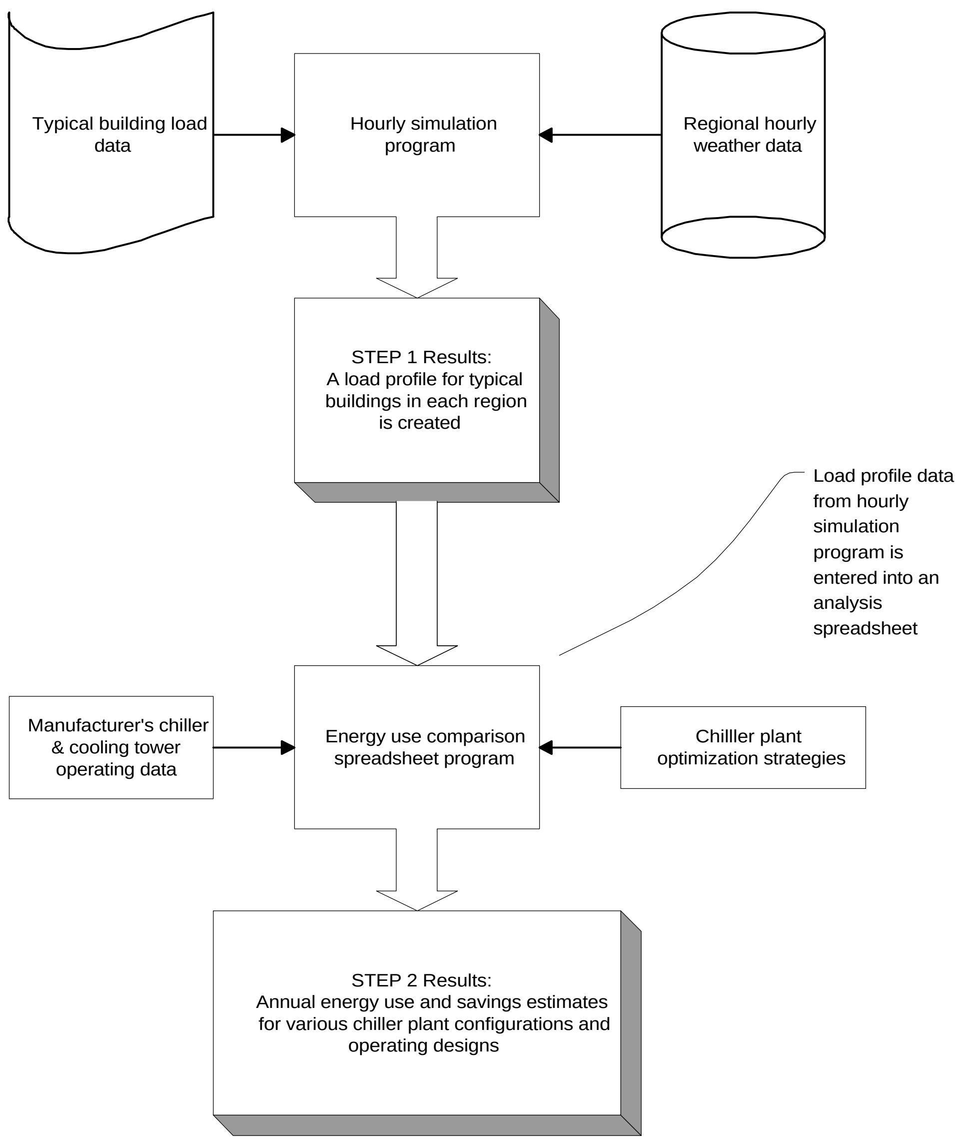


In this figure the chiller compressor head pressure as a function of chiller load is shown for several climates and compared to the ideal case. Notice that the Palm Springs climate does afford a nearly ideal variable speed operation of a chiller compressor. However most climates do not permit the ideal efficiency improvement at part load conditions. Still, as shown by the graph, all climates do offer some reduction in compressor head as load is reduced. This means there must be some opportunity for energy reduction with an all-variable speed chiller plant in all climates.

LOOP Optimization Analysis

We arrived some years ago at this conclusion that an all-variable speed chiller plant which slowed rather than shed chillers at decreasing loads would save energy. But questions remained as to the size of the savings with available chiller equipment, and the complexity of control required to achieve that level of savings. Furthermore, having all plant equipment continue to operate at lower loads means that the plant would be vulnerable to equipment control tuning problems that could lead to excessive energy use. So although we knew the concept was valid, the questions remained "Is it economical?" and "Is it practical?"

To find the answer to these questions, we developed a unique two step analysis tool that has proven to be very successful for chiller plant analysis. The process is shown in the figure below:



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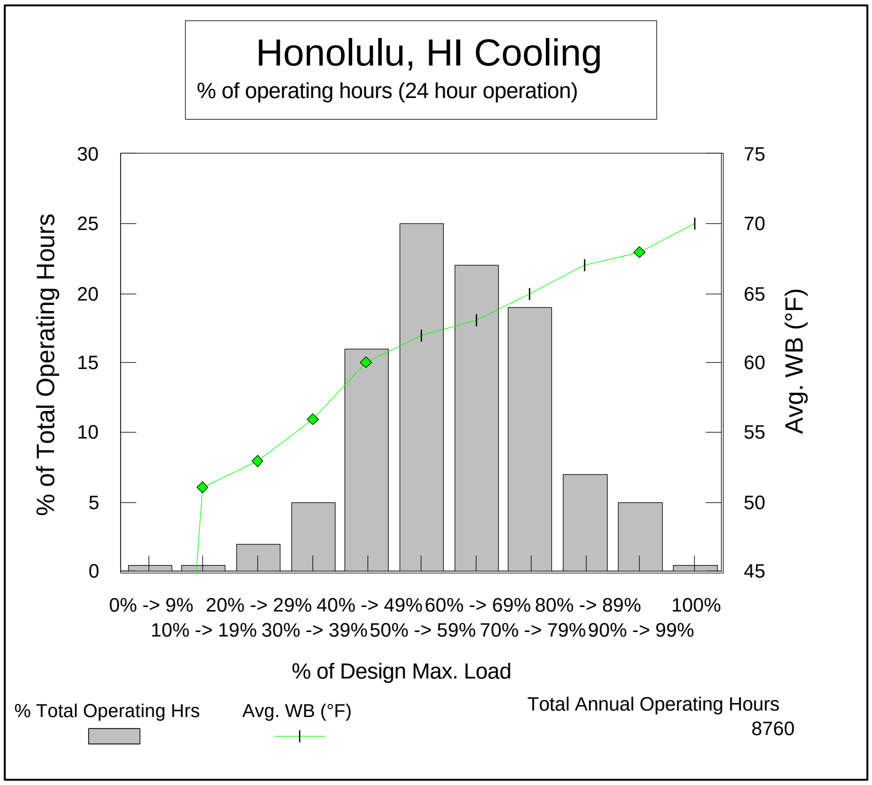
In the first step of this analysis process, typical commercial facilities were evaluated with an hourly simulation program to determine the load profiles and average wet bulb temperature for cooling load levels at 10% cooling load increments. This was performed for a variety of building types and climates to obtain a map of loads and average wet bulb temperatures for each climate. We found the load profiles for different types of structures within each climate to be similar such that we have been able to conclude that within a given climate, the type of structure influences the **size** of the cooling plant required to provide comfort conditioning, but has only a small influence on the **load profile** of any chiller plant within that climate. With this important discovery, we were able generalize for “typical” commercial buildings. Using hourly simulation, we then developed typical comfort conditioning chiller plant load profiles for a variety of climates. The load profile from the step 1 analysis for Honolulu is shown below:



The analysis determined that this cooling profile is a close fit for comfort conditioning chiller plants that serve many different types of commercial buildings in the Hawaiian climate.

This first step in the analysis thus provided such load profiles, complete with an average wet bulb temperature segmented into 10% load increments, for a variety of climates. The data formed a simple but comprehensive database for the next step of determining the operating efficiency of various chiller plant configuration and operating strategies.

The goal of the second step was to determine how much energy reduction is possible by employing an all-variable speed chiller plant compared to an optimized state-of-the-art constant speed plant, and whether the control requirements for such a plant were such that the savings could be reliably obtained with simple and stable control functions.

To accomplish this, the second step involved introducing the load profile data into a spreadsheet analysis, a portion of which is shown below, that was developed to analyze various chiller configuration and operating strategies.
This spreadsheet was specifically designed and preloaded with performance data for pumps, chillers, and cooling towers. This performance data was based on actual manufacturer's ARI and CTI rated equipment to ensure accurate results.

HARTMAN LOOP CHILLER PLANT ENERGY USE AND COST COMPARISON

June 8, 1998; last revised April 3, 1999

DEVELOPING FOR NEW LPP CALCULATIONS - IN PROGRESS

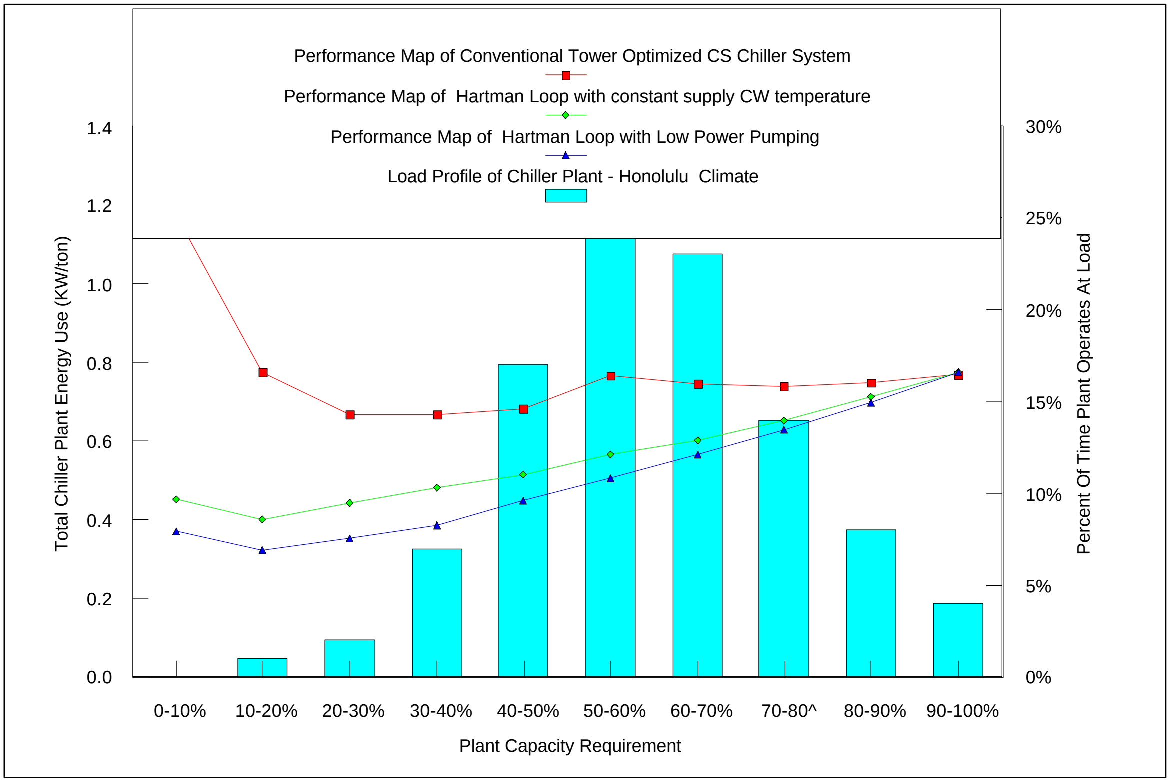
Assumptions:	600	ton chiller plant size	0.62	KW/Ton Chillers at peak load	$0.08	Average Elcctric cost per KWH
	4%	VFD loss as % of pow er	10	Degree F design cooling tow er approach	2	Total Number of Chillers/Tow ers
	12	Min condenser circuit head (ft)	100%	Plant size as % of 100% design size	2.5	Evap & Distribution GPM/Ton @ max load
Hartman Loop +	3	Condenser GPM/Ton @ max load			100	Maximum Dtribution Pump Head

Low Power Pumping			**Performance Map of Hartman Loop with Low Power Pumping**													Comments
Plant Capacity Requirement			10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		Climate		Actual % of full chilled water plant load
Average Wet Bulb Temperature			52	56	58	62	64	66	67	68	70	72		Honolulu		Ave WBT from 24hr operations simulation
% Time at Capacity - full size plant			0%	1%	2%	7%	17%	24%	23%	14%	8%	4%				% time from 24hr operations
% Time at Capacity - actual plant size																interpolating to plant as sized w ith DC
% Time at Capacity - for calculation			0%	1%	2%	7%	17%	24%	23%	14%	8%	4%				selection for calculated average KW/Ton
Number of Chillers Operating			1	1	2	2	2	2	2	2	2	2	Ann	Annual	Annual	Chiller sequenced based Hartman Loop
Chiller 1/ Tow er 1 loading			20%	40%	30%	40%	50%	60%	70%	80%	90%	100%	ave	operat'g	ton-hrs	
Chiller 2/ Tow er 2 loading			0%	0%	30%	40%	50%	60%	70%	80%	90%	100%	ld fac	hours	per ton	
Chiller 3/ Tow er 3 loading			0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	65.0%	8,760	5,694	
% Time at Capacity Requirement			0%	1%	2%	7%	17%	24%	23%	14%	8%	4%				% time from 24hr operations simulation
Chiller Pow er (% of max)			9%	16%	13%	20%	29%	39%	51%	65%	81%	100%	Annual	Percent	Annual	Actual % of full chiller pow er
Tow er fan & CHW Pumps Pow er setting			9%	17%	13%	20%	29%	39%	51%	65%	81%	100%	ave	of total	Energy	Fill in to exact figures of row above
Condenser pump power setting			20%	20%	20%	20%	29%	39%	51%	65%	81%	100%	kw /ton	pow er	Use(kw h)	Adjust from above line to meet min DP&flow
Pow er@Design																
TOWER FAN(S) TOTAL HP	39	HP	0.025	0.024	0.024	0.028	0.033	0.036	0.041	0.046	0.050	0.056	0.041	6.8%	139,622	Flume distribution,low hd,high airflow tow er
COND PUMP(S) TOTAL HP	46	HP	0.066	0.033	0.044	0.033	0.038	0.043	0.048	0.053	0.059	0.066	0.048	8.0%	163,589	Max 14.4 condenser & 12.2 tow er head loss
CHILLER & VFD KW/TON	0.62	KW/ton	0.273	0.260	0.277	0.317	0.368	0.416	0.466	0.517	0.574	0.640	0.465	77.2%	1,588,082	Based on York VS performance
P CHW PUMP(S) TOTAL HP	10	HP	0.007	0.006	0.006	0.007	0.008	0.009	0.011	0.012	0.013	0.015	0.011	1.8%	36,234	Based on preliminary piping sizing
TOTAL PLANT			0.370	0.323	0.352	0.385	0.447	0.505	0.565	0.628	0.697	0.776	0.564	93.7%	1,927,528	AVE ANNUAL PLANT ENERGY
B CHW PUMP(S) TOTAL HP	36	HP	0.023	0.022	0.023	0.026	0.030	0.034	0.038	0.042	0.047	0.052	0.038	6.3%	129,828	AVE ANNUAL DISTRIBUTION ENERGY
TOTAL PLANT & DIST KW/TON			0.393	0.345	0.374	0.411	0.477	0.539	0.603	0.670	0.744	0.828	0.602	100.0%	2,057,356	AVE ANNUAL PLANT & DIST ENERGY
Tons Cooling			60	120	180	240	300	360	420	480	540	600				
Tow er Fan Speed (%max)			38%	52%	46%	55%	64%	72%	79%	86%	93%	100%				
Condenser w ater flow (gpm)			416	416	833	833	1,019	1,180	1,337	1,492	1,643	1,800				
Leaving Tow er Water Temperature (F)			58.0	64.1	64.7	69.8	73.1	75.8	77.1	79.1	81.1	82.5				
Leaving Condenser WaterTemperature (F)			61.7	71.5	70.3	77.3	80.9	84.0	85.6	87.9	90.2	91.9				
Condenser pump head (ft)			23	23	23	23	31	38	47	55	65	75				
Chilled w ater flow (gpm)			283	386	685	828	959	1,073	1,183	1,290	1,394	1,500				
Leaving CW Temperature (F)			53.0	50.7	50.8	50.2	48.6	47.1	45.1	44.2	43.4	42.0				
Return CW Temperature (F)			58.0	58.0	57.0	57.0	56.0	55.0	53.5	53.0	52.5	51.4				
Chilled Water Delta T (F)			5.0	7.3	6.2	6.8	7.4	7.9	8.4	8.8	9.1	9.4				
Chilled Water DP (ft)			3	6	19	28	37	47	57	68	79	92				

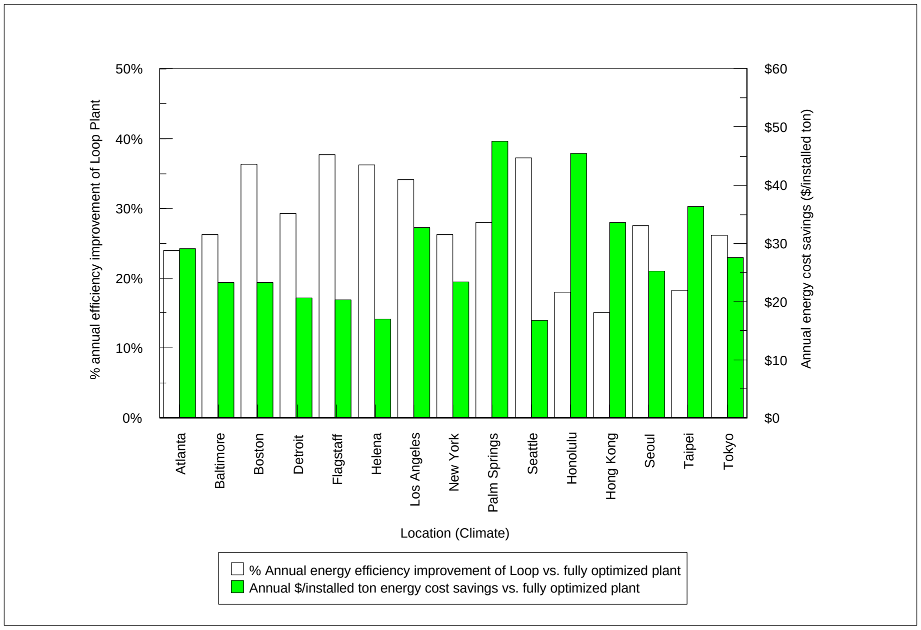
We then manipulated configurations and operating parameters of chillers, towers and pumps to meet the loads, ***first***, as an optimized conventional plant would operate, and ***second***, as an all-variable speed plant would operate most efficiently.

The results showed that for the 15 representative world wide climates we had chosen, an optimized chiller plant employing two nominal 0.62 kW/ton chillers and 10ºF approach towers will deliver chilled water at an annual total plant average energy use of 0.729 kW/ton. This agrees very well with industry experience. Applying what we now call "LOOP" operations to the same configuration, but as an all-variable speed plant, provides a reduction in that annual average down to 0.526 kW/ton, a 28% average total plant energy reduction. Extending LOOP operations to include the chilled water distribution system such that chilled water temperature is also optimized further reduces the annual average to 0.472 kW/ton, a 35% average total plant energy reduction.

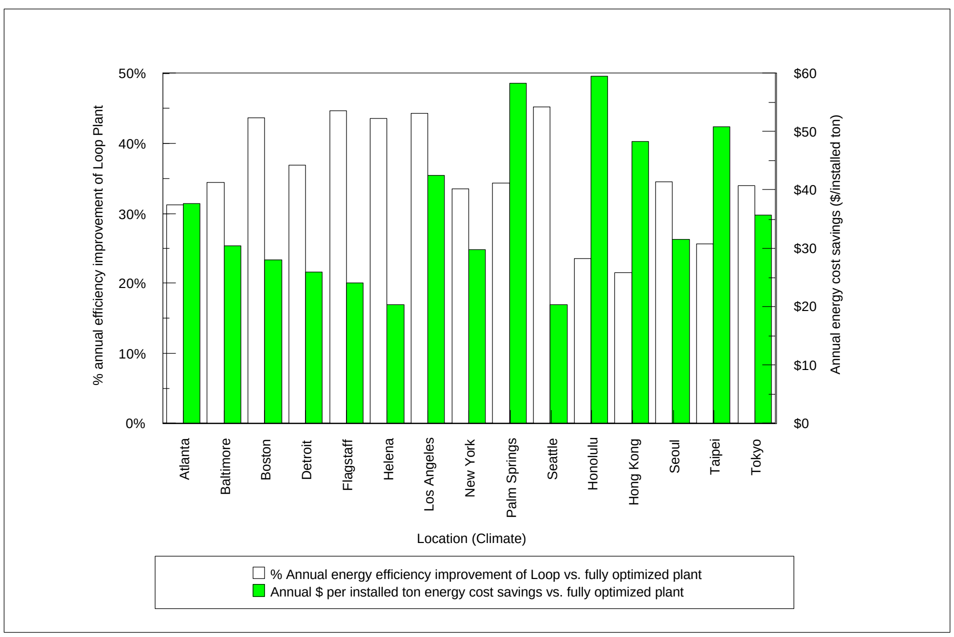
The result of this analysis for the Honolulu climate is shown graphically in the following figure:



As in the window fan analogy, this figure shows that Loop technologies reduce energy use at partial load, but not at full load conditions. Consider, however, that chiller plants in comfort conditioning applications spend only a very small portion of their operating time at or near full load conditions. The amount of energy saved by the LOOP technology depends primarily on the climate as shown in the following “LOOP Energy Reduction” figures:



Percent energy reduction and per-ton annual cost savings for LOOP chiller plant compared to a current technology plant - fixed Chilled Water temperature



Percent energy reduction and per-ton annual cost savings for LOOP chiller plant compared to a current technology plant - variable Chilled Water temperature

The hollow bar in each of the above “LOOP Energy Reduction” graphs shows the percent reduction in total annual energy use for chiller plants employing the LOOP technology when compared to state-of-the-art plants in various climates for both fixed and variable chilled water supply temperature applications. The solid bar shows the annual per-ton energy cost savings for such plants assuming $0.06/kWh electricity cost. For example, a chiller plant in Honolulu employing variable chilled water temperature LOOP operating control will reduce total plant energy use by about 24% compared to a fully optimized plant. This amounts to nearly $60/year per installed ton if electricity costs are $0.06/kWh.

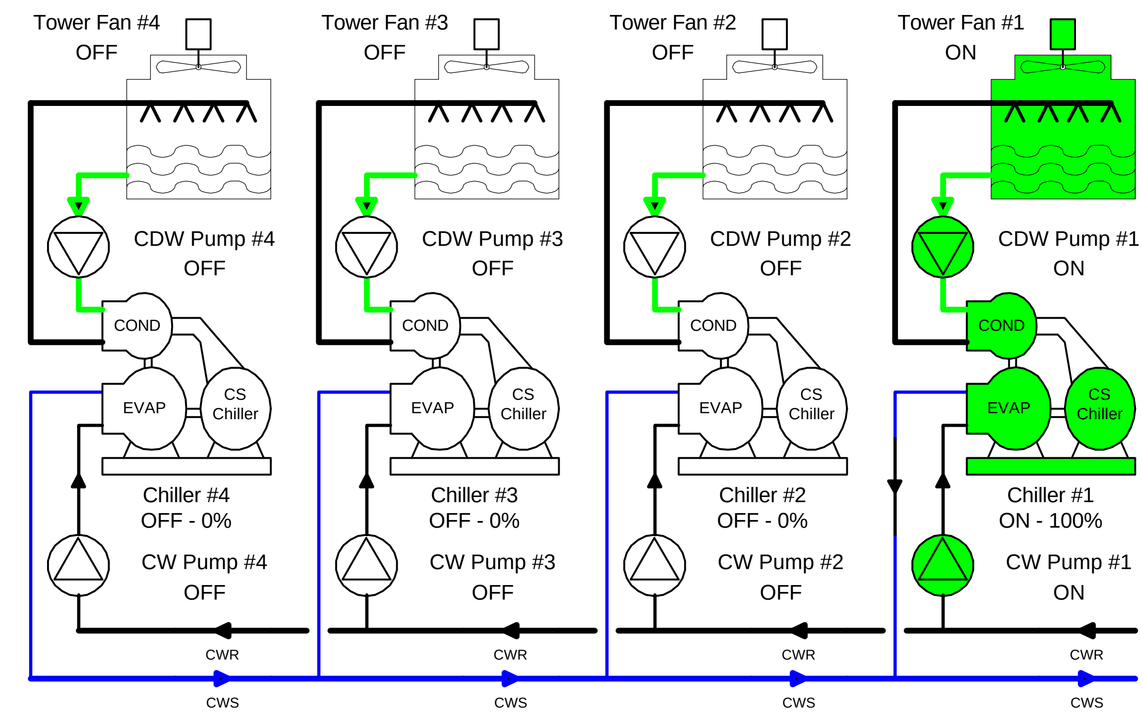
In addition to these substantial savings, this analysis resulted in other important findings concerning the viability of all-variable speed plants. Those are:

1. A simple and straightforward network based operating strategy can be employed to coordinate the operation of all equipment in an all-variable speed chiller plant. This operating strategy is now called the “LOOP” technology and can be implemented and supported by many standard digital control systems employed in chiller plant control today.
2. The percent energy savings for an all variable speed chiller plant utilizing LOOP operating technology change very little as equipment efficiency changes. For example, according to the above figure, an all-variable speed chiller plant in Boston with variable chilled water supply temperature, utilizing LOOP technology will require 45% less energy than a current state-of-the-art plant. This chart was based on a nominal chiller efficiency of 0.62 kW/ton. If a more efficient chiller were substituted, applying LOOP technology would still yield an approximately 45% annual energy reduction below a conventional plant utilizing chillers of the same nominal efficiency.

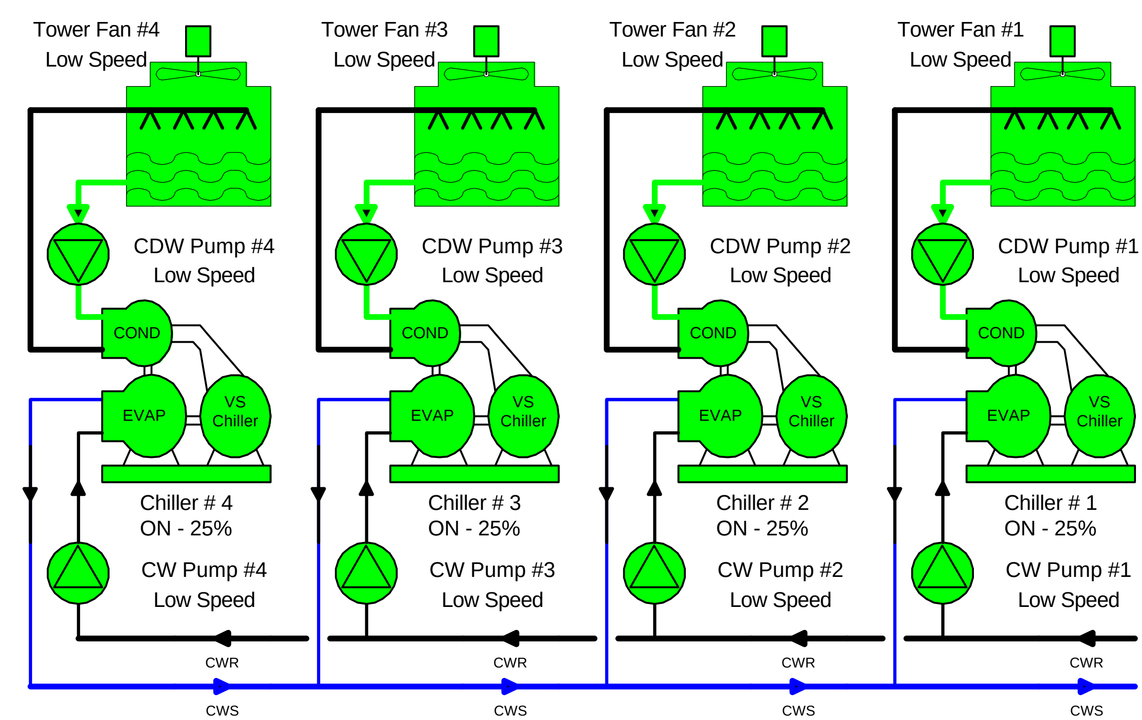
Features of LOOP Chiller Plants

LOOP chiller plants are thus configured very similarly to conventional chilled water plants. In many instances the piping is exactly the same as a conventional chiller plant. However, in LOOP plants, *ALL* equipment is operated with variable speed drives. Control of LOOP plants is provided by an integrated, network based control system that provides coordinated control of all plant equipment based on a series of routines that optimizes the entire plant as a system.

In a LOOP plant, as the load falls, equipment is slowed rather than shut down. Conventional plants shed equipment when the remaining equipment can meet the load. In a LOOP plant, equipment is shed only when it is operating below about 20% load (depending on the exact configuration of equipment). A comparison of how a chiller plant with four equally sized chillers would operate under conventional and LOOP control at 25% load is shown in the drawings on the following page. The first illustrates a conventional plant operating at 25% of full load capacity. The second shows how LOOP plant operation is very different at 25% of full load capacity:



Conventional Plant operating at 25% capacity



LOOP Plant operating at 25% capacity

As shown in the two diagrams, LOOP technology reduces energy use by slowing equipment at part loads to improve efficiency.

The Implications of LOOP Technology

The findings of the analysis of LOOP chiller plant technology have several implications for the building design and construction industry. First among them is that simpler and less costly chillers can perform effectively in LOOP configurations. Under LOOP operations, chiller logic can be much simplified since the required control functions at the chiller are much more limited. Further, many multiple chiller plants can employ variable speed chillers without adjustable vanes.

Technical Support of LOOP Technology

LOOP Technology is not a complex technology, but it does require special attention to chiller, tower and control system features to achieve its expected success. Total implementation support for LOOP Technology is being made available through a site license program. Such site licenses are based on total chiller plant size and cost only a fraction of the annual cost reduction that the technology will provide. LOOP technical support can be provided either to the design team, directly to the installing contractor, or a combination of both, as best suits the requirements of the project. Technical support includes consultation as well as procurement procedures and specifications for chillers, towers, and controls.

Summary and Conclusion

The LOOP analysis has shown quite definitively that this new approach to chiller plant configuration and operation has the capacity to provide average world wide reductions in chiller plant energy use in the 20% to 45% range. Technical support is being developed such that the LOOP technology can be applied to any chiller plant by any design and contracting team, anywhere in the world. As the industry works to update and replace chillers that are now obsolete due to the world wide CFC phase out, this is a technology whose widespread implementation should be encouraged.

Thank you for your attention. A great deal about this remarkable technology has not been covered due to time limitations. I am pleased now to take your questions, and I hope those of you desiring further information will let me know so that I can get information to you.