Ultra-Efficient, All-Variable Speed Chiller Plants A Green Building Imperative

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Synopsis

As energy engineers, we have been continually looking for opportunities to reduce chiller plant energy usage through the use of high efficiency water cooled chillers, "pony" chillers, variable frequency drives, premium efficient motors, low approach/high efficiency cooling towers, sophisticated control strategies, etc. In most cases energy professionals focus on increasing the efficiency of individual components and optimizing the plant based on outdoor wet bulb temperatures, condenser water temperatures, and chilled water and differential pressure reset strategies. In almost all cases building operators try to minimize the amount of online equipment and stage chillers based on their ability to maintain chilled water set point (or when they hit 95% FLA). After analyzing over 300 central plants we have found that current strategies for energy efficiency and sustainability are just not cutting it. Commissioning and retro-commissioning have offered short term solutions to the many issues these systems face.

But now, we have proved, that configuring, controlling and maintaining a chiller plant system to operate 40-60% below current energy optimization standards is not difficult if designers and engineers are ready to replace proportional-integral-derivative (PID) control with new relational networked control strategies. Whether the chiller plant is a new one under design or the result of a decision to retrofit an existing system, achieving successful long term results requires close attention and cooperation by those responsible for the design and operation of the plant. To be successful, an ultra-efficient chiller system requires a new method of automatic control that optimizes the equipment operation under all loading conditions as well as a new methodology for making sure the plant operates at commissioned levels for the life of the system.

This paper will present an introduction to this new paradigm shift for the industry; a completely new model for configuring, implementing, operating, and continuously commissioning chiller plants with relational, demand based control.

About the Author

Ben Erpelding P.E., C.E.M. is the Director of Engineering for Optimum Energy. He has over 11 years of experience in energy efficiency, commissioning, distributed generation, renewable energy, and demand response. Mr. Erpelding has performed over 500 detailed HVAC energy assessments at public, commercial, and industrial facilities throughout the world. From 2001 through 2006 (as part of the non-profit San Diego Regional Energy Office), Erpelding measured and verified actual performance and cost savings for hundreds of energy efficiency retrofits, photovoltaic installations, demand response requests, and combined heat and power projects.

According to the County of San Diego's administration analyst, Erpelding's efforts over the last 6 years resulted in a 16% decrease in the County's energy consumption (roughly 16,000,000 kWh/yr cut from jails, courts, and office buildings).

Erpelding received his Master of Science, with an emphasis in Combined Heat and Power, and a Bachelor of Science in Mechanical Engineering, Magna Cum Laude, from San Diego State University. Mr. Erpelding is a Registered Professional Mechanical Engineer in the State of California and a member of the HPAC Engineering magazine Editorial Advisory Board.

Measuring HVAC Performance

Before one can determine if a central plant (or HVAC) system is energy efficient, we must have a universal metric to measure efficiency. The developed central plant (Figure 1) and HVAC (Figure 2) "miles per gallon" equivalent metric is the kW/ton (COP) charts shown below.

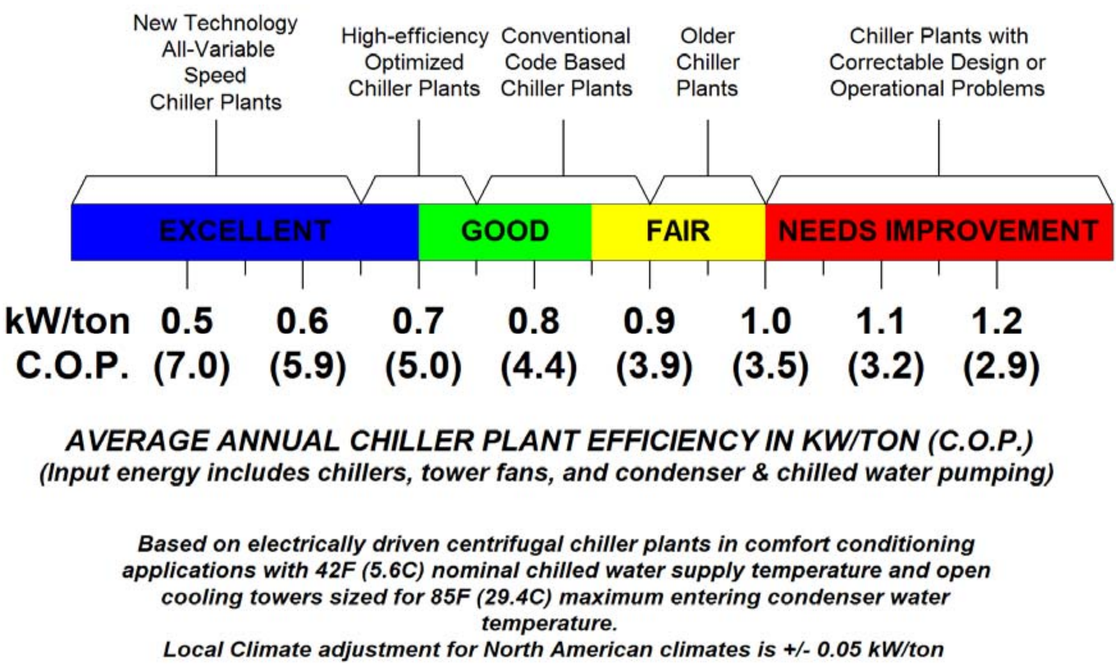
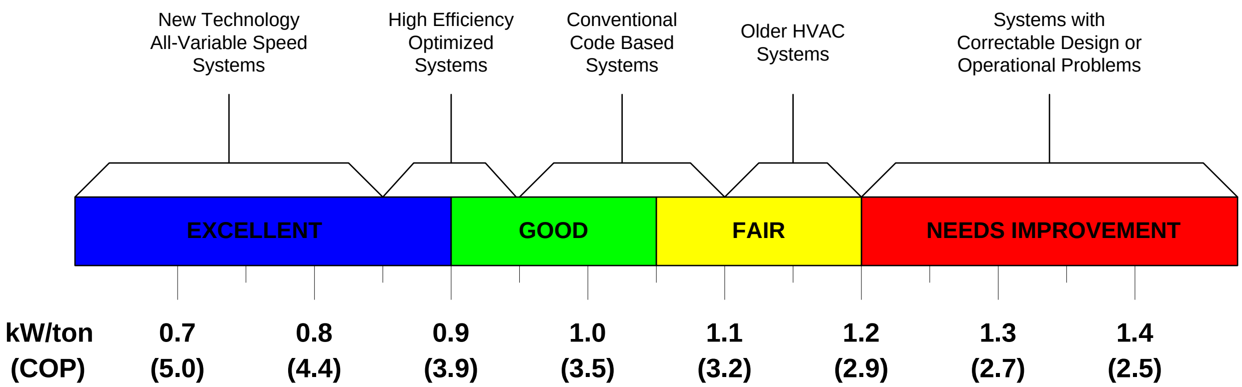


Figure 1: Chiller Plant Energy Use Spectrum.

Figure 1 showcases the average annual efficiency of the chiller plant (wire-to-water efficiency). Exceptions to this rule are air-cooled chiller plants and water cooled plants less than 300-tons. For smaller water cooled plants add a factor of 0.1 kW/ton to this chart. For air-cooled systems add a factor of 0.35 kW/ton to the values shown on this chart.

Likewise, a similar average annual efficiency chart can be presented for entire HVAC system.



AVERAGE ANNUAL HVAC EFFICIENCY IN KW/TON
(Input energy includes all chillers, chilled water pumps, condenser water pumps, cooling tower fans, supply and return air-handler fans, and exhaust fans)

Based on electrically driven centrifugal chillers in comfort cooling applications with 42F nominal chilled water supply temperature and open cooling towers sized for 85F maximum entering condenser water temperature.

Figure 2: Total HVAC Energy Use Spectrum.

Similar exceptions to this rule are air-cooled chiller plants and water cooled plants less than 300-tons. For smaller water cooled plants again add a factor of 0.1 kW/ton to this chart. For air-cooled systems again add a factor of 0.35 kW/ton to the values shown on this chart.

Actual HVAC Performance

Inefficient Chiller Plants

The following is an example of a facility that went after LEED® certification and designed a central plant that came out to be 20% better than Title 24. The plant was equipped with two high efficiency 450-ton centrifugal chillers with variable frequency drives (VFDs), high efficiency cooling towers with VFDs, high efficiency primary chilled water and condenser pumps and motors, and variable flow secondary pumps with VFDs. The following performance was trended shortly after commissioning (Table 1). The plant averaged 0.907 kW/ton ("fair" performance based on Figure 1).

Table 1: Annual Chiller Plant Performance.

Month	Ton-Hrs	kWh	kW/ton
Dec-04	36,988	59,214	**1.60**
Jan-05	36,410	64,781	**1.78**
Feb-05	36,511	63,477	**1.74**
Mar-05	44,632	64,649	**1.45**
Apr-05	59,620	50,824	**0.85**
May-05	102,887	83,835	**0.81**
Jun-05	120,432	91,549	**0.76**
Jul-05	171,554	135,407	**0.79**
Aug-05	219,422	156,954	**0.72**
Sep-05	162,250	116,852	**0.72**
Oct-05	82,280	63,869	**0.78**
Nov-05	46,319	64,333	**1.39**
Total	**1,119,305**	**1,015,744**	**0.907**

Inefficient HVAC Systems

The following three examples showcase total HVAC energy performance (excludes gas usage) in kW/ton. In each case we are using 40% to 60% more energy than is necessary.

- Downtown high rise office (372,000 sq ft), San Diego, CA
  - AHU system = 0.95 kW/ton
  - Pumping system = 0.395 kW/ton
  - Total HVAC system = 1.35 kW/ton
  - Chilled water comes from NRG District Cooling Plant
  - TES chilled water storage tank under building

- Downtown high rise office (330,000 sq ft), San Diego, CA

- AHU system = 0.87 kW/ton
- Chiller plant system = 0.5 kW/ton (Hartman LOOP)
- Total HVAC system = 1.37 kW/ton

- Midrise office building (181,000 sq ft), La Jolla, CA
  - Total HVAC system = 2.0 kW/ton (DX VAV)

Ultra-Efficient Chiller Plants

The goal for ultra-efficient chiller plants in nearly all U.S. climates (temperate, transitional and tropical) is to achieve an annual average efficiency of less than 0.60 kW/ton. Excluding tropical climates (Hawaii, Florida, etc) the goal is to achieve less than a 0.50 kW/ton annual performance. Optimum Energy has proven this reality more than 45 times. Below is one example (Figure 3 and Table 2) of central plant performance at a 74,000 sq ft pharmaceutical facility located in San Diego, CA.

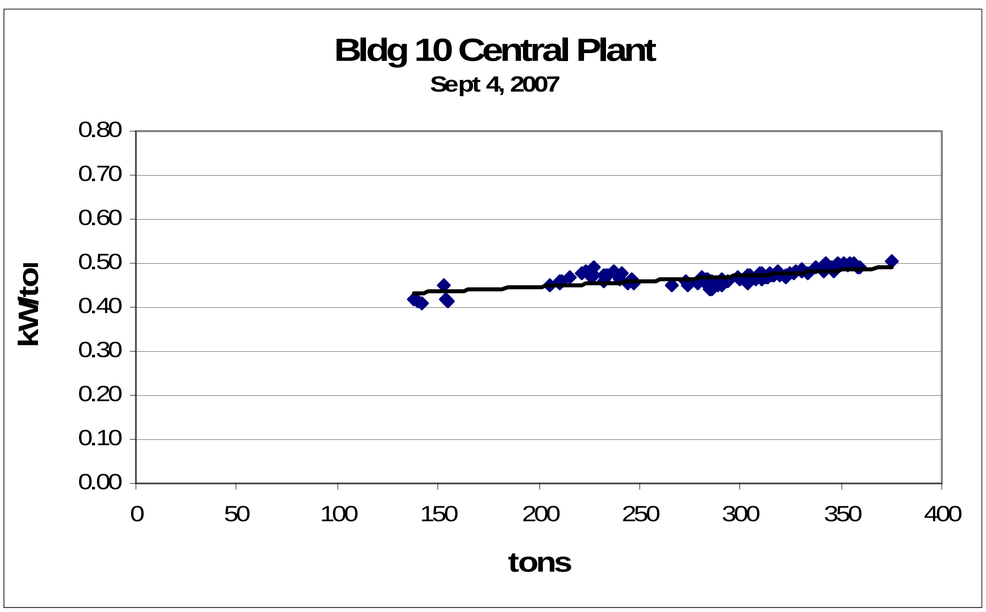


Figure 3: Wire-to-water central plant efficiency (0.47 kW/ton average)

Table 2: Average wire-to-water efficiency for random selected days

Date	Peak Tonnage (tons)	Minimum Tonnage (tons)	Efficiency (kW/ton)
June 25, 2007	118	3.8	0.47
July 24, 2007	204	6.4	0.42
August 29, 2007	304	85.4	0.44
August 30, 2007	308	133	0.46
September 4, 2007	375	138	0.47
October 9, 2007	146	0.9	0.42
October 17, 2007	154	2.8	0.47

Based on the trends collected and analyzed, the plant is performing in the "Excellent" range of Figure 2 and averaged 0.45 kW/ton for the entire year.

SDG&E provides the central plant with retail power under electric schedule ALTOU (Figure 4). Annual electric consumption from November 2005 through October 2006 totaled 888,871 kWhs. Annual electric consumption from November 2006 through October 2007 totaled 359,230 kWhs. This equates to a 60% reduction in energy (pre and post retrofit).

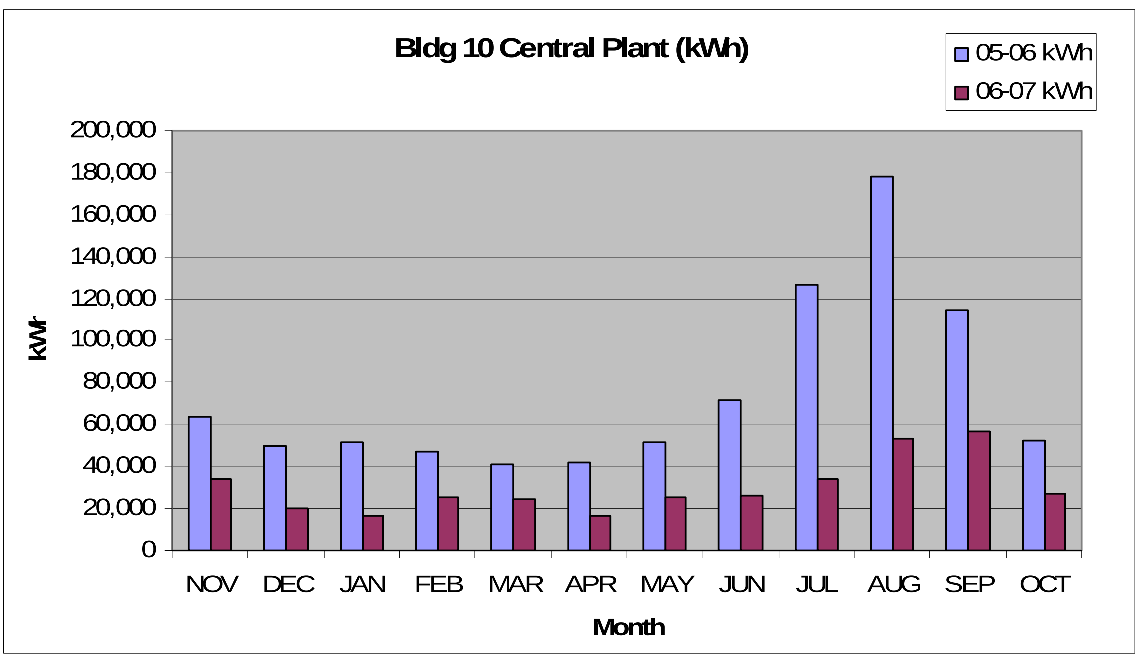


Figure 4: Monthly electrical usage (meter serves the central plant only)

Ultra-Efficient HVAC Systems

The goal for ultra-efficient HVAC systems in nearly all U.S. climates (temperate, transitional and tropical) is to achieve an annual average efficiency of less than 4 COP (0.85 kW/ton). Below is one example (Figure 5) of HVAC performance at an office and laboratory facility located in San Diego, CA. The central plant is a primary-only all variable speed Hartman LOOP system with two 150-ton Turbocor chillers serving a variable air volume lab and office AHU system (50% of the building is lab and 50% is office). The energy usage takes into account all chiller plant energy, all fan energy (supply and exhaust), and heating hot water pump energy. The chart does not include boiler gas usage.

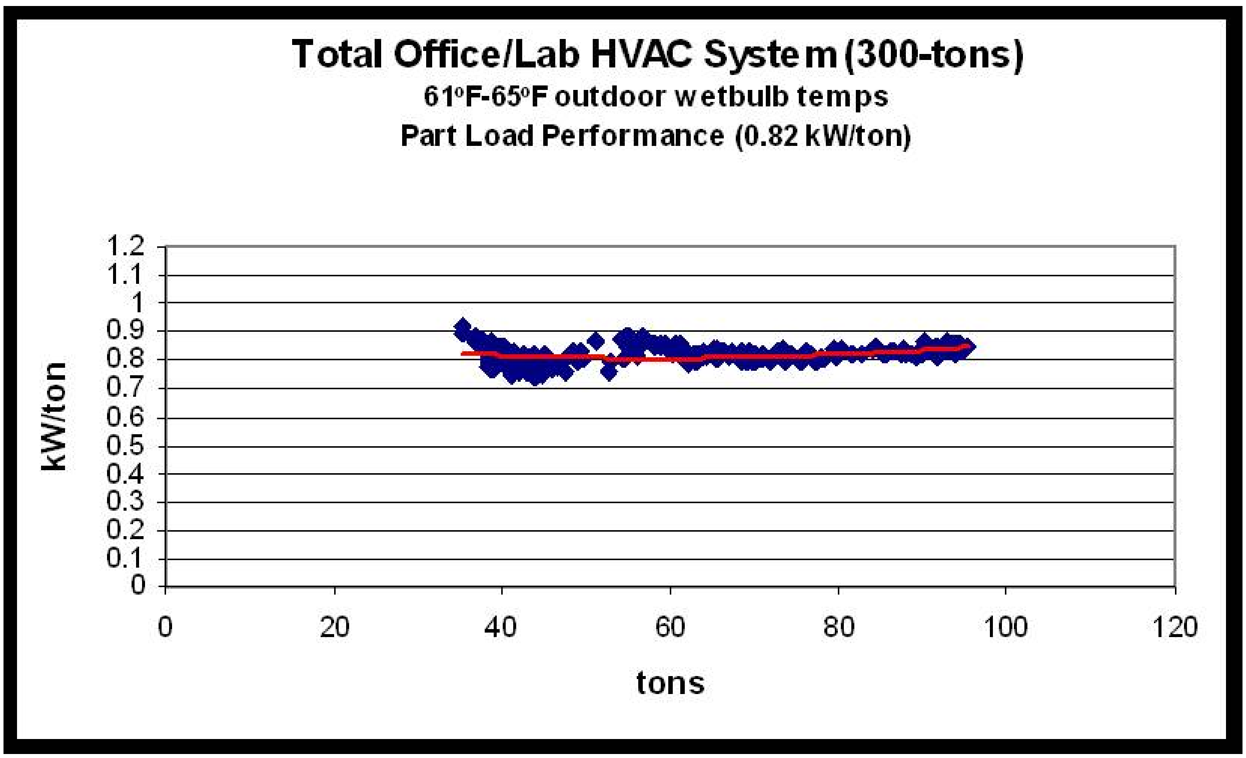


Figure 5: Performance of the entire HVAC system in kW/ton

Maintaining Ultra-High Performance

One of the most important factors in maintaining high performance HVAC systems is to implement a strategy that continuously commissions the system via the direct digital control (DDC) system. Optimum Energy has created one solution not only to maintain savings over time (through performance alarming) but also provide owners and utilities with real time web-based measurement and verification (M&V). The following Figure 6 shows the dashboard used in maintaining savings and performing M&V.

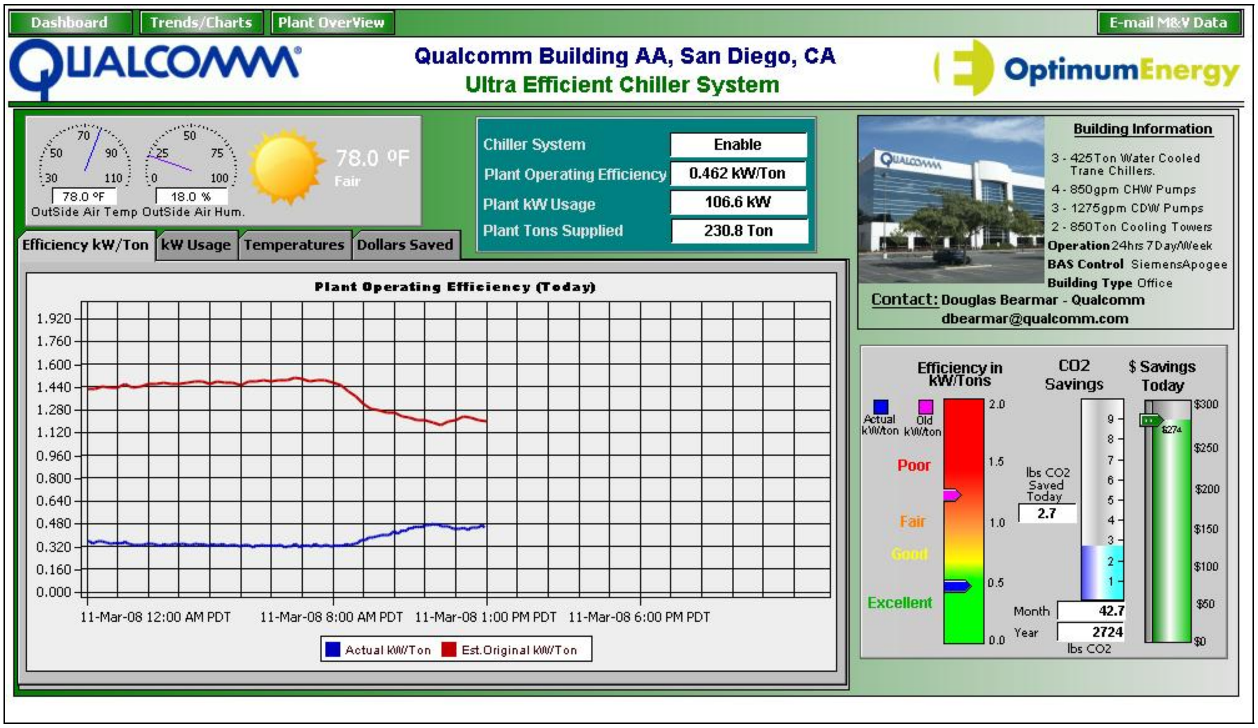


Figure 6: Performance Dashboard (Copy write 2008 Optimum Energy, LLC)

The blue line shows the actual performance of the post retrofit plant. The red line shows what the plant would have been doing prior to the energy retrofit. The pre- retrofit performance was developed using temporary monitoring (kW, flow, delta Ts, etc).

Conclusion

Businesses are leery of making significant capital investment if the resulting energy savings would not present a clear payback. Contractors often claim to be able to improve energy efficiency, but few can clearly verify the return on investment.

Using the metrics and methodologies outlined above, there is now a way to continuously document the impact and return from energy efficiency investments for HVAC systems. In over 45 buildings to date, Optimum Energy has proven the ability to optimize the performance of HVAC systems by 40-60%, resulting in reduced energy usage, decreased operating costs, enhanced occupant comfort.