



ULTRA-EFFICIENT HVAC DESIGN AND CONTROL

MAJOR HEATING, VENTILATING AND AIR-
CONDITIONING REPLACEMENT AT THE COUNTY OF
SAN DIEGO CRIME LAB

December 30, 2005



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Background

The County of San Diego Crime Laboratory is a 102,000 sq ft facility that provides assistance to the criminal justice system by analyzing and evaluating physical evidence in criminal investigations and prosecutions.

Needing additional lab space, but faced with an antiquated HVAC system and escalating energy costs, the County of San Diego Sheriff's Department began searching for ways to reduce electrical usage and demand, and at the same time increase the quantity, quality and reliability of their labs. Two areas of concern were the chilled water plant and air-handling system. Seven original Variable Air Volume (VAV) air-handlers (with rusted guide vanes and economizers) were served by two 18 year old 130 ton air-cooled reciprocating chillers (see Figure 1 above), one 40-ton air-cooled "pony" chiller, three constant speed primary pumps (3 x 3 hp) and three constant speed chilled water secondary pumps (10 hp each).

An extensive energy audit conducted by the San Diego Regional Energy Office helped convince the County that a "band-aid" approach was not the way to go. A new oil-less ultra-efficient all variable speed central plant, new energy management control system, and new VAV air-handler system was installed to improve the facility's office and lab spaces while significantly reducing electrical power consumption.



Figure 1: Rooftop ductwork and existing air-cooled chillers.

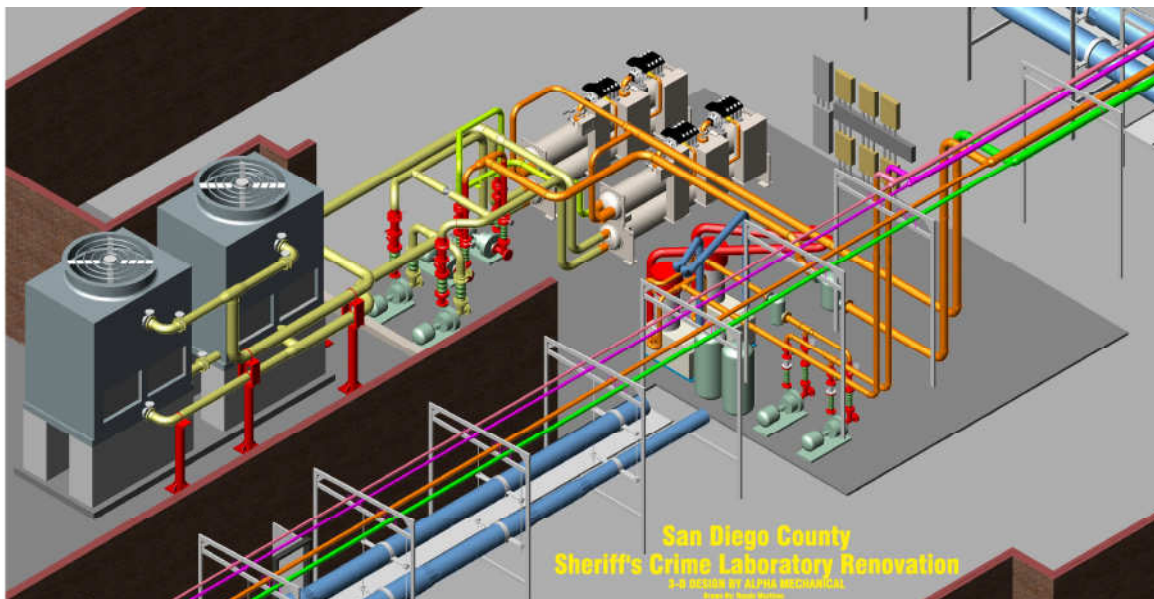


Figure 2: Crime Lab's new central plant design (courtesy of Alpha Mechanical)

Central Plant Energy Assessment

A comprehensive energy assessment was performed on the facility. Based on spot measurements, site utility data, and a building simulation, the pre-existing air-cooled chiller plant operated at a wire-to-water plant efficiency ranging from 1.4 to 1.7 kW/ton (averaged 1.48 kW/ton). The central plant savings were calculated based on two different scenarios: (1) The “band-aid” approach – the County would install new air-cooled screw chillers and a constant speed primary / variable speed secondary chilled water loop; (2) Ultra-efficient water cooled central plant – the County would install two 150-ton water cooled WMC McQuay / Turbocor chillers, primary-only chilled water pumps and condenser water pumps with variable frequency drives (VFDs), and two 200-ton stainless steel induced draft cooling towers with VFDs. The new plant would be controlled by the Hartman LOOP¹. Table 1 below outlines the savings and costs from each potential retrofit.

Table 1. Estimated Energy Savings from Retrofit

	Tonnage (tons)	Est. Annual Electrical Savings (kWh)	Peak Demand Reduction (kW)	Est. Annual Cost Savings	Est. Implementation Cost	SDG&E Incentives	Final cost after incentive	Simple Payback (Years)
Standard Practice - New air cooled chiller plant								
Option 1	300	138,870	15.9	\$16,491	\$400,000	\$0	\$400,000	24.3
Water cooled McQuay WMC150 chillers, all variable speed controlled by the Hartman LOOP								
Option 2	300	509,190	83.0	\$64,990	\$650,000	\$164,000	\$486,000	7.5

After the utility incentive, the incremental cost of the new ultra-efficient plant (versus a like-for-like retrofit) was only \$86,000. With an incremental energy savings of \$48,499/yr, the new simple payback could be calculated at 1.8 years. With these numbers the County decided to move forward with the high efficiency option.



Figure 3: One of the two new WMC150 McQuay Turbocor chillers

¹ Hartman LOOP™ network-based control optimizes all-variable speed plants by taking advantage of the exclusive characteristics of variable-speed pumps, chillers and fans. For more information, see www.hartmanco.com.

Chiller Performance

Data on the new McQuay WMC150 chiller was provided by McQuay. Table 2 below shows the operating conditions of the Turbocor chiller with 44°F leaving chilled water temperature and 80°F entering condenser water.

Table 2. Manufacturer's Data - Operating Conditions of 150-ton McQuay WMC Chiller

Size	Input	Efficiency	RLA	NPLV	75% Load	50% Load	25% Load	Evaporator		Condenser	
Tons	kW	kW/ton	Amps	kW/ton	kW/ton	kW/ton	kW/ton	Ft PD	Temp in	Ft PD	Temp out
150	85.6	0.571	122	0.355	0.434	0.315	0.294	8.5	56	6.6	89.3

Spot measurements were taken on March 7, 2005 at the chiller. The entering condenser water was read at 69.2°F and the chilled water set point was 46°F. The lead compressor was putting out 70 tons and only consuming 25 kW (0.36 kW/ton). Figure 4 and 5 below show the actual monitored performance of the lead chiller during the month of November and August 2005. The chillers averaged 0.315 kW/ton during November 2005 and 0.376 kW/ton during August 2005 with a chilled water set point of 46°F.

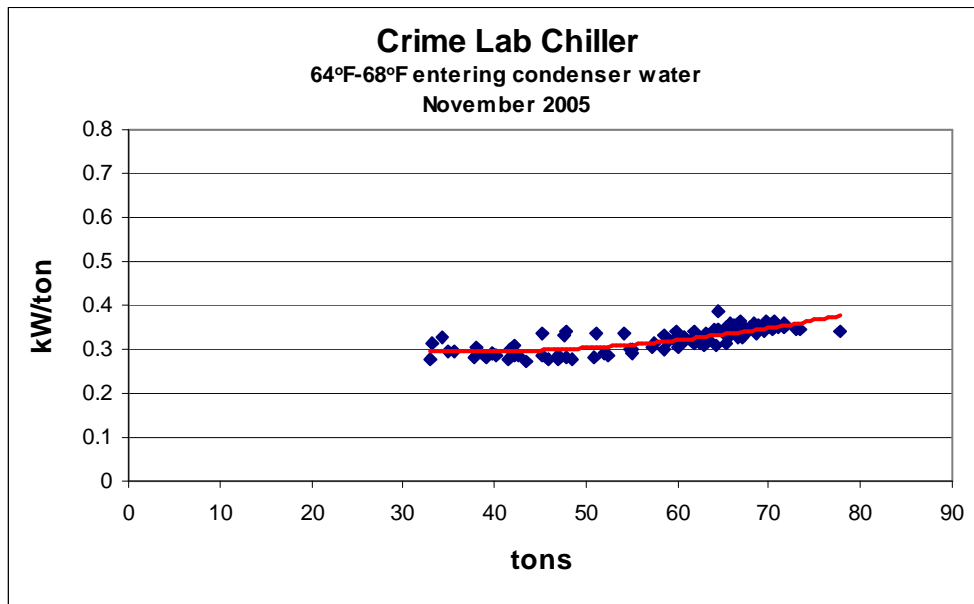


Figure 4: McQuay WMC150 efficiency during November 2005

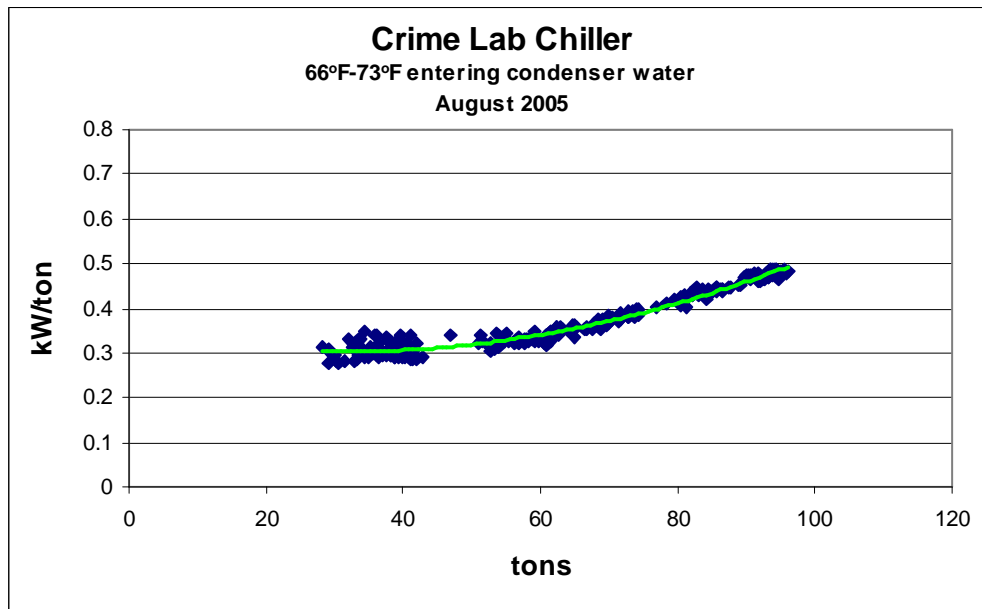


Figure 5: McQuay WMC150 efficiency during August 2005

Central Plant Control Strategy

The chiller and condensing circuit in all-variable speed designs employ coordinated variable speed chillers, variable flow condensing water, and optimized tower fan speed control. The Crime Lab central plant utilizes the following three control strategies.

1. Natural Curve Sequencing of Chillers, Pumps, and Towers

In all-variable speed chiller plants, optimum performance is attained when the equipment is operating at a specific part load that depends on the current condenser and chilled water temperatures. The curve of the loading, at which each variable speed component achieves maximum efficiency as the external conditions (pressure or temperature) vary, is called the “natural curve” of that component. Central plant equipment is sequenced accordingly.

2. Power Based Speed Control of Variable Condenser Pumps and Tower Fans

Conventional cooling tower control involves delivering a specific (sometimes reset) condenser water temperature to the chillers. This is usually delivered with constant speed condenser pumps. Contrary, a Hartman LOOP™ plant uses a straightforward patented demand based control methodology for tower fans and condenser pumps in which the speed of this equipment is based on chiller power [1].

3. Network Control of Chilled Water Distribution Pumping

Chilled water distribution pumps are usually operated to maintain a specific distribution differential pressure. Sometimes this pressure set point is reset based on the maximum position of one or several of the valves on the loads served by the system. However, the use of minimum pressure set points can contribute to substantial wasted pumping energy, especially during periods of low loads which are frequent in systems that operate on a 24 x 7 schedule. In the Crime Lab central plant, the speed of the distribution pumps is controlled according to the “valve orifice area” method [2]. The valve orifice method controls pump speed by using the percentage of total valve orifice area open to determine the required flowrate. This control method allows the head pressure to go to zero as flowrate goes to zero.

Figure 6 below shows the actual monitored performance of the entire central plant (wire-to-water plant efficiency) during the month of November 2005. The wire-to-water plant efficiency includes the power from all chillers, chilled water pumps, condenser water pumps, and cooling tower fans. The central plant averaged 0.538 kW/ton during November 2005.

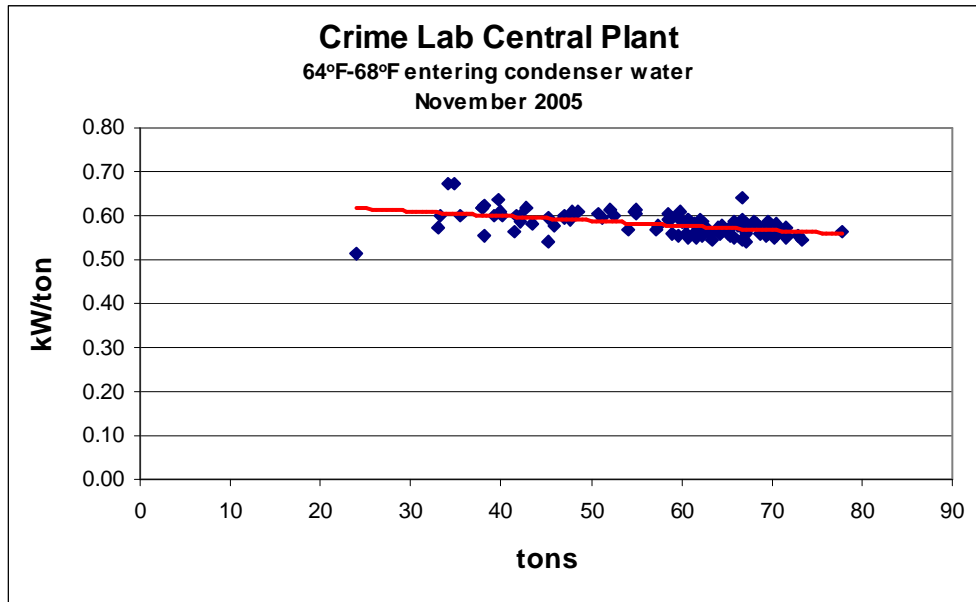


Figure 6: Wire-to-water central plant efficiency during November 2005

Air-Handling System

Seven original Variable Air Volume (VAV) air-handlers (with rusted guide vanes and economizers) served the majority of the offices and labs. Again, the Sheriff’s department was faced with two different retrofit/replacement options: (1) “Band-aid” approach – Keep existing air-handlers and install VFDs, new economizer dampers, and electronic actuators. Also, install additional spot air-handlers for the newly installed labs or (2) Install all new properly designed VAV air-handlers, VAV boxes, and sophisticated DDC controls. Because of the state of the old air-handlers, the County decided to go with Option 2.



Figure 7: Original VAV air-handler at the Crime Lab



Figure 8: New penthouse for new VAV air-handlers

Air-handler Control Strategy

Most VAV systems today are controlled by a constant (sometimes reset) static pressure set point. This type of simple stand-alone, single process feedback control limits the effectiveness and efficiency of modern HVAC systems. The Terminal Regulated Air Volume (TRAV) system used on the Crime Lab project is a network-based controls technology that employs the new capabilities of high-performance DDC systems that result in a VAV system that is more energy efficient and provides improved building comfort [3]. In TRAV systems, the central fan is regulated to meet terminal VAV box airflow requirements rather than a duct static pressure setpoint. When areas of the building are not experiencing design loads, significant static pressure reductions occur that bring corresponding energy reductions. TRAV systems regularly result in 30 percent to 50 percent less energy use than standard VAV systems. See Figures 9 and 10 below.

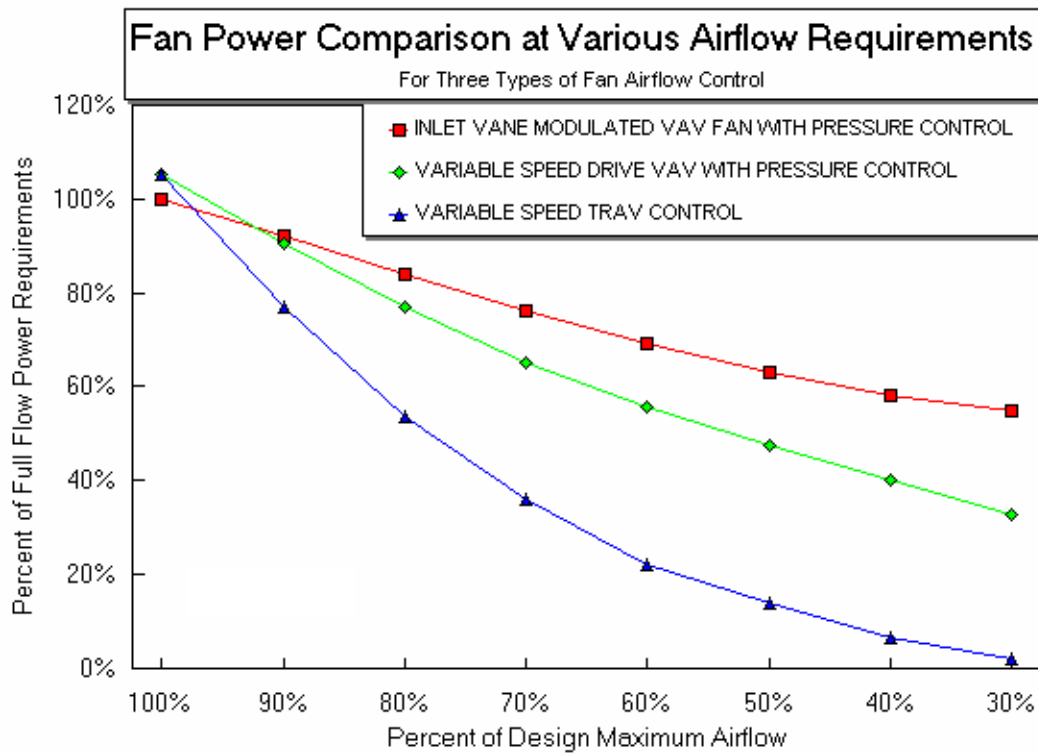


Figure 9: Fan power curve comparisons for standard VAV systems [3]

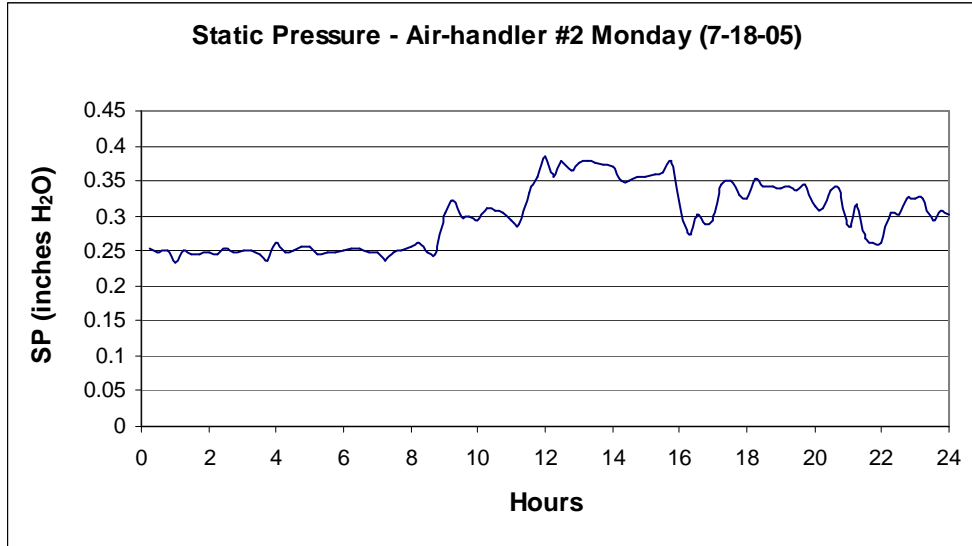


Figure 10: Monitored static pressure for Crime Lab air-handler #2 in July 2005

These systems also achieve much more than lower fan power. The network based controls provide automatic demand based reset of the supply air temperature, automatic self-balancing of the terminal units, and better distribution of ventilation air.

Savings Analysis

The goals of the project have been met. Lab space and lab requirements increased significantly (building ton-hrs) while still decreasing the amount of energy the facility used. Comparing 2004 energy consumption to 2005 energy consumption, total building energy usage decreased by 21% and peak demand by 37%. The Crime Lab now has a building energy density of 16 kWh/ft²-yr while maintaining building environmental conditions 24 hours per day and 7 days per week.

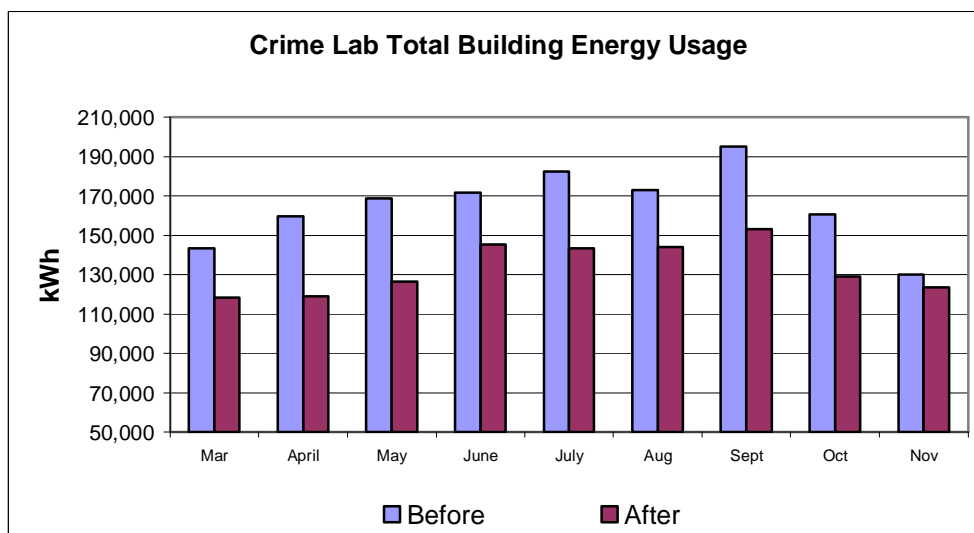


Figure 11: Total building energy usage before and after retrofit

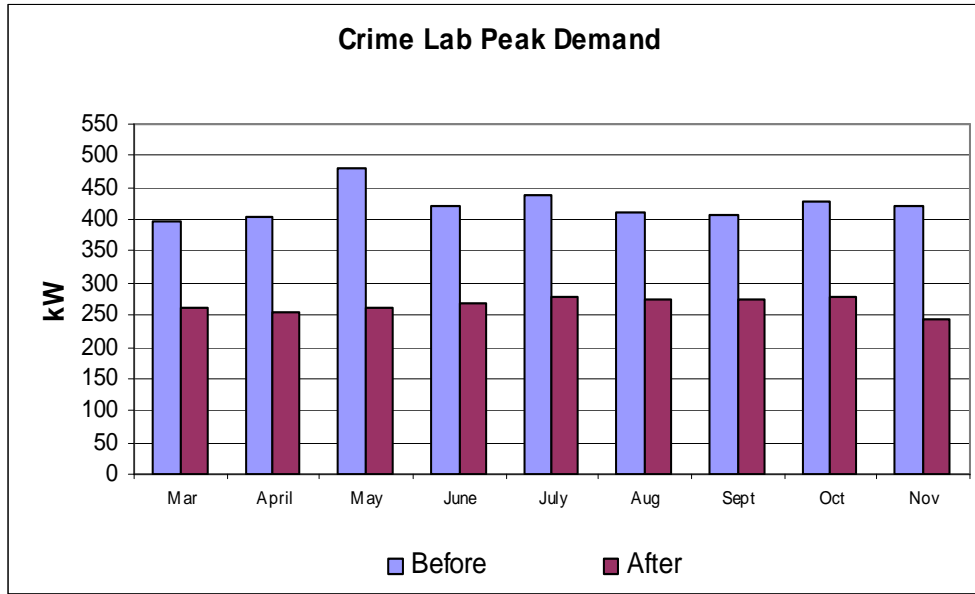


Figure 12: Total building peak demand before and after retrofit

Conclusion

Benefits and points of interest include:

- Maintenance was greatly reduced
- Environmentally friendly R-134a is used in chillers (reducing environmental impact)
- Oil-less chillers were used (reducing our dependency on foreign oil while increasing the efficiency of the machines)
- Noise was greatly reduced
- New lab space requirements are met while reducing energy usage
- Building occupants are comfortable
- Significant portion of the central plant upgrade was covered by utility incentives

For more information about this retrofit please contact Ben Erpelding, P.E. (SDREO's Engineering Manager) at 858-244-1177.

References

1. Hartman, T. December 2001. "Ultra-efficient Cooling with Demand Based Control." Heating/Piping/Air Conditioning Engineering.
2. Hartman, T. 2003. "Presenting Intelligent Iterative Control: PID Replacement for Setpoint Control." (Part 1, 2, and 3) Heating/Piping/Air Conditioning Engineering.
3. Hartman, T. December 1993. "Terminal Regulated Air Volume (TRAV) Systems" ASHRAE Transactions: Symposia 1993 791-800.