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Energy Efficiency Measures for a High-Tech Building with a Solar Roof

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Abstract. This paper presents the implementation of energy efficiency measures in a building that consists of office, lab and clean room area. Total Performance Oriented Optimization and Retrofits (TPORs) were implemented. 594 kW solar panels were installed on the roof and connected to the electrical grid during the optimization process. Ten power meters were installed throughout the building to measure the total building electricity demand, solar generated electricity demand, HVAC and non-HVAC-equipment demand to quantify the energy savings from the implementation of the energy efficiency measures and savings from the solar panels. The electricity savings from optimization on the HVAC system is about 7,209,000kWh/year (194.4kWh/m2-year), which is about 30% of the total building electricity consumption with peak demand reduction of 935 kW. There savings come from the solar panel is 811,925 kWh/yr; however, it effectively reduced the peak electricity demand by 302.6 kW.

Introduction

Solar energy has been considered to be one important source of renewable energy that can help reduce the building energy needs. At the same time, great efforts have been invested in minimizing the energy costs associated with the operation of HVAC systems. Intelligent Energy Management and Control Systems (EMCS) can provide an effective way of decreasing energy costs in HVAC systems while maintaining indoor environmental conditions [1]. However, it is really hard to achieve the computation requirement in real application due to the computational limitation on most available EMCS. A new engineering approach, total performance oriented optimization and retrofit (TPOR), was presented to optimize the whole building energy management system control with minimum retrofit efforts [2].

The study focuses on a high tech building that includes offices, clean room and labs. Clean rooms have unique needs for controlled environmental conditions that are extremely energy-intensive. The HVAC energy intensities for these buildings are 4 to 100 times higher than the average commercial building [3]. Previous studies [4-7] addressed energy-saving opportunities in clean room applications, one of which was to optimize central cooling plant energy performance [4] and other in makeup units [5].

In this study, several energy efficiency measures (EEMs) were implemented through the total performance oriented optimization and retrofit (TPOR) approach. A solar roof was installed during the optimization process with capacity of 594 kW. The results of electricity savings and peak demand reduction from system optimization and solar energy are presented.

System Description and Challenge

Building Description. The target building is a 37,000m^2 building that consists of offices, laboratories, and clean rooms. The building is occupied 24/7 by approximately 1,400 occupants. Most of the building areas are air-conditioned and the HVAC system operates 24/7. The building is located in the northern California, climate zone 4. Figure 1 shows the monthly electricity usage and natural gas consumption of FY 2006 and 2007. The predicted baseline electricity consumption based on the weatherized model is 24,868,689 kWh/year (672 kWh/m^2-year). It can be observed from Figures 1 that in May 2007, there is high energy consumption in electricity. This indicates that there are some operational issues in this building that results in simultaneously heating and cooling.

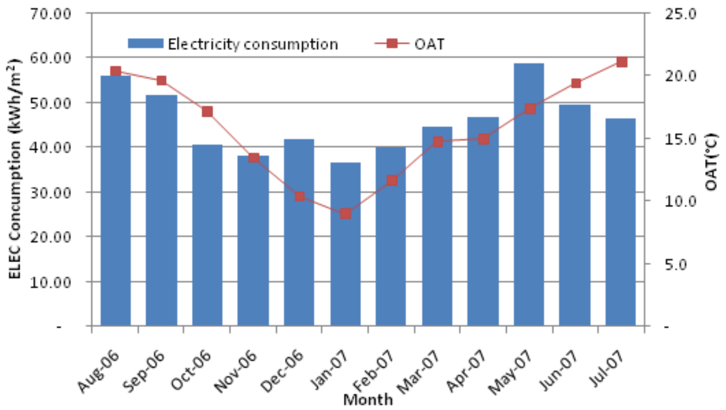

Figure 1. Monthly electricity consumption in FY06-07

HVAC System Description. The chiller plant includes four chillers with total capacity of 11,289 kW each; in addition, there is one (1) CHW thermal energy storage system (TES) with total capacity of 2014 m3, and a heat recovery system from chiller 3. The CHW distribution is a typical primary-secondary loop. The primary CHW loop is served by four (4) 20 kW primary CHW pumps. The secondary has three loops: (1) the first secondary loop serving the lab and office area is served by four (4) 112 kW pumps; (2) the second loop serving the clean room has two (2) 75 kW pumps; (3) the third loop serving the RAH has two (2) 56 kW pumps. Four (4) 56 kW condenser water pumps are used in the condenser loop, along with four (4) cooling towers. All four cooling towers are two-cell towers with a 56 kW fan for each tower. The TES is coupled with two (2) 75 kW pumps. Hot water recovered from chiller 3 is circulated by one (1) 7.5 kW pump. For primary heating, four (4) hot water boilers are used. Total capacity of the boilers is 2,043,000 KCal/hr. The hot water distribution also consists of primary and secondary loop. The primary loop is served by one (1) 2.2 kW pump for the large boiler (boiler #4), and three (3) 1.1 kW pumps for the other boilers. The secondary loop consists of three (3) 15 kW pumps. There are a total of 16 single duct AHUs serving the office areas, Etch lab, and the Cafeteria, in conjunction with 23 exhaust fans and 12 fan coil units (FCU). The FCUs are used as backup and most were not operational during the evaluation. 12 terminal boxes for the AHUs are CAV, and 133 are VAV without reheat for the interior zones. Perimeter heating for the building is done by 61 VAV terminal boxes with hot water reheat and 25 series Fan Powered Boxes with hot water reheat. The CMP laboratory is served by 2 make-up air AHUs (MAU), 40 recirculation AHUs (RAU), 2 FCUs, 244 plenum fans (PLN), 104 fan filter units (FFU), and 8 exhaust fans. In addition, there are 2 make-up air units and 8 exhaust fan units acting as backup for decontamination sequence.

Energy Efficiency Measures

It is recommended to optimize the chiller staging, primary pump staging, condenser water pump and cooling tower staging, condenser water temperature reset, and secondary chilled water loop differential pressure reset in order to improve the mechanical system performance. At the same time, to modulate the condenser water pump speed to maintain condenser water loop differential temperature, and modulate the primary chilled water pump speed to maintain positive bypass flow rate when possible.

Solar Panels. There are a total of 2,883 monocrystalline, 205 watt PV panels that were installed with combined generation capacity of 594 kW. The outputs from the PVs are connected to the electricity grid.

HVAC System. Energy efficiency measures were developed for the terminal units (TBs), fan power boxes (FPBs), office and lab air handling units (AHUs), make up air units (MAUs), Exhausts system, fan filter units (FFUs), plenum units (PLNs) and recirculation air handling units (RAHs), fan coil units (FCUs), central chiller plant and boiler plant. For AHUs: 1) Dynamic Minimum Airflow Reset Technology for the VAV boxes and Fan Powered Boxes; 2) VFDs installation on supply and return fans of AHU B3 and B4 and supply fan of A6; 3) Dynamic Load Reset for AHU-B3, B4, C6 and C7; 4) Optimal speed, supply air temperature and duct static pressure control for the AHUs. For MAUs and Exhausts: 1) Fan air station installation and optimal speed, supply air temperature and duct static pressure control for MAUs; 2) Optimal speed control for exhaust fans. For RAUs: 1) Optimal fan speed control to maintain required particle count requirement and improved space pressure control. For FFUs and PLNs: 1) Optimize VFD speed control to maintain required particle concentration with optimal airflow exchange rate. For central cooling plant: 1)VFDs installation on all primary and condenser water constant speed pumps; 2) Pump flow stations installation on all chilled water primary, secondary and condenser water pumps; 3) Optimal VWV (Variable Water Volume) control algorithm on the chilled/cooling water systems; 4) System-oriented control strategy for optimal supply BW temperature control via direct return water provided from AHUs or other units; 5) Fully use four cells of cooling tower before enable the second cooling tower fan. For boiler heating system: 1) Pump flow stations installation and optimal variable flow control on the heating water system; 2) Optimal boilers stage control and hot water temperature reset schedule. For TES system: 1) Optimal charging/discharging time of TES; 2) Optimal TES pump speed control.

Measurement and Verification

Power meters were installed to measure the electricity demand and verify the energy saving. There are eight permanent power meters covering all HVAC related system load. There are two permanent solar power meters to measure the power generated from the solar panel. In addition, there are eighteen temporary power meters that were installed for a period of two weeks to capture the related non-HVAC loads. The power demand was monitored every 15 minutes.

Energy or demand savings are determined by comparing energy use before and after implementation the energy efficiency measures (EEMs) [8]:

$$\text{Energy}_{\text{Sav}} = \text{Energy}_{\text{Pre-ECM}} - \text{Energy}_{\text{Post-ECM}} \pm \text{Energy}_{\text{adj}} \tag{1}$$

where $\text{Energy}_{\text{sav}}$ is the annual HVAC electricity savings, in kWh; $\text{Energy}_{\text{pre-ECM}}$ and $\text{Energy}_{\text{post-ECM}}$ are the annual HVAC electricity consumption before and after implementation of the ECMs, respectively, in kWh; $\text{Energy}_{\text{adj}}$ is the adjustments counted for operation schedule, occupancy changes and electrical equipment changes in the building, in kWh.

The HVAC load is determined by:

$$Q_{\text{HVAC}} = \sum_{i=1}^{7} Q_i - Q_{\text{NON-HVACi}} \tag{2}$$

where QHVAC is the total HVAC demand, in kW; Q_i is the readings from meters i, in kW; $Q_{\text{NON-HVACi}}$ is the NON-HVAC demand from those sub meters i, in kW.

The total non-HVAC load is calculated by:

$$Q_{\text{NON-HVAC}} = Q_t - Q_{\text{HVAC}} \tag{3}$$

where $Q_{\text{NON-HVAC}}$ is the total NON-HVAC demand, in kW; Q_t is the total building energy demand, in kW.

Power data were gathered for one month to establish the baseline consumption. The data collected for the base line was from July 29, 2008 to August 21, 2008 after the meters were installed. The power demand was monitored every 15 minutes. The outside air temperature was recorded by the temperature sensor installed on one of the MAUs to gather the "on-the-spot" weather condition. Updated data for the total HVAC system electricity consumption were gathered after the implementation, from August 21 to September 6, 2009 and monitored for another two years after project completion. Figure 2 presents the HVAC demand before and after the implementation of the EEMs. The savings comes from the EEMs is 7,209,000kWh/year and the demand reduction is 935 kW (including some EEMs that were implemented before the power meters was installed).

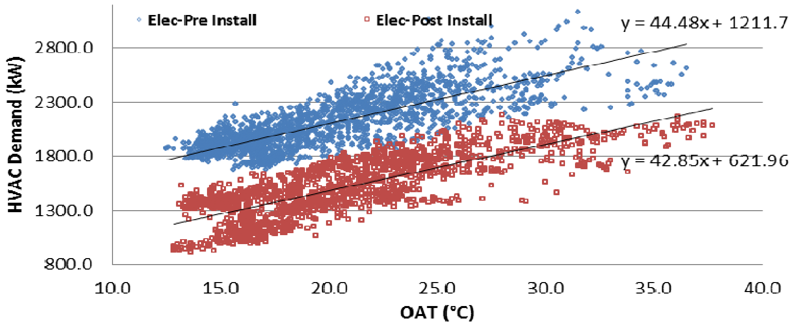

Figure 2 HVAC system demand

The 15 minutes interval data for electricity generation by the solar panel were collected for a whole year in 2010. Figure 3 presents the average monthly electricity demand generated by the solar roof. Figure 4 presents electricity generation for a typical day in December and July. The electricity demand (92.7 kW) is calculated as the baseline to calculate the electricity savings (811,925 kWh/year) by the solar panel. The peak demand reduction calculated from 2PM to 5PM in the three continuous days including the hottest day in 2010 is 302.6 kW.

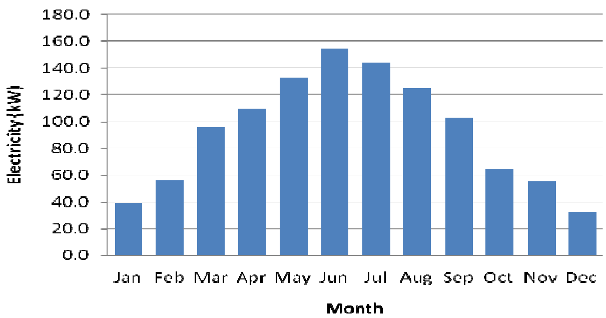

Figure 3. Average monthly electricity demand generated by the solar roof

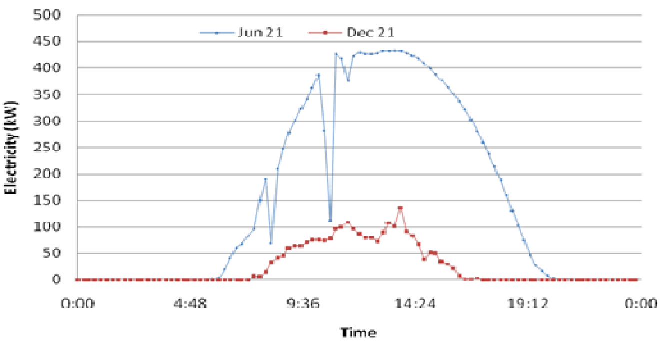

Figure 4. Electricity generation for a typical day in December and July

Figure 5 shows the variation of electricity demand that covers the PLN, RAUs, FCUs before and after implementation of the energy efficiency measures. The demand on those units is not affected by the weather conditions. It can be observed that the total demand was reduced from about 800 kW to 400 kW after the implementation of the EEMs.

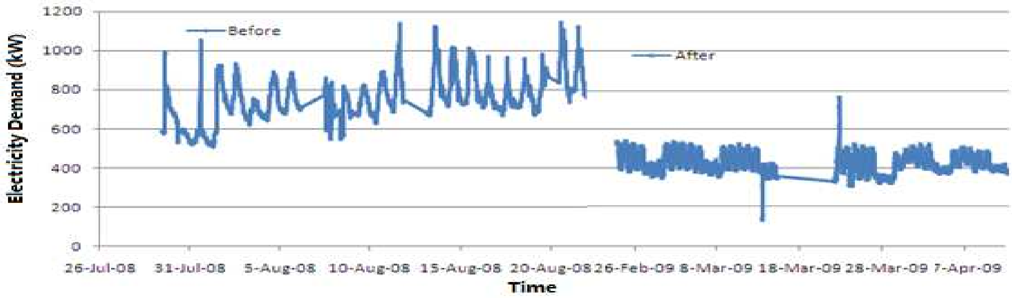

Figure 5 Electricity demand from covering PLN, RAUs, FCUs that are non-OAT related

Discussion and Recommendation

High-tech buildings energy consumptions are much higher than the average commercial buildings. A big proportion of the building energy is consumed by the clean rooms and labs. This is because: (1) there is relatively high cooling loads in the labs and clean rooms throughout the year, which consumes large amount of cooling energy; (2) large amount of fan energy usage is consumed to circulate the air inside the clean room to meet the particle and air flow requirements; (3) because of high air flow rate and low temperature and strict relative humidity requirements, the fresh air need to be treated before sending to the conditioned space. Significant simultaneously heating and cooling can usually be found to treat the fresh air to deliver adequate supply air to the conditioned space due to improper control sequence or hardware problem. Both solar roof and EEMs are capable to reduce the electricity consumption and peak demand. The EEMs are able to reduce the electricity consumption by up to 30% of the total building energy consumption. However, the reduction on the peak demand reduction is moderate and a big proportion is contributed by TES. On the contrary, the solar roof reduces less energy on average but reduces much more on the peak demand compared to its energy savings. Therefore, both system optimization technologies and renewable energy sources need to be combined to achieve the goal for building sustainability.

Acknowledgements

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