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Analysis of savings due to efficiency improvements in multiple office buildings

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Commercial building energy use is 14% of total US energy consumption. About 70% of the primary energy used in commercial buildings is in the form of electricity. Commercial buildings use nearly one-third of the total electrical energy consumed in the United States. Improved understanding of how retrofits save energy in commercial buildings is important to increasing energy efficiency in this sector.

The United Unions building, a CADDET case study building located on New York Avenue in Washington, DC, was selected to analyze the benefits of previously installed building energy retrofits. This building was built and occupied in 1973, then retrofitted with lighting improvements, heating, ventilation and air conditioning (HVAC) improvements, and energy management controls in 1988. The energy savings through retrofits are about 200 MWh per month on average with total demand savings of 600 kW off the summer peak. Total retrofit cost was about USD 700,000, while savings are about USD 160,000 per year.

The building design has a typical plan which consists of an interior zone and four perimeter zones. The interior zone includes core space for vertical circulation and other building services. The building is constructed of structural steel frame with concrete floors and roof. Floor-to-floor height is 3.2 m (10 ft 6-in) and floor-to-ceiling height is 2.7 m (9 ft). Ceilings are suspended acoustical tiles and there are no return air ceiling plenums. Precast concrete exterior cladding of 2.1 m (7 ft) by 3.2 m by 0.1 m (10 ft 6-in by 4-in) thick are used for the vertical enclosure of the building. Windows are 6 mm (1/4-in) double panes with reflective coating on the inside.

South-west view of United Unions building Washington, DC, USA.

Retrofits

Originally most of the lighting in the building was provided by unique six-lamp, 30 watts per lamp, 0.8 x 0.9 m (3x3 ft) fluorescent fixtures. 60 to 300 W incandescent and spot lamps were also used. The fluorescent fixtures were modified in 1988 to maintain the desired illumination with fewer lamps. The lighting system is controlled locally and manually.

A total of 2,329 6-lamp fixtures were fitted with silver reflectors. The reflectors were custom designed, fabricated and installed. The reflectors improved the light output of fixtures so significantly that 2 to 4 of the lamps could be removed from each 6-lamp fixture. The required light levels between 645 x 860 lx (60-80 fc) were still maintained following this activity, while lighting energy demand was reduced by more than 225 kW. In

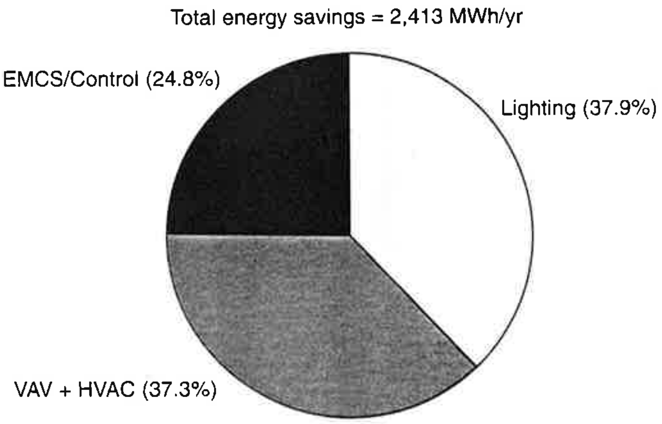

Figure 1: Energy savings from retrofits in 1988.

addition, about 500 recessed incandescent and flood lamps, 60 to 300 W, were replaced with self-ballasted compact fluorescent fixtures, 5 to 13 W, which saved an additional 25 kW. These changes reduced the lighting energy use from about 32 w/m^2 (3 W/sqft) to about 21 w/m^2 (2 W/sqft).

As built, the building had four dual duct air handling systems that distribute heating and cooling air to four vertical zones. Each system had a 37 kW supply air fan and two 22 kW return air fans that provided constant volume air flow. The supply air temperature to each zone was controlled by mixing the hot and cold air stream in a mixing box in each zone. The hot air was provided by electric resistance coils located in the hot deck and the cold air was provided by chilled water coils located in the cold deck. Two 370 tonnes centrifugal chillers, backed up by a third 120 tonnes reciprocating chiller, provided the chilled water. An air economizer was installed, but the unit was deactivated with the damper in a position such that it provided about 30% ventilation air at all times when the system was operating.

The original dual duct constant air volume system in the building was very inefficient because of conflicting thermal loads, as well as excessive fan power requirements. The 251 dual duct mixing boxes in the perimeter zones were replaced with new variable air volume (VAV) boxes having VAV dampers and new thermostatic controls. The boxes supply either cool or warm air to the space depending on load requirements. The existing pneumatic thermostats were refurbished to improve local comfort control. The result was that temperature control was achieved with lower volume of air, and with significant reduction in fan power requirements.

To take maximum advantage of the fan power reduction, variable-frequency motor drives were installed to control the speed of the supply fans (VAV). The eight parallel 22 kW return fans were controlled by return static pressure sensors through an energy management and control system (EMCS). Now even under peak load conditions, four of the eight return air fans can be shut off. The supply fans operate at about 85% of their design speed most of the time consuming only about half their original energy. These HVAC improvements account for 150 kW in monthly demand reduction.

Pneumatic control of the economizer outside air dampers was reactivated and indoor/outdoor sensors were tied into the EMCS to restore air side enthalpy economizer capability, which had been disabled.

The HVAC systems were originally shut down during unoccupied periods without using an EMCS. The retrofit of the building includes adjusting operating hours, improved temperature control, matching equipment capacity to load, demand control, and load shedding via newly installed EMCS. In practice, demand control and load shedding are not used because of the demand reduction achieved through the other retrofits.

Analysis of savings

Short-term field data collection and computer simulation are used to estimate disaggregated savings benefits in this building. Survey data of the building cover time-of-use, occupancy schedules, functional areas, exterior envelope construction, HVAC system, controls, zoning, lighting systems, and equipment. Field test measurements include hourly total electric energy consumption for the whole building, outdoor temperature, and humidity data collected through the existing sensors installed in the building.

Using existing building energy consumption data, simulation program input data for pre-retrofit and post-retrofit conditions are developed and calibrated. Both monthly energy consumption data over a long time and hourly data over a period of less than a year are used to develop the calibration. Then, a series of simulations are conducted for the incremental benefits of each retrofit installation. A special short-term field test was conducted to obtain data for estimating potential benefits of the EMCS if the building HVAC systems had not been shut down originally during unoccupied periods.

Our results for contributions from individual retrofit based on 1989 weather data are shown in Figure 1. (Similar results can be found in CADDET Analyses Series No. 8: Energy Efficient Retrofitting of Office Buildings.)

	Energy use GWh/yr	Percent of energy use	Energy Cost USD/yr	Percent of energy cost
Pre-retrofit	7.00		530,000	
Post-retrofit	4.59		370,000	
Savings				
Total savings actual	2.42	35	160,000	30
Lighting	0.92	13	64,000	12
VAV + HVAC	0.90	13	62,000	12
Time-of-day control without preexisting	1.62	23	61,000	12
Time-of-day control actual	0.60	9	34,000	6

Table 1: Summary of results.

Discussion and summary

The complex interaction of measures makes assigning specific savings values to each measure difficult. The most reasonable assignment of benefits by measure, based on evaluation of all simulation results, is shown in Table 1. The savings for time-of-day without preexisting show what might have been achieved if no unoccupied period shutdown had been used previously.

The overall savings for the retrofits were about 35% of pre-retrofit energy use and 30% of pre-retrofit energy cost, which represent major savings impacts. The installed costs of about USD 675,000 lead to a payback of slightly over 4 years. The simulations show the larger share of savings that time-of-day (start/stop-setback) control would have led to if the building had been maintained at comfort conditions 24 hrs/day, 7 days/wk before the retrofits. Since some night/weekend setback/shutdown of HVAC systems was used before the retrofits, the controls savings were reduced.

The time-of-day controls retrofit, which is a basic function of the EMCS, would have saved about 25% of total energy use if installed by itself without the other retrofits and if manual time-of-day control were not practiced previously. However, since some time-of-day shutdown preexisted before the EMCS installation, savings were only 9% of pre-retrofit energy use. Based on judgment and our simulation results, we conclude that most of the control savings in this building occurs due to the time-of-day capabilities of the EMCS.

Possible energy savings were estimated for an additional control function provided by the EMCS: optimal start/stop. The simulation showed the energy and cost savings from optimal start/stop are limited. This result gave additional evidence that most of the control savings comes from time-of-day control. One additional control function is the HVAC economizer control. Economizer control can be a significant benefit in cases where the air dampers are kept functional, if the EMCS economizer control is more reliable than other control hardware used to control the economizer air dampers. In this building the economizer also had limited benefit, because the maximum outdoor air was only 50% and the systems were shut down at night.

The cost savings for the retrofits indicate the impacts of the utility electricity rate structure for the building. The lighting and VAV retrofits provided significant benefits from reduction of electric demand during peak periods, while the controls retrofit did not. Thus, the dollar savings from the controls retrofits are proportionately less.

For more information, please contact the US National Team (address on page 26).