RETROCOMMISSIONING'S GREATEST HITS

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ABSTRACT

It is possible to save thousands of dollars in energy costs through a few low-cost operational adjustments but those opportunities are often hidden. Retrocommissioning is a systematic investigation process for improving and optimizing the operation and maintenance of buildings. Although owners' priorities for RCX projects may vary, it typically focuses on energy-using equipment such as lighting, HVAC, refrigeration, and the related controls. This paper highlights key findings from several of PECI's retrocommissioning projects that have produced significant benefits for low costs. The RCX measures are described along with the estimated savings, simple paybacks, and related benefits.

INTRODUCTION

Retrocommissioning is an event in the life of an existing building that applies a systematic investigation process that results in improving and optimizing a building's operation and maintenance (O&M) practices. Retrocommissioning primarily focuses on energy-using equipment and low-cost improvements rather than expensive capital-intensive retrofit measures. The investigation may or may not emphasize bringing the building back to its original design.[i] This paper describes several retrocommissioning measures that emphasize optimizing the operation side of the O&M equation. The paper draws on three utility funded studies and one government funded study performed by Portland Energy Conservation, Inc. (PECI) over the last six years. The intention for these studies is to demonstrate the enormous potential of cost effective energy savings that resides in existing buildings.

The 15 individual energy-saving measures selected for discussion in this paper are based on their ease of implementation and a simple payback of one year or less. Several also have high persistence because they are difficult to circumvent once implemented. The measures range from simple scheduling and reset changes to programming improvements integrated with physical repairs. The nine buildings looked at include one long-term care facility, two retail businesses, one high-tech facility, one hospital, three office buildings and a corporate office complex. All together the studies were responsible for implementing 82 low-cost O&M measures leading to an estimated annual energy savings of $503,000. A description of each measure includes the cost to implement, the energy savings in dollars and as a percentage of overall energy costs, and the simple payback.

APPROACH

The investigative approach used for uncovering the findings in this paper included an interview of the key building operating staff along with an intensive building survey and energy bill analysis, extensive data gathering using portable data loggers and energy management system (EMS) trend logging (calibration of EMS sensors was required before installing trends), limited manual testing and observation, and post-monitoring of implemented measures. In the course of the investigation, if indoor air quality or safety issues were uncovered or more intensive capital measures were identified, they were brought to the building owner's attention for consideration. Discussion of these capital-intensive measures is beyond the scope of this paper. Computer simulation tools such as DOE 2 and EZ Sim and typical engineering calculations were used to arrive at energy savings estimates. The overall estimated savings for a package of measures in a building was calculated by summing the savings for individual measures and reducing the total by 15% to account for interactive effects. The savings calculation methodology for each measure is included in Appendix A.

SIGNIFICANT FINDINGS

High-Tech Company

The campus of a high tech company in the Portland area was retrocommissioned as part of Portland General Electric's (PGE) Retrofit Commissioning program. The campus consisted of a group of buildings ranging from 2 to 19 years old, totaling approximately 800,000 square feet. Two central chiller/boiler plants, 34 major air-handling units and several hundred variable air volume terminal units provide heating and cooling to the buildings. The loads are primarily office areas and computer software development labs. The study identified $130,050 of annual energy savings amounting to 9.3% of annual energy costs. The estimated combined study and implementation costs were $124,200 for a simple payback of 0.8 years. The following discusses three significant findings.

Extended surface area filters.

The air handling systems in the high tech campus were equipped with prefilters and final filters. The purpose of the prefilters is to extend the life of the final filters by removing many of the larger particles. However, prefilters add pressure drop to the system and do nothing to make the air that is supplied to the building any cleaner.

This measure required that facility staff eliminate the prefilters and use extended surface area filters with high dust-holding capacity, longer life and lower pressure drops.[ii] These filters fit conventional filter framing systems and can be applied to existing systems without retrofit work. They typically cost more than standard filters but have lower life-cycle costs because of their lower pressure drop and longer life. They are also a "greener" choice because they use fewer consumables and generate a smaller waste stream since they can last three years longer than conventional filters under normal conditions.

Implementation of this measure needs to be done with care. Prefilters were first eliminated on a selected number of air handlers and system performance was evaluated before removing all the prefilters in the system. In this case, synthetic extended surface area filters were selected because they are more immune to biological activity and the filters can be periodically sent to a lab for testing. Extended surface area filters can be installed on variable speed fans without any further adjustments. However, on constant volume fan systems, the fans require resheaving to produce the design flow rates with the reduced pressure drops of the extended surface area filters.

Cost to Implement	$10,700
Energy Savings	$18,000 (1.3%)
Simple Payback	0.6 years

Scheduling and flow settings.

The HVAC systems serving these high-tech buildings operate 24 hours a day, 7 days a week even though the buildings are typically only occupied from 7 am to 8 pm, 5 days a week. In order to accommodate employees working after hours and to maintain temperature and humidity conditions in the computer labs, the HVAC systems were not set back at night. In addition, minimum ventilation rates were based on occupancy projections that no longer reflect the current occupancy level on the site. As a result, the air handling system was moving more air than needed to meet the cooling load causing the space to be reheated most of the time.

During the retrocommissioning study, the schedules for all terminal zones that do not serve computer lab areas were set to normal operating hours. In addition, the high and low temperature limit strategies were set to prevent space conditions from drifting too far during unoccupied periods. Minimum flow rates were also adjusted to reflect actual occupancy levels during both the occupied and unoccupied cycles. All of these adjustments saved heating, cooling, and fan energy.

Cost to Implement	$35,000
Energy Savings	$86,800 (6.2%)
Simple Payback	0.40 years

Excessive simultaneous heating and cooling.

When the computer development labs were remodeled, new stand-alone cooling systems were installed in the computer room to satisfy the cooling and humidity conditions required by the computer labs. Unfortunately, the installation of these new systems was not coordinated with the existing central chiller system that was serving the same area. The central cooling system was trying to maintain a space temperature that was higher than what the stand-alone cooling units were trying to achieve. As a result, air entering the computer labs was being reheated at all times because the central system thought the space was too cold and required reheating. To rectify the problem, the central system minimum flow setting and reheat control was reprogrammed. Overall airflow to the computer room was reduced and the need for reheat virtually eliminated.

Cost to Implement	$17,300
Energy Savings	$23,000 (1.6%)
Payback	0.75 years

SMUD Retrocommissioning Demonstration

This section discusses findings from the Sacramento Municipal Utility District's (SMUD) retrocommissioning demonstration program. Four buildings were retrocommissioned in 1999 as part of this program, two in 2000 and two more are planned for 2001. The following briefly describes two buildings and their related findings.

Hospital

An 8-story, 300,000 square foot hospital in northern California was retrocommissioned. The hospital was completed in 1996 and is used for patient care, family accommodations, research and office space. The building is served by three 750 ton chillers, 12 air handlers, 4 boilers, 74 water source heat pumps, and nearly 500 VAV boxes. As a part of the retrocommissioning study, 19 low-cost measures were identified resulting in $56,865 in energy cost savings with an implementation cost of $29,600 and a simple payback of 0.5 years. The identified savings represent 6.7% of the total energy cost. The following discusses one significant finding.

Pump impellers.

An inspection of the site indicated that the triple duty valves on the condenser pumps were only 20% open. The valves had been throttled because the pumps were significantly oversized and pumping too much water. These throttled valves reduced water flow but also added pressure drop to the system, thus wasting a significant amount of energy. In most cases, water flow is better reduced by trimming the pump impellers and opening the valves at the pump discharge.

In many projects, impellers can be trimmed by in-house facility staff, reducing implementation costs considerably. In this case, the impellers were grossly over sized. Therefore, it was recommended that they replace the 10-1/2 inch impellers with 9 inch impellers rather than trimming the existing impellers. The triple duty valves in the condenser water loop also needed adjustment to ensure proper flow. The 10-1/2 inch impellers were saved in case future operating conditions change.

If pumps or fans are equipped with variable speed drives, it is tempting to balance the system by slowing the pump down with the drive rather than by trimming the impellers. While better than throttling, the result is not optimal since drive efficiency drops as a function of load and drive speed. As a general rule, a system's overall efficiency is best optimized by adjusting the pump's impeller size so that the pump delivers the design flow when the drive is running at full speed. The variable speed drive can then be used to match the actual load conditions.

Cost to Implement	$6,700
Energy Savings	$6,700 (0.8%)
Payback	1.0 year

County Coroner's Office

The SMUD energy-efficiency program also provided for retrocommissioning a County Coroner's office in Northern California. The coroner's office is a two-story, rectangular 94,000 square foot office building, completed in 1997. The facility consists of offices, a morgue and crime labs. Cooling is provided by two 265-ton centrifugal chillers tied to two cooling towers. Heating is provided by two 4,000 MBTU gas boilers. There are also five air handlers (three of which use 100% outside air) with variable speed drives on the pumps and fans. The retrocommissioning study identified four measures to achieve a 14% reduction in energy costs, saving $64,400 annually for an implementation cost of only $4,300. The simple payback for the four measures was 0.07 years. The following discusses two significant findings.

By-pass timers.

In the county coroner's office, the space was being conditioned 24 hours a day, 7 days a week even though the areas were only being occupied from 7 am to 6 pm, 5 days a week. Time-of-day schedules had once been set up in the building automation system (BAS) but were not being used.

As a result of the retrocommissioning study, the air handling units were shut down when the space was not being used (6 pm to 6 am) and existing timing switches were enabled for occupants coming in after normal hours. Implementation costs only included the costs to reprogram the BAS system and install the timing switches.

Cost to Implement	$3,500
Energy Savings	$65,800 (14%)
Simple Payback	0.05 years

Supply air temperature setpoint.

The supply air temperature setpoint in the coroner's office was manually set at 54°F during warm weather months and then changed to 57°F by facility staff during colder weather months. Since many zones did not need 54°F air to satisfy space conditions during warm weather months, air was being reheated before entering the space in these zones. As a result, both cooling and heating energy was being wasted.

The original sequence of operation in the control drawings outlined a control strategy that reset the supply air temperature to a higher value when space-cooling requirements were satisfied. Implementation of this measure involved enabling this sequence and tuning the control loops so that the systems operated properly. Savings for this measure assumed the supply air temperature could be reset 30% of the time the chillers operate during the summer cooling period.

Cost to Implement	$700
Energy Savings	$5,000 (1%)
Simple Payback	0.14 years

Long Term Care Facility

In 1999, PECI, in conjunction with the Institute for Market Transformation and the Pacific Gas and Electric Company, performed a retrocommissioning evaluation of two long-term care facilities in California. One such facility was a 30,244 square foot nursing center built in 1991. The building accommodates 99 residents and 40 staff members. The building is served by 15 rooftop packaged units and has propane-fired hot water heaters.

The study identified nine low-cost O&M measures. Seven of the nine were implemented for an annual savings of $8,600 or 8.3% of overall energy costs. Implementation was projected to cost $13,100, yielding an 18-month payback. In addition to energy savings, the study identified indoor air quality and safety issues for investigation. The following discusses two significant findings.

Economizer controls.

The economizer controls on all rooftop packaged HVAC units were never connected. Furthermore, the facility lacked the proper kind of thermostat to allow the economizers to operate. It was recommended that they install 2-stage thermostats throughout the facility and connect them to allow the economizers to function as the first stage of cooling. Economizing opportunities are especially significant in facilities operating 24 hours a day, because they can take advantage of the free cooling at night. The new thermostats will provide additional savings because they will have setback capabilities. The HVAC systems serving the Administration area and Day Room could adjust setpoints during unoccupied hours.

Cost to Implement	$3,600
Energy Savings	$4,700 (4.5%)
Simple Payback	0.8 years

Hot water piping.

The following is an example of a safety issue identified in the course of the investigation. Investigators noticed that hot water occasionally flows from cold taps in the laundry room. On one occasion, the temperature was measured at 116ºF. The same piping that supplies the faulty “cold” tap also supplies an eye wash, creating the potential for serious injury. In addition this “cold” water line also serves each clothes washer, so energy savings may occur if washers have been using warm or hot water when set to operate on cold.

This finding required investigation and correction of the piping layout. The facilities manager was a licensed pipe welder, so he was able to fix the problem without outside contractors. The energy savings are not calculated, as they are uncertain, but the measure was worth implementing to maintain occupant safety.

Corporate Office Complex

A Boston Edison demonstration project required retrocommissioning of three of five buildings at a corporate office complex in Massachusetts. The buildings house primarily office space, although some process and limited laboratory spaces exist. The total facility is over 540,000 square feet and the three buildings investigated represent over 230,000 square feet. They range from 13 to 38 years old. The observation and data analysis revealed that in general, over 70% of the total energy use in the facility was consumed during non-occupied periods (nights and weekends.) Of twenty-three low-cost O&M measures identified, the owners decided to implement 12. Most of the recommendations were operational in nature and relatively easy to implement, requiring only control setpoint changes or minor programming performed by in-house staff. The measures yielded $121,200 in annual estimated savings, reducing energy costs by 17.6%. They cost approximately $2,000 to implement for a payback of 0.02 years.

Scheduling of equipment and lights.

During a night walk-through, investigators found that a DX unit was on when it wasn’t needed. A facilities staff person was present and fixed the program code before the walk-through was over. A list of fan and pump equipment that was on after-hours was also generated. Estimated savings for this measure alone is $21,400 or 3.1% of energy costs.

In addition, the study found that employees were circumventing the lighting control system and wasting energy. Originally, the system was set up to allow after-hours employees to dial a code to turn on small (2,000 SF) areas as needed. However, dial-in codes had been misplaced, so security staff were turning on lights on an entire floor. When only five people were working in the building, two full floors of lights were on (216,000 SF). To address this problem, the dial-in codes were redistributed to all staff and posted in the zones where they were applicable. Estimated savings for this measure is $45,000 annually or 6.5% of total energy costs.

Cost to Implement	$0
Combined Energy Savings	$66,340 (9.6%)
Simple Payback	Immediate

Additional "soft" savings were identified when investigators noticed that half of the computers and printers were left on at night. They recommended that staff be reminded of the value of turning off equipment at night. Turning off this equipment could provide an estimated $37,600 in additional cost savings, reducing current energy costs by 5.4%.

Economizer settings.

Some of the air handling units have a restrictive economizer changeover setpoint. They use dewpoint of 50ºF as the economizer changeover. However, dewpoint is not a good measure of heat content. It was recommended that they use enthalpy as a better indicator of the economizing threshold. Since an enthalpy sensor was already in place, in-house staff changed the algorithm in the EMS to allow economizing below 70ºF dry bulb and less than 25 Btu/lb enthalpy. This will result in approximately 714 hours of additional economizing annually during occupied hours.

Cost to Implement	$0
Energy Savings	$17,000 (2.5%)
Simple Payback	Immediate

Static pressure reset strategy.

The retrocommissioning analysis discovered that air handlers had no reset strategy for the duct static pressure setpoints. Because there was no documented justification for the static pressure setpoints and no reset strategy, the setpoints were probably higher than necessary. The analysis recommended programming the following static pressure reset sequence, based on the condition of the variable air volume (VAV) boxes:

The following is a sample static pressure reset sequence recommended by the analysis: "Poll all boxes every 5 minutes. If none are more than or equal to 95% open, reduce duct static pressure set point by 7%. If one or more boxes exceed 95% open, increase static pressure set point by 7%. If one or more boxes are equal to 95% open, and none exceed 95%, then do nothing." This programming change was implemented within a month of discovery.

Cost to Implement	$0
Energy Savings	$7,500 (1.1%)
Simple Payback	Immediate

A Five Building Study

This section discusses five significant findings from a five-building O&M investigative case study funded by the Global Change Division of the U.S. Environmental Protection Agency and the U.S. Department of Energy in 1995. The buildings included two retail and three commercial office buildings which are located in various parts of the country. The objectives of the study were to identify and demonstrate the energy savings that can be achieved through application of better O&M practices.[iii] The following briefly describes four of the buildings and their related findings.

Oregon Office Building

This building is a 15-story, class A office building located in Portland, Oregon. The building is all electric and has approximately 240,000 conditioned square feet. Although the first floor houses mainly retail establishments, the study only investigated the office portion of the building and entry lobby. The retail portion of the building is metered separately and is not served by the building's major mechanical systems. The major equipment includes an energy management control system, two 295-ton centrifugal chillers, one cooling tower, two main air handling units, and duct reheat.

Four of nineteen findings for this building were implemented resulting in annual estimated energy savings of $6,885 or 2.0% of energy costs. The total cost of the study including implementation was $12,700. This equates to a 1.8 year simple payback. The following describes one of the findings.

EMS control of duct heaters.

The investigation determined that several duct heaters were on when outside air was above 70ºF. The problem was located in the program of the EMS. The lockout statement was written with an "and" statement instead of an "or" statement. The program was changed causing the duct heaters to be locked out when either the outside air was above 60ºF or the space temperature was at or above set point. This small error in a logic statement can lead to years of energy waste and lost savings. Without rigorous commissioning, this type of deficiency goes unnoticed. The program repair was implemented by the controls contractor as part of their service contract agreement at no additional cost.

Cost to Implement	$0
Energy saving	$3,700 (1.0%)
Simple payback	Immediate

Colorado Retail Facility

This facility is a two-story, 120,000 square foot building built in 1973 and is an anchor store in a retail mall. It was renovated in 1987. The building contains typical department store sections, a hair styling salon and offices. The heating plant consists of two gas boilers and the cooling plant consists of two 150-ton centrifugal chillers. The HVAC distribution system is a two-supply, two return, multizone (seven zones), constant volume system.

Nine of the twenty-eight findings for this building were implemented resulting in annual estimated energy savings of $11,730 or 10.9%. The total cost of the study was $11,300 including implementation. This equates to a one year simple payback. The following describes two of the findings.

EMS night purge and optimum stop strategies.

Using portable data loggers to track temperatures, the investigation revealed that the EMS night purge strategy was, during some mornings, actually increasing space temperature instead of decreasing it prior to occupancy. This had the opposite effect of what is intended by a night purge (or early morning precool) strategy. This occurred because the night purge sequence was programmed to take place when there was not enough difference between the outside air enthalpy and the indoor air enthalpy (parameter was set at zero). Additionally, supply and return fans were also grossly oversized. Heat from the fan motors was being put into the building thus increasing the space temperature and causing the chillers to come on prematurely. This strategy was easily repaired by changing the program parameter so that night purge occured only when the indoor air enthalpy was at least 3 Btu/lb greater than the outdoor air enthalpy. Also, the inside space dry-bulb temperature had to be at least 71ºF to activate the strategy.

Further investigation of the EMS program showed that the optimum stop strategy was set to inactive allowing the chiller to run beyond what was necessary prior to closing time. This was another easy programming repair. The optimum stop sequence was toggled to active. The controls contractor implemented both program repairs as part of the building's service contract agreement.

Cost to Implement	$0
Energy savings	$5,000 (4.7%)
Simple Payback	Immediate

Tennessee Office Building

This building is a 15 story, 250,000 square foot state office building built in 1985 and located in Nashville, Tennessee. The HVAC distribution system is comprised of one supply fan on each floor with variable inlet vanes and VAV terminal boxes. Perimeter reheat is supplied by fan-powered VAV boxes with hot water coils. Cooling is achieved by a chilled-water cooling coil at each air-handling unit. District steam and chilled water from the Nashville Thermal Plant supplies the building for heating and cooling purposes. The steam is converted to hot water on site.

Ten of thirty-two findings for this building were implemented resulting in an annual estimated energy savings of $42,000, reducing energy costs by 9.3%. The total cost of the study including implementation was $24,000. This equates to a seven month simple payback. The following describes two related findings.

Chilled water pump variable frequency drive.

The investigation revealed that the wrong current transformer had been supplied to the variable speed drive on the 40 hp chilled water pump. Because of this, the VFD was off on a fault and had been that way for months according to building personnel. Essentially the VFD was useless in reducing pumping energy. Supplying the correct current transformer partially remedied the problem. However, post-monitoring data continued to show that the pump was still not running optimally. Troubleshooting revealed that due to a combination of problems, including programming set-up errors for the VFD, incorrect pressure set point (160 psi), excessive bypass flows (and "leak-by" at valves) and severe hunting by chilled water valves, the pump would not modulate beyond 40% to 50% of design and continued to go off on fault. Once these problems were repaired, the VFD and pump performed as expected. The pressure set point was reduced to 100 psi and the VFD now consistently runs at about 15 Hz without tripping.

Chilled water piping system bypasses and leaks.

Data from portable loggers along with the EMS trending capabilities revealed numerous bypasses from the chilled water supply to the return as well as valves "leaking by" causing the chilled water pump to run at unnecessarily high speeds. The total waste was 383 gpm or 30% of design flow (1270 gpm). It was found that 200 of the 383 gpm were due to "leak by" at the chilled water valves for several of the air handlers. In part, the cause was a programming error in the EMS. Reprogramming allowed the valves to shut tightly when the units were off or when cooling was not needed. Three valves needed actuator adjustments and one valve need the actuator replaced.

Unneeded bypasses made up the balance of the lost gpms. When the VFD was installed on the chilled water pump, five three-way valves in the piping system were not changed to two-way valves thus allowing unnecessary bypassing to occur. Two of the three-way valves were not needed and were permanently closed off accounting for another 73 wasted gpms. The other three valves needed replacement.

Total for Both Findings:

Cost to Implement	$9,300
Energy Savings	$24,300 (5.4%)
Simple Payback	0.4 years

Massachusetts Retail Building

This is a single-story, 105,000 square foot retail building located in Massachusetts. At the time of the study, the building was three years old. Cooling is accomplished by several packaged roof-top units while heating is accomplished by a furnace and auxiliary ceiling-mounted unit heaters. The refrigeration for the store is configured in parallel and consists of a medium temperature rack and a low temperature rack.

The study identified 29 findings. The top five findings represent a potential annual energy savings of $6,800, reducing energy costs by 2.6%. The cost to implement these recommendations is $3,200, yielding a simple payback of 0.5 years. Although some of the cost savings appear small, the savings become significant when multiplied by the number of stores that could duplicate the measure. Some of the savings included reduced energy charges from a strategy of load shifting. The following illustrates this strategy.

Battery charging schedule changes.

Investigators noted that there are five forklifts requiring daily charging. Forklift operators generally plug the forklifts into the charger when they are finished using them between 4 and 5 pm. This constitutes a significant on-peak load and the energy use rate is higher for on-peak times (8 am to 9 pm on week days). Placing the charging units on a time clock or the EMS that starts the charging during the off-peak energy use hours will not only save on energy charges, but will reduce demand by charging the units during times that are not coincident with peak building demand.

Estimated Cost to Implement: $500
Estimated Annual Savings: $3,700 (1.4%)
Simple Payback: 0.14 years

The following table presents a summary of the 15 energy saving findings.

Table 1: **Summary of Findings and Savings**

	Building	Measure Description	Cost	Savings ($/yr.)	Simple Payback
1	High Tech	Extended Surface Filters	$10,700	$18,000	0.60 years
2		HVAC Scheduling & Flow Settings	$35,000	$86,800	0.4 years
3		Excessive simultaneous heating and cooling	$17,300	$23,000	0.75 years
4	Hospital	Pump Impellers	$6,700	$6,700	1 year
5	Coroner's Office	By-Pass Timers	$3,500	$65,800	0.05 years
6		Supply Air Temperature Setpoint	$700	$5,000	0.14 years

7	Long Term Care Facility	Enable Economizer Controls	$3,600	$4,700	0.8 years
8	Corporate Office	Scheduling Equipment and Lights	$0	$66,400	Immediate
9		Economizer Settings	$0	$17,000	Immediate
10		Static Pressure Reset	$0	$7,500	Immediate
11	Oregon Office	EMS Control of Duct Heaters	$0	$3,700	Immediate
12	Colorado Retail	EMS Night Purge and Optimum Stop Strategies	$0	$5,000	Immediate
13	Tennessee Office	Chilled Water Pump VFD	Combined Measures: $9,300	Combined Measures: $24,300	Combined Measures: 0.3 years
14		Chilled Water Piping System Leaks and Bypasses			
15	Massachusetts Retail	Battery Charging Schedule Changes		$3,700	
	Total		$86,800	$337,600	0.26 years

APPENDIX

Savings Methodology

Extended Surface Area Filters

Energy savings associated with this measure can be calculated using the following methodology: (1) Calculate the fan horsepower requirement at both the existing and proposed fan static pressure values; and (2) subtract the two power requirement values, divide by motor efficiency, and multiply by fan operating hours.

Fan power requirements (Fan HP) and energy savings (ES) are based on the following equations:

$$\text{Fan HP} = \frac{\text{Air flow (CFM)} \times \text{Fan static pressure (in.w.c.)}}{6356\ \text{(CFM-in.w.c./HP)} \times \text{Fan efficiency (\%)}}$$

$$\text{ES} = (\text{Fan HP}_{\text{existing}} - \text{Fan HP}_{\text{proposed}}) \times 0.746\ \text{(kW/HP)} / \text{Motor efficiency (\%)} \times \text{Fan operating hours}$$

Scheduling and Flow Settings

Energy savings for this measure are attributed to two control strategies: (1) rescheduling system operation; and (2) reducing system air flow rates.

Fan energy savings are based the following equations:

$$\text{Fan HP} = \frac{\text{Air flow (CFM)} \times \text{Fan static pressure (in.w.c.)}}{6356\ \text{(CFM-in.w.c./HP)} \times \text{Fan efficiency (\%)}}$$

$$\text{Fan Energy Use} = \text{Fan HP} \times 0.746\ \text{(kW/HP)} / \text{Motor efficiency (\%)} \times \text{Fan operating hours}$$

For schedule changes, energy savings are calculated by subtracting proposed fan operating hours from the existing fan operating hours and then multiplying that value by the fan power. For a reduction in air flow rates, subtract proposed CFM from existing CFM, calculate the amount of fan horsepower saved, and then multiply that value by the fan operating hours to generate energy savings.

Rescheduling fan operation and lowering minimum flow settings will reduce the amount of energy needed to heat and cool mixed air (i.e. return air mixed with outside air) and reduce reheat energy. Heating and cooling energy savings are based on the following equations:

Heating load = 1.08 (Btuh/CFM-°F) x Air flow (CFM) x Air temperature change (°F)

Cooling load = 4.5 (lb/CFM-hr) x Air flow (CFM) x Enthalpy change (Btu/lb)/12000 (Btuh/ton)

Heating source input energy = Heating load x Operating hours / heat source efficiency (%)

Cooling source input energy = Cooling load x Operating hours x cooling source efficiency (kW/ton)

The parameters that can vary in each equation are “Air flow’, “Air temperature change”, “Enthalpy change”, and “Operating hours”. The reduction in mixed air heating and cooling energy can be calculated using bin weather data. Only heating savings are associated with reheat and based on space temperature setpoint, discharge air temperature setpoint, reduced flow, and reduced operating hours.

Excessive Simultaneous Heating and Cooling

Savings associated with reducing reheat energy usage are based the following equations:

Heating load = 1.08 (Btuh/CFM-°F) x Air flow (CFM) x Air temperature change (°F)

Heating source input energy = Heating load x Operating hours / heat source efficiency (%)

Pump Impellers

Energy savings associated with this measure can be calculated using the following methodology. (1) Measure pump pressure values at various operating points (no flow, existing condition, throttling valve wide open, single-pump operation, parallel-pump operation, etc.). (2) Use pump curves and measured data to develop system curves and identify pump operating points. (3) Use pump curves to determine proper impeller size to meet design water flow under all operating conditions. (4) Use flow, head, and pump efficiency values to calculate existing and proposed pump horsepower. (5) Subtract the two power requirement values, divide by motor efficiency, and multiply by pump operating hours to generate energy savings.

Pump power requirements (Pump HP) and energy savings (ES) are based on the following equations:

$$\text{Pump HP} = \frac{\text{Water flow (GPM) x Pump head (ft } H_2O)}{\text{3960(GPM-ft } H_2O\text{ /HP) x Pump efficiency (\%)}}$$

ES = (Pump $HP_{existing}$ – Pump $HP_{proposed}$) x 0.746 (kW/HP) / Motor efficiency (%) x Pump operating hours

By-pass Timers

Energy savings for this measure are attributed to rescheduling system operation. The savings methodology associated with fan energy and heating and cooling energy are outlined below.

Fan energy savings are based the following equations:

$$\text{Fan HP} = \frac{\text{Air flow (CFM) x Fan static pressure (in.w.c.)}}{\text{6356 (CFM-in.w.c./HP) x Fan efficiency (\%)}}$$

Fan Energy Use = Fan HP x 0.746 (kW/HP) / Motor efficiency (%) x Fan operating hours

Fan energy savings are calculated by subtracting proposed fan operating hours from the existing fan operating hours and then multiplying that value by the fan power.

Rescheduling fan operation will reduce the amount of energy needed to heat and cool mixed air (i.e. return air mixed with outside air) and reduce reheat energy. Heating and cooling energy savings are based the following equations:

Heating load = 1.08 (Btuh/CFM-°F) x Air flow (CFM) x Air temperature change (°F)

Cooling load = 4.5 (lb/CFM-hr) x Air flow (CFM) x Enthalpy change (Btu/lb) / 12000 (Btuh/ton)

Heating source input energy = Heating load x Operating hours / heat source efficiency (%)

Cooling source input energy = Cooling load x Operating hours x cooling source efficiency (kW/ton)

The parameters that can vary in each equation are “Air temperature change”, “Enthalpy change”, and “Operating hours”. The reduction in mixed air heating and cooling energy can be calculated using bin weather data. Only heating savings are associated with reheat and based on space temperature setpoint, discharge air temperature setpoint, and reduced operating hours.

Supply Air Temperature Setpoint

Raising the supply air temperature setpoint during summer months will (1) reduce the cooling energy usage; and (2) reduce the amount of reheat for spaces that do not need maximum cooling. Savings are based the following equations:

Heating load = 1.08 (Btuh/CFM-°F) x Air flow (CFM) x Air temperature change (°F)

Cooling load = 4.5 (lb/CFM-hr) x Air flow (CFM) x Enthalpy change (Btu/lb) / 12000 (Btuh/ton)

Heating source input energy = Heating load x Operating hours / heat source efficiency (%)

Cooling source input energy = Cooling load x Operating hours x cooling source efficiency (kW/ton)

For cooling savings, the variables are "Enthalpy change", and "Operating hours", both of which can be calculated using bin weather data. Only heating savings are associated with reheat and based on space temperature setpoint, discharge air temperature setpoint, and chiller operating hours.

Economizer Control

Energy savings associated with economizers can be calculated by the following methodology: (1) calculate existing cooling energy using bin weather data; (2) calculate the amount of cooling energy available in the outside air using bin weather data; and (3) energy savings will be the lesser number of the two. For example, if the cooling energy used is greater than cooling energy available with 100% OSA, then the savings will be the amount that 100% OSA can offset the usage. If the cooling energy used is less than the cooling available with 100% OSA, then the savings will be the cooling energy used.

Savings are based the following equations:

Cooling load (per bin temperature point) = 4.5 (lb/CFM-hr) x Air flow (CFM) x Enthalpy change (Btu/lb) / 12000 (Btuh/ton)

Cooling source input energy (per bin temperature point) = Cooling load x Bin hours x cooling source efficiency (kW/ton)

Total cooling source input energy = Sum of all cooling energy per bin temperature points

EMS Control of Duct Heaters

Energy savings associated with this measure can be calculated using the following methodology: (1) calculate the heating load based on existing and proposed lockout setpoints; and (2) subtract the two heating load values, multiply by heater operating hours (bin hours between existing and proposed setpoints), and divide by heat source efficiency to generate energy savings.

Energy savings associated with changing the reheat lockout point are based the following equations:

Heating load = 1.08 (Btuh/CFM-°F) x Air flow (CFM) x Air temperature change (°F)

Heating source input energy = Heating load x Operating hours / heat source efficiency (%)

EMS Night Purge and Optimum Stop Strategies

Energy savings associated with these measures are based on the following concepts: (1) pre-cooling the building at nights allows the chiller to stay off until later in the morning; and (2) turning the HVAC systems off an hour or two before the building is unoccupied is possible because of thermal lag within the building. The savings methodology behind these two measures rely on calculating heating and cooling loads on an hour-by-hour basis using local weather data and building thermal characteristics. This generally requires the use of a sophisticated simulation program. In general, energy savings are based the following equations:

Heating load = 1.08 (Btuh/CFM-°F) x Air flow (CFM) x Air temperature change (°F)

Cooling load = 4.5 (lb/CFM-hr) x Air flow (CFM) x Enthalpy change (Btu/lb) / 12000 (Btuh/ton)

Heating source input energy = Heating load x Operating hours / heat source efficiency (%)

Cooling source input energy = Cooling load x Operating hours x cooling source efficiency (kW/ton)

Chilled Water Variable Frequency Drive, Leaks and By-passes

Energy savings associated with these measures are based on the following concepts: (1) repair VFD so that it functions correctly; and (2) reduce flow through the system by fixing leaky valves and installing new two-way valves. A variable frequency drive slows the speed of a pump, which reduces the water flow out of the pump. There were several valves that allowed water to flow through them even when they were "closed" (i.e. they leaked) and some valves allowed full flow to by-pass them when the valves were closed. Both of these conditions were fixed and the total flow through the system was reduced. Since power is proportional the cube of the speed and flow is directly proportional to speed (ideal pump laws), a small reduction in water flow dramatically reduces the power used. Energy usage at any given water flow can be calculated using the following equations:

$$\text{Pump HP}_{\text{any flow}} = \text{Pump HP}_{\text{full flow}} \times (\text{Water Flow}_{\text{any flow}} / \text{Water Flow}_{\text{full flow}})^3$$

$$\text{Pump energy usage} = \text{Pump HP}_{\text{any flow}} / (\text{Motor efficiency} \times \text{VFD efficiency}) \times \text{Operating hours}$$

Energy Savings = Existing pump energy usage – Proposed pump energy usage

Static Pressure Reset

Energy savings associated with this measure can be calculated using the following methodology. (1) Calculate the fan horsepower requirement at both the existing and proposed fan static pressure values; and (2) subtract the two power requirement values, divide by system efficiencies, and multiply by fan operating hours. For this particular project, the fan static pressure reset schedule and fan operating hours were based on bin weather data – as the outside air temperature dropped, it was assumed that the VAV dampers would close due to reduced load. In addition, each fan was controlled by a VFD and the air flow rate varied based on existing damper position.

Fan power requirements (Fan HP) and energy savings (ES) are based on the following equations:

$$\text{Fan HP} = \frac{\text{Air flow (CFM)} \times \text{Fan static pressure (in.w.c.)}}{6356\ \text{(CFM-in.w.c./HP)} \times \text{Fan efficiency (\%)}}$$

$$\text{ES} = (\text{Fan HP}_{\text{existing}} - \text{Fan HP}_{\text{proposed}}) \times 0.746\ \text{(kW/HP)} / \text{Motor efficiency (\%)} / \text{Drive efficiency (\%)} \times \text{Fan operating hours}$$

Economizer Settings

Energy savings associated with economizers can be calculated by the following methodology. (1) Calculate existing cooling energy using bin weather data. (2) Calculate the amount of cooling energy available in the outside air using bin weather data. (3) Energy savings will be the lesser of the two numbers. For example, if the cooling energy used is greater than cooling energy available with 100% OSA, then the savings will be the amount that 100% OSA can offset the usage. If the cooling energy used is less than the cooling available with 100% OSA, then the savings will be the cooling energy used.

Savings are based the following equations:

Cooling load (per bin temperature point) = 4.5 (lb/CFM-hr) x Air flow (CFM) x Enthalpy change (Btu/lb) / 12000 (Btuh/ton)

Cooling source input energy (per bin temperature point) = Cooling load x Bin hours x cooling source efficiency (kW/ton)

Total cooling source input energy = Sum of all cooling energy per bin temperature points

Schedule Equipment and Lights

Energy savings for this measure are attributed to rescheduling system operation and are outlined below and based on the following equations:

Existing Power = Full load power rating per piece of equipment (kW) x Quantity of each piece of equipment

Energy Use = Existing power x change in equipment operating hours

For schedule changes, energy savings are calculated by subtracting proposed operating hours from the existing operating hours for each piece of equipment and then multiplying that value by the existing power for that equipment.

Battery Charging Schedule Changes

Savings associated with this measure include peak demand savings as well as demand and energy cost savings. Savings methodology is based on the following equations:

Charger power = Full load power rating per battery charger (kW) x Quantity of chargers

Energy use = Charger power x Charger operating hours

Peak demand savings = Charger power (operation is shifted to off-peak hours)

Demand cost savings = Peak demand savings x demand charge

Energy cost savings = Energy usage x (on-peak energy charge – off-peak energy charge)

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