Introduction to Commercial Building Audits

Course No. ENRG 50

Outline

A. Introduction to concept of commercial building energy auditing

1. Why energy efficiency (EE) is important
2. Energy use and waste in commercial building operations
3. Prioritizing energy efficiency over renewable energy generation

B. Ordinances, policies and standards governing commercial building audits

1. San Francisco Existing Commercial Buildings Performance Ordinance
2. State of California energy goals
3. ASHRAE standards, including Building Energy Assessment Professional (BEAP)
4. Other audit standards

C. Three ASHRAE audit levels

1. Preliminary energy use analysis
2. Level 1, Walk-through analysis
3. Level 2, Intermediate, energy survey and energy analysis
4. Level 3, Detailed analysis of capital-intensive modifications

D. Developing the scope of work in a commercial building audit

1. Objectives of the audit, including needed data and resources
2. Assessment management
3. Responsibilities of audit team members

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2. Geographical and climatic review
3. Review and analysis of current energy use and costs
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1. Common safety hazards and field safety techniques
2. Occupant interviews and assessment of building operations
3. Building envelope
4. Electrical systems
5. HVAC&R systems
6. Lighting systems and use
7. Miscellaneous other energy use systems
8. Domestic water systems and use
9. Indoor environmental quality

G. Analysis of data collected

1. Identify opportunities for efficiency improvement
2. Calculate value of efficiency improvements and return on investment
3. Prioritize options based on client criteria

H. Audit completion activities

1. Prepare and present written report
2. Assist with development of implementation plan

G. Analysis of data collected

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Identify opportunities for efficiency improvement

- HVAC

  - The most “bang for the buck” comes from **controls**

  - Lead with simple measures like time clocks and programmable t-stats

  - Economizers fail frequently and make a big difference in CA climates

  - A lot can be accomplished through good management

  - Evaporative cooling avoids compressor energy use and can result in big savings

  - Replacing unitary equipment can yield big savings but at high cost

Identify opportunities for efficiency improvement

- Lighting
  - Change out inefficient lighting

    Replace incandescent lamps

    replace halogens used as ambient sources

    Replace T-12 fluorescents

    Replace magnetically ballasted fluorescents

    Replace mercury vapor lamps

    Use LED for exit signs and signage

Identify opportunities for efficiency improvement

- Lighting
  - De-lamp in over-illuminated spaces or service areas
  - Add lighting controls
    - Sweeps
    - Timers
    - Occupancy sensors
    - Daylighting/photosensor controls

Identify opportunities for efficiency improvement

- Motors
  - Focus on motors with long run times
  - Data collected by loggers can help identify opportunities
  - Match motor size to the actual load
  - Consider VFD’s for applications with variable loads

Identify opportunities for efficiency improvement

- Motors

  - Focus on motors with long run times

  - Data collected by loggers can help identify opportunities

  - Match motor size to the actual load

  - Consider Adjustable Speed Drives (ASD) for applications with variable loads

  - PG&E incents ASD for HVAC fans& air handlers

Identify opportunities for efficiency improvement

- Miscellaneous

  - Choose Energy Star equipment and look up available incentives

  - Set up office equipment automatically if not being used

  - Use plug-load controllers

  - Timer controls

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Energy saving equation

Power = The Rate of Consumption kilowatts kW

Time = The Duration of Consumption

Energy = Power X Time

= Total Consumption in Kilowatt hours kWh

Control strategy: regulate the rate of consumption (power), or the duration of consumption (time), or both.

Energy saving calculation

Energy = Power X Time = Total kWh

1. If reducing power only (e.g. de-lamping, re-lamping):

   Δ Energy = Δ Power X Time = ($Power_1$ – $Power_2$)X $Time_2$

2. If reducing time only (e.g. timer control):

   Δ Energy = Power X ΔTime = Power X ($Time_1$ – $Time_2$)

3. If both power and time reduced (e.g. install VFD)

   Δ Energy = $Power_1$ X $Time_1$ – $Power_2$ X $Time_2$

An example: Motor Power Equations

Using information from the nameplate, motor usage can be estimated as:

1. kWh = (hp)(0.746kW/hp)(%Loaded)(hours)/Efficiency
2. kWh = (FLA)(Volts)(PF)(%Loaded)(hours)(Phase^$^{1/2}$)

hp: horsepower

FLA: full load amps

PF: power factor

Motor Power Equations

Calculate percent load (%Loaded)

1. Measure RPM
2. Find nameplate RPM
3. Identify synchronous speed from table
4. Apply equation

Motor Power Equations

Induction motor synchronous speeds

Pump shaft rotational speed - ω - (rev/min, rpm)						
Frequency - f - (Hz)	Number of poles - n					
	2	4	6	8	10	12
10	600	300	200	150	120	100
20	1200	600	400	300	240	200
30	1800	900	600	450	360	300
40	2400	1200	800	600	480	400
50[1)]	3000	1500	1000	750	600	500
60[2)]	3600	1800	1200	900	720	600
70	4200	2100	1400	1050	840	700
80	4800	2400	1600	1200	960	800
90	5400	2700	1800	1350	1080	900
100	6000	3000	2000	1500	1200	1000

Motors designed for 50 Hz are common outside US
Motors designed for 60 Hz are common in US

Motor Power Equations

Slip Load Calculation

$$Load = \frac{Slip}{S_s - S_r} \; x \; 100\%$$

Where:

Load	= Output power as a % of rated power
Slip	= Synchronous speed - Measured speed in rpm
S_s	= Synchronous speed in rpm
S_r	= Nameplate full-load speed

Motor Power Equations

Slip Load Calculation example:

Given: Synchronous speed in rpm = 1800

Nameplate full load speed = 1750

Measured speed in rpm = 1770

Nameplate rated horsepower = 25 hp

Determine actual output horsepower

By slip load calculation equation:

$$Load = \frac{1800 - 1770}{1800 - 1750} \times 100\% = 60\%$$

Actual output horsepower would be 60% X 25 hp = 15 hp

Motor Power Equations

MOTOR CHALLENGE

F A C T S H E E T

a Program of the U.S. Department of Energy

DETERMINING ELECTRIC MOTOR LOAD AND EFFICIENCY

Most likely your operation's motors account for a large part of your monthly electric bill. Far too often motors are mismatched—or oversized—for the load they are intended to serve, or have been rewound multiple times.

To compare the operating costs of an existing standard motor with an appropriately-sized energy-efficient replacement, you need to determine operating hours, efficiency improvement values, and load. Part-load is a term used to describe the actual load served by the motor as compared to the rated full-load capability of the motor. Motor part-loads may be estimated through using input power, amperage, or speed measurements. This fact sheet briefly discusses several load estimation techniques.

Reasons to Determine Motor Loading

Most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load. Thus, a 10-horsepower (hp) motor has an acceptable load range of 5 to 10 hp; peak efficiency is at 7.5 hp. A motor's efficiency tends to decrease dramatically below about 50% load. However, the range of good efficiency varies with individual motors and tends to extend over a broader range for larger motors, as shown in Figure 1. A motor is considered underloaded when it is in the range where efficiency drops significantly with decreasing load. Figure 2 shows that power factor tends to drop off sooner, but less steeply than efficiency, as load decreases.

Reading link:

http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/10097517.pdf

Excel practice

1. Δ Energy = Δ Power X Time = $(Power_1 - Power_2)$ X $Time_2$
2. Δ Energy = Power X ΔTime = Power X $(Time_1 - Time_2)$
3. Δ Energy = $Power_1$ X $Time_1$ – $Power_2$ X $Time_2$

Blended energy rate ($/kWh)										
annual $/kWh	0.151623									
				Annual	Annual	Annual	Annual	Annual	Annual	
	Pre kW	Post kW	kW reduced	Pre hours	post hours	hours (savings)	energy savings	energy saving %	dollar ($) savings	
Sample - notes			=B6-C6			=E6-F6	=(B6*E6)-(C6*F6)	=H6/(B6*E6)*100%	=H6*B2	
Lighting I - de-lamping	1.46	0.96	0.50	1246	1246	0	618.51	34.00%	$ 93.78	
Lighting II - occupancy	1.46	1.46	0	1246	747.6	498.40	727.66	40.00%	$ 110.33	
Lighting III - combine I & II	1.46	0.96	0.50	1246	747.6		1,101.46	60.55%	$ 167.01	
Motor 5HP	4.37	4.29	0.08	3431	3431	0	274.48	1.83%	$ 41.62	
Motor 7.5 HP	4.37	4.22	0.15	3431	3431	0	514.65	3.43%	$ 78.03	

Simple payback

Estimated cost:

- when the aging equipment need to be replaced, or for scheduled renovation, the cost will be the difference between the high-efficient product/service and code-required one, not the full cost of the high efficient one.

Annual saving = (average utility rate) X (Δ Energy)

Simple payback period = estimated cost / annual savings

Capital Project metrics

- Present worth (PW) [Present Value]
- Future worth (FW) [Future Value]
- Annual worth (AW)
- Internal rate of return (IRR)
- External rate of return (ERR)
- Minimum attractive rate of return (MARR)
- Payback period

Note: payback is generally not appropriate as a primary decision rule!

Internal Rate of Return Method (IRR)

- One of the more popular measure of investment performance
- Comparison of IRR among alternatives can result in incorrect decisions
- Compare IRR only to MARR
- The base alternative must be attractive (rate of return greater than the MARR)
- The additional investment in other alternatives must itself make a satisfactory return on the increment

Financial analysis template

Measure	Description of Measure	Annual Savings (kW)	Annual Savings (kWh)	Estimated Implementation Cost	Simple Payback (years)	Internal Rate of Return (%)
Measure 1						
Measure 2						
Measure 3						
Measure 4						

Audit report example

Measure Number	Measure Description	Annual Energy and Cost Savings				Payback		Payback with Incentive			
		Peak Savings (kW)	Electricity Savings (kWh)	Gas Savings (therms)	Total Cost Savings	Measure Cost	Simple Payback (yr)	Potential PG&E Incentive	Net Measure Cost	IRR	Simple Payback (yr)
NCM-1	Modify CRAC Humidification Controls	35.2	308,352	0	$ 41,165	$ -	0.0	$ -	$ -	n/a	0.0
LCM-2	Install High-Capacity Pre-Filters on Supply Fans	3.3	4,631	0	$ 618	$ 327	0.5	$ -	$ 327	89%	0.5
LCM-3	Implement Static Pressure Reset on Supply Fans	0.0	36,652	0	$ 4,893	$ 5,850	1.2	$ 2,925	$ 2,925	167%	0.6
LCM-4	Install VFDs and Controls for Primary Condenser Water Pumps	17.5	86,934	0	$ 11,606	$ 14,737	1.3	$ 6,955	$ 7,783	149%	0.7
CIM-5	Install Photocells to Control Lighting Near Windows	0.0	56,022	0	$ 7,479	$ 13,200	1.8	$ 2,801	$ 10,399	72%	1.4
CIM-6	Implement Data Center Airflow Improvements and Install VFDs on CRAC Fans	12.1	106,174	0	$ 14,174	$ 40,642	2.9	$ 8,494	$ 32,148	44%	2.3
	SUB-TOTALS	**68.1**	**598,765**	**0**	**$ 79,935**	**$ 74,756**	**0.9**	**$ 21,175**	**$ 53,582**	**148%**	**0.7**
Demand Response											
DR-1	Reduce Office Lighting Levels By One-Third	48.1	1,924	0	$ 930	$ 10,000	10.8	$ -	$ 10,000	-1%	10.8
DR-2	Turn Off Garage Lighting	2.5	99	0	$ 48	$ 600	12.6	$ -	$ 600	-4%	12.6
DR-3	Reduce Ventilation by 20%	20.2	808	0	$ 390	$ 1,000	2.6	$ -	$ 1,000	37%	2.6
	SUB-TOTALS	**70.8**	**2,830**	**0**	**$ 1,368**	**$ 11,600**	**8.5**	**$ -**	**$ 11,600**	**3%**	**8.5**
TOTALS (Recommended Measures)		**138.8**	**601,595**	**0**	**$ 81,303**	**$ 86,356**	**1.1**	**$ 21,175**	**$ 65,182**	**123%**	**0.8**

Assuming Electricity Cost	$ 0.1335	/kWh	(Average for recent 12 months, this account)
Assuming Gas Cost	$ 1.49	/therm	(Average GNR1 rate, weighted summer/winter)

Sample report – con'd

LCM-4: Install VFDs and Controls for Primary Condenser Water Pumps

Annual Savings				Payback			
Peak Period Savings (kW)	Electricity Savings (kWh)	Gas Savings (therms)	Total Cost Savings	Potential PG&E Incentive	Net Measure Cost	IRR	Simple Payback (yr)
17.5	86,934	0	$ 11,606	$ 6,955	$ 7,783	149%	0.7

Observations

The existing primary condenser water (CW) distribution system uses two pumps in parallel. As described in Section 2, the primary condenser water system is used to provide heat rejection for the chillers, and for a heat exchanger to a secondary circuit for water-cooled heat pumps located in telecom rooms on each floor. One primary pump runs all of the time to serve the secondary condenser water loop, and to serve the lead chiller when it runs. When a second chiller starts, the second pump starts as well.

There are two modulating isolating valves on the circuit, one for each chiller. They are two-position valves, either closed to isolate the chiller, or open at a fixed position ("40%" open based on audit observations), thus throttling the condenser water flow.

Sample report – con'd

Recommendations

We recommend installing VFDs to the primary condenser water pumps to allow control of their speed, and thus of the condenser water flow. This will provide savings in two ways, without affecting chiller operation.

We conservatively recommend that when a chiller is operating, flow to the chiller should be at a constant rate as specified by the chiller manufacturer. This will be achieved with a constant but reduced pump speed, in combination with fully-opened throttling valves. A new water balance must be performed to determine the required pump speed to achieve specified flow. For the hours that one or two chillers is operating, this measure will save energy by running the pumps at lower speed while providing full constant flow to the chillers.

In addition, there are over 5,000 hours per the year when chillers are off and the condenser water is only being used to remove heat from the secondary heat pump circuit. In these conditions, actual CW flow can be significantly reduced, and still meet the heat rejection needs of the secondary loop. We recommend reducing the pump speed to 60% (36 Hz) during these hours. This speed will maintain flow above the typical minimum flow required by cooling towers to avoid fouling and other issues.

Note - Alternately, some of the energy savings could be achieved by installing smaller pump impellers to reduce the capacity (and power demand) of the pumps at all times. This is a relatively inexpensive option.

Sample report – con'd

The following summarizes the recommended control strategy.

1. When no chillers are operating, set CW pump speed to 60% (36 Hz).
2. When a chiller is operating, run its corresponding CW pump at a constant speed. A water balance is required to determine this speed. The required speed is to be determined by measuring condenser water flow at the chiller. The pump speed must provide recommended design CW flow to each chiller.
3. When two chillers are operating, both pumps operate at the same speed.
4. The two chiller isolation valves are to open fully when their corresponding chiller is operating.

Sample report – con'd

Costs and Assumptions

We evaluated the proposed case by assuming a linear pumping profile that follows the chiller load profile, which in turn is linked to the load on the cooling coil, accounting for economizer operation.

We used the pump curve, observed pressure reading, and design flow to estimate that the pump speed during chiller operation will be reduced to approximately 75%, with pump efficiency improved from 70% to 83%.

Costs were based on RS Means data for installation of two custom-engineered 15-hp VFDs, 16 hours of controls and commissioning work at $150 per hour, and an allowance for water balancing.

The potential incentive was based on the calculated savings at $0.08 per kWh for Motors and Other Equipment (including Controls). Please see the following web link for information on applying for customized (calculated) incentives:

http://www.pge.com/mybusiness/energysavingsrebates/rebatesincentives/ief/

G. Analysis of data collected

1. Identify opportunities for efficiency improvement
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Prioritize options based on client criteria

- Based on customers demand/concern/situation

  - If the owners/users are going to remodel the facility, it will be a good time for EEMs implementation. (HVAC, lighting, etc)

  - If the owners want to get LEED certificate, it will be feasible to implement the most EEMs and install renewable energy.

  - If one or more major equipments close to the end of life, it will be a good to upgrade to high-efficiency one. (furnace, boilers, motors, etc)

  - If a lot of concerns or complains, it will be a good time to change and implement EEMs accordingly. (lightings, HVAC, etc)

Prioritize options based on client criteria

- Based on timing/financial factors

  - Avoid peak season

  - The owners/users may have financial freeze period, or spending season

  - May limit by capital cap, cost less than certain amount may be easier

  - financial analysis: IRR method or simple payback

  - if can’t implement all, start with “low hanging fruits”

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Prepare and present written report

An example:

Contents

http://inside.redwoods.edu/StrategicPlanning/AccreditationSS/documents/EnergyAudit.KEMA.pdf

Prepare and present written report

An example:

Table of Contents

Prepare and present written report

Prepare to present the report/proposal to the clients:

- Prepare both short and long version of presentation
- Prepare PPT file and also print out and bring hardcopy, in case may not have chance to use a computer/projector
- Depending on audience, the focus may vary
- There may be more than one presentation and discussion. After getting feedback from the client, one may modify and adjust proposed EEMs.

Assist with development of implementation plan

Assist clients if necessary:

- Find contractors/professionals
- Make sure the implementation plan meets the code/standard and the designed saving goal
- Claim rebate/incentives properly
- Commissioning and Retro-commissioning
- Revisit clients regularly to follow up

Useful resource:

BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
Marketing Resources

BEST
Building Efficiency for a Sustainable Tomorrow

NSF
National Science Foundation