LESSON 25 – ENERGY MANAGEMENT OPPORTUNITIES IN LIGHTING

QEM 570
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Southern Illinois University Department of Technology

Learning Objectives

After this presentation you will be able to:

- Identify potential energy management opportunities (EMOs) in lighting systems.
- Compute savings from proposed lighting system changes.
- List and explain the operation of common lighting control systems.
Identifying EMOs in Lighting

Goal – Reduce cost and increasing efficiency

Lighting Evaluation Check List

- How much light is needed?
- How must the light be controlled?
- How can the light be delivered most efficiently?

Cost savings from lighting improvements

- Reduced energy and power demand
- Reduced heat production; lower cooling load
- Reduced maintenance
- Increased safety and productivity
- Reduced life-cycle costs
Lighting Recommendations

Lighting Redesign Process

1. Identify and characterize tasks
2. Use daylight and task specific lights
3. Determine correct light level and quality
4. Select alternative systems and determine costs
   
Select best alternative based on effectiveness and cost

Typical Recommendations

De-lamping
- Remove lamps from fixtures when tests indicate excessive lighting levels
- Remove or disconnect ballasts
- Remove pairs

Task Lighting
- Use specific luminaires directed on tasks instead of area lights

Re-lamping
- Replace existing lamps with devices that have higher efficacy
Re-Lamping Examples

**Example 1:** A workshop currently uses 200 4 lamp fixtures that contain 40 W F40T12 lamps. Compute the annual savings realized from re-lamping the fixtures with 34 W lamps. The standard 40 W lamps cost $1.10 each and have a life of 12,000 hours. The 34 W high-efficiency lamps cost $1.75 each and last for 20,000 hours. Electricity costs 0.10 $/kWh and the power demand charge is $6.00 /kW. The shop is not air conditioned and operates on a 24 hour, 365 day schedule.

**Define formulas**

**Annual energy savings**

\[ AES = F \cdot n_f \cdot (P_{LE} - P_{HE}) \cdot H_o \]

Where:

- \( AES \) = annual energy savings (kWh)
- \( F \) = number of fixtures
- \( n_f \) = number of lamps/fixture
- \( H_o \) = annual operating hours
- \( P_{HE} \) = power consumption of high efficiency lamps (kW)
- \( P_{LE} \) = power consumption of low efficiency lamp (kW)

**Define formulas**

**Demand Reduction**

\[ DR = N \cdot (P_{LE} - P_{HE}) \]

Where:

- \( DR \) = Demand reduction (kW)
- \( N \) = total number of lamps \( (F \cdot n_f) \)
- \( P_{HE} \) = power consumption of high efficiency lamps (kW)
- \( P_{LE} \) = power consumption of low efficiency lamp (kW)

**Annual Lamp Cost Savings**

\[ ALCS = 12 \cdot r_D \cdot DR + r_e \cdot AES + NLRC \]

Where:

- \( ALCS \) = Annual lamp cost savings ($)
- \( r_D \) = power demand rate ($/kW)
- \( r_e \) = electric energy rate ($/kWh)
- \( NLRC \) = Net lamp replacement costs ($)
Re-Lamping Examples

Compute the net lamp replacement cost NLRC
Lamps have unequal lives that must be converted to annual costs. Compute total annual lamp-hours

\[ LH = N \cdot T_h \cdot D \]  

Where:  
\[ T_h = \text{operating hours/day} \]  
\[ D = \text{operating days/year} \]  
\[ LH = \text{annual lamp-hours} \]

\[ LH = (800 \text{ lamps})(24 \text{ hrs/day})(365 \text{ day/yr}) = 7,008,000 \text{ lamp-hrs/yr} \]

Compute lamps replaced per year for low efficiency lamps

\[ n_{AS} = \frac{LH}{L_{LE}} \]  

Where:  
\[ n_{AS} = \text{number of standard low efficiency lamps replaced/year} \]  
\[ L_{LE} = \text{average life of standard lamps (hours)} \]

\[ n_{AS} = \frac{LH}{L_{LE}} = \frac{7,008,000 \text{ lamp-hrs}}{16,000 \text{ hrs}} = 584 \text{ lamps/yr} \]

Re-Lamping Examples

Compute the net lamp replacement cost NLRC – number of Hi-E lamps

\[ n_{AE} = \frac{LH}{L_{HE}} \]  

Where:  
\[ n_{AE} = \text{number of Hi-E lamps replaced/year} \]  
\[ L_{HE} = \text{average life of Hi-E lamps (hours)} \]

\[ n_{AE} = \frac{LH}{L_{HE}} = \frac{7,008,000 \text{ lamp-hrs}}{20,000 \text{ hrs}} = 350 \text{ lamps/yr} \]

Compute the annual replacement costs of each lamp type

Define lamp purchase prices:  
- Hi-E lamp price: \( p_{HE} = $1.75/\text{lamp} \)  
- Standard lamp price: \( p_{LE} = $1.10/\text{lamp} \)

**Standard Lo-E**  
\[ RC_s = n_{AS} \cdot p_{LE} = 584 \cdot ($1.10/\text{lamp}) = $642.40/\text{yr} \]

**Hi-E**  
\[ RC_{Hi} = n_{AE} \cdot p_{HE} = 350 \cdot ($1.75/\text{lamp}) = $612.50/\text{yr} \]
Re-Lamping Examples

**Compute the net replacement costs and the annual savings**

\[
NLRC = R_G - R_H = n_{AE} \cdot P_{LE} - n_{AE} \cdot P_{HE}
\]

\[
NLRC = $642.40/yr - $612.50/yr = $29.90/yr
\]

**Now compute the total annual savings**

\[
AES = F \cdot n_t \cdot (P_{LE} - P_{HE}) \cdot H_o
\]

\[
AES = (200)(4)(0.040 - 0.034)kW(8760 \text{ hrs}) = 42.048 \text{kWh}
\]

\[
DR = N \cdot (P_{LE} - P_{HE})
\]

\[
DR = (800)(0.040 - 0.034)kW = 4.8 \text{kW}
\]

\[
ALCS = 12 \cdot r_d \cdot DR + r_e \cdot AES + NLRC
\]

\[
r_d = 6.00 \$/kW
\]

\[
r_e = 0.10 \$/kWh
\]

\[
ALCS = 12(6.00 \$/kW)(4.8 \text{kW}) + 0.10 \$/kWh(42.048 \text{kWH}) + 29.90
\]

\[
ALCS = $345.60 + $4202.80 + $29.90 = $4578.30
\]

---

Re-Lamping Examples

**Example 2:** A hospital operates 415, 2 lamp T12 fluorescent fixtures year round (8760 hrs). The firm is considering replacing the current fixtures and ballasts with T8 lamps and electronic ballasts for an expected 35% energy reduction from the current system. The new system will produce less power losses decreasing the air conditioning load in summer and increasing the heating load in the winter. The air conditioner has a coefficient of performance (COP) of 2.6 and runs at full load 2200 hrs/year. The heating system has an 82% efficiency and operates 1700 hrs/year. For the energy cost and fixture data given below, find the annual energy cost savings

<table>
<thead>
<tr>
<th>Energy Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>0.10 $/kWh</td>
</tr>
<tr>
<td>Power Demand</td>
<td>120 $/kW-yr</td>
</tr>
<tr>
<td>Fuel (Nat. Gas)</td>
<td>4.00 $/MCF</td>
</tr>
</tbody>
</table>
Re-Lamping Examples

Example 2 fixture data

<table>
<thead>
<tr>
<th>Existing Fixture Data</th>
<th>Proposed Fixture DataLa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Fixture Power</td>
<td>Total Fixture Power</td>
</tr>
<tr>
<td>92 W</td>
<td>72 W</td>
</tr>
<tr>
<td>Lamp Life</td>
<td>Lamp Life</td>
</tr>
<tr>
<td>20,000 hrs</td>
<td>20,000 hrs</td>
</tr>
<tr>
<td>Lamp Cost</td>
<td>Lamp Cost</td>
</tr>
<tr>
<td>$1.50 each</td>
<td>$3.25 each</td>
</tr>
</tbody>
</table>

Electronic Ballast Cost $18.00 each

Retrofit labor $45/fixture

Start by computing the power demand and annual energy savings

Compute the annual demand savings first

\[
DR = N \cdot (P_{t2} - P_{t1})
\]

\[
DR = (415 \text{ fixtures})(2 \text{ lamps/fixture})(0.092 - 0.072 \text{ kW})
\]

\[
DR = 830(0.020 \text{ kW}) = 16.6 \text{ kW}
\]

Compute the annual energy savings

\[
AES = F \cdot n_t \cdot (P_{t2} - P_{t1}) \cdot H_o
\]

\[
AES = (16.6 \text{ kW})(8760 \text{ hr}) = 145,416 \text{ kWh}
\]

\[
H_o = 8760 \text{ hr/yr}
\]
Re-Lamping Examples

**Heating and cooling impacts**

**Cooling energy reduction**

\[
CER = DR \cdot T_{AC} \cdot \left( \frac{1}{\text{COP}} \right)
\]

Where: \( T_{AC} \) = annual air conditioning operating hours

\[
CER = 16.6 \text{ kW} (2,200 \text{ hr/yr}) \cdot \left( \frac{1}{2.6} \right)
\]

\[
CER = 14,046 \text{ kWh}
\]

**Heating energy increase**

\[
HE = DR \cdot T_{AC} \cdot \left( \frac{3412 \text{ BTU}}{1 \text{kWh}} \right) \cdot \left( \frac{1}{\text{H}} \right)
\]

Where: \( T_{AC} \) = annual air conditioning operating hours
\( \eta_H \) = heating system efficiency

\[
HE = 16.6 \text{ kW} (1,700 \text{ hr/yr}) \cdot \left( \frac{3412 \text{ BTU}}{1 \text{kWh}} \right) \cdot \left( \frac{1}{0.82} \right)
\]

\[
HE = 117.4 \times 10^6 \text{ BTUs}
\]

**Compute the cost of the increased heating load due to better lamp efficiency**

\[
\text{HEC} = r_h \cdot \text{HE} \cdot \left( \frac{1 \text{ cf}}{1000 \text{BTU}} \right) \cdot \left( \frac{1 \text{ MCF}}{1000 \text{cf}} \right)
\]

Where: \( r_h \) = heating energy rate ($/MCF)
\( \text{HE} \) = heating energy (BTU)
\( \text{HEC} \) = heating energy cost ($)

\[
\text{HEC} = 4.00 \text{$/MCF} \cdot 117.4 \times 10^6 \text{ BTU} \cdot \left( \frac{1 \text{ cf}}{1000 \text{BTU}} \right) \cdot \left( \frac{1 \text{ MCF}}{1000 \text{cf}} \right)
\]

\[
\text{HEC} = $470
\]

**Compute the net replacement costs**

\[
\text{NRC} = F \cdot \eta_L \left( \frac{H_0}{L_{T8}} \cdot p_{T8} - \frac{H_0}{L_{T12}} \cdot p_{T12} \right)
\]

Where: \( L_{T8} \) = life of T8 lamp (hrs)
\( L_{T12} \) = life of T12 lamp (hrs)
\( p_{T8} \) = price of T8 lamp ($)
\( p_{T12} \) = price of T12 lamp ($)
Re-Lamping Examples

Compute the net replacement costs

\[
NRC = 415 \cdot 2 \left( \frac{8760 \text{ hr}}{20,000 \text{ hr}} \cdot (3.25 \$/\text{lamp}) - \frac{8760 \text{ hr}}{20,000 \text{ hr}} \cdot (1.25 \$/\text{lamp}) \right)
\]

\[
NRC = (830 \text{lamps}) \cdot (1.4235 \$/\text{lamp} - (0.5475 \$/\text{lamp})) = 727.08
\]

Now compute the total annual savings from the re-lamping including the additional heating and replacement costs.

\[
ALCS = r_e \cdot DR + r_e \cdot AES + r_e \cdot CE - HEC - NRC
\]

Where:
- \( r_e \) = electricity rate ($/kWh)
- \( r_D \) = demand rate ($/kW-year)
- \( CE \) = cooling energy savings (kWh)

Now compute the simple payback period by computing the cost of replacement

\[
ALCS = 14,541.60 - 727.08 = 13,814.52
\]

\[
ALCS = 1,992.00 + 14,541.60 = 16,533.60
\]

\[
ALCS = 1,404.60 + 14,541.60 = 15,946.20
\]

\[
ALCS = 17,938
\]

Answer
Simple Payback Period

Compute to cost of replacement of ballasts and the labor

Ballast cost: $18.00 each
Labor: $45/fixture

Total project cost is sum of ballast cost and labor

\[ C_p = F \cdot (P_b + W_f) \]

Where:
- \( C_p \) = total project cost
- \( F \) = number of fixtures
- \( P_b \) = price of replacement ballast (each)
- \( W_f \) = labor rate ($/fixture)

\[ C_p = 415 \text{ fixture} \cdot ($18/\text{fixture} + $45/\text{fixture}) \]
\[ C_p = $26,145 \]

Simple Payback Period:

\[ \text{Payback} = \frac{C_p}{ALCS} = \frac{$26,145}{$17,938/\text{year}} \approx 1.5 \text{ year} \]

Lighting Examples - CFL Retrofit

Example - Replacing incandescent lamps with CFLs

A hotel lobby has 150 single lamp incandescent fixture that operate 24 hour a day year round. The incandescent lamps are all rated at 100 W input. The firm is considering replacing all these lamps with the lumen-equivalent CFL that consumes 26W. The incandescent lamps have an average life span of 1000 hours and the CFL's 6000 hours. Electricity costs 0.1$/kWh and the demand charge is $120/kW-year. The hotel operates its heating system 3500 hour/year and the air conditioning 5000 hours/year. The hotel pays $5.50/MMBTU for heating fuel and the heating plant is 85% efficient. The air conditioning system has a COP=2.5 The lamps will be group replaced at 80% of their average lives. The maintenance labor rate is $35/hour. a.) What is the annual cost saving from this change? b.) What is the simple payback time for this investment.
Other cost and maintenance information is listed below

<table>
<thead>
<tr>
<th></th>
<th>CFL</th>
<th>Incandescent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp price (each)</td>
<td>$4.00</td>
<td>$1.00</td>
</tr>
<tr>
<td>Replacement time (ea.)</td>
<td>6 minutes</td>
<td>4 minutes</td>
</tr>
</tbody>
</table>

Retrofit Costs

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$20/fixture</td>
</tr>
<tr>
<td>Materials</td>
<td>$20/fixture</td>
</tr>
</tbody>
</table>

Solution: Define some variables

\[ \begin{align*}
    P_{ei} := 0.100 \text{kW} & \quad \text{power consumption of incandescent lamp} \\
    P_{ec} := 0.026 \text{kW} & \quad \text{power consumption of CFL lamps} \\
    I := 0.8 & \quad \text{Lifetime re-lamp fraction} \\
    PC := 4.00 \text{dollars/lamp} & \quad \text{CFL lamp price} \\
    PI := 1.00 \text{dollars/lamp} & \quad \text{Incandescent lamp price} \\
    F := 150 \text{fixtures} & \quad \text{Number of fixture and lamps per fixture} \\
    n_f := 1 & \quad \\
\end{align*} \]
CFL- Retrofit

Group re-lamping times/lamp

\[ t_{Lc} := \frac{6 \text{ min}}{\text{lamp}} \quad \text{For CFLs} \quad t_{Li} := \frac{4 \text{ min}}{\text{lamp}} \quad \text{For incandescants} \]

\[ W := 35 \text{ dollars/hr} \quad \text{Labor rate} \quad H_o := 8760 \text{ hr} \quad \text{Annual lamp operating time} \]

Compute the annual power demand reduction

\[ DR := F \cdot t_f \cdot (P_{ei} - P_{ec}) \quad DR = 11.1 \text{ kW} \]

Compute the annual energy savings

\[ AES := F \cdot t_f \cdot (P_{ei} - P_{ec}) \cdot H_o \quad AES = 97236 \text{ kW.hr} \]

CFL- Retrofit

Now compute the net replacement cost of the incandescent lamps and CFL's, accounting for their longer life

\[ C_i := \left( \frac{p_i + G_i}{I} \right) \]

Where:

\[ G_i := \left[ \frac{t_{Li}}{60 \text{ min/hr}} \cdot W \right] \quad G_i = 2.33 \text{ dollars/lamp} \]

\[ G_c := \left[ \frac{t_{Lc}}{60 \text{ min/hr}} \cdot W \right] \quad G_c = 3.5 \text{ dollars/lamp} \]

Labor cost per lamp for the incandescent and the CFLs
CFL- Retrofit

Add the purchase price of the lamps to get the per lamp maintenance costs

\[
C_L = \frac{P_L + Q_L}{I} \quad \text{(dollars lamp)}
\]

For the incandescent lamp

\[
C_L = \frac{P_L + Q_L}{I}
\]

For the CFL lamp

\[
C_C = \frac{P_C + Q_C}{I}
\]

\[
C_C = 9.38 \text{ dollars lamp}
\]

\[
C_L = 4.17 \text{ dollars lamp}
\]

Determine the number of times the fixtures would be re-lamped based on the average life

\[
L_C := \frac{6000}{\text{hr lamp}} \quad \text{Average life of the CFLs}
\]

\[
L_I := \frac{1000}{\text{hr lamp}} \quad \text{Average life of the incandescent lamp}
\]

Number of group replacements/year for both incandescent and CFLs

\[
AR_i := \frac{H_w}{L_i I} \quad \text{AR}_i = 10.95
\]

\[
AR_c := \frac{H_w}{L_c I} \quad \text{AR}_c = 1.83
\]

\[
\text{Included because of replacement at 80% of life}
\]

CFL Retrofit- Net Replacement Costs

Compute the net replacement costs with the number of replacements included

\[
NRC = P_L (C_C \ AR_C - C_L \ AR_L) \quad NRC = -4277.34 \text{ dollars}
\]

\[
150(1) \quad 9.38(1.83) \quad 4.17(10.95)
\]

Negative indicates a cost savings from fewer re-lampings

Now compute the savings from the reduced heating load during the cooling season
CFL Retrofit - Lower Air Conditioning Energy

The (Coefficient of Performance) COP is the efficiency of the AC system and is given by:

\[
\frac{P_o}{P_i} = \text{COP}
\]

Where:

- \(P_o\) = output power (W)
- \(P_i\) = input power (W)

For this example, \(\text{COP} = 2.5\)

\(\text{DR} = 11.1 \text{ kW}\)

\(T_c = 5000 \text{ hr}\)

Annual cooling hours

\[
\text{CER} = \text{DR}.T_c\left(\frac{1}{\text{COP}}\right)
\]

\[
\text{CER} = 22200 \text{kW} \cdot \text{hr}
\]

CFL Retrofit - Increased Heating Energy

Compute the increase in heating load due to the reduction in lamp power losses

- Annual heating hours \(T_H = 3500 \text{ hr}\)
- \(r_H = 5.50 \text{ dollars} \cdot 10^6 \text{ BTU}\)
- Heating plant efficiency \(\eta_H = 0.85\)

\(\text{DR} = 11.1 \text{ kW}\)

Power reduction due to retrofit

\[
\text{Energy consumed (BTU)} = \text{DR} \cdot T_H \left(\frac{3412 \text{ BTU}}{1\text{-kW-hr}}\right) \left(\frac{1}{\eta_H}\right) = 1.56 \times 10^8 \text{ BTU}
\]

\[
\text{HEC} = r_H \cdot \text{DR} \cdot T_H \left(\frac{3412 \text{ BTU}}{1\text{-kW-hr}}\right) \left(\frac{1}{\eta_H}\right)
\]

\[
\text{HEC} = 857.72 \text{ dollars}
\]
CFL Retrofit - Total Annual Savings

Compute the annual lamp savings by including the cost and the savings associated with the incandescent lamp replacement. Initial retrofit labor and materials not included.

Electricity rates:
\[ r_D := 120 \frac{\text{dollars}}{\text{kW}} \quad r_e := 0.1 \frac{\text{dollars}}{\text{kW/hr}} \]

\[ \text{ALCS} := r_D \cdot D + r_e \cdot \text{AES} + r_e \cdot \text{CER} - \text{HEC} - \text{NRC} \]

Where:
- \( \text{NRC} = -4277.34 \text{ dollars} \)
- \( \text{AES} = 9723 \text{ kWh} \)
- \( \text{CER} = 2220 \text{ kWh} \)
- \( \text{HEC} = 857.72 \text{ dollars} \)

\[ \text{ALCS} = 16695.23 \quad \text{Answer} \]

CFL Retrofit - Simple Payback Period

Compute the simple payback time of this project.

Determine the total cost to perform the retrofit of all the fixtures.

Define the labor and materials variables:
- \( W_r := 20 \frac{\text{dollars}}{\text{fixture}} \) Labor to retrofit the CFLs
- \( M_C := 20 \frac{\text{dollars}}{\text{fixture}} \) Materials to retrofit the CFLs
- \( F = 150 \text{ fixtures} \) Simple payback is given as

Define the total project cost:
\[ \text{TPC} := F \left( W_r + M_C \right) \]

\[ \text{TPC} = 6000 \text{ dollars} \]

Simple payback:
\[ \text{SP} := \frac{\text{TPC}}{\text{ALCS}} \]

\[ \text{SP} = 0.36 \text{ year} \]

Convert to months:
\[ 12 \times \text{SP} = 4.31 \text{ months} \]

\[ \text{Answer} \]
Lighting Control Technologies

Overview of control techniques

Manual Controls
- On/Off Switches
- Reduce number of fixtures/switch
- Separate Switches
  - Move light level control
  - Less waste
  - Ganging promotes
  - All on/All off

Automatic Controls and Sensors
- Photocells
- Timers
- Occupancy Sensors

Automatic Lighting Control

Control with Photocells
- Ideal for security lighting (dusk to dawn)
- Select type that fail on
  (Easier fault detection)
- Combine with dimmers and central control
  (constant light levels)
Automatic Lighting Control

Control with Timers

Timers
- Can be used with photocells for greater control
- Require resetting
  - Power outages
  - Daylight savings
- Can be over-ridden with manual controls

Control with Occupancy Sensors

Occupancy Sensors
- Reduce unnecessary lighting use
  - (Restrooms)
- Infrared-Directional
- Ultrasonic-Fairly non-directional
- Need full coverage to prevent nuisance cutoffs
Automatic Lighting Control

Control with Dimmers

Dimmers

- Reduce lamp voltage
- Reduce lamp light
- Extends life

- Requires special ballasts for fluorescent and HID lamps

- Good for areas that require wide range of light levels

End Lesson 25 Energy Management Opportunities in Lighting