An Energy-Efficiency Workshop and Exposition
Orlando, Florida

The ABCs of Energy – Part 1

Understanding Lighting Systems and Retrofits

A Workshop Developed by Effective Lighting Solutions, Inc
And Advance Transformer Company

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Please be courteous to our speakers

Turn off all cell phones
and
Set pagers to vibrate

Session Objectives

- Review of terms and basic concepts
- Review building lighting systems
- Learn how to perform a self- check of building lighting systems
- Outline 10 steps to improve lighting systems to reduce energy and maintenance cost and improve lighted workspaces
- Learn how to avoid lighting retrofit pitfalls
- Avoiding common ballast application mistakes

Terms & Basic Concepts

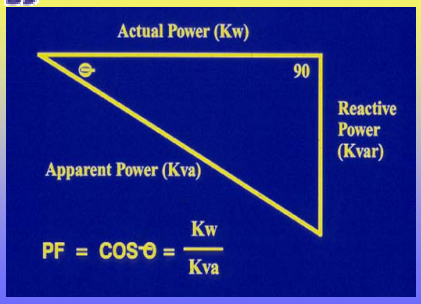
Energy Terms

- Energy is ability or capacity to do work
  - Measured in kWh
- Power is rate of using electrical energy
  - kWh/hr = kW
    - 1kW = 1,000 watts
- Demand is highest average power in demand interval
  - Peak demand

Electrical Terms – Power Factor (PF)

- Describes how power is consumed by the load in an AC circuit
- Value of 100% (or 1) is ideal
  - Describes a resistive circuit
  - Ex: Incandescent filament lamp
- Value less than 1 causes losses in transmission system from the power system to the load

Electrical Terms - PF



Electrical Terms - PF

Power = volts x amps x PF

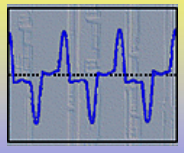
Ex: 18 HPF HID fixtures

V = 480 vac I = 18 amps PF = 90%

P = 480 x 18 x 0.9

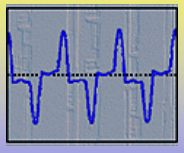
P = 7.8 kW

Electrical Terms – Total Harmonic Distortion (THD)



- Harmonic currents are generated by non-linear loads
- Electronic lighting uses switch-mode power supplies that generate harmonics
- Office equipment is more of a concern than lighting
  - Computers, laser printers, fax machines, etc, all generate higher levels of harmonic current than lighting equipment

Electrical Terms - THD



120V magnetic ballast w/20% THD has harmonic current = 0.17 A

120V ELB w/20% THD has harmonic current = 0.1 A 40% less!

- CFL (screw base)
  - Although electronic ballast can have high THD (>100%), distortion current is so low as to not be a concern
- Electronic ballasts (ELB)
  - % THD about the same as magnetic ballasts, ***BUT*** harmonic current lower

Electrical Terms - THD

- End-user Viewpoint
  - Interferes with adjacent voice and data phone lines
  - Keep lines separated in co-located closets
  - Reduces safe current capacity of customer's circuits
    - False circuit breaker tripping
  - Overheating causes transformer saturation, high-frequency dissipation in PF correction capacitors, and overloaded 3-phase neutrals

Lighting Definitions

- Lumen output – total light from a source
  - Unit of luminous flux
- Candela – unit of luminous intensity
  - ordinary wax candle has luminous intensity of 1 candela)

Candlepower – Luminous intensity expressed in candelas

Lighting Definitions

- Illuminance
  - Light level measured in footcandles or lux

$$\text{Footcandles} = \frac{\text{lumens}}{\text{square feet}}$$

$$\text{Lux} = \frac{\text{lumens}}{\text{square meters}}$$

Lighting Definitions

- Luminance
  - Reflected light (or "brightness") measured in candelas per square meter
  - Obsolete unit is footlambert
  - To convert footlamberts to candelas per square meter
    - Multiply footlamberts by 3.426

Lighting Definitions

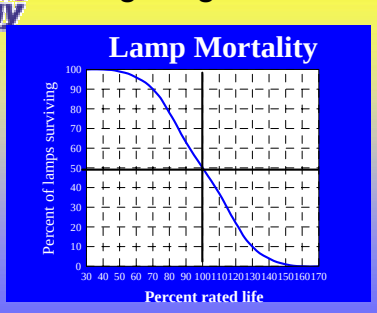
- Lamp efficacy (efficiency) – light output per input watt
  - Lumens Per Watt (LPW)

$$\text{LPW} = \frac{\text{light output (lumens)}}{\text{power input (watts)}}$$

Lighting Definitions

- Average rated life is point at which 50% of an infinitely large group of lamps will have failed (50% survive)
- Rated life does not mean every lamp will burn than long
- Burnout rate follows a statistical (bell shaped) curve

Lighting Definitions

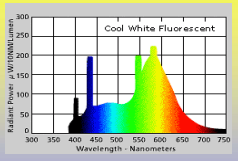


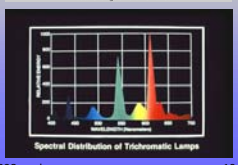
Lighting Definitions
Color Temperature

- Color temperature – appearance of light source measured in absolute temperature
  - Measured in degrees Kelvin (K)
  - Correlated to reference source (black-body radiator)
  - Describes 'warm' or 'cool' appearance
    - Higher color temp is cooler appearance
      - (Ex: 4100K – cool fluorescent)
    - Lower color temp is warmer appearance
      - (Ex: 2700K incandescent)

Color Temperature of Fluorescent Lamps

- Phosphor coating on inside of lamp sets color temperature and CRI
- Colors
  - 3000K (warm)
  - 3500K (neutral)
  - 4100K (cool)
  - 5000K (daylight)
- CRI
  - 75
  - 85
  - >90 (special)





Lighting Definitions
Color Rendering Index

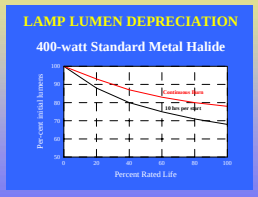
- Color rendering – appearance of colored objects when viewed under a light source compared to when viewed under daylight (of same color temp)
  - Relative measure in %
    - range from 0 – 100%
  - Ex: T8 lamps are avail in 75 or 85 CRI for commercial applications

Lighting Terms
Color Rendering Index

Lamp	CRI
Incandescent/Halogen	100
Fluorescent T12 – "Cool White"	62
Fluorescent T12– "Warm White"	53
Fluorescent T10	80
Fluorescent T8 (all colors)	75 – 85
Mercury vapor – clear/coated	22/52
Metal halide – clear/coated	65/85
High-pressure sodium – std/enhanced	25/34
Low-pressure sodium	0

Lighting Definitions
Lumen Maintenance

- Most lamps lose ability to produce light after burning for some time
  - ***Exception: LPS***
- Lumen maintenance measures the rate of depreciation and indicates the remaining light output



Initial lumens measured at 100 hrs

Lighting Definitions
Lumen Maintenance
a.k.a Lumen Depreciation

$$LLD = \frac{\text{Mean Lumens (@ 40\% life)}}{\text{Initial Lumens (catalog)}}$$

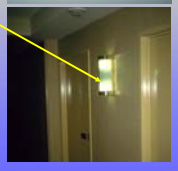
Mean lumens also called Design lumens
(because that's what we design for!)

Ex: 32-w T8 (75 CRI) $LLD = \frac{2610}{2900} = 0.90$

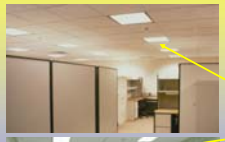
Building Lighting Systems

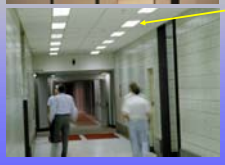
Building Lighting Systems - Incandescent

- Downlights (recessed)
  - A lamps, ER lamps, R or PAR lamps
- Sconces
  - Indirect, wall mounted, 1 or 2 A lamps or showcase lamps
- Track Lights
  - Directional spots or floods
  - Line or low-voltage
- Chandeliers and other decorative
  - Decorative sources



Building Lighting Systems- Fluorescent, Direct



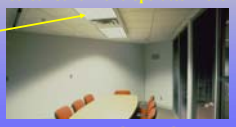


- Recessed troffers
  - Mounted into grid ceiling system
  - Fit ceiling openings and sit on T-bar
    - Main Ts support short ends of fixture
  - 2x2, 2x4, 1x4, 20”
  - Static or air-handling
  - Spacing set by grid
  - Max spacing set by S.C.
  - Lamps shielded to control glare by lens, louver, baffle
  - 1, 2, 3, or 4 lamps
  - T8, T10, or T12

Building Lighting Systems- Fluorescent, Direct

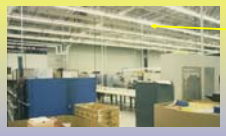
- Surface mounted
  - Mounted on plaster or grid ceiling
  - 2x2, 2x4, 1x4, wrap-around
  - Spacing NOT set by grid; max spacing by S.C.
  - Lamps shielded to control glare by lens, louver, baffle
  - 1, 2, 3, or 4 lamps
  - T8, T10, or T12 lamps

This “smart” fixture has occupancy sensor built-in and operates 2-level



No space above ceiling

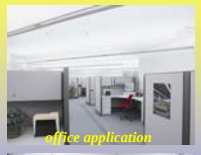
Building Lighting Systems- Fluorescent-Industrial



- Most common fluorescent fixture is 2-lamp, 8’T12 (slimline or HO) system
- Lamp is F96T12 or HO
  - 75-w Std; 60-w RW
  - 110-w HO; 95-w RW HO
- Ballast usually 2-lamp magnetic
  - Standard
  - “Energy-saving” (ESB)

Building Lighting Systems- Fluorescent-Indirect

- Radiate light up to reflecting ceiling
- High quality office solution for computer screen glare
- Higher, more uniform brightness
- Reduced shadows from partitions
- Myth that indirect is not efficient
  - Based on old technologies
- New designs calculate to 1 w/SF or less and are as energy-efficient as down lighting solutions
- Best success when maintain high ceiling reflectance



office application

classroom application

Building Lighting Systems- Fluorescent-Direct/Indirect

- Pendant/aircraft cable suspension
- Office lighting/control system
- 1, 4’ (3-lamp) direct/indirect luminaire per cubicle for optimal location of:
  - Luminaire, occupancy sensor, daylight sensor
- 2 lamps down illuminates task
  - Louvers shield against glare
- 1 lamp up illuminates ceiling
- New construction & retrofit
- Ledalite – “Ergolight”

Building Lighting Systems - Task

Desktop PIR occupancy sensors are available that turn off task lights when occupant not present

- Used w/task-ambient systems
- Ambient (overhead) system
  - 20-30 FC (IESNA RP-1)
- Task lighting supplements ambient system to light reading/writing material
- Provides energy-effective solution when task lights turned off

Building Lighting Systems - HID

- Cafeteria application e/w 100 W metal halide lamp in recessed downlight (no uplight)

- High bay application e/w 400 W metal halide lamp in glass refractor (20% uplight)

Building Lighting Systems- Emergency

- Unit equipment
  - Wall or ceiling mounted 'heads' and battery packs
  - NEC requires 90 min

- Exit signs
  - 24/7 operation
  - Red or green
  - EnergyStar qualified units meet UL924

How to Perform a Self-check of Building Lighting Systems

Lighting System Self-Check

- Check performance
  - Light levels
  - Power density (W/SF)
- Other measurements
  - Voltage
  - Flicker
  - Veiling reflections
- Visual clues
  - Exit signs
  - State of maintenance & problems
  - Controls
- Look for opportunities for improvement

Lighting System Self-Check – Light Levels

Photo shows over 100 FC

- Too high – wastes energy & reduces lighting quality

- Too low – owner liability issue
  - Potential for law suits

Lighting System Self-Check – Light Levels

- Increasing amount of incident light may be counterproductive
- Glare may be produced that washes out details
  - Decreases visibility
- More light does NOT mean better sight
- Reducing amount of incident light can improve lighting quality

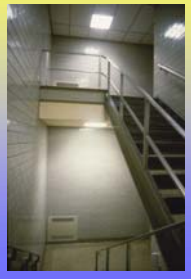
Lighting System Self-Check – Light Levels

- Do not use analog meter (+/- 20%)
- Use good digital meter (+/- 5%)
- Recommend model that measures in tenths of FC below 50 FC
- Keep calibrated
  - Annually

Lighting System Self-Check – Light Levels

- Survey building spaces & record light levels
  - Use good digital meter
- Compare to IESNA* recommendations
- Make improvements

Spotting Areas with Low Light Level



- Areas commonly found with low light level
  - Stairwells
  - Measure half way down the stairs
    - From the landing

Locating Areas of Low Lighting Efficiency

- Lighting power density (PD) is best indicator of lighting efficiency
- Photo shows continuous rows of 4 lamp, 40w T12 fixtures
  - > 4 W/SF

Lighting System Self-Check - Power Density

- PD is lighting allowance for building lighting
  - Codes and standards (ASHRAE/IESNA 90.1)
- Measured in watts/SF
- Higher efficiency – lower PD

Lighting System Self-Check - Power Density

- Best indicator of lighting efficiency
  - Screen for potential retrofit or re lighting projects by locating systems with high PD
- Good indicator of potential savings
  - When compared with state of the art designs
    - Ex: Office lighting system that calculates to 3 w/SF can be upgraded to new or retrofit at 1 w/SF
    - Savings = 3 – 1 = 2 w/SF

Lighting System Self-Check – Exit Signs

- Tip – Older, "thick" exit signs usually are equipped with incandescent A lamps

- BUT – sometimes there are surprises!

Check Lighting System Voltage

- Measure at lighting distribution panel
  - Breaker box
- Qualified electrician
- Use r.m.s. meter
- Look for circuit voltages that are too high
  - Or too low

Lighting System Self-Check - Flicker

- Spin under fixtures in question (CW)
- 'Strobing' of patterns indicate flicker present from magnetic ballasts
  - Strobing' looks like wagon wheels rotating backwards
- Daylight and incandescent sources do not flicker and can "wash out" flicker from fluorescent or HID sources
- Electronic ballasts operate at high-frequency and do not flicker

Look for Controls

1. None
2. Circuit breakers–***Is breaker rated for switch duty?***
3. Wall switches
4. Push buttons & contactors
5. Low voltage switches and latching relays
6. Photocell
7. Timer
8. Occupancy sensor

Lighting System Self-Check – Lighting Logger

- To identify areas where occupancy sensors can be effective
- Integral PIR sensor detects occupancy
- Integral light sensor detects lights on
- Data collection via connection to PC or LT
  - Serial port (RS-232)

Software prepares reports % savings w/installation of occupancy sensor

Lighting System Self-Check Dimming Opportunities

- Look for opportunities for dimming
- Manual dimming
  - Presentation areas & conference rooms
    - One fluorescent system
      - Can eliminate incandescent downlights
  - Classrooms
  - Control rooms
  - CAD areas
- Automatic
  - Daylight harvesting

Determining State of Maintenance

- Look for unlighted fixtures
  - Lamp or ballast problem?
  - Or is it just turned off?
- Look for "old" lamps
  - Dark ends
  - Low light output
- Look for dirty fixtures
- Look for dirty finishes – ceilings and walls

Re-Lamping Check List

- ✓ Replace lamps on group basis or as they burn out (spot re-lamping)
- ✓ Replace both lamps in 2-lamp fixtures
- ✓ Wipe reflecting surfaces clean
- ✓ Dispose of spent lamps using environmentally sound practices

10 Steps to Improve Lighting Systems

10 Steps to Improve Lighting Systems

1. Perform a facility self-check or contract outside audit
2. Clarify scope of project
3. Determine cost and potential project payback
4. Establish feasibility of project
5. Decide how project will be accomplished
6. Develop bid documentation
7. Bid the project
8. Perform re-lighting or retrofit project
9. Commission the project
10. Measure and Verify results

Steps to Improve Lighting Systems - Step 1

- Perform a facility self-check
  - Using information in previous section
  - Good approach for simple projects
    - Lamp/ballast upgrades
    - Exit light replacements
  - Low-cost approach
  - Usually uses existing staff
  - Limited
    - May not capture all opportunities

Steps to Improve Lighting Systems - Step 1

- Contract outside audit
  - Independent
  - Experienced
  - Professional
    - Certified with credentials (C.L.E.P., CLMC, or LC)
  - Can provide Investment Grade Audit
    - Report that can be used for funding project

Steps to Improve Lighting Systems - Step 2

- Clarify scope of project
  - Identify which lighting systems to be improved
  - What types of improvements
    - Retrofit vs. re-lighting
      - Lamp/ballast upgrade
      - Fixture replacement
        - » Changes in lamps/fixture?
        - » Changes in BF?
        - » New layout?
    - Exit lights
    - Controls

Steps to Improve Lighting Systems - Step 3

- Determine cost and potential project payback
  - Estimate cost of materials, labor, disposal project management, commissioning, M&V – everything!
  - Estimate savings using the same method as electricity provider calculates bill
    - Do NOT use average cost!
    - Include Demand charges
    - Watch time-of-use and declining block rates
  - Calculate payback
    - SPB
    - LCC

Steps to Improve Lighting Systems - Step 4

- Establish feasibility of project
  - Project economics
    - Does project meet or exceed hurdle criteria
      - LCC
  - Project practicability
    - "Doable"
  - Project achievability
    - Design project for success

Steps to Improve Lighting Systems - Step 5

- Decide how project will be accomplished
  - Part of a larger energy management project
    - ESPC
  - Stand alone lighting project
    - Internal staff
      - Consider for small projects
        - » Exit lights
    - ESCO
    - Electrical contractor

Steps to Improve Lighting Systems - Step 6

- Develop bid documentation
  - Write complete specifications
    - Not combinations of attributes from various sources
  - Avoid vague terminology
    - "electronic ballast"
  - Require maintenance documentation
  - Include information regarding:
    - Access (hours, keys, etc.)
    - Storage (where, how much space, when, etc.)
    - Clean up + 100 more

Steps to Improve Lighting Systems - Step 7

- Bid the project
  - Use contract specialists
  - RFQ
    - Qualified list
  - RFP

Steps to Improve Lighting Systems - Step 8

- Perform re-lighting or retrofit project
  - Use project manager
  - Daily contact
  - Written communications
    - Exceptions
    - Change orders
  - Do not "sign off" until job complete
    - Including maintenance instructions

Steps to Improve Lighting Systems - Step 9

- Commission the project
- Necessary to ensure:
  - specified equipment has been installed
  - equipment has been installed according to specifications
  - operated in manner for which it was designed
  - meets facility needs
- Done before responsible contractor leaves the site or equipment turned over to on-site facilities control

Steps to Improve Lighting Systems - Commissioning

- Steps to commissioning process:
  1. Verify work is completed and meets specifications
  2. Perform operational checks
  3. Prepare an Operation & Maintenance (O&M) plan

Steps to Improve Lighting Systems - Step 10

- Measure and Verify results
  - Use M&V methodology of Method #LE A2 described in Section II, Chapter 5 of the Department of Energy's "Measurement & Verification Guideline for Federal Energy Projects" (publication #DOE/GO 10096 248).

Avoiding Lighting Retrofit Pitfalls

Avoiding Lighting Retrofit Pitfalls

- On the road to successful lighting upgrade projects, a number of things can go wrong
- Fortunately, we know what many of them are and will list 10 of them so you can avoid

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 1 – Lighting systems not designed
  - Laid out using a pattern
    - What is target light level?
    - Repeat mistakes of past?
    - Is lighting providing for current visual tasks?
  - Better if systems are designed for current visual tasks
    - Ambient system supplemented by task lighting
    - For correct light levels

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 2 – Using the wrong compact fluorescent lamp
  - CFLs suffer from multiple sensitivities, which lower lumen output
    - Position
    - Temperature
    - Lumen Maintenance (i.e. LLD)
    - Ballast Factor (BF)
  - Use amalgam lamps in base up position

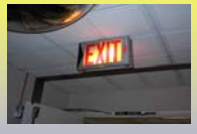
Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 3 – Retrofit vs. Re-lighting
  - Retrofit
    - Limited change potential
    - Do when have quality fixtures or have ACM in ceiling
  - Re lighting
    - Broader change potential
      - Change technology, distribution, number of fixtures, layout
    - Do when have worn-out sockets
    - More contractors know how to install new fixtures than know how to retrofit effectively

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 4 – Using the wrong exit sign technology
  - Incandescent and CFL are obsolete sources for this application
    - Short life sources consume up to 10 times the power of LED exit signs
    - CFL signs are not uniformly lighted & flicker at end-of-life
  - Use LED, LightPanel, or Photoluminescent
    - <5-w, ¼-w, 0-w

Exit Signs



Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 5 – Changing well-established lamp color temperature and CRI
  - Occupants do not like drastic changes
    - Ex: from a cool color lamp (4100K) to warm color (3000K)
  - If changing, consider neutral color (3500K)
  - Note: When CRI increased, apparent brightness increases
    - Ex: T12 CW (62) to T8 4100k (75 or 85)
    - Take into consideration

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 6 – Maintenance considerations
  - Can't easily reach fixtures to change lamps
    - Stairwells – use wall-mount fixtures that can be reached with short ladder
  - Too many lamp types
    - Try to minimize
      - Ex: 4' & 8' lamps
  - Re lamp both tubes in 2 lamp fixture at same time
  - Clean fixtures when re lamp

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 7 – Reflectors & spacing criteria (SC)
  - Be aware that some generic reflector retrofits redirect light from the 30–60 deg zone to the θ 30 deg zone and this affects spacing criteria
    - Dark walls – cave-like appearance
  - Use custom reflector that maintains S.C.
  - Use a trial installation for one area of building
    - Get feedback from occupants for appearance of lighted space

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 8 – Using the wrong occupancy sensor technology
  - Use PIR in small offices, conference rooms, etc.
    - Clear line-of-sight
  - Use ultrasonic in restrooms
    - Avoid problems with PIR in restrooms
  - Use dual-technology models for difficult applications where neither PIR or Ultrasonic alone is inadequate
    - False offs
  - Follow manufacturer's installation advice

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 9 – Mismatching lamps and ballasts
  - Fluorescent lamps should not be used with a ballast that is not specifically identified as being suitable for that type of lamp
    - Symptoms:
      - Actual performance will be less than published
      - Reduced lamp life
  - Match the number of lamps on the ballast label
    - Reduced lamp life
    - Void lamp warranty
    - Void UL listing

Avoiding 10 Lighting Retrofit Pitfalls

- Pitfall 10 – Using the wrong ballast or applying it wrong
  - Issues:
    - Instant-start vs. Program-start or Rapid-start
    - Ballast Factor (BF)
    - Multi-lamp Ballasts
    - Input Voltage
    - THD