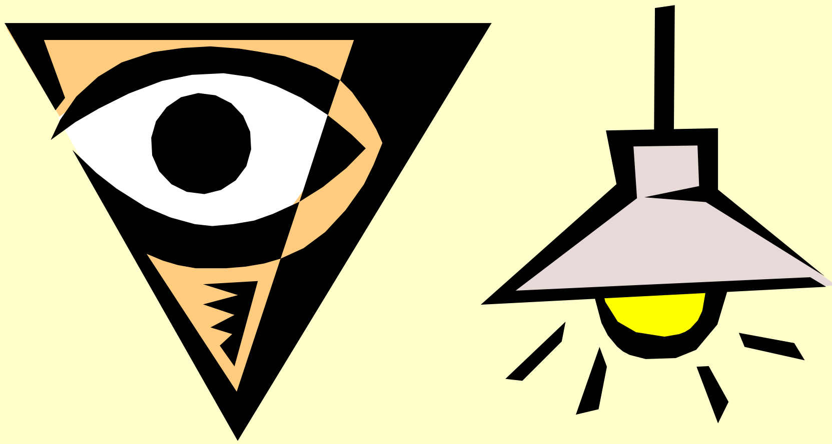


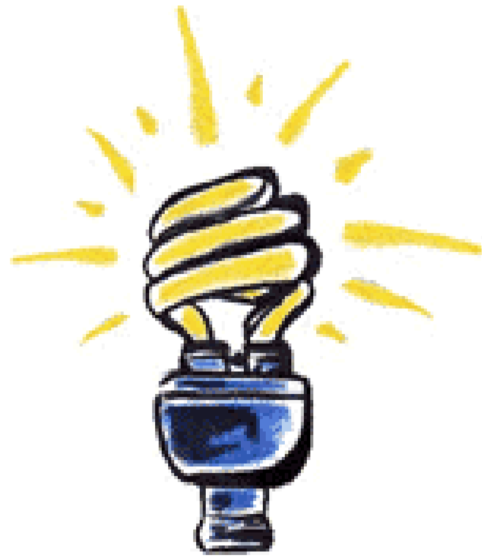
Lighting Energy Management

Ir. Dr. Sam C. M. Hui
Faculty of Science and Technology
E-mail: cmhui@vtc.edu.hk

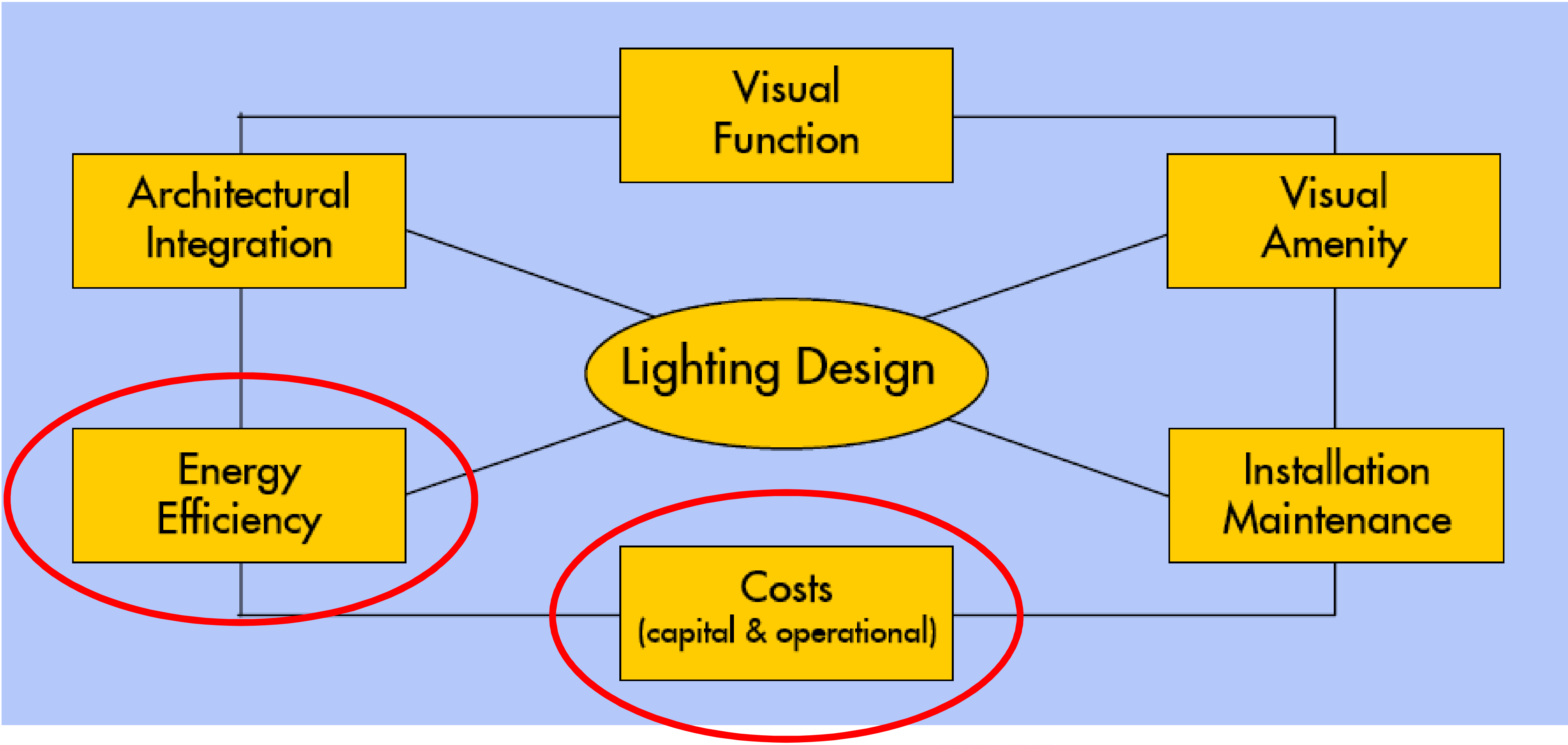
Sep 2017

Content

- Lighting Energy Use
- Energy Efficient Lighting
- Lighting Economics
- Existing Buildings
- Lighting Surveys & Audits



Energy efficiency and costs are two important criteria for lighting design

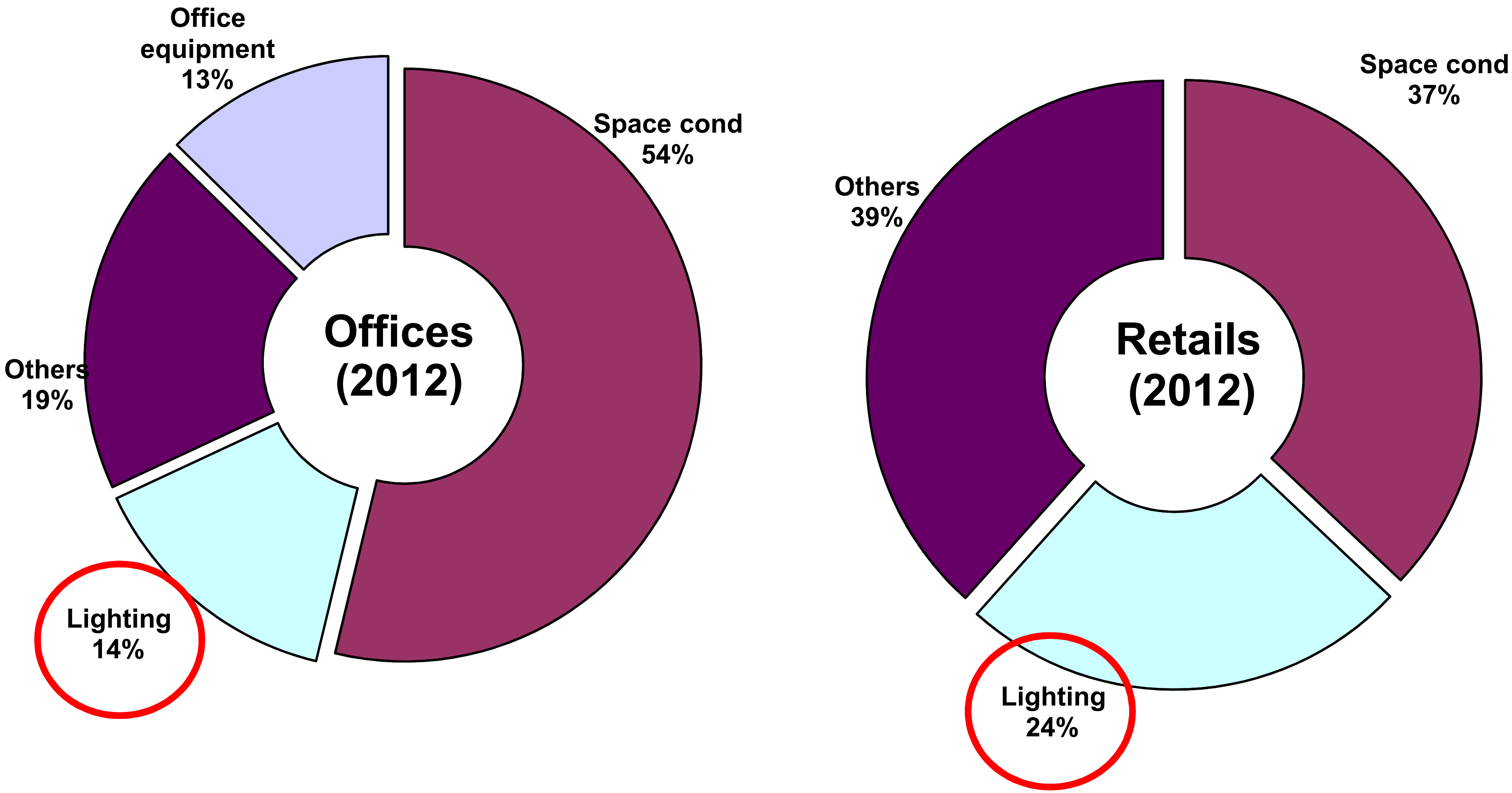


Lighting Energy Use

- Lighting consumes a great share of energy use in buildings
  - Consumption of electricity
  - Indirectly affect the cooling systems (due to heat)
  - Operating & maintenance costs
- The need to manage the lighting energy
  - Prevent energy wastage & save energy costs
  - Ensure good quality visual environment
  - Reduce greenhouse gas or CO_2 emission

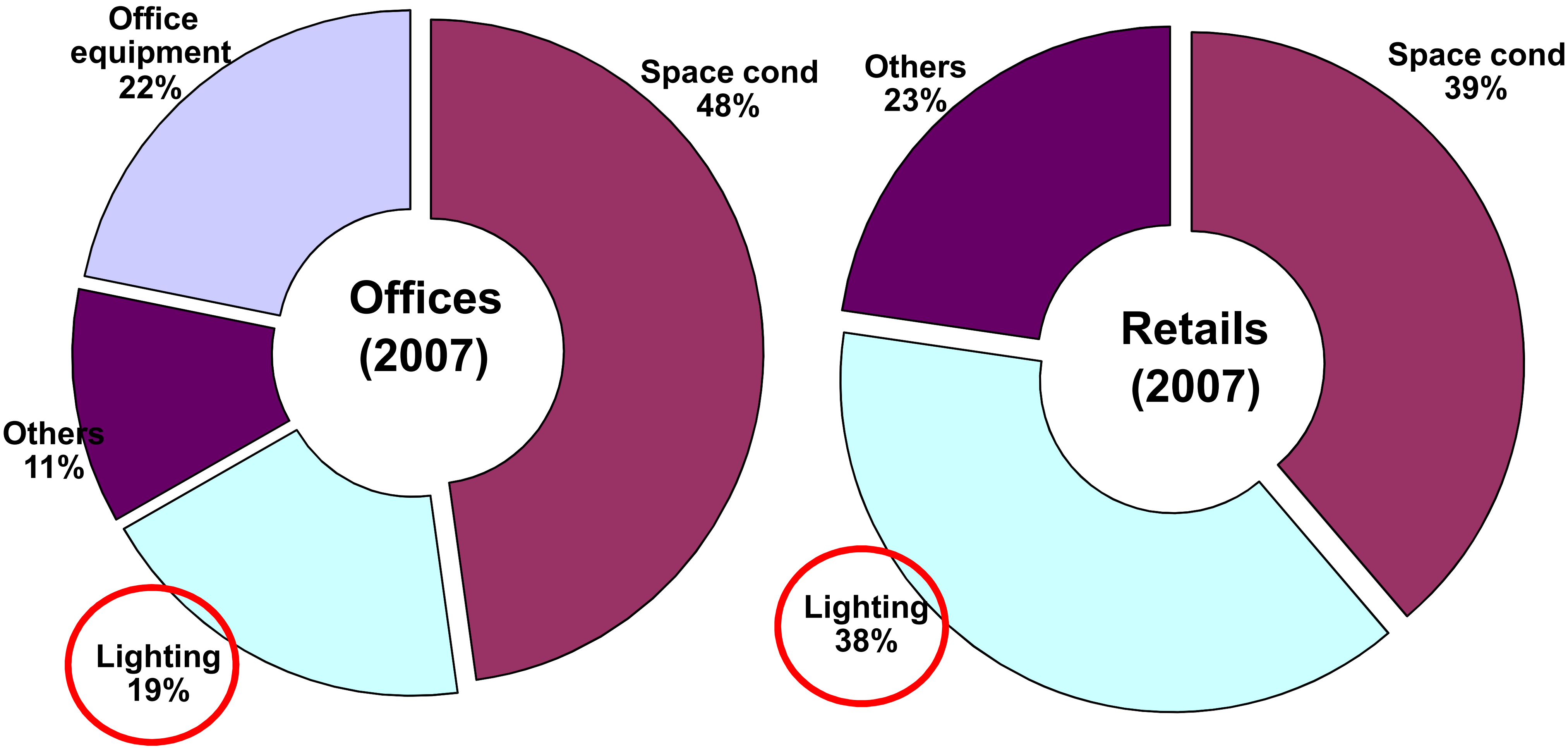
(Video: Lighting and the environment (1:59) http://www.youtube.com/watch?v=lAS02FhvhSw)

Do you know what are the direct and indirect energy consumption of lighting?



Energy consumption patterns in offices and retails
(Data source: Energy Efficiency Office, HK)

Do you know why the lighting contribution % varies between 2012 and 2007?



Energy consumption patterns in offices and retails
(Data source: Energy Efficiency Office, HK)

Lighting Energy Use

- HK Building Energy Code (BEC)*
  - Code of Practice for Energy Efficiency of Building Services Installations
    - 2015 Edition & 2012 Edition
  - Technical Guidelines on Building Energy Code
    - 2015 Edition & 2012 Edition
- Energy Efficiency Labelling Scheme (HK)*
  - Compact fluorescent lamps (CFLs), LED

(* See also www.beeo.emsd.gov.hk and www.energylabel.emsd.gov.hk)

(Source: EMSD)

(See http://www.beeo.emsd.gov.hk for details)

This indicates the energy efficiency grading of the model. Grade 1 products are most efficient (green) and have an average lamp life of 8,000 hours or above. Grade 5 products have an average lamp life of below 6,000 hours (red).

Lamp luminous efficacy of the model. A higher number indicates that the product is more efficient.

PERCENTAGE OF ENERGY SAVING

Compact Fluorescent Lamps (CFLs)

Grade 1 vs Grade 5

18%

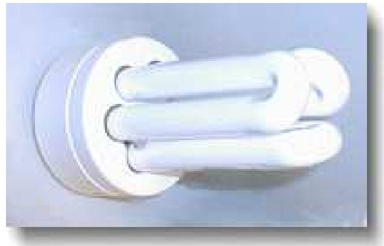
TIPS

Switch off lights that are not in use.

(Source: EMSD)

(See www.energylabel.emsd.gov.hk for details)

Energy Efficient Lighting



- HK Building Energy Code: energy efficiency requirements for lighting installation
  - 1. Lighting power density (LPD)
    - Reduce lighting power
  - 2. Lighting control point
    - Facilitate effective operation; reduce energy use
  - 3. Automatic lighting control
    - Such as daylight responsive control, occupant sensor, time scheduling, dimmer control system

Table 5.4 : Lighting Power Density and Automatic Lighting Control for Various Types of Space

Type of Space	Maximum Allowable LPD (W/m^2)	Automatic Lighting Control Required (Yes / No)
Atrium / Foyer with headroom over 5m	17	Yes
Bar / Lounge	14	No
Banquet Room / Function Room / Ball Room	20	No
Canteen	11	No
Car Park	5	Yes, at parking spaces only
Classroom / Training Room	12	Yes
Clinic	15	No
Computer Room / Data Centre	15	Yes
Conference / Seminar Room	14	Yes
Corridor	8	Yes
Court Room	15	Yes
Dormitory	8	Yes
Entrance Lobby	14	Yes
Exhibition Hall / Gallery	17	No
Guest room in Hotel or Guesthouse	13	No
Gymnasium / Exercise Room	13	Yes
Kitchen	13	No
Laboratory	15	No
Lecture Theatre	13	Yes
Library – Reading Area, Stack Area or Audio Visual Centre	15	No
Lift Car	11	Yes
Lift Lobby	11	Yes
Loading & Unloading Area	8	Yes
Office, enclosed (Internal floor area at or below $15m^2$)	13	Yes
Office, open plan or with internal floor area above $15m^2$	12	Yes

(Source: BEC 2015)

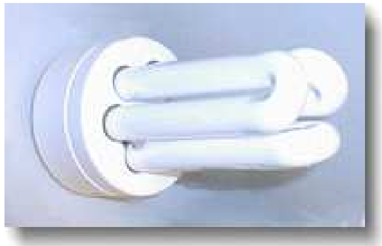
Sample calculation for lighting power density (LPD)

Table 5.7.1 : LPD Calculation for Multi-functional Space

Space Function	Function-specific Luminaires			LPD (W/m^2)	
	Luminaire Designation	Quantity	Total Circuit Wattage (W)	Calculated	Max Allowable
Banquet room	LT1	96	576	[576 + 3330 + 1344] / 264 = 19.9	20
	LT2	90	3330		
	LT3	8	1344		
	LT4	Excluded in LPD			
Ball room	LT2	90	3330	[3330 + 1344] / 264 = 17.7	20
	LT3	8	1344		
	LT4	Excluded in LPD			
Seminar room	LT1	96	576	[576 + 2240] / 264 = 10.7	14
	LT5	112	2240		

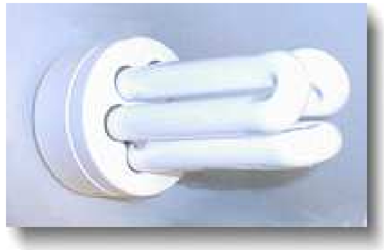
(Source: Technical Guidelines on Building Energy Code 2015)

Energy Efficient Lighting



- **Typical lighting requirements**
  - Minimum allowable luminous efficacy
    - Choose appropriate type of lamps
  - Maximum allowable lamp controlgear loss
    - Energy efficient ballast for fluorescent lamps
  - Maximum allowable lighting power density (LPD)
    - Design suitable amount and type of lighting systems
  - Interior lighting controls (switching)
    - Number of control points (to facilitate effective operation)

Energy Efficient Lighting



- Lighting efficiency principles:
  - 1. Lighting hardware efficiency
    - Includes light source, control gear, optical system, luminaire housing, etc.
  - 2. Lighting installation efficiency
    - Largely dependent on the choice, location, and setting up (e.g. aiming) of the lighting hardware
  - 3. Usage efficiency
    - Depends largely on the type of lighting controls

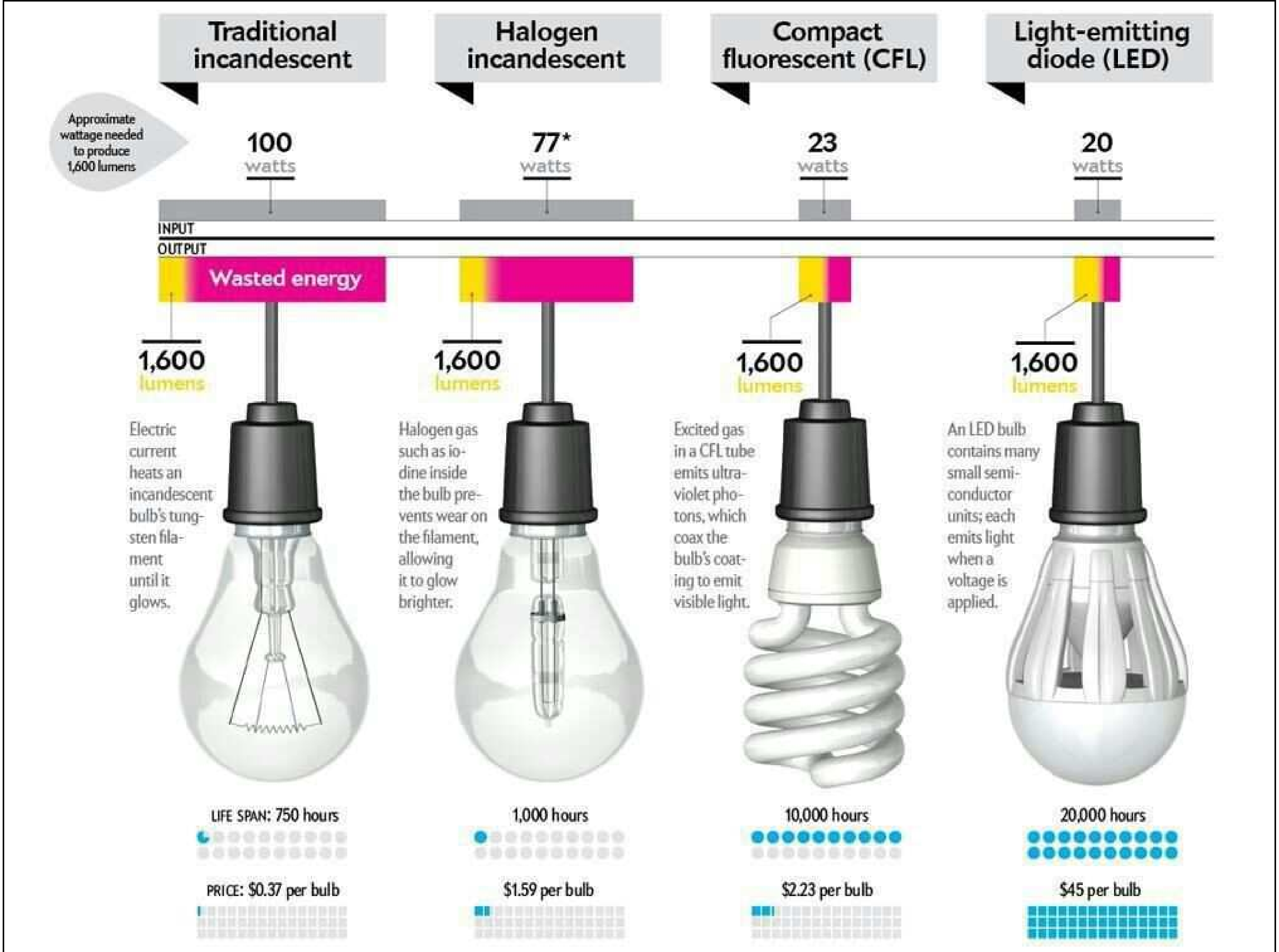
Evolution of light bulbs

Edison lamp

Incandescent lamp

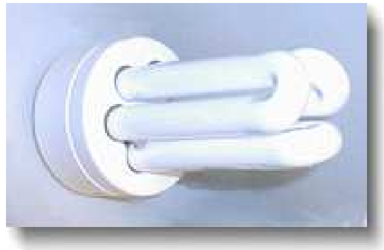
Compact fluorescent lamp

LED lamp



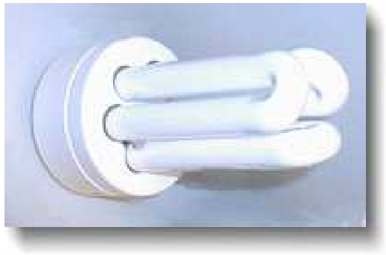
Traditional incandescent
Halogen incandescent
Compact fluorescent (CFL)
Light-emitting diode (LED)
Approximate wattage needed to produce 1,600 lumens
100 watts
77* watts
23 watts
20 watts
INPUT
OUTPUT
Wasted energy
1,600 lumens
1,600 lumens
1,600 lumens
1,600 lumens
Electric current heats an incandescent bulb's tungsten filament until it glows.
Halogen gas such as iodine inside the bulb prevents wear on the filament, allowing it to glow brighter.
Excited gas in a CFL tube emits ultraviolet photons, which coax the bulb's coating to emit visible light.
An LED bulb contains many small semiconductor units; each emits light when a voltage is applied.
LIFE SPAN: 750 hours
1,000 hours
10,000 hours
20,000 hours
PRICE: $0.37 per bulb
$1.59 per bulb
$2.23 per bulb
$45 per bulb

Energy Efficient Lighting



- Video: Energy 101: Light Bulbs (4:47)
  - http://youtu.be/Pk60-D61h34
  - Our animated correspondent, 'Little Lee Patrick Sullivan,' kicks off our "Energy 101" series with an inside look -- literally -- at light bulb technology. He goes inside an incandescent, a compact fluorescent and an LED bulb to see what makes them work, and their potential drawbacks.

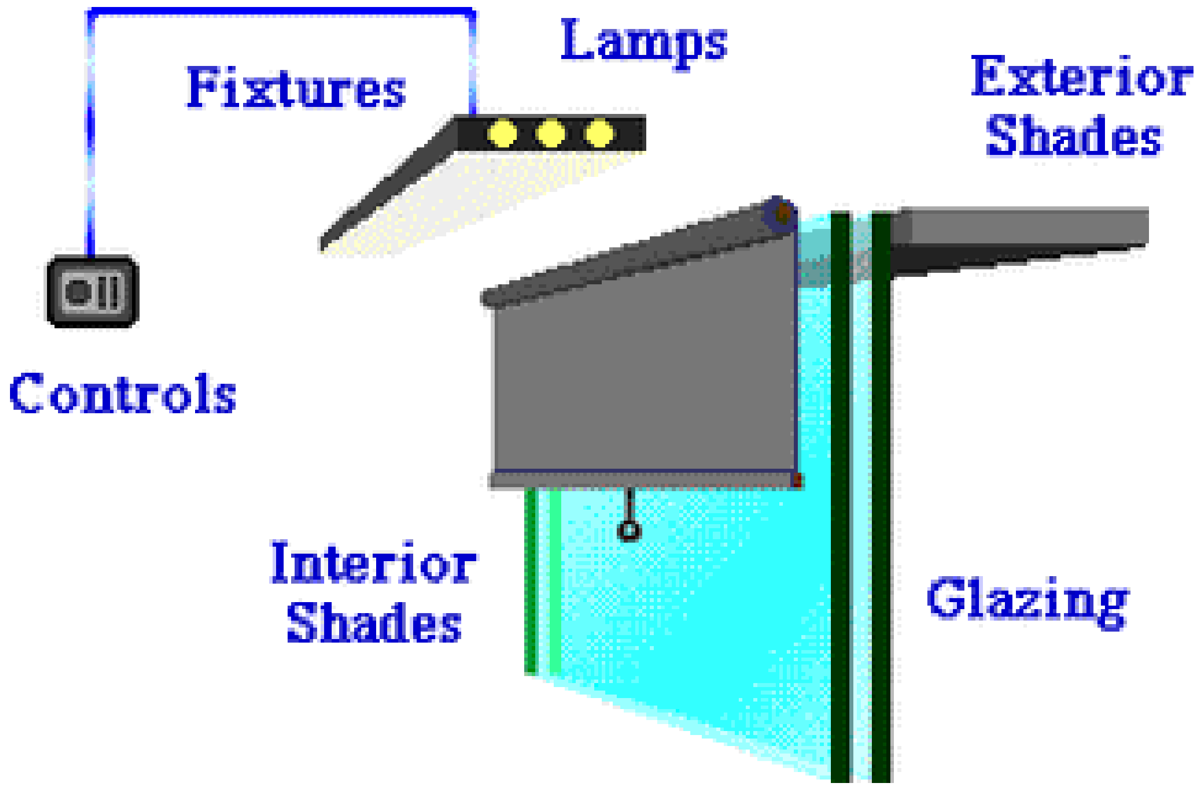
Energy Efficient Lighting



- Principles of efficient lighting design
  - Meet target light levels
  - Efficiently produce light
    - Use natural light or efficient light sources
  - Efficiently deliver light
    - Balance efficiency with aesthetics, lighting quality, visual comfort
  - Automatically control lighting operation
    - Switch off or dim unnecessary lighting equipment

Energy efficient lighting design strategies

Energy efficient fittings (e.g. compact fluorescent lamps, LED)



Lighting controls and interactions with windows

Example: Integrated controls for lighting luminaires

Vertically Integrated Design

<u>Personal Control Features:</u>

•Direct/ Indirect Pendant Luminaire

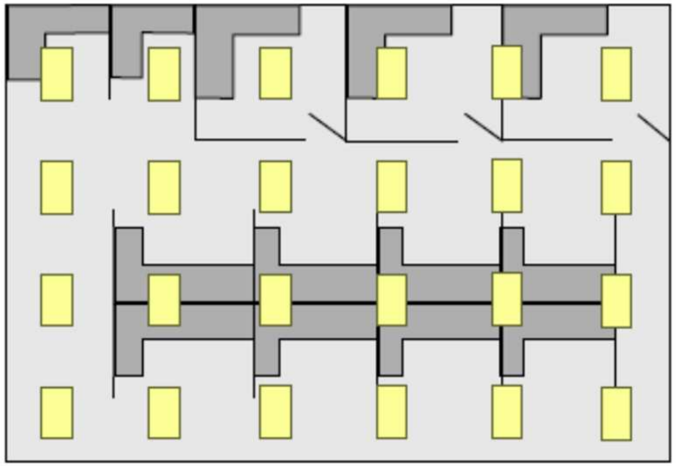
•Task light: 2T8-PS Dimmable EB (64W)/ 100%-5%

•Ambient light: 1T8-PS EB (31W)/ ON/OFF only

•Photocell Sensor built in

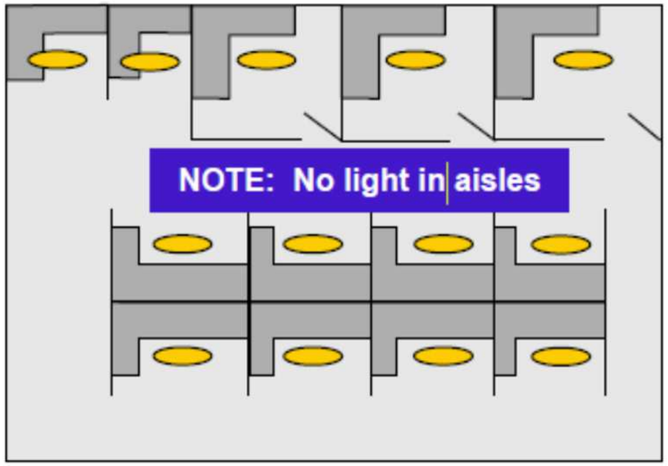
•Occupancy Sensor built in

Comparison to a Standard Troffer Layout:



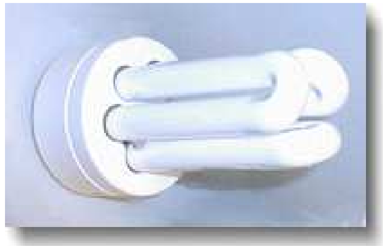
- 2x4 Parabolics
- **<u>24 Luminaires</u>**
- 72 lamps
- **~2300 watts**

- Direct Indirect
- **<u>13 Luminaires</u>**
- 39 lamps
- **~1250 watts**



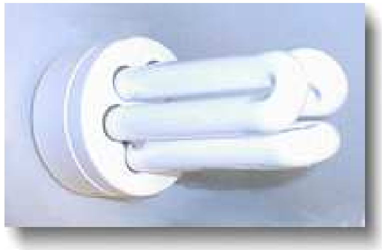
(Source: http://lightingdesignlab.com)

Energy Efficient Lighting



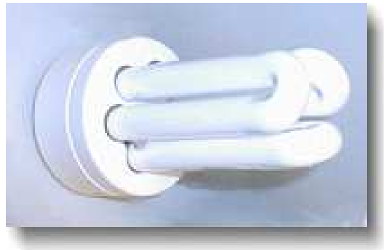
- The key is to understand lighting needs & operation
  - Space design & utilisation
  - Daylighting potential
  - Light sources
  - Luminaires
  - Lighting controls
  - Operation & maintenance

Energy Efficient Lighting



- Recommendations by IESNA
  - Design lighting for expected activity (higher light levels for "working“, lower levels for "walking")
  - Design with more effective fixtures & fenestration
  - Use efficient light sources (higher lumen per watt output)
  - Use more efficient fixtures
  - Use thermal controlled fixtures
  - Use lighter finish on ceilings, walls, floor & furnishings

Energy Efficient Lighting



- Recommendations by IESNA (cont'd)
  - Use efficient incandescent lamps
  - Turn off lights when not needed
  - Control window brightness
  - Use daylighting as practicable
  - Keep lighting equipment clean and in good working condition
  - Post instructions covering operation & maintenance

Lighting Economics

- Lighting system --- life cycle costs (LCC)
  - Initial costs
    - Equipment, installation, wiring, HVAC
  - Energy costs
    - Direct lighting costs
      - Energy use (kWh) = lighting power (kW) x operating time (hr)
    - Lighting-related HVAC (indirect) costs
      - Lighting heats up the space & require cooling
    - Total cost savings = energy costs + demand costs
  - Maintenance costs

(Video: What does lighting cost (4:30) http://www.youtube.com/watch?v=wflEn2mWCcI)

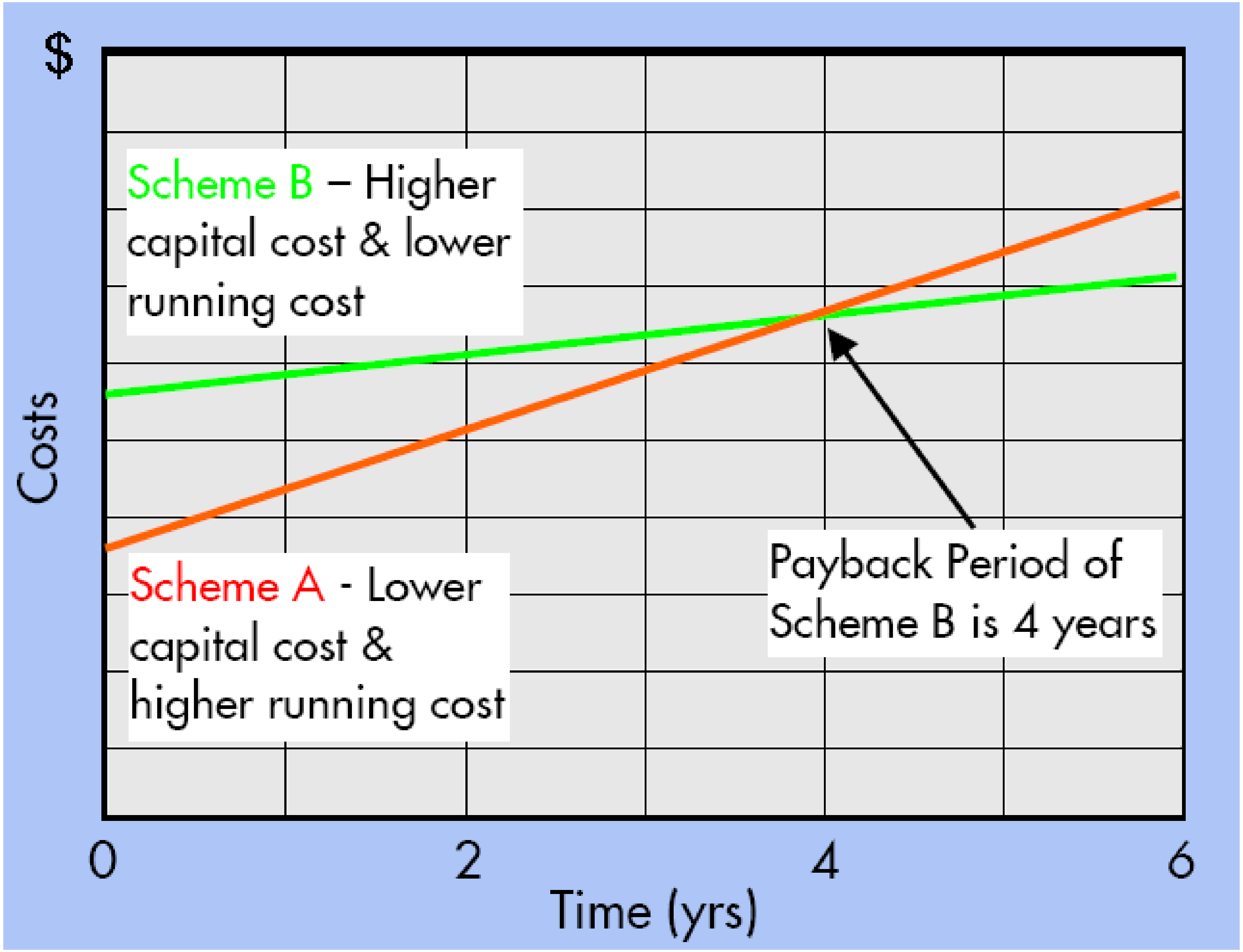
Lighting Economics

- Lighting maintenance
  - Relamping
  - Reballasting
  - Cleaning
  - Miscellaneous maintenance
    - e.g. replace lenses or louvers, damaged parts
  - Insurance & property taxes
  - Depreciation

Lighting Economics

- Investment costs
  - Luminaire, including control gear (where applicable)
  - Lighting control systems (e.g. dimmers)
  - Mounting accessories
  - Electrical wiring
  - Installation costs
- Running costs
  - Energy
  - Lamp replacement
  - Maintenance
  - Amortization (disposal)

(Video: Economics of Light (3:22) http://www.youtube.com/watch?v=QzSAKWR_zv4)



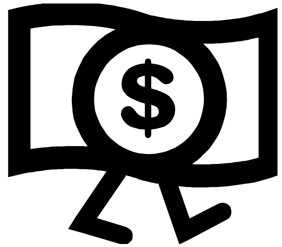
Payback period of lighting scheme

[Source: Thorn Lighting]

Replace a 60 W incandescent light bulb with a 9 W compact fluorescent lamp will generate how much electrical energy saving?

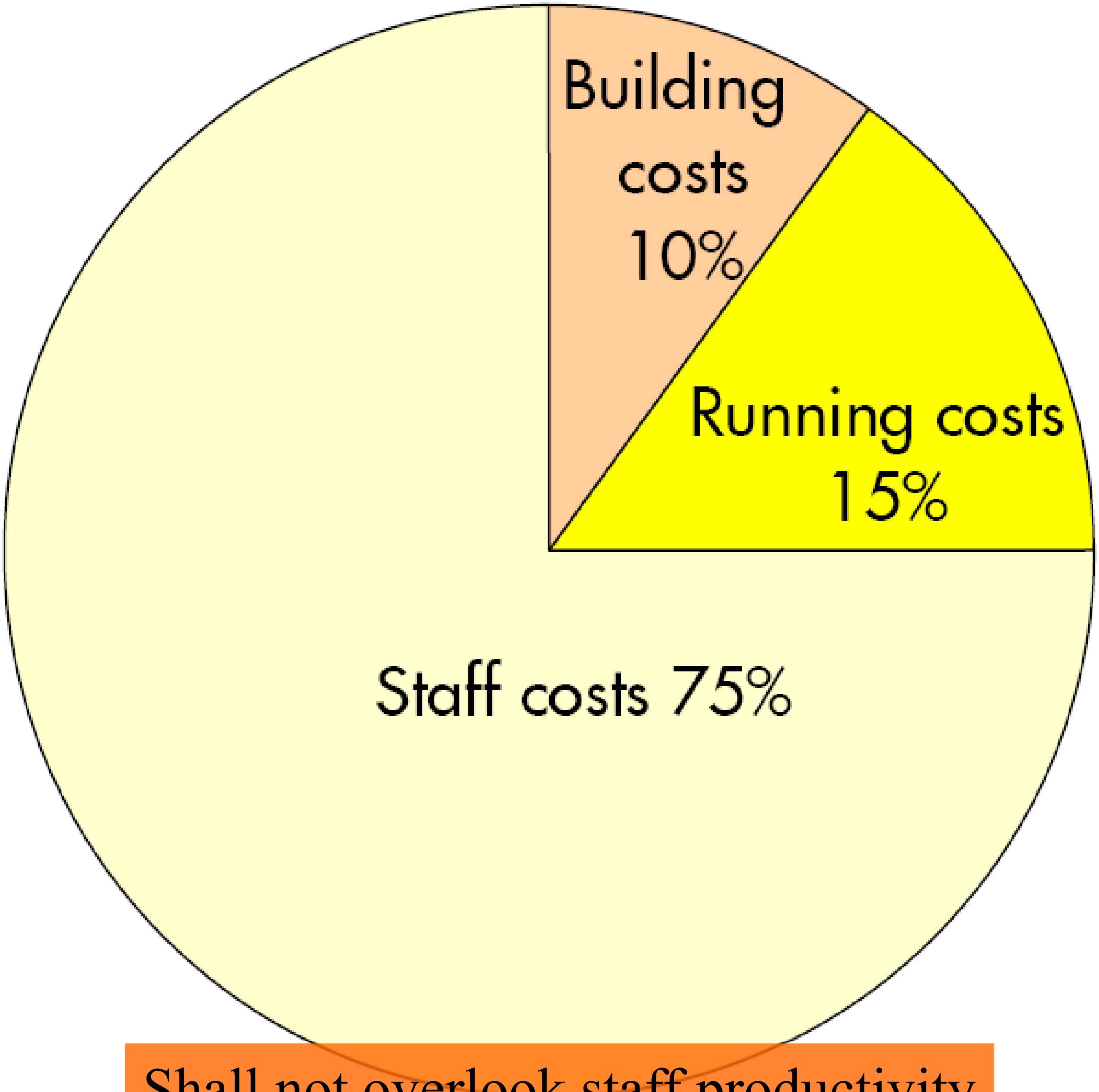
A. 75%	B. 80%
C. 85%	D. 90%

Lighting Economics



- Economic analysis techniques:
  - Payback (simple, discounted)
  - Escalating costs, future costs
  - Principles of life cycle costing (net present value)
  - Investment analysis
    - Total life cycle cost
    - Payback
    - Return on investment (ROI)
- Lighting analysis software:
  - Lighting design, energy auditing, building simulation, economic analysis

(Video: Lighting Economics (4:53) http://www.youtube.com/watch?v=CD8crNMAtfI)



Shall not overlook staff productivity

[Source: Thorn Lighting]

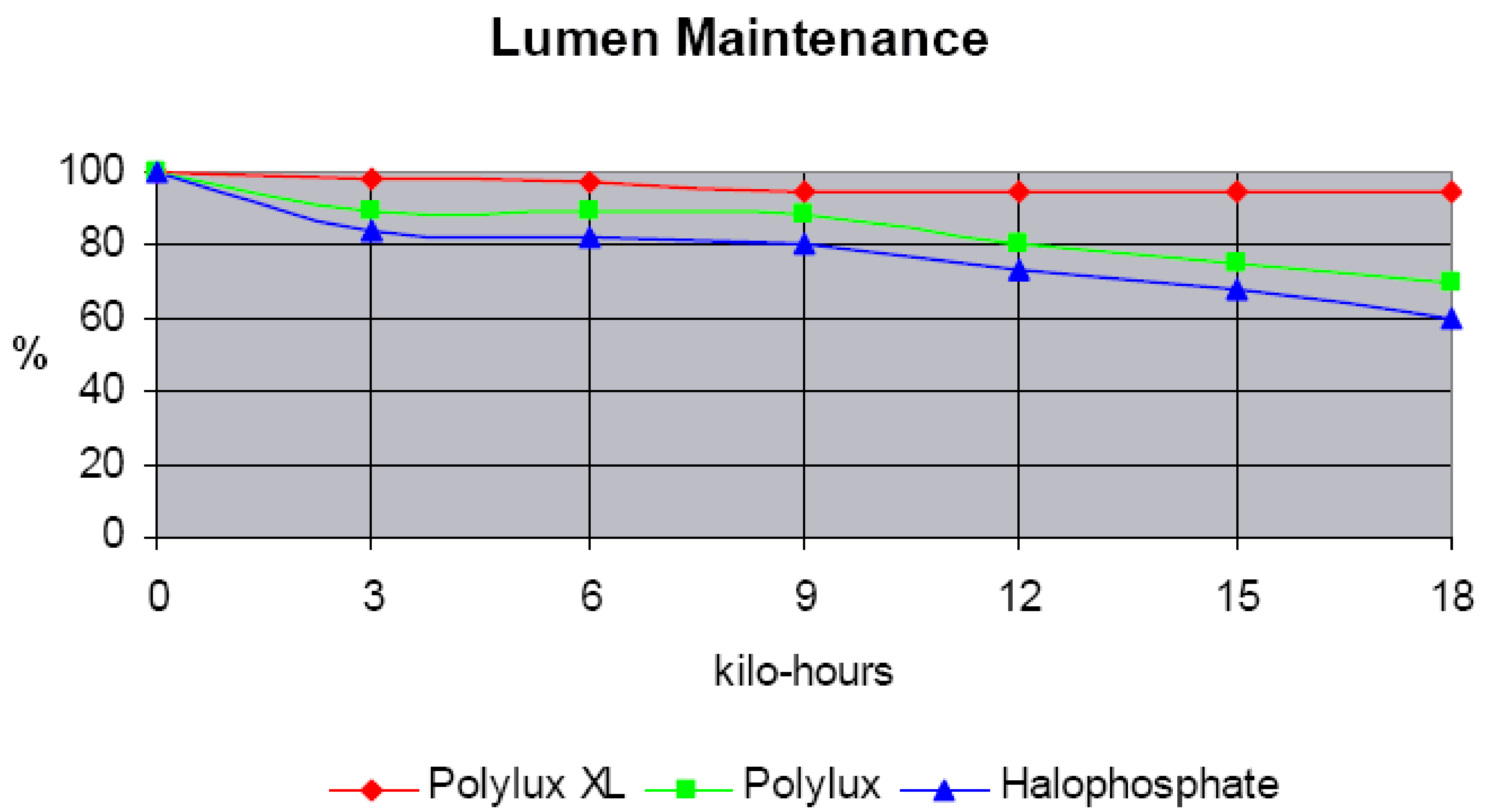
Existing Buildings

- Energy management for existing buildings
  - Building survey
  - Power budget & limit determination
  - Energy limit determination
  - Energy limit analysis
- Critical issues to consider
  - Maintenance of lighting system
  - Lighting upgrade strategies
  - Environmental aspects

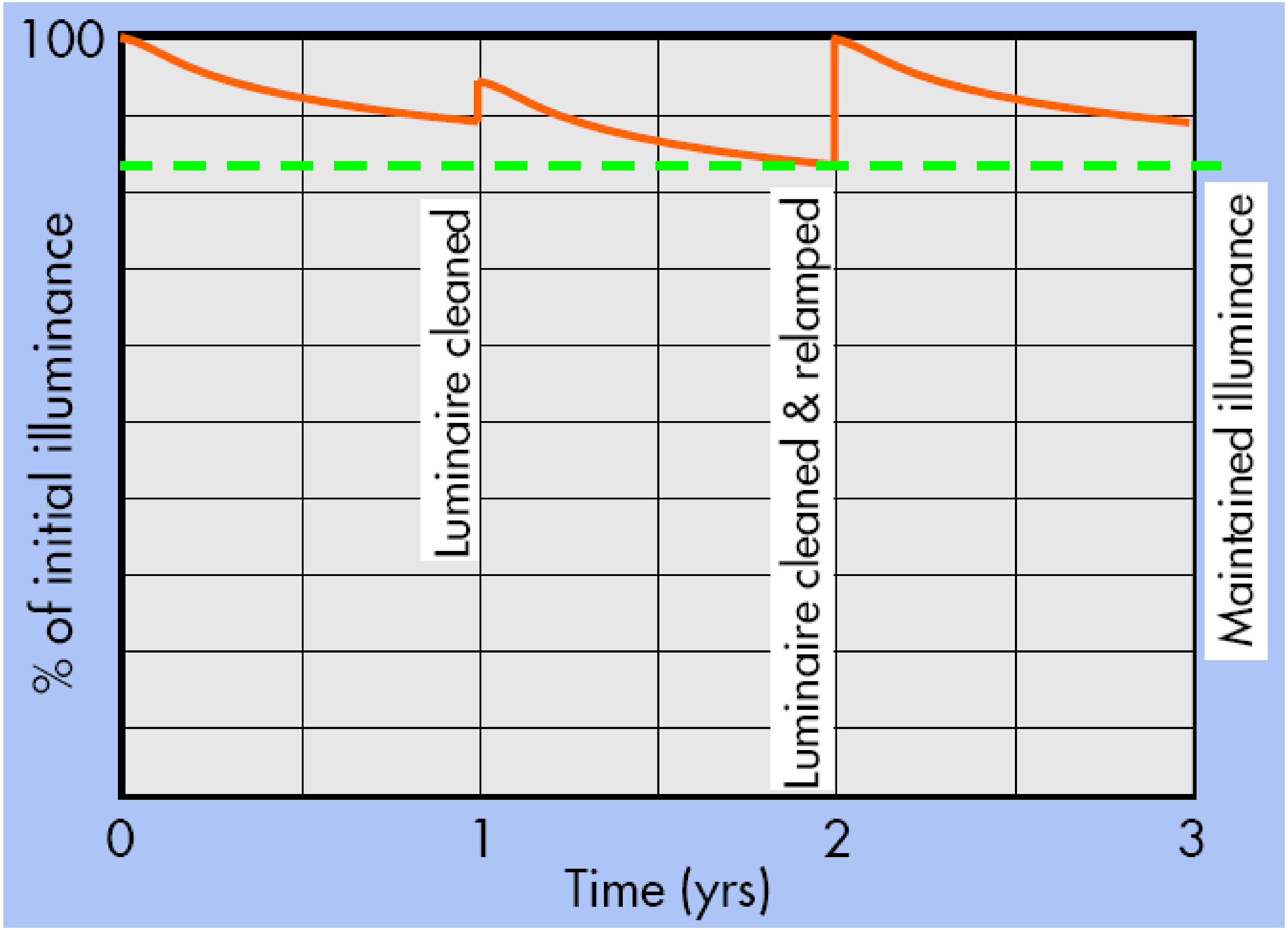
Existing Buildings

- Maintenance of lighting system
  - Periodic cleaning of lighting fixtures & lamps
    - Decreases light loss & improve light levels
  - Spot or group replacement of lamps based on the economics of the system
  - Periodic repainting or cleaning of the room surfaces (ceiling, walls, and floor) to maintain optimum light reflection characteristics
- Concept of "lumen maintenance"

(See also: Maintenance Factor : Taking the reduction of luminous flux into account http://www.erco.com/guide/simulation-and-calculation/maintenance-factor-2713/en_us/content-1.php)

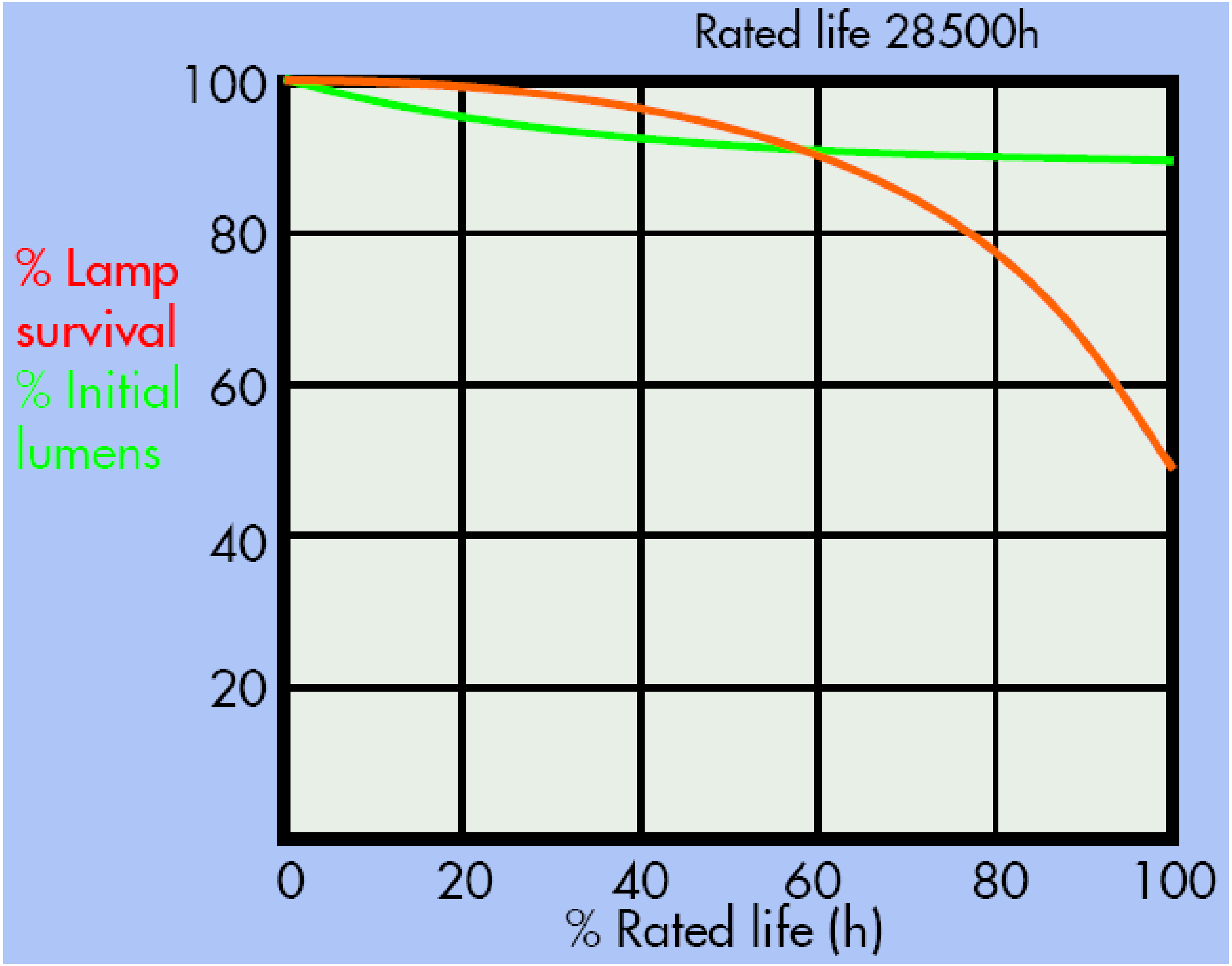


[Source: Thorn Lighting]



Lamp maintenance effect

[Source: Thorn Lighting]



Lamp maintenance effect

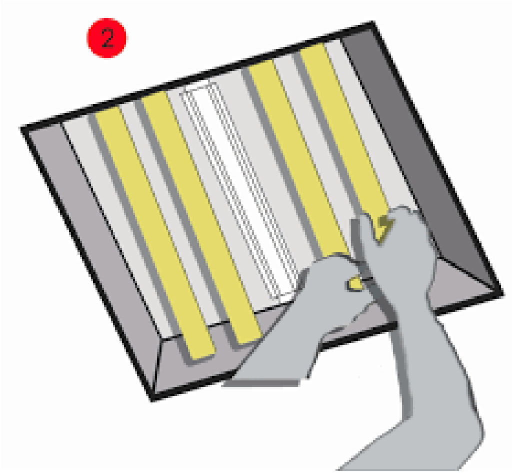
[Source: Thorn Lighting]

Existing Buildings

- Common lighting upgrade strategies
  - Upgrade with reduction in light levels
    - If original design is excessive
  - Increase light levels
  - Maintain light levels
  - Focus light levels
    - Task lights or accent lighting
  - Reduce hours of use
    - Add time schedule or automatic controls

Existing Buildings

- Upgrading fluorescent fixtures
  - Improved fluorescent lamps
    - T-8, T-10. T-12 tri-phosphor lamps
    - New T-5 lamps
    - New induction lamps (long life)
  - Electronic ballasts
    - Standard non-dimmable
    - Consider dimming balasts
    - New programmable balasts
  - Reflectors



Existing Buildings

- Typical fluorescent fixture upgrades
  - T8 lamp/ballast system
  - T5 twin-tube lamp/ballast system
  - Specular reflectors/delamping
  - Current limiters
  - Daylight-dimming systems
  - 25W T12 lamps/T8 ballasts
  - Premium magnetic, cathode cut-out (hybrid), electronic ballasts (full output, dimmable, light-level switching and low-wattage)
  - Lens/Louvre upgrades
  - Indirect lighting w/task lighting
  - Task lighting w/reduced ambient lighting
  - New fixtures

Existing Buildings

- Compact lighting upgrades
  - Compact fluorescent lamps
  - Halogen lamps
  - Krypton incandescent lamps
  - Electrodeless downlight lamps
  - Compact HID lamps
  - New fixtures
- High-intensity discharge (HID) lighting upgrades
  - Energy-saving metal halide and high pressure sodium (HPS) lamps
  - Switching to metal halide or HPS systems
  - HID fixture reflectors
  - High-bay compact fluorescent lamps
  - Dimming ballasts
  - New fixtures

Existing Buildings

- Typical exit sign upgrades
  - Compact fluorescent lamps
  - Low-wattage incandescent lamps
  - LEDs
  - Electroluminescent panels
  - New exit signs

- Typical control upgrades
  - Lighting management systems
  - Dimmable fluorescent & HID ballasts
  - Daylight- & lumen maintenance-dimming systems
  - Electronic timeclocks
  - Occupancy sensors (many options available)
  - Manual, step-level & panel-level dimming systems
  - Current limiters
  - Capacitive-switching HID systems

Existing Buildings

- Lighting retrofit economics ($$$)
  - Must understand current energy consumption
  - Payback & return on investment (ROI)
    - Simple payback usually
  - Life cycle cost (LCC) analysis
- Impact of lighting on building HVAC
  - Lighting & HVAC interactions
  - Cooling energy savings

(Video: What is 1 watt? (4:52) http://www.youtube.com/watch?v=9N05bf6G-YE)

Existing Buildings

- Other considerations:
  - Calculate energy usage and costs
  - Power quality: power factor & harmonic distortion
  - Daylighting
  - Lighting vs. HVAC
  - Energy audit & lighting studies
  - Economic analysis
  - Load shape impacts

Existing Buildings

- Environmental aspects of lighting
  - Disposal
    - Lighting waste disposal (e.g. lamp & ballast)
  - Green lights
    - Minimum efficacy standards for lamps
  - Emissions (e.g. mercury)
    - During manufacturing
    - During operation

Lighting Surveys & Audits

- Major tasks:
  - Collect financial information
    - Utility rate & tariff structure, average charges for energy (kWh) and demand (kW), rebates or subsidies
  - Collect general information
    - Floor plans, reflected ceiling plan, room dimensions
  - Collect occupant information
    - How they feel about the lighting system

Lighting Surveys & Audits

- Major tasks: (cont'd)
  - Collect lighting information
    - Hours of operation
    - Type, size & nos. of fixtures
    - Nos. of lamps per fixture, no. of lamps per ballast
    - Type of lamps, type of ballasts, specular reflectors (if any)
    - Fixture condition, whether fixtures are air-handlers
    - Availability of daylight
    - Tasks performed in the space
    - Use of partitions
    - Unique fixture types or physical features
    - Area dimensions, height of the tasks, fixture mounting height
    - Surface reflectances, colours of major objects & room surfaces

Lighting Surveys & Audits

- Instrumentation
  - Illuminance measuring equipment
  - Luminance measuring equipment
  - Daylight factor meters
- Survey methods
  - Number of measuring points
  - Presentation of information
  - Method of evaluating daylight & artificial lighting
  - Calculation using lumen method

Minolta Illuminance Meter
T-10 (luxmeter)

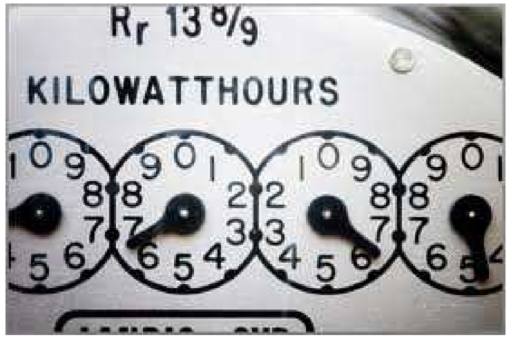
Minolta Luminance Meter
LS-110

Lighting measuring equipment

(http://www.konicaminolta.com.cn/instruments/)

Lighting Surveys & Audits

- What to look for?
  - Lighting equipment inventory
  - Lighting loads
  - Room dimensions
  - Illumination levels
  - Hours of use
  - Lighting circuit voltage & control



Lighting Surveys & Audits

- Potential lighting energy saving measures
  - Fluorescent upgrades
  - Delamping
  - Incandescent upgrades
  - HID upgrades
  - Control upgrades
  - Daylight compensation

- Three major areas of lighting improvement
  - Replace incandescent lamps with fluorescent or CFL/LED
  - Upgrade fluorescent fixtures with improved components
  - Install lighting controls to minimise energy costs

Electromagnetic vs. Electronic Ballasts

	Electromagnetic Ballast	**Electronic Ballast**
Heat	Generates about 30 deg. C more heat than electronic	Internal losses are less than 8 watts
Light Flicker	60 Hz frequency causes light flicker levels of 30% or higher	20,000-25,000Hz frequency produces virtually no detectable flicker
Noise	Vibrations induced by electromagnetic field causes humming noise	No audible noise
Weight	Heavy components coated in heavy protective material	Weighs about half as much as electro-magnetic type

(* See also http://en.wikipedia.org/wiki/Electrical_ballast)

Lighting Surveys & Audits

- Applications of compact fluorescent lamps
  - Task lights
  - Downlights
  - Wallwashers
  - Outdoor fixtures
  - Exit signs
  - Can be dimmed (e.g. in conference rooms)
  - Can be used in refrigerators & freezers

Further Reading

- Energy Efficient Lighting Checklists [PDF]
- Energy Efficient Lighting (Eartheasy.com)
  - http://eartheasy.com/live_energyeff_lighting.htm
- Energy Efficient Lighting (State of Michigan)
  - http://www.michigan.gov/documents/CIS_EO_Lighting_167401_7.pdf
- Energy Performance Assessment of Lighting Systems [PDF]
- Economics of Energy Effective Lighting for Offices (FEMP Lights) [PDF]

Further Reading

- HK EE Net: Lighting
  - http://ee.emsd.gov.hk/english/lighting/light_intro/light_intro.html
  - Lamp & luminaire
  - Ballast
  - Control systems
  - Other EE lighting systems
  - Emerging EE lighting technologies

References

- Benya, J. R. and Leban, D. J., 2011. *Lighting Retrofit and Relighting: A Guide to Green Lighting Solutions*, Wiley, Hoboken, NJ.
- DiLouie, C., 2011. *Lighting Redesign for Existing Buildings*, Fairmont Press, Lilburn, GA and Taylor & Francis, Boca Raton, FL.
- EMSD, 2015. *Code of Practice for Energy Efficiency of Building Services Installation*, 2015 Edition, Electrical and Mechanical Services Department, Hong Kong.
- EMSD, 2015. *Technical Guidelines on Code of Practice for Energy Efficiency of Building Services Installation*, 2015 Edition, Electrical and Mechanical Services Department, Hong Kong.
- Fetters, J. L., 1998. *The Handbook of Lighting Surveys and Audits*, CRC Press, Boca Raton, FL.