MECH3422 Building Services Engineering I

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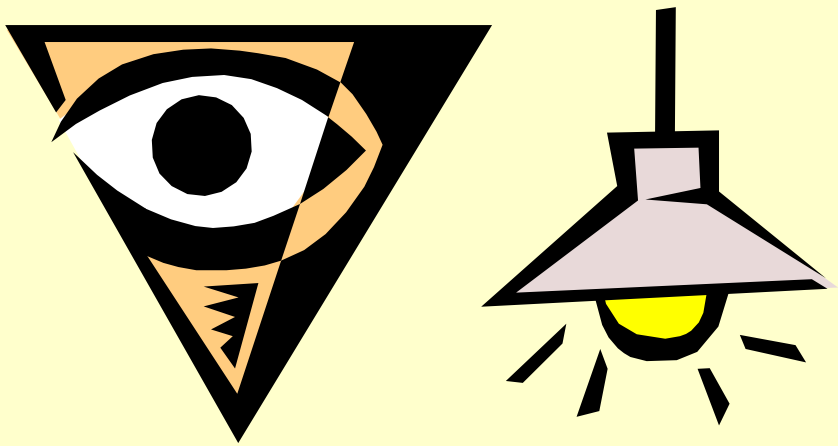

# Lighting Systems – Lighting Design

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# Content

- Basic Principles
- Design Process
- Lighting Calculations
- Daylighting Design
- Exterior & Emergency Lighting
- Energy Efficient Lighting
- Lighting Economics

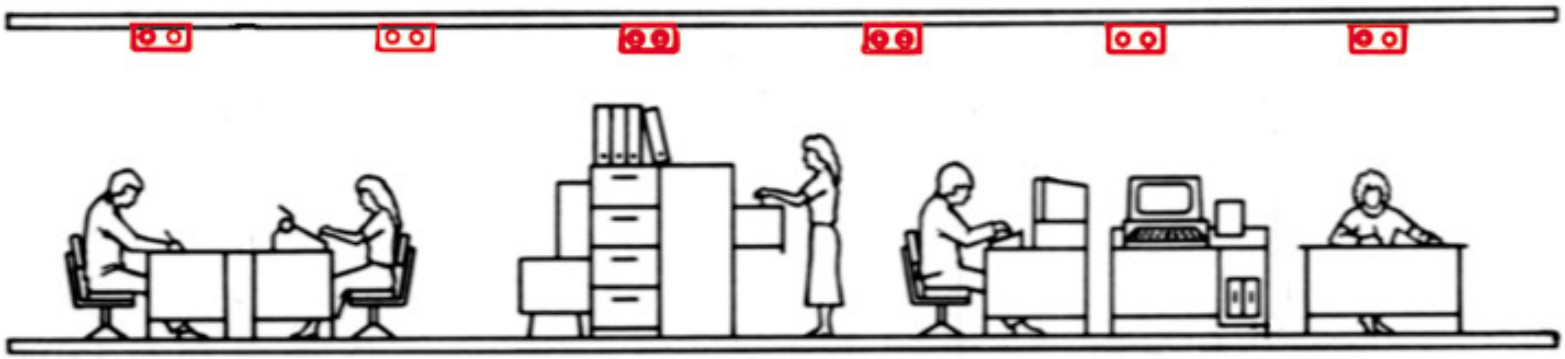
# Basic Principles

- Lighting of interior as a whole is affected by:
  - General brightness
  - Patterns of light, shade, colour
  - Degree of glare
  - Modelling of people, objects and features
- Illuminance needed for the task depends on:
  - Visual difficulty & complexity of the task
  - Average standard of eyesight
  - Level of visual performance required

# Basic Principles

- Effect of lighting
  - On architecture (defines space & shows form)
  - On interior design (reveals texture & colour)
- Psychological effects of an environment are as important as the physiological
  - Good quality light to "see by" and to "feel by"
- Three main aspects to consider:
  - General lighting
  - Localised lighting
  - Local (task) lighting

# General lighting



[Source: CIBSE Lighting Code]

# Localised lighting

[Source: CIBSE Lighting Code]

# Local (task) lighting

[Source: CIBSE Lighting Code]

# Basic Principles

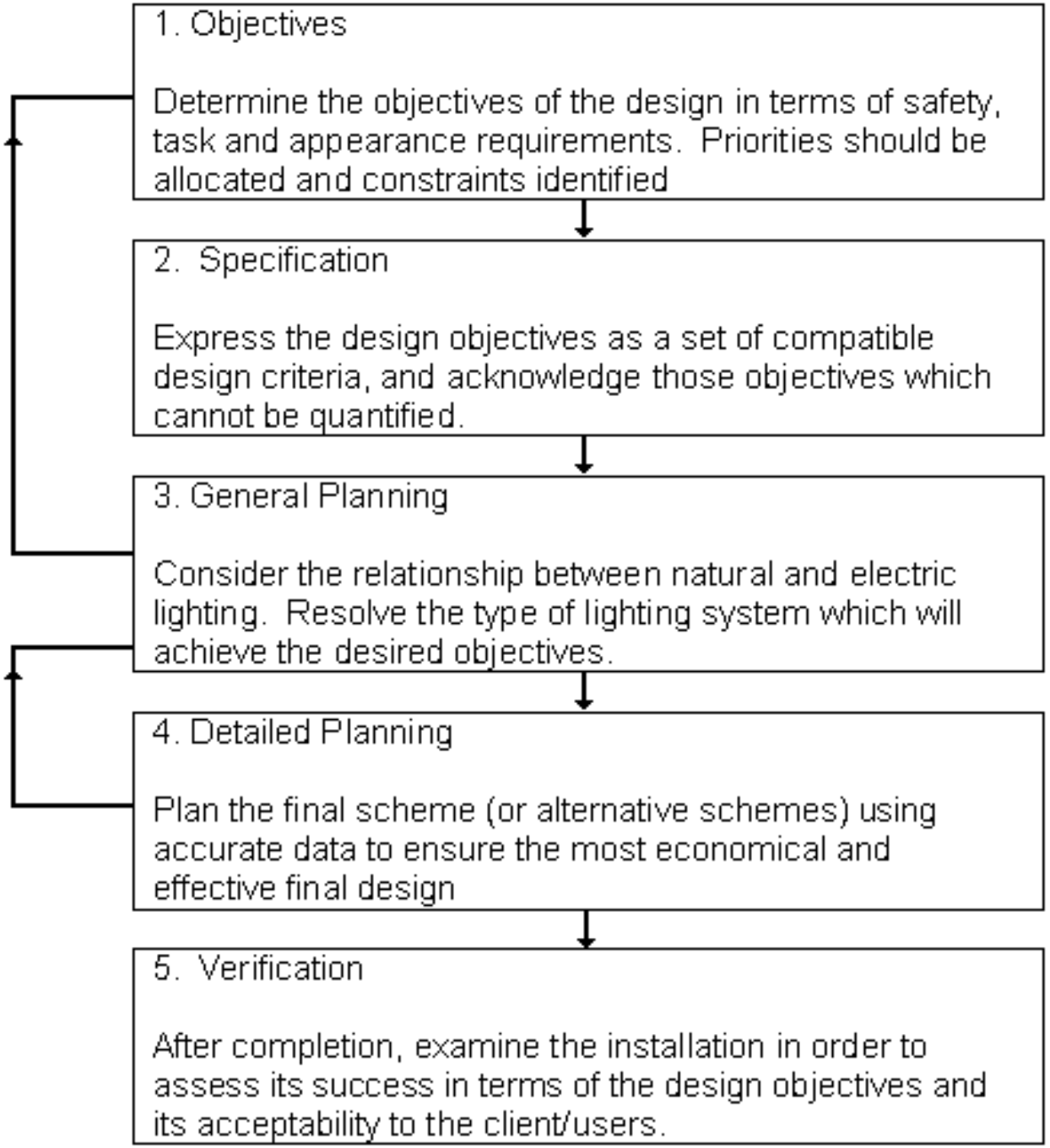
- Methods for creating the total (visual) environment:
  - Ambient lighting
  - Accent lighting
  - Task lighting
  - Perimeter lighting

# Basic Principles

- Ambient lighting
  - Provides general, overall illumination
  - Defines the space, and makes it a comfortable visual environment
  - Two approaches:
    - Direct lighting (brightens objects and surfaces)
    - Indirect lighting (can give the feeling of spaciousness)
- Accent lighting
  - Focuses on selected objects and surfaces, providing drama and excitement
    - Such as key light, fill light and silhouetting, sparkle & glitter

# Basic Principles

- Task lighting
  - Illuminates areas where work is performed, such as concentrated light from above
- Perimeter lighting
  - By lighting vertical surfaces to emphasize the architecture of the space and provide the necessary surround brightness
  - Two common approaches:
    - Wall Washing: appropriate for smooth surfaces; provide a uniform wash of light from floor to ceiling
    - Grazing: for non-uniform surfaces; emphasize the features of rough surfaces, e.g. wood-grain finishes, stone, brick and other textured surfaces




Set the goals

Specify criteria

System type

Calculations/ details

Verification

Lighting design and planning

[Source: CIBSE Lighting Code]

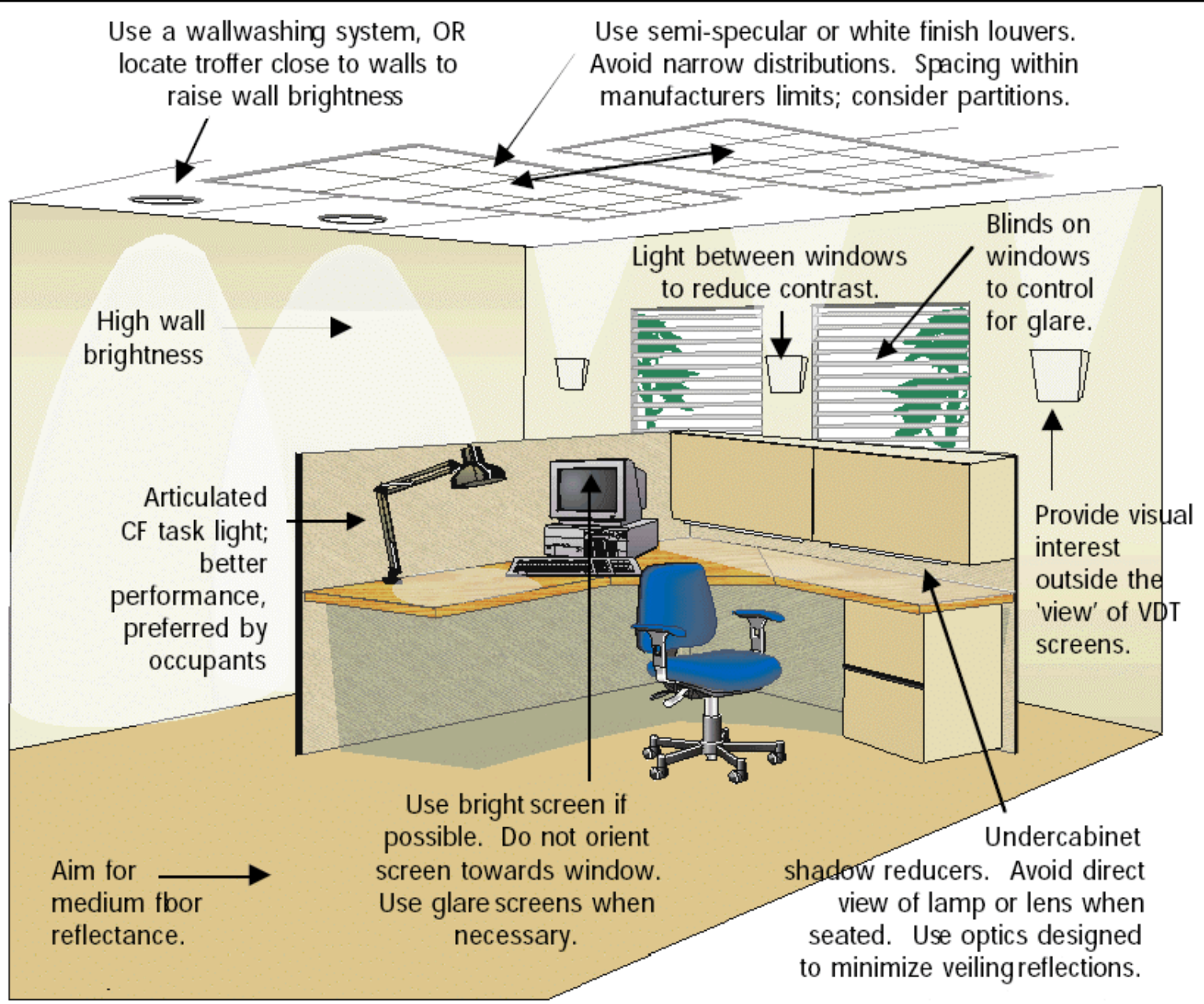



*Figure 1. Graphic showing Lighting Quality Recommendations for Open Plan Spaces. The contribution of the IESNA Quality of the Visual Environment Committee is gratefully acknowledged.*

(Source: *Federal Lighting Guide*, USDOE, June 1998)

# Design Process

- Basic approach to lighting design
  - Determine lighting design criteria
    - Quantity of illumination (lighting level, lux)
    - Quality of illumination (e.g. overall appearance, colour)
    - Codes and regulations (e.g. building, electrical, energy)
  - Record architectural conditions & constraints, e.g.
    - Window location & size, ceiling height, finish materials
  - Determine visual functions & tasks to be served
  - Select lighting system to be used

# Design Process

- Basic approach to lighting design (cont'd)
  - Select luminaire and lamp types
    - To produce the desired light & fit the client's needs
  - Determine number & location of luminaires
    - Through calculations & assessment
  - Place switching & other control devices
    - User convenience & energy management
  - Aesthetic & other intangibles
    - Aesthetic & psychological factors

# Design Process

- The process of designing with light focuses on:
  - What to light
  - How to light it
  - What to light it with

# Design Process

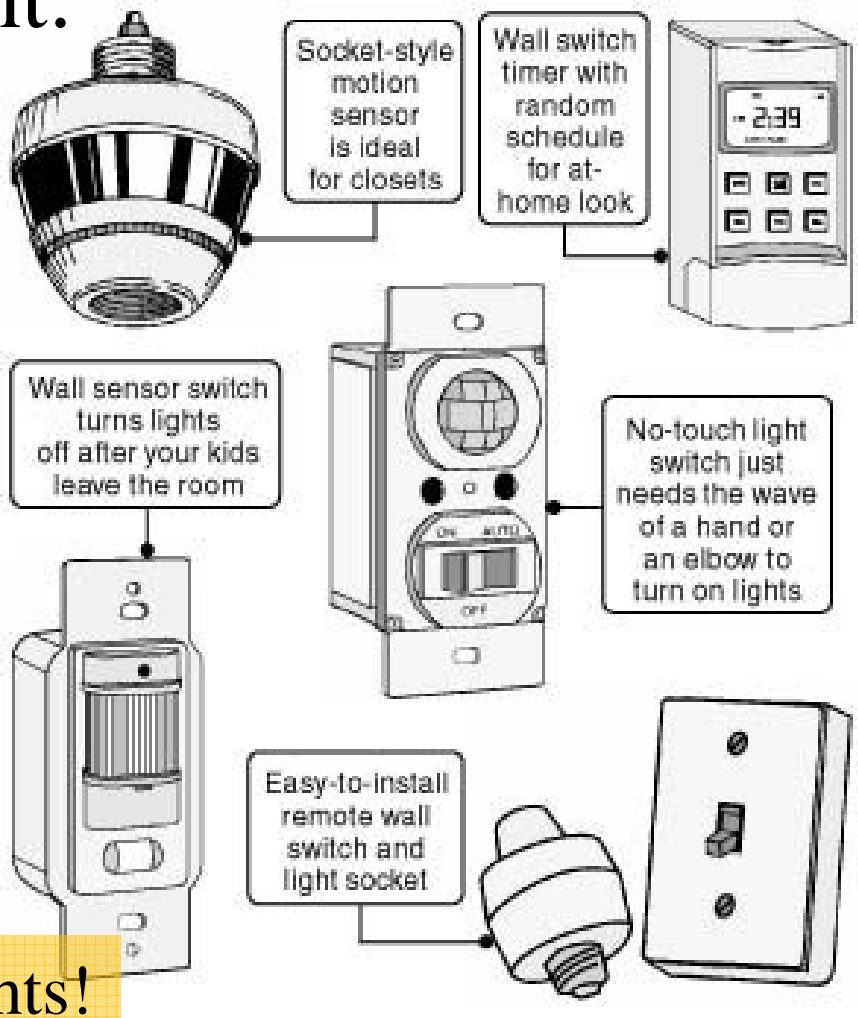
- What to light
  - Setting priorities
    - Give the space a focus
    - Consider the space as a whole
  - Analyse the space
- How best to light it
  - Using ambient, accent, and task lighting
- How much light
  - Depends on these factors: age, speed, accuracy, and the reflectance of the task
  - Also consider architectural and energy/environment

# Design Process

- Where to place the light
  - To avoid glare and veiling reflections
  - To emphasize or minimise surface texture
- What to light with
  - The lamp, the luminaire, and the controls
  - Choosing the lamp
    - Light distribution
    - Electric energy consumed
    - Colour rendering and color appearance
    - Maintenance costs

# Design Process

- Lighting control equipment:
  - Switches
  - Occupancy sensing
  - Scheduling (timeclocks)
  - Daylight dimming
  - Tuning
  - Preset dimming
  - Building management




Remember: switch off unnecessary lights!

# Lighting Calculations

- Predict general & ambient light levels
  - Rough estimation based on a Watts/sq.m method
    - Not very accurate, but good for prelim. planning
  - Lumen method calculations
    - Average illuminance
    - Good for general lighting
  - Point-by-point computer calculations
    - Most complicated, start from fundamental laws
    - Can be used for outdoor lighting

## Rough estimation based on a Watts/sq.m method

| **Average light level desired & typical application** | **Watts/sq.m of fluorescent, CFL or HID lights** | **Watts/sq.m of incandescent or halogen lamps** |
|---|---|---|
| 25-50 lux<br>Hotel corridors, stair towers | 1-2 | 3-7 |
| 50-100 lux<br>Office corridors, parking garages, theatres (house lights) | 2-4 | 7-10 |
| 100-200 lux<br>Building lobbies, waiting areas, malls, hotel function spaces | 4-8 | 10-20 |
| 200-500 lux<br>Office areas, classrooms, lecture halls, conference rooms, ambient retail lighting, workshops | 15-25 | Not recommended |
| 500-1000 lux<br>Grocery stores, laboratories, work areas, big box retail stores | 12-20 | Not recommended |

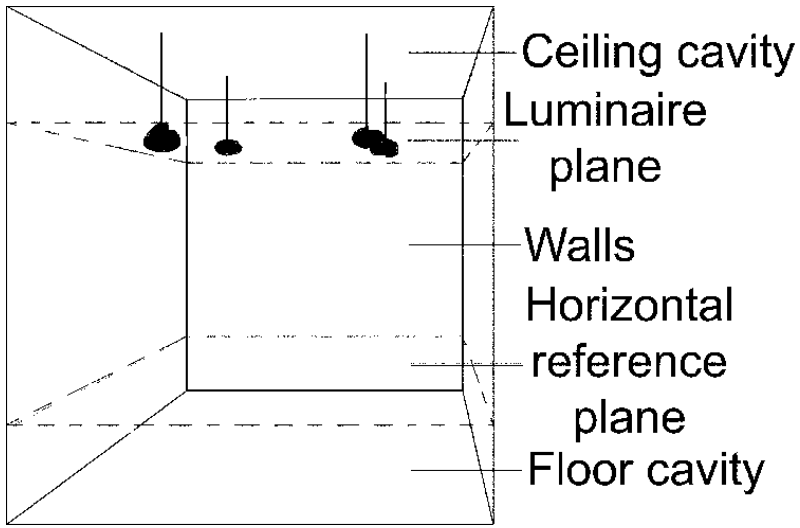
[Source: Adapted from Karlen and Benya, 2004. *Lighting Design Basics*]

# Lighting Calculations

- Lumen Method: average illuminance ($E$) is

$$E = \frac{F \times n \times N \times UF \times MF}{A}$$

  - $F$ = initial bare lamp luminous flux (lumens)
  - $n$ = number of lamps per luminaire
  - $N$ = number of luminaires
  - $UF$ = utilisation factor
  - $MF$ = maintenance factor
  - $A$ = area of the surface ($m^2$)

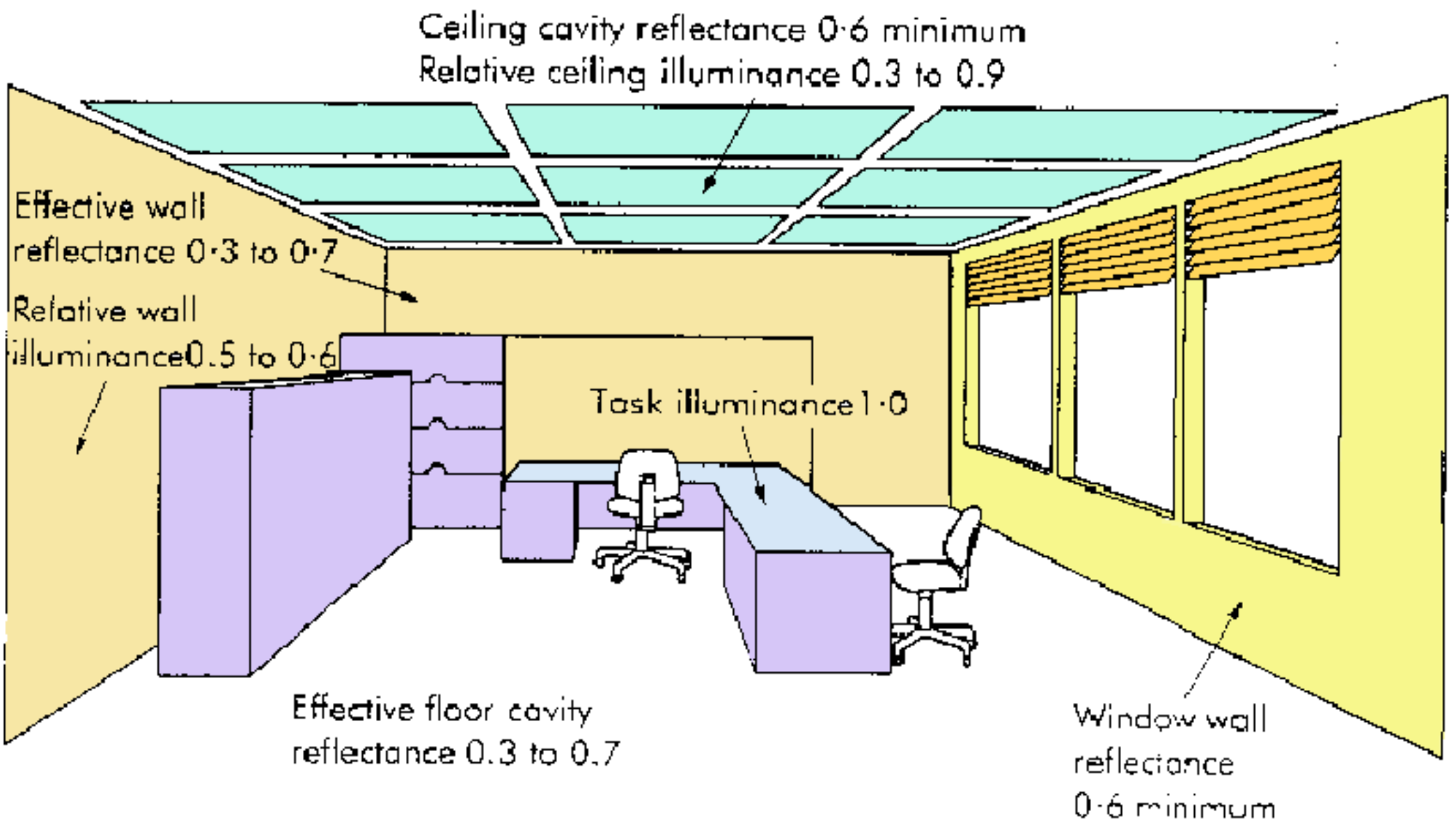


# Lighting Calculations

- Utilisation factor (*UF*)
  - Ratio of total flux received by the surface to the total lamp flux of the installation
  - UF tables are prepared for general lighting with regular arrays of luminaires, for 3 main room surfaces: ceiling cavity, walls, and floor cavity or horizontal reference plane
- Maximum spacing to height ratio ($SHR_{max}$)
  - Luminaire spacing shall not exceed the max. to ensure uniformity

# Lighting Calculations

- Room index (K): a measure of the proportions of the room, for rectangular room
  - $K = (L \times W)/(L + W)\ h_m$
    - L = length of the room
    - W = width of the room
    - $h_m$ = height of luminaire above horiz. reference plane
- Effective reflectances of ceiling, walls & floor
  - Cavity index (CI) = $(L \times W)/(L + W)\ h = K \times h_m/h$
    - h = depth of the cavity (ceiling or floor)
  - Determine effective reflectance from tables or formulae (see examples in *CIBSE or SLL Lighting Code*)




Recommended room reflectances & illuminance ratios

[Source: CIBSE Lighting Code]

# Lighting Calculations

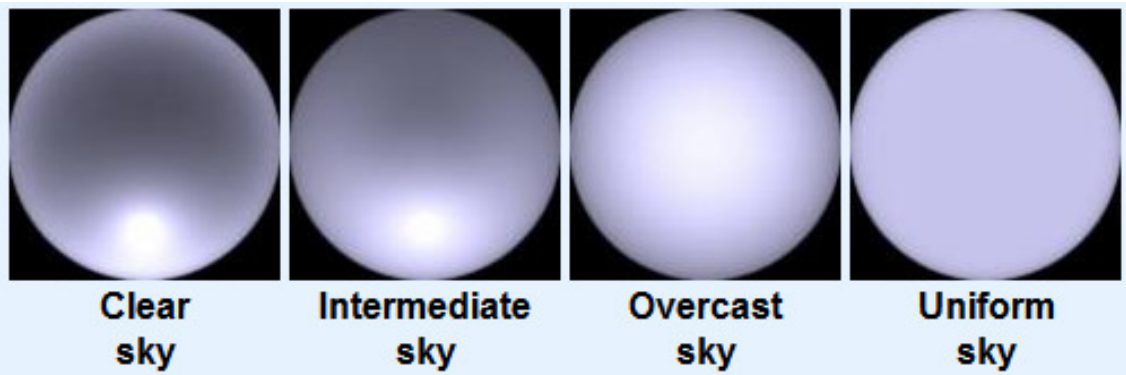
- Maintenance factor (*MF*)
  - Ratio of maintained illuminance to initial illuminance (losses for lamp lumen maintenance)
  - *MF* = LLMF x LSF x LMF x RSMF
    - Lamp lumen maintenance factor (LLMF)
    - Lamp survival factor (LSF)
    - Luminaire maintenance factor (LMF)
    - Room surface maintenance factor (RSMF)
  - See *CIBSE Code of Lighting* for description

# Lighting Calculations

- Lumen method: calculation procedure
  - Calculate room index K, floor/ceiling cavity index
  - Calculate effective reflectances of ceiling cavity, walls & floor cavity
  - Determine utilisation factor (*UF*) from manufacturer's data, using the room index and effective reflectances
  - Determine maintenance factor (*MF*)
  - Obtain nos. of luminaires required (using lumen method)
  - Determine a suitable layout
  - Check that the geometric mean spacing-to-height ratio
  - Check the layout does not exceed $SHR_{max}$
  - Calculate illuminance achieved by the final layout

# Daylighting Design

- The source of daylight is the SUN
  - A black body radiator at temperature 6000 K
    - Scattering of the radiation produces blue sky
    - Direct sunlight, scattered & reflected daylight
  - Sky conditions
    - Overcast sky and uniform sky
      - Luminance of all parts of the sky is the same



# Daylighting Design

- Benefits of daylighting
  - Improve life-cycle cost
    - Energy & cost saving on electric lights
  - Increase user productivity
    - Increase user satisfaction & visual comfort
  - Reduce greenhouse gas emissions
    - Reduce energy use and slow fossil fuel depletion
  - Reduce operating costs
    - Savings from less electric lights & cooling energy

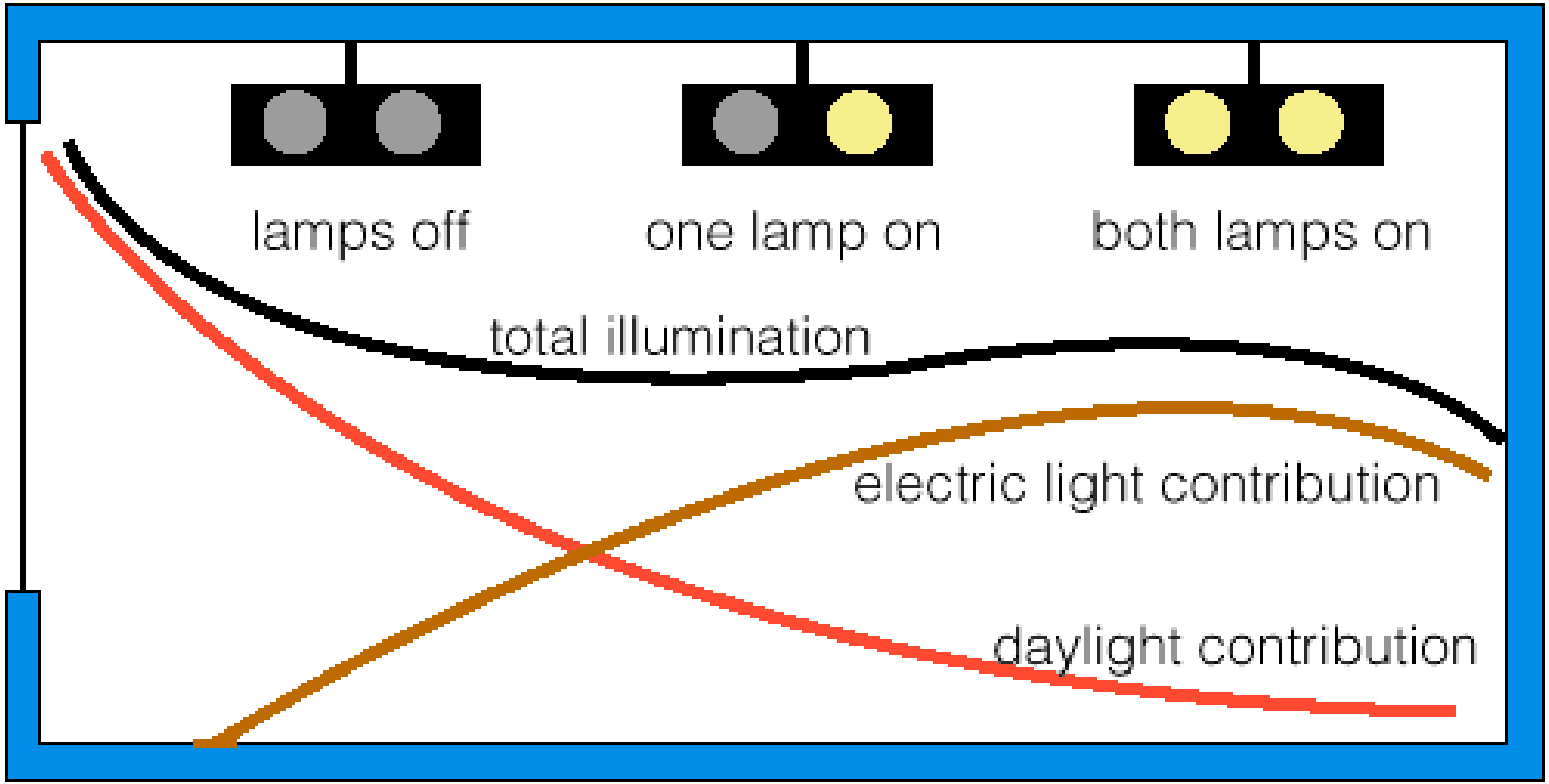
(Video: Energy 101: Daylighting (2:44), www.youtube.com/watch?v=-7EG4d-W4W8)

# Daylighting Design

- Daylighting concepts
  - Require integration of many disciplines including architectural, building services, and lighting
  - Major design issues:
    - Distribution – controlled daylight into building interior
    - Glare – excessive brightness contrast within field of view
    - Veiling reflections – of high brightness light sources off specular (shiny) surfaces
    - Variety – to create “visual interest”

# Daylighting Design

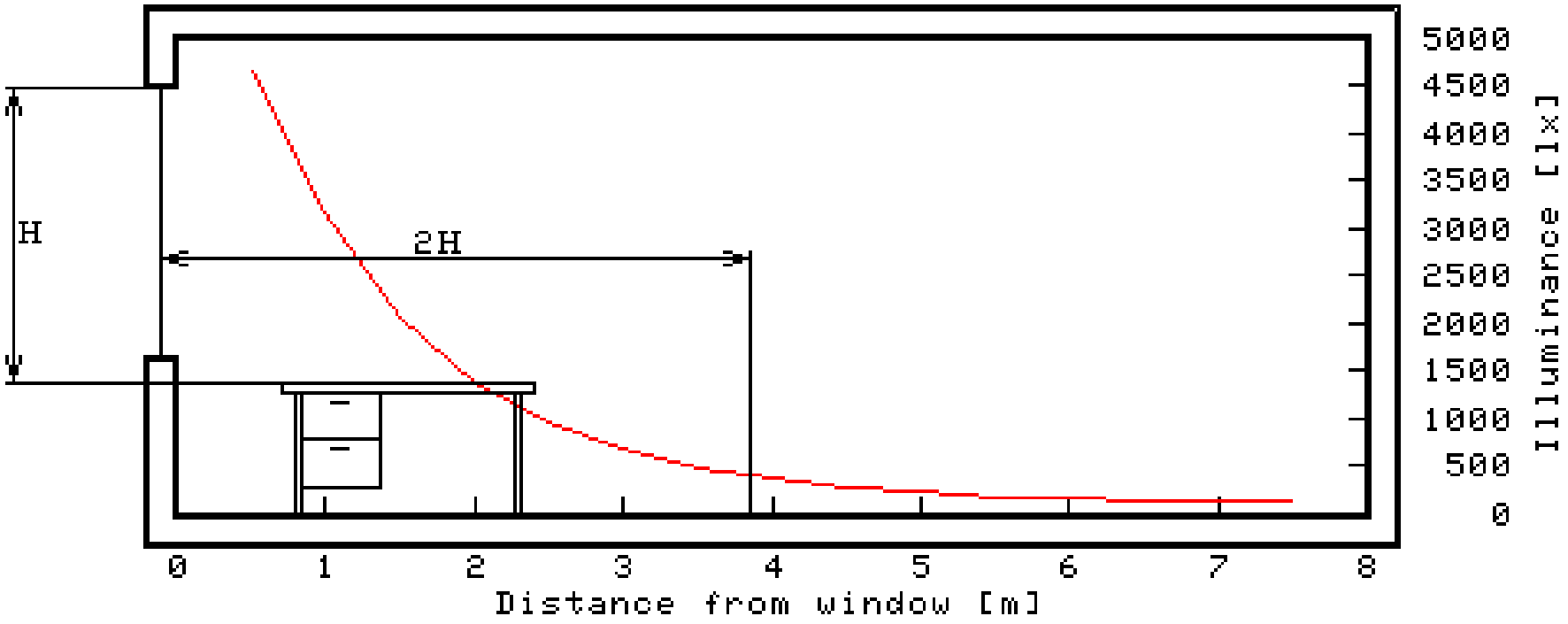
- Daylighting concepts (cont'd)
  - Good daylighting requires attention to both qualitative and quantitative aspects of design
  - To be effective, daylighting must be integrated with electric lighting design
    - Lighting controls for energy saving, e.g.
      - Switching controls – on/off controls
      - Stepped controls
      - Dimming controls
  - Adverse effects of sunlight
    - Solar heat gain, glare and UV damage to works of art




Daylight contribution and lamps control

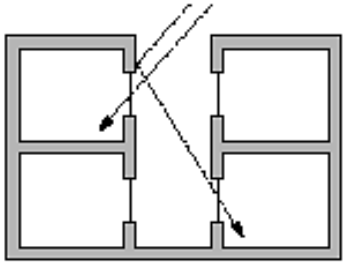
# Daylighting Design

- Design activities
  - Siting the building (orient for best solar exposure)
  - Massing the building (surfaces toward the sun)
  - Choosing fenestration (windows)
  - Shading façade & windows from unwanted sun
  - Adding shading devices to allow occupant to control over daylight
  - Design electric lighting for energy saving

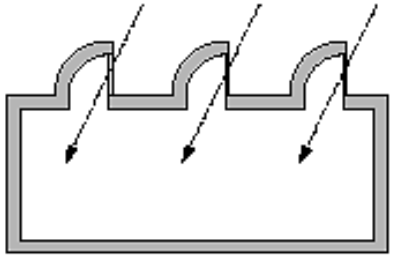



# Daylighting design guideline

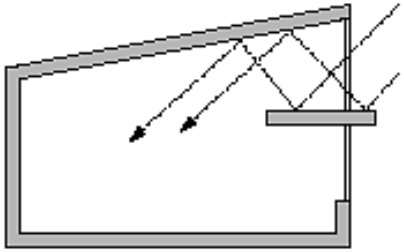
[Source: London Metropolian University]



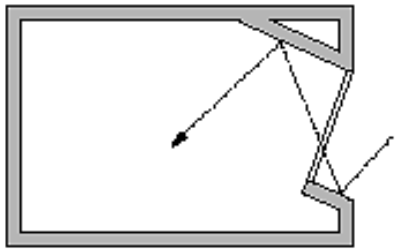
Light well



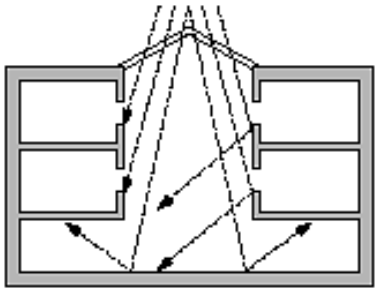
Roof monitor



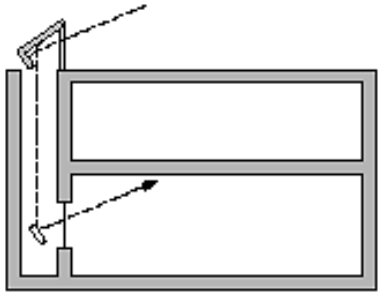
Light shelf



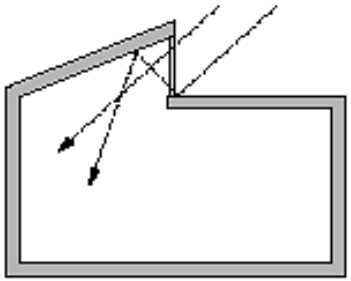
External reflectors



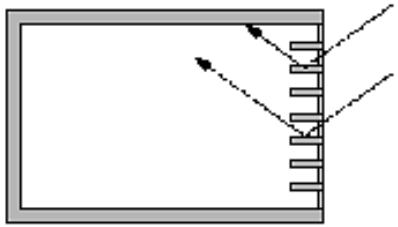
Atrium



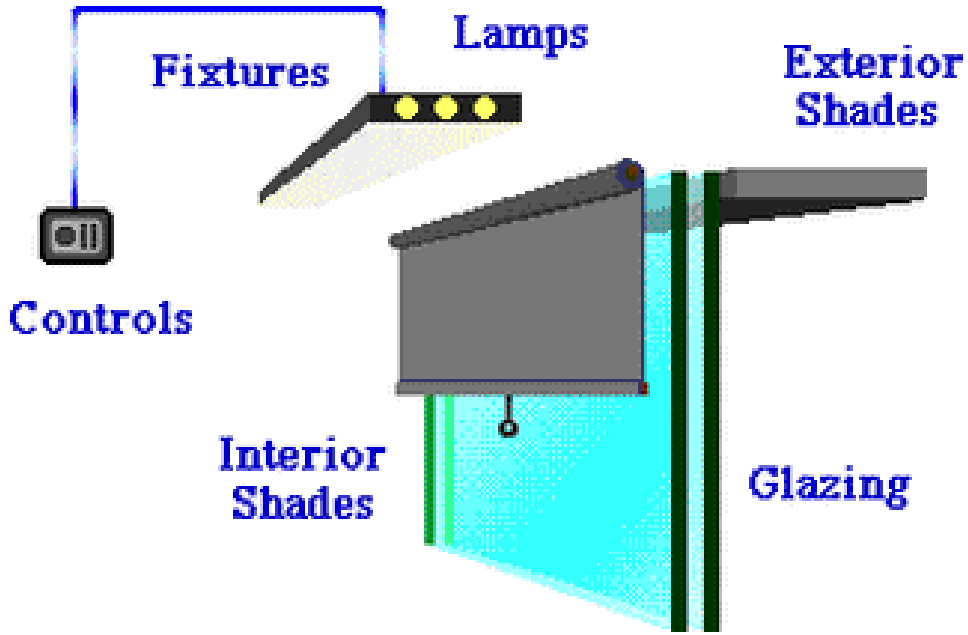
Light duct



Clerestory



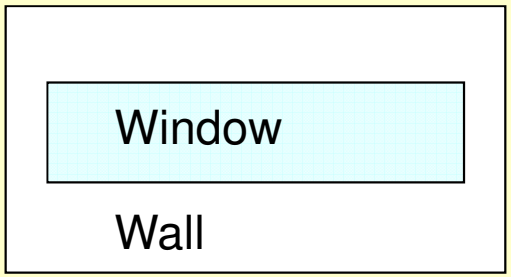
Reflective blinds



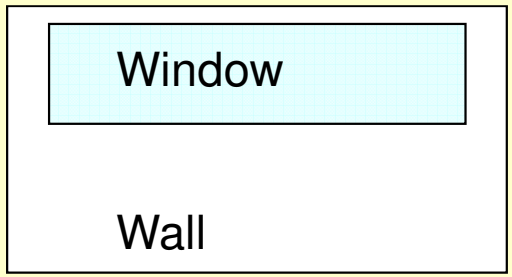

Daylighting design and control

Which of the following window patterns will give better daylighting in a room? (the total area of window glazing is the same in each case)

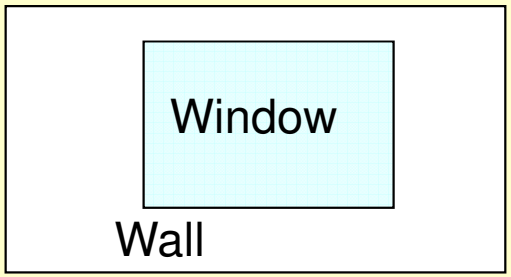
A.



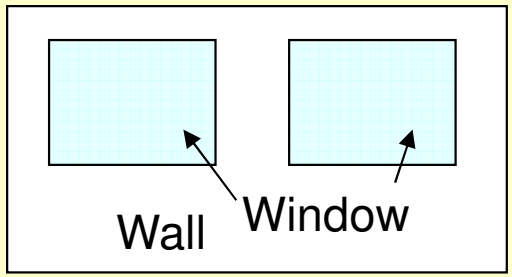

B.




C.




D.

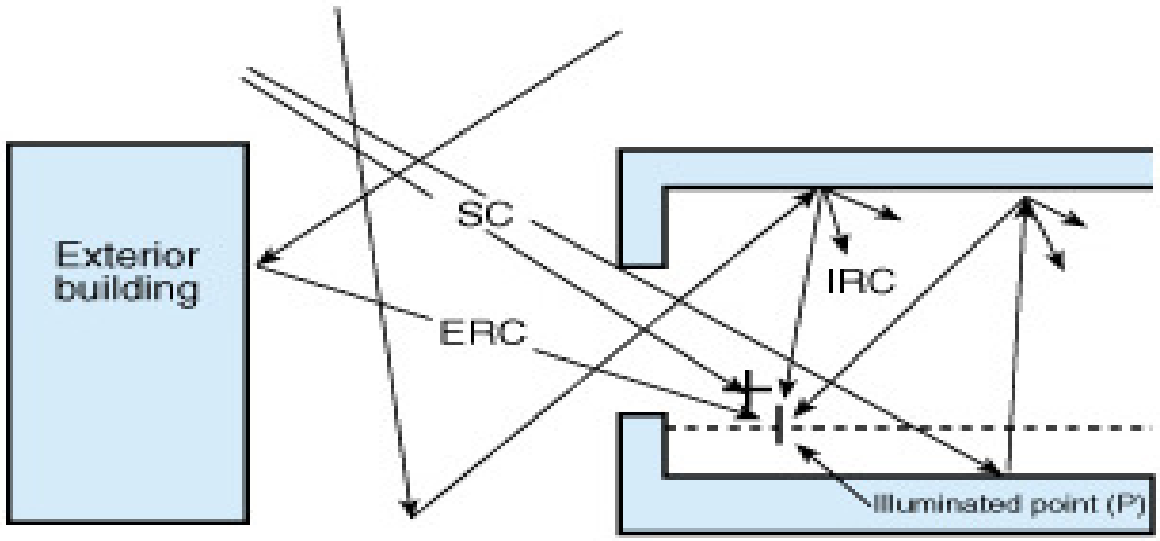


# Daylighting Design

- Daylight factor (DF)
  - An indication of amount of daylight at a point
  - DF = ratio of daylight illuminance to the instantaneous illuminance outside the building from a complete hemisphere of sky (excluding direct sunlight)
  - To assess a given window configuration
    - For simple design, some tables, diagrams, nomograms & formulae can be used to calculate DF
    - For complicated situation, computer program is used

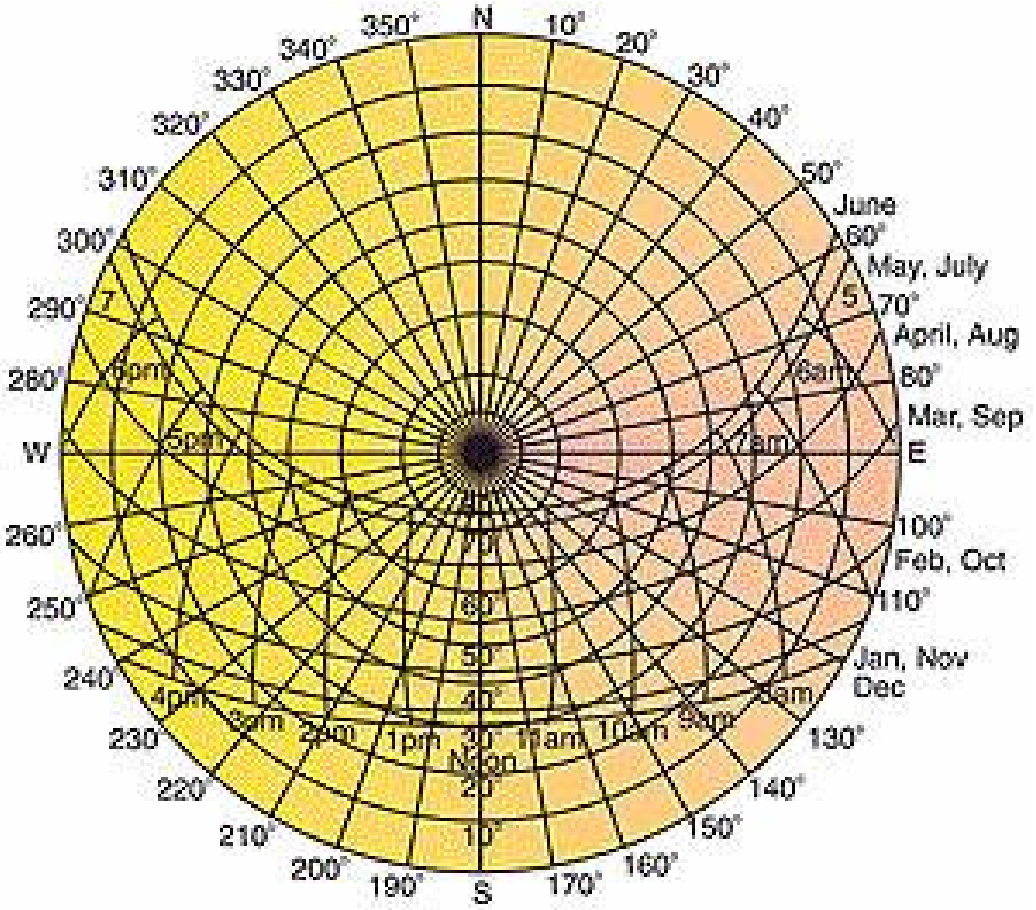
# Daylighting Design

- Daylight factor (DF) determination
  - DF = SC + ERC + IRC
    - SC: sky component
    - ERC: externally reflected component
    - IRC: internally reflected component

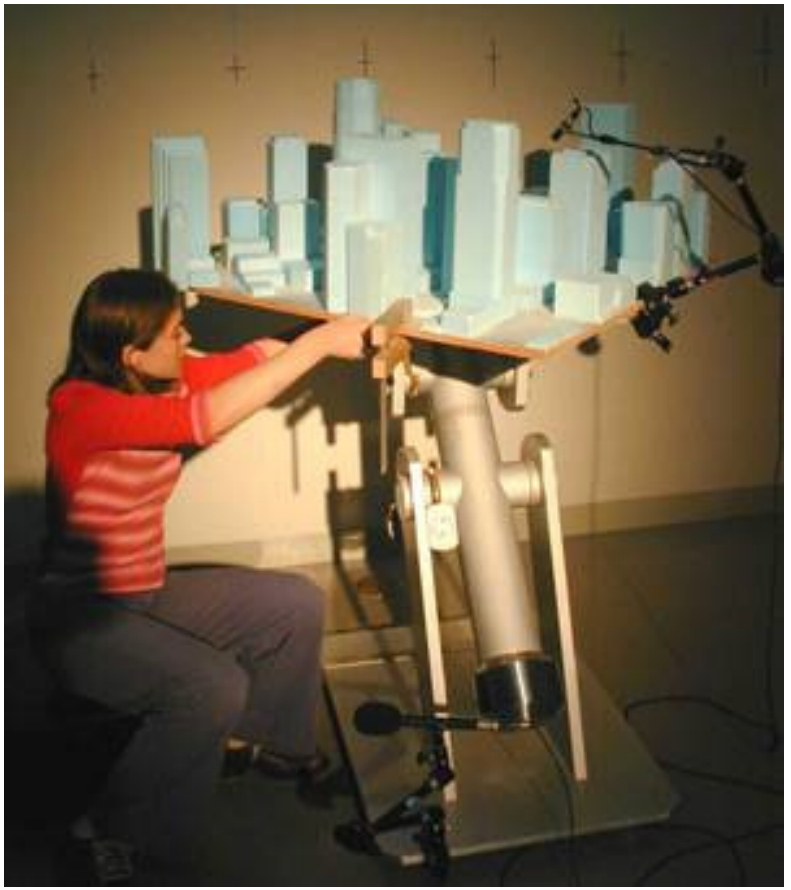


# Daylighting Design

- Sky glare
  - Greater glare from sky if:
    - Dark interior decorations & furniture of low reflectance
    - A large area of bright sky in the visual field
  - Reduce sky glare by:
    - More artificial lights or brighter interior
    - Solar control (e.g. screens, louvres, blinds, curtains)
  - Balance between glare control and use of daylight
    - By using light shelves, prismatic glazing & hologram

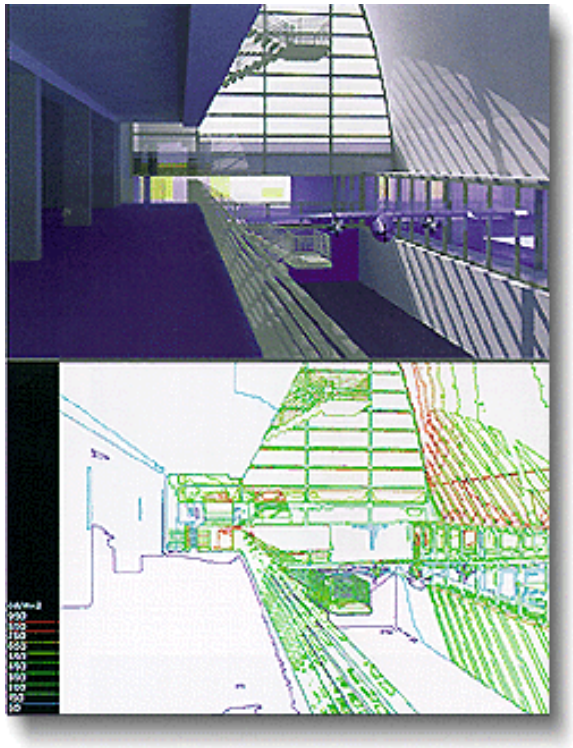



Sunpath diagram



Heliodon studies

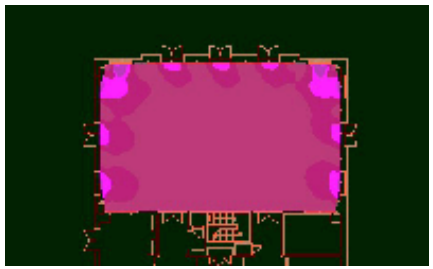
Daylighting design and analysis tools

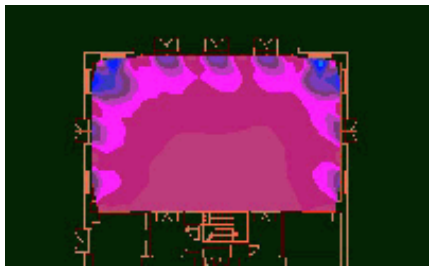


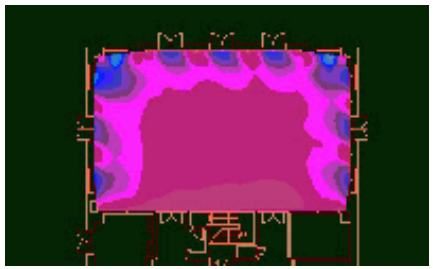
Daylight simulation using RADIANCE

9:00am 12:00 noon 3:00pm

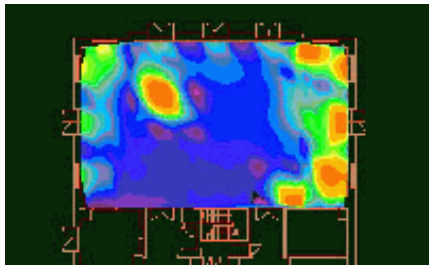
Cloudy:

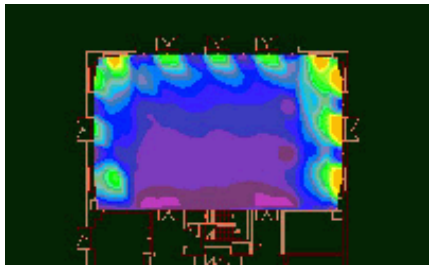


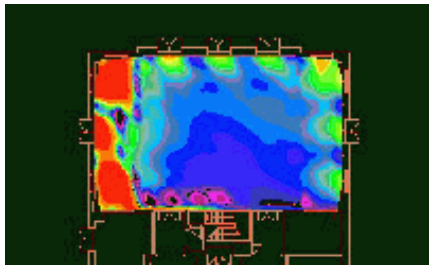




Sunny:





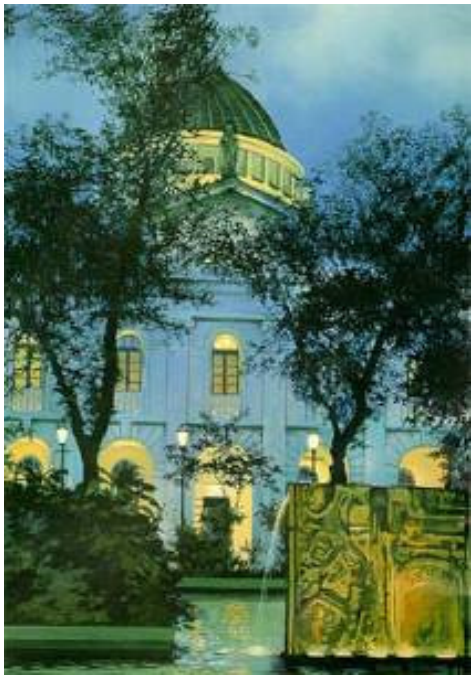


Daylighting analysis

# Exterior & Emergency Lighting

- Exterior lighting (or outdoor lighting)
  - Floodlighting: flooding a surface with light
    - Achieve illumination on vertical or horizontal surfaces
  - Design issues
    - Appearance during daytime
    - Glare from the installation
    - Decorative lighting
    - Lighting for specific outdoor activities e.g. sports
  - Applications:
    - Building façade, sports, road lighting

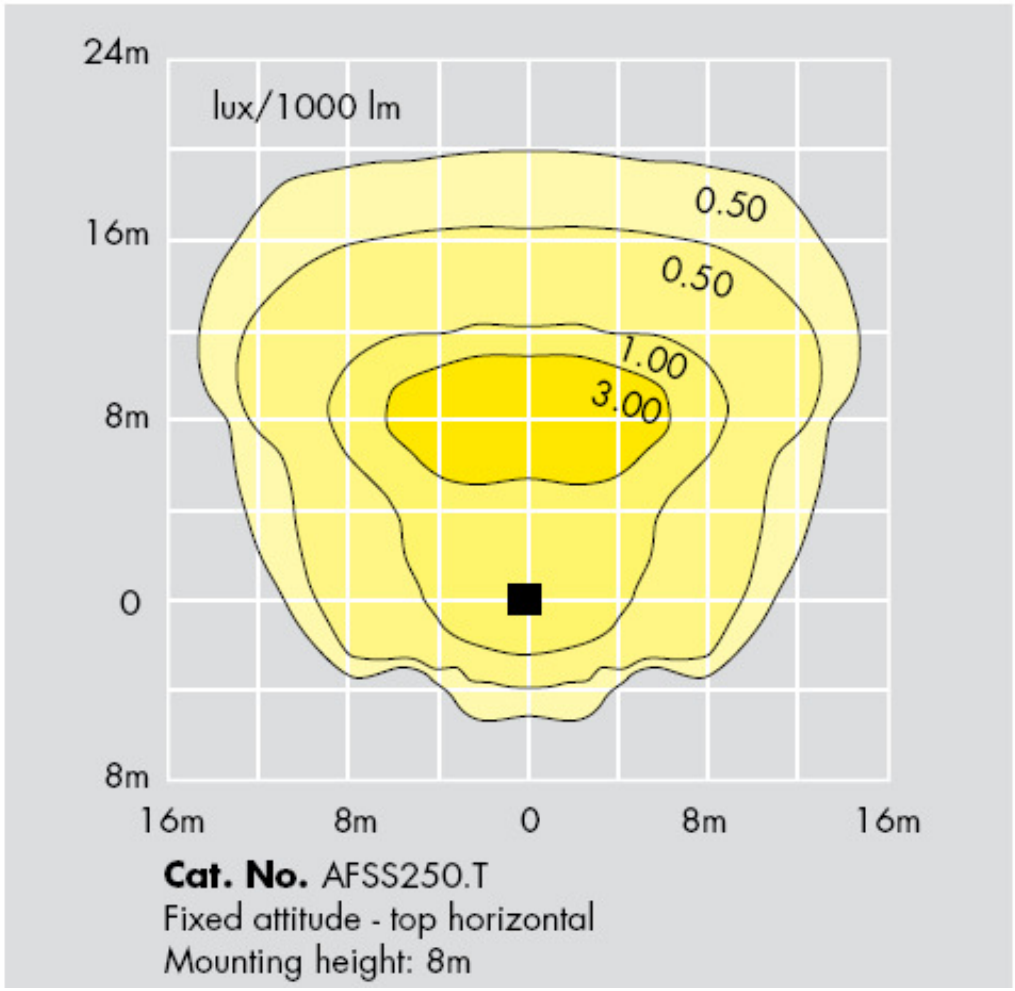
# Legislative Council Building at daytime and night-time

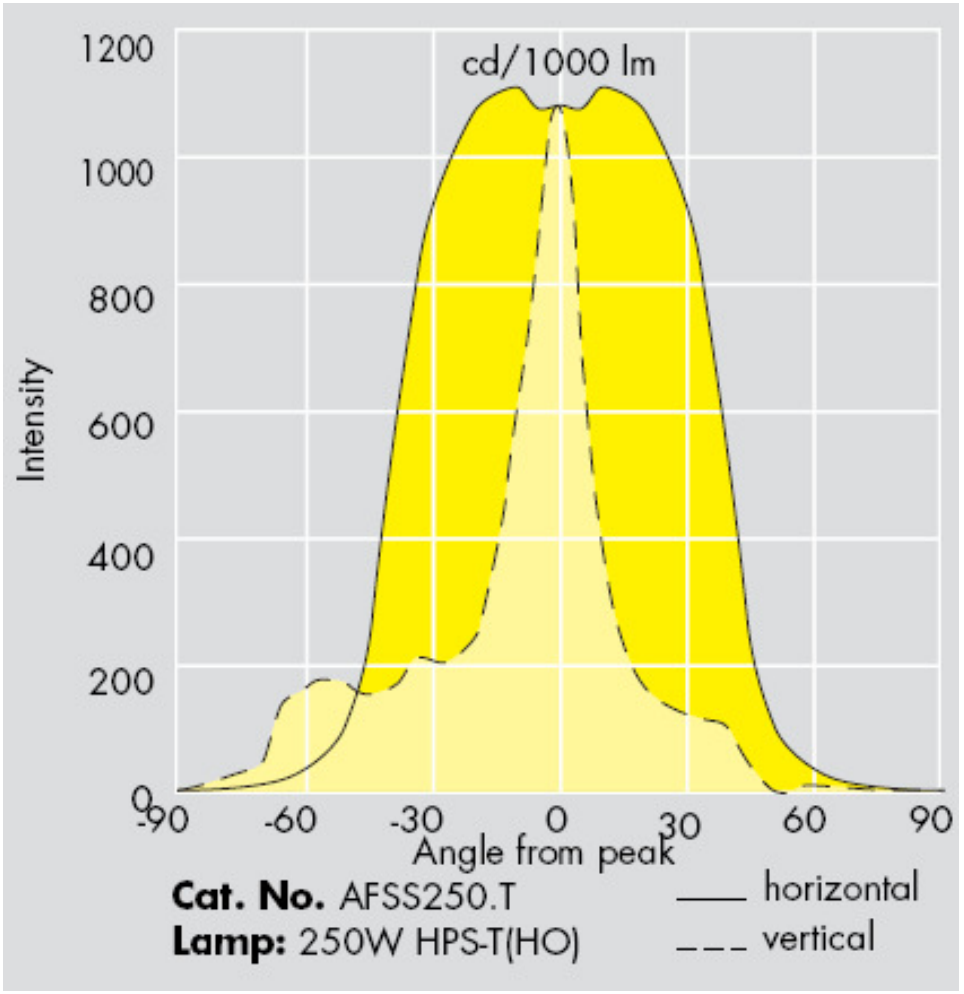


# Exterior & Emergency Lighting

- Exterior lighting (cont'd)
  - Floodlighting a building
    - Requires a sense of drama and colour
    - Select locations for putting floodlights & aiming points
      - Peak intensity & beam angle
    - Usually all the beams from each floodlight shall overlap
      - Uniformity ratio (max : average) about 5:1
  - Floodlighting a horizontal open area
    - Use isolux diagram (horizontal illumination plots)
      - Or isocandela and zonal flux diagram
    - Calculate using inverse square law and cosine law

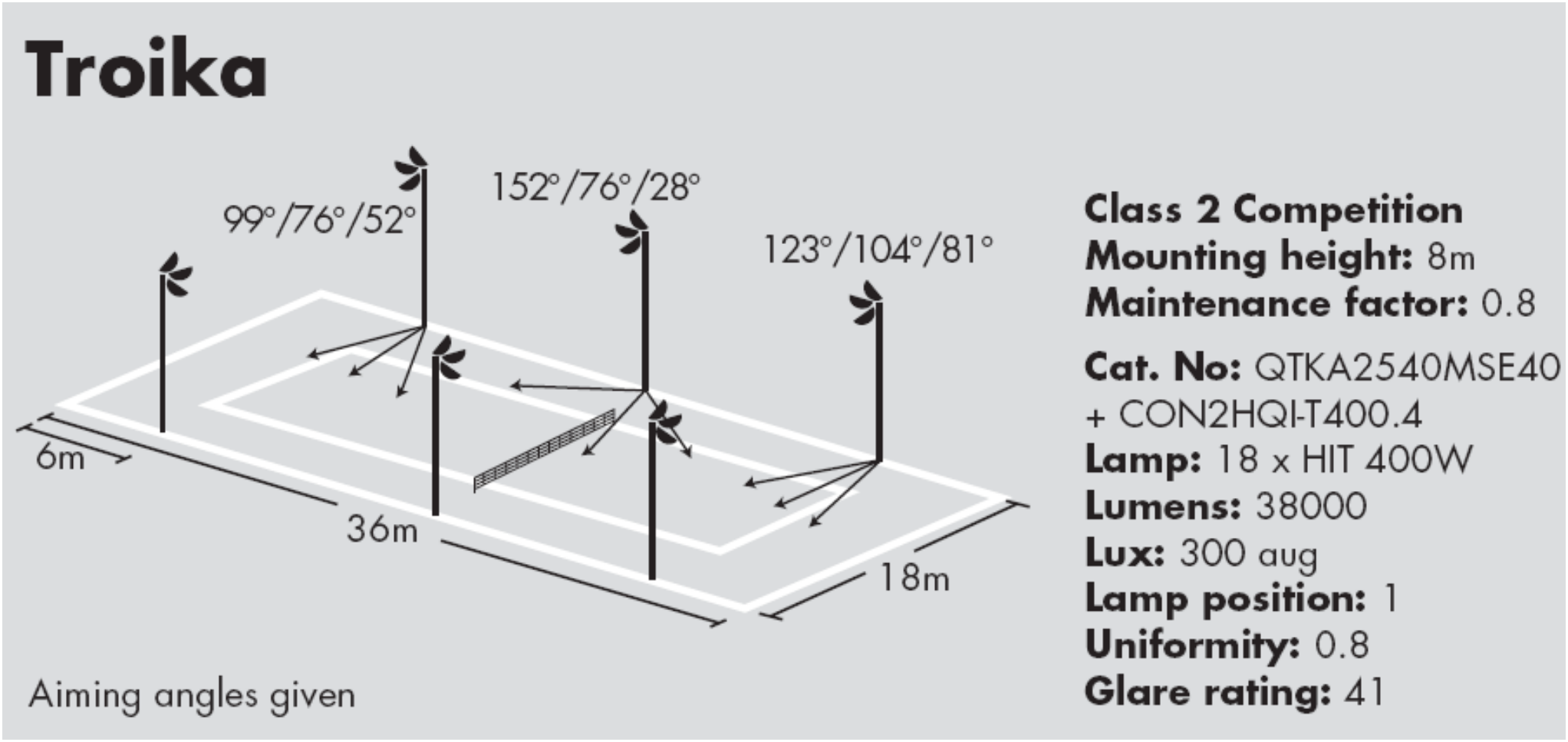
# Floodlight Data




Floodlight design data

[Source: Thorn Lighting, UK]




Sample floodlight design for a tennis court

[Source: Thorn Lighting, UK]

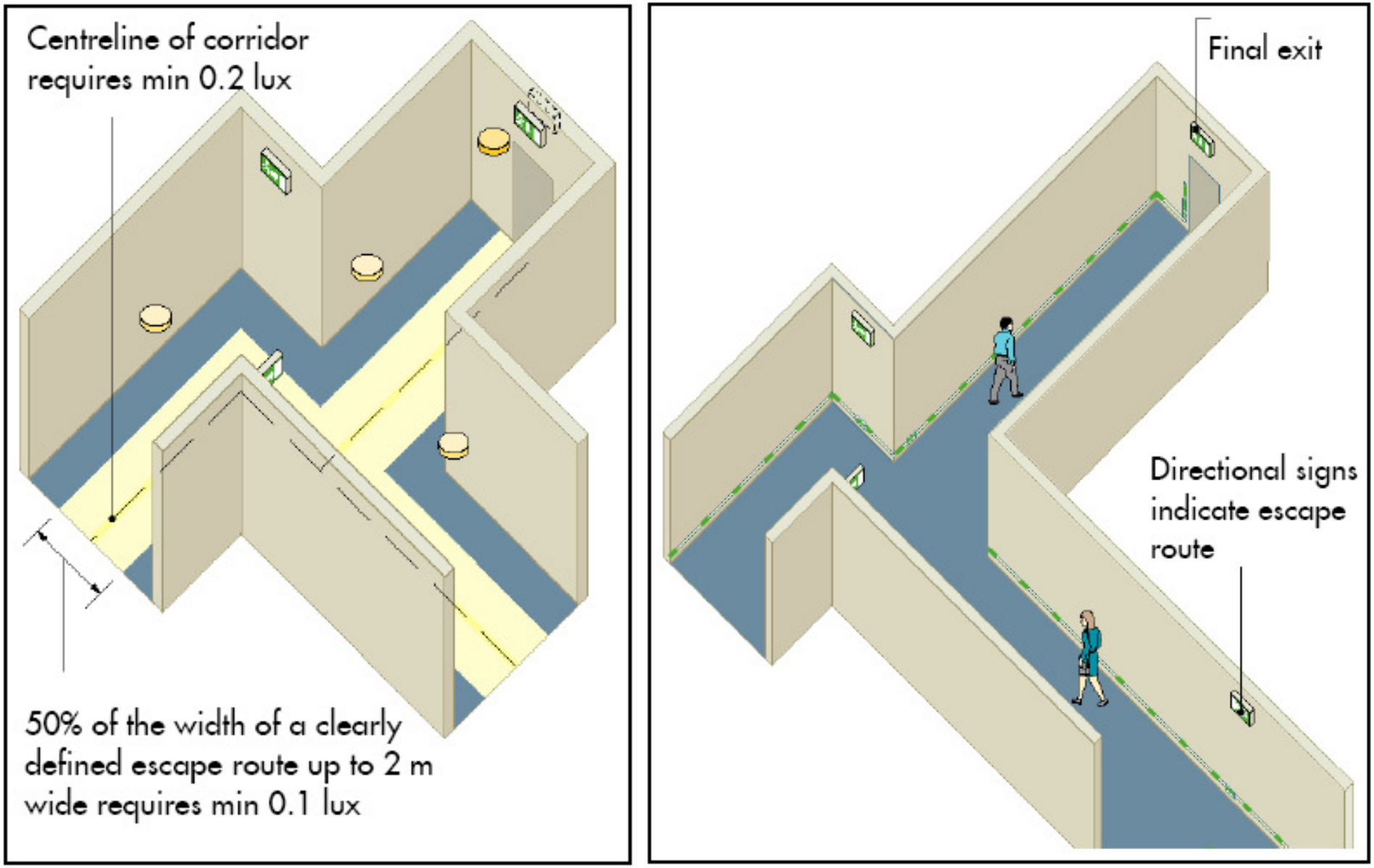
# Exterior & Emergency Lighting

- Emergency lighting
  - Main purpose
    - Guide people quickly & safely from the building
    - Enable specific tasks to be completed
    - Avoid panic
    - Restore confidence

  - Design shall follow the relevant regulations (e.g. fire services) & standards/codes (e.g. BS5266)
  - Also, exit signs & signage lights

# Exterior & Emergency Lighting

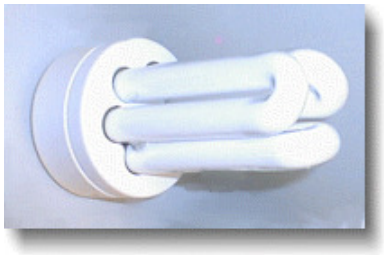
- Emergency lighting (cont'd)
  - Three types:
    - Emergency lighting (when normal lighting fails)
    - Escape lighting (assure means of escape)
      - Escape route, open area (anti-panic), high risk task area
    - Standby lighting
  - Design requirements
    - Illumination level = 1 lux
    - Must be in operation within 5 sec, last for 1 or 2 hours
    - Correct positioning & power supply
    - Maintained and non-maintained operation



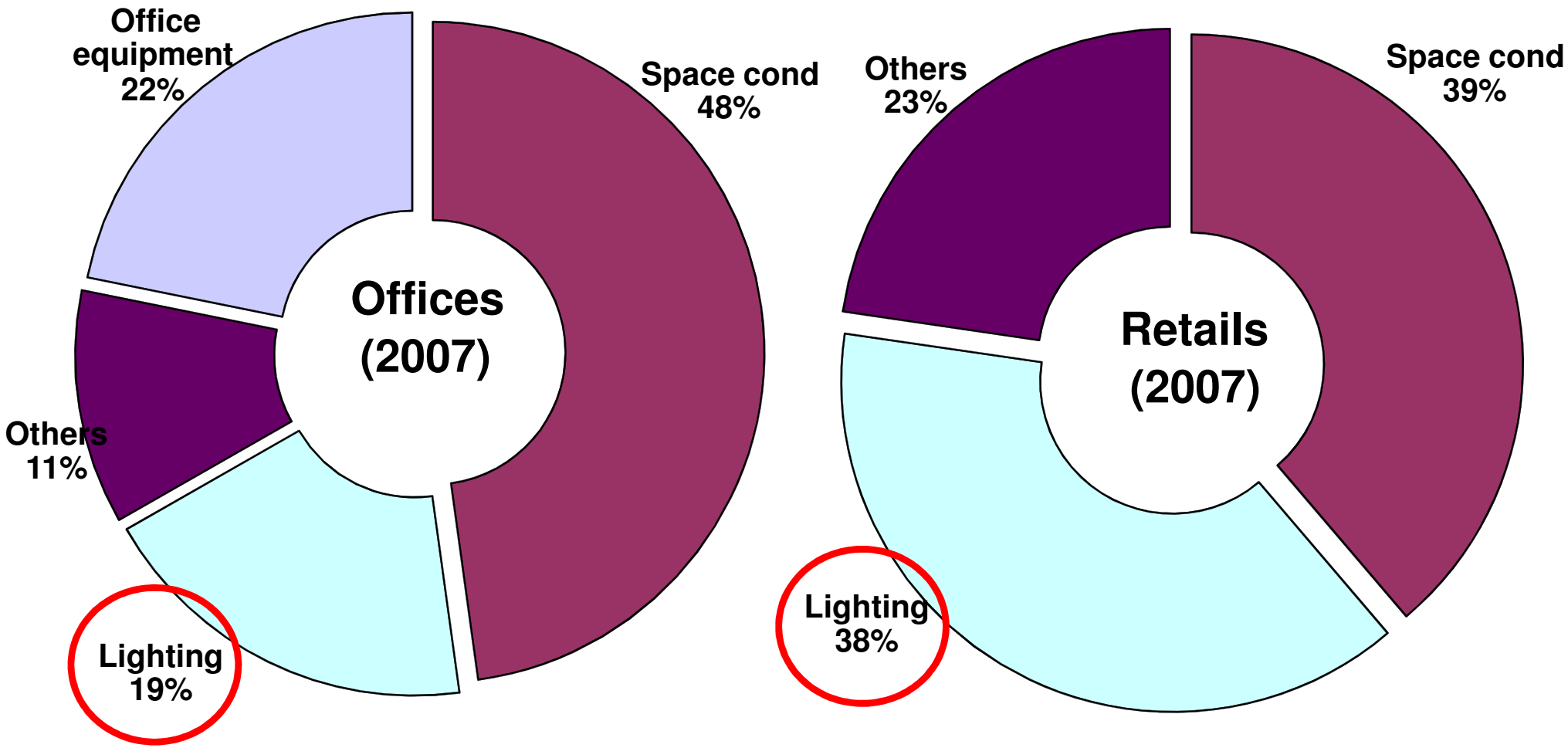

Emergency lighting & signage on escape route

[Source: Thorn Lighting, UK]

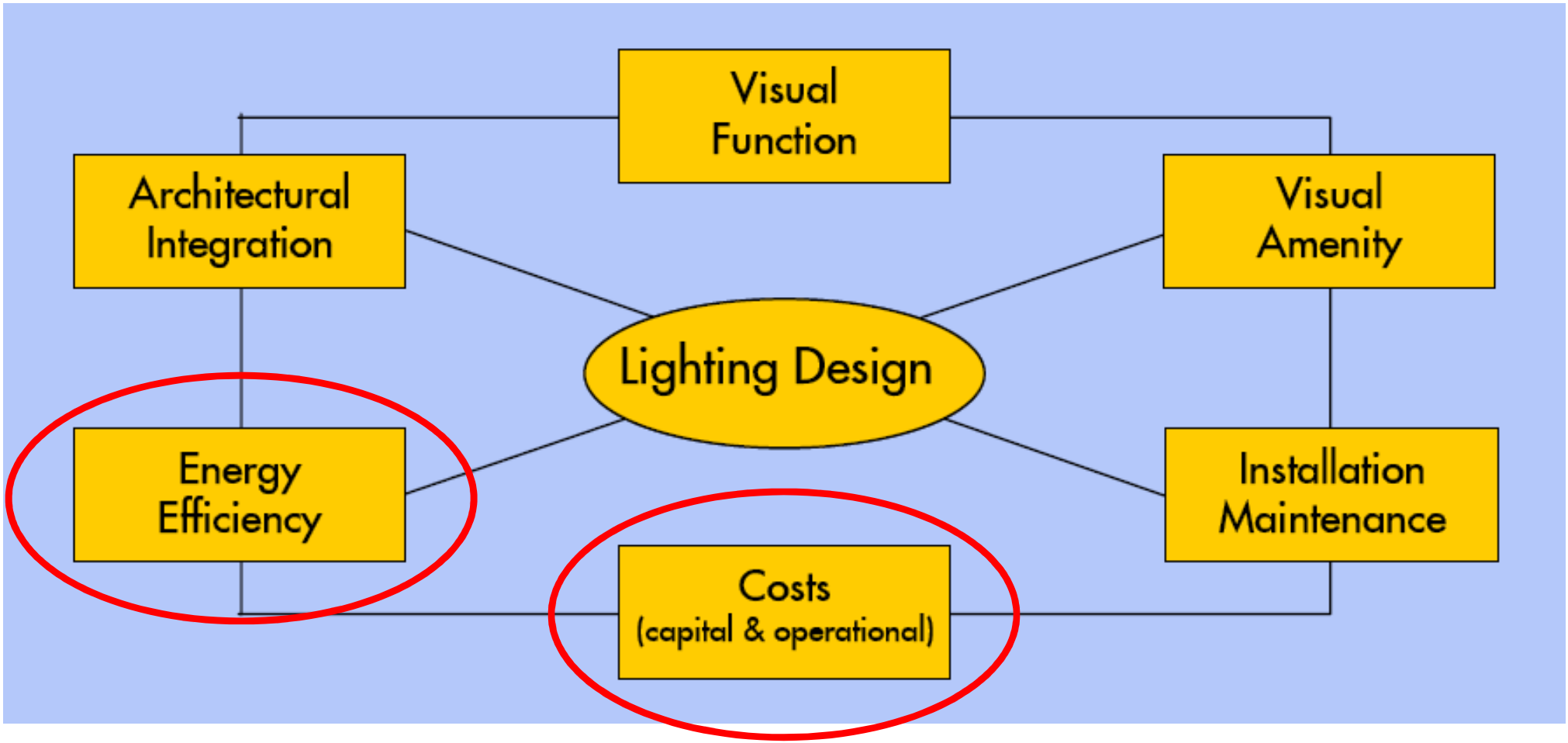
# Energy Efficient Lighting



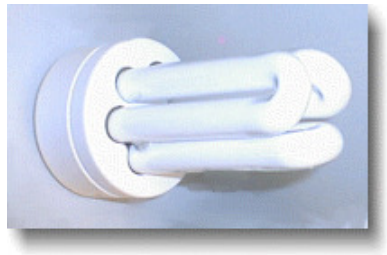
- Lighting consumes a great share of energy use in buildings
  - Consumption of electricity
  - Indirectly affect the cooling systems (due to heat)
  - Operating & maintenance costs
- The need to manage the lighting energy
  - Prevent energy wastage & save energy costs
  - Ensure good quality visual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




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


Visual Function
Architectural Integration
Visual Amenity
Lighting Design
Energy Efficiency
Installation Maintenance
Costs
(capital & operational)

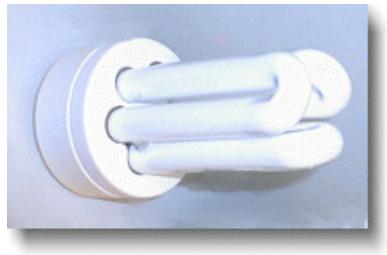
# Energy Efficient Lighting



- HK building energy codes (by EMSD)*
  - Code of Practice for Energy Efficiency of Building Services Installations (2012)
  - Code of Practice for Energy Efficiency of Lighting Installations (2007)
  - Guidelines on Energy Efficiency of Lighting Installations (2007)
- Energy Efficiency Labelling Scheme (HK)*
  - Compact fluorescent lamps, LED

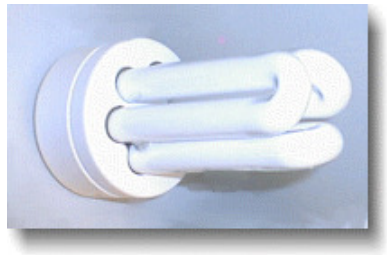
(* See also www.beeo.emsd.gov.hk and www.energylabel.emsd.gov.hk)

# Energy Efficient Lighting



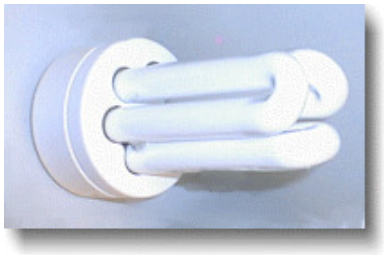
- **EMSD lighting code requirements *****
  - Minimum allowable luminous efficacy
    - Choose appropriate type of lamps
  - Maximum allowable lamp controlgear loss
    - Energy efficient ballast for fluorescent lamps
  - Maximum allowable lighting power density (LPD)
    - Design suitable amount and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

# Energy Efficient Lighting

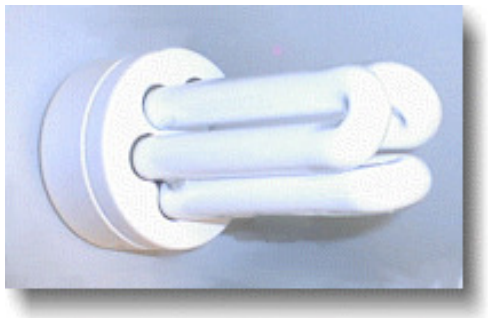


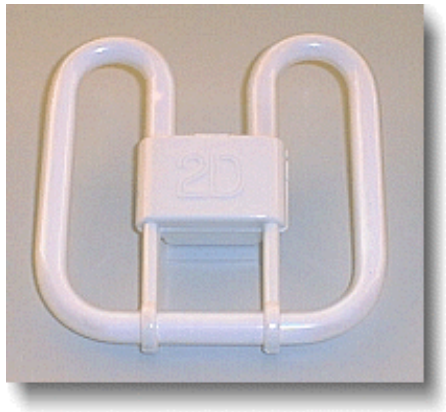
- Lighting efficiency
  - Lighting hardware efficiency
    - Includes light source, control gear, optical system, luminaire housing, etc.
  - Lighting installation efficiency
    - Largely dependent on the choice, location, and setting up (e.g. aiming) of the lighting hardware
  - Usage efficiency
 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

# Energy Efficient Lighting

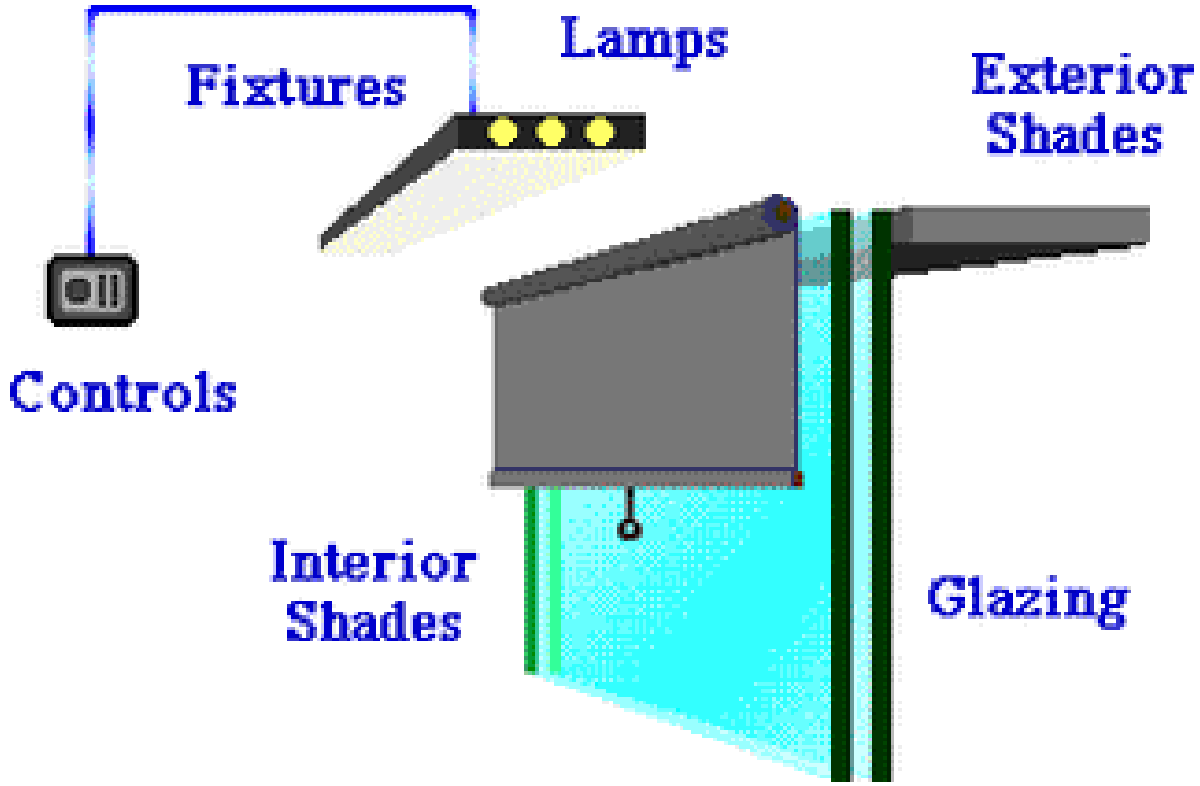


- Principles of efficient lighting design
  - Meet target light levels
  - Efficiently produce light
    - Use natural light or efficient light sources
  - Efficiently deliver light
    - Balance efficiency with aesthetics, lighting quality, visual comfort
  - Automatically control lighting operation





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




Lighting controls and interactions with windows

Energy efficient lighting design strategies

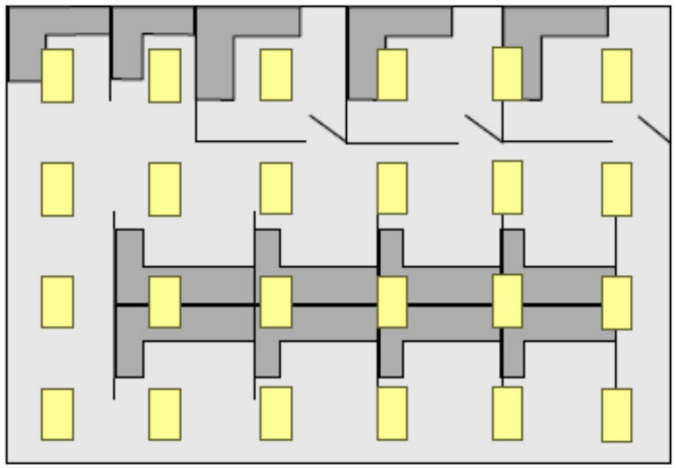
# Integrated controls for lighting luminaires

**Vertically Integrated Design**

Personal Control Features:

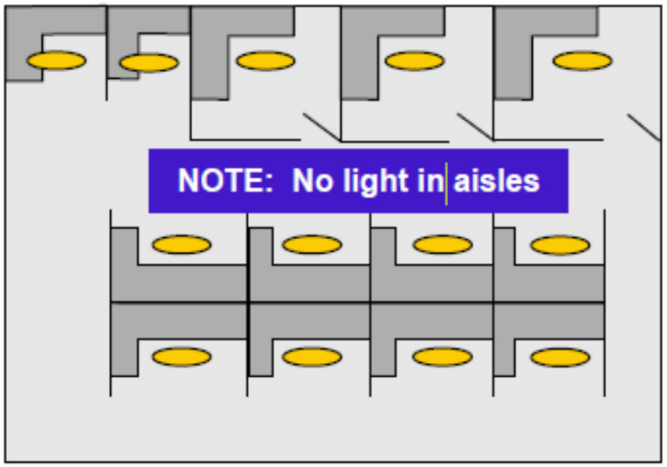
- Direct/ Indirect Pendant Luminaire
- Task light: 2T8-PS Dimmable EB (64W)/ 100%-5%
- Ambient light: 1T8-PS EB (31W)/ ON/OFF only
- Photocell Sensor built in
- Occupancy Sensor built in

Comparison to a Standard Troffer Layout:



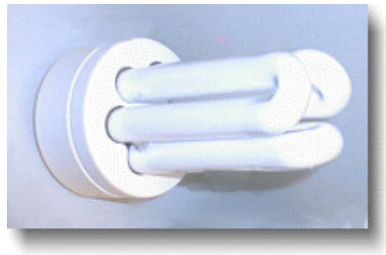
- 2x4 Parabolics
- **24 Luminaires**
- 72 lamps
- **~2300 watts**

- Direct Indirect
- **13 Luminaires**
- 39 lamps
- **~1250 watts**



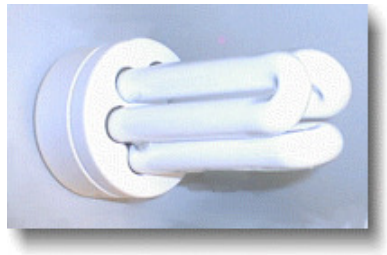

(Source: http://lightingdesignlab.com)

# Energy Efficient Lighting



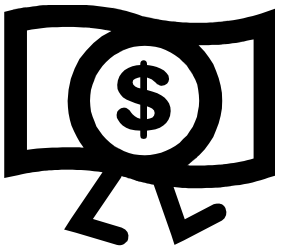
- Recommendations by IESNA
  - Design lighting for expected activity (higher light levels for "working“, lower levels for "walking")
  - Design with more effective fixtures & fenestration
  - Use efficient light sources (higher lumen per watt output)
  - Use more efficient fixtures
  - Use thermal controlled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

# Energy Efficient Lighting



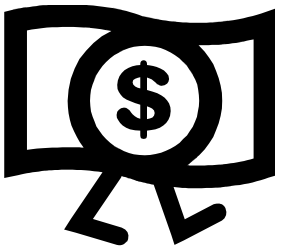
- Recommendations by IESNA (cont'd)
  - Use efficient incandescent lamps
  - Turn off lights when not needed
  - Control window brightness
  - Use daylighting as practicable
  - Keep lighting equipment clean and in good working condition
  - Post instructions covering operation & maintenance

# Lighting Economics



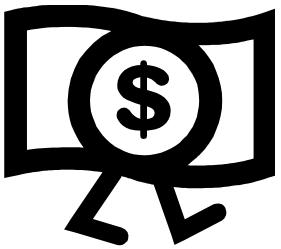
- Lighting system life cycle costs
  - Initial costs
    - Equipment, installation, wiring, HVAC
  - Energy costs
    - Direct lighting costs
      - Energy use (kWh) = lighting power (kW) x operating time (hr)
    - Lighting-related HVAC (indirect) costs
      - Lighting heats up the space & require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

# Lighting Economics

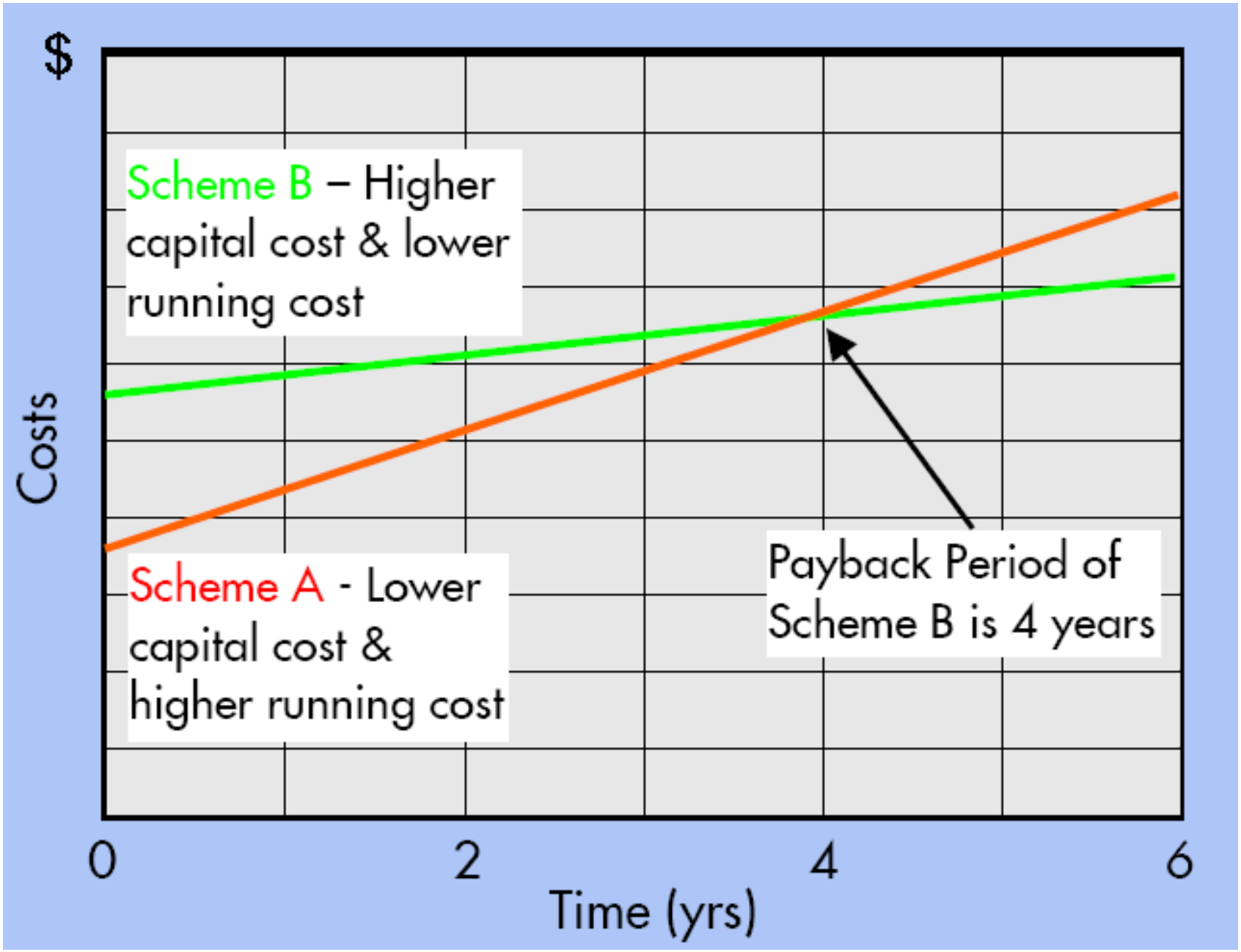


- Lighting maintenance
  - Relamping
  - Reballasting
  - Cleaning
  - Miscellaneous maintenance
    - e.g. replace lenses or louvers, damaged parts
  - Insurance & property taxes
  - Depreciation

# Lighting Economics



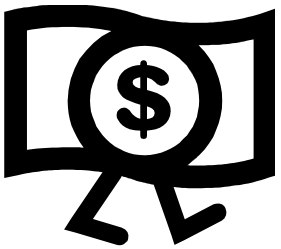
- Investment costs
  - Luminaire, including control gear (where applicable)
  - Lighting control systems (e.g. dimmers)
  - Mounting accessories
  - Electrical wiring
  - Installation costs
- Running costs
  - Energy
  - Lamp replacement
  - Maintenance
  - Amortization (disposal)




Payback period of lighting scheme

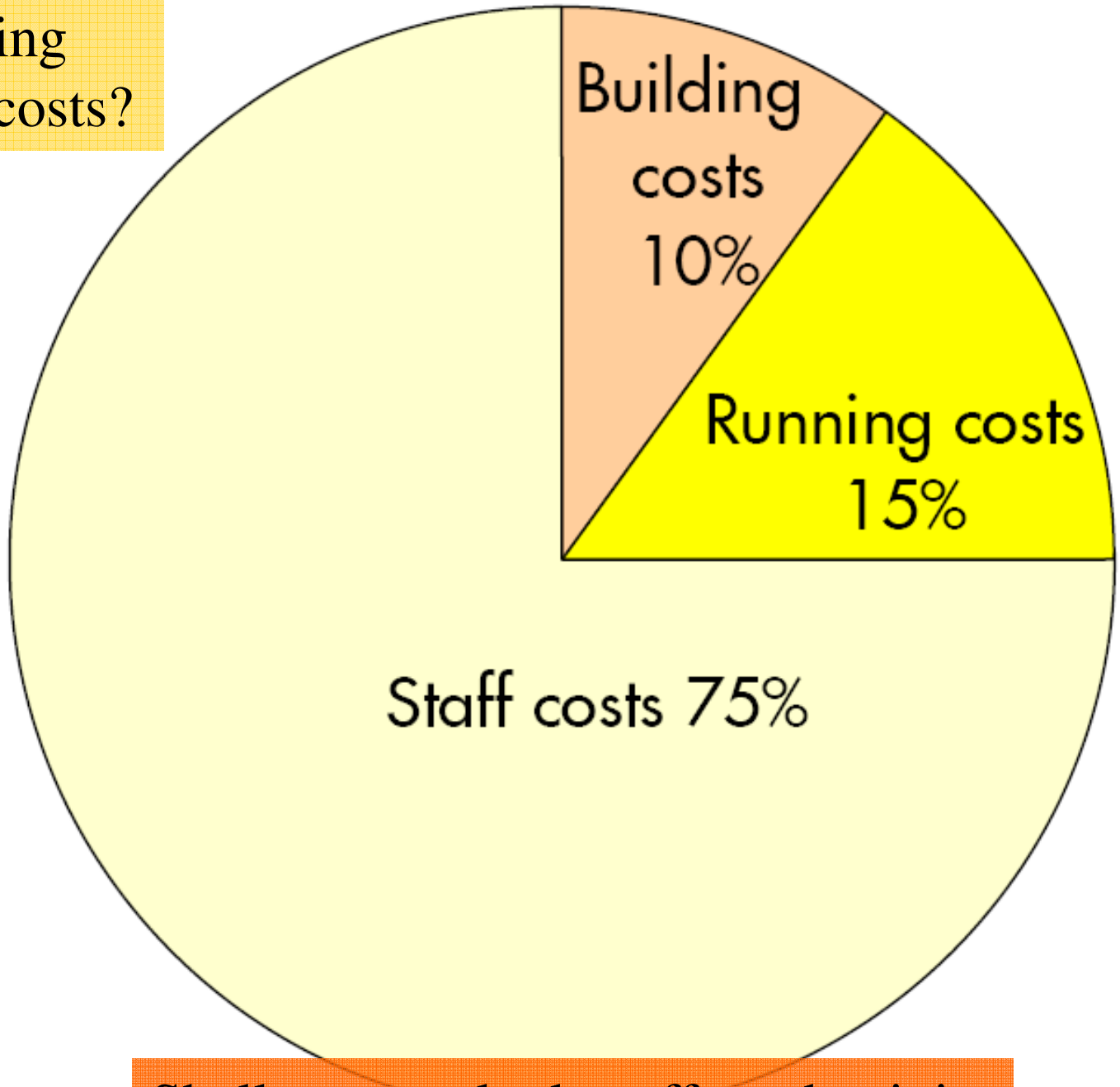
[Source: Thorn Lighting]

# Lighting Economics



- Economic analysis
  - 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

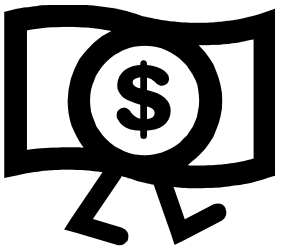
Q: Do you know how lighting affects staff costs?




Shall not overlook staff productivity

[Source: Thorn Lighting]

# Lighting Economics



- 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