78053

# SUSTAINABLE LIGHTING DESIGN & TECHNOLOGY

Organised by: BCA ACADEMY
of the built environment

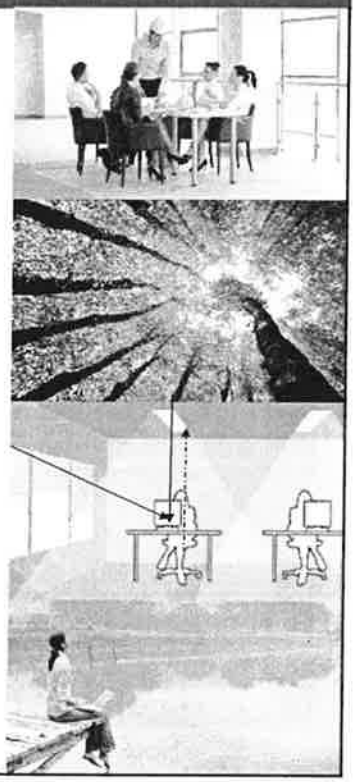
200 Braddell Road
Singapore 579700
Tel: 6248 9999
Website: http://www.bcaa.edu.sg
Email:bca_academy@bca.gov.sg

# Sustainable Lighting Design & Technology

## GMFP- GMP

## BCA Academy

## 1. General Principles of Lighting, Units and Terminologies

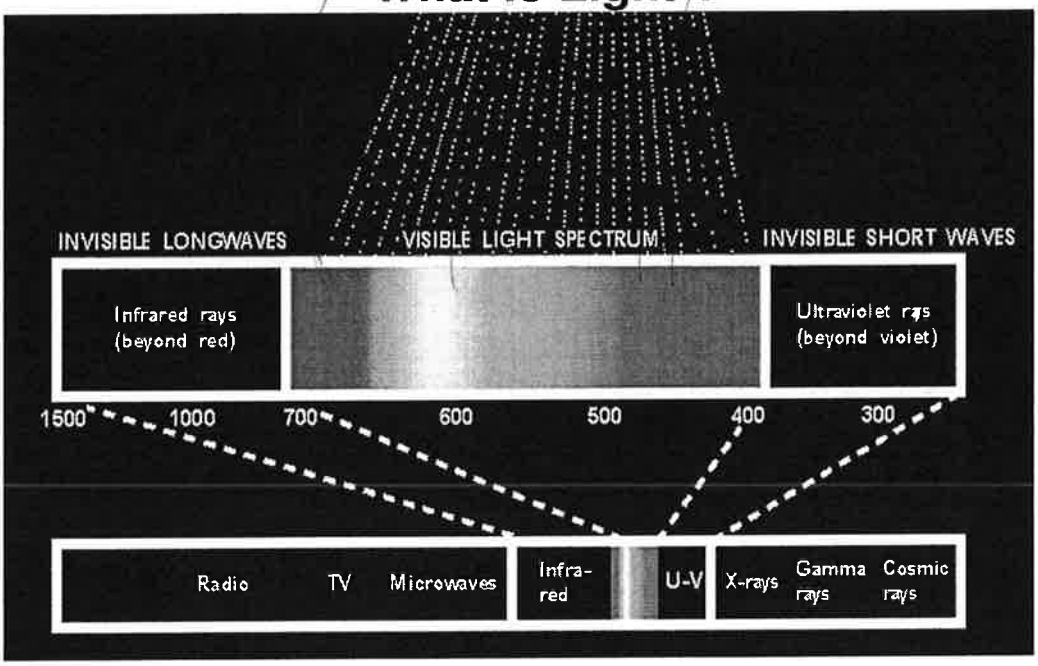




## Key things to know for GMP-GMFP

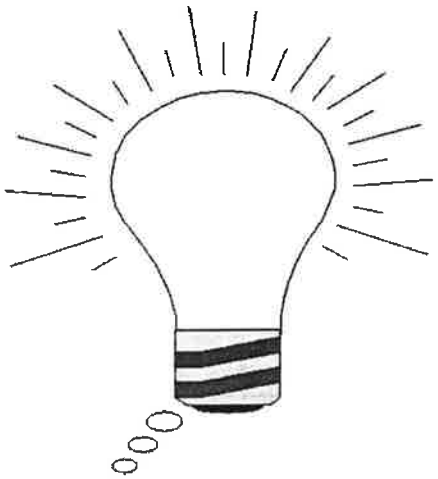
- Light Output
- Efficacy
- Illuminance
- Intensity
- Luminance
- Colour temperature
- Colour Rendering Index
- Life time
- Power Density in Watts / $M^2$

# What is Light ?






# Light Output (= Luminous flux)

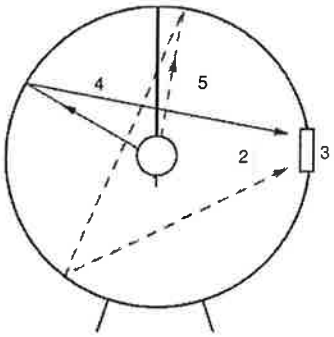


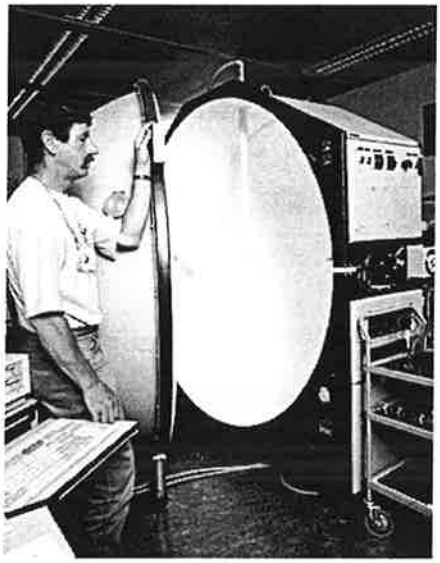
Total quantity of light (= energy in the wave band of 400-700 NM) emitted by a light source per second

Unit Lumens

# Measuring Light Output

1. Source
2. Opaque screen
3. Photocell
4. Light ray (reflected once)
5. Light ray (reflected twice)





# Examples of Light output

| Lamp | Power (W) | Light output (Lumens) |
|---|---|---|
| Incandescent Lamp | 75W | 900 |
| Compact Fluorescent Lamp (CFL) | 15W | 900 |
| Fluorescent tube Cool Daylight | 36W | 2500 |
| Fluorescent tube Tri-Phosphor | 36W | 3200 |
| Light Emitting Diode (at Performance level) | 1-5W | 30-600 |
| High Pressure Sodium Tubular | HPS 400W | 56000 |

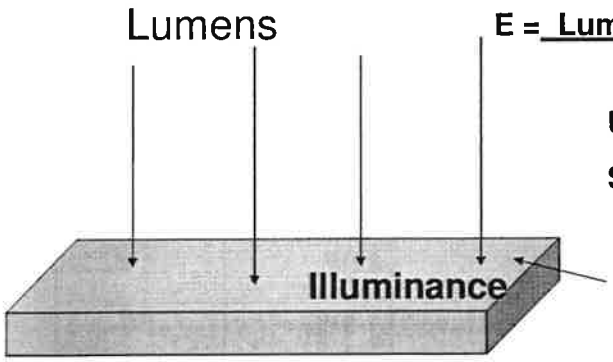
# Examples of Efficacy

| Lamp | Power (W) | Light output (Lumens) | Efficacy = Lumens per W) |
|---|---|---|---|
| Incandescent Lamp | 75W | 900 | 12 |
| Compact Fluorescent Lamp (CFL) | 15W | 900 | 60 |
| 4-ft Fluorescent tube Cool Daylight | 36W | 2500 | 69 |
| 4-ft Fluorescent tube Tri-Phosphor | 36W | 3200 | 89 |
| Light Emitting Diode (at Performance level) | 1-5W | 30-600 | 30-120 |
| High Pressure Sodium | HPS 400W | 56000 | 140 |



# Illuminance (= Lighting Level)

Luminous flux incident on a surface divided by area of that surface




$$E = \frac{\text{Lumens} \times (\text{certain Factors}^*)}{\text{Area}}$$

**Unit : Lux**

**Symbol : E**

Area( $m^2$ )

* These factors will vary with the room dimensions, type of fitting used, reflectance of walls & ceiling, height of fitting suspension etc

# Measuring Illuminance

Lux meter









# The human eye

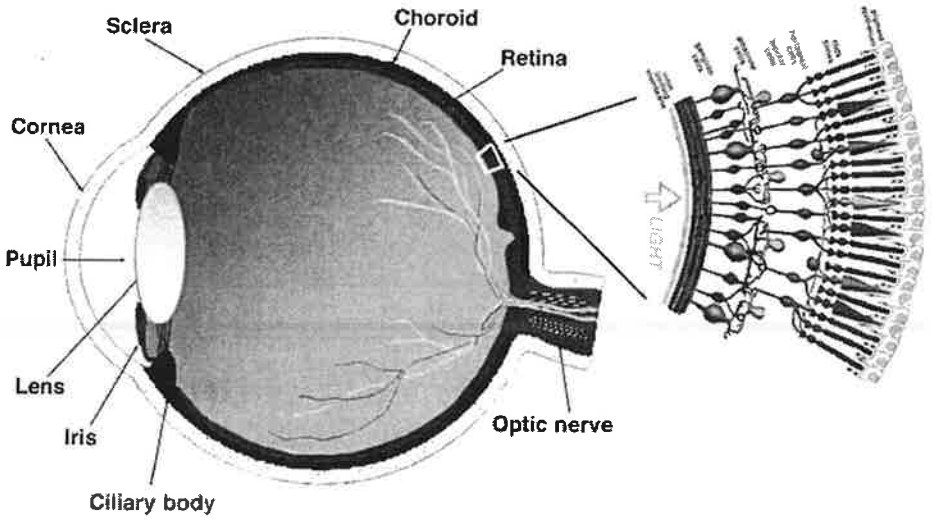
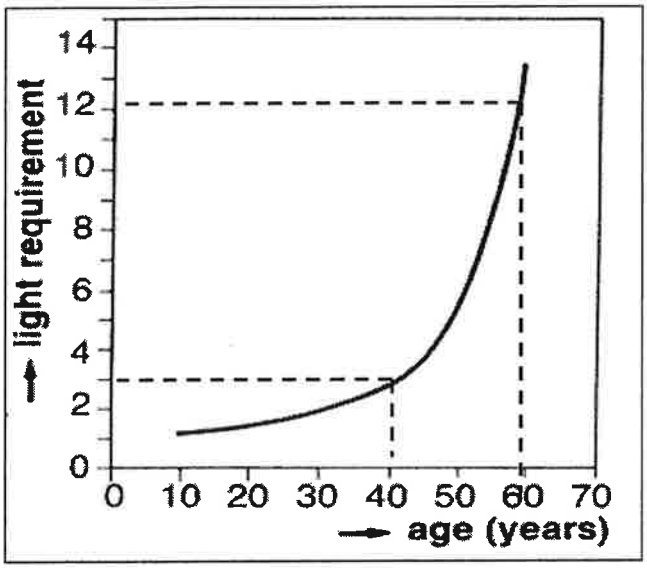



*Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.*

# Age Vs Light requirement




Because of our eyes' deterioration with age, Lighting requirement at 60 is much higher than at 10 & 40.

**Ophthalmologic findings**



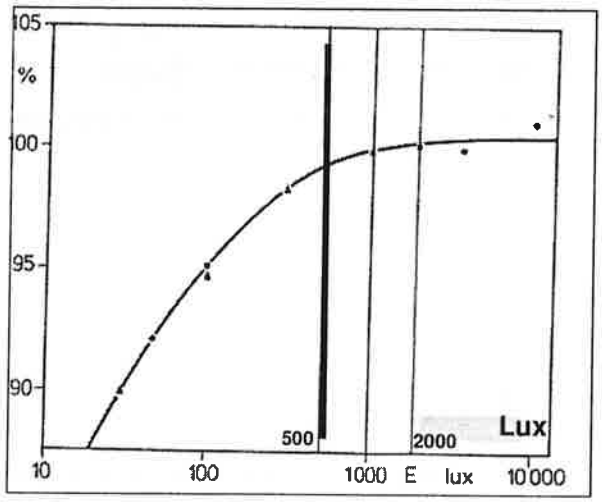
# Visual Acuity

***Visual Acuity depends on :***

- ***Quality of the 'eye'***
- ***Contrast Detection***
- ***Observation Time***

***Age has a negative effect on Visual Acuity***

# Illuminance and Productivity

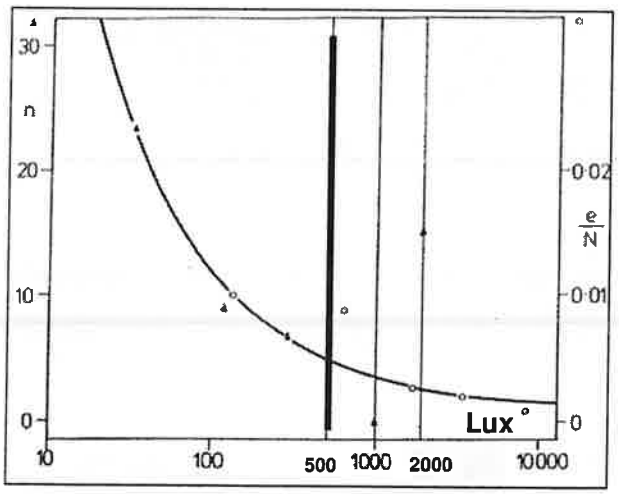



**Productivity and Task Illuminance**

Dr.D.Fischer, International Lighting Review 85/2



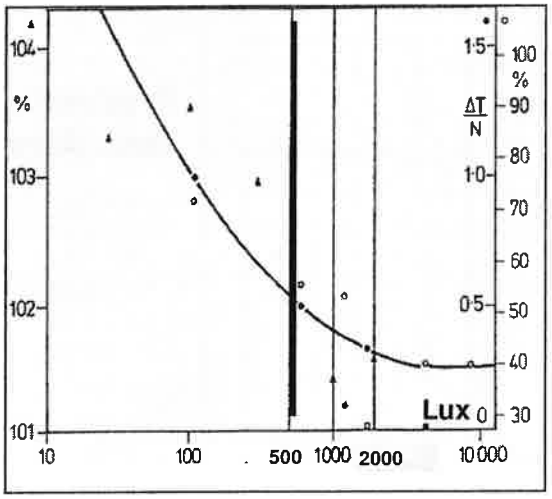
# Illuminance and Safety / Errors




***Errors and Task Illuminance***

Dr.D.Fischer, International Lighting Review 85/2

# Illuminance and Fatigue




***Fatigue and Task Illuminance***

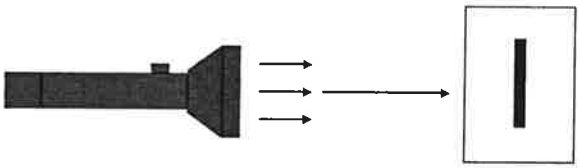
Dr.D.Fischer, International Lighting Review 85/2





# Intensity

The amount of light radiated by a light source ***per solid angle***



Unit: candela (cd)



# What is a solid angle ?

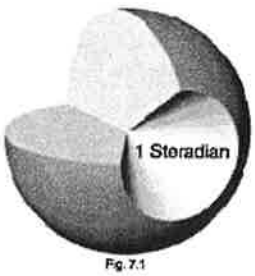



Fig. 7.1

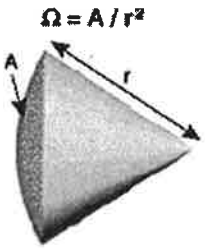
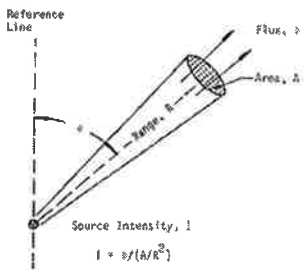



Fig. 7.2 Solid angle

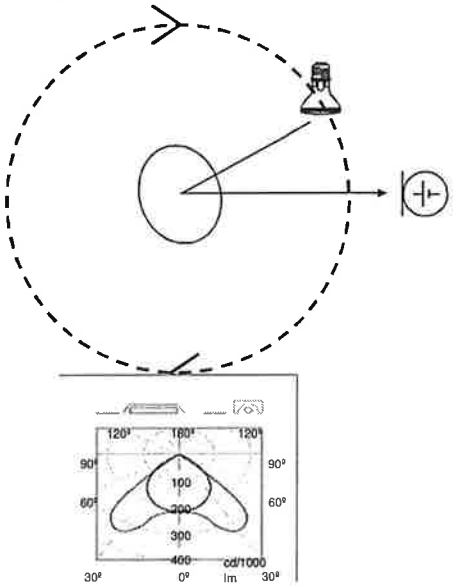


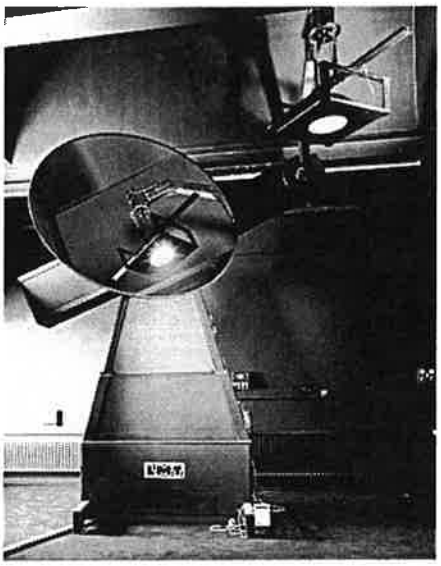

Cone of solid angle Ω = 1 Steradian
Solid angle Ω = area of surface A / radius$^2$

Radiant intensity

# Measuring Intensity

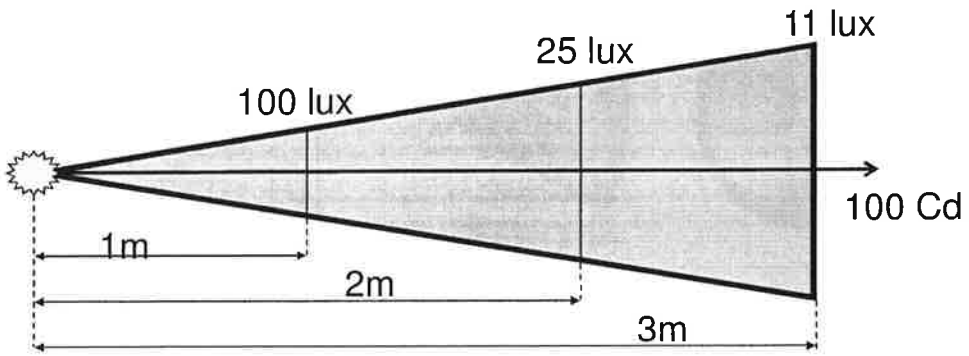
Gonio photometer



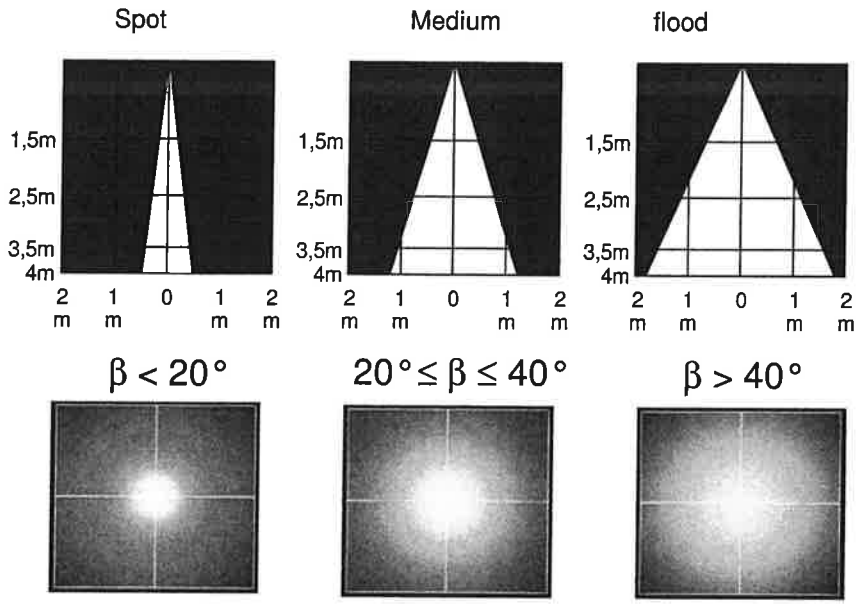





# Inverse Square Law



# Inverse Square Law application

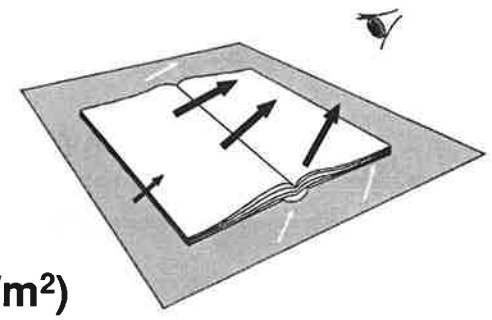





# Luminance

The amount of light radiated by a unit of apparent surface in a given direction

L



Unit: **candela per $m^2$ ($cd/m^2$)**

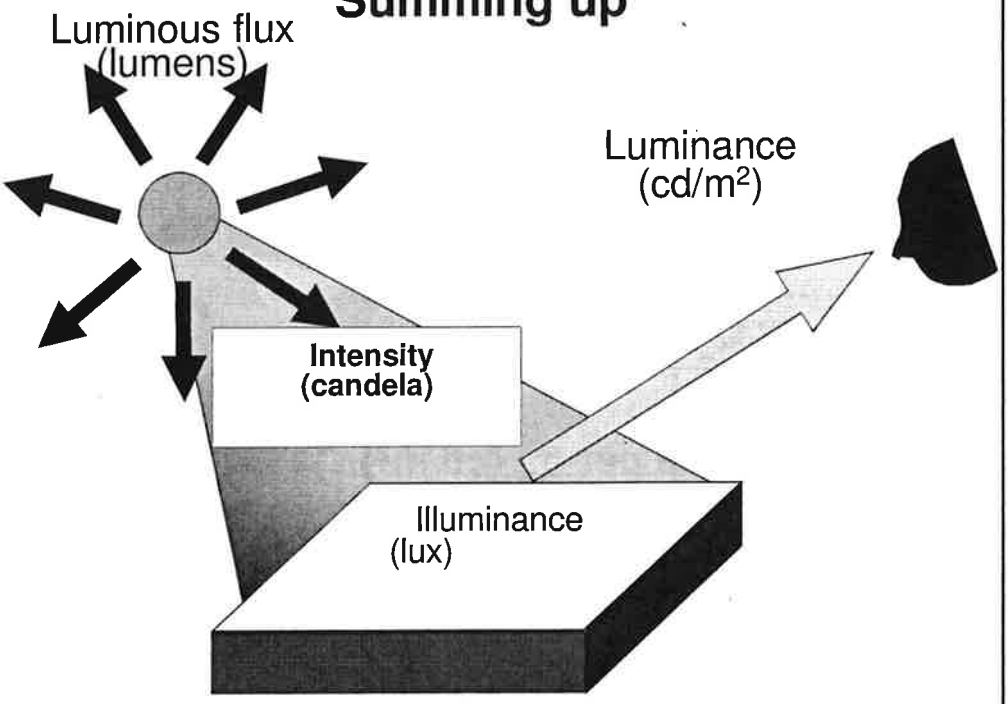
# Measuring Luminance



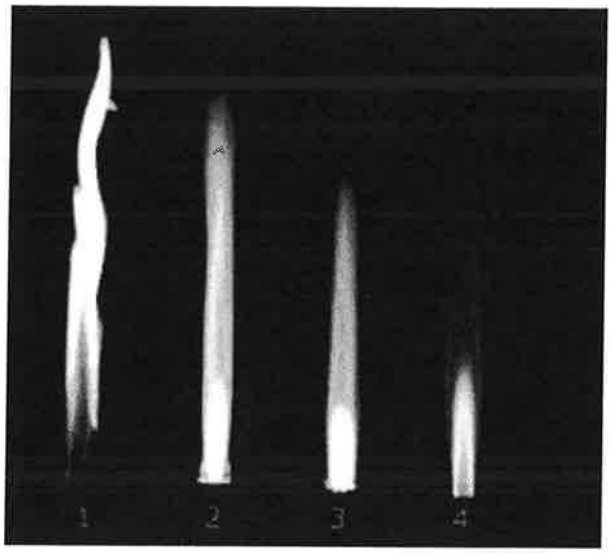




# Summing up

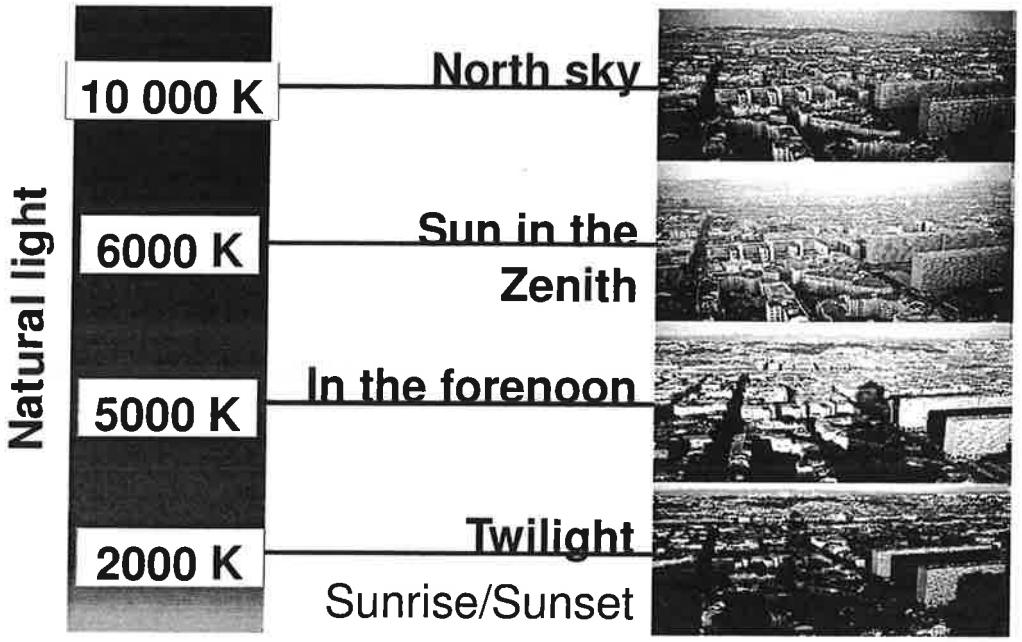


# Colour Temperature (Kelvin)

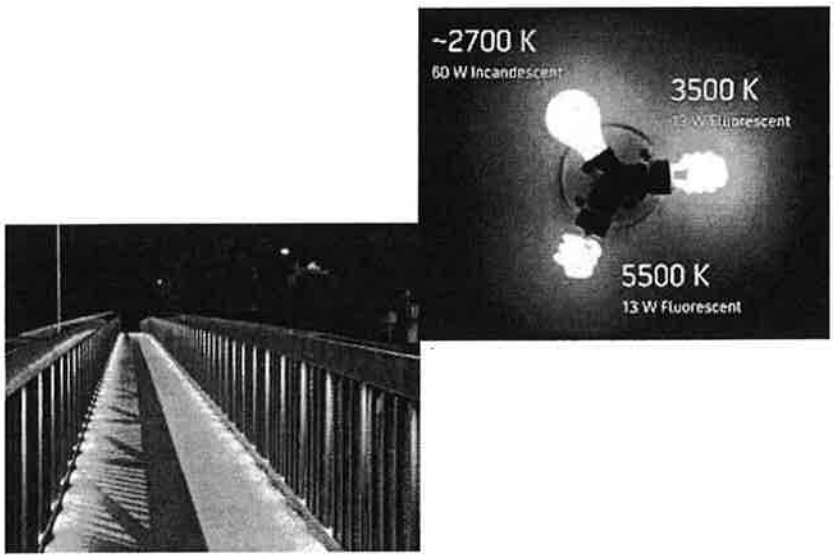





# Colour Temperature (Kelvin)



# Corelated Colour Temperature (Kelvin)



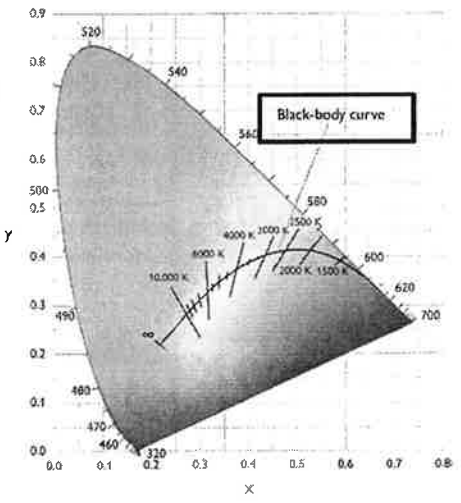


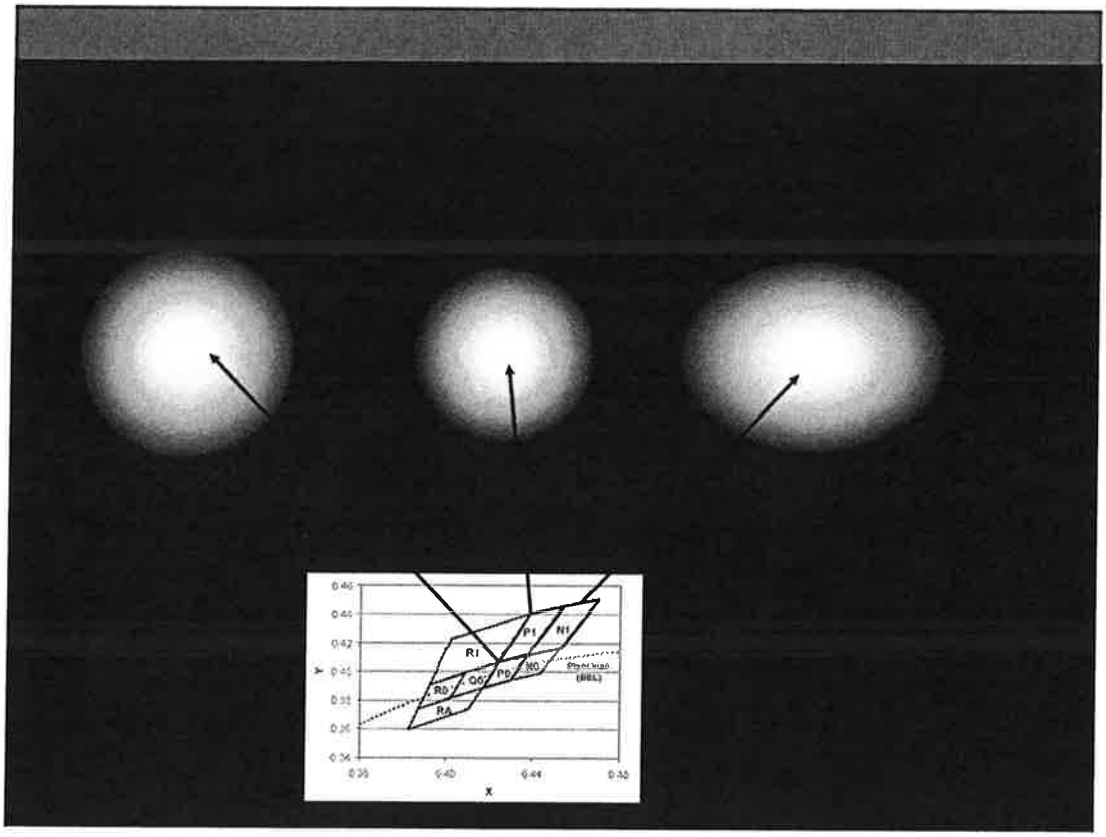

# CIE chromaticity diagram

**Co-related Colour Temperature (CCT)**

- CCT describes whether the light appears warm, neutral or cool (bluish)
- CCT is based on so-called Black body source
- As the black body gets hotter, it turns red, orange, yellow, white, **and finally blue**
- White LED is classified often as

| | |
|---|---|
| Warm white | = 2700K – 3500K |
| Neutral white | = 3500K – 4500K |
| Cool white | = 4500K – 6000K |

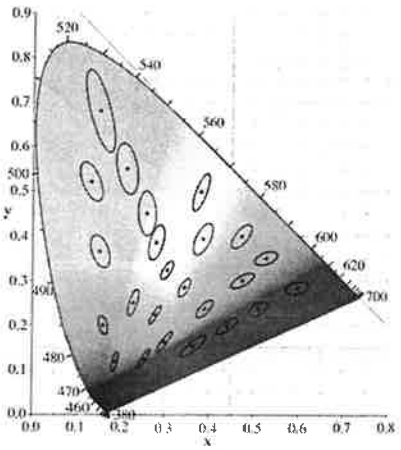




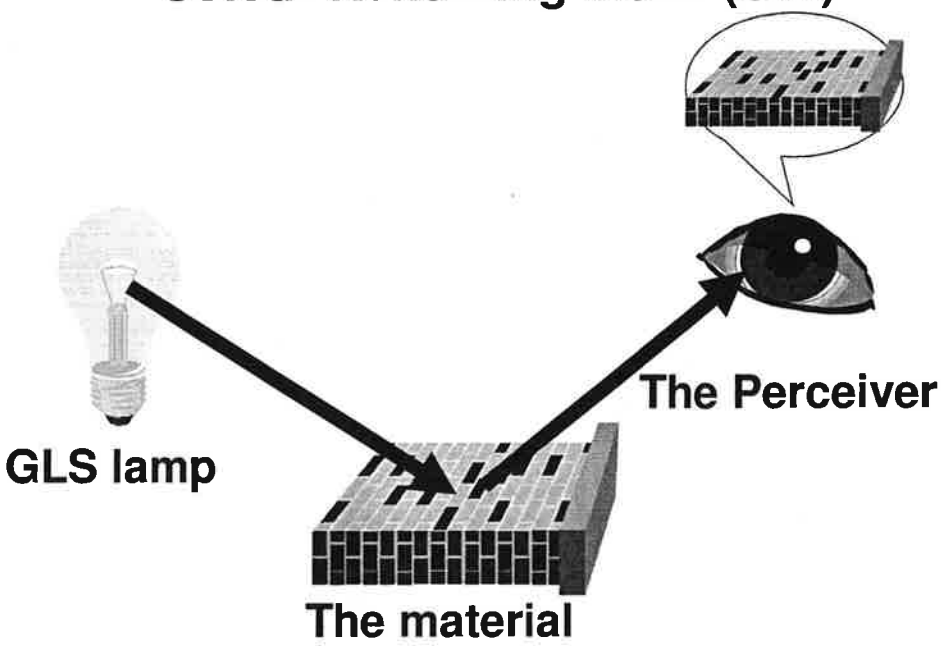

# MacAdam Ellipses (SDCM)

- Threshold at which color difference becomes perceptible is defined by a MacAdam ellipse
- Scale of a macadam ellipse is determined by SDCM (**S**tandard **D**eviation **C**olor **M**atching)

- SDCM -1 is not visible,
- SDCM - 2 to 4 is barely visible
- SDCM - 5 or more is readily noticeable

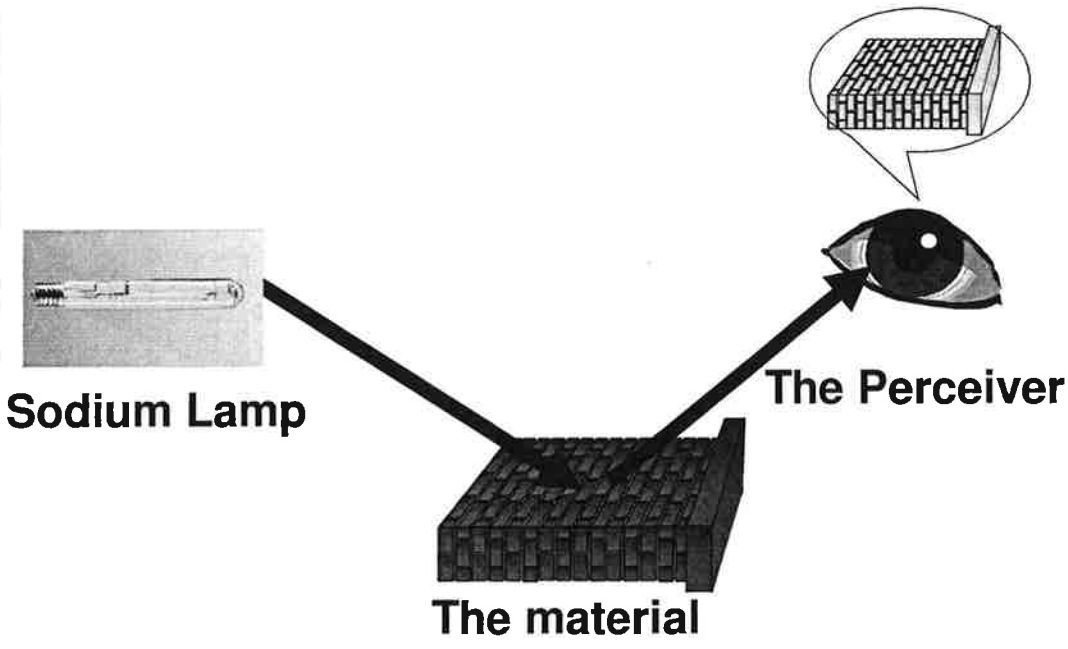


# Colour Rendering Index (CRI)

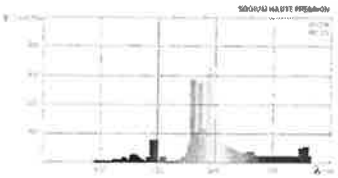


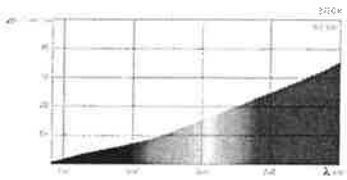


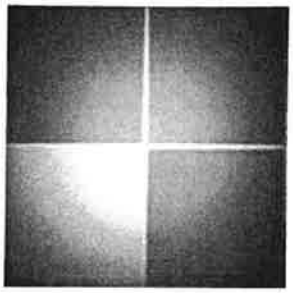

# Colour Rendering Index (CRI)



# Colour Rendering Index







| | |
|---|---|
| *Blue* | *Green* |
| *Yellow* | *Red* |



*Sodium HP Lamp*

*Incandescent Lamp*



# Colour aspects




warmer ⟷ cooler

73

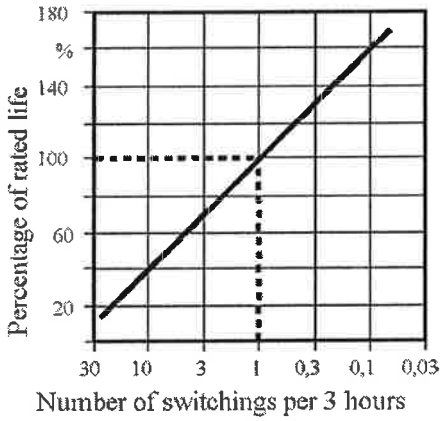
83

93



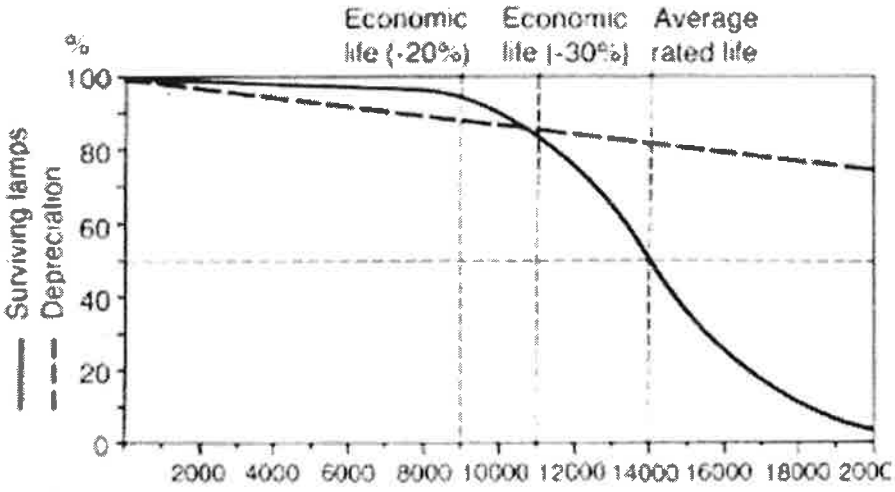
# Life time of a lamp





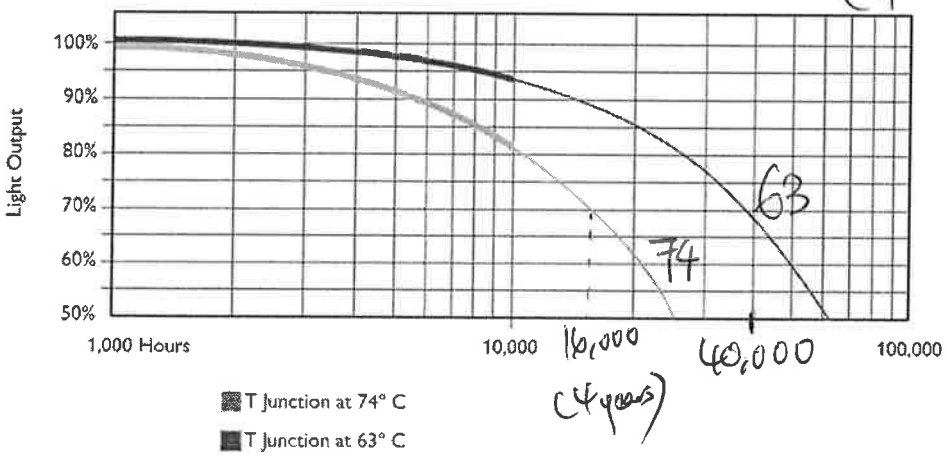

# Life time of lamp




**Manufacturers' Published life is the 50% failure life**
**At 3 hours of use per Start**

# LED Life and Junction temperature

Higher temperature means faster lumen depreciation






# Estimating Load in your premises

| Tube & Length | Ballast type | Lamp W | Ballast loss | Total W / lamp |
|---|---|---|---|---|
| T8-18W 0.60 m | EM | 18W | 9W | 27W |
| T8-18W 0.60 m | EL | 16W | 4W | 20W |
| T8-36W 1.20 m | EM | 36W | 9W | 45W |
| T8- 36W 1.20 m | EL | 32W | 4W | 36W |
| T5-14W 0.60 m | EL | 14W | 3W | 17W |
| T5- 28W 1.20 m | EL | 28W | 3W | 31W |

**EM = Electro Magnetic ballast EL = Electronic ballast.**
**Ballast is an essential accessory. Without it, the Fluorescent lamp will draw a high current and destroy itself in seconds.**

## Load density in W / $M^2$

- Calculate the load (in Watts) per luminaire.
- Multiply by all luminaires to get total load
- Calculate the area of interior in $M^2$
- **Power Density = Total Watts / $M^2$**

**Compare it with Maximum Power density allowed as per Code of Practice SS 530: 2006. E.g.**

| | |
|---|---|
| **Offices** | **15W / $M^2$** |
| **Lobby** | **10W / $M^2$** |



## Thank you !

# Sustainable Lighting Design & Technology

**GMFP- GMP**

**BCA Academy**

## 2. Eco-friendly indoor Lighting design





# Changing Scenario Indoors



**Performance**



**Cost**



**Comfort**



**Image**



**Ambience**

# Changing Scenario Indoors

- **Change in Lighting Parameters**
- **Lighting Equipment : As per Trends in lamps, ballasts and luminaires**
- **Light Quantity ( lux) : As per National Standards**
- **Light Quality : Glare Control**
  **: Colour Temperature**
  **: Colour Rendition**
- **Lighting Controls : Flexibility to users**
  **: Energy Savings Vs investment ??**



# Optical Systems : Evolution

- Bare fittings
  - ➢light in all direction
  - ➢lamp visible .. glare
  - ➢Basic look

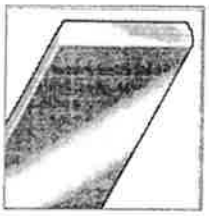


- Simple white reflector
  - ➢upward light directed downward
  - ➢no "shape" in light distribution
  - ➢lamp still visible .. no ambience



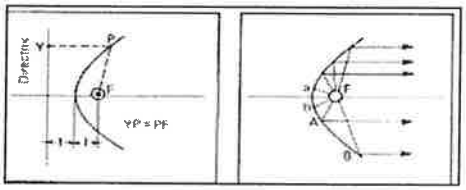
# Optical Systems : Evolution

- Opal / Prismatic cover
  - ➢diffused lights
  - ➢Can be somewhat glaring
  - ➢decorative look
  - ➢high absorption of light
  - ➢reduction in efficiency





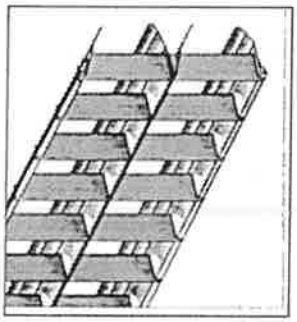
- Mirror systems
  - ➢"Shaping" light distribution
  - ➢Control of glare
  - ➢Improves System and energy efficiency

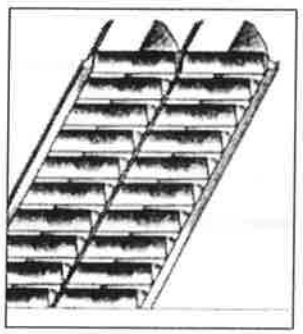


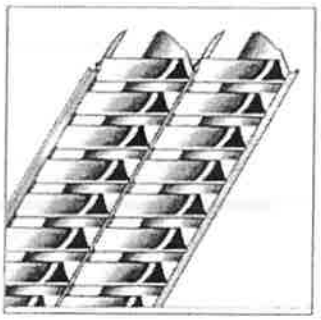



# Optical Systems: Evolution

**Different Types of Mirror Optic louvers**





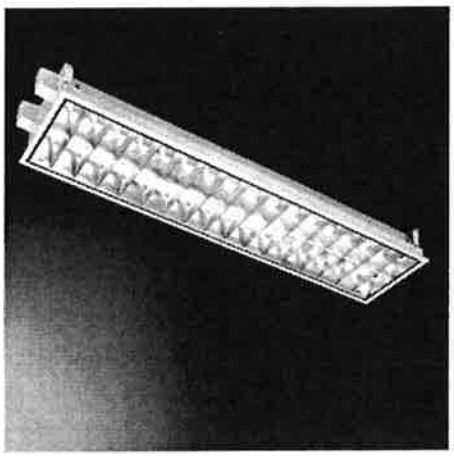


# Mirror optic Systems: Advantages

- *Precise control of light distribution*
- *Directs light to " where needed"*
- "The right light at the right place"

**Consists of**

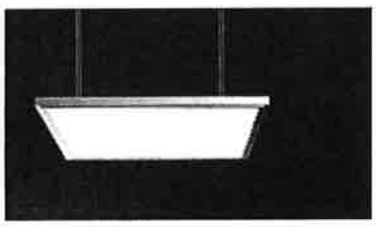
- Side Reflectors and cross lamellae
- Glare-control is good





# LED diffusor luminaires

LED will call for a diffusor. Light absorption and glare may increase









# Recommendations and Standards



## SS 531: 2006 Indoor areas

| Quality aspect | Quality parameter |
|---|---|
| Lighting level | maintained illuminance |
| Uniformity | $E_{min} / E_{av}$ 0.7 |
| Glare restriction | UGR |
| Colour rendering | CRI 80 |

# SS 531: 2006 Office areas

| Sl.No | Type of Interior | E (Lux) | UGR | CRI |
|---|---|---|---|---|
| 3.1 | Filing, copying | **300** | 19 | 80 |
| 3.2 | Writing, reading, Data processing | **500** | 19 | 80 |
| 3.3 | Technical drawings | **750** | 16 | 80 |
| 3.4 | CAD work stations | **500** | 19 | 80 |
| 3.5 | Conf&Meeting rooms | **500** | 19 | 80 |
| 3.6 | Reception desk | **300** | 22 | 80 |
| 3.7 | Archives | **200** | 25 | 80 |



# Ceiling-Wall-Floor Reflectances to be high

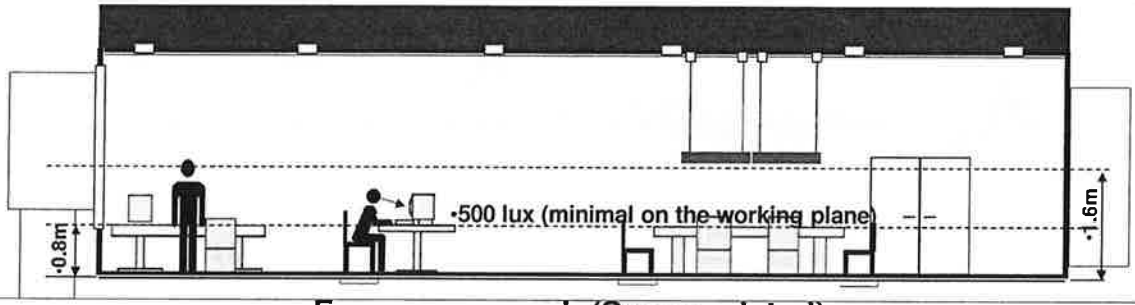
That will ensure higher light-Utilisation and greater energy-efficiency

**Luminance distribution is determined by:**

- Reflectance of surfaces

| | **Useful reflectance** | **Min. – Max.** |
|---|---|---|
| – Ceiling | 0.7 | 0.6 – 0.9 |
| – Wall | 0.5 | 0.3 – 0.8 |
| – Working plane | 0.6 | 0.2 – 0.6 |
| – Floor | 0.3 | 0.1 – 0.5 |

# Lighting requirements (Traditional)



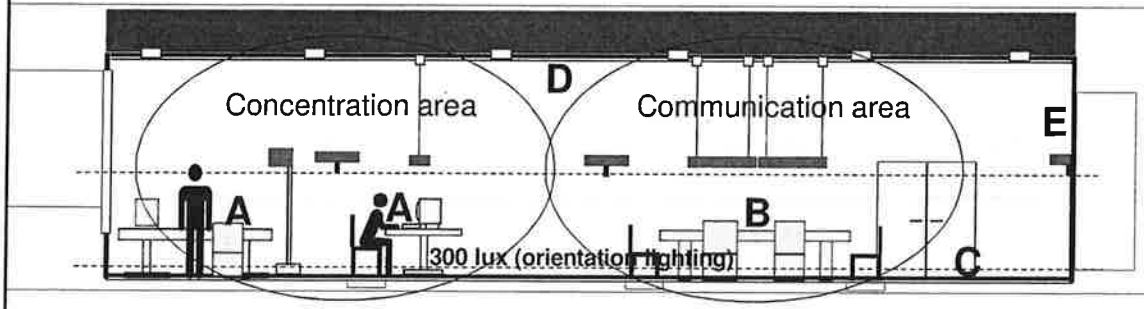

**Former approach (Space related)**

Average illuminance levels on the working plane

| | |
|---|---|
| filing, copying, circulation areas | 300 lux |
| writing, typing, reading, data processing areas | 500 lux |
| technical drawing offices | 750 lux |
| CAD work stations | 500 lux |
| conference and meeting rooms | 500 lux |
| reception desk areas | 300 lux |
| archives | 200 lux |



# SS 531 calls for a 'Luminous environment'




Individual task

**TASK - concentration zone (A)**
Lighting level : 300-1000 lux
Colour Temp. : 3000-5000K
Colour rendering: 80-100
Glare restriction :<1000cd/m²/65°
uniformity :>0.7 (task area)
Beam shape : triangle or asym

**TASK - Communication zone (B)**
Lighting level : 300-1000 lux
Colour Temp. : 3000-5000K
Colour rendering: 80-100
Glare restriction :No direct glare
uniformity :> 0.5 (table)
Beam shape : wide beam

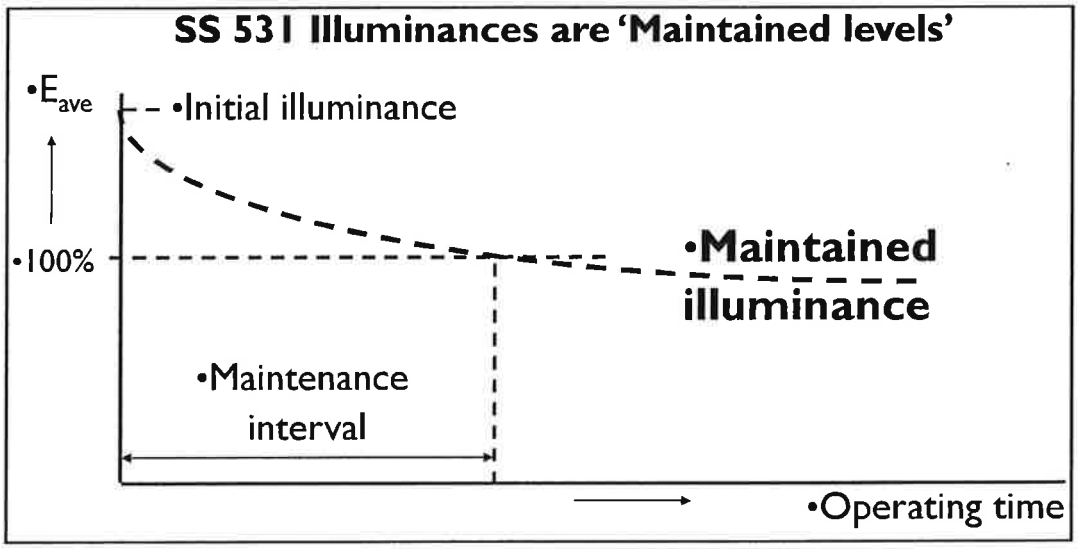
Collective space

**ROOM - Floor (C)**
Lighting level : > 300 lux (hor.)
Colour Temp. : 3000-4000K
Colour rendering: 80-100
Glare restriction : -
uniformity : > 0.3
Beam shape : -

**ROOM - Ceiling (D)**
Lighting level : > 150 lux
Colour Temp. : 3000-4000K
Colour rendering: 80-100
Glare restriction : -
uniformity : > 0.5
Beam shape : -

**ROOM - Walls (E)**
Lighting level : > 200 lux (Vert.)
Colour Temp. : 3000-4000K
Colour rendering: 80-100
Glare restriction : -
uniformity : > 0.1
Beam shape : -

# Maintenance factor



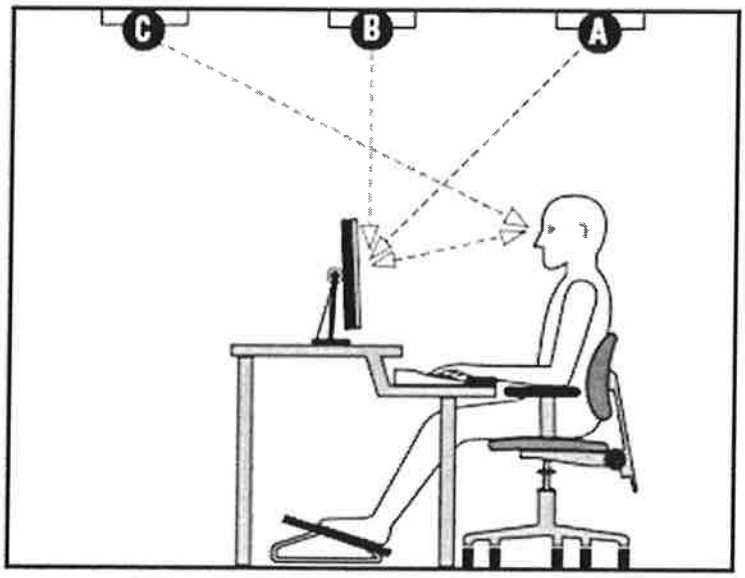



# How do we tolerate 100,000 Lux in the open?



# Why does 500-750 Lux look so 'bright'?

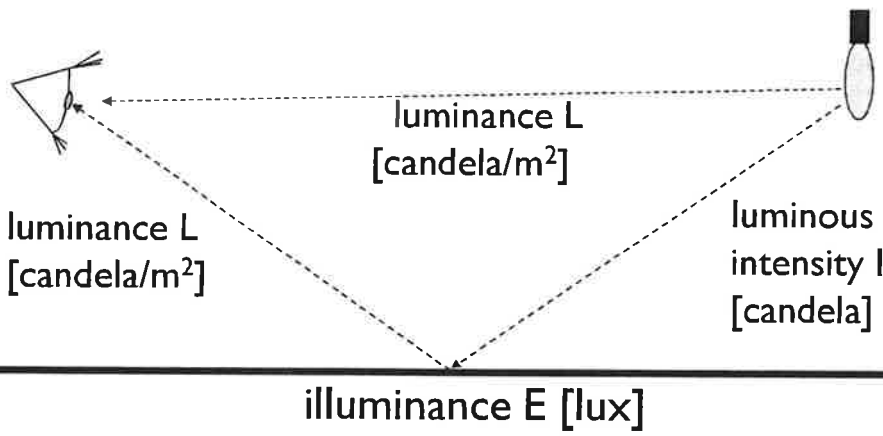
**Closeness of lamp makes people mistake Glare for 'Lighting level'. So Glare has to be minimized**






# Glare factors

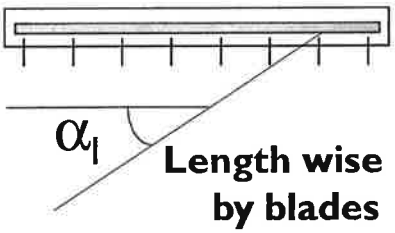
- Luminance and illuminance



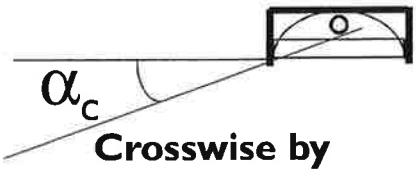
# Glare factors

Bright lamps should be screened off to prevent direct glare

| Lamp luminance | Shielding angle |
|---|---|
| 20 – 50 kcd/m$^2$ | $\alpha > 15^0$ |
| T8 12 kcd/m$^2$ | Open reflector allowed |
| T5 HE 17 kcd/m$^2$ | Open reflector allowed |




**Length wise by blades**




**Crosswise by optics**



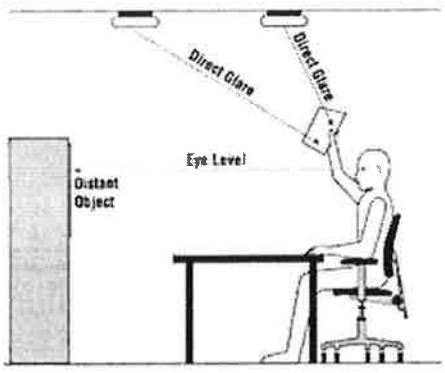
# Direct Glare = Unified Glare Rating (UGR)

## UGR

Complicated system to limit direct glare caused by the luminaires in the room

Table 5.3 — Offices

| 3 | Offices | | | | |
|---|---|---|---|---|---|
| Ref. no. | Type of interior, task or activity | $E_m$ | UGR | $R_a$ | Remarks |
| 3.1 | [illegible] | [illegible] | [illegible] | [illegible] | |
| 3.2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 3.3 | Technical drawing | 750 | 16 | 80 | |
| 3.4 | CAD work stations | 500 | 19 | 80 | [illegible] |
| 3.5 | Conference and meeting rooms | 500 | 19 | 80 | Lighting [illegible] |
| 3.6 | Reception desk | 200 | 22 | 80 | |
| 3.7 | Archives | 200 | 25 | 80 | |



# Unified Glare Rating - UGR

Complicated system to limit direct glare caused by the luminaires in the interior

$$UGR = 8\log\left[\frac{0{,}25}{L_b}\sum\frac{L^2\Omega}{p^2}\right]$$



# Reflected Glare

Luminance limits for luminaires which can be reflected in the screen

For two luminaire classifications:

**–Screen quality**
Good/medium < 1000 cd/m$^2$

**–Screen quality**
Poor < 200 cd/m$^2$



# Industrial lighting

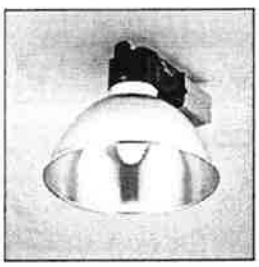


# Industry Lighting

**Basic lighting solutions:**
- **Linear light sources**
- **(Fluorescent lamps)**

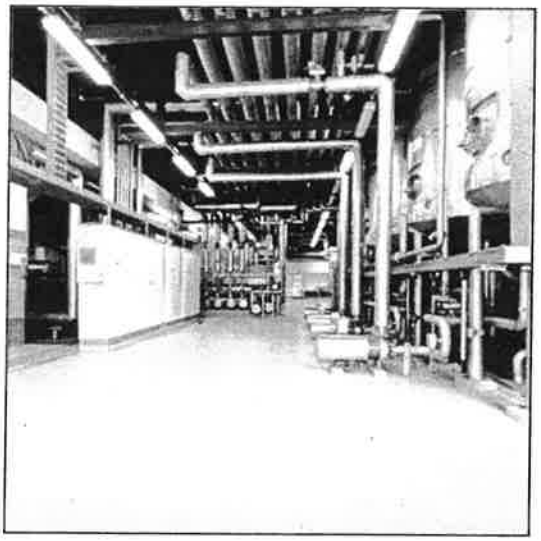


**Point light sources**
- **(High intensity**
- **Discharge lamps)**



# Industry Lighting

- Application h < 6 m
- 95-100 % 'TL or LED'
- 5% HID lamps





# Industry Lighting

- Application h 6 to 16 m

HID + Induction lamps



# Lighting Design Principles



# Guidelines

**1.Determine the function and need**

**2. Select Lighting level from relevant Standards for particular function**

# •Guidelines

Input Preparation

**3.Determine lighting parameters**

- lighting level
- uniformity
- colour Rendering
- colour temperature
- glare

**4.Select Equipment**

- lamp
- luminaire
- gears
- control

Output Preparation

**5.Calculate No. of luminaires**

- Prepare layout
- Prepare Recommendation
- Cost Calculation



# Lumen method of Calculation

1. Determine , length , width and height of working space
2. Calculate Room Index
3. $K = \dfrac{\text{length} \times \text{width}}{\text{Mounting height} \times (\text{length} + \text{width})}$
4. Select the reflection factors of ceiling/wall /floor $r_c$ / $r_w$/ $r_f$ (For offices , 0.7 . 0.5,0.3 .are common values)
5. Select the luminaire and lamp types
6. Choose Utilisation factor (UF) from the UF table
7. Select Maintenance factor (MF)
8. Use the pre-selected illuminance
9. Calculate no. of luminaires
10. Arrange the luminaires in a suitable grid

# Utilisation Factor Table

| | reflectances (%) for ceiling, walls and working plane | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| room | 80 | 80 | 70 | 70 | 70 | 70 | 50 | 50 | 30 | 30 | 0 |
| index | 50 | 50 | 50 | 50 | 50 | 30 | 30 | 10 | 30 | 10 | 0 |
| K | 30 | 10 | 30 | 20 | 10 | 10 | 10 | 10 | 10 | 10 | 0 |
| 0.60 | 0.44 | 0.42 | 0.43 | 0.42 | 0.41 | 0.37 | 0.37 | 0.34 | 0.37 | 0.34 | 0.33 |
| 0.80 | 0.52 | 0.49 | 0.51 | 0.50 | 0.48 | 0.44 | 0.44 | 0.41 | 0.43 | 0.41 | 0.40 |
| 1.00 | 0.58 | 0.54 | 0.57 | 0.55 | 0.54 | 0.50 | 0.49 | 0.47 | 0.49 | 0.47 | 0.45 |
| 1.25 | 0.64 | 0.59 | 0.63 | 0.60 | 0.58 | 0.55 | 0.54 | 0.52 | 0.54 | 0.52 | 0.50 |
| 1.50 | 0.68 | 0.62 | 0.67 | 0.64 | 0.61 | 0.58 | 0.58 | 0.55 | 0.57 | 0.55 | 0.54 |
| 2.00 | 0.74 | 0.66 | 0.72 | 0.69 | 0.66 | 0.63 | 0.62 | 0.61 | 0.62 | 0.60 | 0.59 |
| 2.50 | 0.78 | 0.69 | 0.76 | 0.72 | 0.68 | 0.66 | 0.65 | 0.64 | 0.64 | 0.63 | 0.61 |
| 3.00 | 0.80 | 0.70 | 0.78 | 0.74 | 0.70 | 0.68 | 0.67 | 0.66 | 0.66 | 0.65 | 0.63 |
| 4.00 | 0.83 | 0.72 | 0.81 | 0.76 | 0.71 | 0.70 | 0.69 | 0.68 | 0.68 | 0.67 | 0.65 |
| 5.00 | 0.85 | 0.73 | 0.82 | 0.77 | 0.72 | 0.71 | 0.70 | 0.69 | 0.69 | 0.68 | 0.66 |
| | suspension ratio: 0 | | | | | | | | | | |
| | calculated acc. to CIE publication 40 and 52 LVW1076900-00 | | | | | | | | | | |

- ☑Indication of efficiency of luminaire
- ..... with respect to
- ☑Room Index
- ☑ Surface Reflection factors
- ☞ ***Designer's tool for calculation of quantity of luminaire by Lumen Method***



# Maintenance Factors: Guidelines

WTF

| | |
|---|---|
| Air Conditioned interiors | 0.85 |
| Non Air-conditioned interiors | 0.80 |
| Industrial Areas ( normal) | 0.7 - 0.75 |
| Industrial Areas ( dusty) | 0.65- 0.7 |

# Step by Step Approach for Calculation

**Calculation of No. of luminaires (N) by Lumen Method**

$$N = \frac{E \times L \times W}{C \times T \times UF \times MF}$$

where ,

E = Average Illuminance (lux)

L = Length of room in 'm'

W = Width of Room in 'm'

C = Light output / lamp lumens

T = No. of lamps per luminaire

UF = Utilisation factor

MF = Maintenance Factor



# Thank you !

GMFP-GMP (BCA Academy)
Sustainable Lighting Design & Technology
Lighting Design Exercise

---

Wessler Health Group (WHG) has 7 hospitals under its group. They want to reduce their lighting bill and minimize replacement of lamps which disturbs patients and visitors. As a first step, they want to consider the use of recessed **LED luminaire** for all the common areas (corridors, passages, lift lobbies etc). You are their Lighting Consultant. Their other details are:

| | | | |
|---|---|---|---|
| • | Total of common Areas | = | 7600 Sq,Metres (7 hospitals) |
| • | One typical corridor | = | 28 x 4 Metres (112 $m^2$) Say 68 corridors |
| • | Ceiling height | = | 2.8 Metres |
| • | Design illuminance | = | 150 lux on the Floor |
| • | Luminaire | = | LED 50W (rectangular) recessed |
| • | Maintenance Factor | = | 0.90 |
| • | Room Reflectance | = | 80, 50 and 30 (CUF = 0.62) |
| • | Output of 50W LED luminaire | = | 3200 lm |
| • | Driver loss | = | Included in Luminaire rating |
| • | Usage time | = | 10 hrs / day |
| • | Energy tariff | = | 30 cents (S$) per kW hr. |

**Question**

1) Make use of UF Table on the reverse of this page
2) Use a typical corridor dimensions for calculation of no. of luminaires. Then proceed to expand the no. of luminaires for all 7 WHG hospitals
3) What is the WHG energy bill to light up common areas of all hospitals per day?
4) What is their Power density in Watts/Sq m?

2) $K = \frac{28 \times 4}{2.8 \times (28+4)} = 1.25$

$N = \frac{150 \times 28 \times 4}{3200 \times 1 \times 0.62 \times 0.9} = 9.4$



3) Total kW = $68 \times 10 \times 50W = 34000W = 34kW$
10 hrs/day = 34kWh/day @ \$0.30 ⇒ \$102/day

4) $34000W / 7600 m^2 = 4.5 W/m^2$

# *Utilisation Factor (UF) Table*

| | | |
|---|---|---|
| Luminaire. | : | Rectangular 50W recessed luminaire |
| Light source | : | LED |
| Measurement code: | : | LVK0148500-08 |
| Measurement status | : | Released June 2012 |

## Utilisation Factor Table

| **Room index K** | **Reflectance (%) for ceiling, walls and working plane** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **80** | **80** | **70** | **70** | **70** | **70** | **50** | **50** | **30** | **30** | **0** |
| | **50** | **50** | **50** | **50** | **50** | **30** | **30** | **10** | **30** | **10** | **0** |
| | **30** | **10** | **30** | **20** | **10** | **10** | **10** | **10** | **10** | **10** | **0** |
| **0.60** | 0.43 | 0.41 | 0.43 | 0.42 | 0.41 | 0.37 | 0.37 | 0.34 | 0.37 | 0.34 | 0.33 |
| **0.80** | 0.51 | 0.48 | 0.50 | 0.49 | 0.47 | 0.44 | 0.43 | 0.41 | 0.43 | 0.41 | 0.39 |
| **1.00** | 0.56 | 0.52 | 0.56 | 0.54 | 0.52 | 0.49 | 0.48 | 0.46 | 0.48 | 0.46 | 0.45 |
| **1.25** | 0.62 | 0.57 | 0.61 | 0.58 | 0.56 | 0.53 | 0.53 | 0.50 | 0.52 | 0.50 | 0.49 |
| **1.50** | 0.65 | 0.59 | 0.64 | 0.61 | 0.59 | 0.56 | 0.55 | 0.54 | 0.55 | 0.53 | 0.52 |
| **2.00** | 0.71 | 0.63 | 0.69 | 0.66 | 0.63 | 0.61 | 0.60 | 0.58 | 0.59 | 0.58 | 0.56 |
| **2.50** | 0.74 | 0.65 | 0.72 | 0.68 | 0.65 | 0.63 | 0.62 | 0.61 | 0.61 | 0.60 | 0.59 |
| **3.00** | 0.76 | 0.67 | 0.74 | 0.70 | 0.66 | 0.65 | 0.64 | 0.63 | 0.63 | 0.62 | 0.61 |
| **4.00** | 0.79 | 0.68 | 0.77 | 0.72 | 0.68 | 0.67 | 0.65 | 0.65 | 0.64 | 0.64 | 0.62 |
| **5.00** | 0.81 | 0.69 | 0.78 | 0.73 | 0.68 | 0.67 | 0.66 | 0.66 | 0.65 | 0.65 | 0.63 |
| | suspension ratio : 0<br>calculated acc. to CIE publication 40 and 52 LVK0148500-08 | | | | | | | | | | |

# Sustainable Lighting Design & Technology

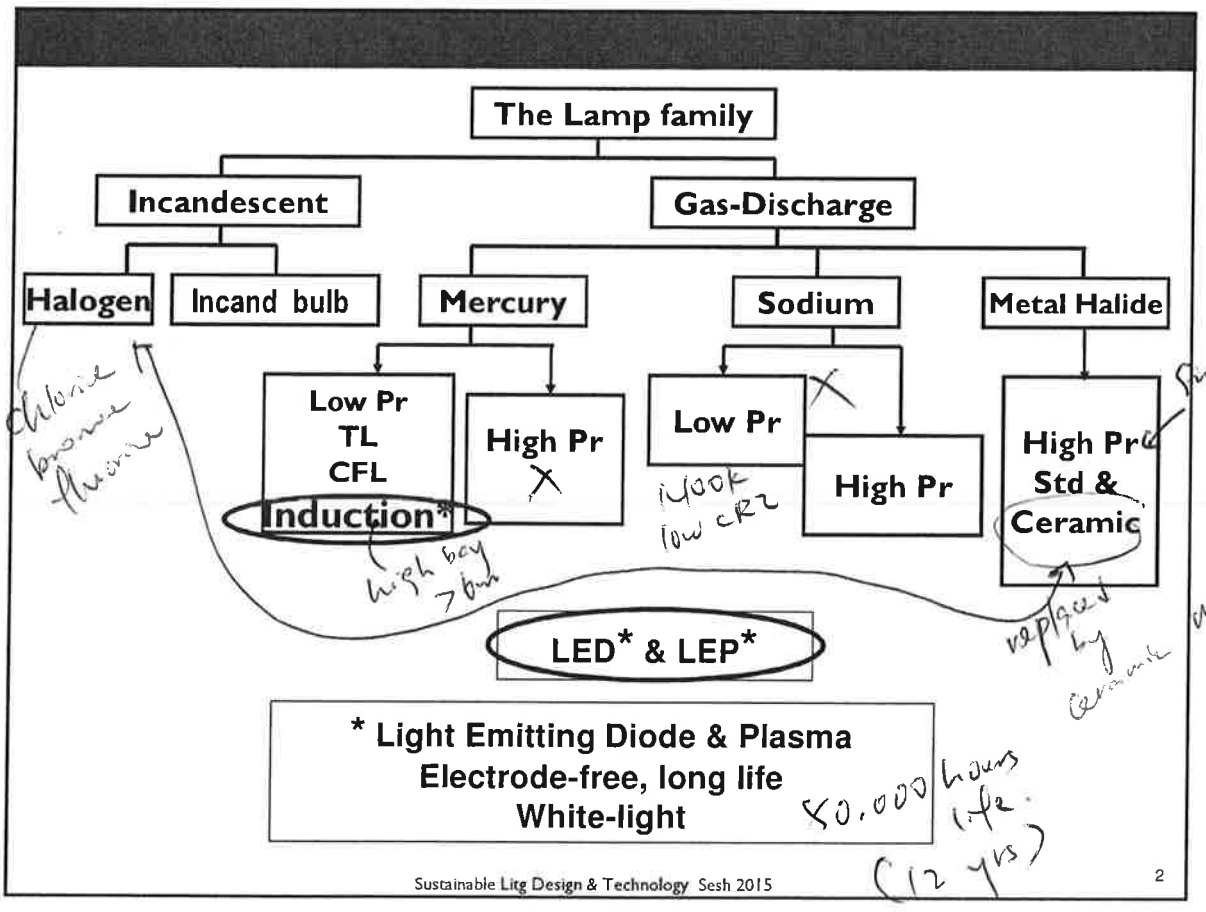
## GMFP- GMP

## BCA Academy

## 4. Lamps-LED-Ballast-Drivers and Applications







# The incandescent bulb

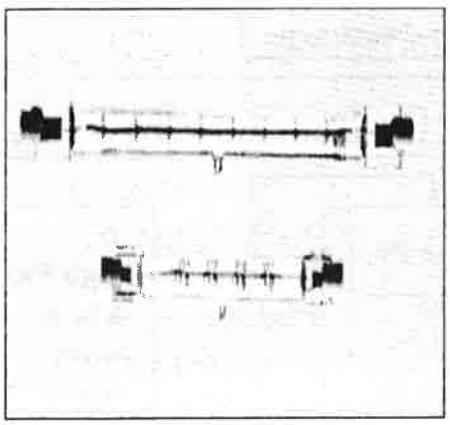


- **Glass Shell**
  - **Clear , frosted or opal finish**
  - **Protects the filament**
- **Fill Gas**
  - **Reduces the evaporation rate of tungsten**
  - **Inert (Argon and Nitrogen)**
- **Filament**
  - **Tungsten , light emitter 2700 K**
- **Lamp Cap - brass or aluminium**

- ***Because of low efficacy and heat, this lamp is gradually phased out of many countries***



# Halogen lamp



Double-ended 230V

- Cool Beam
- Precise angles
- UV protection with glass



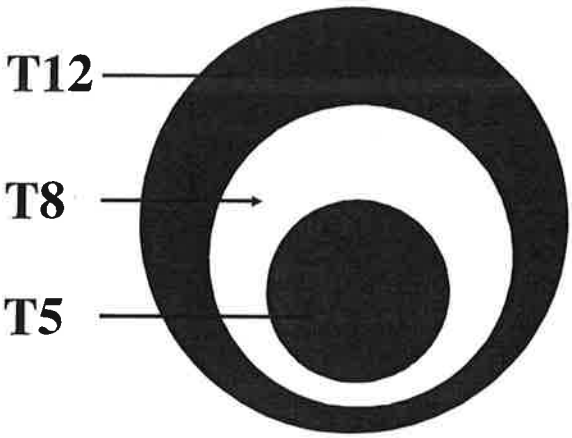
Single-ended 12V

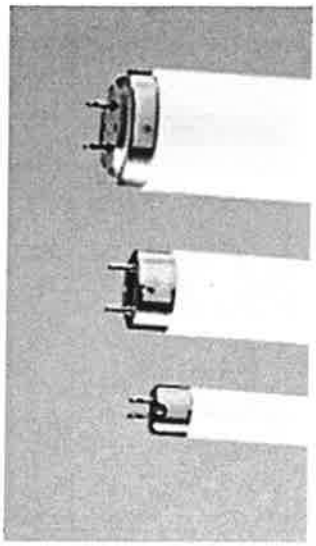
- **Warm Colour Appearance, 3000- 3200K**

**Excellent Colour rendition , Ra (= CRI) =100**

**Life 2000-5000 hrs**

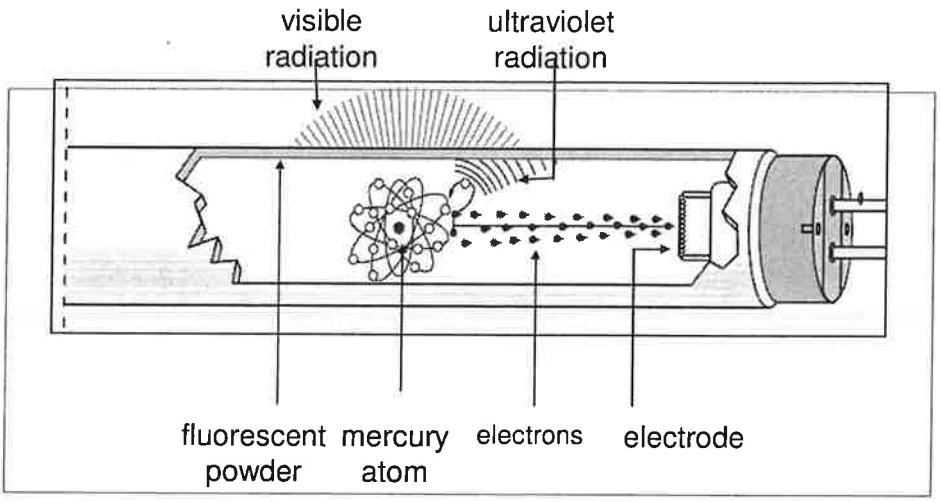
# Straight Fluorescent lamps



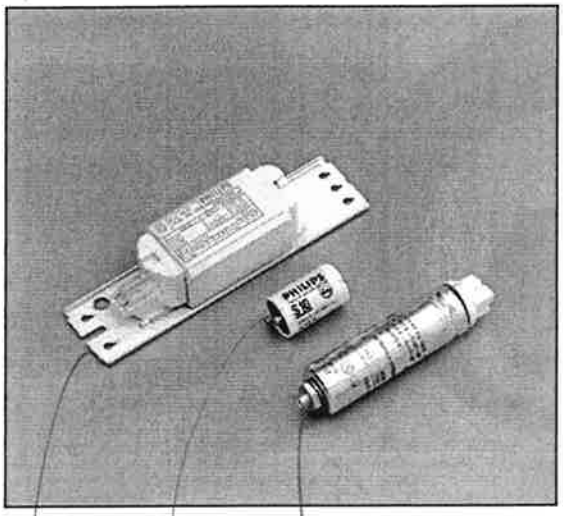



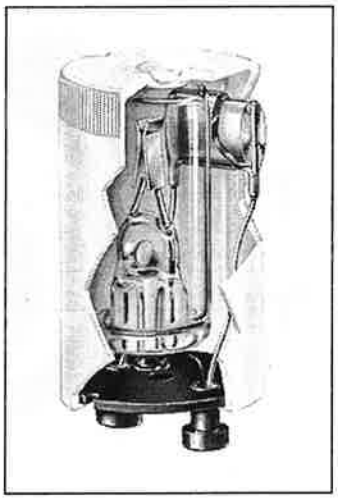


# The fluorescent lamp operation



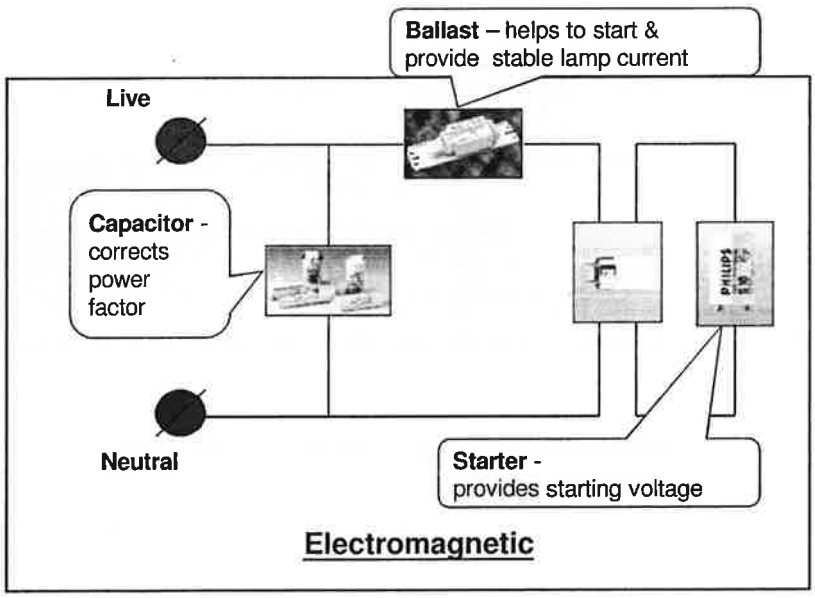
# Electro Magnetic (EM) ballast



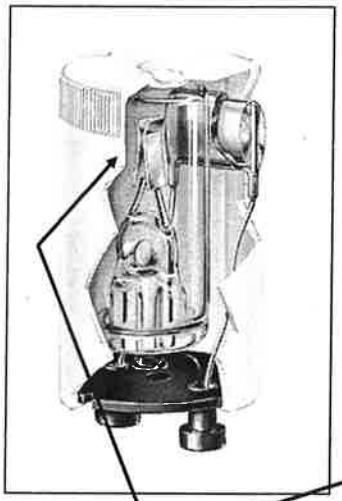



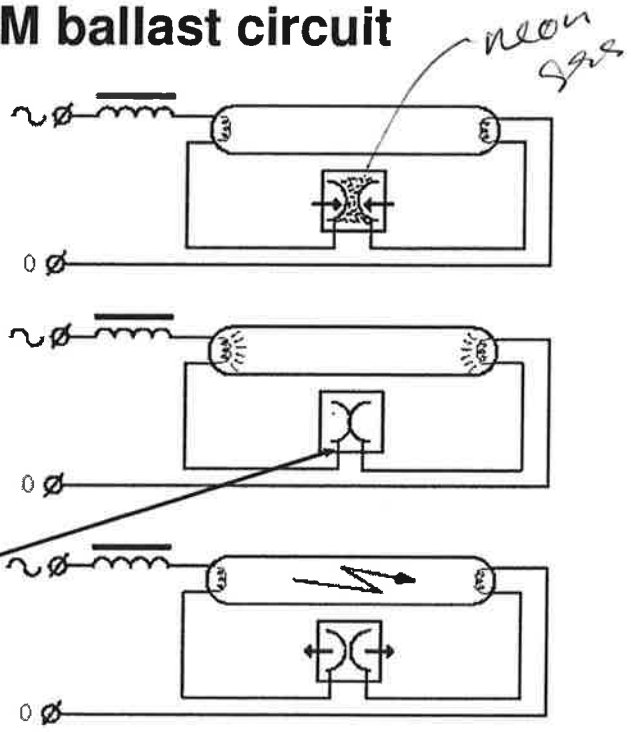


# EM ballast circuit



# EM ballast circuit

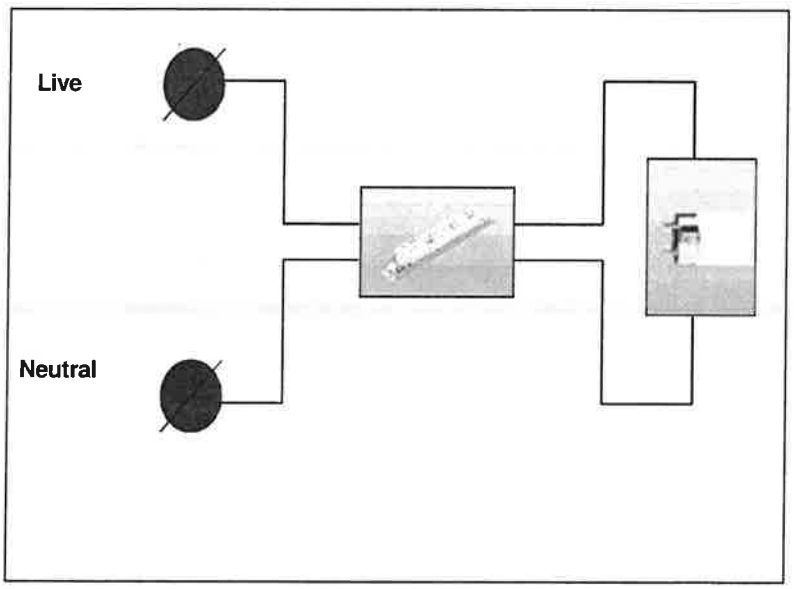





Bi-metallic contacts



# Electronic (EL) ballast circuit



# EL ballast - Advantages

**Hard argument** 1. saves money

**Soft arguments** 2. comfort & health
3. flexibility



# Lamp power + ballast loss = Total load

| Lamp | Ballast type | Lamp power | Ballast loss | Total power |
|---|---|---|---|---|
| T8 36W | EM | 36W | 9W | 45W |
| T8 36W | EL | **32W** | **4W** | **36W** |

# EL ballast saves money

**EM= ElectroMagnetic**

- energy costs relatively high compared to HF
- additional costs for PF capacitor > air conditioning costs because of heat generation
- normal lamp life
- relatively high lumen depreciation

**EL= Electronic**

- **TLD 36W operates at 32W**
- energy savings up to 20% compared to conventional
- no additional cost for PF capacitor
- Air conditioning load reduced because of less heat radiation (20% less)
- 50% longer lamp life, less maintenance costs
- lower lumen depreciation



# Energy saving with EL ballast

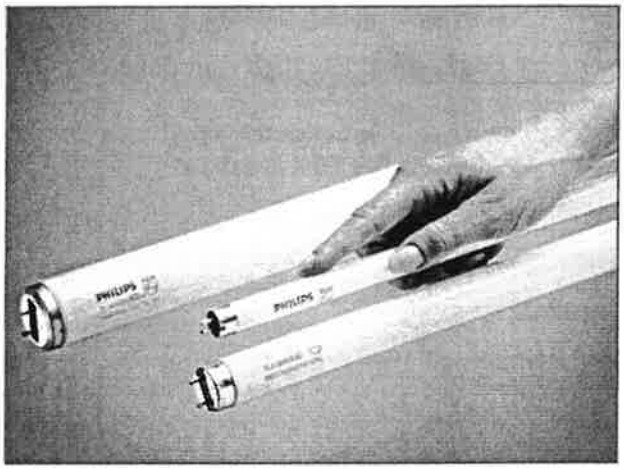
- 2 (Lamps + Ballast loss) with EM ballast = 90W
- 2 (Lamps + Ballast loss) with EL ballast = 72W
- Load reduction per fitting = 18W
- For 4000 hrs per year, energy saved = 72 KW hrs
- @ 30 Cents per KW hr, cost saved = S$ 21.6 / year
- Extra cost for EL ballast = S$ 20
- Time to recover extra cost = About 0.9 yr !

# T5 technology

***Miniaturisation***

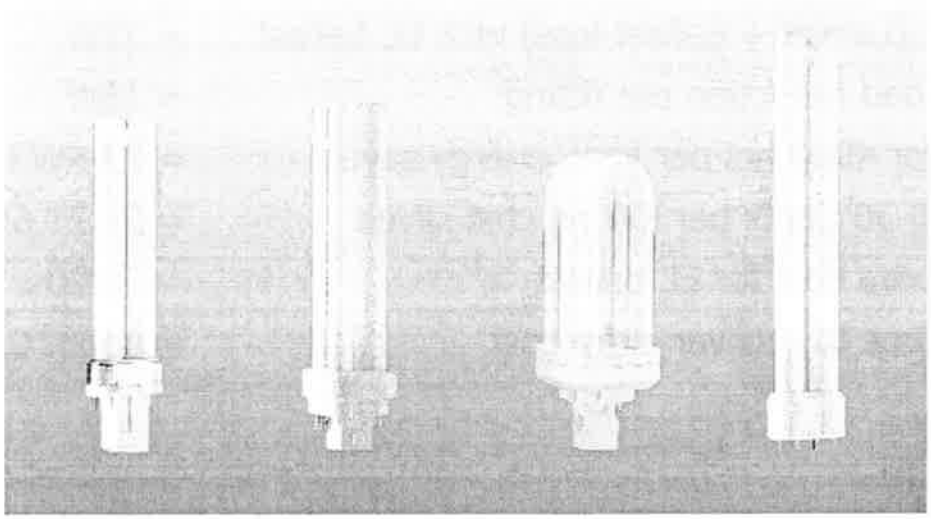
- ***Diameter 16 mm***
- ***Shorter length***

- ***More precise optical control***
- ***Shallow Luminaires***
- ***can fit into any metric system ceiling***

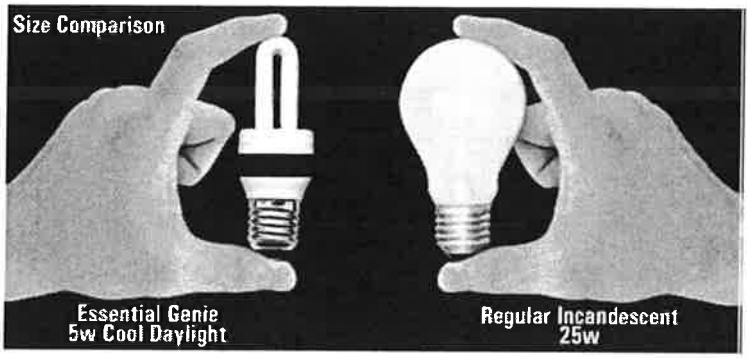




# CFL – Non Integrated. Ballast is external



# CFL – Integrated. Ballast is internal




**CFL 20W = GLS 100W**

**CFL 15W = GLS 75W**

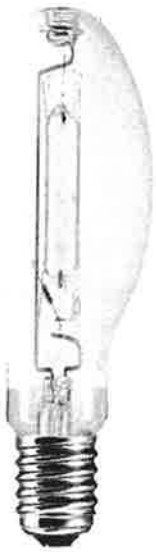
**CFL 11W = GLS 60W**



General Lighting Service

# High Pressure Mercury Lamp

Applications:High bay interiors, Shopping malls, Residential roads, Parks, Landscape etc. Has a life over 15000 hours.



# High-bay Application





# Metal Halide lamp

Mercury Halide

It has more lumens/ Watt and higher colour rendering than HPMV & suitable for Sports lighting, floodlighting of buildings etc.



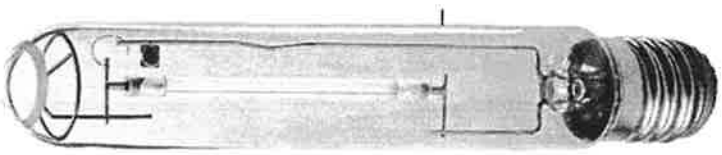
# Metal Halide mainly for Sports





# High Pressure Sodium lamp

Golden yellow light with high output up to 140 lumens/watt.

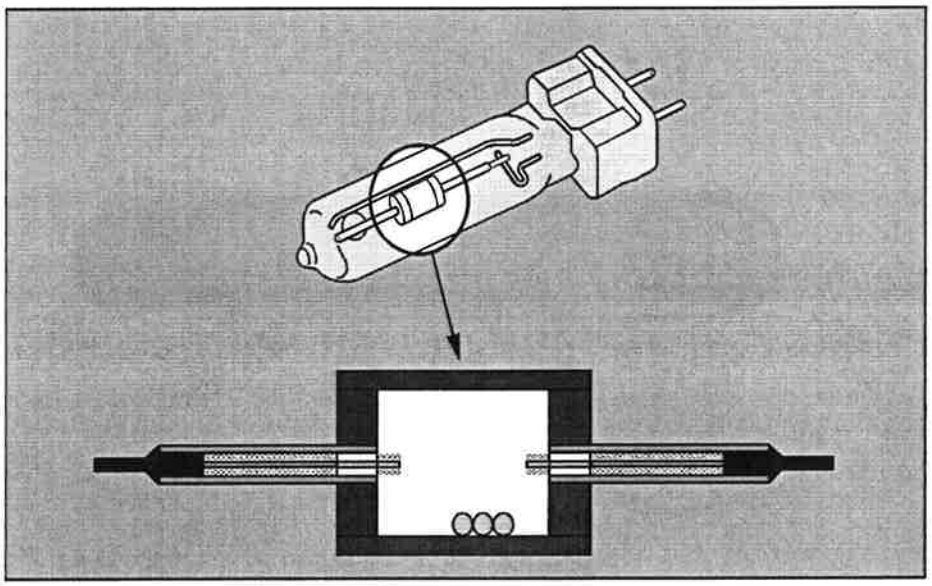


# Sodium mainly for Road lighting





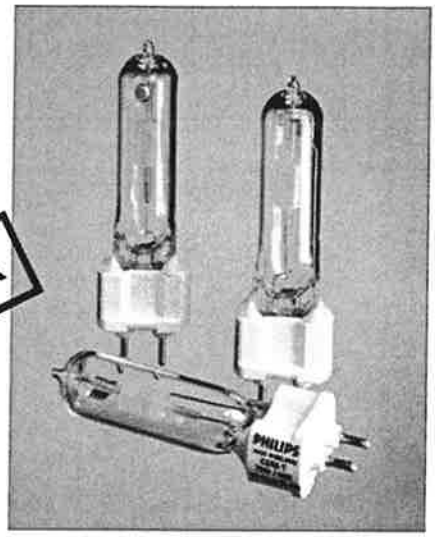
# Ceramic Metal Halide (CMH) Lamp



# CMH Lamp

- High beam intensities, high light output
- High efficacy
- Choice in 3000-4200K
- Long life
- Colour stability
- High CRI
- UV-block

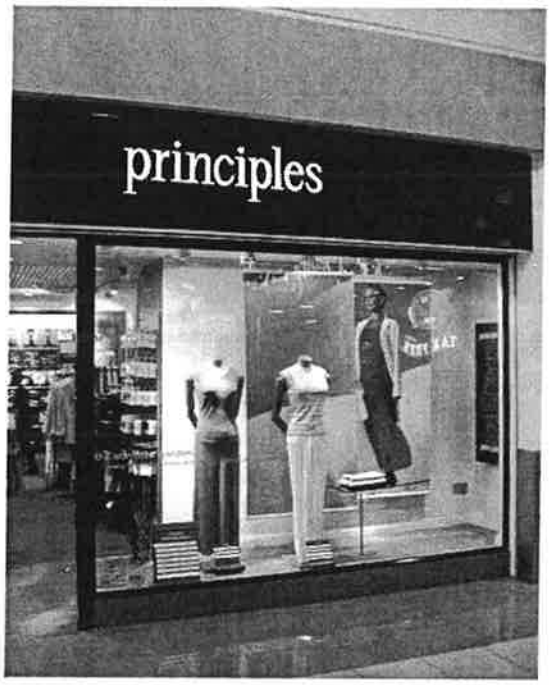
UV-block




**Best substitute for halogen !**



# CMH best suited for Shop lighting



# Control gear for discharge lamps

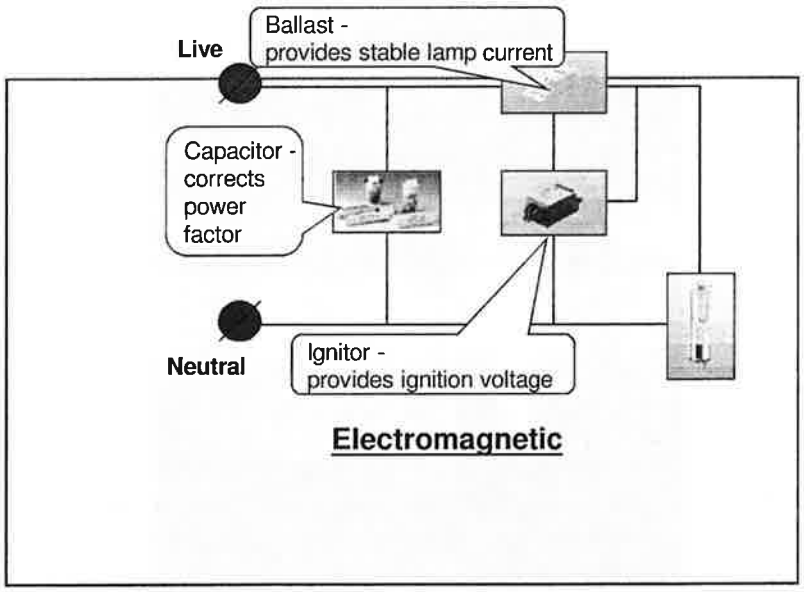
consists of :

- Ballast
- Ignitor (Starter)
- Capacitor

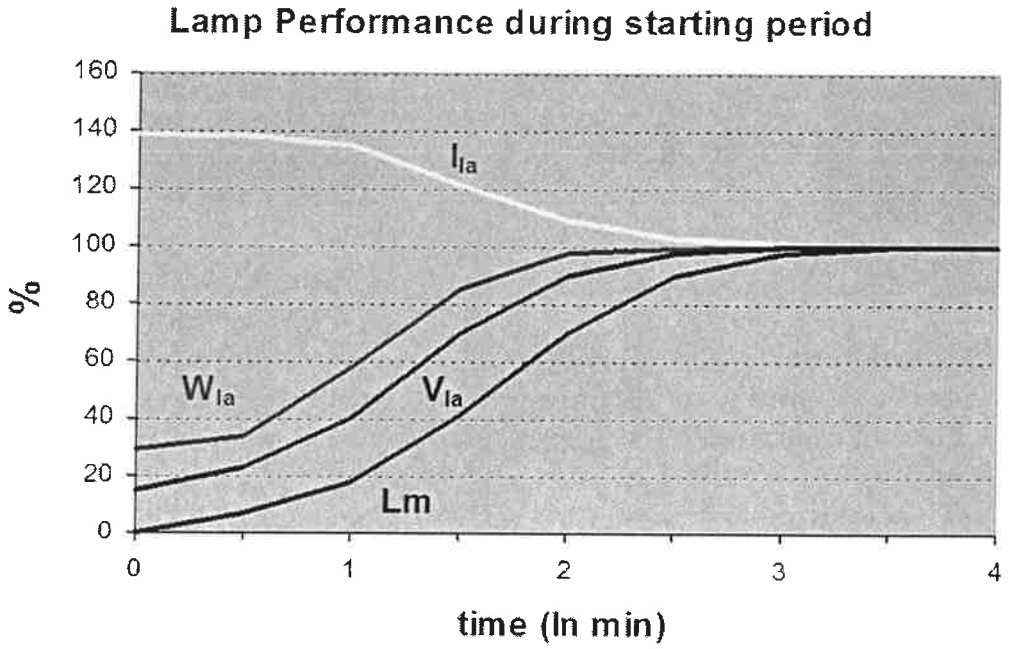


# Ballast for HID Lamps

## System configuration



# HID lamps run-up behaviour






# Electrode-less Light Sources

1. LED
2. Induction
3. Light Emitting Plasma

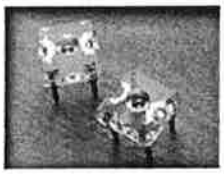
# Type of LEDs



Surface mount LEDs
- Computers
- mobile phones

BACKLIGHT





INDICATION

5 mm LEDs
- Traffic signals
- Auto indicator lights
- Exit light signs

Power LEDs:
- Accent Lighting
- Low illuminances
- Torch
- Entertainment



ILLUMINATION





1) NICHIA

2) SUJI NAKAMURA

3) OSRAM 4) PHILIP (LUMILED)

# Indication & Illumination

5) CITIZEN 6) SAMSUNG 7) LG

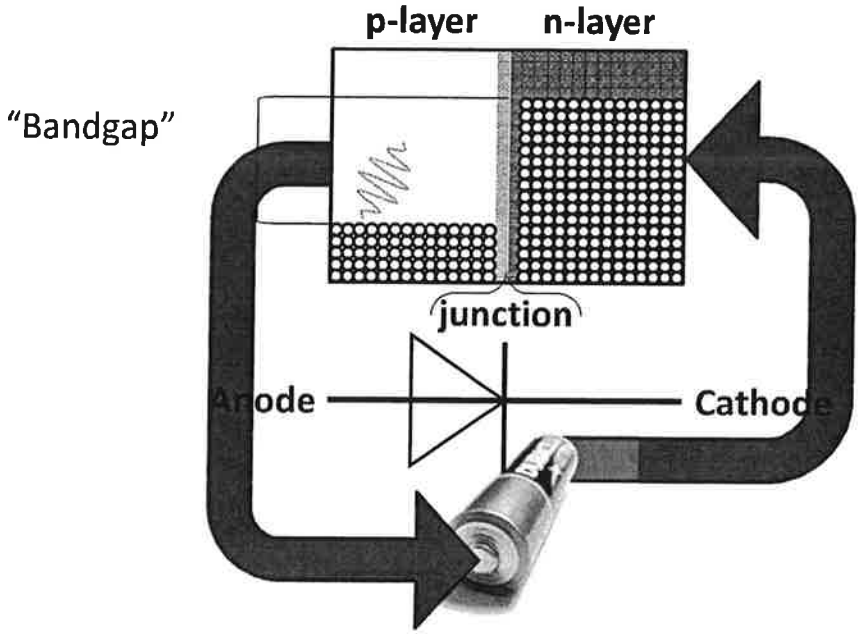



INDICATION



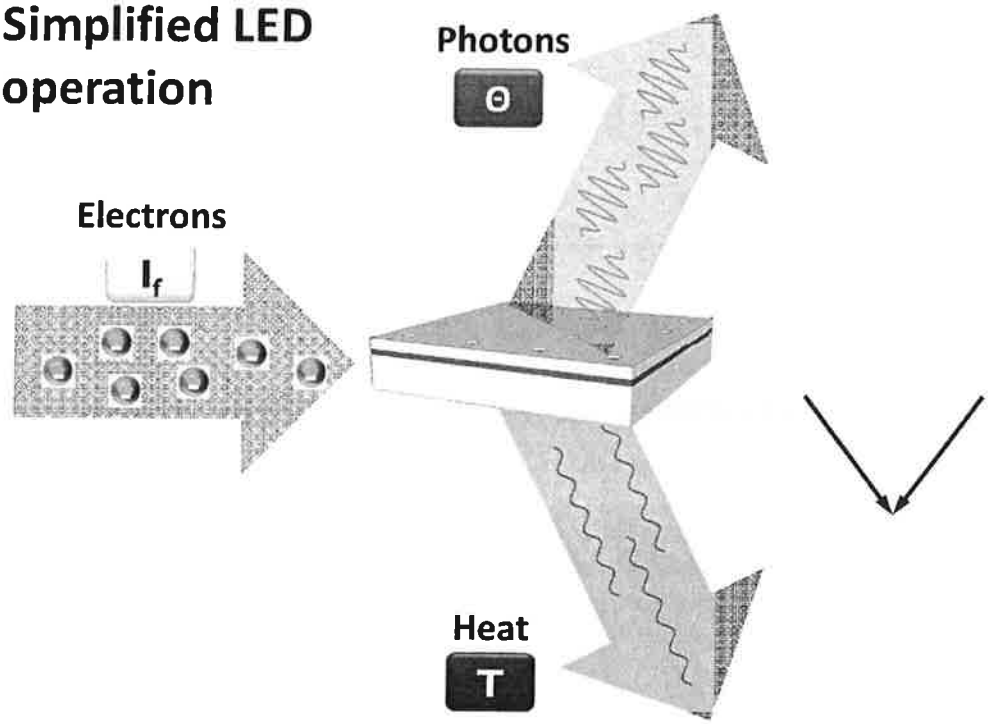
ILLUMINATION

# Technology LED

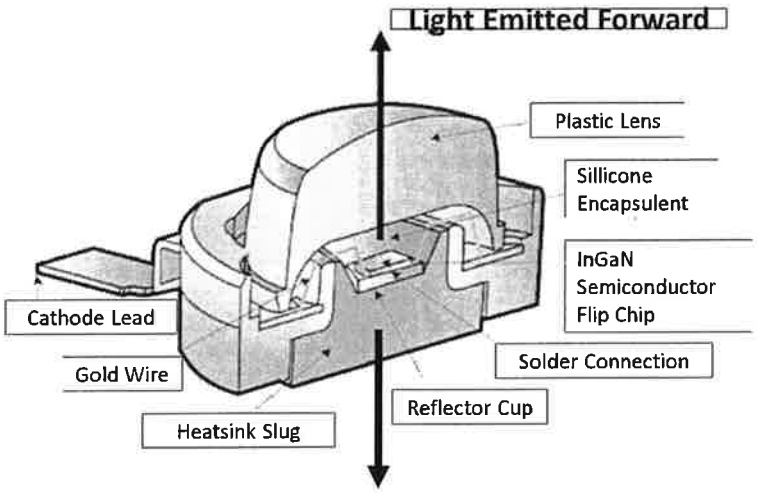





# Simplified LED operation

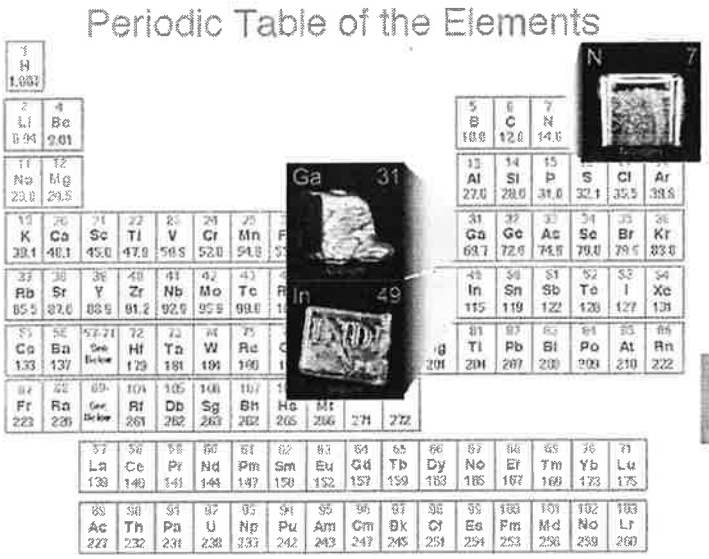


# LED heat has to be managed






# Blue Green InGaN LED

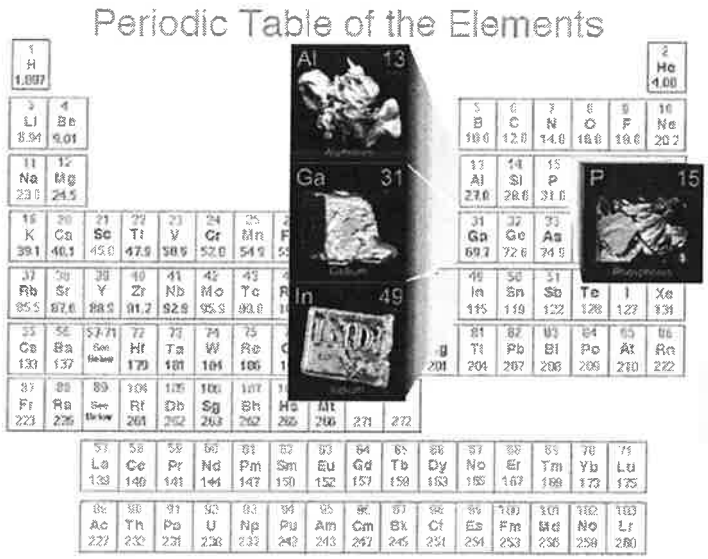



InGaN



Cold

# Yellow Red AlInGaP LED

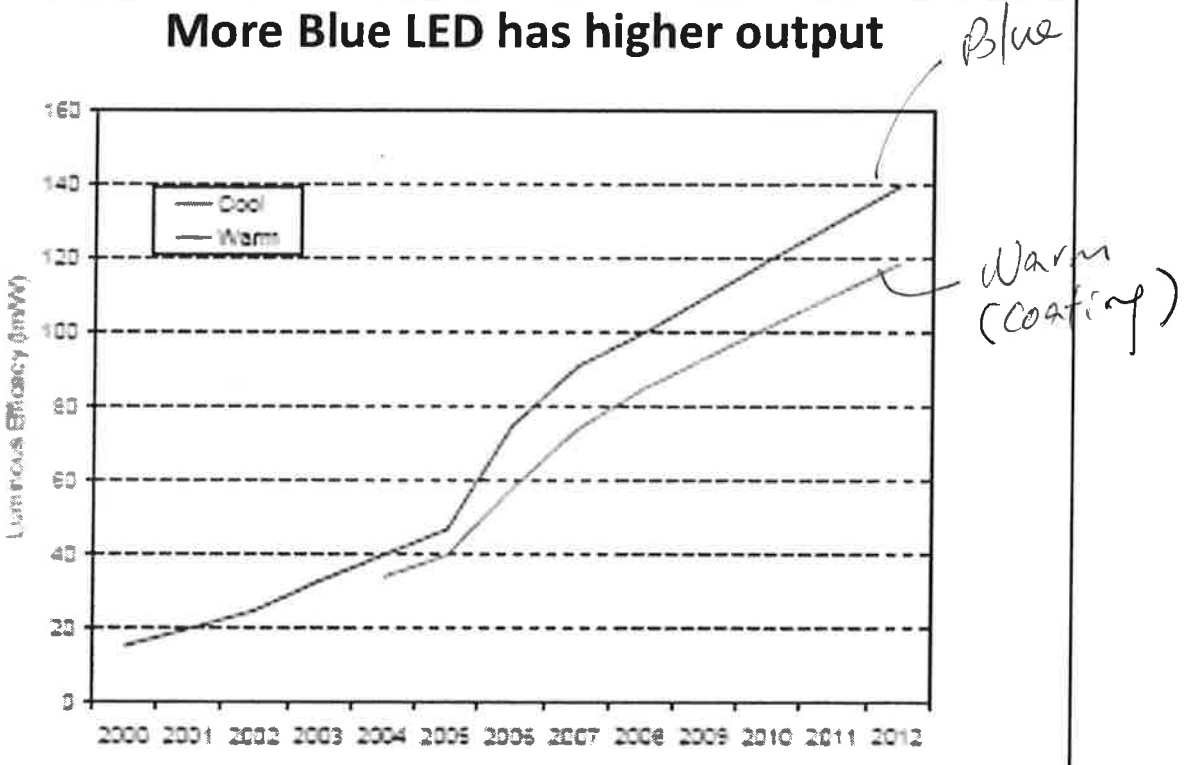



**AlInGaP**

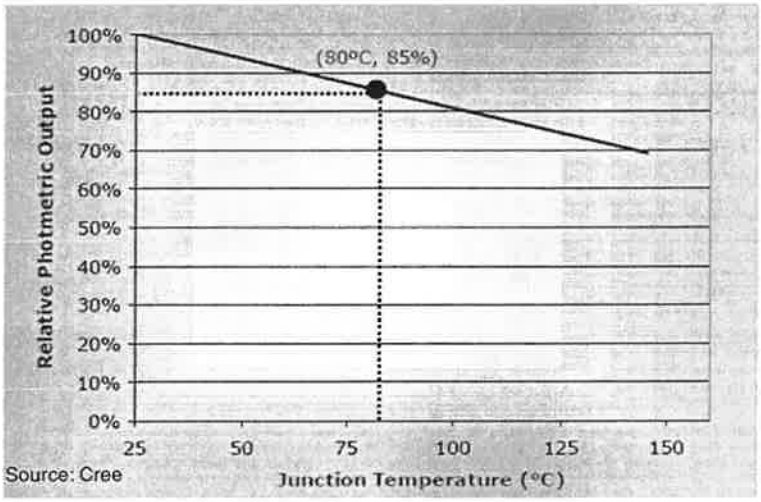
Warm



# More Blue LED has higher output



# Light output depends on Tj



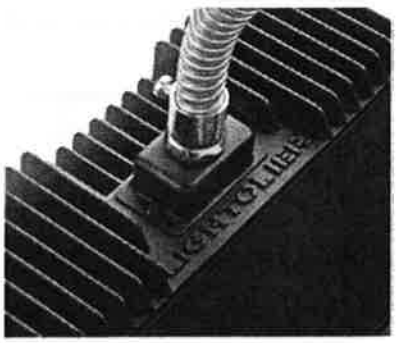

- Light output goes down as junction temperature goes up
- 100 lumens @ 25°C Tj goes down to 85 lumens @ 80°C Tj



→ light output at operating junction temperature

# The Heat sink

- A heat sink is typically required to dissipate the heat produced by the LED sources
- The interface between the circuit board and the heat sink is critical
- A thermally conductive material is typically used between the PCB and heat sink to minimize air gaps which reduce the transfer of heat





# Driver

- LEDs are typically driven by a constant-current DC power source
- High Power ED generally refers to a package of roughly 1.2W at a drive current of 350 mA
- Drivers also contain temperature sensitive electronic components



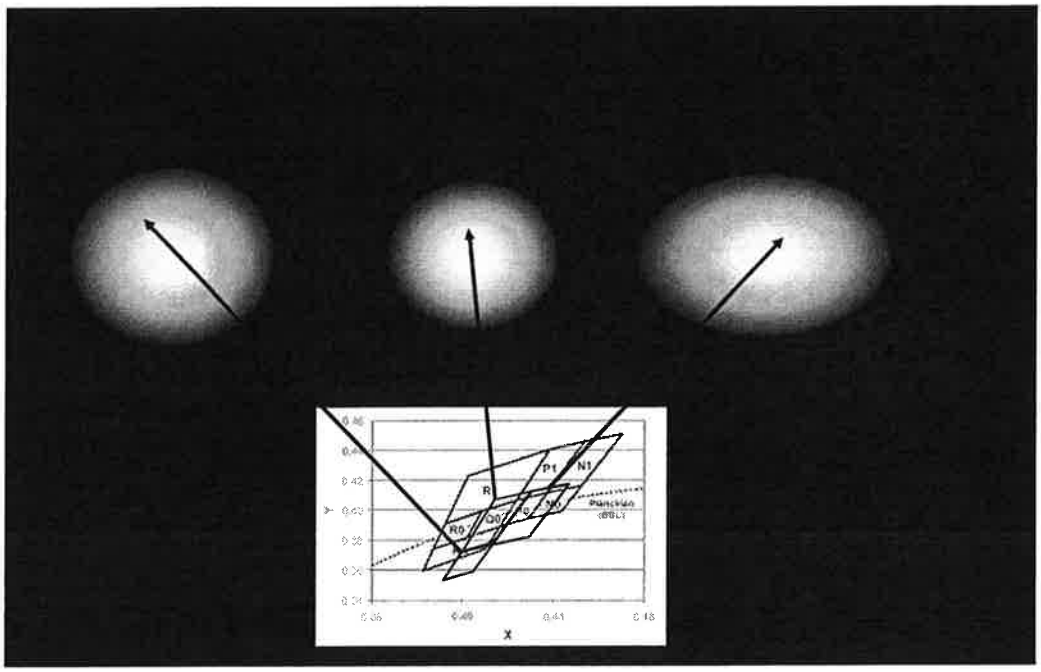




# Light Efficacy (Examples)

| Lamp | Power (W) | Light output (Lumens) | Efficacy Lumens/ Watt |
|---|---|---|---|
| Incandescent Lamp | 75W | 900 | 12 |
| Compact Fluorescent Lamp (CFL) | 15W | 900 | 60 |
| Fluorescent tube Cool Daylight | 36W | 2500 | 69 |
| Induction | 250W | 21250 | 85 |
| LED (Performance Level) | 1-5W | 30-600 | 30-120 |
| High Pressure Sodium | 400W | 56000 | 140 |

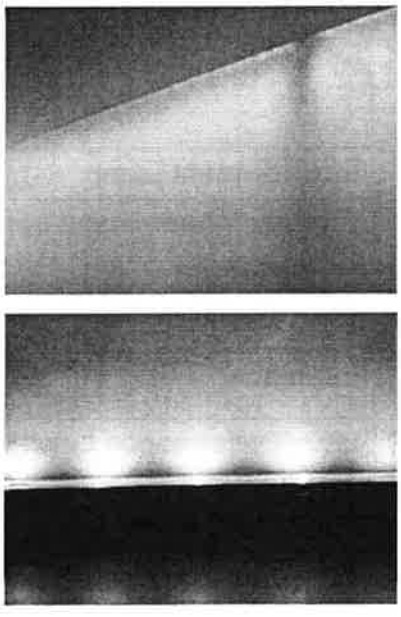
# LED Colour shift



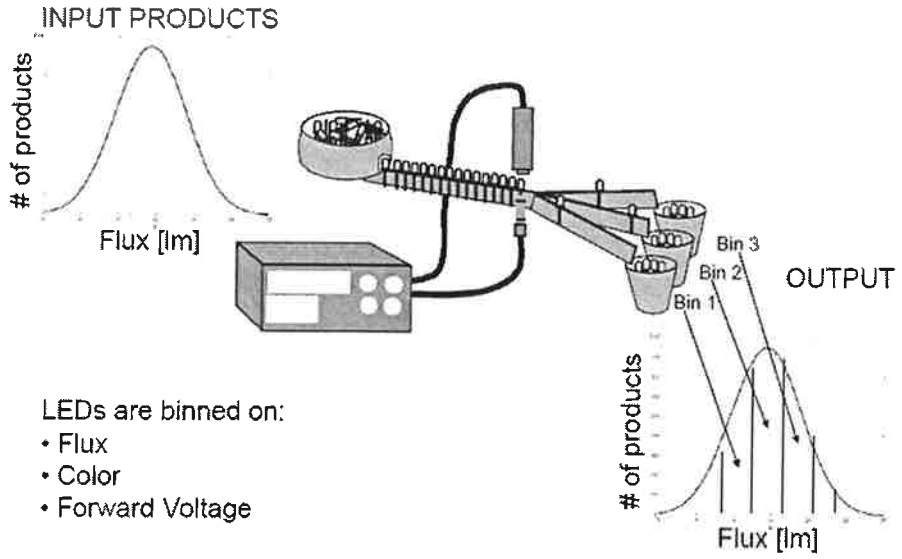



# Colour shift in applications

- In any array, you will inevitably have a mixture of LED sources with varying output and color
- LED source-binning and selection for fixture provide a solid foundation for success
- LED sources can exhibit color shift over life which increases with higher junction temperatures



# Binning of LED



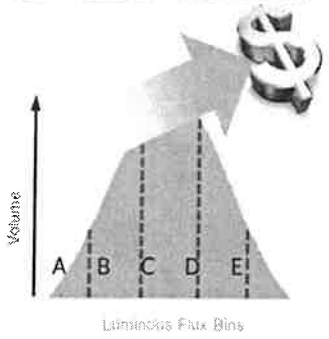

LEDs are binned on:
- Flux
- Color
- Forward Voltage



# Binning of LED

- Since individual LEDs are never exactly the same, those with similar performance are grouped together by manufacturers into bins
- Each LED manufacturer has its own unique bin parameters
- LED devices are typically binned separately by **output and color**
- Tighter the bin,or the higher the flux, the higher the cost (can be a factor of 2X-3X)





## Practical LED Applications now As per Dept of Energy US

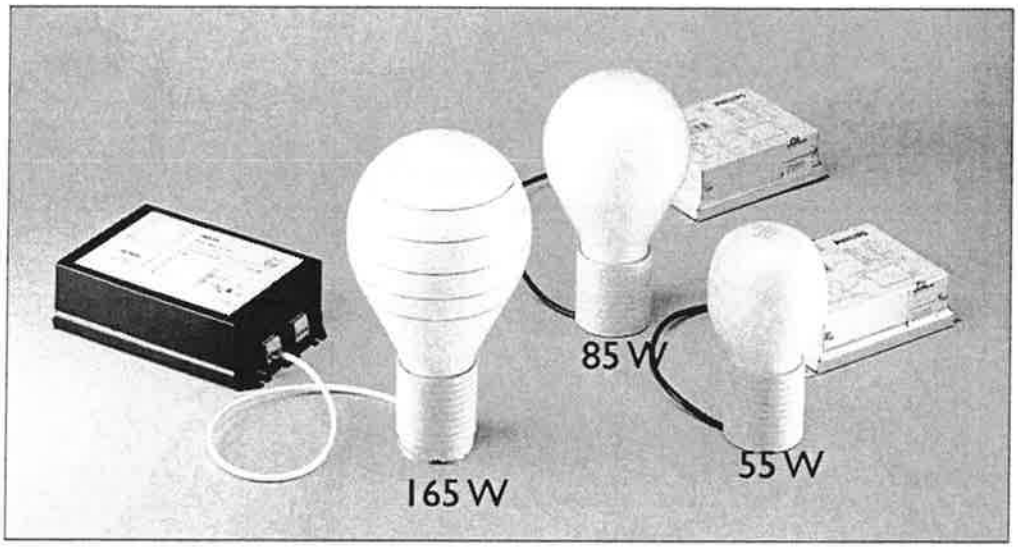
- Downlights, focused light applications
- Task lights, desk lights
- Social areas in hotels etc
- Under-cabinet
- Display cases, including refrigerated ones
- Lifts – vibration resistance, long life
- Public housing common areas – durability & minimum maintenance



## LED Summing up

- LEDs are available in Colours & White
- They already have many useful applications
- LEDs are more efficient and environment-friendly than Bulbs and CFL
- They will become more affordable in the coming years for work-place lighting

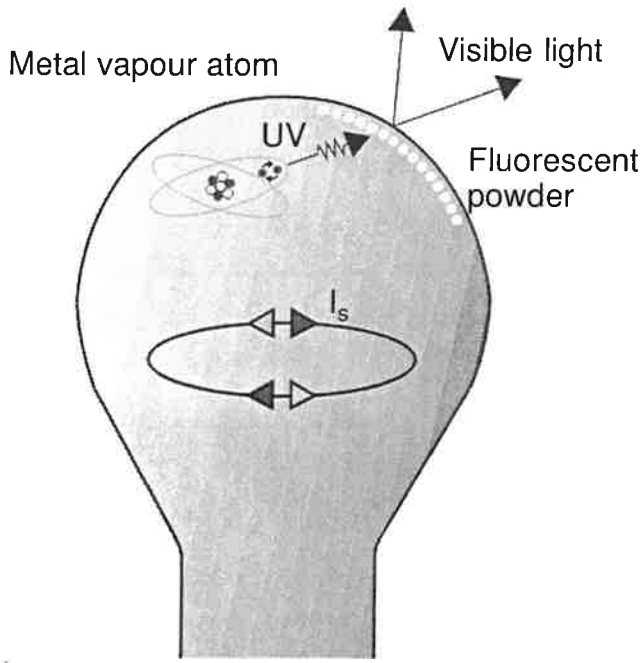
# Induction lamp family



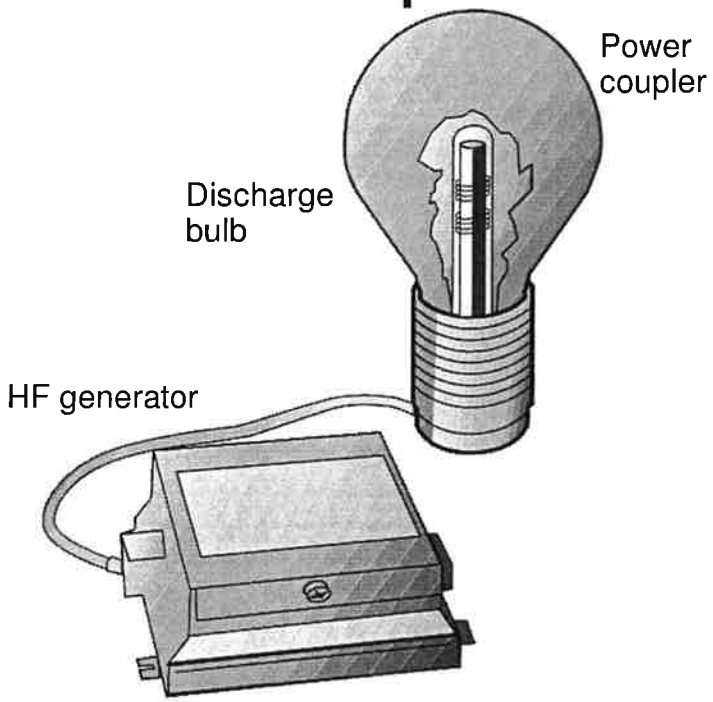



# Induction lamp

Discharge Principle

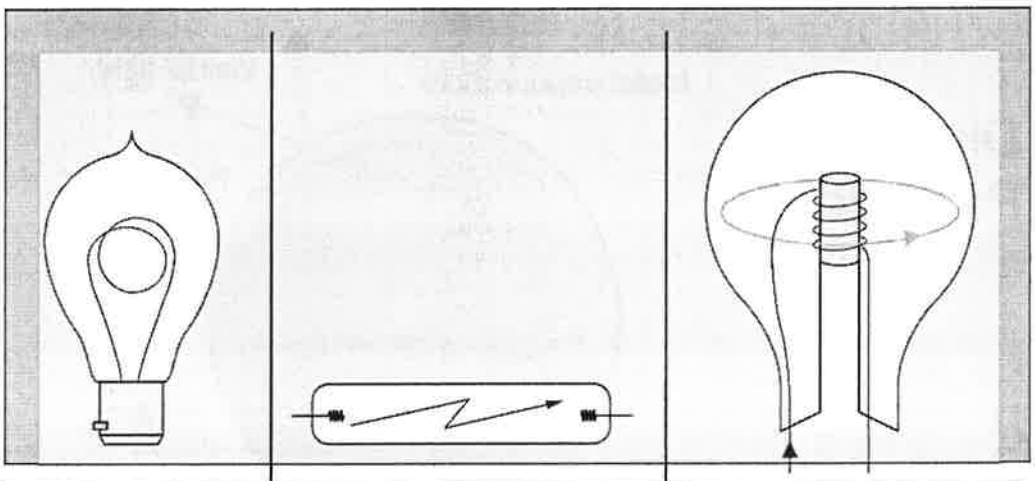


# Induction lamp






# Lifetime



| Incandescent lamp → 4,000 hrs | Conventional discharge lamp 1,000 → 20,000 hrs | Induction lamp 60 - 80,000 hrs |
|---|---|---|

# Changi Airport Budget Terminal



**Old : 150W Metal Halide**
**Height : 6m**
**Effect : Poor Lighting distribution**



**New: 100W Induction**
**Height : 6m**
**Effect : Even distribution**
**Comments : Energy Saving of 40%**



# Warehouse application





**Old: 400W Mercury**
**Height : 7m**



**New: 200W Induction**
**Height: 7m**
**Effect: same**
**Comments: Energy Saving 50%**

# Postal sorting bays

Singapore POST







**Old: 250W Metal Halide**
**Height : 4.5m**
**Effect : Nil**
**Comments : High maintenance cost**

**New: 150W Induction**
**Height : 4.5m**
**Effect : Better CRI**
**Comments : Energy Saving of 40%**



# LED Vs. Induction

| Parameter | LED | Induction |
|---|---|---|
| Luminaire Cost | 2 – 4 times that of HID | About 70% more than HID. |
| | | |
| Rated Life and Warranty | Approx 50,000 Hours | Approx. 80,000 Hours |
| Heat / Heat Sink issues of Components | Possible | No |

# LED Vs. Induction

| Parameter | LED | Induction |
|---|---|---|
| Energy Savings | ~50% | ~50% |
| Impact of High Ambient Temperature | Life & Lumen Depreciation | Hardly felt |
| Mercury | None. A sustainable advantage | Mercury is present as Amalgam. Because of Induction lamp's very long life, it is accepted within RoHS limits in Europe |



Thank you !

# Sustainable Lighting Design & Technology

## GMFP- GMP

## BCA Academy

## 5. Energy Management & Sustainability

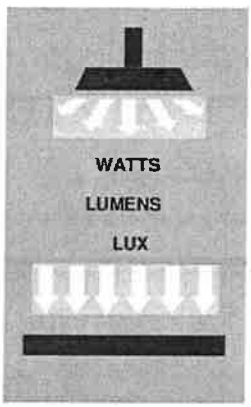




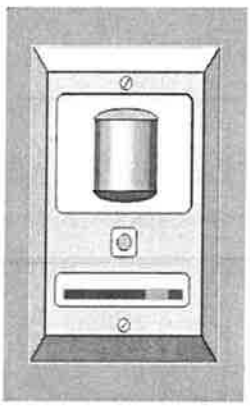
# 3 important aspects for saving energy




**Target lighting Level, CRI & Glare**




**Energy-efficiency**



**Lighting Controls**

# Relationship between Lamp and Energy

| Lamp | Ballast loss | Total | Life Hrs | Energy Consumed in lifetime | Cost of energy @S$ 0.30 per Unit | Lamp cost |
|---|---|---|---|---|---|---|
| Bulb 75W | Nil | 75W | 1000 | 75 KwHrs | S$ 22.50 | S$ 0.80 |
| 36W tube | 9W | 45W | 12000 | 540 KwHrs | S$ 162.00 | S$ 3.50 |

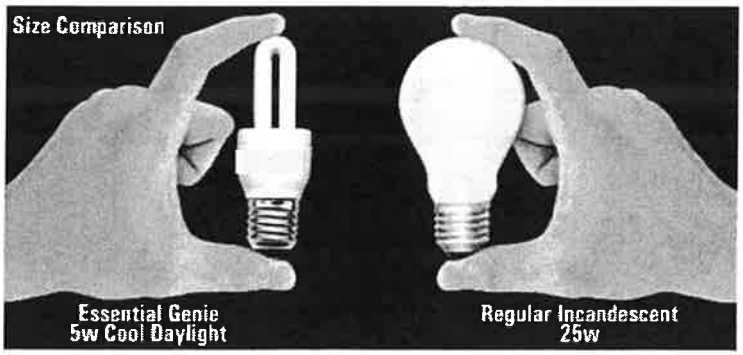
**A Lamp consumes about 25-45 times more Energy than its own price !**

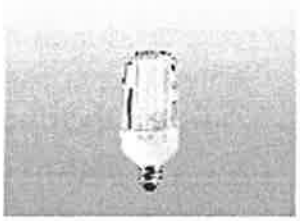


# Some practical energy saving ways

- CFL replacing the GLS incandescent lamp (retro-fit)
- CMH lamp replacing the Halogen lamp (new points)
- Tri-Phosphor tube replacing the Cool Daylight tube (retro-fit)
- Use of T5 tubes (new points)
- Electronic Ballast replacing Magnetic ballast (new points)
- Lighting Control & Daylight-linking (new points)
- LED White light for many applications (new points)

# Integrated CFL





**CFL 11W = GLS 60W**

**CFL 15W = GLS 75W**



# Savings with CFL Energy-saver

**Load reduction per point (60W - 11W) = 49W**

**Saving for 8000hrs life**
**= 8000 x 49 Watt Hrs**
**= 392 kw Hrs**

**At S$ 0.30 / kW Hr, money saved = $ 117.6**

**Avoiding 8 X GLS lamps @$ 0.80 each = $ 6.4**

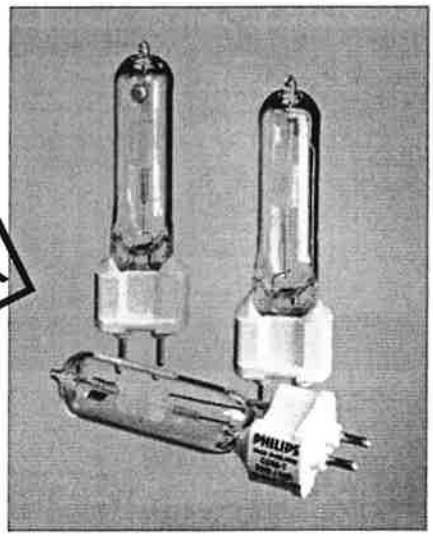
**Total savings by each Lamp = $ 124.00**

**CFL price = $ 8?**

# CMH Lamp

High beam intensities, high light output
High efficiency
Choice in 3000-4200K
Long life
Colour stability
High CRI
UV-block

**Best substitute for halogen !**






# CMH Vs Halogen at a Department Store

| New Lamps | Number | Total load including Ballast loss | Halogen 50W points replaced +10W | Total Halogen load including Gear loss | Load reduction Due to CMH | Energy saved for 4000 hrs per year KW Hrs |
|---|---|---|---|---|---|---|
| **CMH 35W** +10W | 1500 | 67.5 KW | 3000 | 180 KW | 112.5 KW | 450,000 |
| **CMH 70W** | 1000 | 80.0 KW | 3500 | 210 KW | 130.0 KW | 520,000 |
| | 2500 | 147.5 KW | 6500 | 390 KW | 242.5 KW | 970,000 KW Hrs ! |

X 22 days

# Energy Saving with Tri-Phosphor tubes

**30 % increase in illuminance ( Lux) !**

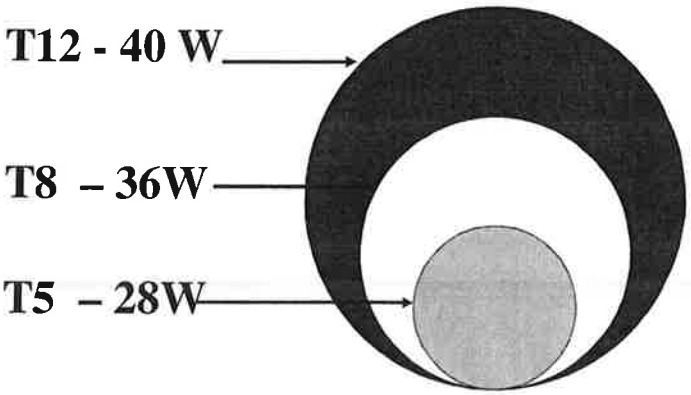
**Visual satisfaction and Colour appreciation will be superior**

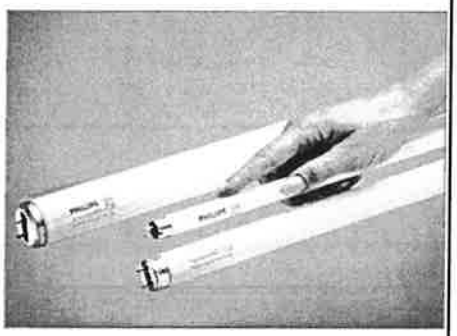
**You can use 30 % less luminaires**

**Electrical reduction, air-con reduction and savings in capital and energy costs**



# Advantages of T5



Fully recyclable fluorescent lamp (with no loss of quality)

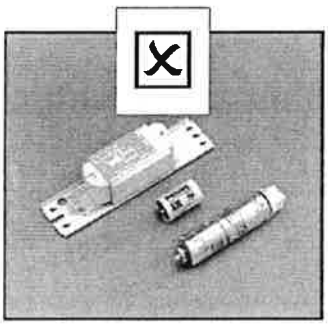
Lowest mercury content in the market

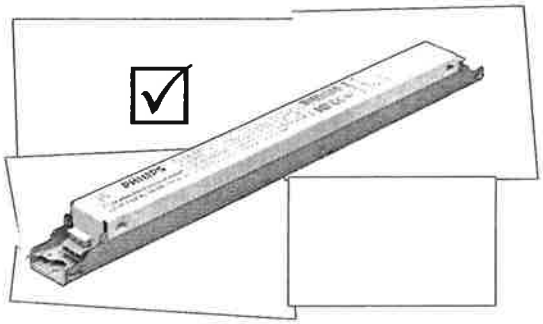
Maximum of 10% light-output loss over entire lifespan

Useful life: 20,000 hours with electronic ballast

# Why Electronic ballast ?

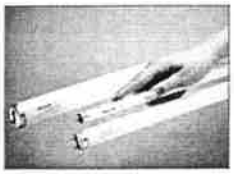
- Saves energy & running cost
- Easy to dim for flexible lighting level
- Visual comfort with less eye-fatigue
- Cooler operation of lamp & ballast
- Less Air-conditioning load
- Longer lamp life







# Use of LED lighting

| Lamp | Watts | Light output (Lumens) | Efficacy Lm / W | |
|---|---|---|---|---|
| Fluorescent tube Tri-Phosphor type 4ft with Electronic ballast | 32W | 3,200 | 100 |  |
| LED (in stabilised condition) with Electronic Driver | 5W | 600 | 120 |   |

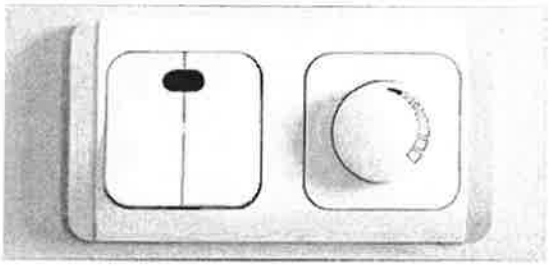
# Switches-Timers & Dimmers



**Switch off when room is unoccupied**



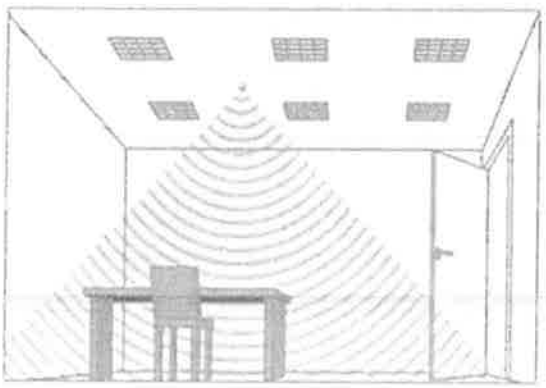
**Timers are useful for specified duration of use**



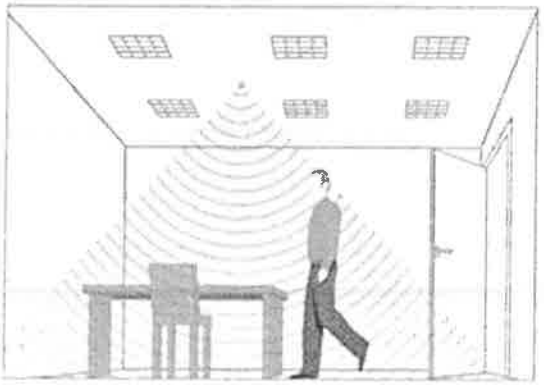
**Dimmer: Ensure that Fluorescent Luminaires Have dimmable ballast**



# Presence Detectors



No presence detected, lights off

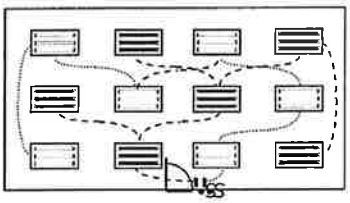


Presence detected, lights on

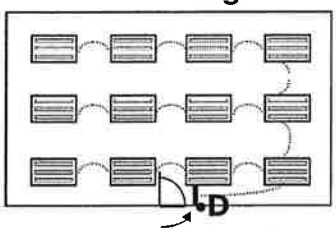
# Light reduction control

- ✓ Dimming all lamps or luminaires
- ✓ Dual switching of alternate rows or alternate luminaires or alternate lamps
- ✓ Switching middle lamp in luminaires independently from the outer lamps

**Alternate Luminaires**

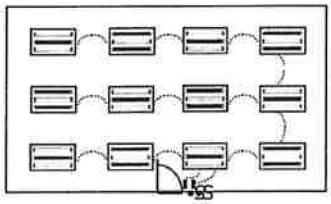


**Dimming**



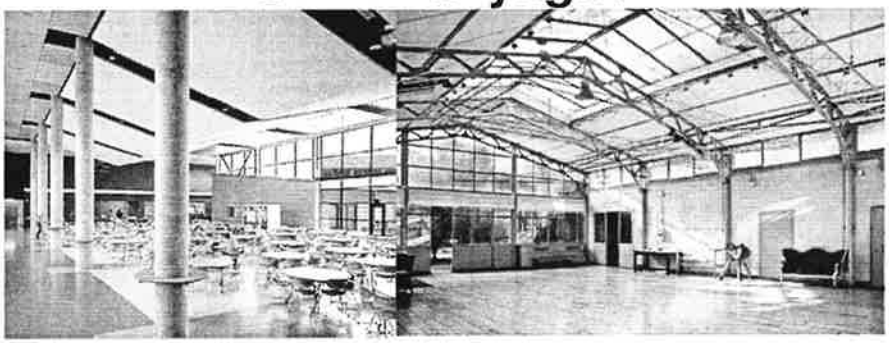

• ***Dimmer Switch***

**Alternate Lamps**





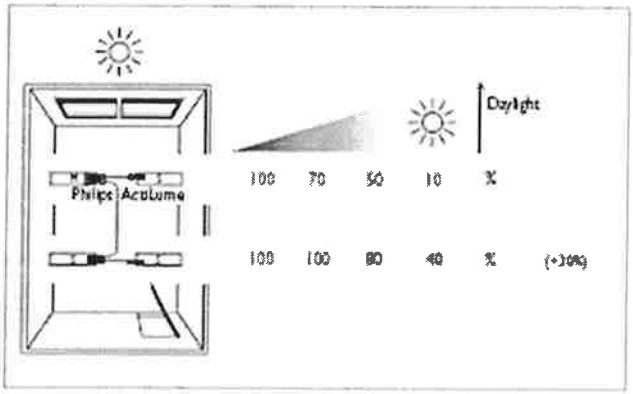
# Use of daylight



- Daylight can supplement electric lighting. However, daylight will vary with the time of the day, season of the year and orientation of building.
- SS 531-1 calls for the recommended illuminances to be maintained whether by electric lighting or daylighting or both.
- In Tropical climates like ours, daylight can allow substantial heat through windows. While it may save some lighting load, it may increase the Air-con load. Reckon with this, while recommending daylight.

# Daylight linking : a *green* tool

Automatic offset - no programming necessary




Thanks to the two outputs (window and corridor side), the settings of the lighting control are preprogrammed according to the place of the luminaire. Therefore the Philips ActiLume system does not require any programming or commissioning.



# SS 530: 2006 Power densities allowed

| No | Type of usage | Maximum lighting power budget Watts/M2 |
|---|---|---|
| 1 | Offices | 15 |
| 2 | Class rooms | 15 |
| 3 | Lecture theatres | 15 |
| 4 | Auditoriums / Concert halls | 10 |
| 5 | Shops / Supermarkets / Departmental Stores (including general, accent & display lighting | 25 |
| 6 | Restaurants | 15 |

# SS 530: 2006 Power densities allowed (Continued)

| No | Type of usage | Maximum lighting power budget Watts/M2 |
|---|---|---|
| 7 | Lobbies / Atriums / Concourse | 10 |
| 8 | Stairs / Corridors | 10 |
| 9 | Car parks | 6 |
| 10 | Electronic manufacturing and fine detail / Assembly industries | 20 |
| 11 | Medium and heavy industries | 15 |
| 12 | Warehouses / Storage areas | 10 |



# Total Cost Of Ownership (TCOO)

# Why TCOO?

A Customer's decision when based only on the initial price, can lead to:

Long term high energy expenditure

Frequent lamp replacements &

Defects & Maintenance !

TCOO is one way of highlighting such costs to help understand the most economic and most durable solution

Financial Decision-makers often prefer to know what is the long term costs (=TCOO) !



# Simple Payback

Simple Payback is the number of years it takes for the price difference between 2 energy saving alternatives (Price Delta) to be recovered via energy saved. It does not account for the time value of money and it also does not consider the savings that occur after the payback point.

Most private companies require a simple payback of 3 years or less. For state-of-the art materials, they will sometimes accept 4 to 5 year payback.

# Return on Investment – ROI

ROI is the inverse of Simple Payback and has all of the qualifiers of a simple payback. It does not account for the time value of money and also it does not consider the savings that occur after the payback point. It is sometimes called Rate of Return.

ROI is expressed as a percentage. It is often compared to other investment yields.



# What is Total Cost-of-Ownership

**= THE 'ANNUALISED' COST OF (INVESTMENT + MAINTENANCE). In other words, if the lighting installation has a life of 10 years, we have to calculate the cost of owning it each year.**

## Total Cost-Of-Ownership

Annualized Capital Cost =

**Taken at 10% of initial investment on Luminaires excluding cost of lamp which has shorter life. *Lamp-replacements are treated under annual maintenance cost (next)***



## Total Cost-of-Ownership

Annual Maintenance =

- Energy cost / yr = (Load KW x Burning hrs per year) x Tariff charge per KwHr

- Lamp cost = Pro-rated for each year =

$$\frac{\text{( No.of lamps x price per lamp x Burning hrs per year)}}{\text{Lamp life in hours}}$$

- cleaning charges

# Total Cost-of-Ownership

How to reduce other Maintenance costs?

lamp with long life and low early failure rate
ballast with low loss & long life
luminaire with correct IP rating
luminaire which is easy to maintain
-- 'Group' replacement of lamps

Inrush Protection



## Life Cycle study of same luminaire with EM or EL ballast

| | | 2 X EM ballast | 1 X EL (Twin) ballast |
|---|---|---|---|
| 1. | No. of luminaires (say) | 100 | 100 |
| 2. | Price of Luminaire | S$ 80 | S$ 100 |
| 3. | Luminaire cost | S$ 8000 | S$ 10000 |
| 4. | 10% depreciation / yr | S$ 800 | S$ 1000 |
| 5. | Two lamps' load | 72W | 64W |
| 6. | Two lamps' Ballast loss | 18W | 8W |
| 7. | Total luminaire load | 90W | 72W |
| 8. | Load for 100 lums | 9.0 KW | 7.2 KW |

# Life Cycle study of same luminaire with EM or EL ballast

| | | 2 X EM ballast | 1 X EL (Twin) ballast |
|---|---|---|---|
| 9. | Energy for 4000 hrs / yr | 36000 KW hrs | 28800 KW hrs |
| 10. | @ 30 cents / KW hr | S$ 10800 | S$ 8640 |
| 11. | Lamp life | 12000 hrs | 15000 hrs |
| 12. | Lamp replacements / yr | 67 | 53 |
| 13. | Price of spare lamp | S$ 4 | S$ 4 |
| 14. | Lamp replacement cost | S$ 268 | S$212 |
| 15. | TCOO (4 + 10 + 14) | S$ 11868 | S$ 9852 |
| 16. | Annual savings with EL | --- | S$ 2016 |
| 17. | Initial Lums extra cost | --- | S$ 2000 |
| 18. | Time to recover it | --- | Just 1Yr ! |



# Thank you !

# GMFP-GMP (BCA Academy)
# Sustainable Lighting Design & Technology
## Energy saving and Life Cycle study

MF = 0.8 . UF.

The Imperial Shopping Centre is renovating its premises. They plan to use recessed down lights with Halogen lamps. Their M&E consultant has designed with 1000 x Halogen 50W down lights to provide an average illuminance of 300 Lux. The Imperial Owner prefers a warm ambience, small circular downlights on the ceiling and CRI of at least 90 . However, he feels there would be a lot of heat and high energy consumption from Halogen lamps. So he has asked the M & E consultant to approach you as a Green Mark Professional.

You can consider the lamps and luminaires from the list overleaf. Please study and select one of them keeping in mind the customer preference. You have to present your case to Imperial Owner through a Total Cost Of Ownership (TCOO) study.

Their ceiling is quite high and so the uniformity of light will be acceptable even if the number of luminaires is reduced.

**You may use the following data:**

All three luminaires (shown further) have the same Utilization Factor.
Lighting level is directly proportional to total lumens installed. So to produce the same lighting level, there can be less luminaires if the lamp output is more.
Annual usage of lighting = 4000 hrs.
Energy tariff = S$ 0.30 per KW Hr.

$N_1 = \frac{300 \times L \times W}{1200 \times 1 \times UF \times MF}$

$N_2 = \frac{800 \times L \times W}{3300 \times 1 \times UF \times MF}$

$N_2 = 1000 \times \frac{1200}{3300}$

$\Rightarrow N_2 = 364 \text{ nos}$

Sustainability Case Study –
**Imperial Shopping Centre**
(Alternatives to choose from)

| System | Product | Price of each product S$ | Output of each Lamp (Lumens) | Ballast loss per lamp (W) | CRI | Lamp life |
|---|---|---|---|---|---|---|
| A | Presently specified Halogen Downlight (without lamp)<br>Halogen Lamp 1 x 50W | 30.00<br>3.00 | 1200 | 12W | 100 | 3000 hrs |
| B | Recessed fluorescent luminaire suitable for twin T5 lamps<br>T5 Lamp 2 x 14W | 80.00<br>6.00 | 1200 | 3W | 85 | 15000 hrs |
| C | Ceramic Metal Halide (CMH) Downlight<br>CMH Lamp 1 x 35W | 150.00<br>30.00 | 3300 | 10W | 90 | 12000 hrs |

Qty 1000

300 lux

| | Halogen | CMH | Net Diff. |
|---|---|---|---|
| No. | 1000 | 364 | |
| | $30 | $150 | |
| capital cost | $30,000 | $54,600 | 24,600 |
| Depreciation | $3,000 | $5,460 | |
| Energy Cost | (50+12)W×1000 ×0.30×4000 = $74,400 | (35+10)W×364 ×0.30×4000 = $19,656 | |
| Lamp cost | $1000 \times \frac{4000}{3000} \times 3$ = $4,000 | $364 \times \frac{4000}{12000} \times 30$ = $ ~~4247~~ 3640 | |
| TCOO | = $81,400 | $ ~~29,363~~ 28,756 | Diff = ~~$52,037~~ $52,614 |