LIGHTING DESIGN CALCULATION EXERCISE
(Lumen Method)

- Area = 48m x 20m x 2.8m
- Design illuminance = 500 lux
- Luminaire = TCS214 / 2 x 36W with C6 Mirror
- Lamp = TLD36W/840 x 2 lamps
- Maintenance Factor = 0.85
- Room Reflectance = 70, 30 and 10
- Light output per lamp = 3275 lm
- Ballast loss = 8 Watts for 2 lamps
- Usage = 10 hrs / day
- Energy tariff = 20 cents (S$) per kW hr.

Question

1) Estimate the no. of luminaires using the lumen method.
2) What is the load in Watts/Sq m?
3) There are 140 staff members in this office. How much is the Energy cost per day per staff?

July 2007

Utilisation Factor (UF) Table

Luminaire : TCS214/236 C6
Lamp : 2 x TL-D36W/840
Measurement code : LVK0148500-00
Measurement status : Released
Utilisation Factor Table

Room index K	Reflectances (%) 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 calculated acc. to CIE publication 40 and 52										LVK0148500-00

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Part 1: Basics, Units, Measurements and Principles of Lighting

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Self Introduction

- Name
- Organisation
- Function
- Expectation from this course

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Ways to enjoy and benefit more

- Turn-off or silence your mobile phone
- Be punctual (after also the break !)
- Speak up anytime !
- Take notes in the material provided
- Be here!

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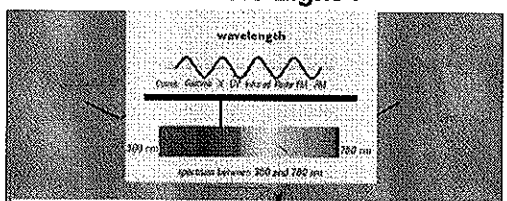
What is Light ?



- *Light is electromagnetic radiation(similar to radio and TV waves) travelling in space*
- *Creates the sensation of 'vision', when enters our eyes*
- *Light is thus a perceived phenomenon & depends on the sensitivity of eye*

Invisible until it hits a surface.
cosmic - short wavelength and high freq.
380nm - violet 780nm - Red
>780nm - Infra Red
<380nm - Ultra violet
visible in vacuum 710,000nm

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Definitions and Terminology

- Luminous flux ϕ
- Luminous efficacy η
- Colour temperature Tk
- Colour rendering Ra or CRI

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Luminous Flux (= Light output)

Total quantity of light emitted by a light source per second

Unit Lumens

Symbol ϕ



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Luminous Flux (= Light output)

Lamp type	Power	Light output (lumens)	Luminous Efficacy Lumens / W
Torch Lamp	3W	30lm	10
Incandescent Lamp	GLS 75 W	900lm	12
Compact Fluorescent Lamp (CFL)	PLEU 15W	900 lm	60
High Pressure Mercury Vapour Lamp	HPLN 400W	25000 lm	63
Fluorescent Lamp Cool Daylight	TLD 36W/54	2500lm	69
High Pressure Sodium Lamp	SONT Plus 400W	56000 lm	140
Low Pressure Sodium Lamp	SOX-E 131 W	26 000 lm	200

18,000 lm ?

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Efficacy - η of the lamp only

Efficient - η of the fitting, including ballasts

Compact fluorescent includes ballast - hence called energy saver and compared with incandescent lamp

HPS → η but warm feeling - street lamps.

Lux level @ entrance to tunnel - 7000 lux international specification.

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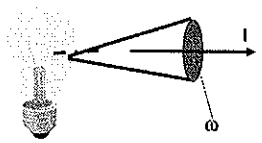
Luminous Intensity I



Light output in a certain direction, radiated per solid angle (of steradian = ω

$I = \frac{\text{Luminous flux}}{\text{Solid Angle}} = \frac{\Phi}{\omega}$

Unit : Candela

Symbol : I

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3 X 18 W — 3600 lumen - light radiates in a wide angle so not blending. Downlight a torch with 30 lumen output but radiated in a small angle is blinding.

Smaller the light source - brighter the intensity.

Fluorescent - low intensity discharge lamp. (LID)

Mercury - HID.

Fluorescent light - low intensity only can't throw light up to 5m

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Luminous Intensity

Some practical examples

Torch lamp (open)	2.5 cd
Torch lamp with reflector	250 cd
Dichroic Halogen lamp 12V 50W 36Deg	1800 cd
ArenaVision 2kW floodlight	3 Million cd



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Training Room = 36 lamps x 1200 lumens =
Area of Room = 6m x 8m

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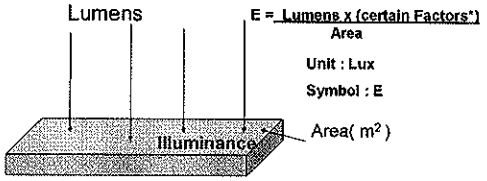
Illuminance (= Lighting level)

Luminous flux incident on a surface divided by the area of that surface : also called Lighting Level



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

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room reflectances, fitting q, lamp depreciation will reduce the actual lumen.

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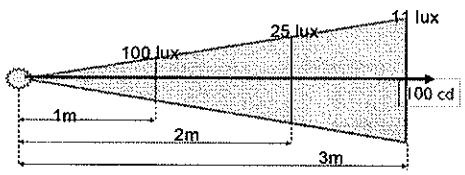
Inverse Square Law



As you go away from the lamp or fitting , the illuminance will reduce inversely proportional to the square of the distance from the lamp

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umbra, penumbra

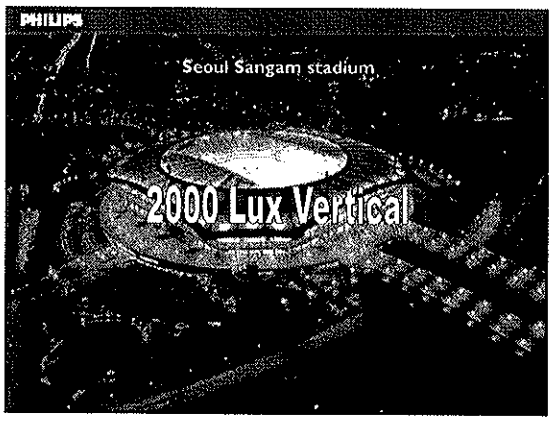
100/1² : 100 lux

100/2² : 25 lux

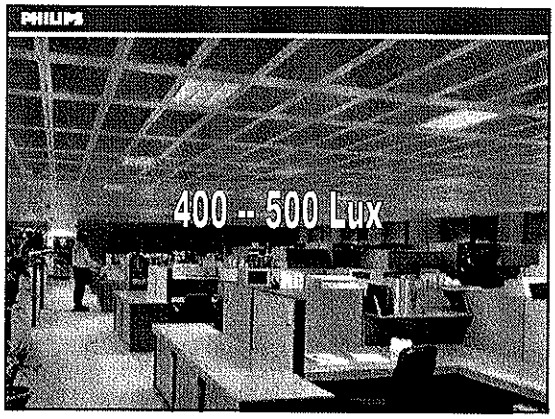
100/3² : 11 lux

As the light source is further away, the area illuminated will increase but the illuminance will decrease.

+ 2 methods to cal. lux. – lumens / area receiving light
– Int units / distance²



For good colour Telebroadcasting, you need 2000 lux.



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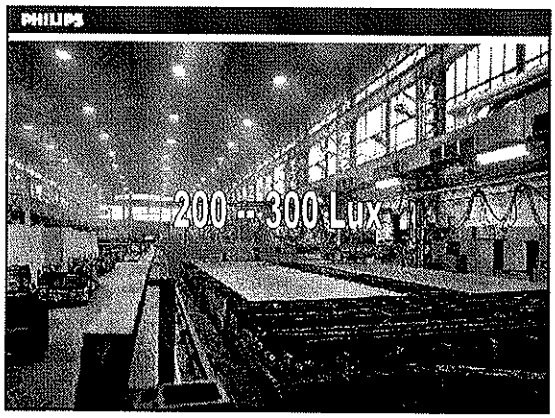

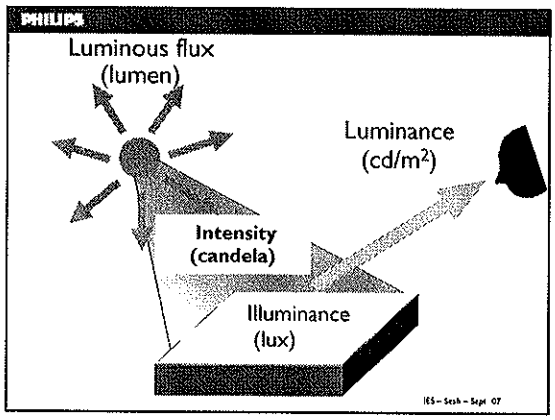

Reflectance of the object affects what we see.
Luminance is what we see; unfortunately it is a vector, direction dependant, hence luminance will vary. Therefore, we cannot use luminance to define the lighting level, use lux. (Scalar)

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Luminance

Some practical examples

Fluorescent lamp	5000 - 15000 cd/m^2
Surface of the full moon	2500 cd/m^2
Sunlit Beach	1,500 cd/m^2
Road Surface lighted at night	1 - 2 cd/m^2 30/lux

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circulation area - measure @ 1m

under shade of tree - 10,000 lux

outdoor - 100,000 lux

Full moon - 0.25 lux

Stars (New Moon) - 0.05 lux

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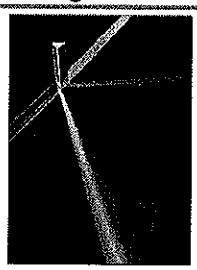
Light Consists of Colours



- Light waves constituted of colours
- Light can be split into its component colours
- Each colour is identified by its *wavelength*

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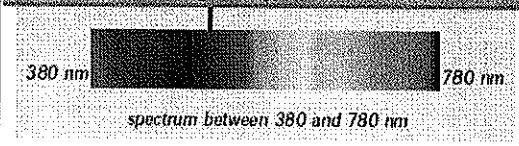
Light Spectrum



- Wavelength of 380nm - 800 nm is occupied by *Light waves.*
- *It is identified by colours Violet to Red*

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Colours perceived

380 nm — 780 nm

Colour impression	Wavelength (nm)
	630-780
Orange	600-630
Yellow	565-600
Green	500-565
	435-500
Violet	380-435

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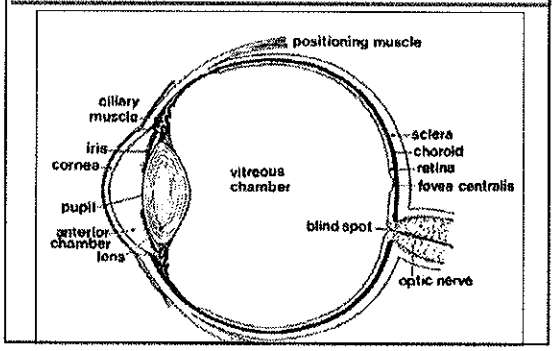
Human Eye is the Light Sensor



near object – convex

far object – concave . – stretch

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Visual Ability

Depends on :

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

Age has a negative effect on Visual Ability

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Age vs Illuminance

(For continuous Working)

12 years = 200 lux

40 years = 600 lux

60 years = 3000 lux

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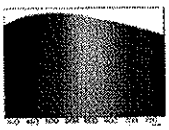
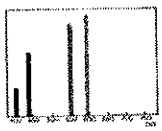
Light generation

By Thermal Radiation
Continuous Spectrum



Example :
Sunlight

By selective Radiation
Line Spectrum



Example :
Discharge Lamps
Xenon, Mercury

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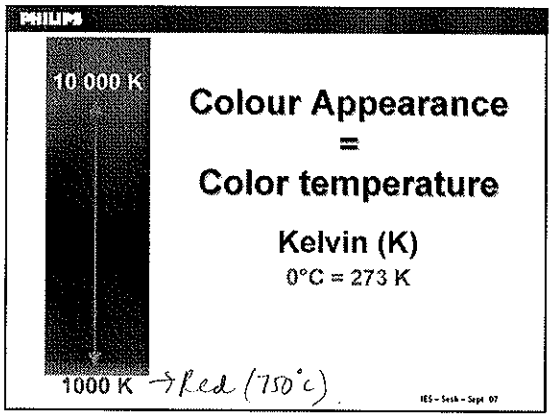
Colour Criteria

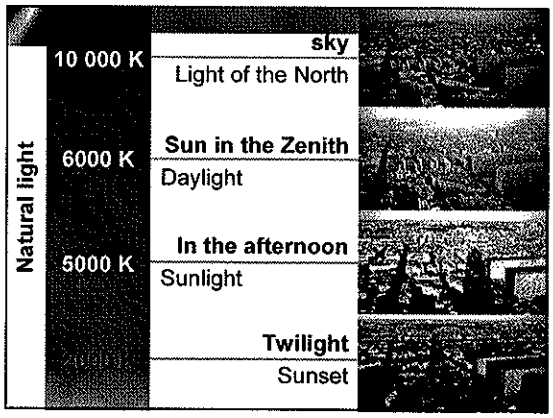
Colour Appearance of Lamp

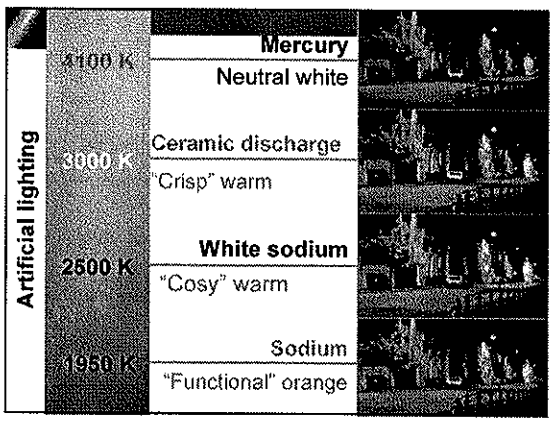
Colour Rendering of Objects

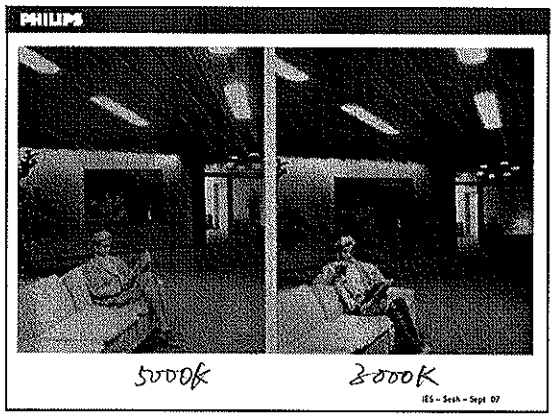


yellow flame is not as hot as blue flame
heat a piece of metal – red – white – blue
hotter it is, the more blue it appears
Temp. of blue sky – 10,000K

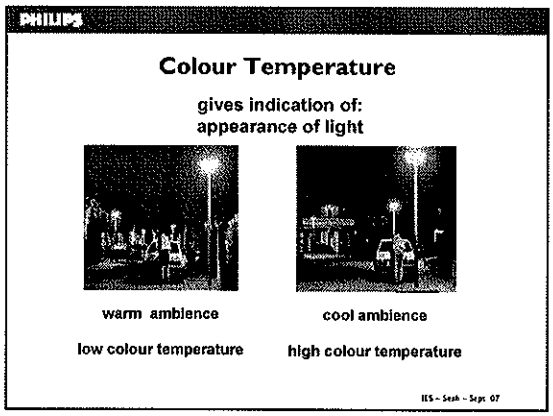
Physical temp. is not related to colour temp.
Fluorescent tube: physical temp = 55°C
colour temp = 4000K

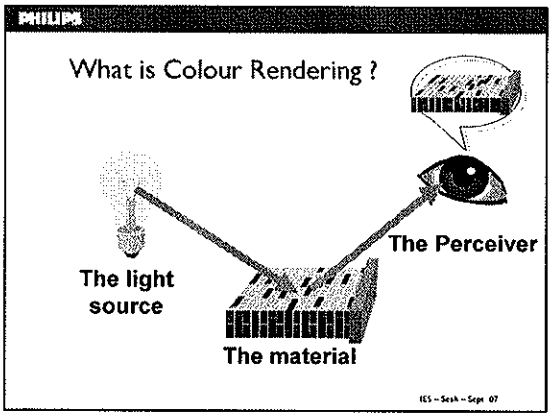






Tropical countries - 4000 - 5000k; cooler
Temperate countries - 3000°K; warmth

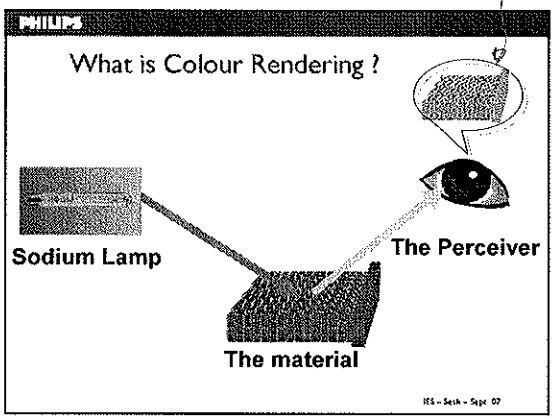


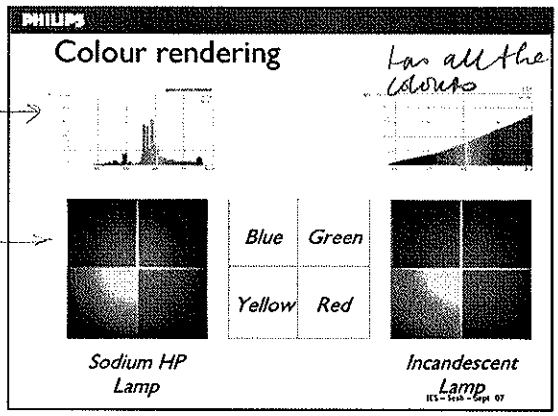


The incandescent lamps, gives light whose frequency is or or the full spectrum.

Rendering - how the object looks to you.

objects looks yellow though the colour of the object is not yellow.





does not have all the colours

blue looks green.

has all the colours

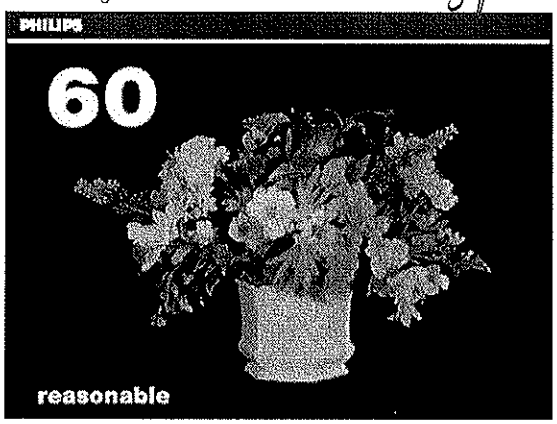
(Sun)

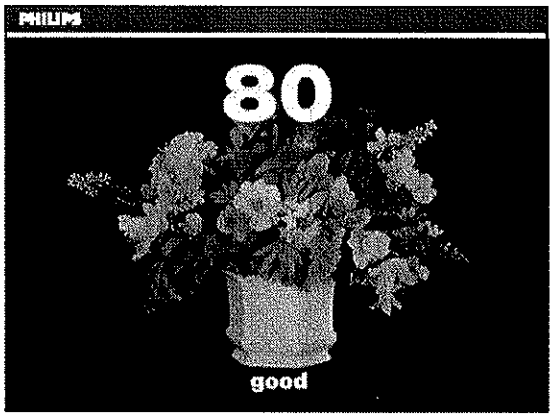
Full colour rendering – 100 (CRI)

Incandescent – 100 } Filament lamps

halogen – 100 } shop lighting - bring out the colours of the products.

Colour rendition using fluorescent

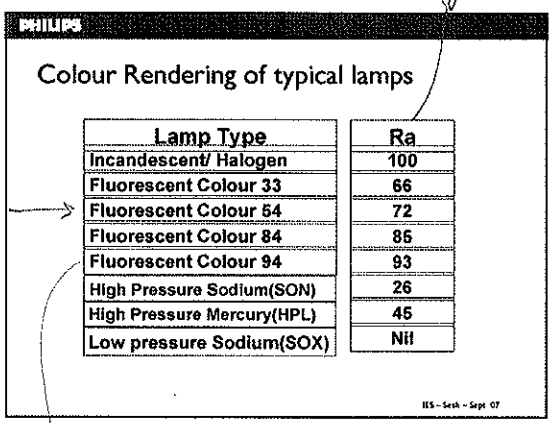






Fluorescent lamps

Rendering absolute



Working Daylight

powder is very expensive

Driving – must see 80m ahead to brake

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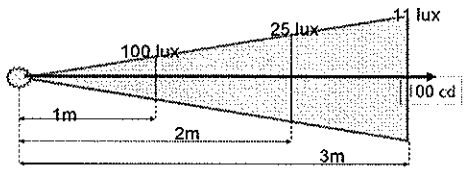
Inverse Square Law



As you go away from the lamp or fitting , the illuminance will reduce inversely proportional to the square of the distance from the lamp

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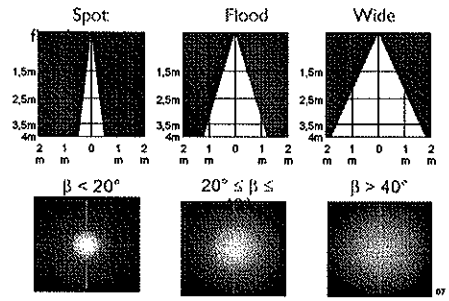
Classification of beam spreads

(e.g. reflector lamps) all same wattage



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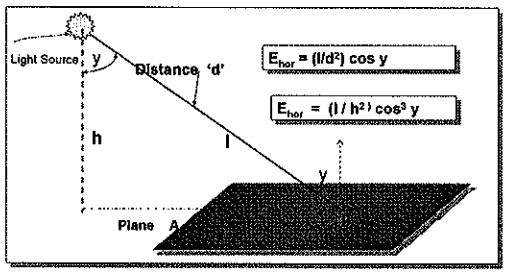
Cosine Law – Horizontal Illuminance



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Lighting.

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dialux patch

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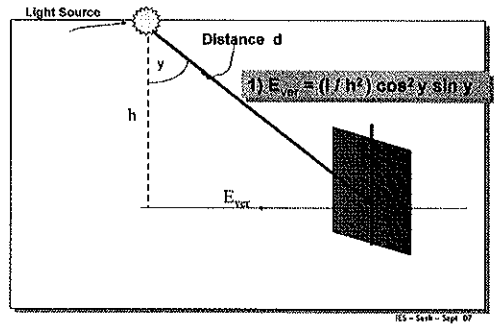
Cosine Law Vertical illuminance



1) $E_{ver} = (I / h^2) \cos^2 y \sin y$

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Tunnel Effect Syndrome

well recognised from

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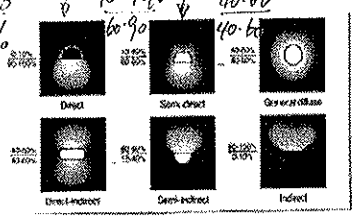
Different Light Distributions

0-10%
90-100%

10-40%
60-90

40-60
40-60



40-60
40-60

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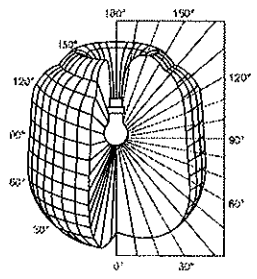
Light distribution in a 3D space



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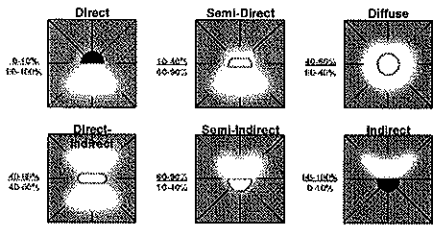
Classification of Light distributions



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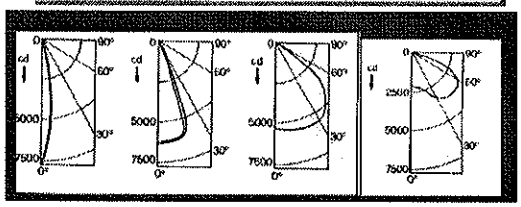
Light Distributions : Beam Shapes



Narrow Beam	Medium Beam	Wide Beam	Batwing distribution

They are usually plotted in Cd / 1000 lumens of lamp output

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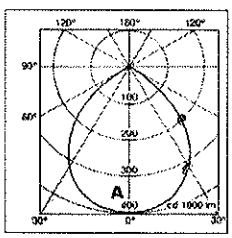
Light Distribution Diagram



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Intensity at 0°c = 400 cd/1000lm.

Light o/p of 2 x TLD36w/84c = 6500/m

Real intensity = $(400 \times 6.5)/3^2 = 288$ lux

Illuminance @ 3m.

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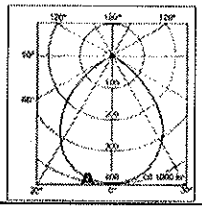
Light Distribution Diagram

Intensity at 0 deg vertical = 400 cd / 1000 lm
Light output of 2 x TLD 36W / 84 = 6500 lm

Questions:

What is the actual intensity at 0 deg ?
What is the illuminance, if Point A is at 3Metres from fitting ?



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$\frac{400\ cd \times 6.5}{3^2 (=9)} = 288\ lux.$

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Part 2: Interior

Lighting Design Principles

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Changing Scenario of Offices











Cost of Lighting : 70% for every $100

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Changing Scenario in Offices

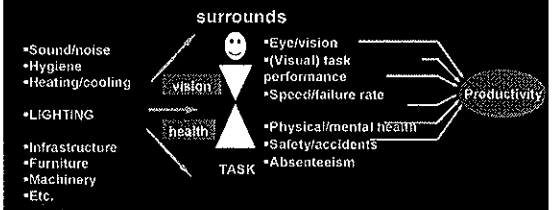
What does this mean for Lighting ?

Change in Lighting Parameters

• Lighting Equipment	: 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 ??

What is good Lighting ?

WORKING ENVIRONMENT



Lighting is a Facilitator of ***vision and health***

Unified Glare Rating

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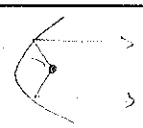
SS 531 – 1 Standard 2007 2006

Sl.No	Type of Interior	E (Lux)	UGR	Ra
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

Imndia.
T5 - 6/8/11



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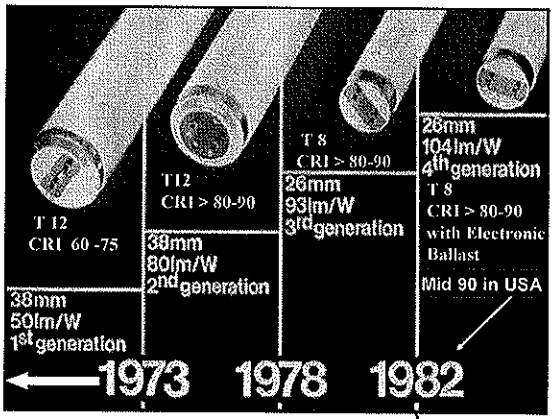
Trends in Lamps

LAMPS

- **More lumens / watt**
- **Higher Colour Rendering**
- **Choice of Colour Temperature**
- **Slimmer Dimensions**

IES – Sesh – Sept 07

Too small light tube, light too intense, will cause glare.



low loss ballast → ← HF Ballast

T = 1/8; T12 - 12/8

CRI > 80

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Fluorescent Lamps Type Nos

Lamp	CRI	Col Temp	Light Output
TLD36W/ 827	>80	2700 K	3200 lm
TLD36W/ 830	>80	3000 K	3200 lm
TLD36W/ 840	>80	4000 K	3350 lm
TLD36W/ 850	>80	5000 K	3200 lm
TLD36W/ 865	>80	6500 K	3200 lm

Changi Airport T2 →

NTUC Supermarket →

cool daylight homes, art gallery, →

IES – Seth – Sept 07

The lower the no, the warmer it is.

→ halogen RA = 100

surgery → 20,000 ~ 30,000 lux

→ general level – 2000, RA = 90

GH uses all RA = 90

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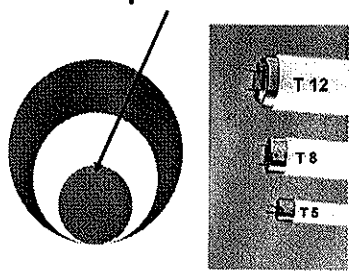
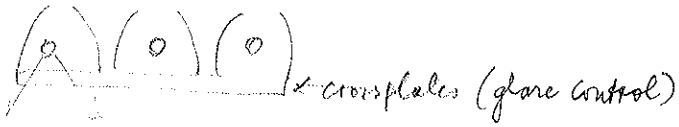
T 5 lamp - 1995



10yrs

IES – Seth – Sept 07



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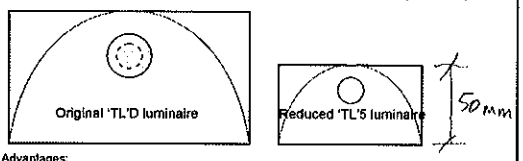
TL5 and OLC Optics

Omnidirectional Luminance Control (OLC)



Advantages:

Precise control of light distribution

Low luminance at all viewing angles : Good Glare Control

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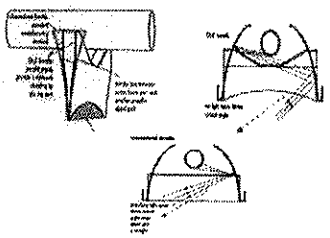
TL5 : Optics



OLC Lamellae offer

- *Optimal efficiency*
- *Avoids Patch luminances*

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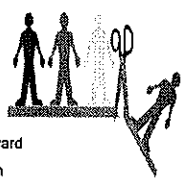
Optical Systems : Evolution

- Bare Battens
  - ➢light in all direction
  - ➢lamp visible .. glare
  - ➢Basic look
- White reflector
  - ➢upward light directed downward
  - ➢no "shape" in light distribution
  - ➢lamp still visible .. no ambience



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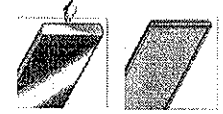
Optical Systems : Evolution

- Opal/Prismatic cover
  - ➢ diffused lights
  - ➢ lamp not visible .. glare reduction
  - ➢ decorative look
  - ➢ high absorption
  - ➢ reduction in efficiency
- Mirror systems
  - ➢ "Shaping" light distribution
  - ➢ Controls glare
  - ➢ Improves System and energy efficiency





* Diffuser reduce glare but absorpt alot of light

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Optical Systems : Evolution

- Mirrors
  - *Precise control of light distribution*
  - *Directs light to "where needed"*
    "The right light at the right place"
- **Consist of**
  - Side Reflectors and cross lamellae
  - Shape , Size and Finish determines light distribution / screening

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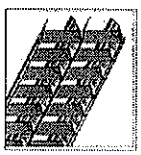
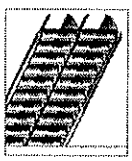
Optical Systems : Evolution

Different Types of Optical Systems



M2 facetted mirror with profiled lamellae



M5 parabolic side-mirrors with parabolic lamellae

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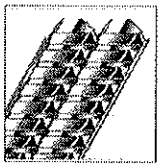
Optical Systems : Evolution

Different Types of Optical Systems



C6 (High Gloss) parabolic mirror and special parabolic lamellae

The more glossy the reflector, the less glare it will produce.
Specular deflection
matt reflectors - diffuse reflection.

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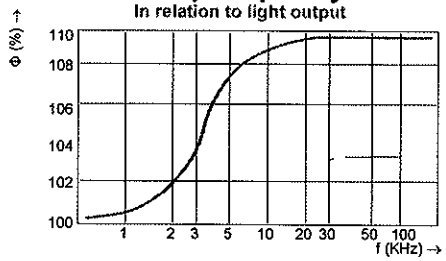
Lamp frequency

In relation to light output



output frequency of hf ballast - 30kHz
low loss ballast - lamps switching on/off 100 times/sec.
Anything that moves > 25 times/sec, the eye sees it as continuous.
THD < 10% for high quality HF ballasts
THD < 30% still complies to IEC Std.
THD = 180% Computer
THD = 200% TV

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Recommendations and Standards

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Key Lighting Parameters

Office Lighting

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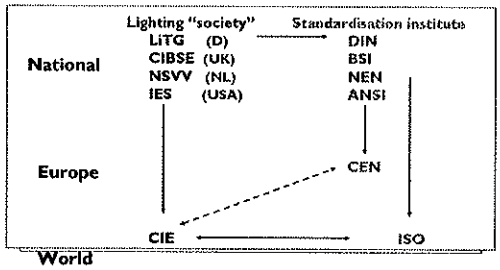
Recommendations for indoor lighting

Standardisation



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Recommendations for indoor lighting

Standardisation

- **CIBSE**: (now Society of Light & Lighting) standardLL) CAT 1, 2, 3: Withdrawn from October 2001
- **CEN:** EN 12464 since Sept. 2002
- Also to be followed by CIE

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Lighting levels for indoor work
EN 12464-1 2002
Soon to become CIE standard

Quality aspect	Quality parameter
Lighting level	maintained illuminance
Uniformity	E_{min} / E_{av} ≥ 0.7
Glare restriction	UGR
Colour rendering	Ra

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EN12464-1 Standard 2002

Sl. No	Type of Interior	E (Lux)	UGR	Ra
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

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Lighting of Indoor workplaces
LIGHTING ENVIRONMENT

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Lighting for indoor work places
Definitions Luminance distribution

Luminance distribution is determined by:

- Reflectance of surfaces
- Illuminance 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

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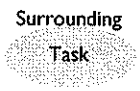
Lighting for indoor work places
Definitions Task and surrounding areas

Task / Surrounding area



> 0.5 m

- Illuminance

Task	Surrounding
≥ 750 lux	500 lux
500 lux	300 lux
300 lux	200 lux
≤ 200 lux	200 lux

- Uniformity (E_{min}/E_{ave})

Task	Surrounding
≥ 0.70	≥ 0.50

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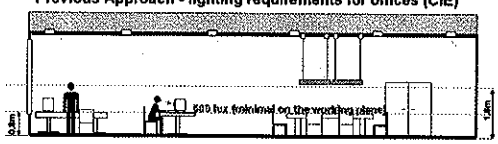
Lighting requirements (Traditional)

Previous Approach - lighting requirements for offices (CIE)



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

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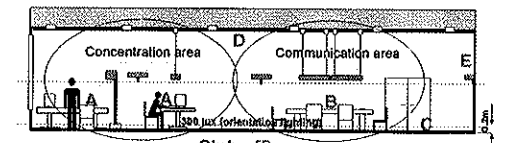
New Direction **Lighting requirements**



TASK - concentration zone (A)	TASK - Communication zone (B)		Control switching steps	Decorative elements Variation & surprise How often are the interiors applied?
ROOM - Floor (C)	ROOM - Ceiling (D)	ROOM - Walls (E)	Control collectively controlled	

luminous environment not uniform environment.

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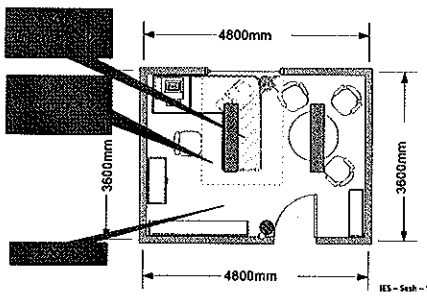
Lighting for indoor work places
Example Office Lighting



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Lighting for indoor work places
Definitions **Luminance distribution**

- **Consequences:**
  - Close interaction with future user (or general approach)
  - Project layout need to be known
  - Detailed lighting calculations required
- **Opportunities**
  - More detailed lighting advise
  - Advanced & detailed lighting installations to meet clear task area specifications
  - General design for total area as well

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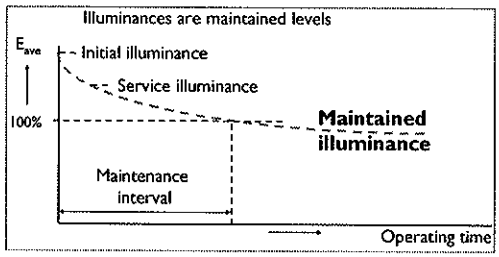
Lighting for indoor work places
Definitions Maintenance factor



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Lighting of Indoor workplaces
DIRECT AND INDIRECT GLARE

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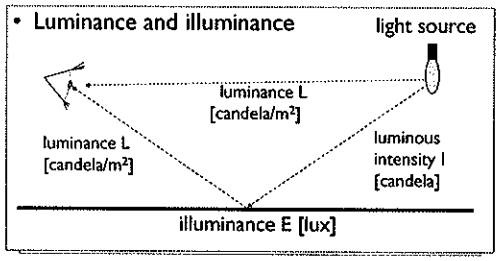
Lighting for indoor work places
Definitions (direct and indirect glare)

- Luminance and illuminance



glare in whole room is "sparkling".

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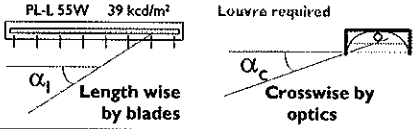
Lighting for indoor work places
Definitions (direct glare)

Bright lamps should be screened off to prevent direct glare

Lamp luminance		Shielding angle
20 – 50 kcd/m²		$\alpha > 15^0$
TL D	12 kcd/m²	Open reflector allowed
TL 5 HE	17 kcd/m²	Open reflector allowed
TL 5 80W	30 kcd/m²	Louvre required
PL-L 55W	39 kcd/m²	Louvre required



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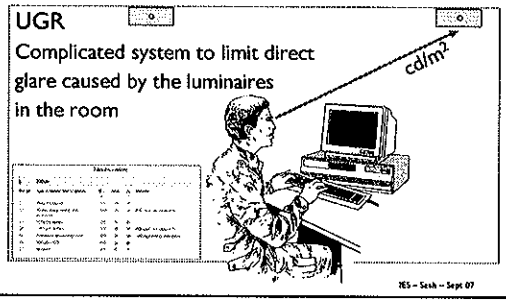
Lighting for indoor work places
Definitions (direct glare) UGR

UGR

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



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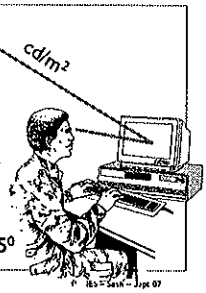
Lighting for indoor work places
Definitions (indirect glare)

Luminance limits for luminaires which can be reflected in the screen

Two luminaire classifications:

- Screen quality good/medium < 1000 cd/m²
- Screen quality poor < 200 cd/m² above 65°



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Lighting for indoor work places

Definitions **(indirect glare)**

Luminance limits of luminaires which can be

Screen classes in accordance with ISO 9241-7	I	II	III
Screen quality	good	medium	poor
Average luminance of luminaires which are reflected in the screen	≤ 1000 cd / m²		≤ 200 cd / m²

Note: In some special places 55° should be applied
For display screen with screen tilt up to 15°

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Lighting for indoor work places

Definitions **(indirect glare)**

- **Consequences:**
  - In general (slightly) less severe luminance limits
- **Threats**
  - High-end optics (C7, D7, C6 and D6) only for 'poor quality' screen applications
  - Also medium-end optics (e.g. M6) for 'good/medium quality' screen applications
  - Opportunities for our less-advanced optics (lower specified products of competitors)

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Industrial lighting

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Industry Lighting

Basic lighting solutions:

- **Linear light sources** $z' \times y'$
- **(Fluorescent lamps)**



Point light sources

- **(High intensity**
- **Discharge lamps)**



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Industry Lighting

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



can use linear lighting

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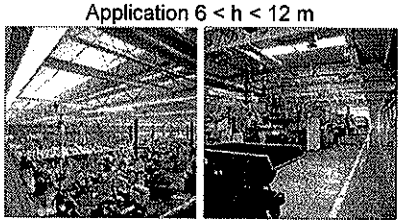
Industry Lighting

Application 6 < h < 12 m



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Industry Lighting

- Application h. 12 m
- HID lamps



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Lighting Design Principles

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Guidelines

1.Determine the function and need

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

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Guidelines

Input Preparation

Determine lighting parameters
- lighting level
- uniformity
- colour appearance
- colour temperature
- glare

Select Equipment
- lamp
- luminaire
- gears
- control

Output Preparation

Calculate No. of luminaires
- Prepare layout
- Prepare Recommendation
- Cost Calculation

- It is always recommended to provide alternative solutions to compare the cost-economics between at least two systems.

IES – Seah – Sept 07

Uniformity
Tank : 0.7
Corridor : 0.5
Emergency = 0

SS 531, UGR < 19 convenience in steps of 3.
Cat 2 UGR 19
Cat 1 UGR 16
EBP → Performance Ballast 45% more $27 expensive than
EBS — Standard HF Ballast $18

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Lumen method of Calculation

- Determine , length , width and height of working space
- Calculate Room Index

$$K = \frac{\text{length x width}}{\text{Mounting height x (length + width)}}$$

All dimensions are in "m"
- 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)
- Select the luminaire and lamp types
- Choose Utilisation factor (UF) , from the table corresponding to the luminaire
- Select Maintenance factor (MF)
- Determine the illuminance level required
- Calculate no. of luminaires
- Arrange the luminaires in a suitable grid
- Check the spacing to height ratio in both direction

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MH = working plane to ceiling ht.
WP = 0.8m for office , 0 for corridor & emergency.
If K < 5 , take it as 5 (Max for photometrics is 5)
Reflectances 7, 5, 3
Dark Ceiling take 0.5
If no ceiling, wall take 0,0

(Published by manufacturer

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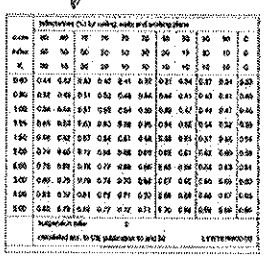
Utilisation Factor Table



- ☑ 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*

IES – Seah – Sept 07

higher UF, less fittings,
lower UF, more fittings.
If you do not know k or reflectances assume 0.5.

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Maintenance Factors : Guidelines

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

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A/C interior MF = 0.85, after 1yr 100 lux becomes 85 lux, so need to increase the lux level so that after 1yr, the lux level will be 100 lux.

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Step by Step Approach for Calculation

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

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

where ,

E = Average Illuminance (lux)
L = Length of room in 'm'
W = Width of Room in 'm'
O = Light output / lamp
T = No. of lamps per luminaire
UF = Utilisation factor
MF = Maintenance Factor

IES – Sesh – Sept 07

When HF ballast is used, 36W will consume 32W due to power limiter.

HF ballast will give 10% more output, so in order to maintain the output lumen (3275 lumen), the power input is reduced by 10%.

Using hf ballast, the power input is 32W.

Dimming is not to save money, only for ego satisfaction

LIGHTING DESIGN CALCULATION EXERCISE
(Lumen Method)

•	Area	=	48m x 20m x 2.8m
•	Design illuminance	=	500 lux
•	Luminaire	=	TCS214 / 2 x 36W with C6 Mirror
•	Lamp	=	TLD36W/840 x 2 lamps
•	Maintenance Factor	=	0.85
•	Room Reflectance	=	70, 30 and 10
•	Light output per lamp	=	3275 lm
•	Ballast loss	=	8 Watts for 2 lamps
•	Usage	=	10 hrs / day
•	Energy tariff	=	20 cents (S$) per kW hr.

Question

1) Estimate the no. of luminaires using the lumen method.
2) What is the load in Watts/Sq m?
3) There are 140 staff members in this office. How much is the Energy cost per day per staff?

July 2007

1. $K = \frac{48 \times 20}{2 \times (48+20)} = \frac{480}{68} = 7.05$

UF = 0.67

$N = \frac{500 \times 48 \times 20}{3275 \times 2 \times 0.67 \times 0.85} = 128.67$ say 130

2. $= \frac{130 \times (80)}{48 \times 20} = 10.83 W/m^2$

uniformity; $0.7 = \frac{min}{Ave}$

3. $= \frac{130 \times 80 \times 10 \times 20 ¢}{140 \times 1000} = 14.85 ¢ \simeq 15 ¢$

$hf. = \frac{130 \times 72}{48 \times 20} W/m^2$

$= 10 W/m^2$.

Utilisation Factor (UF) Table

Luminaire : TCS214/236 C6
Lamp : 2 x TL-D36W/840
Measurement code : LVK0148500-00
Measurement status : Released
Utilisation Factor Table

Room index K	Reflectances (%) 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 calculated acc. to CIE publication 40 and 52 LVK0148500-00										

IES
Lighting Design Exercise – Sept 07

Spencer Food Industry Pte Ltd (CFI) plans to start operations in a high-ceiling building. You are their Lighting consultant. The following are their parameters:

1. Illuminance = 400 Lux
2. Mounting Height = 10 Metres
3. Hall dimensions = 80 X 20 Metres
4. The side walls have glass windows that do not reflect back much light
5. The ceiling is dark painted
6. Luminaire suggested = HDK 900 high bay light fitting
7. Lamp type = MHN 400 W Metal Halide
8. Light output = 32500 lumens
9. Ballast loss = 30W
10. Utilisation Factor table = given
11. Maintenance Factor = The factory has air Conditioned interior
12. Electricity tariff = S$ 0.20 / Unit

ASSIGNMENT

- Calculate the number of Luminaires required
- Suggest an approximate layout
- What is the Lighting Power Density in Watts / Square meter?
- What are the additional precautions that you will suggest?
- How much is the lighting energy cost per shift of 8 hours?
- With 120 employees per shift, what is the lighting cost per person per day?

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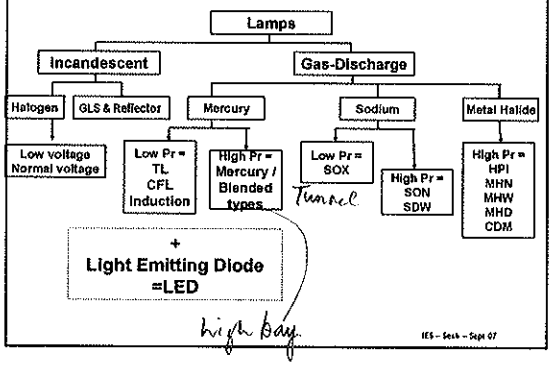
Part 4: Characteristics of Lamps and Ballasts

PHILIPS

The Electric Lamp Family



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Incandescent (Reflector)& Halogen Lamps

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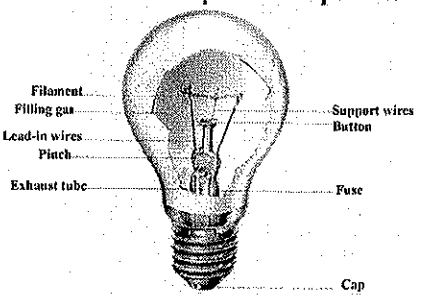
Incandescent lamp & its components



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Edison used carbonised bamboo.
Philips first to use tungsten filament
92% heat, 8% light

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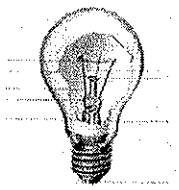
GLS Lamp



- 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*

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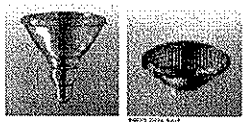
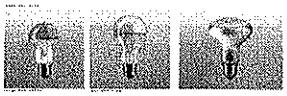
Reflector Lamps



PAR 38 & PAR 56

Blown bulb Reflector



- Special shape
  - – Pressed Glass
  - – Blown bulb
- Internal Aluminum reflector
- Choice of beam angles

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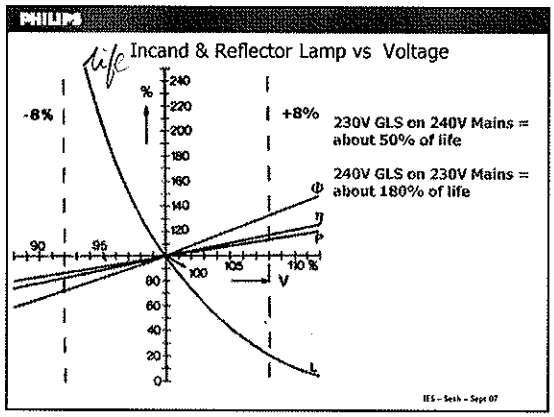
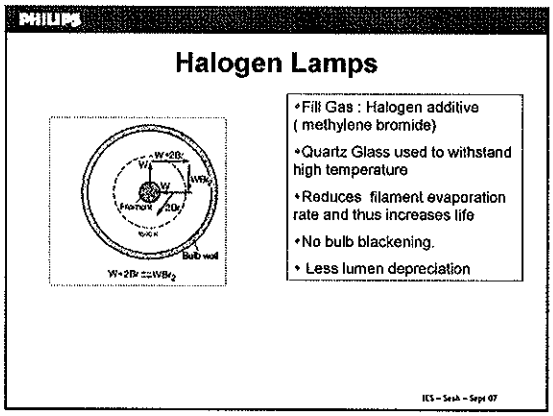
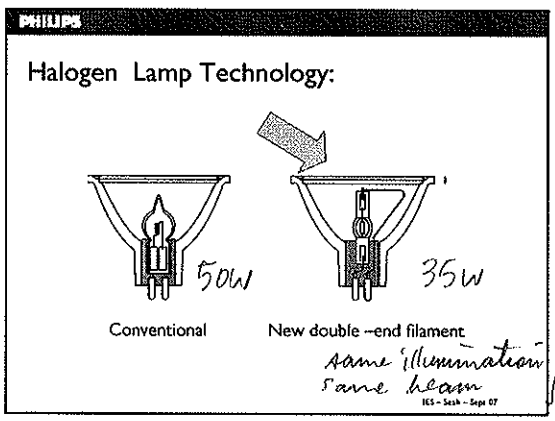
PAR - Parabolic angle reflector
Fails because the rubber gasket
fail



W – Tungsten It gradually evaporates and eventually snaps.



Halogen. – One type Bromine
Evaporate Tungsten will combine with Bromin when hot and separate when cool.
will increase the temp; originally 2700°K
with halogen increase to 3000°K.
higher temp → becomes whiter, more blue
higher temp → higher lumen.



Touch lamp with hand, impurities from hand & body salt will settle on the lamp and due to high temp. of lamp, will puncture the lamp and

88% heat 12% light

Not all halogen lamps are provided with cover.
only Philips

PET - Permissible Exposure Time
w/o glass cover, the halogen lamp PET is 7hrs. (UV light)

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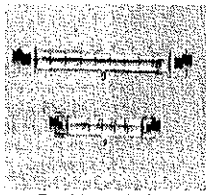
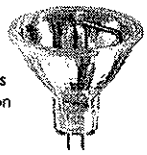
Mains Voltage Halogen Lamps



Double-ended

Low voltage Halogen Dichroic lamp

- Cool Beam
- Precise angles
- UV protection with glass



Single-ended

- Warm Colour Appearance, 3000- 3200K
- Excellent Colour rendition , Ra =100
- Life 2000-5000 hrs

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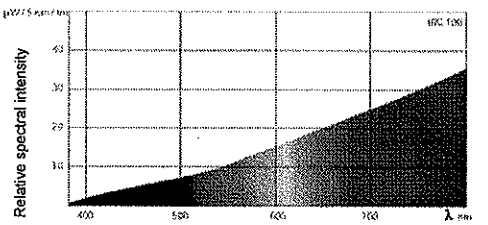
GLS/Reflector/Halogen Spectral intensity distribution



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FLUORESCENT LAMPS

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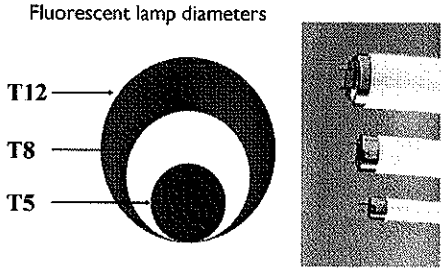
Fluorescent lamp diameters



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Low Pressure Gas Family

When the arc is bend it is a compact lamp

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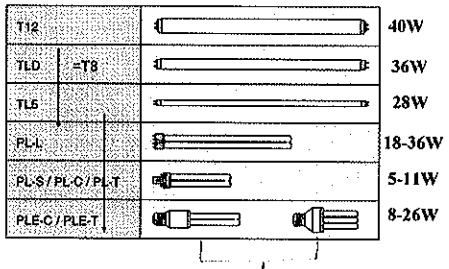
Miniaturisation of Fluorescent Lamps



with built-in ballast

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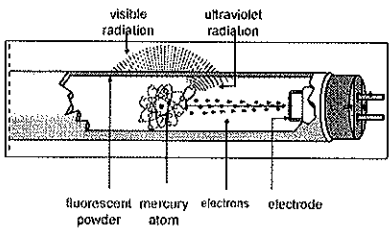
Fluorescent Lamp Operation



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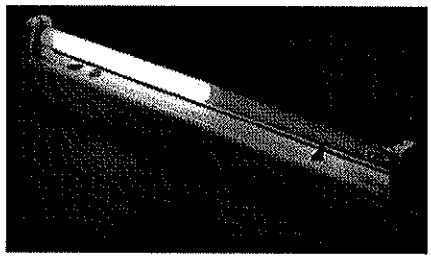
Fluorescence



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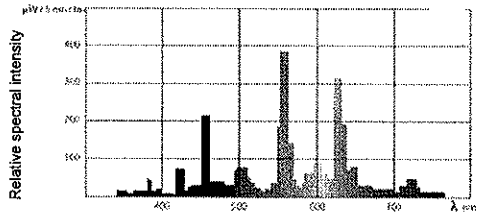
TLD (Colour 840) = 4000K
CRI > 80



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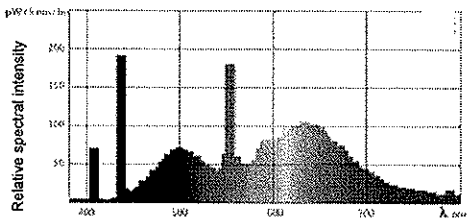
TLD (Colour 940) = 4000K
CRI > 90



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Improve CRI by manipulating the phosphorous powder. CRI > 90 cost 3 times more than CRI > 80.

STRIATION – Due to impurities in the phosphorous powder.

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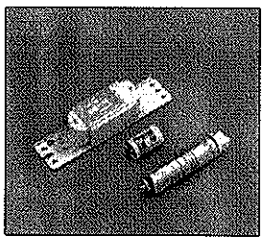
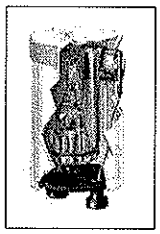
Common TL/TLD components





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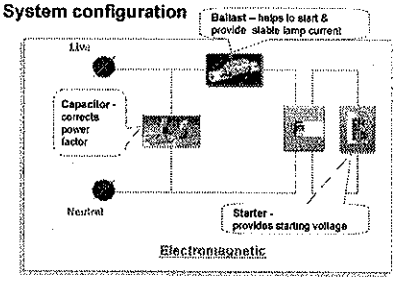
Electromagnetic ballast for TL/TLD

System configuration



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Fluorescent lamp - negative gas discharge, w/o ballast, lamp will fail.
-ve gas discharge cannot control its current.

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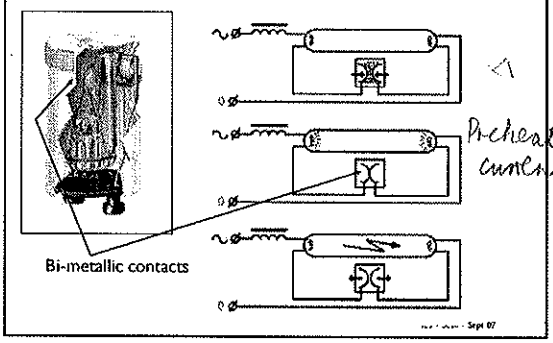
Working principle of starter circuit



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gas discharge hot
← Mercury atom being bombarded.
Preheating current

← When contacts open, due to EM induction, a high voltage is induced in the ballast and excite the mercury atoms.

ignitor → 2 - 3 kV.

Mercury in fluorescent lamp: 3 - 5 mg

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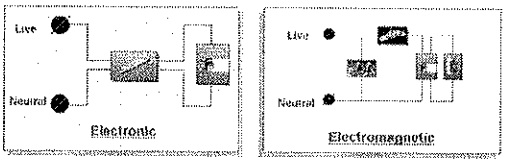
Electronic Ballast for fluorescent Lamps



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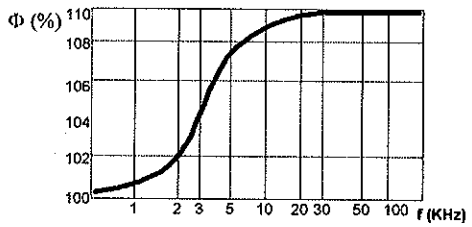
Lamp efficacy

Lamp frequency in relation to light output



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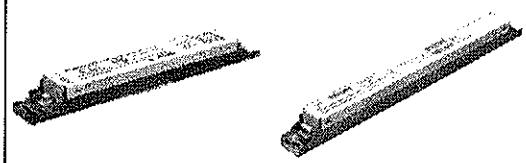
Miniaturization



'TL'8 gear
Typical cross-section 39x28mm

'TL'5 gear
Typical cross-section 30x28mm

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2 lamps controlled by 1 ballast

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Why electronic ballasts?

Features & Benefits

Hard argument 1. saves money

Soft arguments 2. comfort & health
3. flexibility

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Ballast loss

Lamp type	Ballast type	Ballast loss
TL = T12	Electro Magnetic	9 W
TLD = T8	Electro Magnetic	9 W
TLD = T8	Electro Magnetic Low Loss	6 W
TLD = T8	Electronic	4 W
TL5 = T5	Electronic	3 W

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Saves money

Electromagnetic	Electronic HF
energy costs relatively high compared to HF	energy savings up to 25% compared to conventional
additional costs for PF capacitor	no additional cost for PF capacitor
> air conditioning costs because of heat generation	Air conditioning costs reduced because of less heat radiation (25% less)
normal lamp life	50% longer lamp life, less maintenance costs
relatively high lumen depreciation	lower lumen depreciation depreciation

Thorn, Philips, Helvar, Atco,

Low loss ballast – filament costs up momentary; cathode emission loss.

HF ballast – high frequency, no change for cathode emission loss.

HF ballast $15.00 } Extra money recovered
Low loss $9.50 } by energy savings in 1½ hrs

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comfort & health

Electromagnetic	Electronic HF
Starting blips	Smooth rapid start
disturbing lamp flicker	flicker free
no dimming possible	dimming possible
annoying humming possible	silent
not controlled end of life of lamps	reliable lamp switch off

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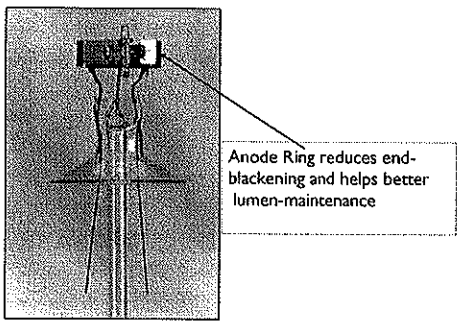

Use high frequency to break the inner gas to

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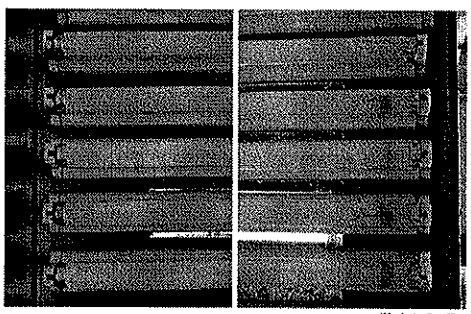
End blackening with & without Anode Rings inside



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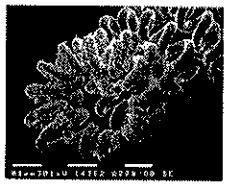
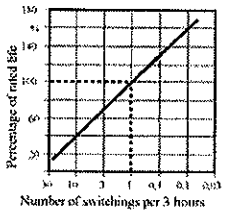
Lamp Life





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Lamp life time: how is it measured?

- 50% failure on 3 hour switching cycle

depreciation of lamp output

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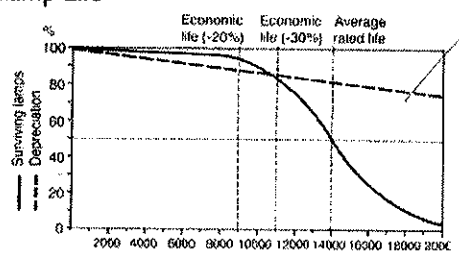
Lamp Life



Manufacturers' Published life is the 50% survival life !

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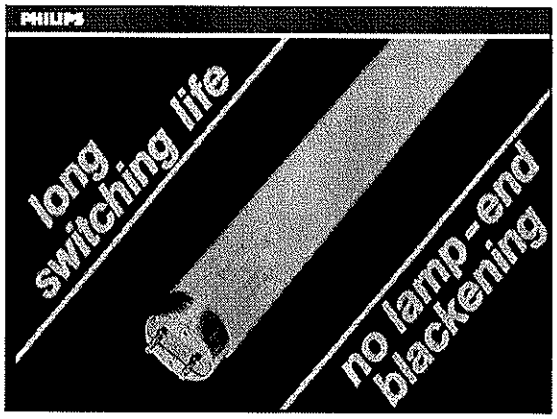

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Breakthrough TL5 technology

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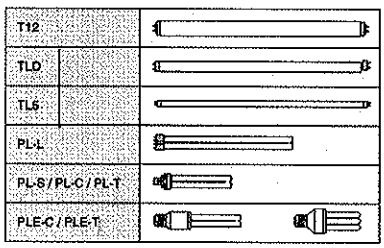
Miniaturisation of Fluorescent Lamps



TL5 – 2" shorter than T12 & TLD
and only on HF ballast.
Uses krypton to reduce the wattage. (28W)
T12 & TLD – slightly longer
TL5 – 2" shorter to fit into ceiling module.

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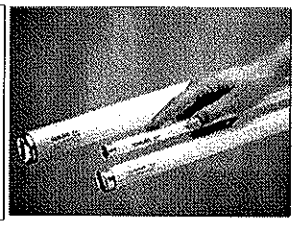
TL 5 technology

Miniaturisation

- Diameter 16 mm
- Shorter length

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



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Compact Fluorescent Lamps

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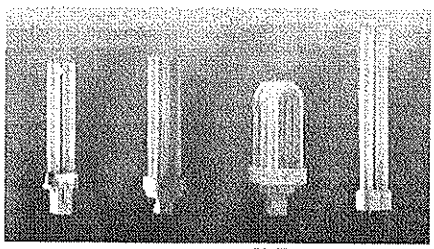
CFL– Non Integrated type. Ballast has to be external (Electro Magnetic or Electronic)



PL-S PL-C PL-T PL-L

Ballast in fitting. More economical and starter is integrated

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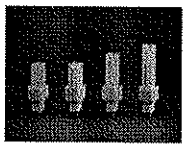
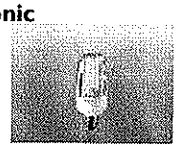
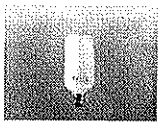
CFL - Integrated (with Electronic ballast at the lamp base)







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This is meant for retro fitting since it is screw type lamp base.

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CFL Equivalents for Light Output Example

CFL 20W	=	**GLS 100W**
CFL 15W	=	**GLS 75W**
CFL 11W	=	**GLS 60W**

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The incandescent lamp has more illuminance since the light is emitted via a small wire. PL lamps light emitted over a wider area, so it looks more dull.

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High Intensity Discharge (HID) lamps

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Dalton's law of partial discharge of gas.

HID, the discharge is only a few inches long

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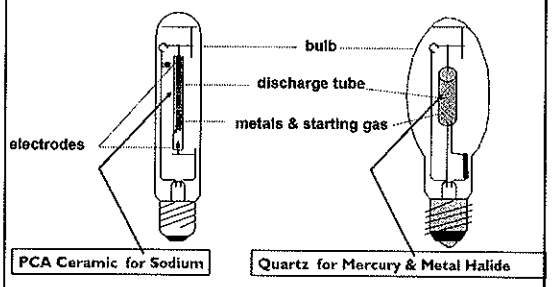
Components of a HID lamp



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Mercury. They to establish current with ignitor 3KV. Mercury does not want the atom and bounds it off

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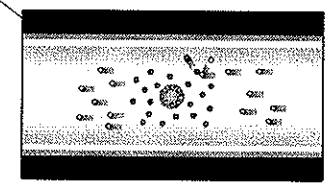
Operation of a gas discharge

discharge tube



Heat development & excitation of colliding atom

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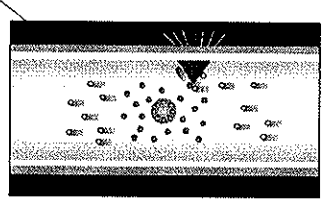
Operation of a gas discharge

discharge tube



Electromagnetic radiation

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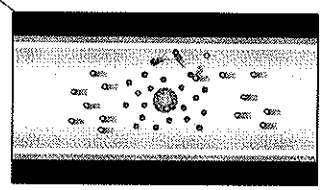
Operation of a gas discharge

discharge tube



Free electrons keep the discharge going

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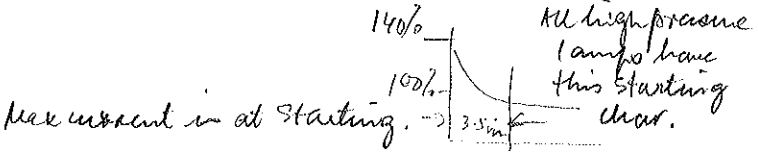
Stadium – Dual redundant supply.
Halogen – 20lux
20% of high-hot restrike – 32kV



All high pressure lamps have this starting char.

Max current in at starting.

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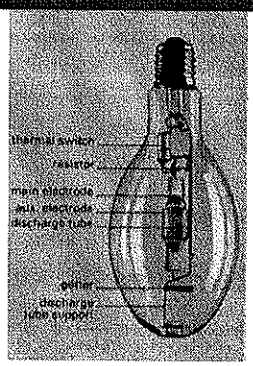
HPL Mercury Lamp



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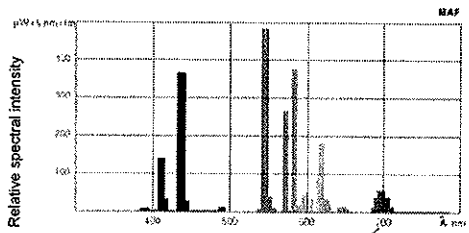
High Pressure Mercury Lamp

Spectral intensity distribution



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Very weak in red.
Colour rendition very bad.

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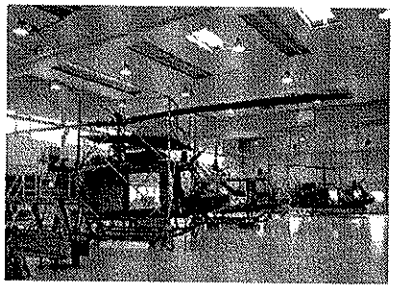
High-bay Application



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high bay 76m

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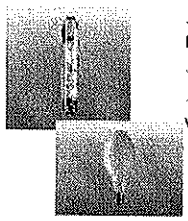
Metal Halide Lamp



- Metal Halide Additives with Mercury
- Improves Colour Properties
- Mercury regulates the arc voltage and heat

IES – Sesh – Sept 07

Fluorin can carry the additives very well but it attacks glass.

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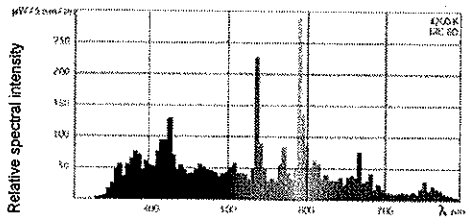
Metal Halide Lamp

Spectral Intensity distribution



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Spectral intensity distribution improves with addition of metal halide.

Moon - 4000°K. For zoo, animals used to moonlight.
Metal halide - used with halogen - 3000°K
use filter to subtract the red component and increase the colour temp to 9000°K

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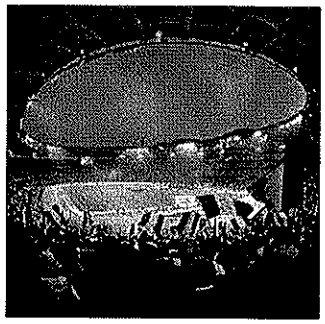
Metal Halide in Sports



IES – Sask – Sept 07

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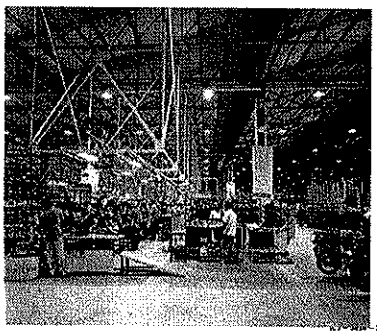
Metal Halide in Industrial High bay



Sept 07

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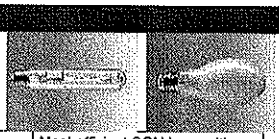
High Pr Sodium: SON and SON-T



SON Plus Lamps - up to 150lm/W	Most efficient SON lamp with high reliability,lowest cost of ownership, retrofit on all HPS systems
SON Comfort - Ra = 65 - Tc = 2200K	Golden white SON lamp with good colour rendering and acceptable efficacy for city beautification
Standard SON - up to 130 lm/W	Efficient SON lamp with low cost of ownership
SON-H - 220W and 350W	SON-H lamp directly retrofits on existing Mercury ballast, giving high cost savings on energy

IES – Sask – Sept 07

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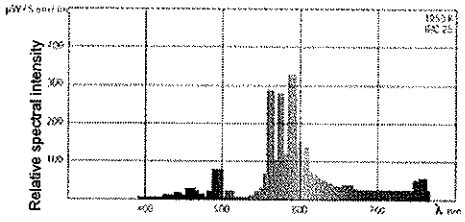
High Pressure Sodium Lamp

Spectral intensity distribution



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Colour rendition poor.

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Sodium in Street lighting



IES – Sesh – Sept 07

2000°K

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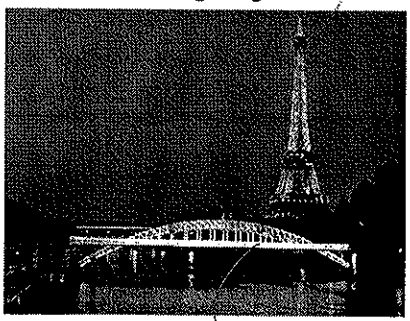
Sodium for floodlighting



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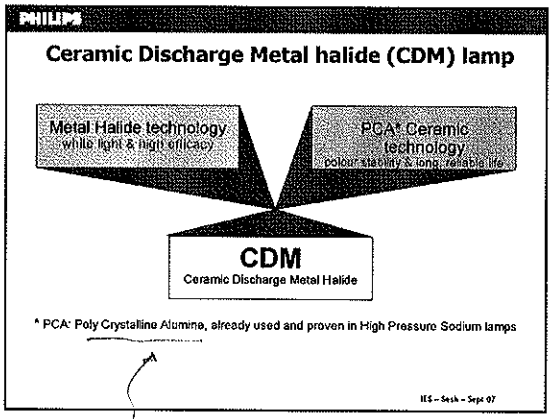
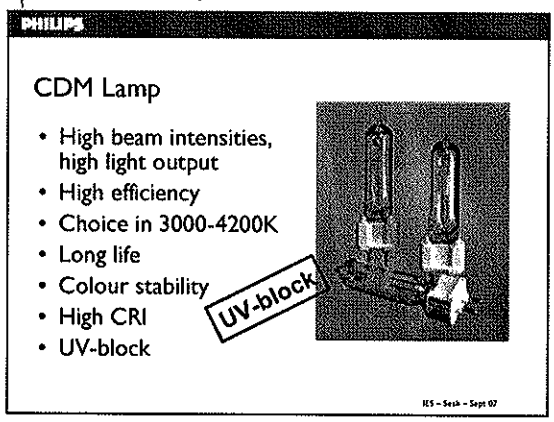
4000°K (metal halide)

Architect wanted a contrast bet^n the bridge and tower lighting.

MH attack the electrode and tube junction when you add MH into the ceramic.

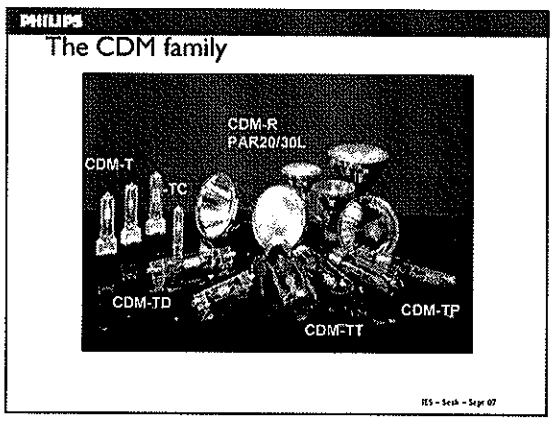


a grade of ceramic patented by Philips.



halogen 88% heat : 12% light.

S'pore uses 4 million halogen; low efficacy 12 lm/w



Lamp comes with its own reflector.

heat : 17% ; light 83% ; requires electronic ballast.

(50W) halogen + T/F = $25

(20W) CDM = $140 ; life much longer } Additional cost can recover in 1½ yrs

save R/C costs and elect. cost

Hanoi Parliament : 300W PAR 64 (Cold in winter, double up as heating)

PAR superceded → Halogen → CDM

Halogen - 12V, very sensitive to voltage.

supply 1 T/F for 1 halogen lamp

Supply 1 T/F for 4 halogen lamps so when 1 lamp fails, voltage ↑ and other lamps fail.

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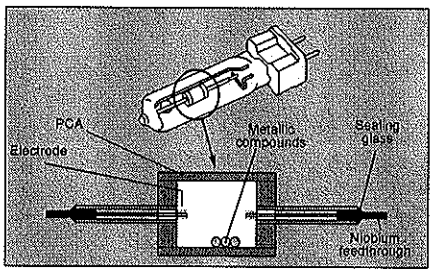
CDM Lamp



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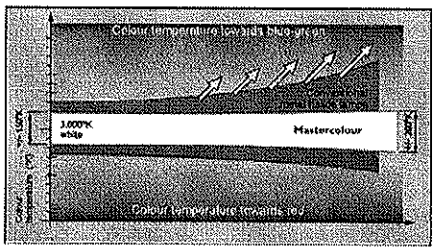
Stable colour over life



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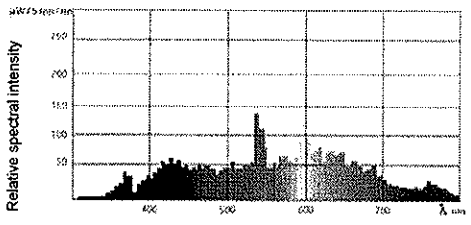
CDM-T Lamp

Spectral intensity distribution



Wavelength (nm)

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Low Pressure Sodium (more commonly used in Europe for Road and Security lighting)



Efficient lamps with very long life.

Standard SOX - 35..180W - up to 176 lm/W	Most efficient light source for road lighting in 'foggy' climates
SOX -E - 18..131W - up to 200 lm/W	Compared to SOX, SOX- E has reduced heat losses and hence higher efficacy
SOX-HF - 35-55-66W - up to 170 lm/W	SOX(-E) lamps wired with High Frequency electronic ballast

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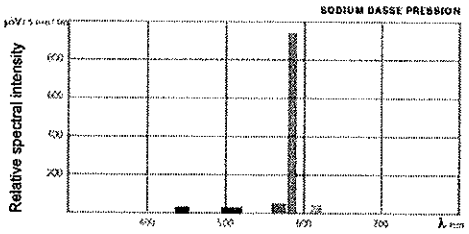
Low Pressure Sodium Lamp

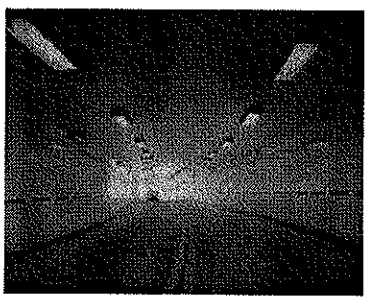
Spectral Intensity distribution



Wavelength (nm)

PHILIPS

SOX in Tunnel lighting



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Control gear for discharge lamps

consists of : - Ballast
- Ignitor
- Capacitor

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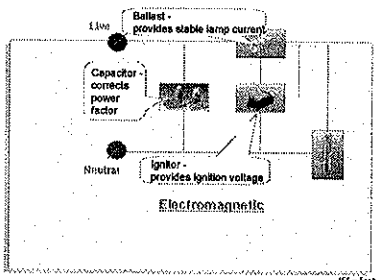
Ballast for HID lamps

System configuration



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Consequences of operating HID Lamps:

- Control gear for HID lamps
- Types of ballasts & circuits
- Effects of mains voltage variations

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Types of ballasts

- **Resistors**
  (Hardly used other than for Self ballasted Mercury blended lamps)
- **Electro Magnetic ballasts**
  To be used if mains voltage is about twice the arc voltage (for Mercury,Sodium, Metal Halide etc)
- **Autoleak transformers**
  To be used if mains voltage is lower than twice the arc voltage (eg:Low Pressure Sodium) -- More for 110V countries
- **Constant wattage Ballasts**
  Heavy and expensive and used more in 110V countries

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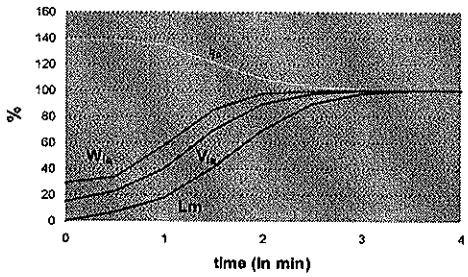
Sodium run up behaviour

Lamp Performance during starting period



Lm - Lumen output

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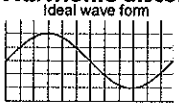
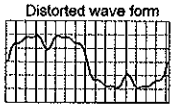
Harmonic distortion

Ideal wave form



Distorted wave form



- Total Harmonic Distortion (THD)
  Harmonic distortion can expressed as a %-value of the amount of deviation from ideal wave form
- Categories of THD
  - → >30%, not complying to any norm
  - → <30%, complying to norm but nothing extra
  - → <20%, Better then norm
  - → <10%, can be seen as best in class

IEC 61000 - 2 - 3 harmonic Std

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Harmonic distortion



Negative effects of Harmonic distortion

- Odd harmonics (thirds, ninths, etc.) result in large currents on the neutral line in a four-wire 3-phase system.
- Odd harmonic distortion may result in incorrect operation of other equipment connected to the same mains.

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Harmonic distortion



THD of current in Computers and Monitors in offices ?
About 100 - 250 % !
The total load of computers often is higher than Lighting load !

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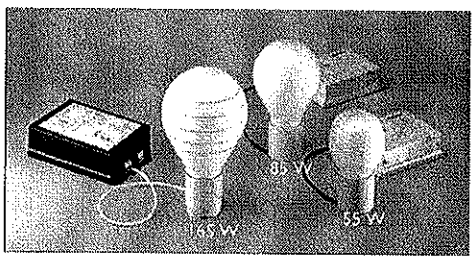
QL Induction lamp family



highly permeable core, surrounding air is ionised.

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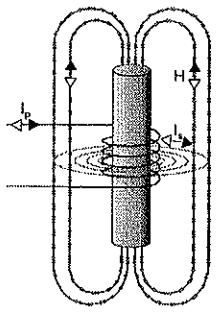
Induction principle

$f = 2.85$ MHz



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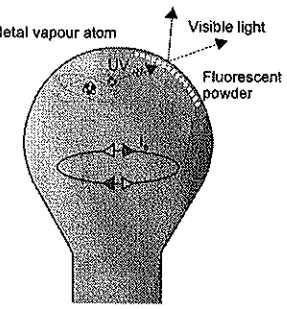
Discharge principle



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lamp life

HF generator, 80,000 hour life, 24hrs – 8yrs.

low pressure lamp instant restrike.

$300/lamp.

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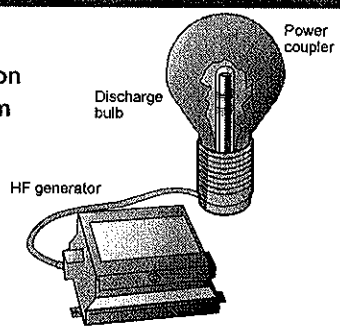
QL induction lamp system



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Lf current flows @ 160V T1 & T2, Taka

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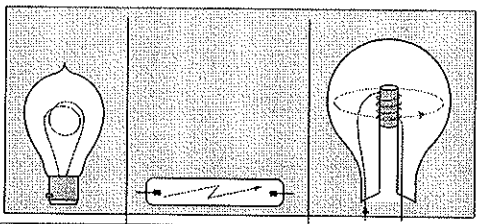
Lifetime



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

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Light Emitting Diode (LED)

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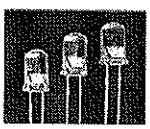
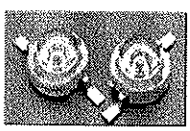
LED packages



Conventional LED (5mm)
0,5-2 Lumen
25-100 mW



High Flux Power Chip LED
10-50 lumen
625-1200 mW

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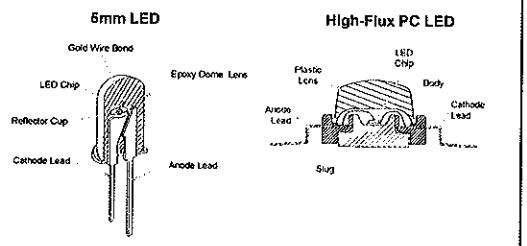
LED flux enhancements



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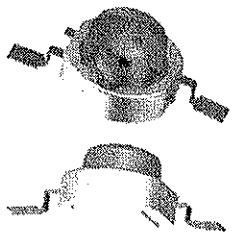
High-Power Chip LED Package



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Max power = 3W. commercially
light output = 50lm/wax
luminance is high but what
we need is illuminance, which
is 1lm/W for LED.
Life with very good heat sink,
100,000hrs. but since expensive
to make good heat sinks, 50,000 hrs.

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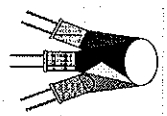
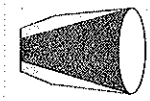
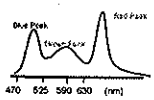
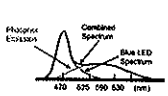
How to make white Light







By mixing Red, Green and Blue (RGB) sources any colour light, including White, can be made



Blue emission is converted to yellow by the phosphor coating over the chip and reflector cup. The mixture of blue and yellow light appears white

IES – Sesh – Sept 07

lumiLED – a Philips Co.
largest LED company in
world.
Colour kinetics

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Part 5: Sustainability, Energy efficiency & life cycle economy

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Lighting level and energy consumption

Our eye is used to	= 100,000 lux
Recommended office lighting level	= 500 lux
Electrical load for this illuminance	= 10 Watts/m^2
Average space per office staff	= 8 m^2
So, the Lighting load per staff	= 80 Watts
For 10 hrs per day, energy consumed	= 80 x 10 WHr = 0.80 Kw Hr
@S$ 0.25 / KwHr, the cost of energy / day	= $0.20!

How much does a cup of coffee cost ?

How many cups would we drink everyday?

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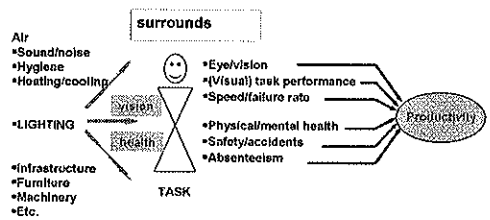
Drivers of Productivity

WORKING ENVIRONMENT



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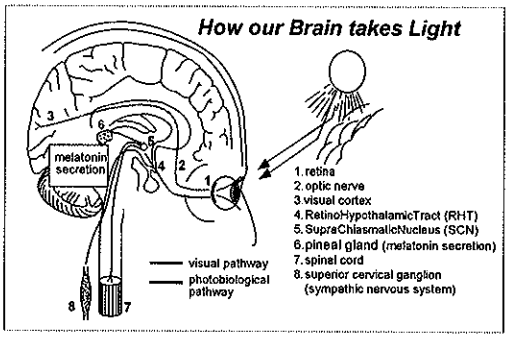
How our Brain takes Light



1. retina
2. optic nerve
3. visual cortex
4. RetinoHypothalamicTract (RHT)
5. SupraChiasmaticNucleus (SCN)
6. pineal gland (melatonin secretion)
7. spinal cord
8. superior cervical ganglion (sympathic nervous system)

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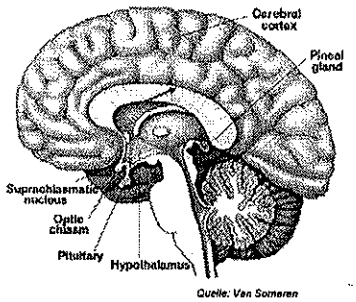
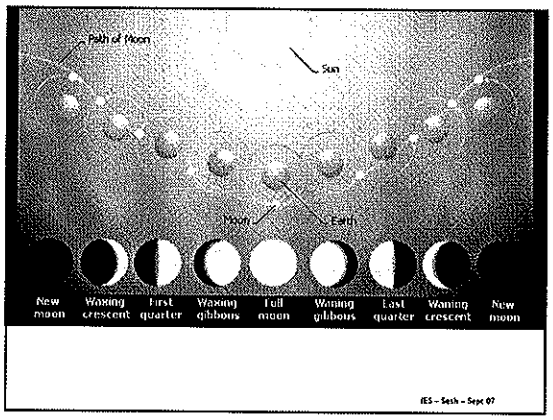
Biological Clock

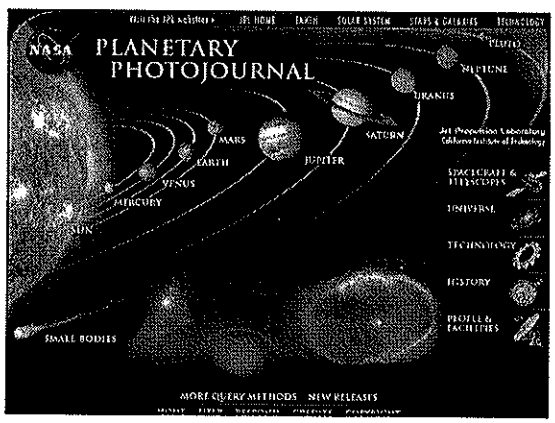


Quelle: Van Someren

- Controls biological rhythms
- Controls various glands (hormone release)







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Circadian rhythms

- Mood, performance, alertness
- Body temperature
- Hormone production by pineal gland (melatonin, seratonin)
- Hormone production by pituitary gland (prolactine, growth hormone)
- Hormone production by adrenaline cortex (cortisol)
- Structure of EEG
- Urination and composition
- Sleep/wake pattern

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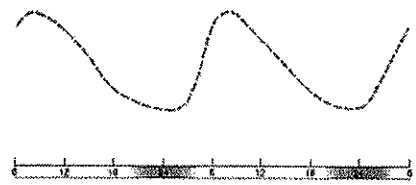
Circadian Rhythms



cortisol

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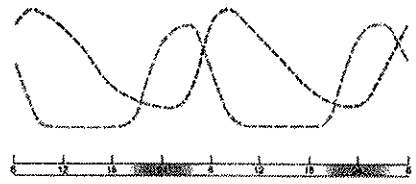
Circadian Rhythms



cortisol melatonin

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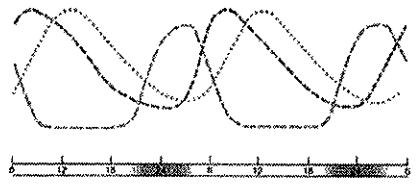
Circadian Rhythms



cortisol melatonin

alertness

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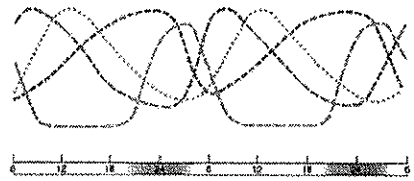
Circadian Rhythms



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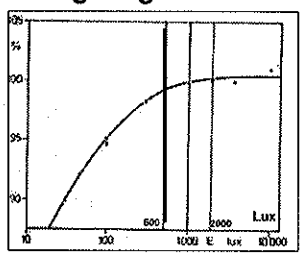
Lighting and Productivity



Productivity and Task Illuminance

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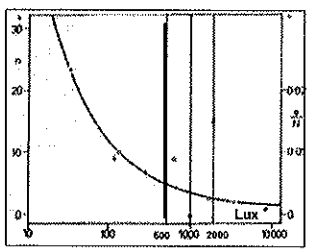
Lighting and Errors



Errors and Task Illuminance

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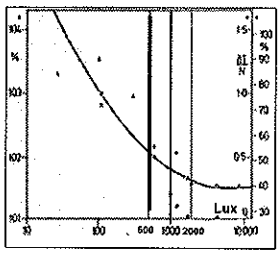
Lighting and Fatigue



Fatigue and Task Illuminance

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Recommended Illuminance

for various Areas and Activities

Illuminance (lux)	Area of Activity
100	Circulation Areas, Simple Orientation
300	Visually Simple Tasks
500	Offices, Average Tasks in Industries
750	Visually demanding Tasks, Electronic and Precision Industry,Drawing offices
1000	Graphic Reproduction
30,000	Task Lighting in Operating Theatre (example)

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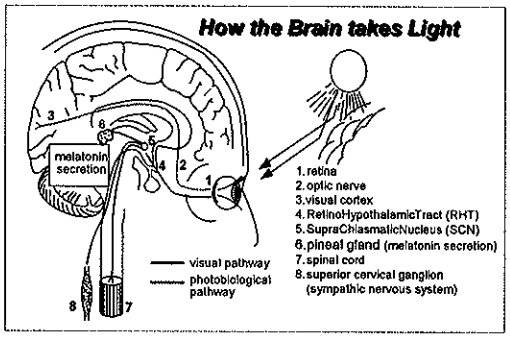
How the Brain takes Light



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Photobiological effects, ocular

- *mood*
- *performance*
- *well being*
- *biological clock*
- *immune system*
- *direct stimulation*
- *therapies*

\+ vision =

- *communication*
- *performance*
- *comfort*
- *safety*

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Biological clock

- Located in the SCN
- Entrained by light through the eye
- Controls body rhythms
  - ultradian (min./hour cycles)
  - circadian (daily)
  - circalunar (monthly)
  - circannual (seasonal)

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Circadian rhythms

- Mood, performance, alertness
- Body temperature
- Hormone production by pineal gland (melatonin, seratonin)
- Hormone production by pituitary gland (prolactine, growth hormone)
- Hormone production by adrenaline cortex (cortisol)
- Structure of EEG
- Urination and composition
- Sleep/wake pattern

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Relationship between Lamp and Energy Consumption!

Lamp	Ballast Loss	Total Watts	Life	Energy consumed	Cost of Energy @ S$0.20 kWHr	Price of Lamp (approx)
Bulb 75W	Nil	75W	1000 hrs	75 kW Hrs	$ 15.00	$ 1.00
TLD 36W	9W	45W	14000 hrs	630 kW Hrs	$ 126.00	$ 3.50

A Lamp consumes about 15-40 times more Energy than its own price !

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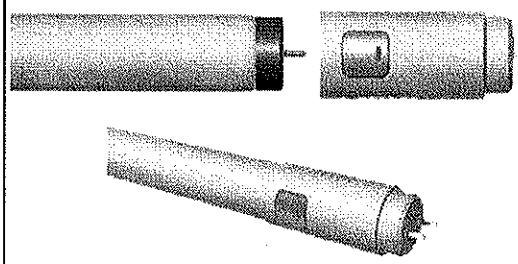
The Adapter Concept



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Concept of Click-2-Save

Normal TL-D 36W (1200mm)

Philips TL-D 30W (1150mm)

C2S Adaptor (50mm)

Assembled TL-D 30W + C2S (1200mm)

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Concept of C-2-S

Objectives

- Reduce energy but maintain the same lighting level
- Retrofit 40W / 36W lamps that have now 2500 lumens
- No change of ballast or luminaire. Negligible labour cost
- Quick payback

Working concept

- Use a new T8 – **30W/865** lamp to ensure 2,600 lumens.
- Use an Electrical Adaptor to control the current / lamp power and adjust length to original 1200 mm

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Specifications:

"Daylight" color	TLD36W /64	"C2S / 865"	"Super80 / 865"	TL40W / 54
Power (W)	36	30	36	40
Lumens @ 100h	2,500	2,600	3,250	2,500
Efficacy (lm/W)	70	83	85	63
Lumens @10,000hrs	2,000	2,340	2,925	2,000
Lifetime (Hrs)	13000	15,000	15,000	13000
Color Rendering	70	80	80	70
Mercury Content	13mg	3mg	3mg	+15mg

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Click-2-Save ™: Specification

- Uses a 30 W Triphosphor tube
- Rated average lamp life: 15,000 hour
- Adaptor life: 75,000 hours. Hence life > 15 yrs ! (In 12 hrs use per night)
- Light Output
  - color 865 at 2,600 lm
  - Lumen maintenance at 10,000 hours: >90%
- Color rendering (Ra): ≥ 85
- Mercury content < 3mg

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Click-2-Save ™: End Users Benefits

- **Saves 6W or 13% vs 36W per system***
  10 W or 20% vs 40W per system*
- ***Simply click in. No change of ballast or fittings.***
- Same re-lamping cost (due to longer lamp life)
- Better appearance of lighted space, products and people (high color rendering)
- Better environment (Low mercury content <3mg).
- Short Payback period: less than 1 year

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The Adapter Concept



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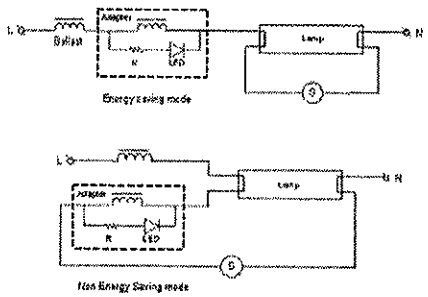
Click-2-Save : Circuit Diagram



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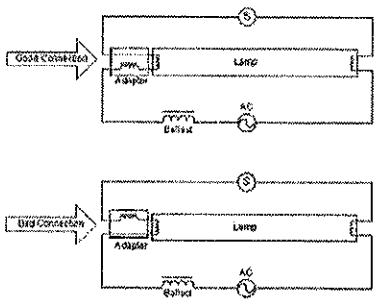
Click-2-Save : Circuit Diagram



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ENERGY SAVING UPGRADES

- **35W Masterline Halogen lamp instead of standard 50W Halogen**
- **Compact Fluo Lamp instead of Incandescent lamp**
- **TLD Super 80 tube instead of Cool Daylight**
- **Electronic ballast instead of Electromagnetic ballast**

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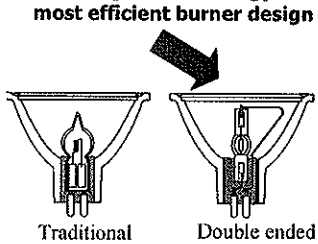
Halogen Technology: most efficient burner design



Traditional Double ended

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Energy saving with Masterline Energy Saver Halogen

- Load reduction per point(50W - 35W) = 15W
- Saving for 5000hrs life
  = 5000 x 15 Watt Hrs = 75 kw Hrs
- At S$ 0.20 / kW Hr, money saved = $ 15.00

Avoiding 2 X Std Halogen lamp = $ 6.00

- Total savings by each Lamp = $ 21.00
- Masterline Halogen price = $ 5.00

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Energy Saving with Masterline Halogen

- Direct energy saving
- Air Con load saving
- Less Heat in Interior and more comfort
- Longer lifetime

Benefit to User : Happier Customers & Staff

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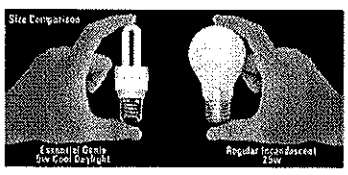
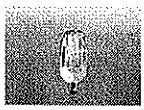
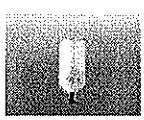
Integrated CFL







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Equivalent CFL for GLS

(example)

CFL 11W	=	GLS 60W
CFL 15W	=	GLS 75W

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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$ 0.20 / kW Hr, money saved = $ 78.4
- Avoiding 8 X GLS lamps @$ 1.0 each = $ 8.0
- Total savings by each Lamp = $ 86.4
- CFL price = ?

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Energy saving with TLD 36W /840 instead of Cool Daylight tube

- 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

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Total Cost Of Ownership (TCOO)

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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) !

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What is Total Cost-Of-Ownership

= THE 'ANNUALISED' COST OF (INVESTMENT + MAINTENANCE)

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Total Cost-Of-Ownership

Annualised Investment = Taken at 10% of initial investment to create the Light points. Eg. for street lighting, the investment for each point will include the following:

A.Cost of Transformer,switch gear, cables and installation

B.Pole & bracket

C.Luminaire with gear

Usually, (A+B) is U$ 1000 per streetlight point !

© is usually about U$ 125 for SON 250W lantern

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Total Cost-Of-Ownership

Annual Maintenance =

- ✓ Energy / yr = (Load KW x Burning hrs per year)
- ✓ 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

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Total Cost-Of-Ownership

- How to reduce investment cost?

-- For Office/Industry lighting :

Replace with the most efficient lighting system (ie.lamp efficacy and luminaire Utilisation Factor)

--For Street lighting :

Use superior optics= increase the luminaire spacing to minimize no.of lanterns per Km

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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

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Maintenance & Energy saving

	Brand X (conventional)	Superior Luminaire (Pot Optics)
Spacing for same Lux	30m	35m
Luminaires per km	34	30
Cost per point (usual)	S$ 1500	S$ 1500
Price of lantern	S$ 200	S$ 250
Cost / point	S$ 1700	S$ 1750
Investment per KM	S$ 57800	S$ 52500
10% depreciation / yr	S$ 5780	S$ 5250
Electrical load per point	280W	280W
Total load	9.52 KW	8.40 KW

The Lantern costs < 15 % of the total cost per point !

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Maintenance & Energy saving

	Brand X (conventional)	Superior type (Pot Optics)
Energy per year	38080 KW Hrs	33600 KW Hrs
Energy cost per year	S$ 7616.00	S$ 6720.00
Lamp replacements / yr	8.50 lamps	7.50 lamps
Lamp unit price	S$ 30.00	S$ 30.00
Lamp cost / yr	S$ 255.00	S$ 225.00
TCOO / yr	S$ 13711.00	S$ 12195.00
Net savings / yr	-----	S$ 1516.00 !