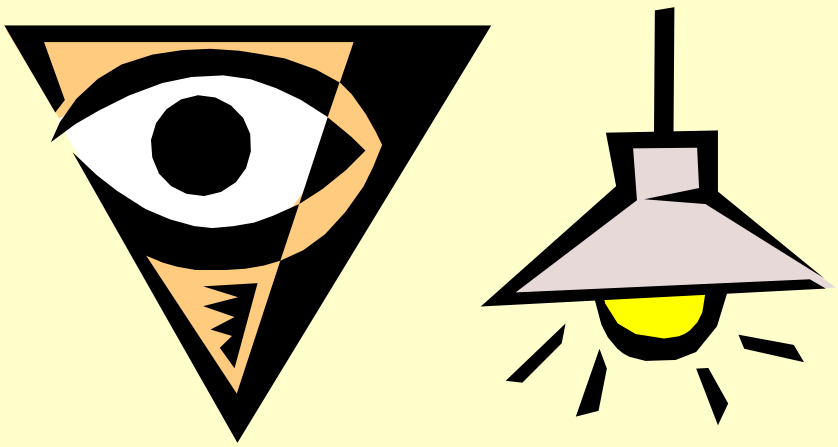
IBTM 5680 Lighting Engineering

http://ibse.hk/IBTM5680/



Introduction to Lighting Engineering

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http://ibse.hk/cmhui/

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About the Lecturer

- ***Ir Dr. Sam C. M. Hui*** *許俊民 博士 工程師* http://ibse.hk/cmhui
  - Adjunct Assistant Professor 客席助理教授, HKU Dept of Mech Engg
  - PhD, BEng(Hons), CEng, CEM, BEAP, BEMP, HBDP, MASHRAE, MCIBSE, MHKIE, MIESNA, LifeMAEE, AssocAIA

    - CEng = Chartered Engineer
    - CEM = Certified Energy Manager
    - BEAP = Building Energy Assessment Professional
    - BEMP = Building Energy Modeling Professional
    - HBDP = High-performance Building Design Professional
    - LifeMAEE = Life Member, Association of Energy Engineers
    - AssocAIA = Associate Member, American Institute of Architects
  - ASHRAE Distinguished Lecturer (2009-2011)
  - President, ASHRAE Hong Kong Chapter (2006-2007)

- Illuminating Engineering Society of North America (IESNA) [now renamed as IES]
- Society of Light and Lighting (SLL)(under CIBSE)

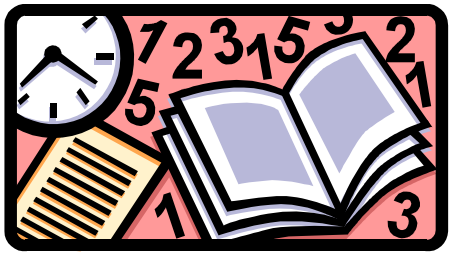
Contents

- Course background
- Lighting design
- Purpose of lighting
- Terminology
- Practical skills

Nowadays, An Exciting Time for Lighting…

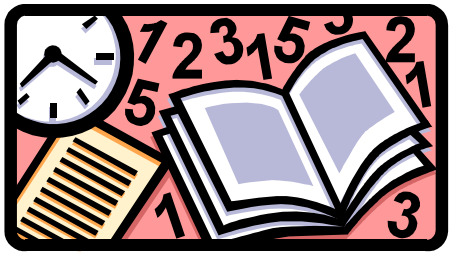
☼ Energy efficient lighting, LED, daylight harvesting, digital & wireless controls, smart lighting, human centric lighting…

Course background

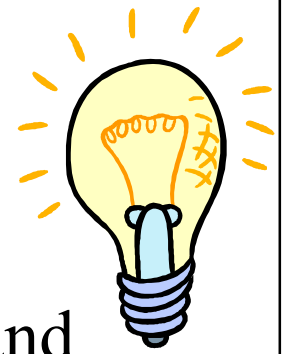


- Educational Objectives:
  - To introduce the important design concepts, principles and technical calculations of lighting engineering and systems
  - To enable students to appreciate the design practice and advanced practical skills for lighting design, daylighting design and lighting energy management

Course background



- Learning Outcomes:
  - 1. Explain the important design concepts and basic principles of lighting engineering
  - 2. Evaluate the components of artificial light sources and luminaires
  - 3. Perform technical calculations of lighting systems for buildings and facilities
  - 4. Apply the design practice for indoor and outdoor lighting design and assessment
  - 5. Appraise advanced practical skills for daylighting design and lighting energy management



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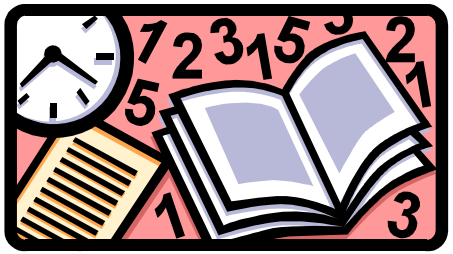
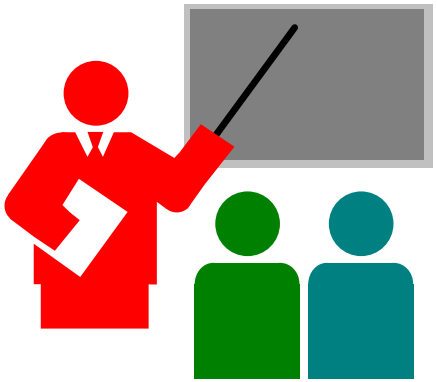


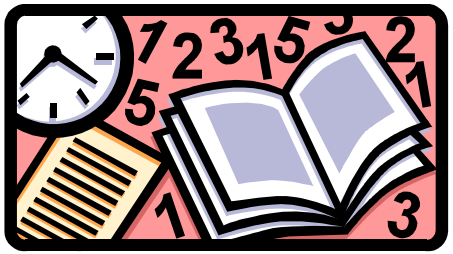
- Prerequisite:
  - Engineering fundamentals on physics and basic electrical engineering
- Assessment Methods:
  - 60% by written examination (2 hours)
  - 40% by continuous assessment (2 nos. assignments)
- Course Website:
  - http://ibse.hk/IBTM5680/



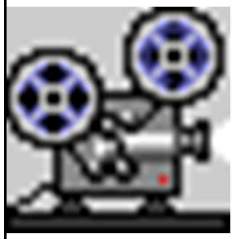
IBTM 5680 Lighting Engineering: Study topics

1. Introduction to Lighting Engineering 2. Basic Concepts of Lighting 3. Principles of Vision & Colour	Basic concepts & principles
4. Light Sources & Luminaires 5. Lighting Systems & Components	Systems & components
6. Indoor Lighting Design 7. Outdoor Lighting Design 8. Daylighting Design 9. Lighting Calculations 10. Computer-aided Lighting Design	Design & calculations
11. Lighting for Emergency, Safety & Security 12. Lighting Energy Management	Emergency, safety & energy efficiency

Course background



- Study methods
  - Lectures (core knowledge & discussions)
  - Further Readings (essential study information)
  - Videos (illustration & demonstration)
  - References (useful supporting information)
  - Web Links (related links & resources)
- Assignments
  - Practical skills & applications



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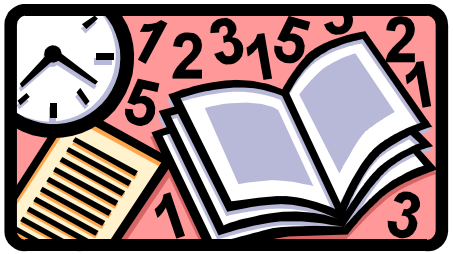
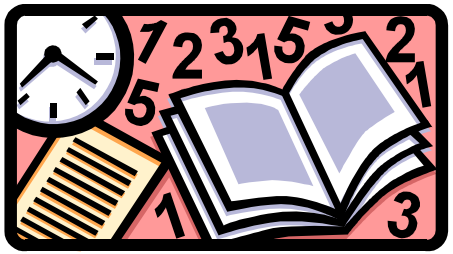


- Design guides:
  - Karlen M., Benya J. R. & Spangler C., 2014. *Lighting Design Basics*, Wiley, Hoboken, NJ.
  - Pritchard D. C., 1999. *Lighting*, 6th ed., Longman, Harlow.
  - Simons R. H. & Bean A.R., 2001. *Lighting Engineering: Applied Calculations*, Architectural Press, Oxford.
  - SLL, 2022. *The SLL Code for Lighting*, Society of Light and Lighting (SLL), London.
  - Winchip S. M., 2017. *Fundamentals of Lighting*, Fairchild Publications, New York.

Course background



- Reference books:
  - Benya J., et al, 2003. *Advanced Lighting Guidelines* [CD-ROM], 2003 ed., New Buildings Institute, White Salmon, Washington. [https://www.lightingassociates.org/i/u/2127806/f/tech_sheets/Advanced_Lighting_Guidelines_2003.pdf]
  - IESNA, 2011. *The Lighting Handbook: Reference & Application*, 10th ed., Illuminating Engineering Society of North America, New York, N.Y.
  - SLL, 2018. *The SLL Lighting Handbook*, Society of Light and Lighting (SLL), London.
  - Handbook of Lighting Design (ERCO Edition) https://download.erco.com/en/media/handbook
  - The Lighting Handbook (Zumtobel) http://www.zumtobel.com/PDB/teaser/EN/lichthandbuch.pdf

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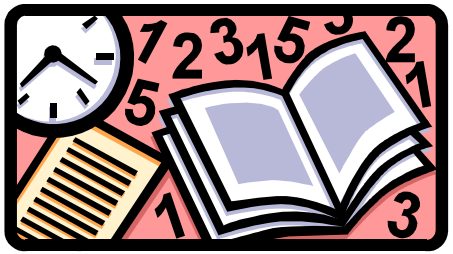


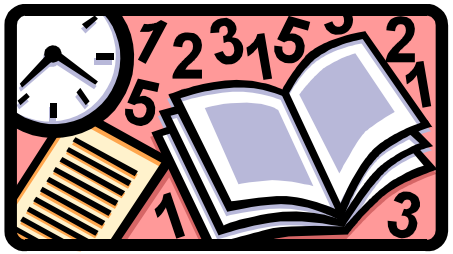
- Related professional institutions:
  - Chartered Institution of Building Services Engineers (CIBSE) http://www.cibse.org
    - CIBSE Hong Kong Region http://www.cibse.org.hk/
    - Society of Light and Lighting (SLL) http://www.sll.org.uk/
  - Hong Kong Institution of Engineers (HKIE) 香港工程師學會 http://www.hkie.org.hk/
    - Building Services Division 屋宇裝備分部 https://www.hkie-bsd.org/

CIBSE

HKIE THE HONG KONG INSTITUTION OF ENGINEERS 香港工程師學會

Building Services Division
屋宇裝備工程分部

Course background



- Admission requirements for HKIE Building Services Discipline
  https://hkie.org.hk/en/membership/download_mem2/
  - Top up requirements - Six core subject areas:
    - Heating, Ventilation and Air-Conditioning (HVAC)
    - Electrical Services
    - Fire Services
    - Utility Services
    - Lighting Engineering
    - Project and Engineering Management

Lighting design

- Lighting/Illumination Engineering 照明工程
  - It is concerned about the aesthetics, efficiency, and quality of light and lighting products in our built world/environment (buildings & facilities)
    - Architectural lighting design (both interior & exterior)
  - *Lighting Engineers* deploy skills of product design, electrical engineering, civil engineering, and mechanical engineering to generate innovative product and lighting layout designs to improve user quality of life and safety

(Source: https://engineering.purdue.edu/ENE/Academics/Undergrad/MDE/PlansofStudy/lighting-engineering)

Lighting design

- Who are involved in Lighting Design?*
  - Architects
  - Engineers
    - ***Building Services Engineers***
    - Electrical Engineers
    - Lighting Engineers
  - Interior Designers
  - Lighting Designers (specialist)

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

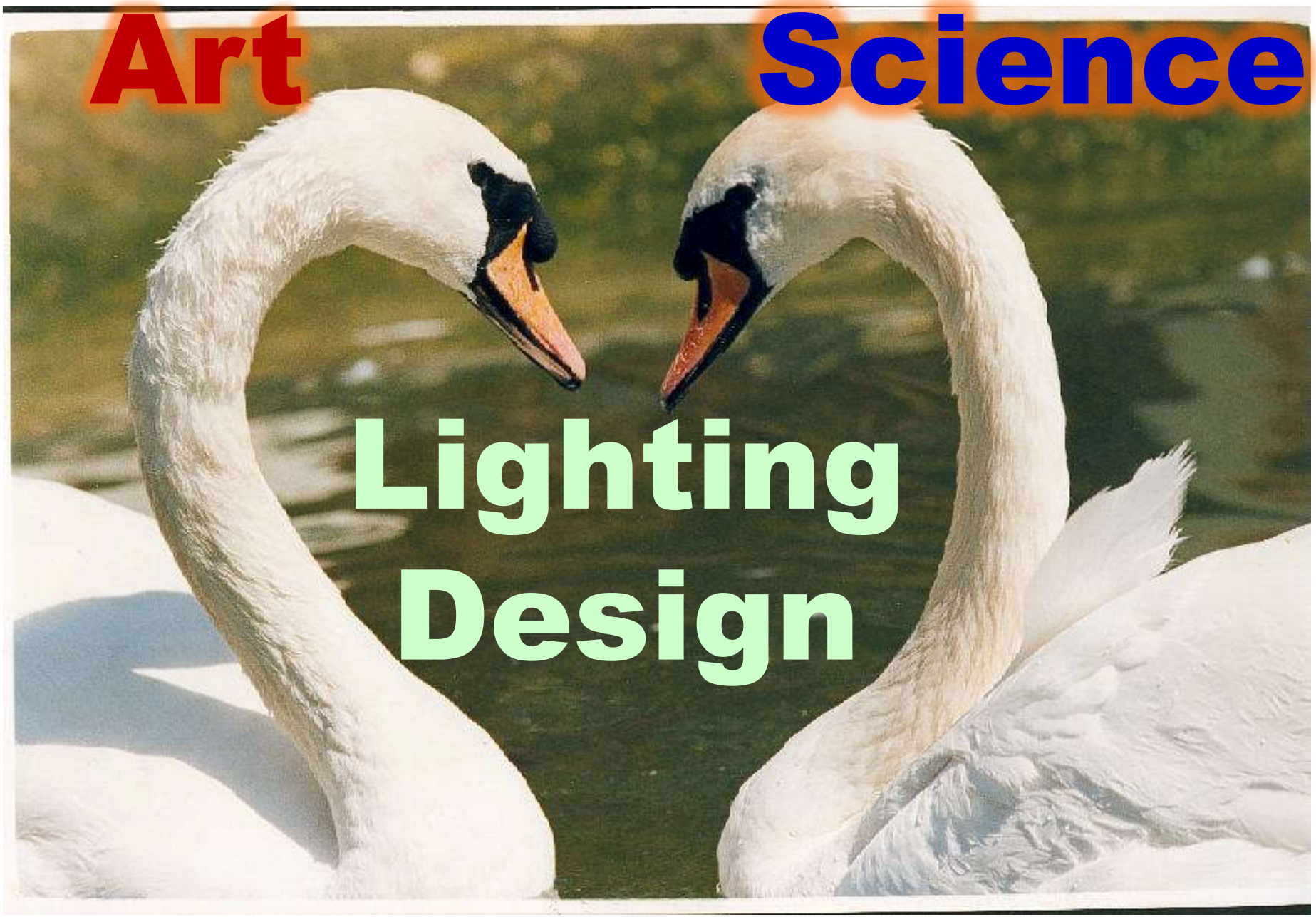
Lighting design

- Professional societies on *Lighting Design*
  - Illuminating Engineering Society of North America (IESNA) [now renamed as IES]
    - http://www.ies.org
  - Commission Internationale de l'Eclairage (CIE) (International Commission on Illumination)
    - http://www.cie.co.at
  - Society of Light and Lighting, UK (under CIBSE*)
    - http://www.sll.org.uk/

*CIBSE = Chartered Institution of Building Services Engineers

Lighting design

- Basic concepts & principles
  - Light & lighting, human vision & colour
  - Light sources & luminaires
  - Lighting systems & components
- Forms of lighting design
  - Indoor lighting design
  - Outdoor lighting design
  - Daylighting design
- Design practice & skills
  - Codes, emergency lighting & energy efficiency


Art
Science
Lighting
Design

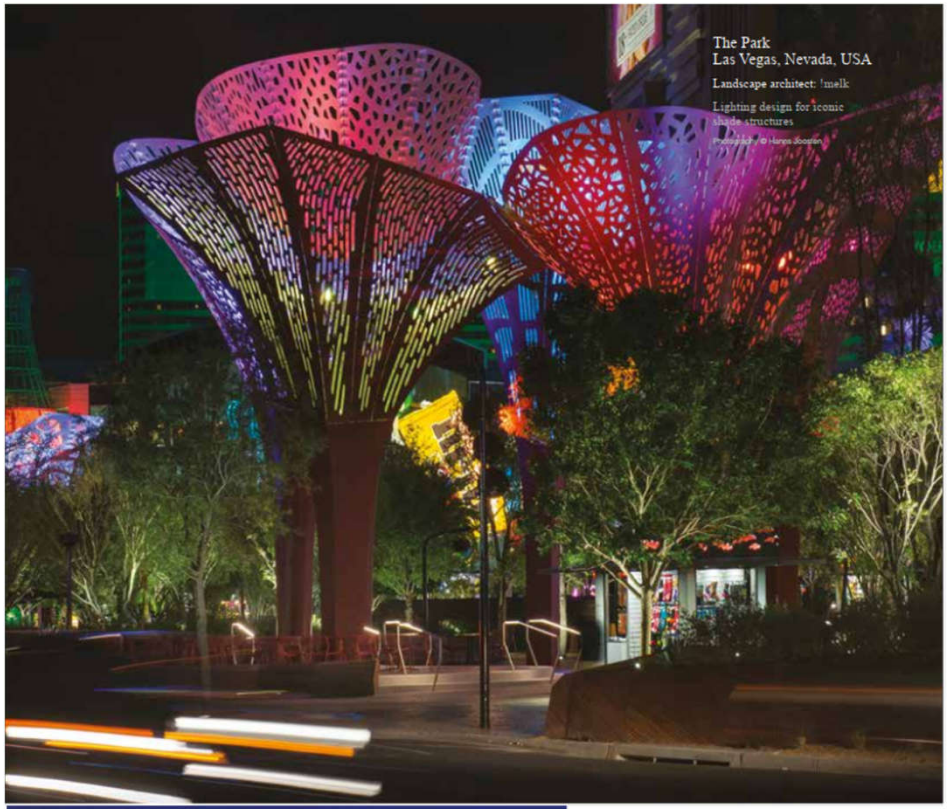
Lighting design

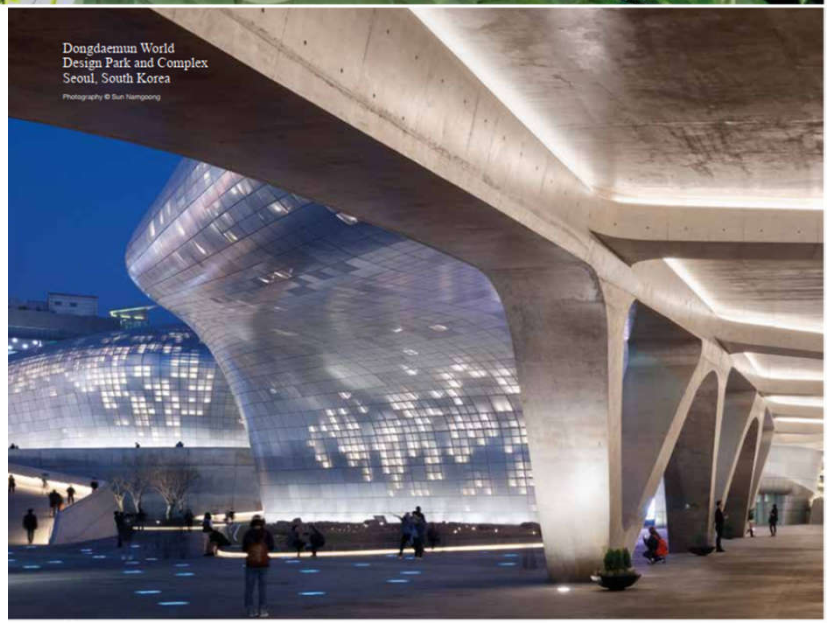
- Lighting design is the science and art of making things useful to humankind; and it is the application of lighting -- including daylight when it is specifically used as a source of lighting -- to human spaces
- Lighting design relies on a combination of specific scientific principles, established standards and conventions, and a number of aesthetic, cultural and human factors applied in an artful manner

Lighting design

- As a **SCIENCE**
  - The amounts of illumination needed and certain aspects of the quality of light are quantified
- As an **ART**
  - Attaching numbers is meaningless because light is an experience of the SENSES
    - Lighting can motivate people to be active, relaxed, productive, lively or depressed
    - Create an atmosphere pleasing to the occupants
    - Provide visibility, character, and mood as well as relate harmoniously to the space in which it is used

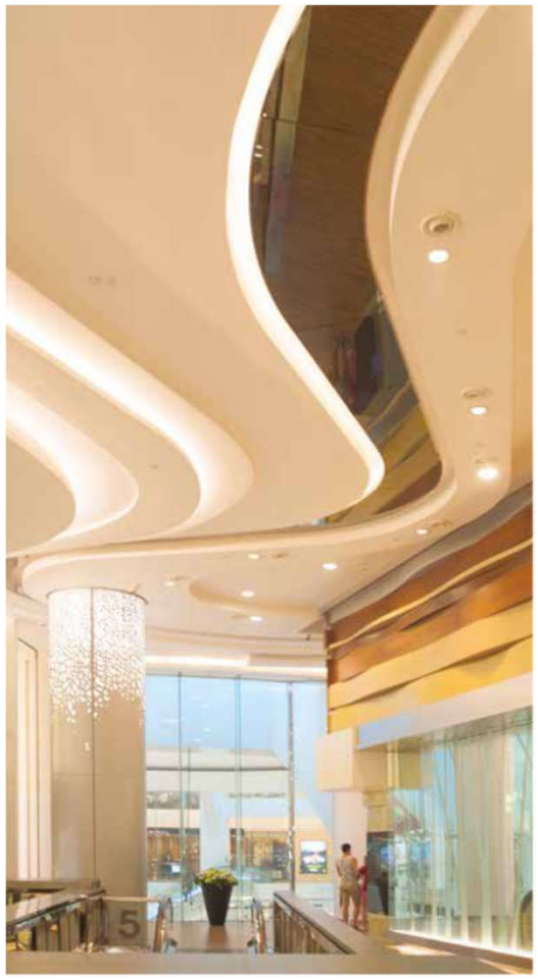
Examples of interesting lighting design in the world

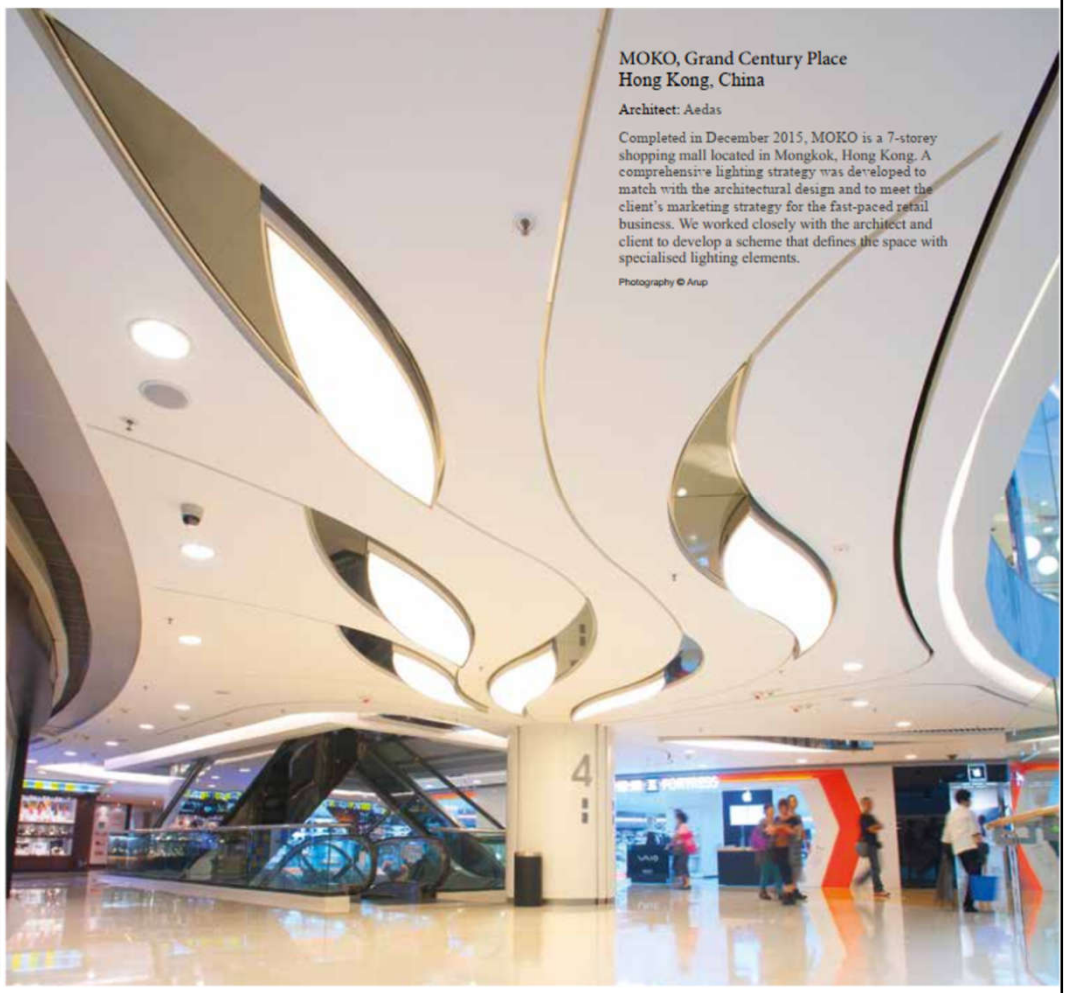




(Source: https://www.arup.com/perspectives/publications/promotional-materials/section/lighting-design)

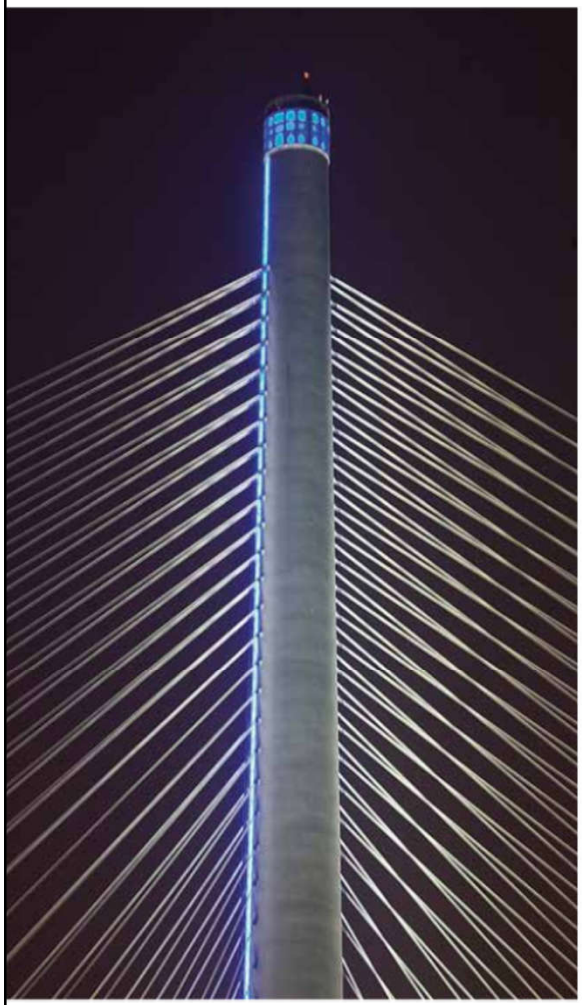
An example of lighting design for a shopping mall in Hong Kong





(Source: https://www.arup.com/perspectives/publications/promotional-materials/section/lighting-design)

An example of outdoor lighting design in Hong Kong (Stonecutters Bridge)



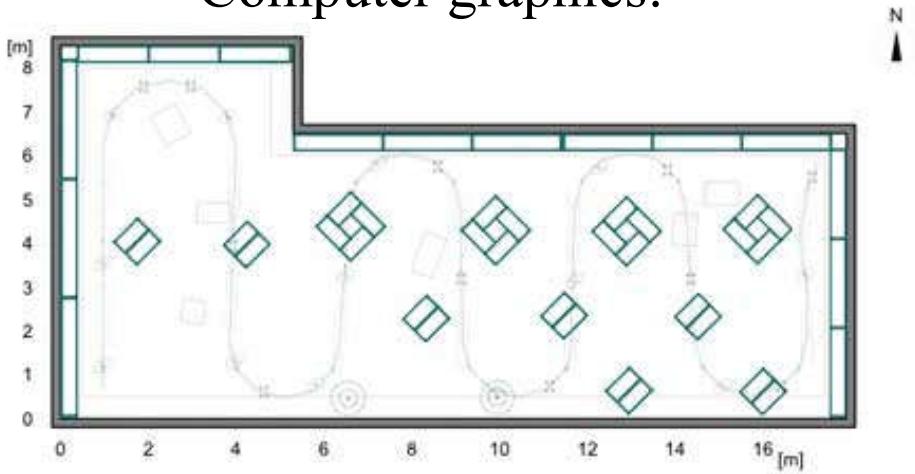
(Source: https://www.arup.com/perspectives/publications/promotional-materials/section/lighting-design)

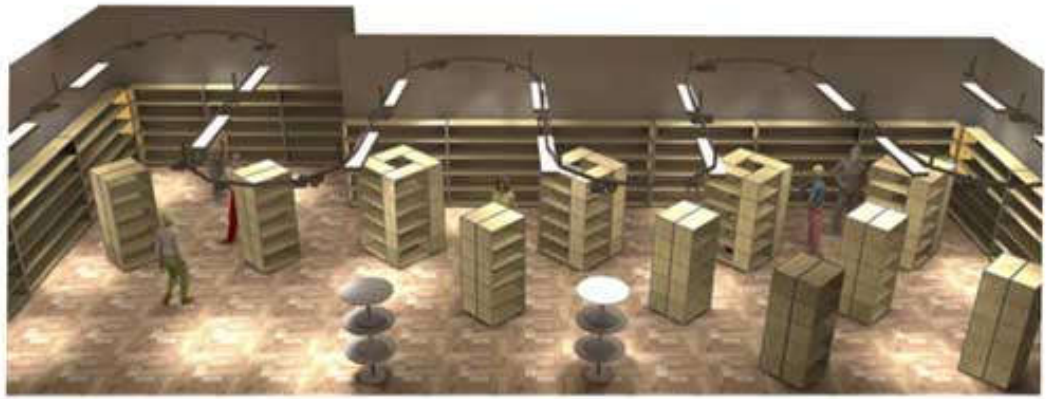
Examples of lighting design & analysis

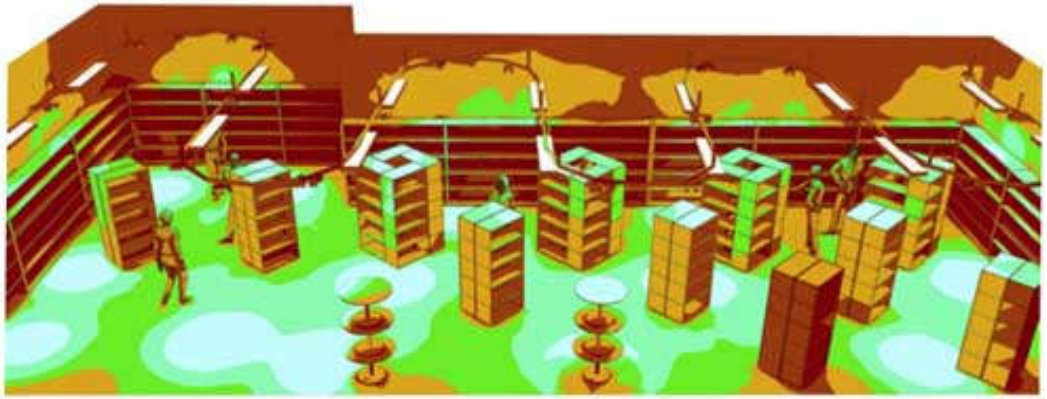
Real pictures:

Student union rotunda with view of campus courtyard.

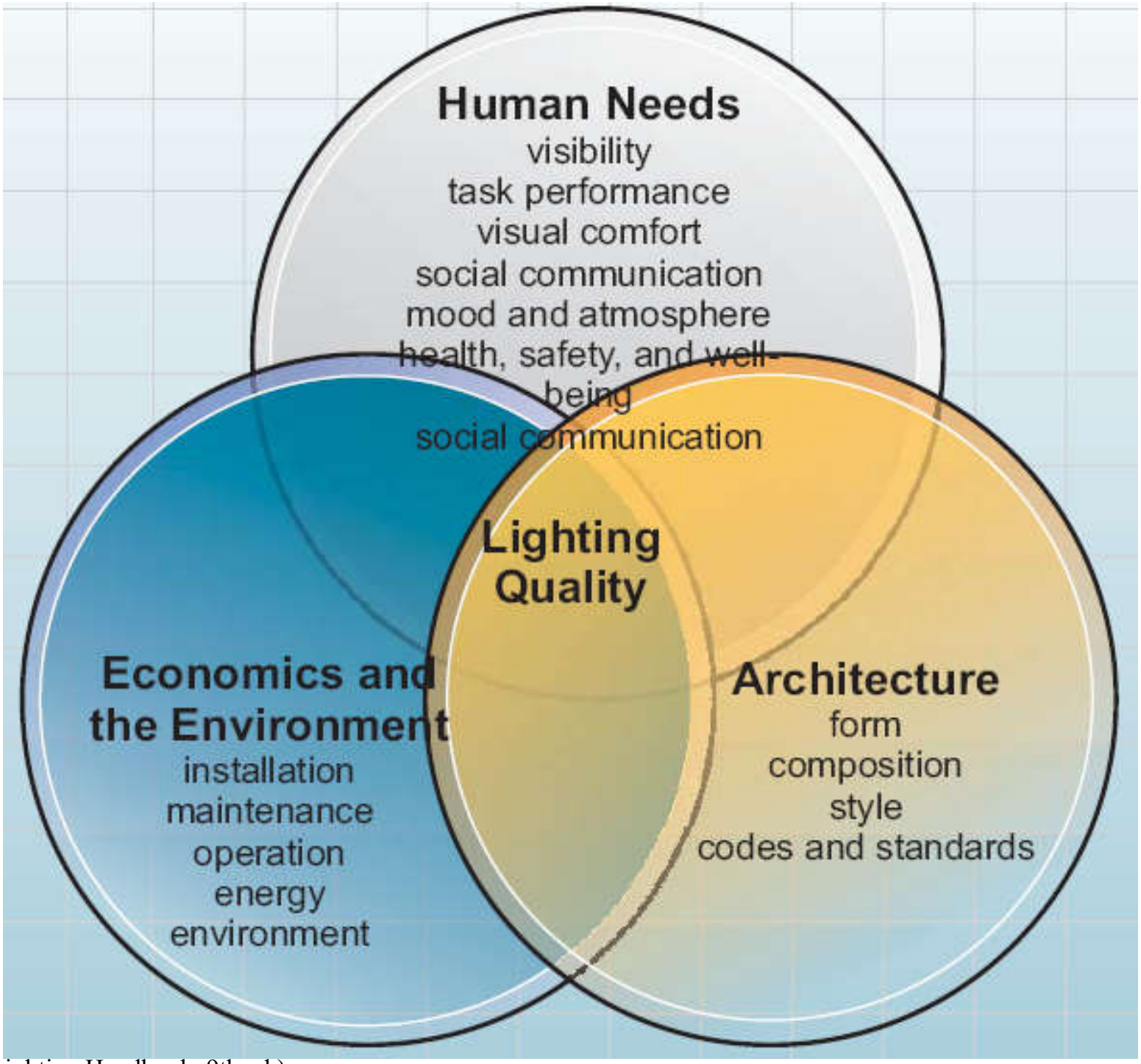
Computer graphics:





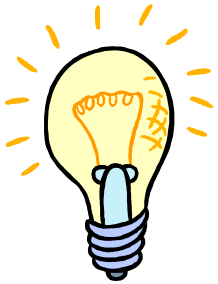


Overlapping lighting issues



(Source: IESNA Lighting Handbook, 9th ed.)

Purpose of lighting



- *Lighting Quantity*
  - Setting criterion illumination level
  - Illumination level based on light source spectrum
- *Lighting Quality*
  - Light distribution (e.g. task & ambient lighting)
  - Space and workplace considerations (e.g. daylight integration and control)
  - Colour appearance, flicker, glare
  - Modelling of faces/objects, highlights

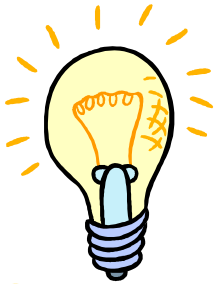
(Video: Quality of light and lighting (3:27) https://youtu.be/xUkxrKlPg48)

Quality characteristics of lighting

Traditional quality criteria:	**New quality criteria:**
– Sufficient illumination level – Harmonious brightness distribution – Glare limitation – Avoidance of reflections – Good modelling – Correct light colour – Appropriate colour rendering	– Changing lighting situations – Personal control – Energy efficiency – Daylight integration – Light as an interior design element

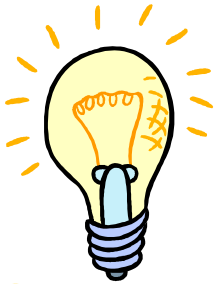
(Source: The Lighting Handbook (Zumtobel) http://www.zumtobel.com/PDB/teaser/EN/lichthandbuch.pdf)

Purpose of lighting



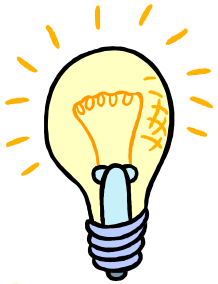
- Two main concerns of lighting design:
  - Provide *illumination* for people to use a space and to see well enough to FUNCTION at their designated tasks [practical & functional]
  - Create *perception* of the space(s) or form(s) so that the designer's CONCEPT is communicated and/or felt [aesthetic & sensory]
- Effect of lighting
  - On architecture (defines space & shows form)
  - On interior design (reveals texture & colour)

Purpose of lighting



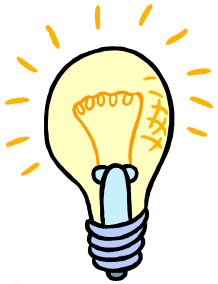
- The complex and temporal nature of lighting is one of the least understood of its many variables. Because of this complexity, lighting design can be one of the most creative areas of all of architecture
  - Light defines space, reveals texture, shows form, indicates scale, separates functions, creates mood
  - Good lighting makes a building look and work the way the architect intended at all hours of day and night

Purpose of lighting



- Lighting contributes to the character, to the desired attitude toward form and space, and to the effective functioning of that space
  - Lighting is dynamic. Change the lighting and the world around us changes
  - Light can make or break a space both functionally and aesthetically

Purpose of lighting

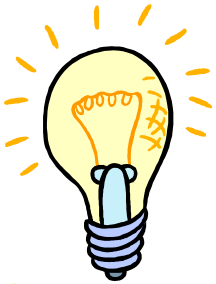


- Three main functions of lighting:
  - Ensure the safety of people
  - Facilitate the performance of visual tasks
  - Aid the creation of an appropriate visual environment

Lighting art creation

(Source: https://www.arup.com/perspectives/publications/promotional-materials/section/lighting-design)

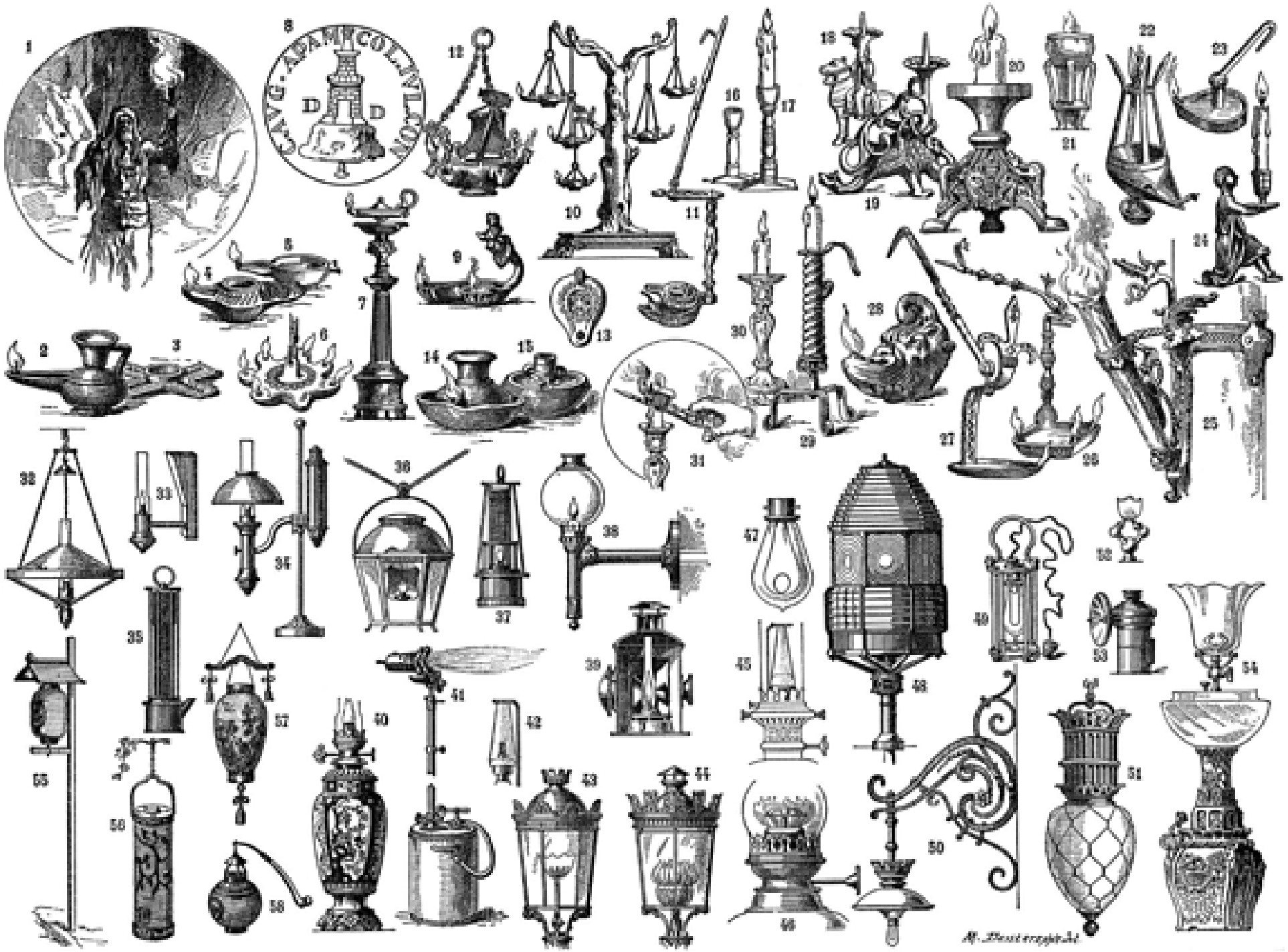
Purpose of lighting



- Two sources of light:
  - Natural sources of light (daylight)
    - People prefer daylight to “windowless” rooms
    - Windows provide a view & connection to outdoor
  - Artificial or man-made (electric light)

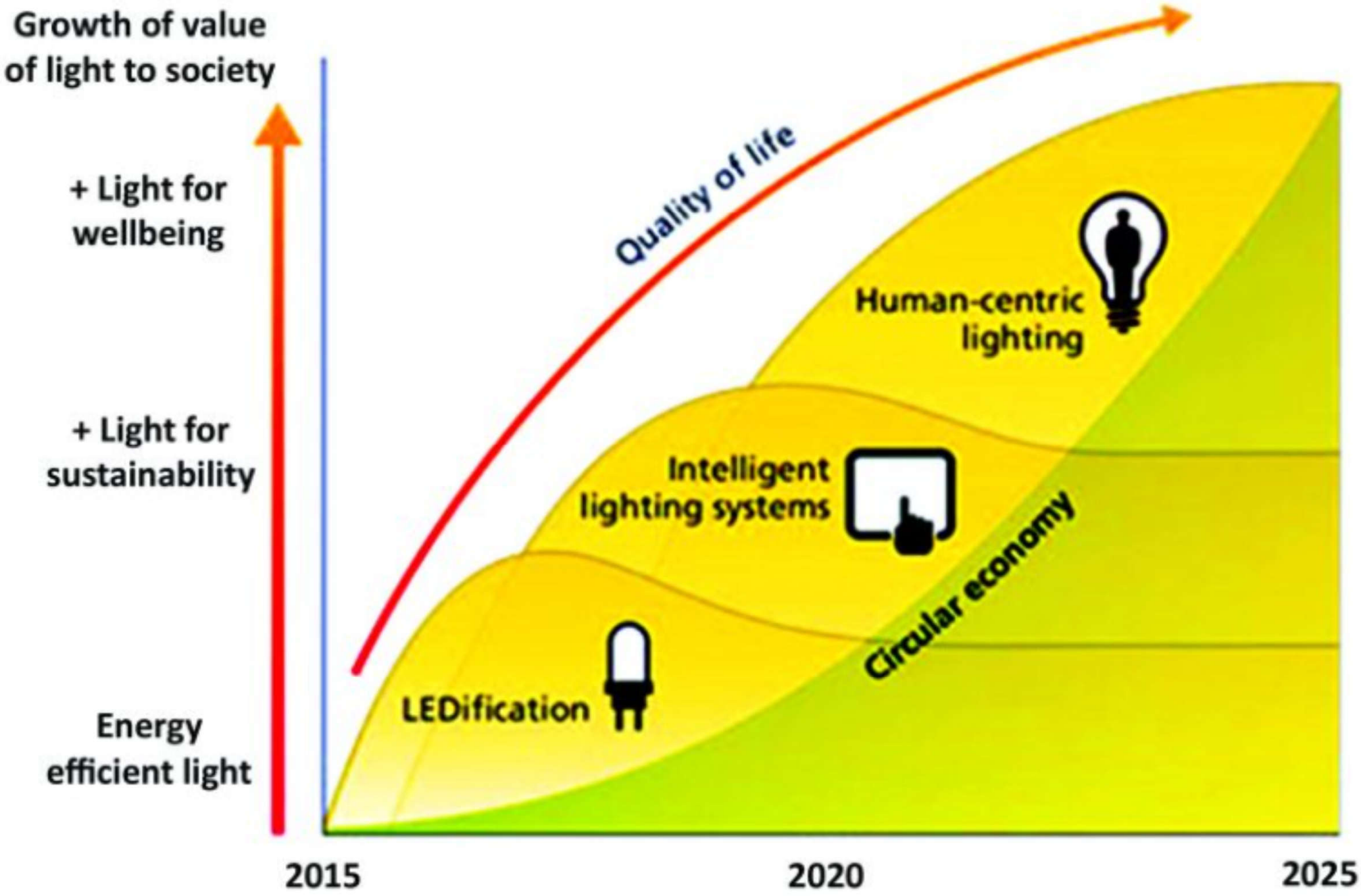
- Electric lighting and the daylighting should be complementary to ensure
  - Efficient use of energy
  - High quality lighting

The history of lighting technology



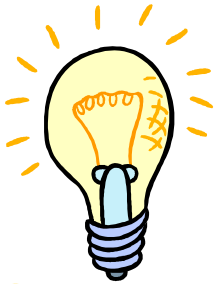
(Source: https://www.stouchlighting.com/blog/the-historical-evolution-of-lighting)

The continuing evolution of artificial lighting technologies



(Source: https://www.actis.co.in/human-centric-lighting-hcl-why-is-it-a-buzzword-in-the-lighting-industry)

Purpose of lighting



- Human Centric Lighting (HCL)
  - Expresses the positive effect of light & lighting on the health, well-being & performance of humans
  - Has both short & long-term benefits
  - Considers both the visual & non-visual effects of exposing humans to light
    - Such as visual performance & comfort, sleep quality, alertness, mood & behaviour with consequences for human health, learning & spending
  - A new land waiting to be explored
  - Connection between technical & human aspects

Triple effects of light

1. Light for visual functions

- Illumination of task area in conformity with relevant standards
- Glare-free and convenient

2. Light for emotional perception

- Lighting enhancing architecture
- Creating scenes and effects

3. Light creating biological effects

- Supporting people's circadian rhythm
- Stimulating or relaxing

(Source: The Lighting Handbook (Zumtobel) http://www.zumtobel.com/PDB/teaser/EN/lichthandbuch.pdf)

Terminology

- Lighting science terminology
  - Photometry 光度學
    - Science of measuring visible light in units that are weighted according to the sensitivity of the human eye
  - Radiometry 輻射測量學
    - Science of measuring light in any portion of the electromagnetic spectrum
  - Colorimetry 色度學
    - Science of the measurement of colour, replacing subjective responses of colours with an objective numerical system

Terminology

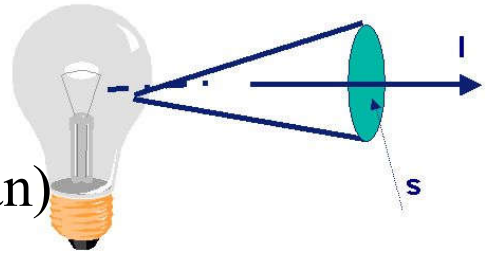
- Lighting terminology
  - Luminous flux 光通量 (lumen, lm), Φ

Radiation value

  - Light power emitted by a source or received by a surface (radiant flux according to the spectral sensitivity of the human eye)
  - A candle flame generates about 12 lumens
  - Fluorescent lamp 32W = 3,300 lumens
  - Luminous intensity 光強 (candela, cd), *I*

Sender-side value

  - Luminous flux per unit solid angle in the direction in question, $I = d\Phi / d\omega$ (ω = solid angle, in steradian)



  - Illuminance 照明度 (lm/m^2, or lux), *E*

Recipient-side value

  - Light energy arriving at a real surface, $E = d\Phi / dA$ (*A* = receiving surface area) (“lumen per unit area”)

Terminology

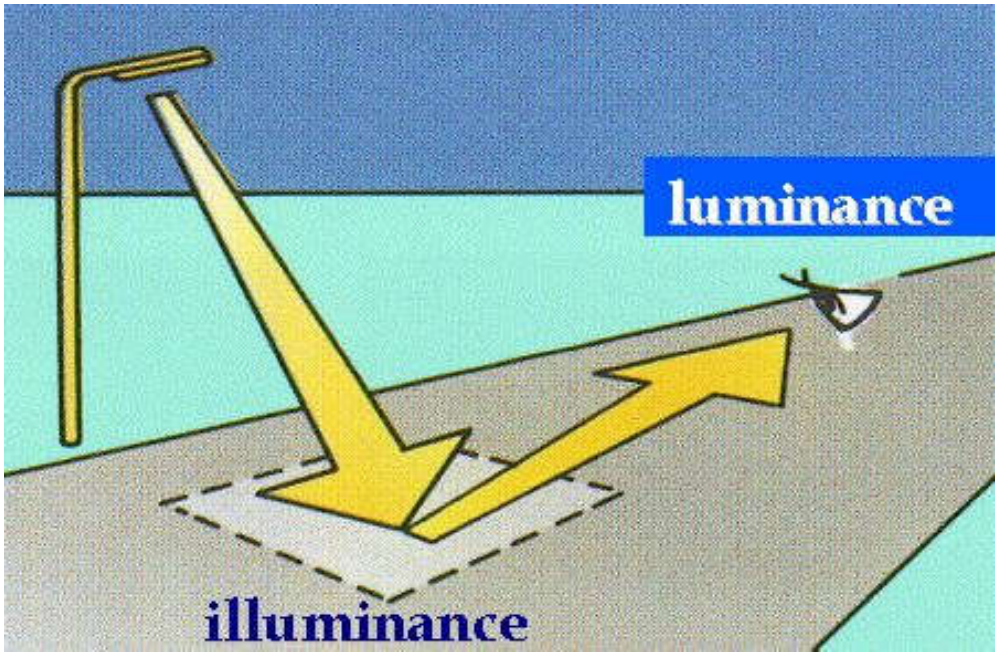
- Lighting terminology*
  - Luminance 亮度 (cd/m^2), L

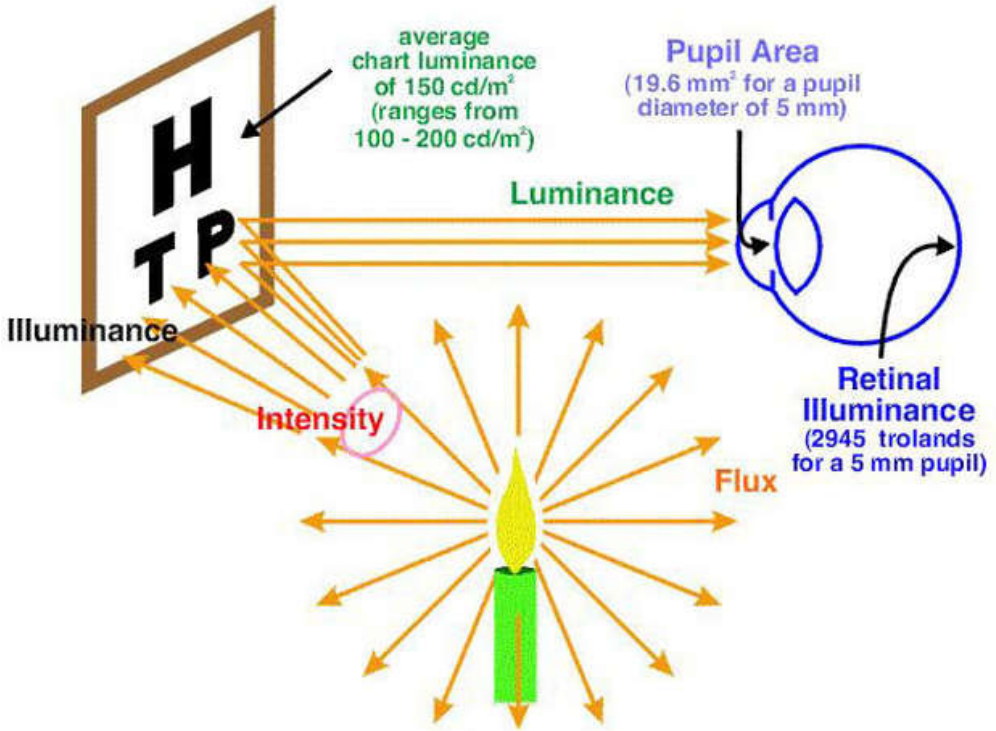
Sender-side value

- Luminous flux density (I) leaving a projected surface in a particular direction (often called "brightness")
- $L = I / dA.\cos\theta = (d\Phi/d\omega) / dA.\cos\theta$
  - $d\omega$ = solid angle containing the given direction
  - dA = area of a section of that beam (the source side) containing the given point
  - θ = the angle between the normal to that section and the direction of the beam

(* See also http://hyperphysics.phy-astr.gsu.edu/hbase/vision/photomcon.html)

Illuminance and luminance

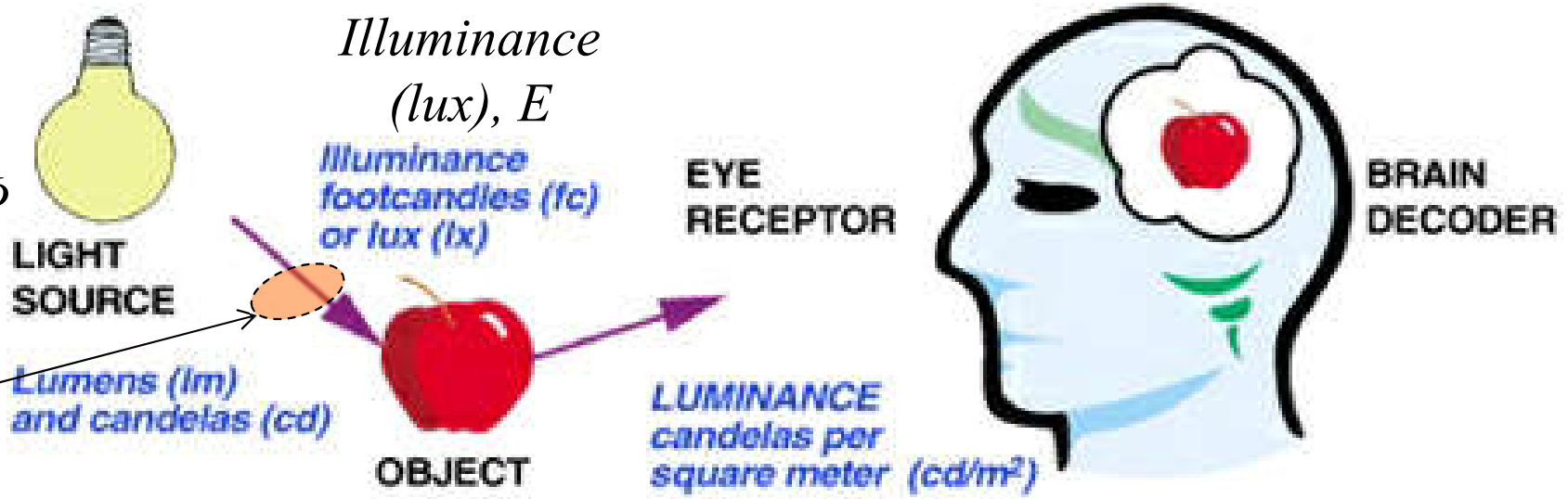




Luminous flux (lm), Φ

Illuminance (lux), E

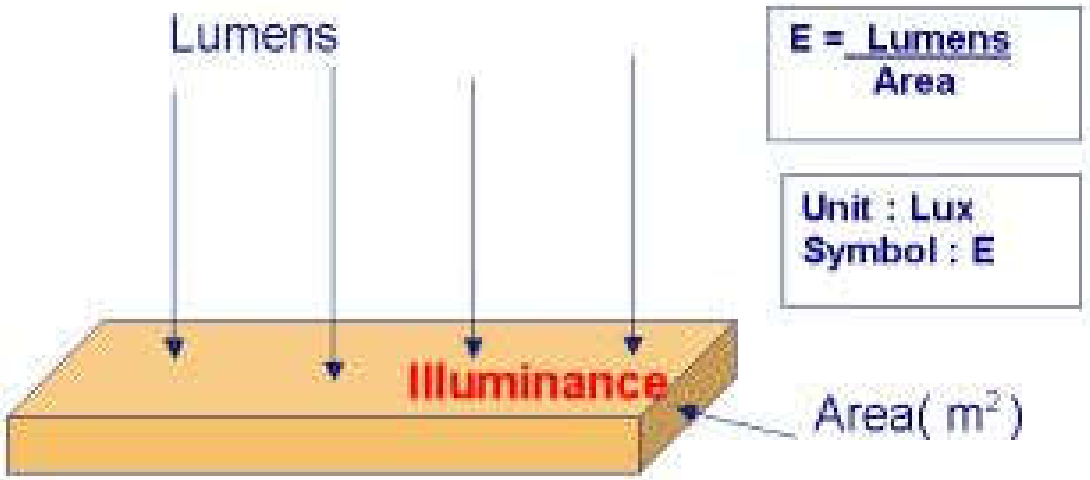
Luminous intensity (cd), I



Luminance (cd/m²), L

(Source: Lessons in Lighting, http://www.lightolier.com)

Practical examples of illuminance



Summer, at noon, under a cloudiness sky	100 000 lux
Ditto, but in the shade	10 000 lux
In the open under a heavily-overcast sky	5000 lux
Artificial light, in a well-lit office	1000 lux
Artificial light, average living-room	100lux
Street lighting	5-30 lux
Full moon, on a clear night	0,25 lux

(Source: Philips Lighting, http://www.lighting.philips.co.in)

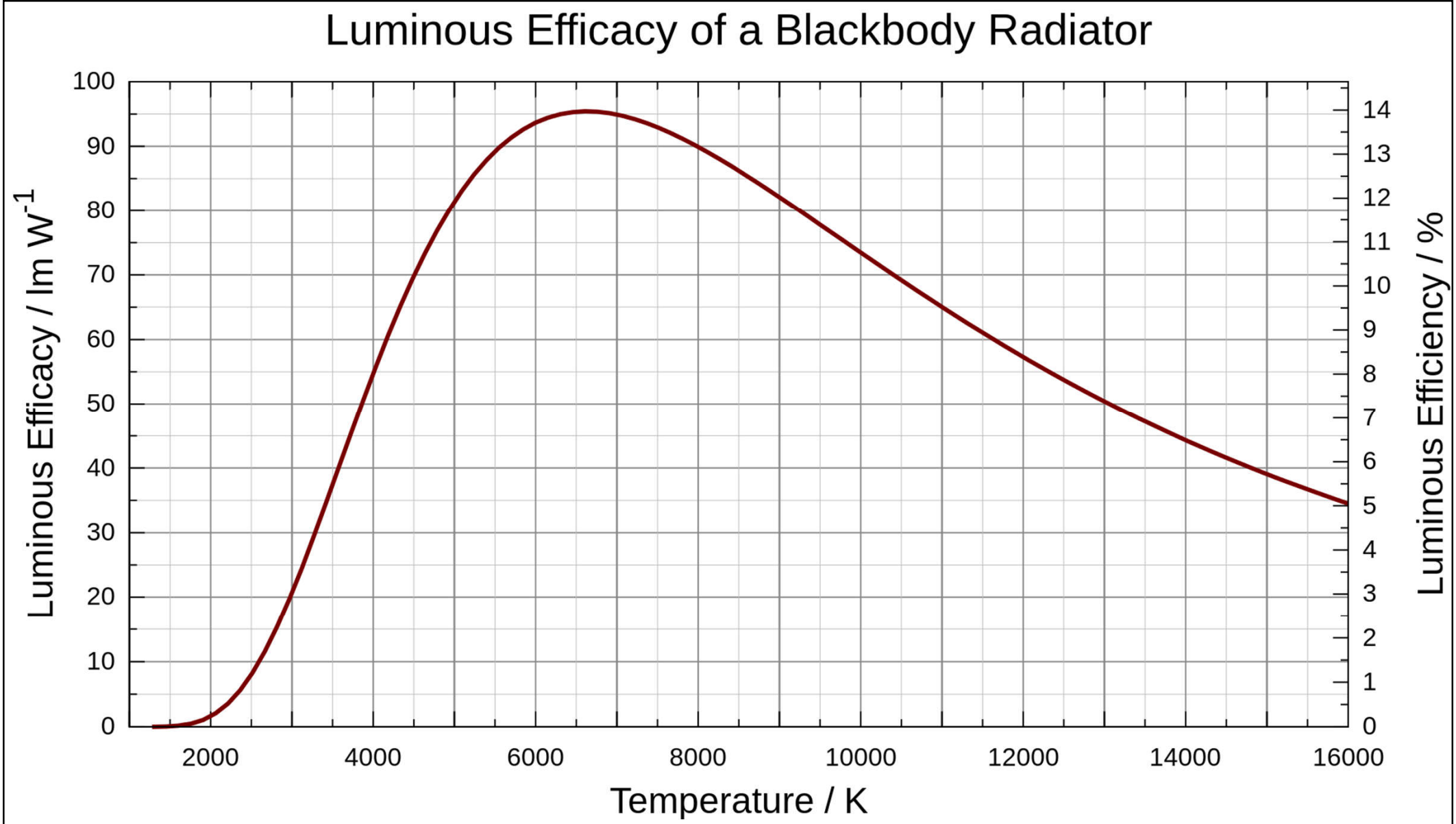
Practical examples of luminance

Surface of the sun	1 650 000 000 cd/m^2
Filament of a clear incandescent lamp	7 000 000 cd/m^2
Bulb of an 'Argenta' incandescent lamp	200 000 cd/m^2
Fluorescent lamp	5000 -15 000 cd/m^2
Surface of the full moon	2500 cd/m^2
Sun-lit beach	15 000 cd/m^2
White paper (reflectance 0,8) under 400 lux	100 cd/m^2
Grey paper (reflectance 0,4) under 400 lux	50 cd/m^2
Black paper (reflectance 0,04) under 400 lux	5 cd/m^2
Road surface under artificial lighting	0,5 - 2 cd/m^2

(Source: Philips Lighting, http://www.lighting.philips.co.in)

Terminology

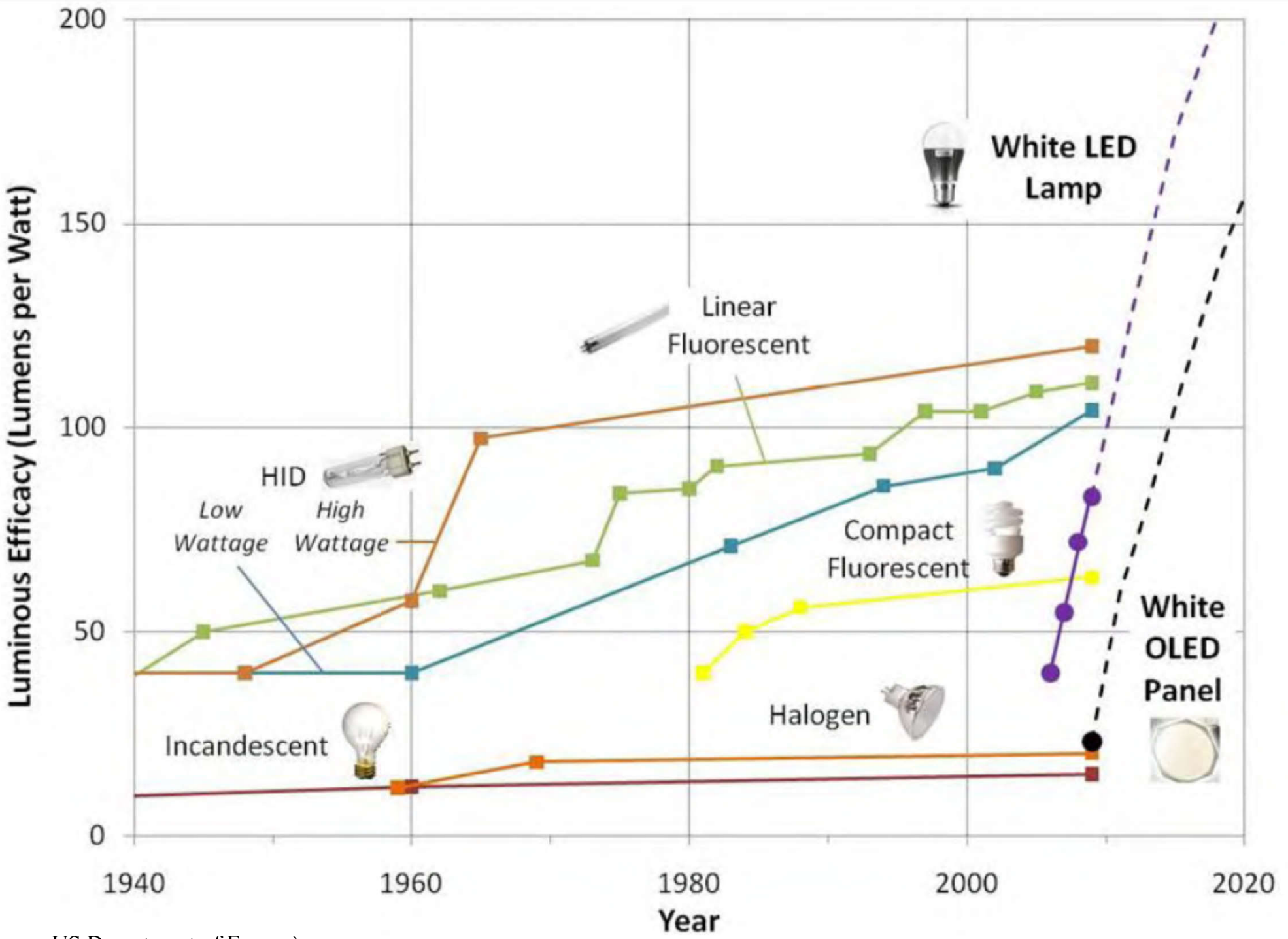
- Lighting terminology
  - 發光效能 Luminous efficacy of a source (lm/W), η
    - Ratio between the luminous flux emitted and the power consumed by the source
    - How well a light source produces visible light
    - http://en.wikipedia.org/wiki/Luminous_efficacy
  - 光譜功率分配 Spectral power distribution (SPD) curves
    - Curves to show the visual profile and colour characteristics of a light source
    - Plot of relative power emitted in the different regions of the spectrum



$$\text{Luminous Efficacy}, K = \frac{\text{Luminous Flux}(F \text{ in Lumens})}{\text{Radiant Flux}(P \text{ in Watts})}$$

(Source: https://en.wikipedia.org/wiki/Luminous_efficacy)

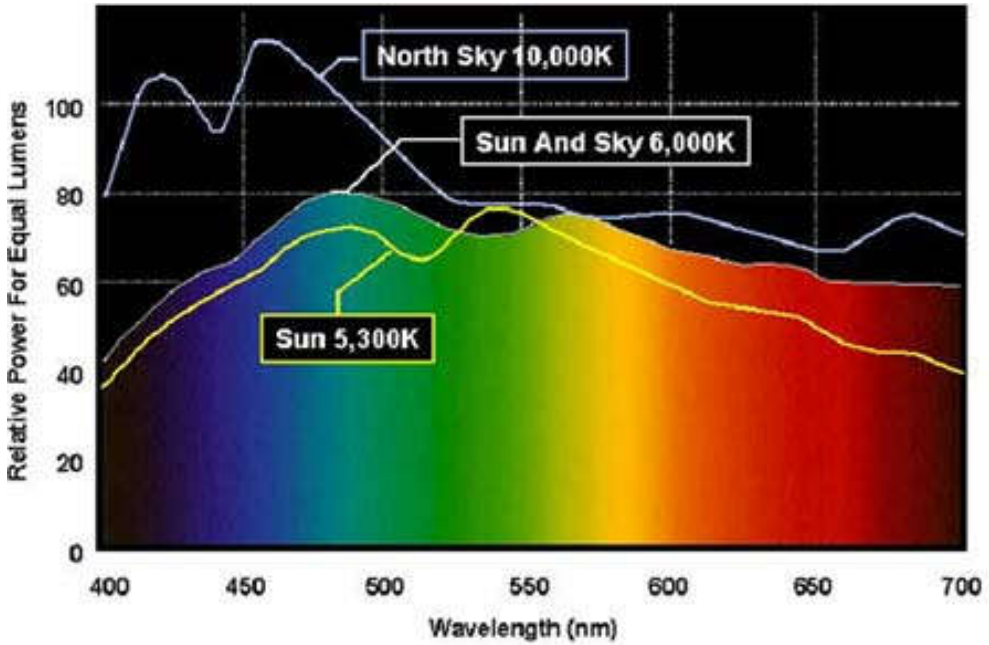
Historical and predicted luminous efficacy of light sources



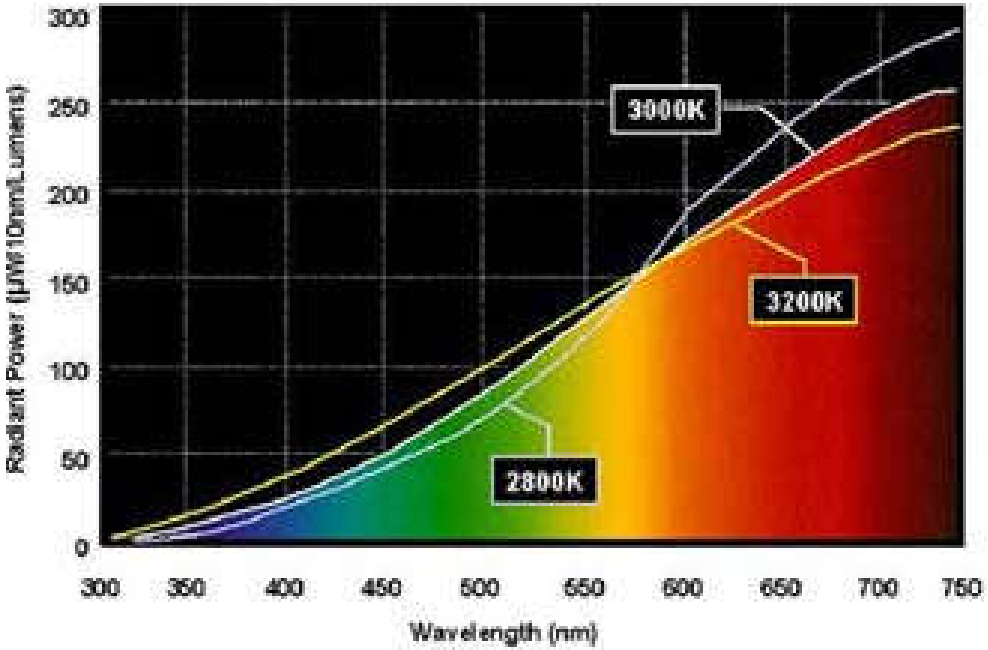
(Source: US Department of Energy)

Spectral power distribution (SPD) curves

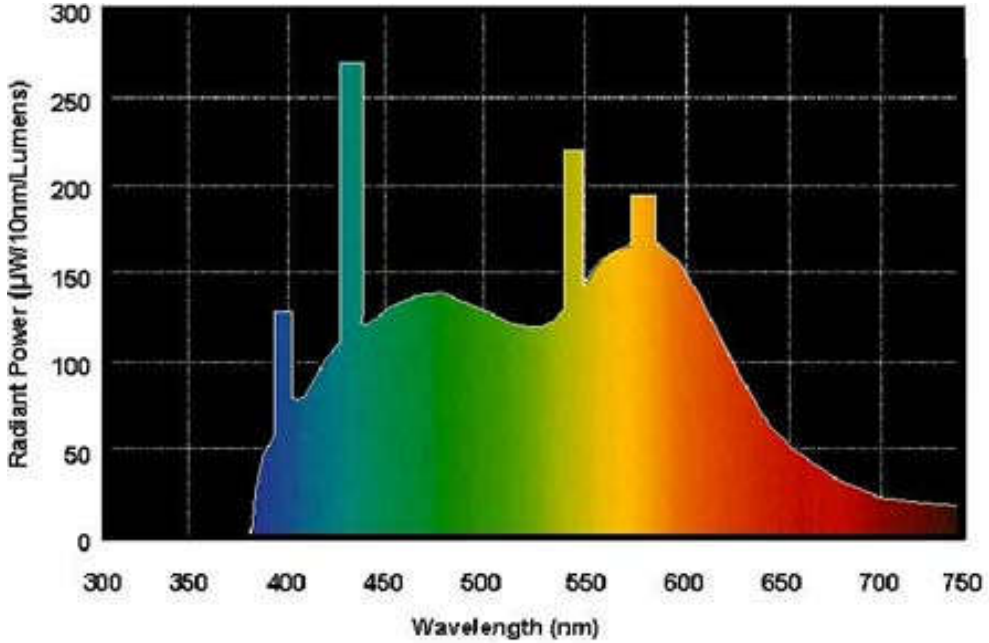
Outdoor daylight



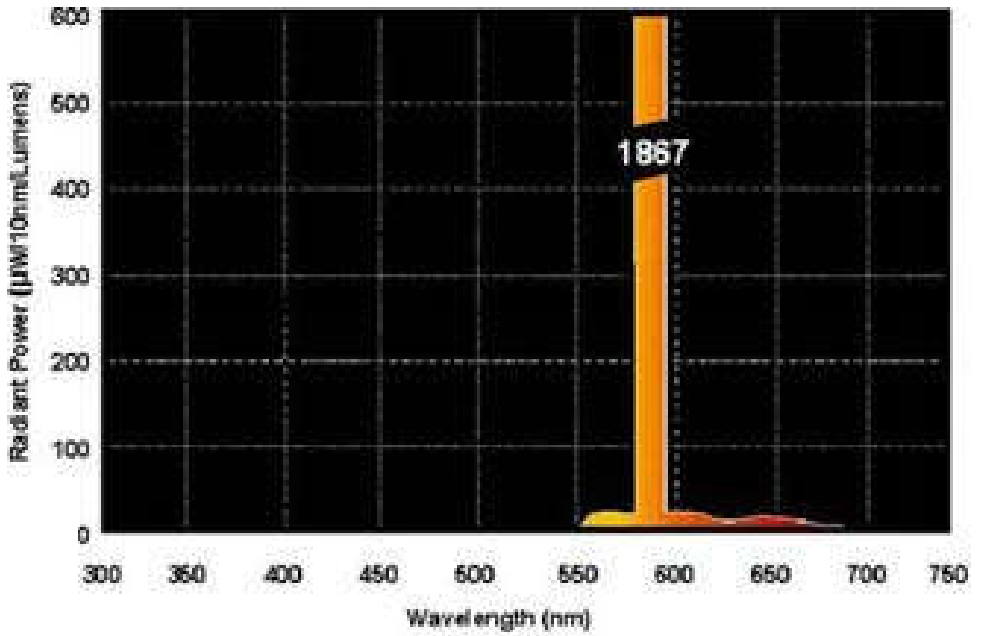
Incandescent



Fluorescent lamp (Daylight)

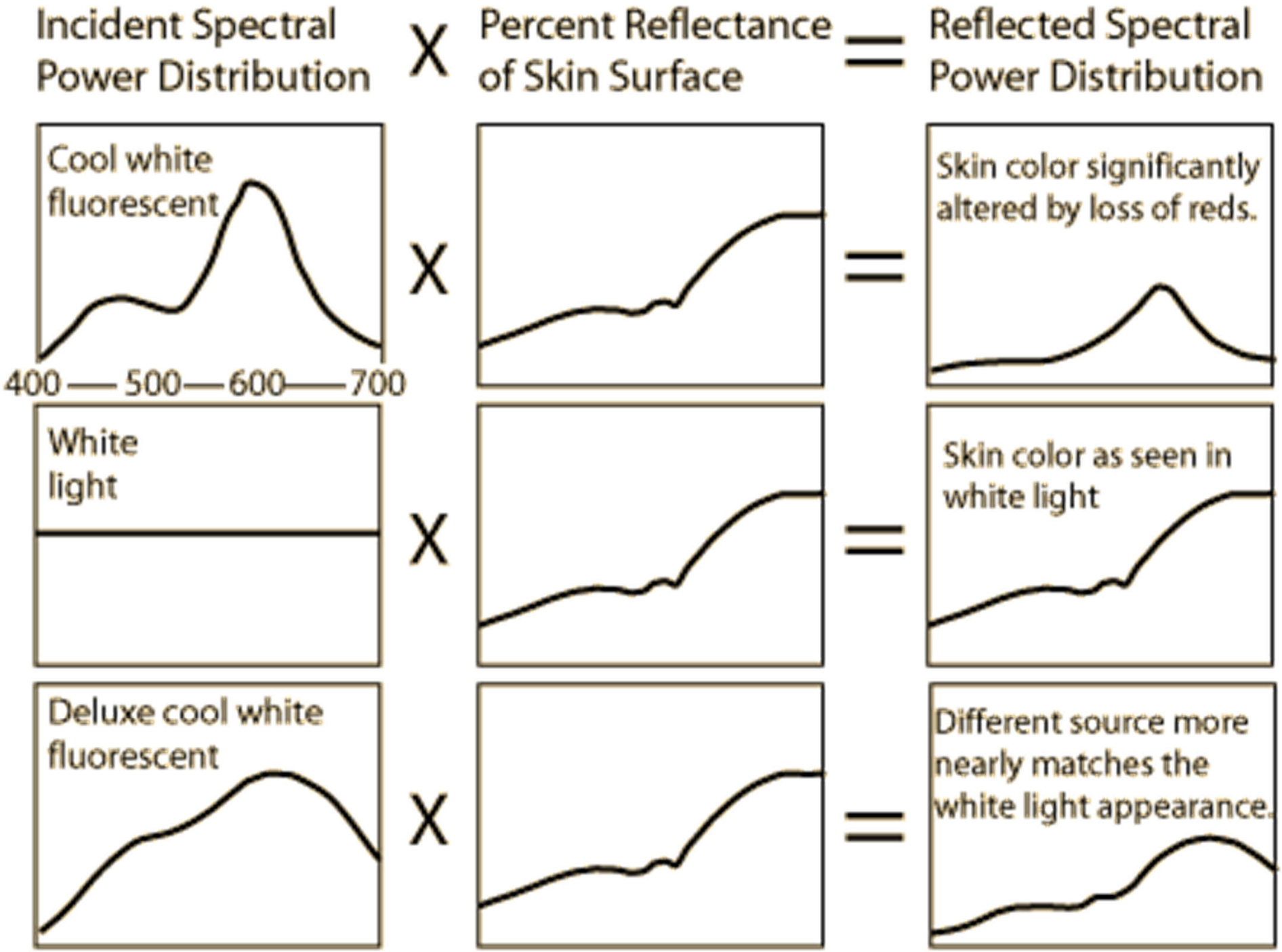


Low pressure sodium (LPS)



(Source: GE Lighting, http://www.gelighting.com)

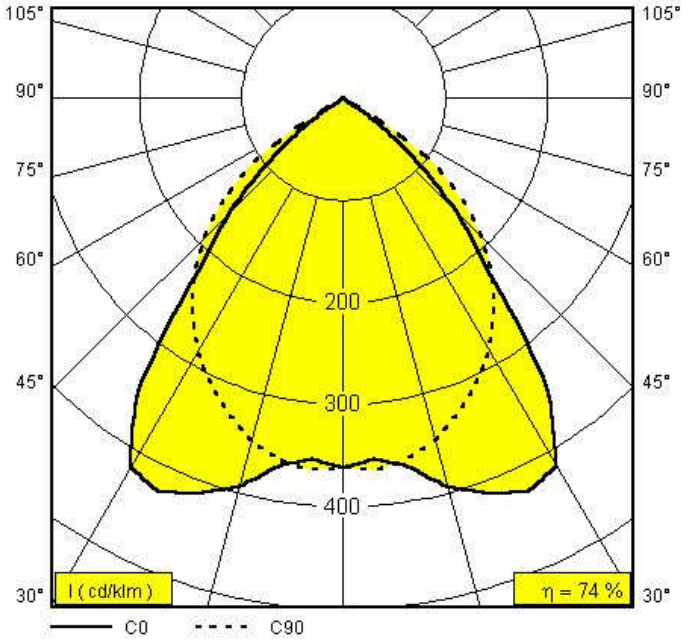
Example of spectral power distribution application



(Source: http://hyperphysics.phy-astr.gsu.edu/hbase/vision/spd.html)

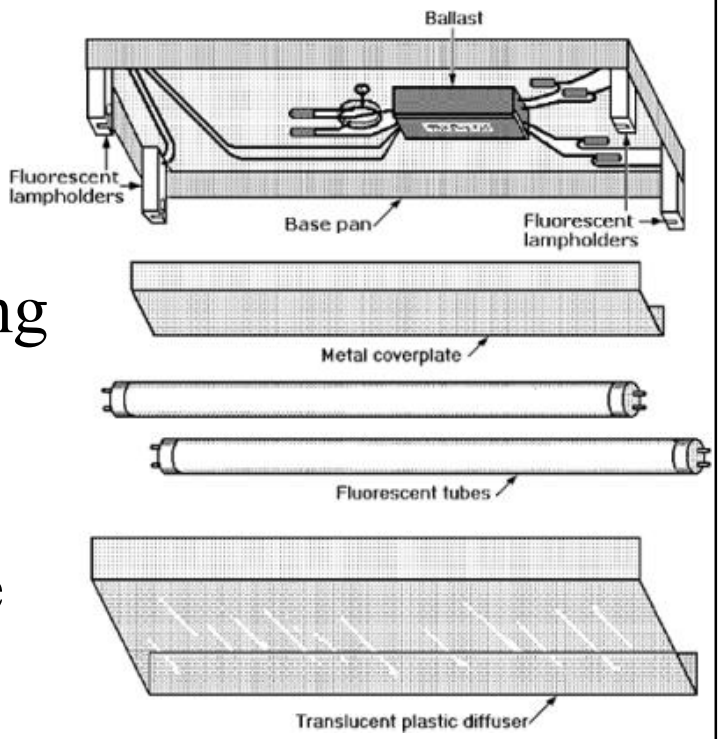
Terminology

- Lighting terminology
  - Photometric data
    - Indicate how a particular lamp or luminaire “sends out” light – light distribution in terms of intensity and direction
  - Glare
    - Visual discomfort/disability caused by excessive brightness or extreme contrast
    - Glare index or limiting glare rating



Practical skills

- Anatomy of a “lighting system”
  - Lighting components
    - Power source
    - Power controller: switching/dimming
    - Power regulators: ballasts
    - Light source: lamp
    - Optical control: luminaire or fixture
  - Environmental components
    - Room finishes: reflectances and texture
    - Spatial envelope: room boundaries
    - Fenestrations: windows and skylights

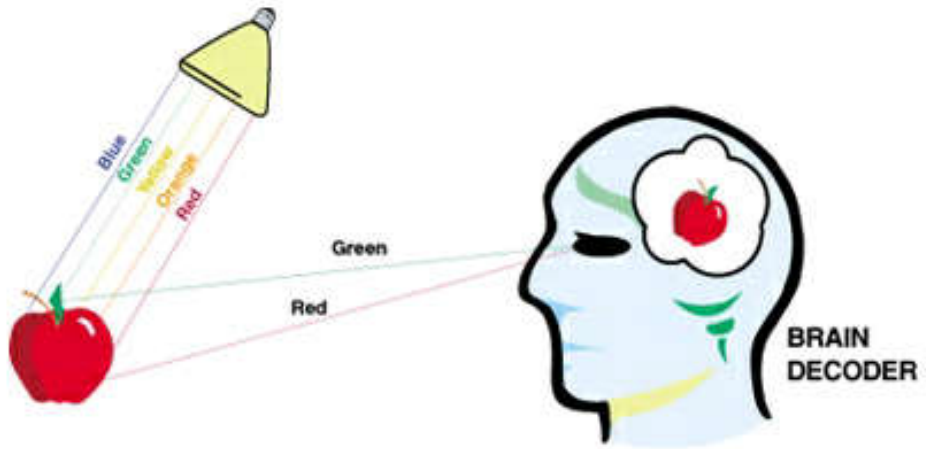


Examples of light sources for general lighting

(Source: Advanced Lighting Guidelines)

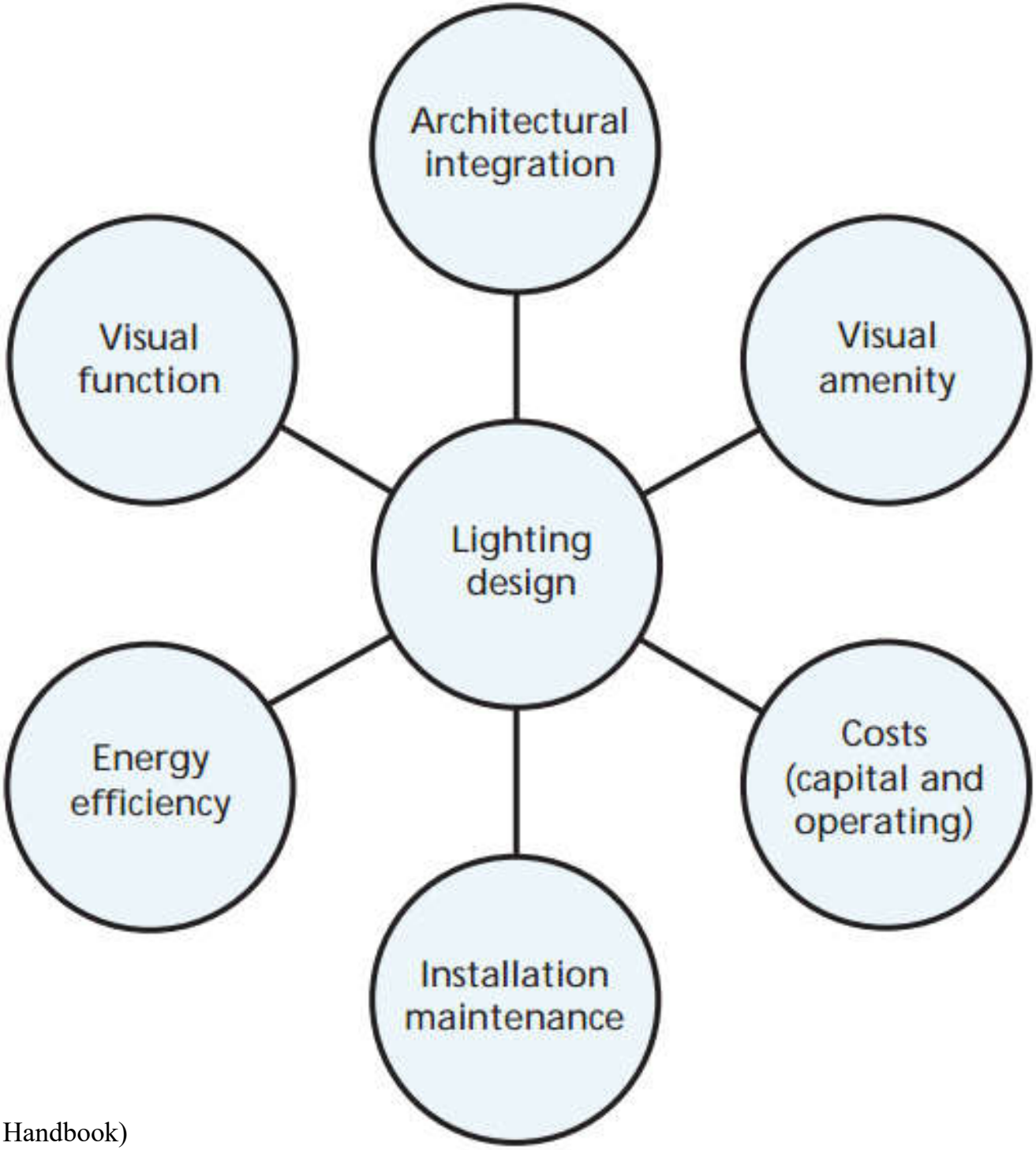
Practical skills

- Anatomy of a “lighting system” (cont’d)
  - Human components
    - Visual receiver: Eye
    - Visual acuity: Vision
    - Visual decoder: Brain
  - Task components
    - Task finishes: texture, colour, reflectance, specularity
    - Task size: object size
    - Task brightness: luminance
    - Contrast: brightness ratios
    - Speed and accuracy: time



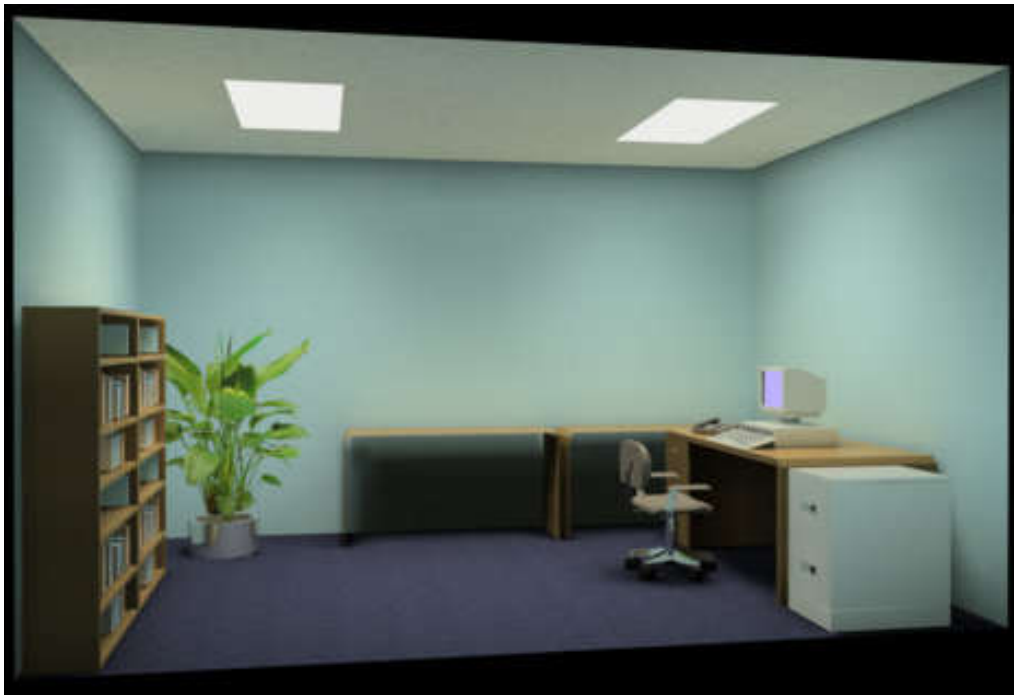
Objects as selective reflectors.

Considerations for lighting design



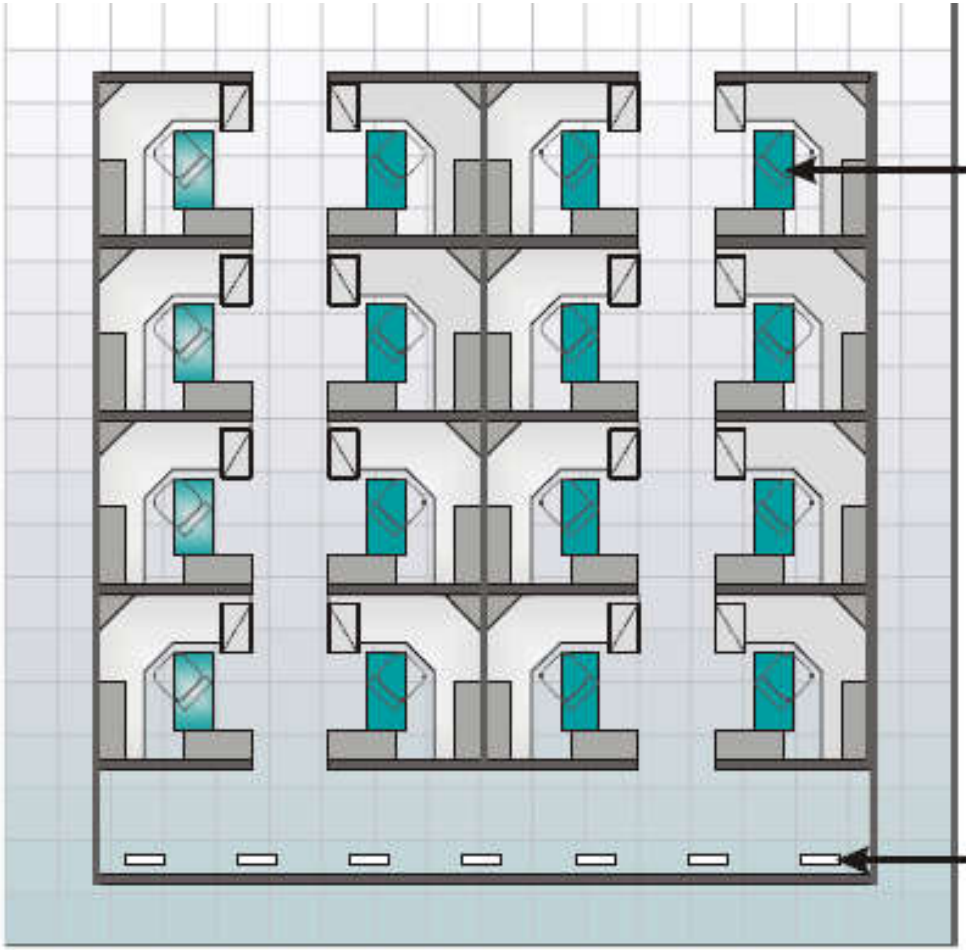
(Source: The SLL Lighting Handbook)

Different lighting effects in a private office



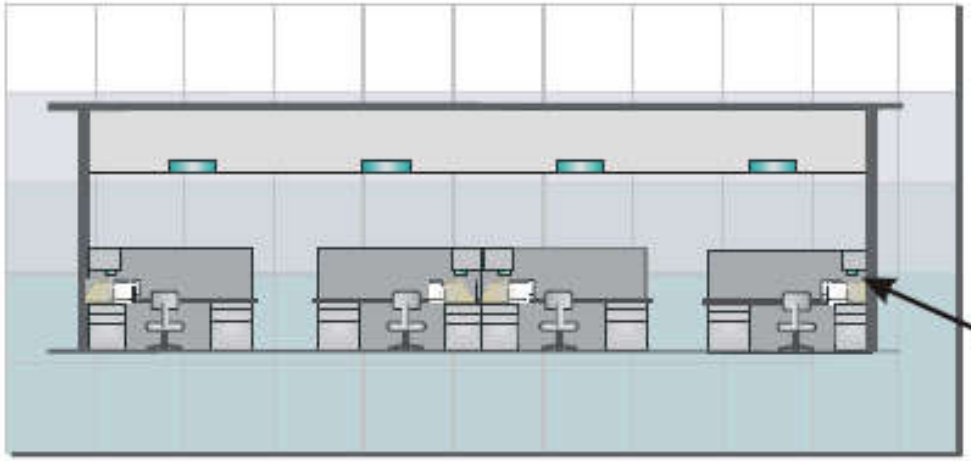
(Source: https://www.lightnowblog.com/2016/03/introduction-to-lighting-design/)

Lighting design for open plan office



Recessed parabolic 2x4 louver troffers with F32T8 lamps direct light downward over each workstation. Individual dimming ballasts allow worker control of task area light levels.

Recessed linear wallwashers, each with one CF40T5 lamp, allow a uniform wash of light from top to bottom. Control with dimming ballasts and an adaptive compensation system that dims overhead lighting at night.



Undercounter task light, with one F25T8 lamp allows high illumination levels at task surface. User control or occupancy sensor.

(Source: Advanced Lighting Guidelines 2001)

Practical skills

- Basic practice of illuminating engineering
  - Hand calculations, e.g. Lumen method
    - Predict the average illuminance level in a room
    - Also known as zonal cavity calculation
    - Typical templates for spreadsheet programs or short routines built into handheld computers
  - Basic point-by-point lighting computer programs
    - Determine light levels at specific locations in a space
    - Predict brightness of room surfaces (e.g. by gray-scale plots and isolux plots

File Help Tools

Visual Interior Tool™

AcuityBrands.

Settings

Units: Meters - Lux

Room Dimensions

Length [X]	10	m
Width [Y]	8	m
Height [Z]	3.5	m
Workplane	1	m
Ceiling Type	2x2	

Room Reflectances

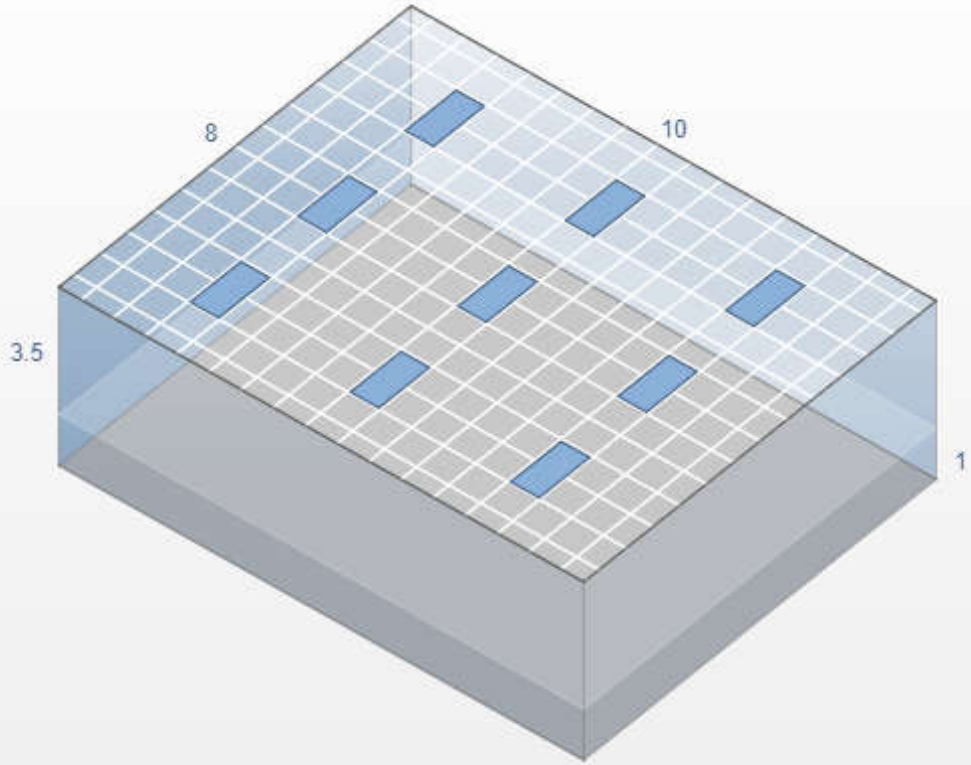
Ceiling	80	%
Walls	50	%
Floor	20	%

Criteria

Illuminance	500	lux
Power Density		W/m²
Quantity		

Constraints

Spacing X [SC=3.6]		m
Spacing Y [SC=3.1]		m
Rows		
Columns		



Calculation Results [A]

Illuminance	462 lux
Power Density	6.52 W/m²
Quantity	9

Spacing Results [A]

Spacing	3.05 x 2.44 m
Arrangement	3 x 3
Outside Spacing X	1.68 m
Outside Spacing Y	0.99 m

Display

Dimensions Room ☑ Layout ☐

Show Zonal Cavity Info [+]

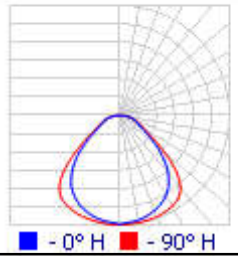
Project Information

A

Holophane

[A] - HT24 2 32 A12 GEB10IS

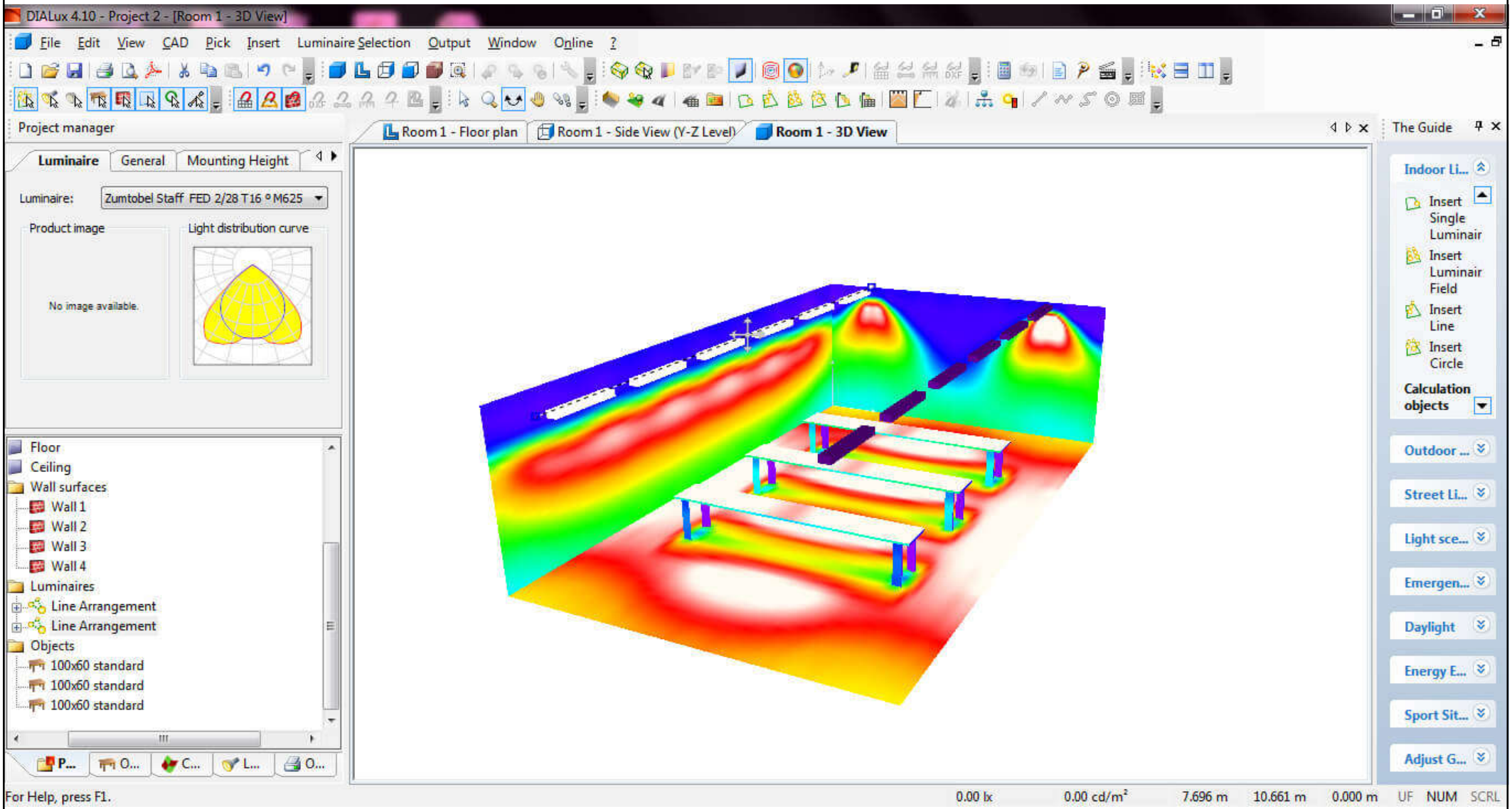
Light Loss Factor	1	Symbol Shape	Rectangular	Lamp Quantity	2
Suspension Length	0	Symbol Length	.54	Lumens Per Lamp	2850
Orientation	0	Symbol Width	1.15	Wattage	58



Practical skills

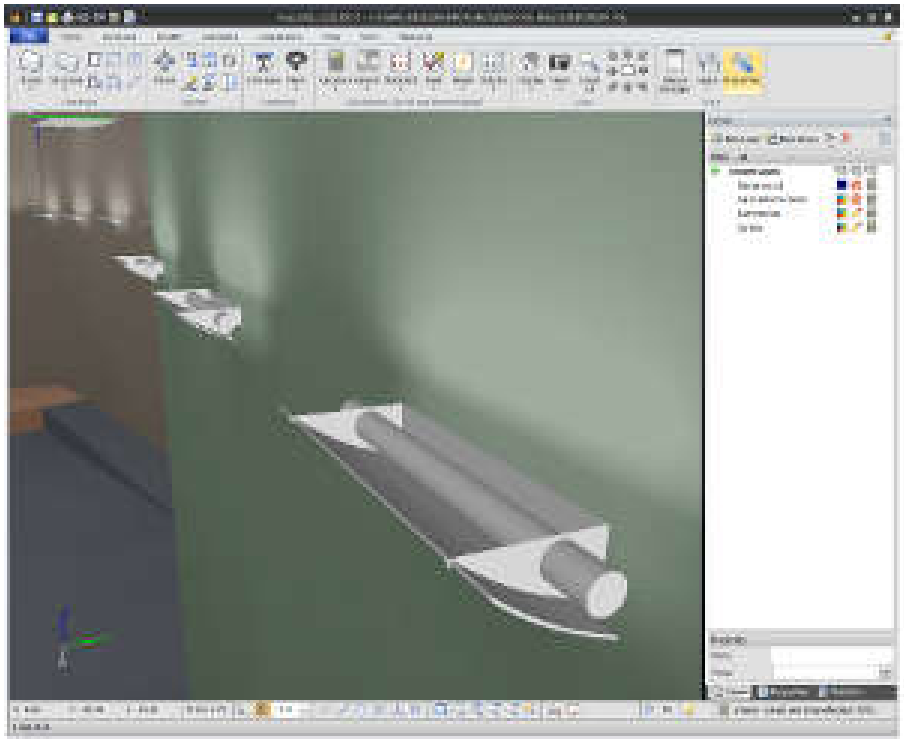
- Basic practice of illuminating engineering (cont'd)
  - Advanced lighting programs, e.g. radiosity & ray-tracing programs ➔ semi-photorealistic images
    - Extreme accuracy in spaces of complex geometry
  - Specialty calculations, e.g. exterior lighting, daylighting, energy simulation, economic analysis
  - Scale models (usually by architects)
  - Lighting audits, retrofit assessment

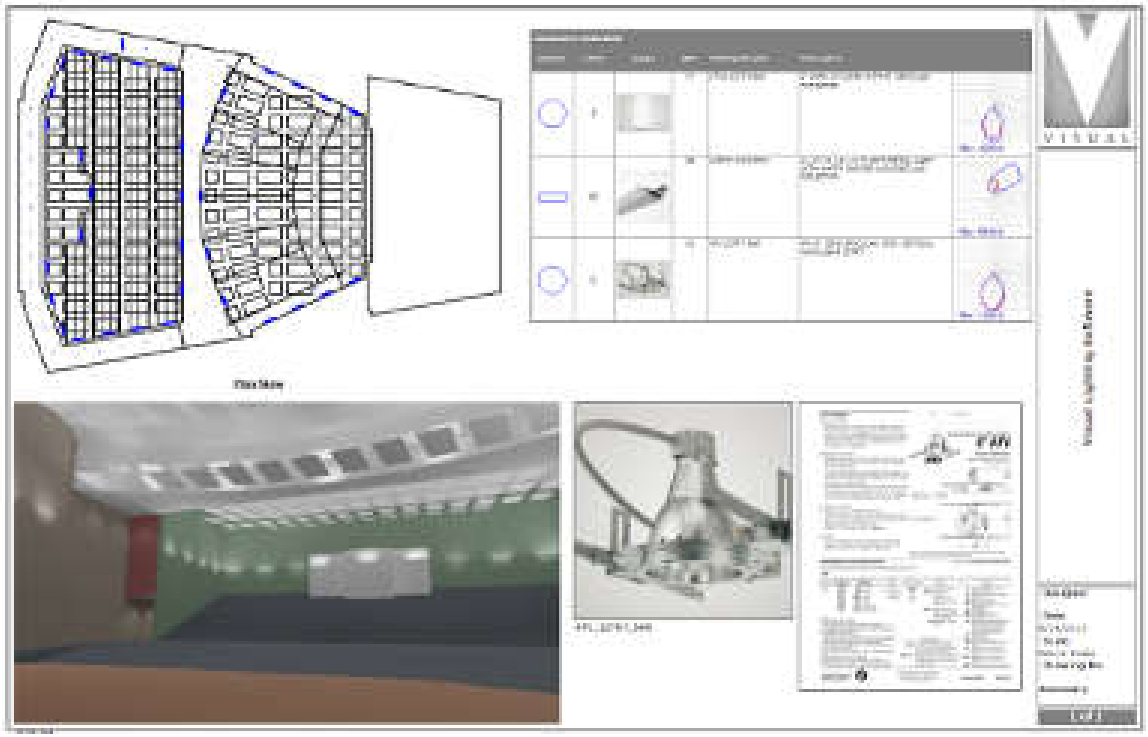
Lighting calculations and simulation with DIALux 4.10

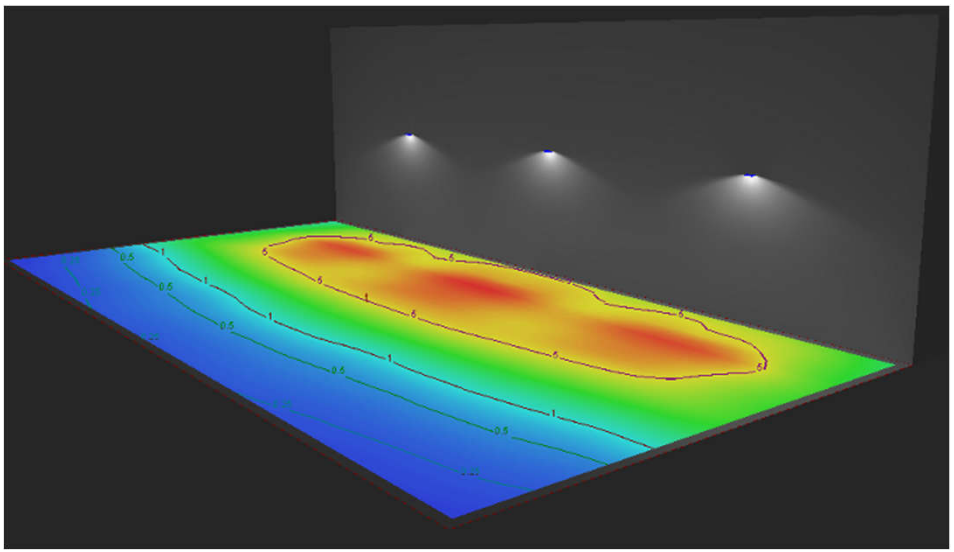


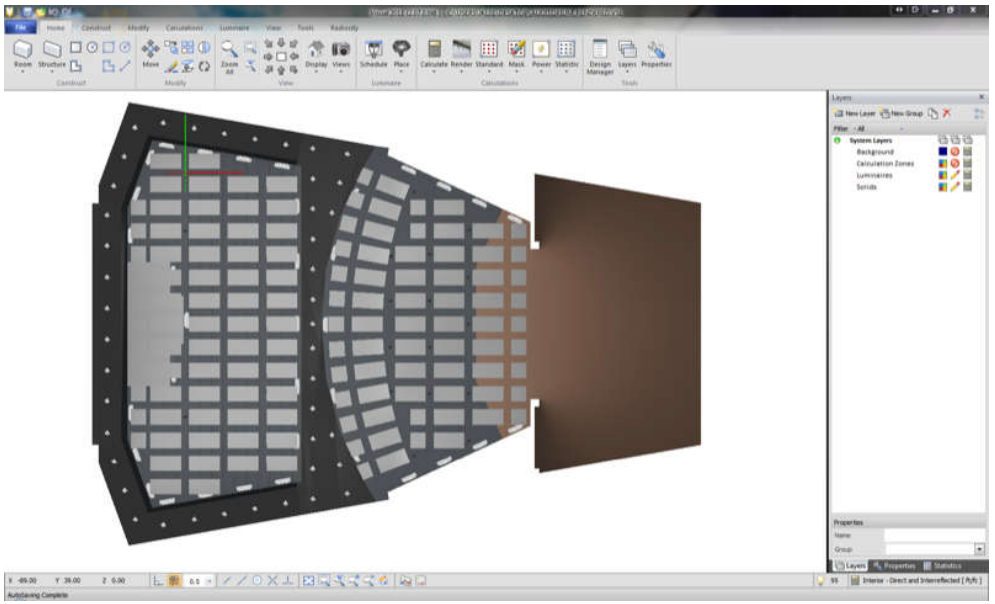
(Further information: DIALux http://www.dial.de/)

Visual Lighting software (from Acuity Brands)





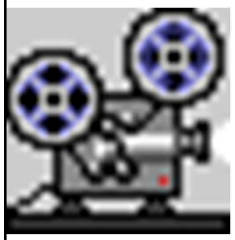




(Source: http://www.acuitybrands.com/resources/tools-and-documents/visual-lighting-software)

Further Reading

- Lighting theory essentials (Philips Lighting/Signify) https://www.signify.com/global/lighting-academy/browser/course/lighting-theory-essentials



  - Light and health (4:56) https://youtu.be/GbHGRMv7rDE
  - Lighting terminology (5:50) https://youtu.be/9nPIzyV1mW0
  - Luminous flux (1:22) https://youtu.be/V_bZhzCpCcs
  - Luminous intensity (1:00) https://youtu.be/78cxI5LhTlY
  - Luminance and illuminance (2:07) https://youtu.be/2D8wtLRGKYo
  - Photometrics (5:59) https://youtu.be/hByR2V4qyq8