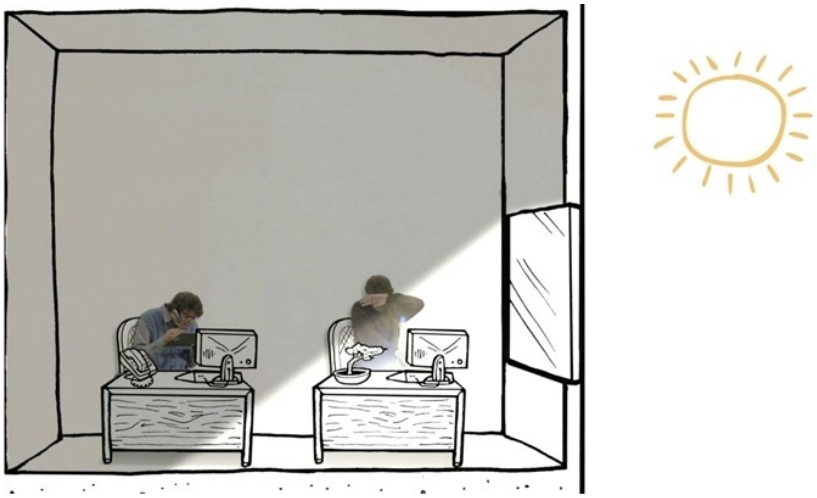
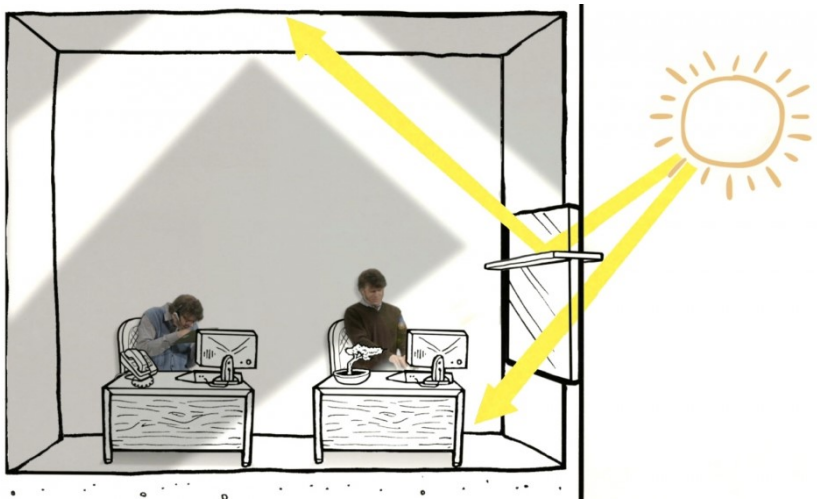
3A - Visual Comfort Background and Concepts

Prof. William (Liam) O'Brien

Topics

1. Brief Intro to Visual Comfort
2. Importance of lighting and daylighting
3. The nature of light
4. Eyes and vision
5. The Big 6 lighting metrics





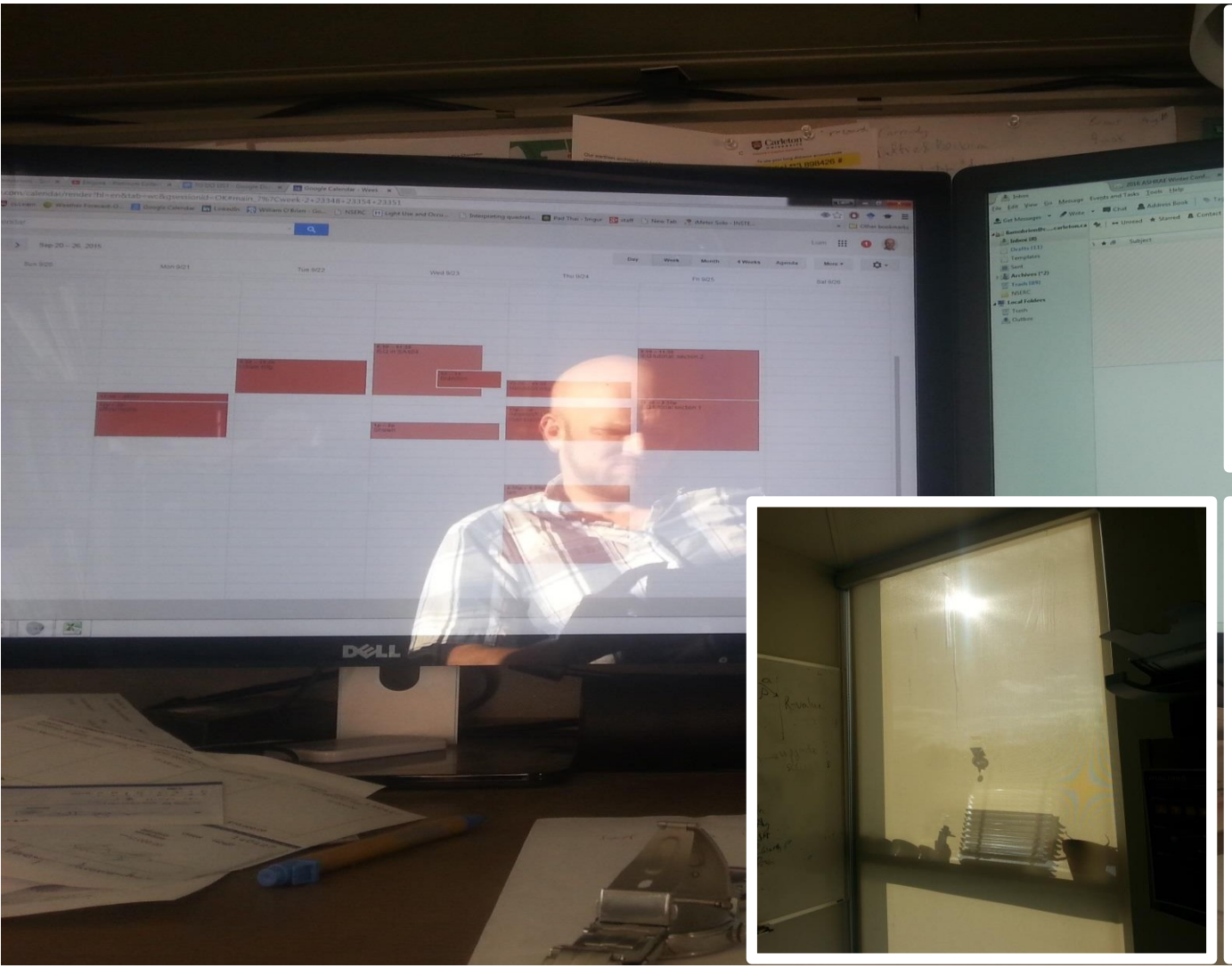
ROCKS and MINERALS

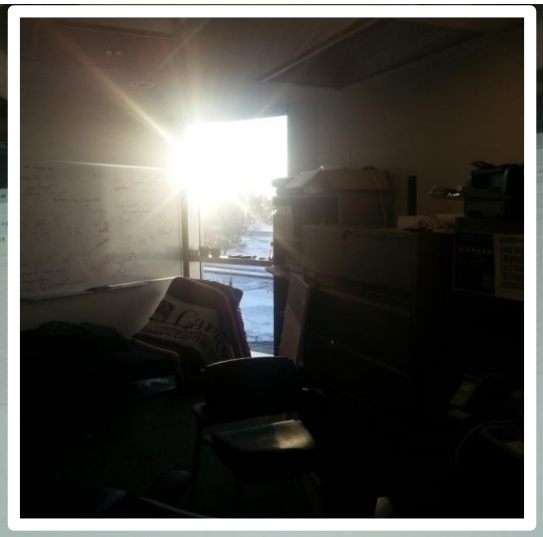
WE LOVE
NONFICTION
5 Star Listener
Mar. 29
Geometric Shapes
Our Missi

15
16

a place of mind
UBC
Pacific Museum of the Earth

ΑΣΙΑΛΕΙΟΝ


DELL



0930
PHILIPS
9:31
PHILIPS

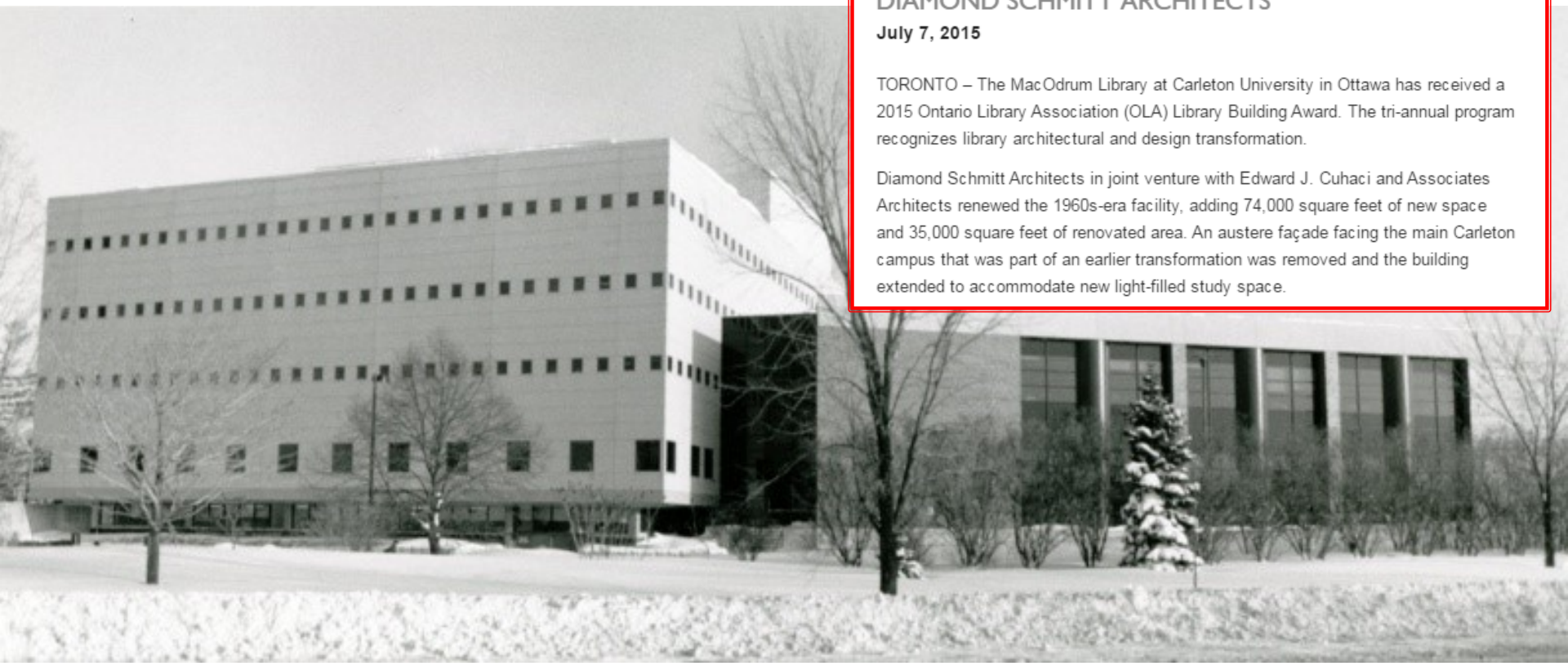
CARLETON UNIVERSITY LIBRARY WINS DESIGN TRANSFORMATION AWARD

DIAMOND SCHMITT ARCHITECTS

July 7, 2015

TORONTO – The MacOdrum Library at Carleton University in Ottawa has received a 2015 Ontario Library Association (OLA) Library Building Award. The tri-annual program recognizes library architectural and design transformation.

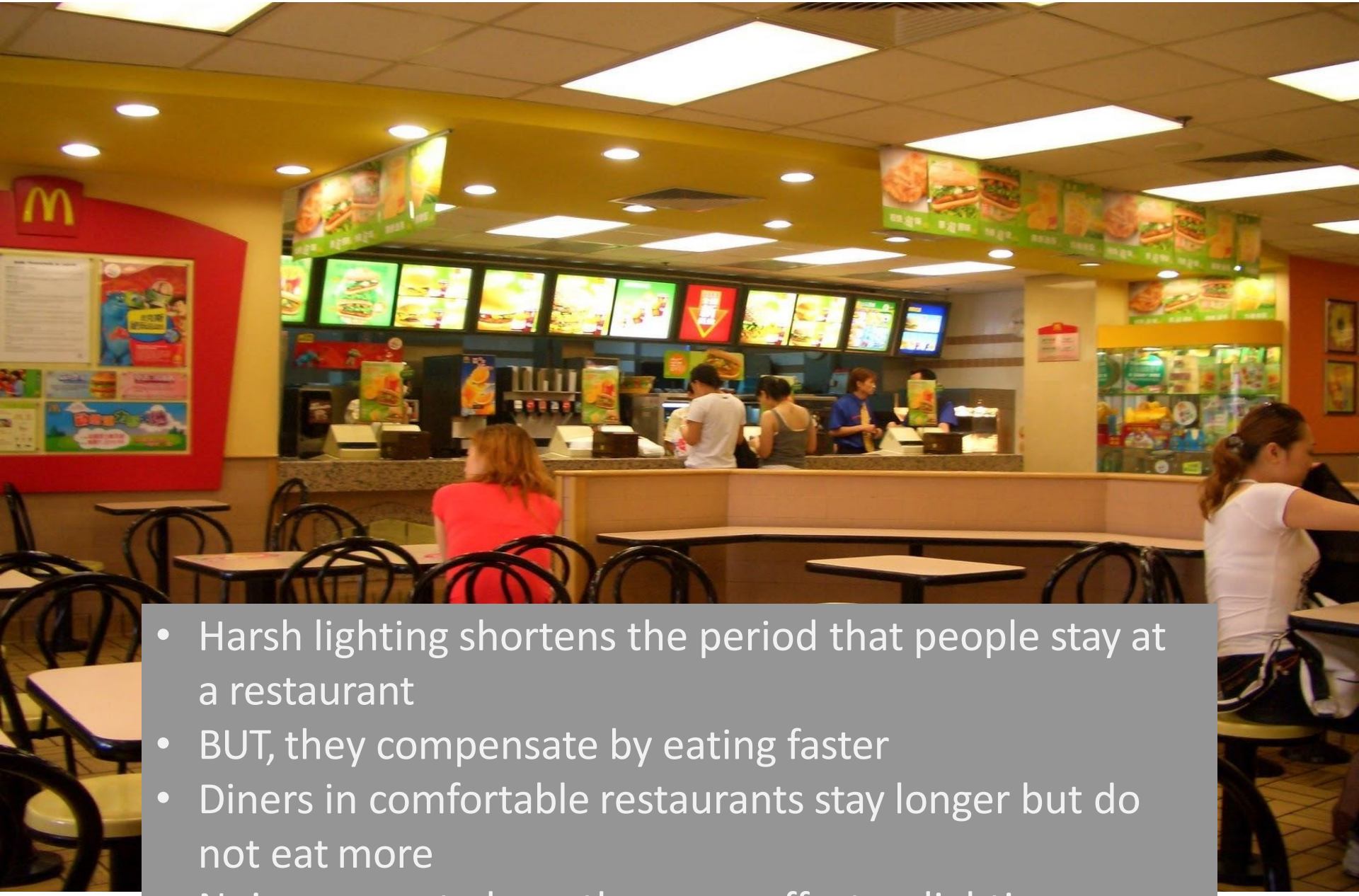
Diamond Schmitt Architects in joint venture with Edward J. Cuhaci and Associates Architects renewed the 1960s-era facility, adding 74,000 square feet of new space and 35,000 square feet of renovated area. An austere façade facing the main Carleton campus that was part of an earlier transformation was removed and the building extended to accommodate new light-filled study space.



R-1
PARKING BEYOND THIS POINT
RESERVED FOR R - 1 PERMIT
HOLDERS ONLY FROM
7AM - 4PM MON - FRI
(UNLESS PRE - AUTHORIZED
BY PARKING SERVICES)
VISITORS ARE WELCOME AFTER 4PM ONLY
PLEASE PURCHASE A TICKET FROM
THE PAY MACHINE PRIOR TO
LEAVING YOUR VEHICLE
ALL VEHICLES MUST BE REMOVED
FROM LOT BY 2AM

Ryerson Library

gym at st. conrad ces



- Harsh lighting shortens the period that people stay at a restaurant
- BUT, they compensate by eating faster
- Diners in comfortable restaurants stay longer but do not eat more
- Noise seems to have the same effect as lighting

CLOVERDALE
SATURDAY & SUNDAY
$4 BREAKFAST SPECIAL
$7 BREAKFAST MENU
11AM - 3PM
HENRY
Park

Role of lighting/daylighting on visual comfort

- Occupant functionality/productivity
- Occupant mood
- Colour rendering
- Seasonal Affective Disorder
- Circadian rhythm
- Connection to outdoors/views
- Mental and visual stimulation
- Building aesthetics

Daylight and learning

- A trend in the 1960s to 90s saw windowless classrooms
  - No glare
  - No solar gains
- Study by Heschong et al. (2002) found out of large number of classrooms in California, Washington, and Colorado:
  - Students in best daylit classrooms performed 20% better in math and 26% better in reading, with respect to worst daylit classrooms
  - All demographic and educational variables were eliminated.
  - Unclear WHY this effect was observed (no proven causal effect)

Hospital Patients and Daylight

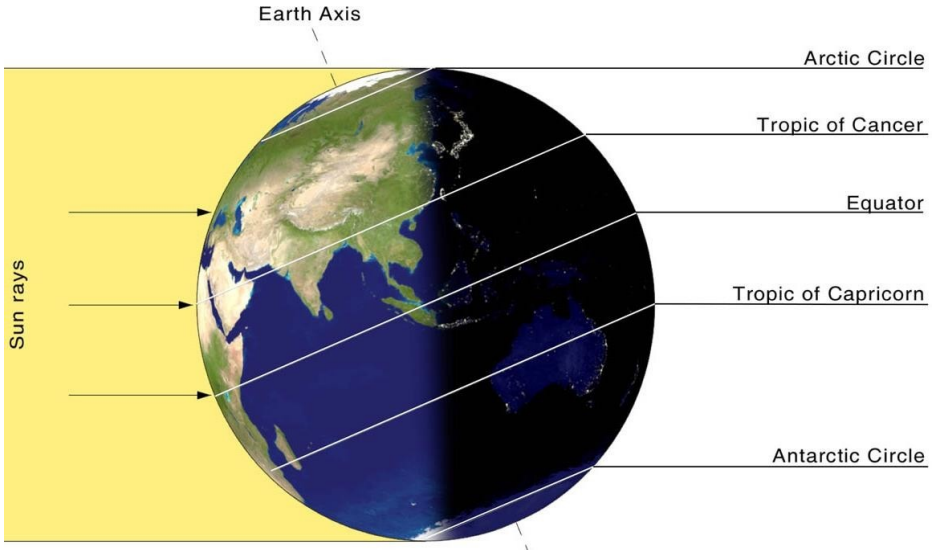
- Walch et al., (2005) exposed one group of patients to 46% more daylight than the control group.
- They found the daylit patients had 21% less medication cost than the control group
- Other benefits: reduced stress and anxiety, lower blood pressure, improved post-operative recovery, shorter hospital stays.

SAD (seasonal affective disorder)

- Seasonal depression caused primarily by lack of daylight and cold in winters.
- Symptoms: depression, lack of energy, nausea, overeating, oversleeping
- Root: possibly evolved from our ancestors when we went into quasi-hibernation
- Solutions: light therapy (10 klux full spectrum; blue light at 2.5 klux or green light at 350 lux); exercise; possibly vitamin D supplements

Vitamin D and the Arctic

- Vitamin D is required for body to use calcium and for bone tissue mineralization (rickets disease)



Tropicana sun in Inuvik: https://www.youtube.com/watch?v=4Krky4i6Xk8

We all need the D.

Even me!

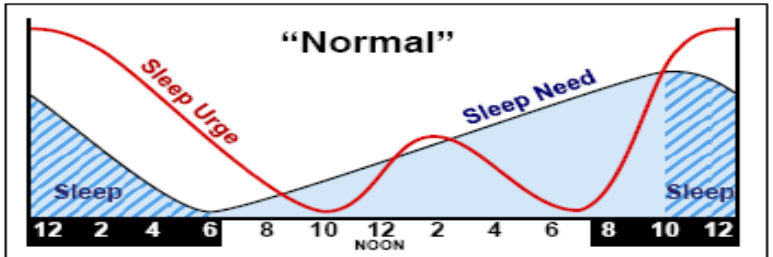
Yukoners need vitamin D at every stage of life, year round.

It is difficult to get enough vitamin D through food alone. You can take a vitamin D supplement or a multivitamin with vitamin D in it.

For more information visit us on
yukonhss or hss.gov.yk.ca

Circadian Rhythm

- A 24-hour cycle that helps define our sleep/awake patterns.
  - The natural human cycle has been found to be 24.15 hours
- Circadian rhythms are endogenous but readjusted according to daylight.
- Jet-lag is a sign that circadian rhythm has been disturbed.



Normal circadian sleep rhythm. Sleep urge is greatest at night with a small increase at mid day. Sleep need increases throughout the waking hours and is replenished during sleep.

06:35 06:45 07:00

Design for safety/security

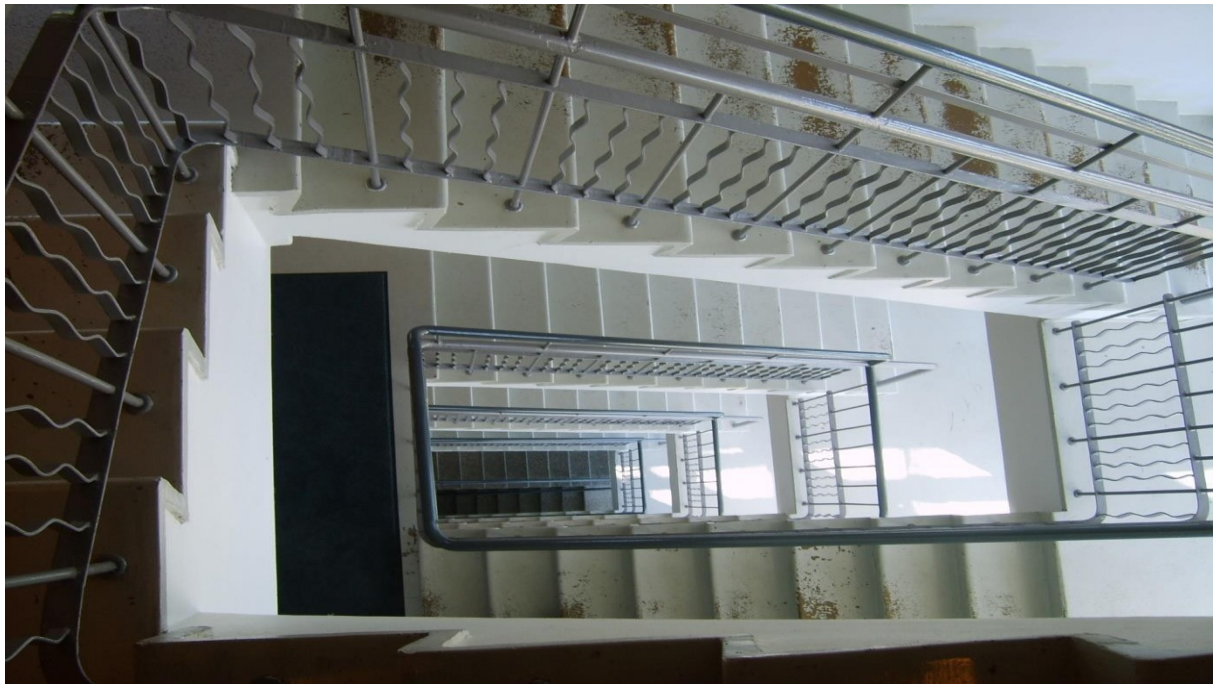
Half Moon Bay Park community questions lack of lighting

Community association says 2 children beat up in unlit park on Monday

CBC News Posted: Nov 06, 2015 8:08 AM ET | Last Updated: Nov 06, 2015 8:08 AM ET

Safety conditions of lighting

Design for safety/security

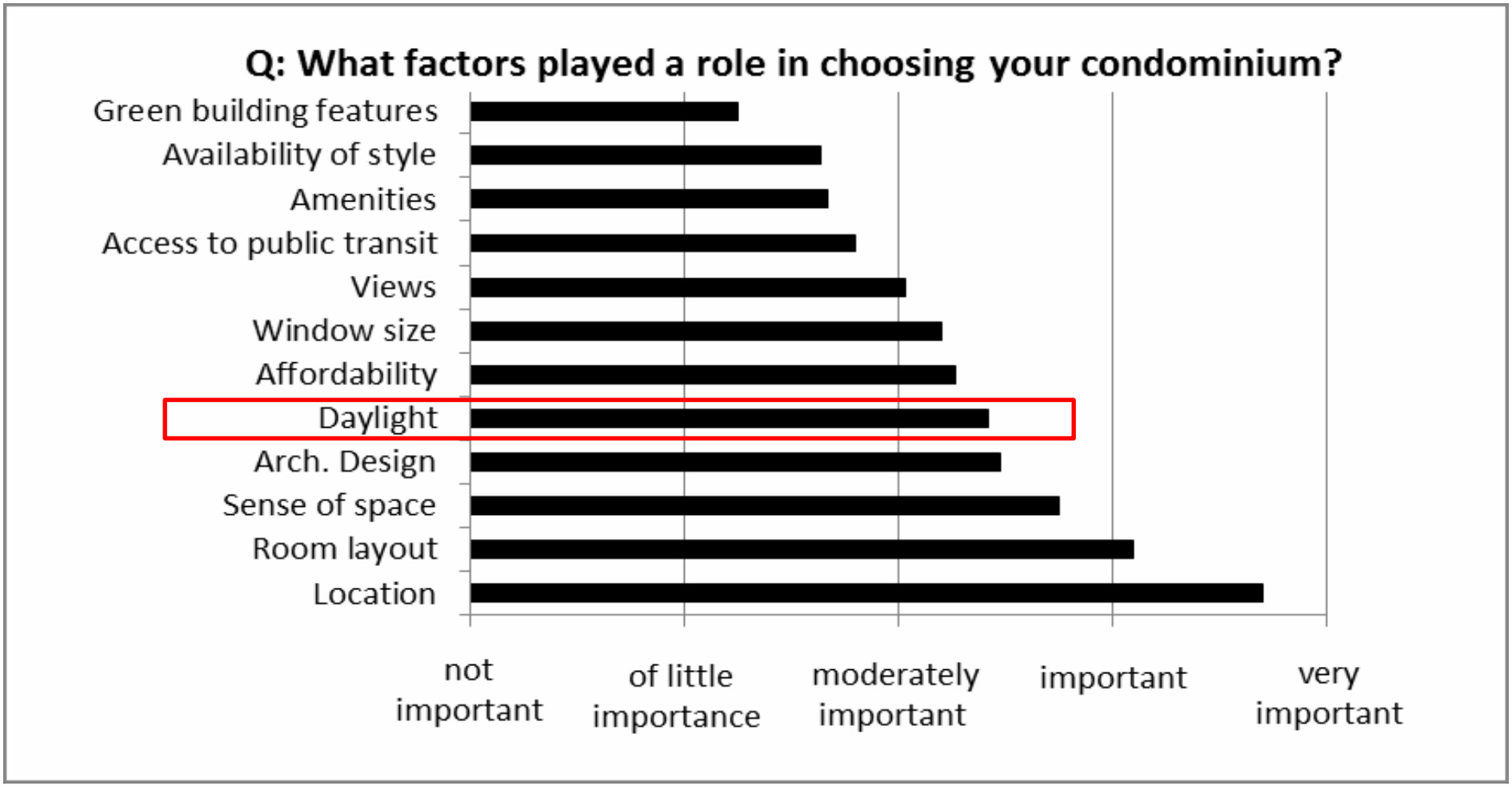


Property values

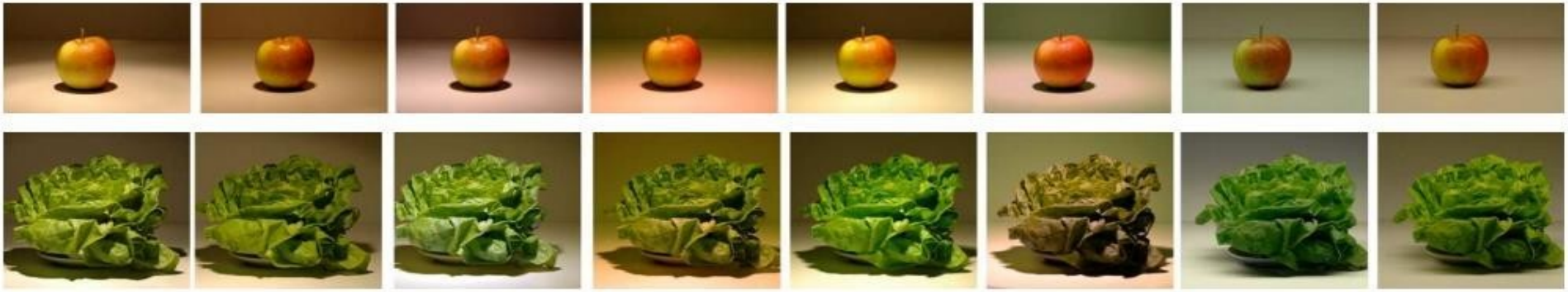
Property values

“The highest-quality ocean views are found to increase the market price of an otherwise comparable home by almost 60%; the lowest-quality ocean views are found to add about 8%.” – Benson, Hansen et al. (1998)

Home buying decisions



Lighting and retail



Why is achieving visual comfort difficult?

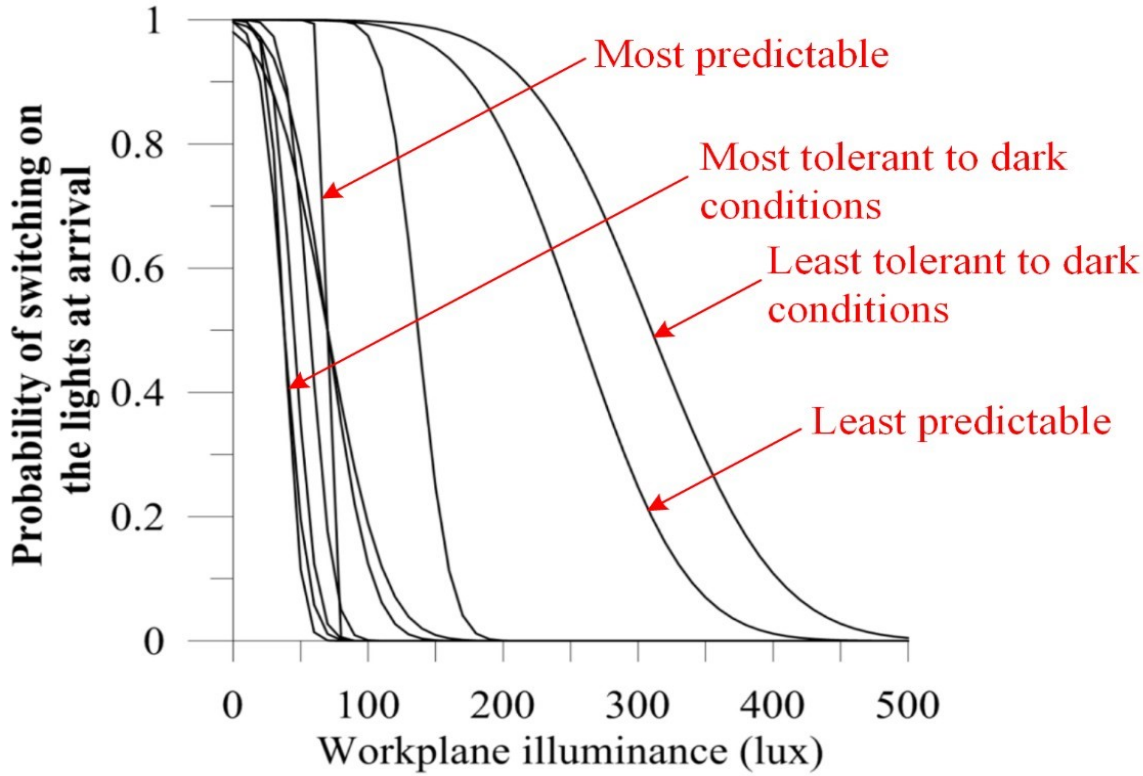
- Inter-individual differences that cannot be explained by age alone
- High spatial variation in a space (position and orientation of occupant)
- Variety of task types and associated optimal conditions
- Quantification of visual comfort is still not an exact science; it’s considerably less advanced than thermal comfort
- Solar variation by time and space

Behavioural aspect of lighting

- Research has shown we would rather have personal control than the “perfect” lighting level!

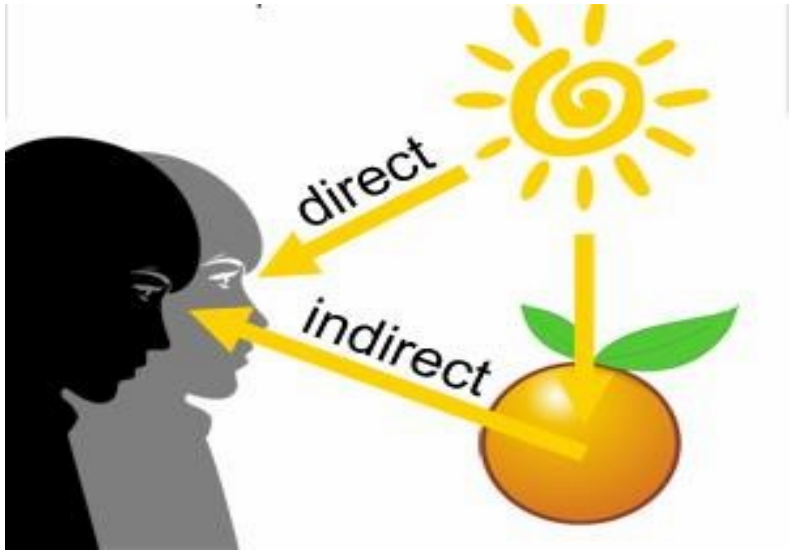
Observed light switch-on actions

Occupants have been observed to have considerable diversity regarding conditions at which they switch lights on.



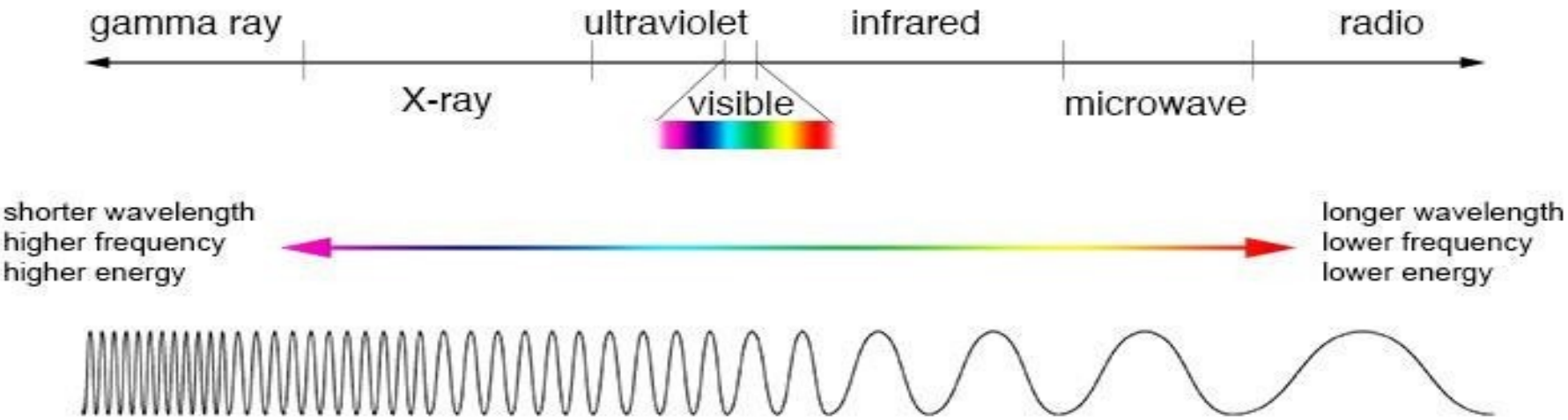
WINGSCAPES
RB-WEST
26 AUG 2015 09:00 am

Source -> Path -> Eye -> Brain

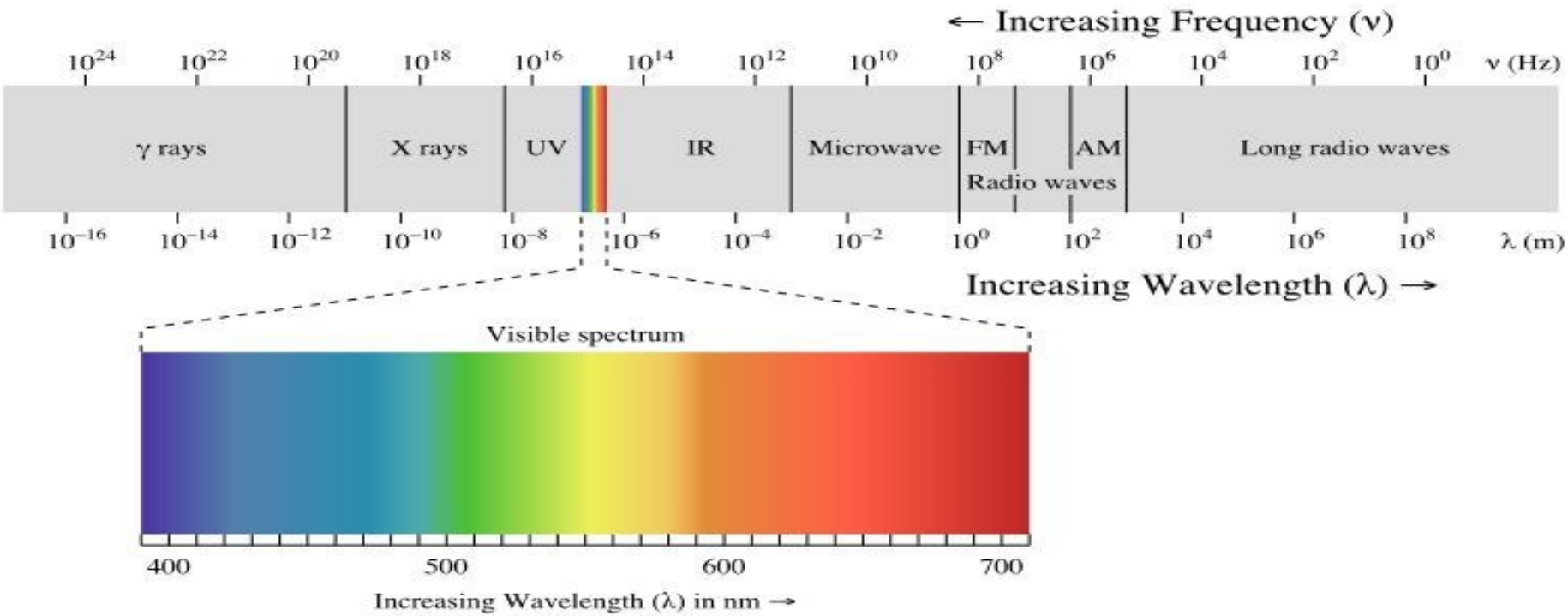


What is light?

- A visible part of the electromagnetic spectrum
- Light can be described as:
  - Waves (cyclical fluctuation of electromagnetic waves) that transport energy between points
  - Stream of photons (massless particles)

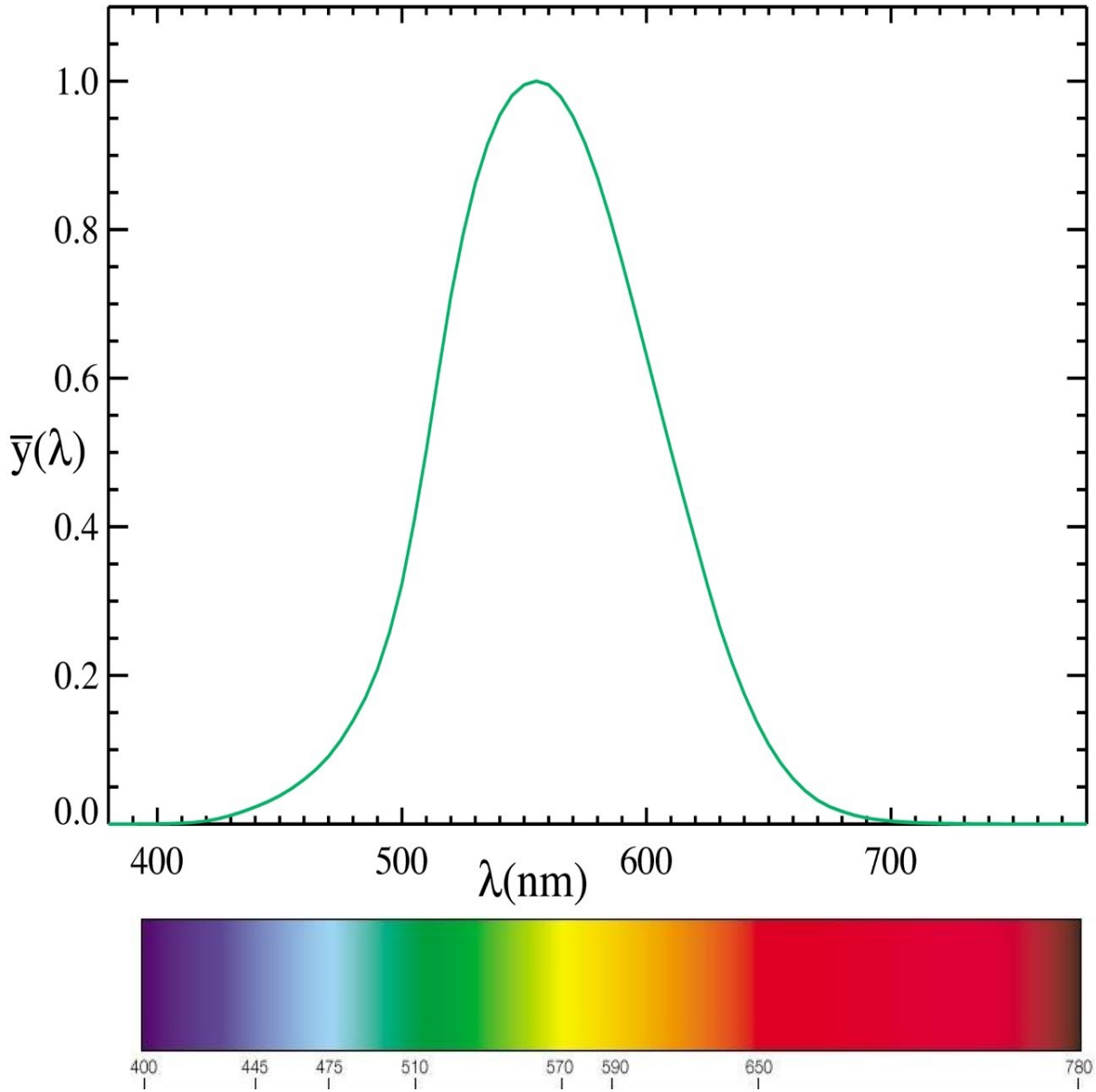


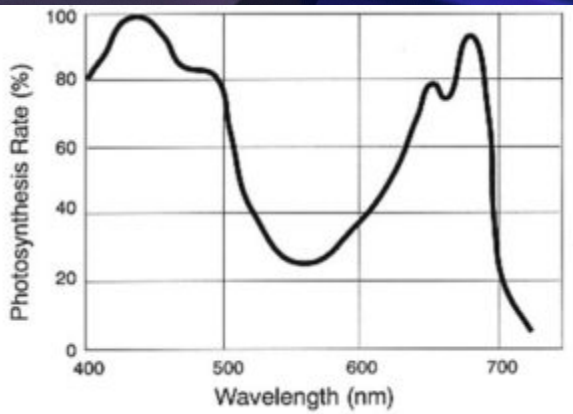
Electromagnetic spectrum

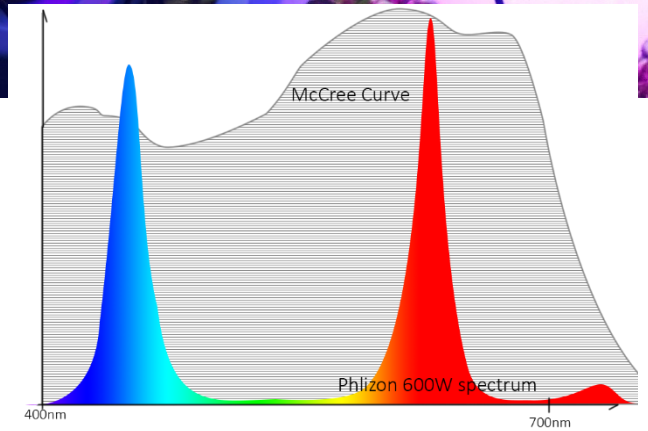


Visible range: ~400 to 700 nm (10^{-9} m)

Relative eye efficiency




Photosynthesis Rate (%)
100
80
60
40
20
0
400
500
600
700
Wavelength (nm)


McCree Curve
Phlizon 600W spectrum
400nm
700nm

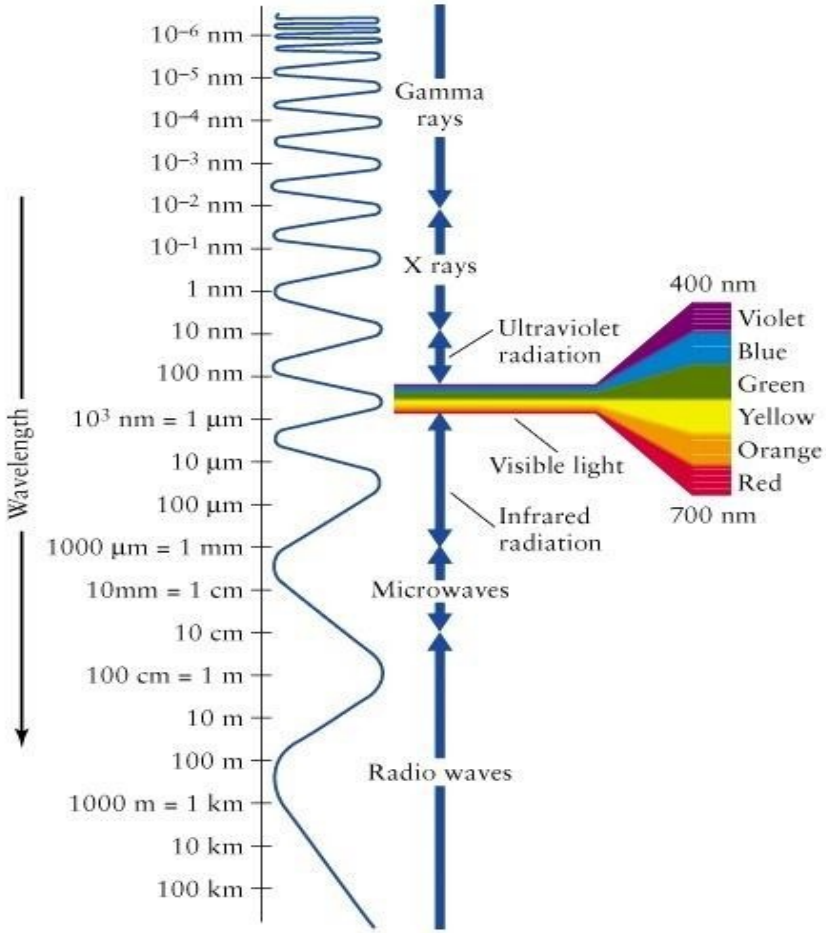
SANSUN

Properties of light waves

- Speed of light, $c = 3 \cdot 10^8$ m/s

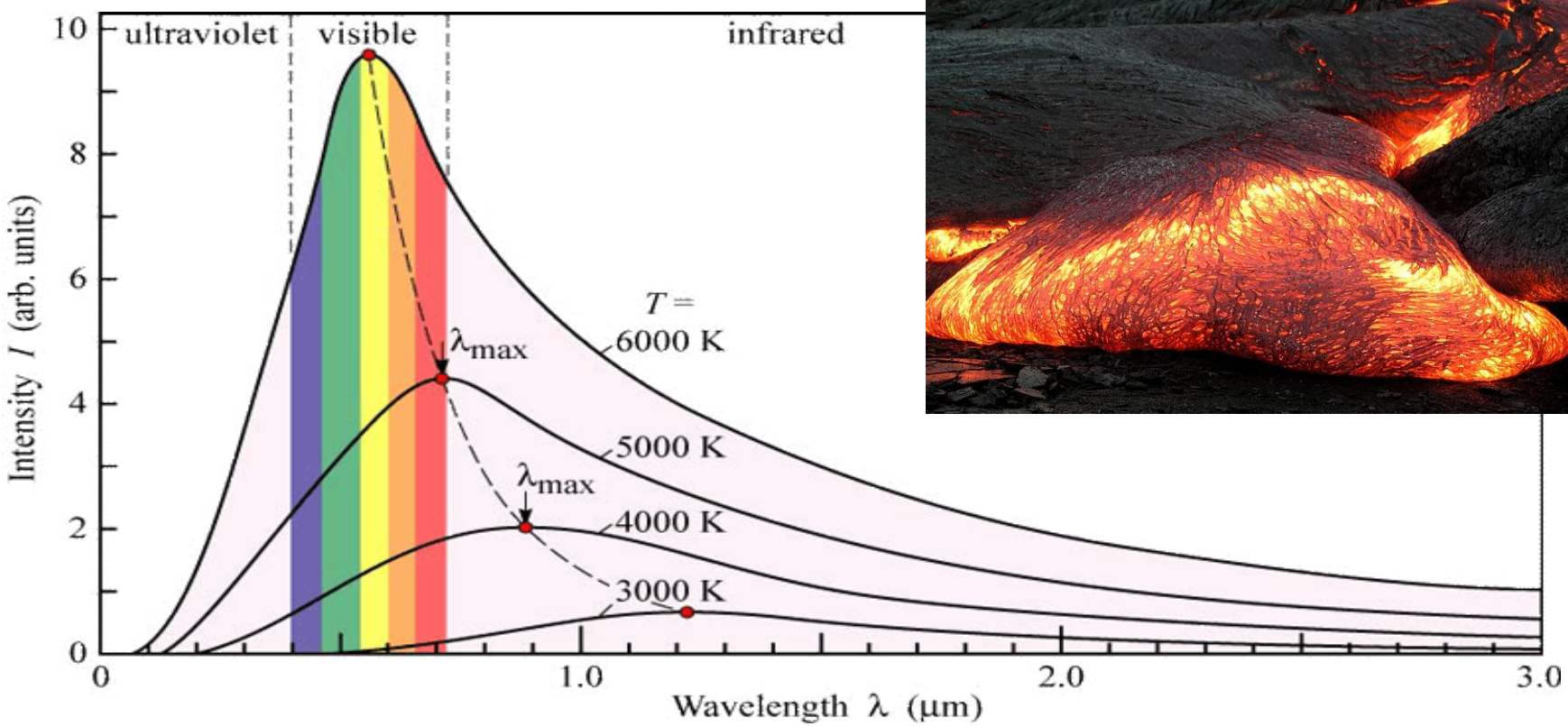
- $c = \lambda f$ (wavelength in meters × frequency in Hz)
- $E = hf$

$h = 6.626 \cdot 10^{-34}$ Js

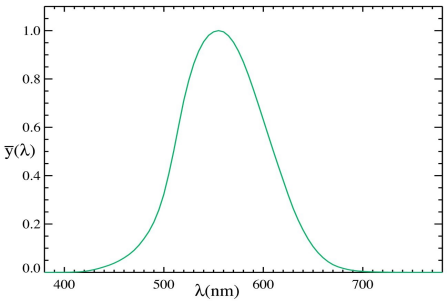


Blackbody radiation curves

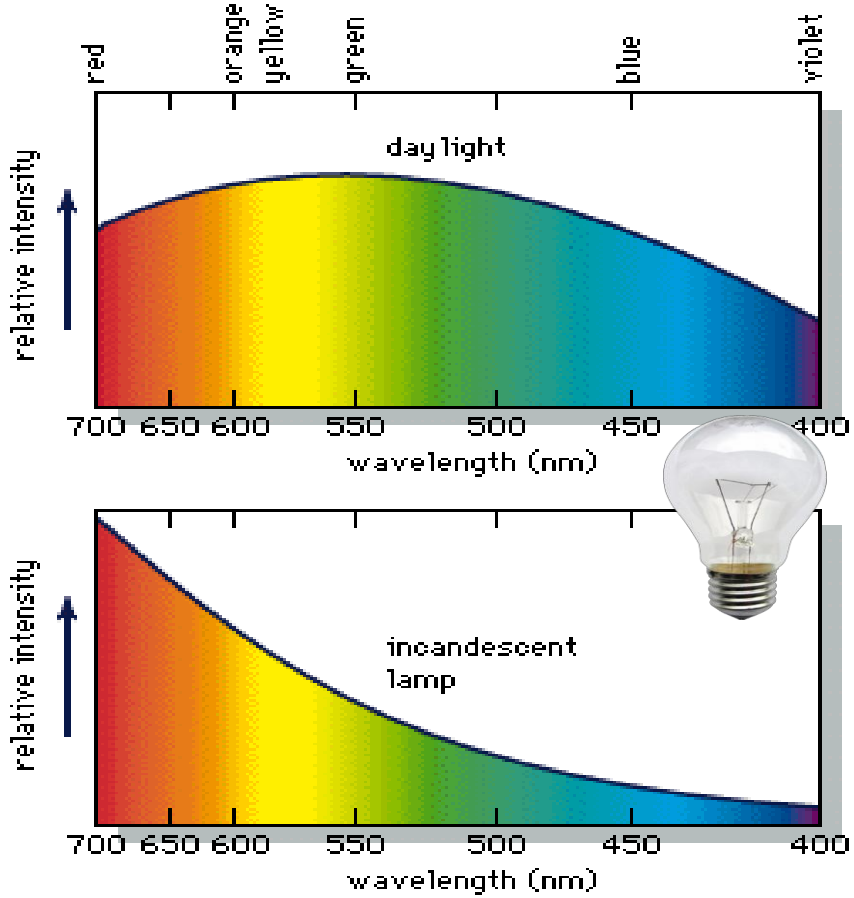
Sun temperature is 5778 K
Incandescent bulb: 2700 K



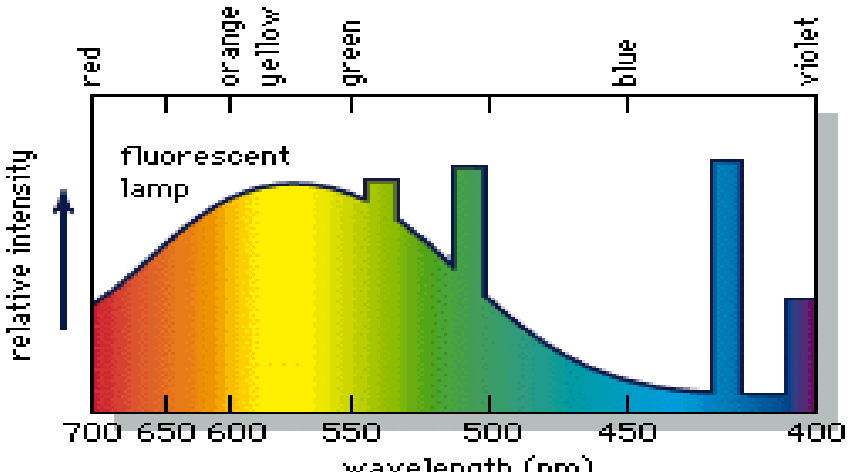
Colour and Temperature



Fluorescent lamps ionize mercury vapour in a glass tube. Electronics in the gas emit photons at UV frequencies, which are made visible by the phosphorous coating on the tube.

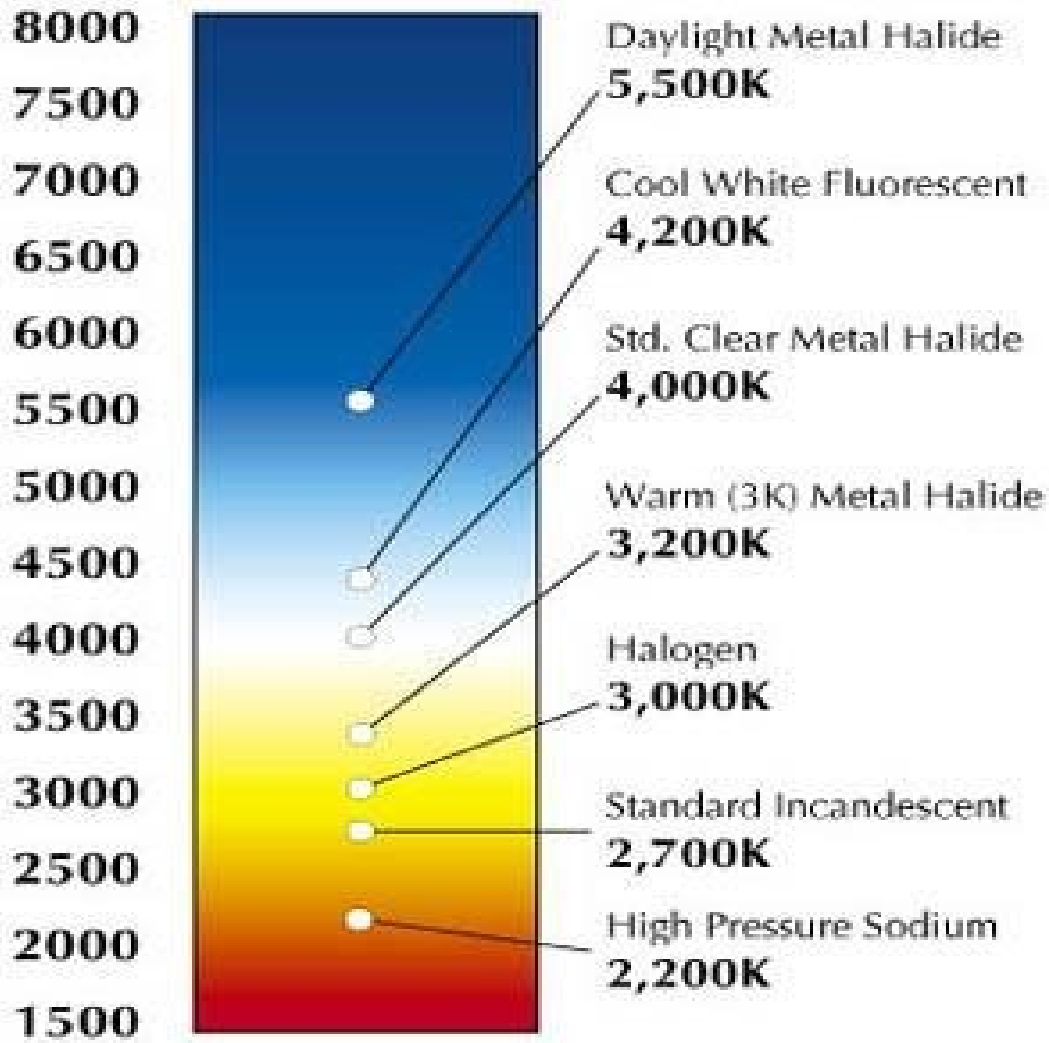


Note backwards scale



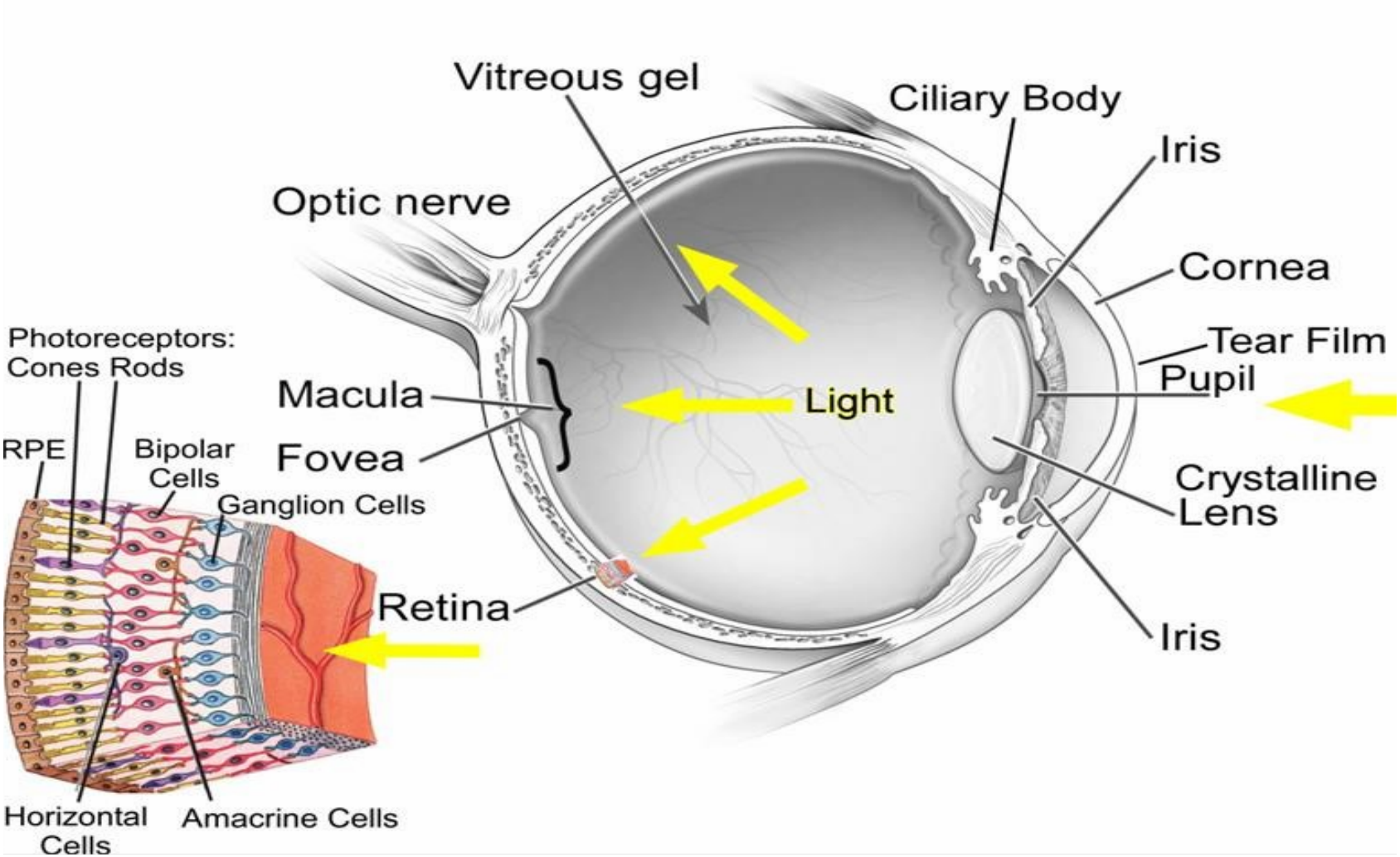
Colour and Temperature

The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source.



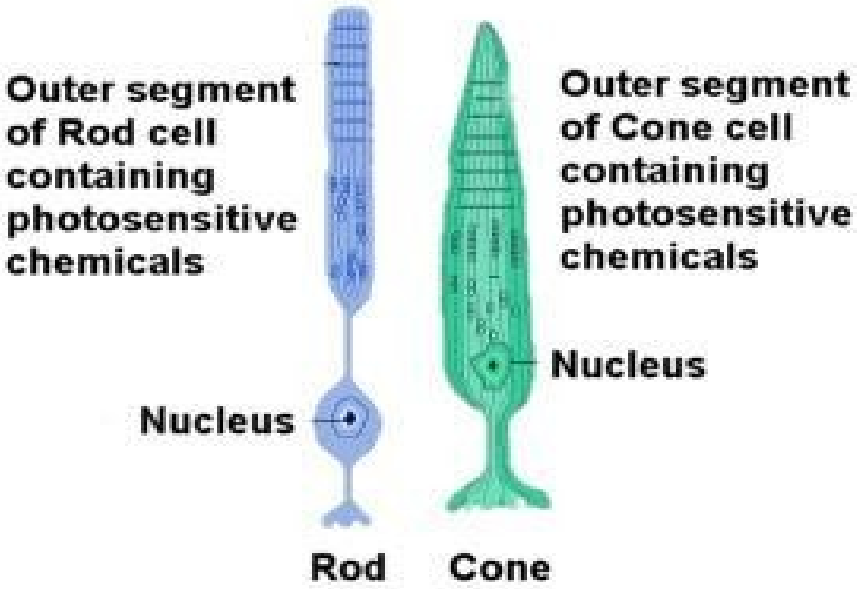
Colour and Temperature

Human Eye and Vision: Physiology



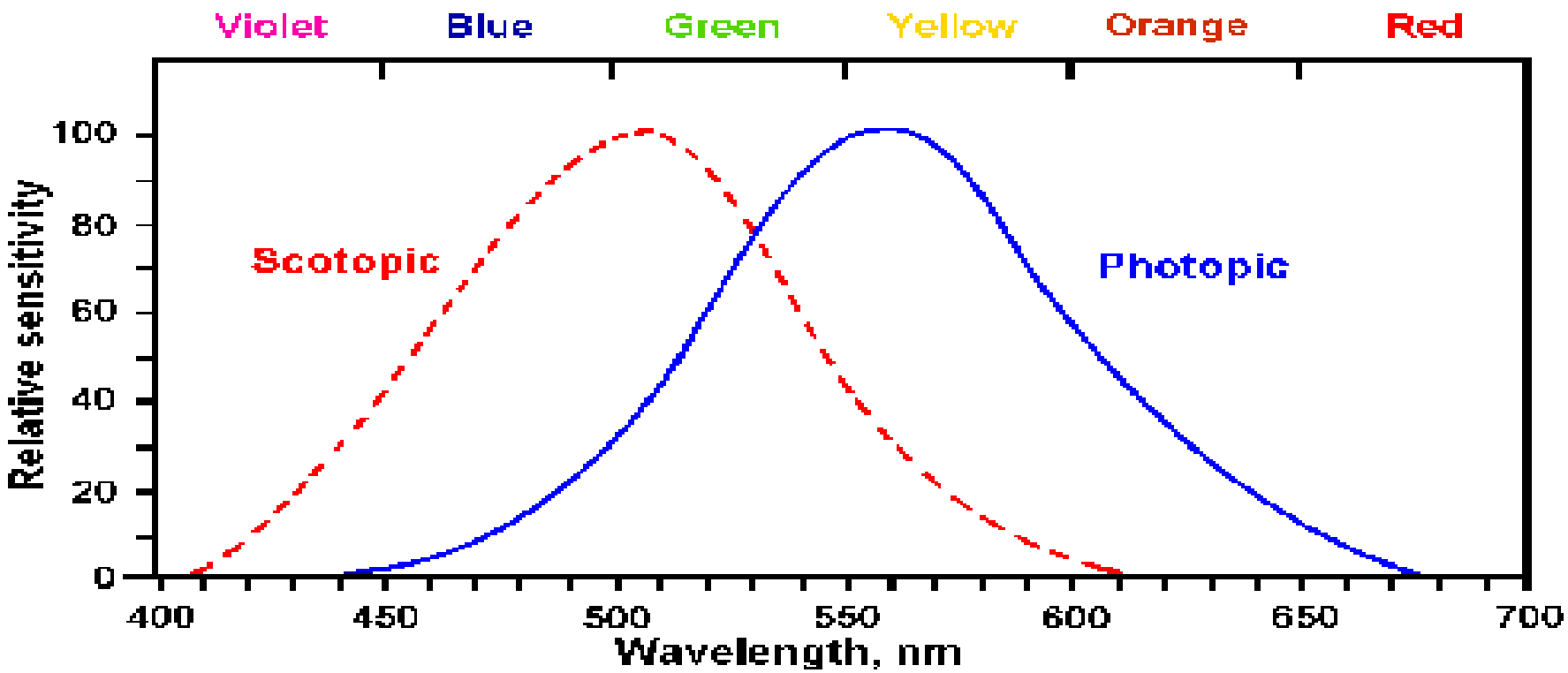
Two types of sensors in our eye

- **Cones**: sense daytime light; three types exist for green, red, blue (>3 cd/m^2) (photopic)
- **Rods**: sense nighttime and peripheral vision (<0.001 cd/m^2) (scotopic), but not sensitive to colour.

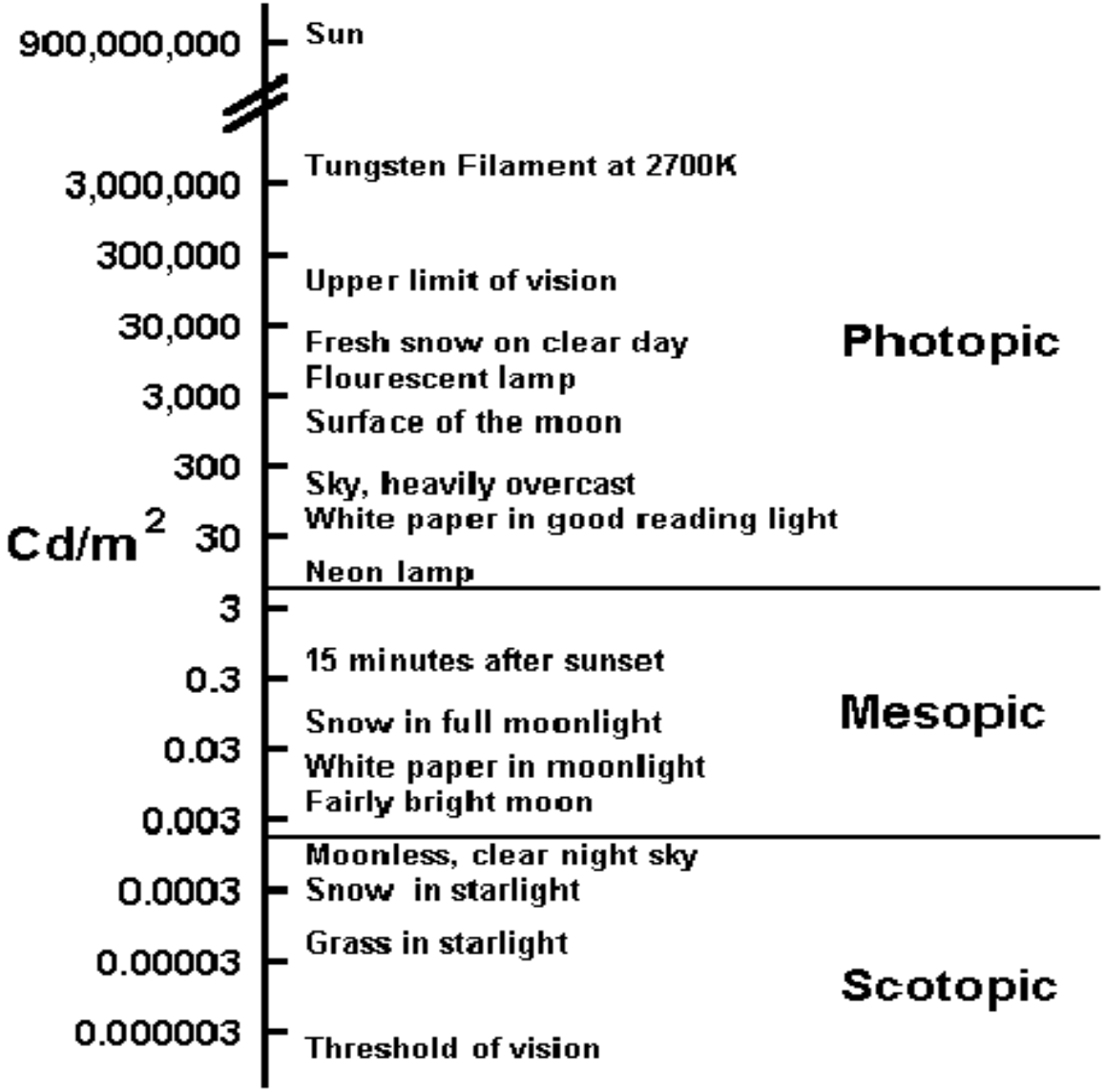


Photopic (day) and Scotopic (night)

- Our eyes are most sensitive at 555 nm during the day and 507 nm at night.



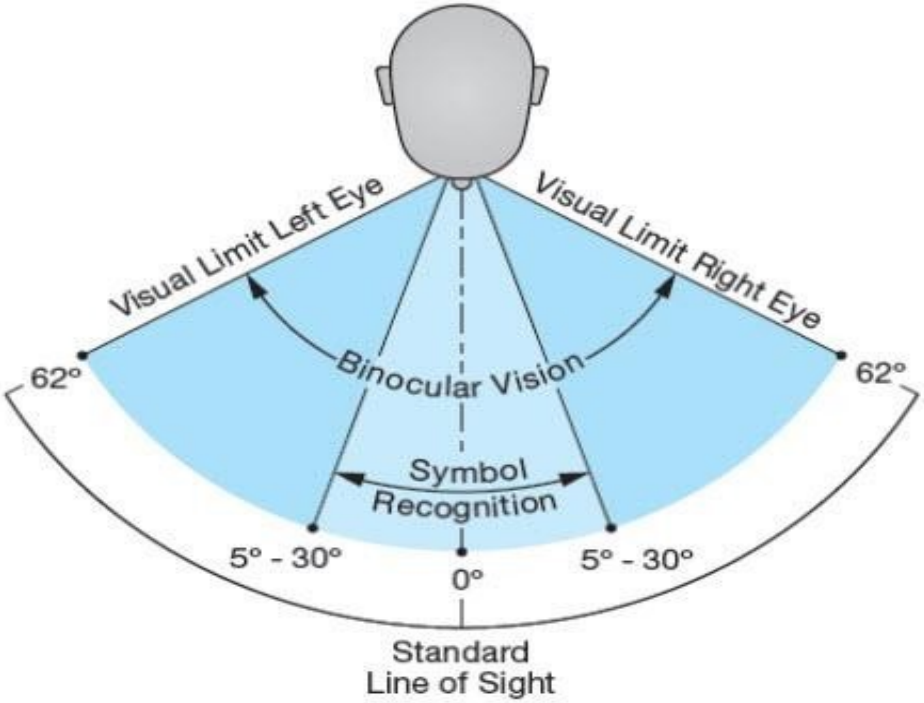
Daylight, moonlight, and eye sensitivity

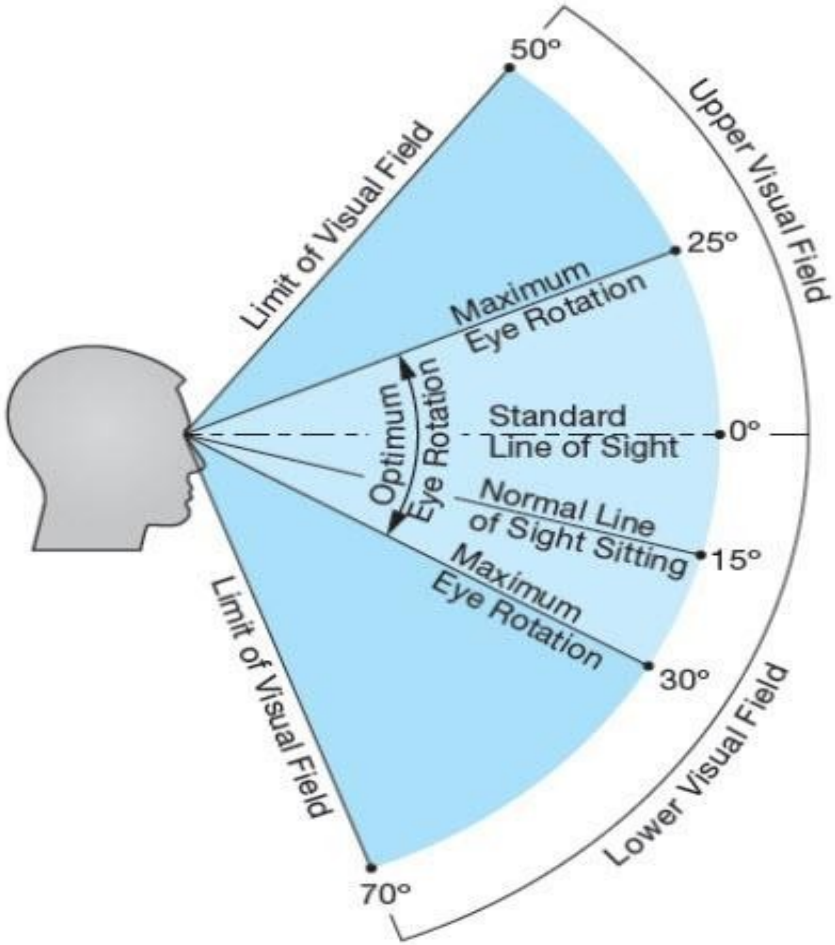


Adaptation to light

- Our range of adaptation is from about 10^{-6} to 10^{6} cd/m^2
  - 12 orders of magnitude!
- Dilation achieves about a factor of 16 of this.
- Photochemical changes account for the majority of adaptation (10^8).
- The full adaptation takes 20-30 minutes
- At any given time, the maximum perceptible contrast ratio is about 1,000

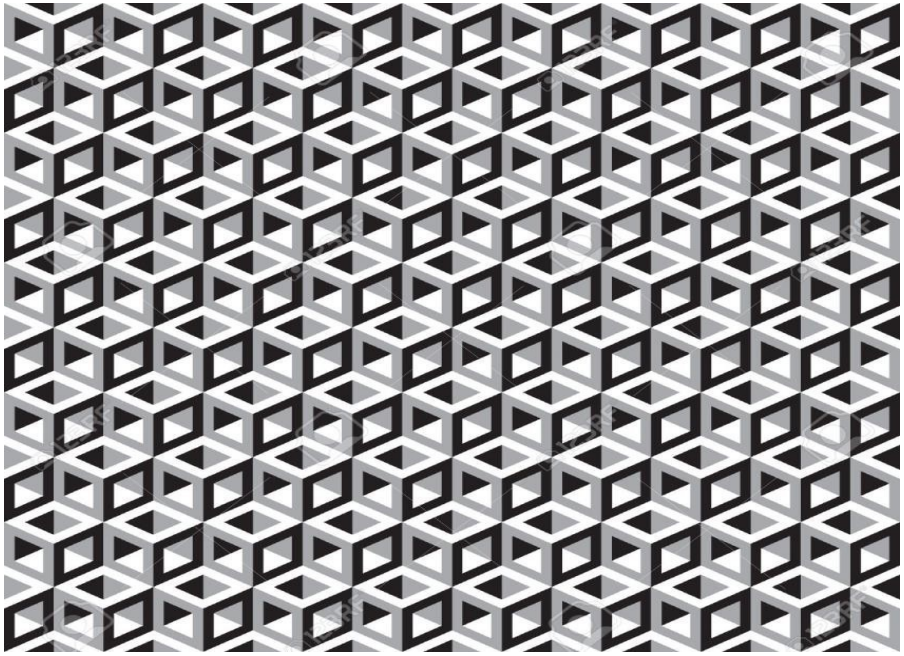
Field of view of the human eye

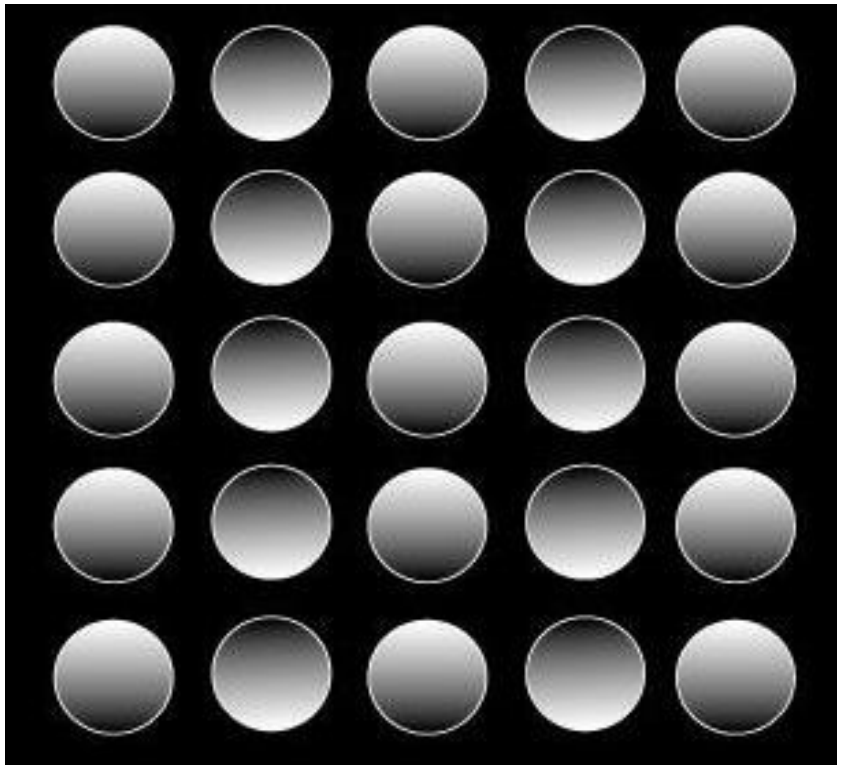




Light perception

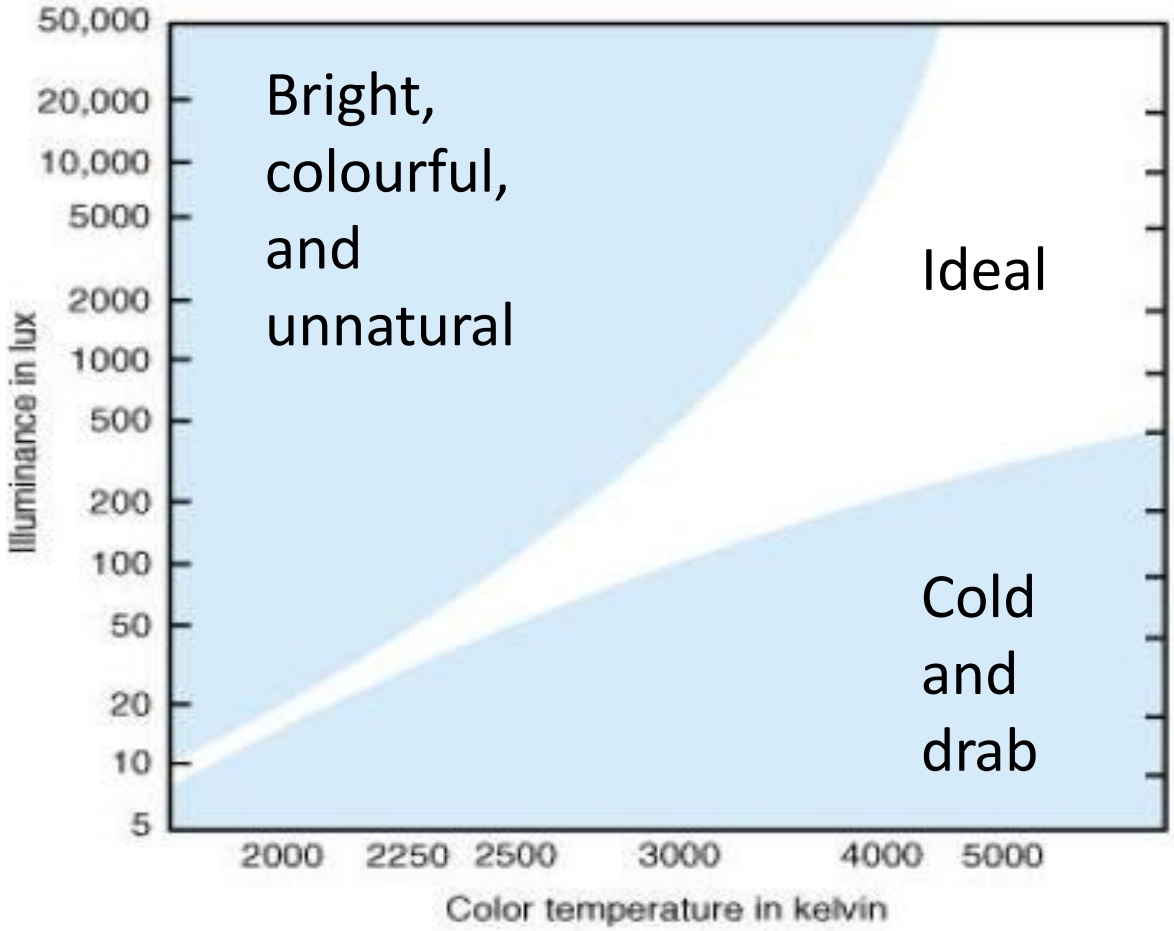
- We have adapted to assume light comes from above (the sun)





Preferred colour and illuminance

Kruithof effect: preferred lighting colour depends on brightness

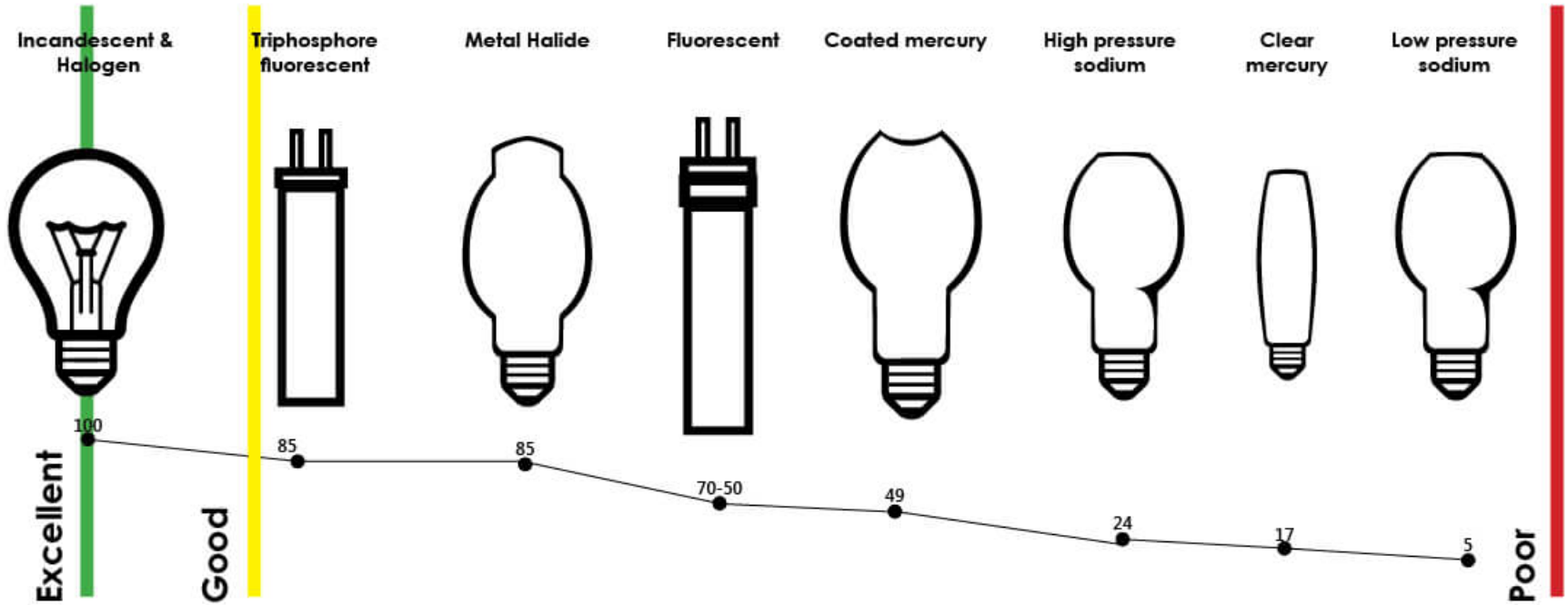


Colour Rendering Index (CRI)

- Ability of a light source to realistically/naturally illuminate an object as it would be seen in daylight.

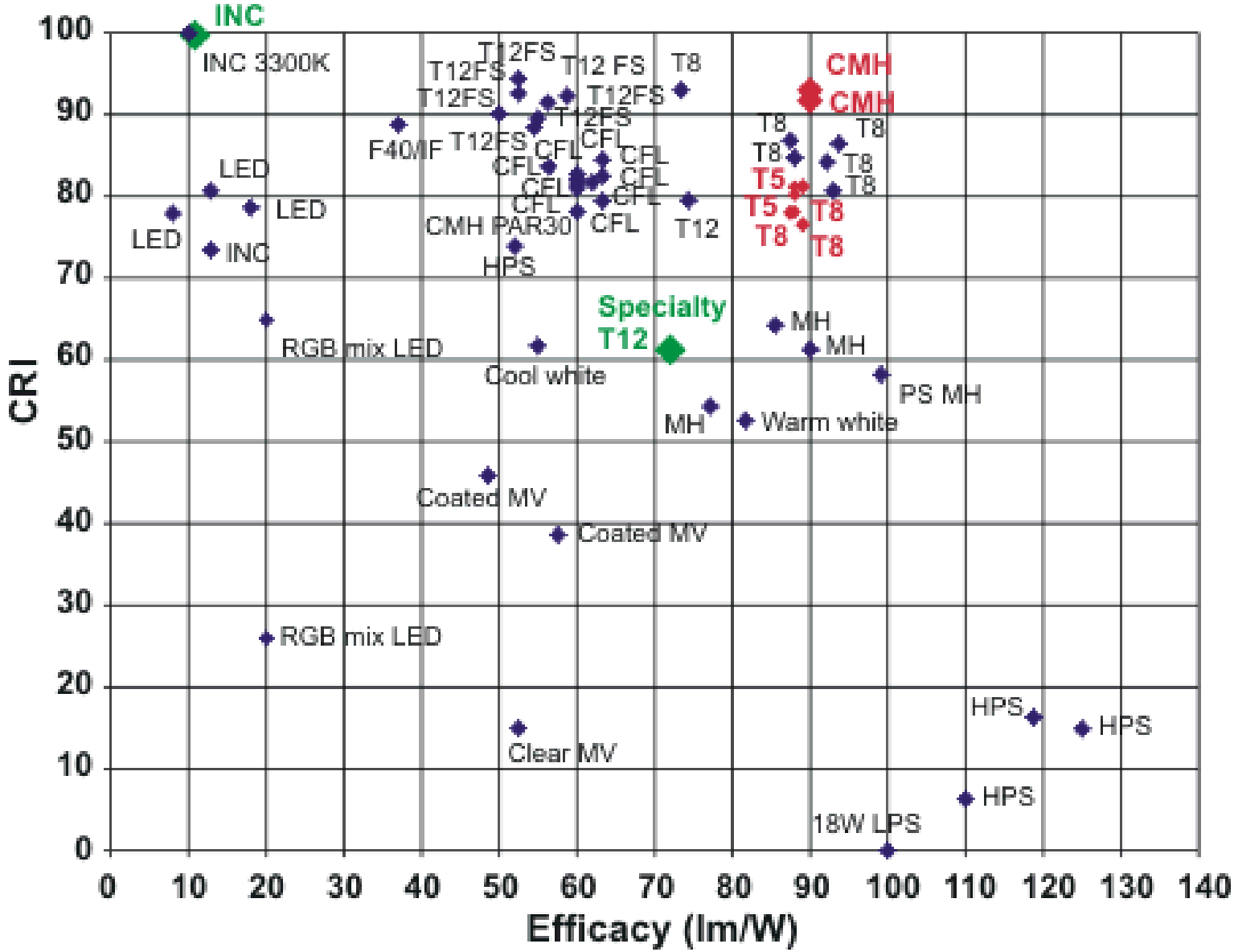
CRI = 51 CRI = 80 CRI = 90

Colour Rendering Index (CRI)
for different types of lamps



- LEDs are now achieving CRI of >90

CRI vs. luminous efficacy



AmbientLED A19 Bulb 2700K

lighting facts[CM]

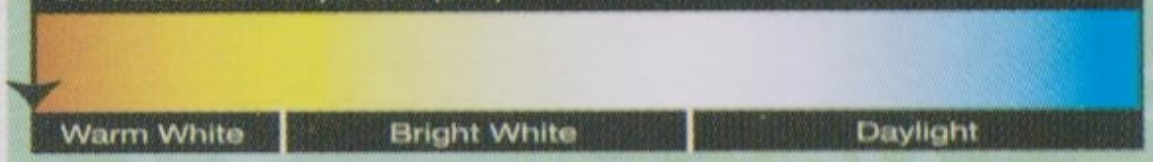
A Program of the U.S. DOE

Light Output (Lumens)	**800**
Watts	**12.5**
Lumens per Watt (Efficacy)	**64**

Color Accuracy Color Rendering Index (CRI)	**80**

Light Color **2700 (Warm White)**

Correlated Color Temperature (CCT)



All results are according to IESNA LM-79-2008: *Approved Method for the Electrical and Photometric Testing of Solid-State Lighting*. The U.S. Department of Energy (DOE) verifies product test data and results.

Visit www.lightingfacts.com for the *Label Reference Guide*.

Registration Number: ZC23-5RLZ31

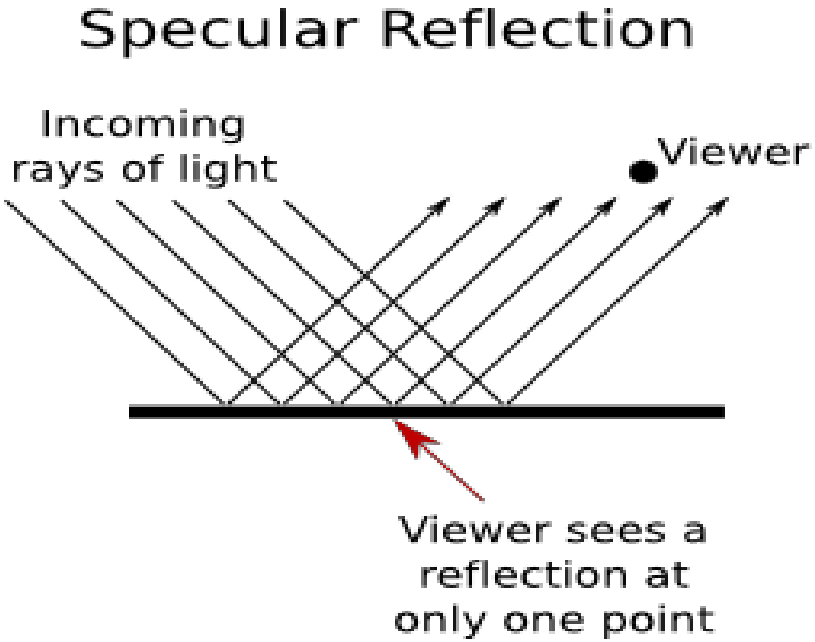
Model Number: 12E26A60

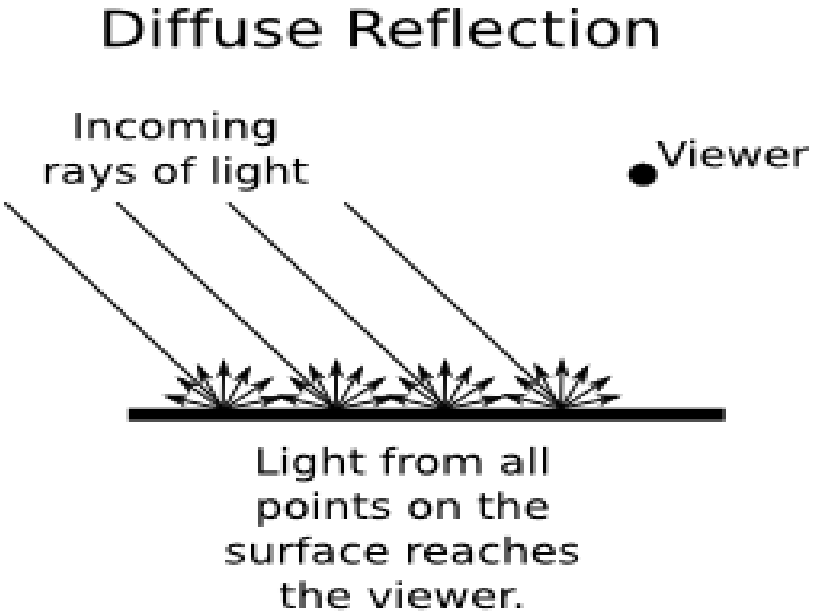
Type: Replacement lamp - Omnidirectional (A Lamp)

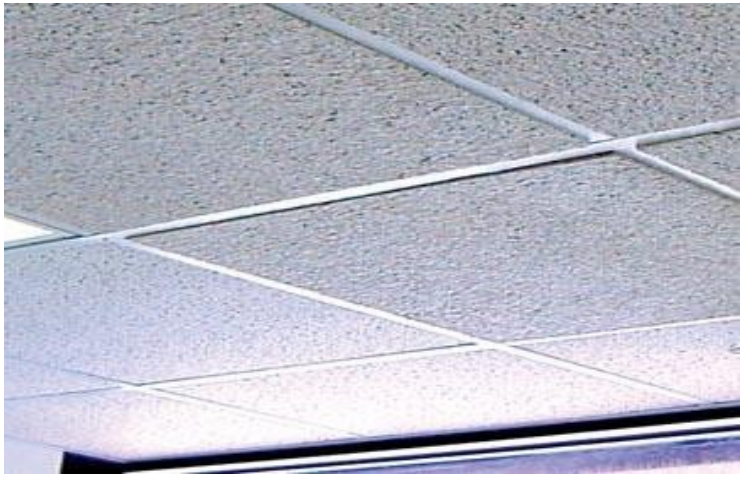
Contrast

- Relative difference in luminance of objects within the field of view.
- $C = (L_{background} - L_{target})/L_{background}$
- $L_{background}$ is the background (surroundings) luminance

Direct vs. diffuse reflection





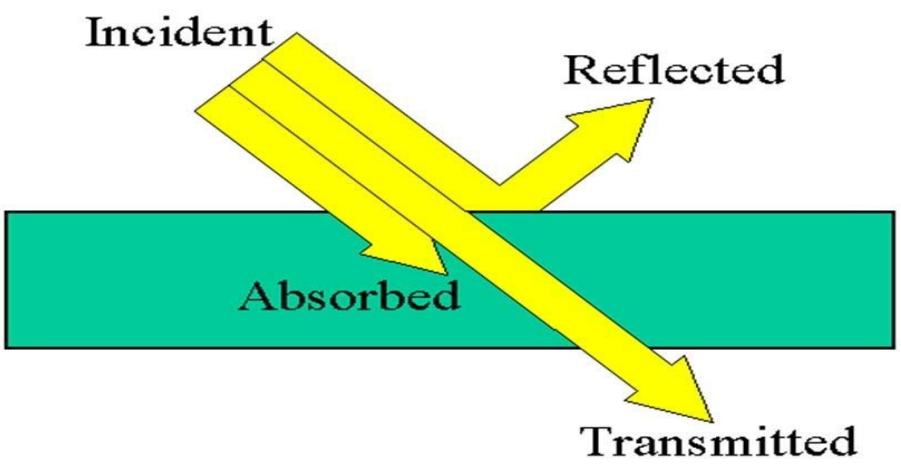


Trains
Pay Station
Guichet de paiement
INFORMATION
INFORMATION

Diffuse vs. Direct (Specular)

- Direct light occurs when the view directly looks at a lighting source or if there's only a mirror (or specular reflector) between the two.
- Diffuse light occurs when light has been reflected off one or more diffuse surfaces (e.g., matt painted wall, ceiling tiles, carpeting).
- Diffuse is highly preferable for visual comfort, but it could be harder to control/harvest.

Reflection, absorption, transmission



ρ = reflectance

τ = transmittance

α = absorptance

For any surface:

$$\rho + \tau + \alpha = 1$$

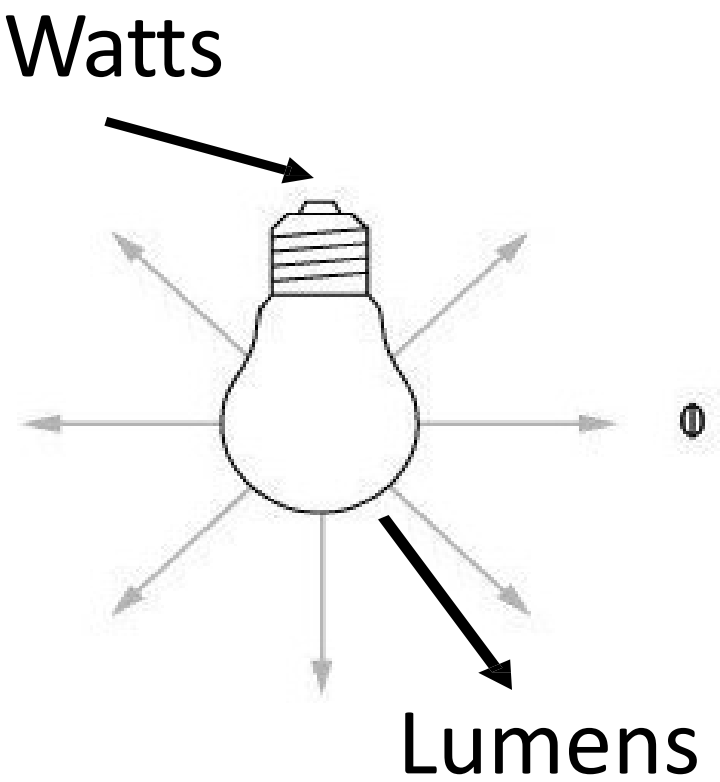
Typical Room Reflectances

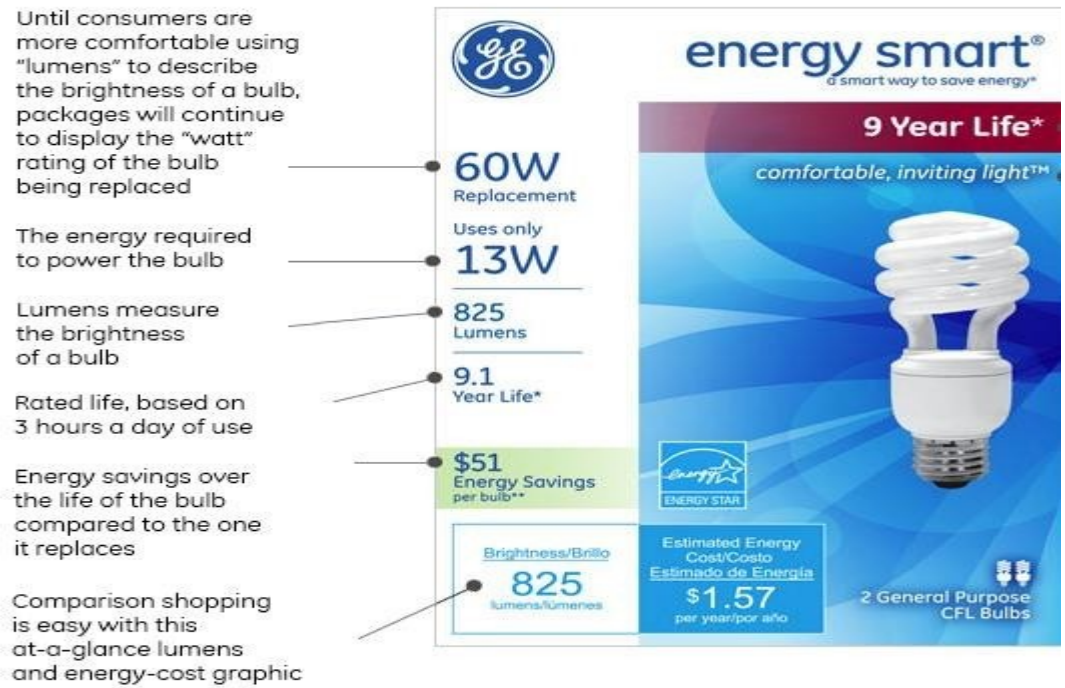
- Floor: 10-20%
- Ceiling: 80%
- Walls: 30-50%

The Big 6 Lighting Metrics

1	Φ	Luminous Flux	Lumen (lm)
2	I	Luminous Intensity	Candela (cd)
3	E	Illuminance	Lux (lx)
4	L	Luminance	Candela/m^2 (cd/m^2)
5	M	Luminous Exitance	Lumen/m^2
6	Q	Quantity of Light	Lumen-second (lm-s)

Luminous Flux (Φ)



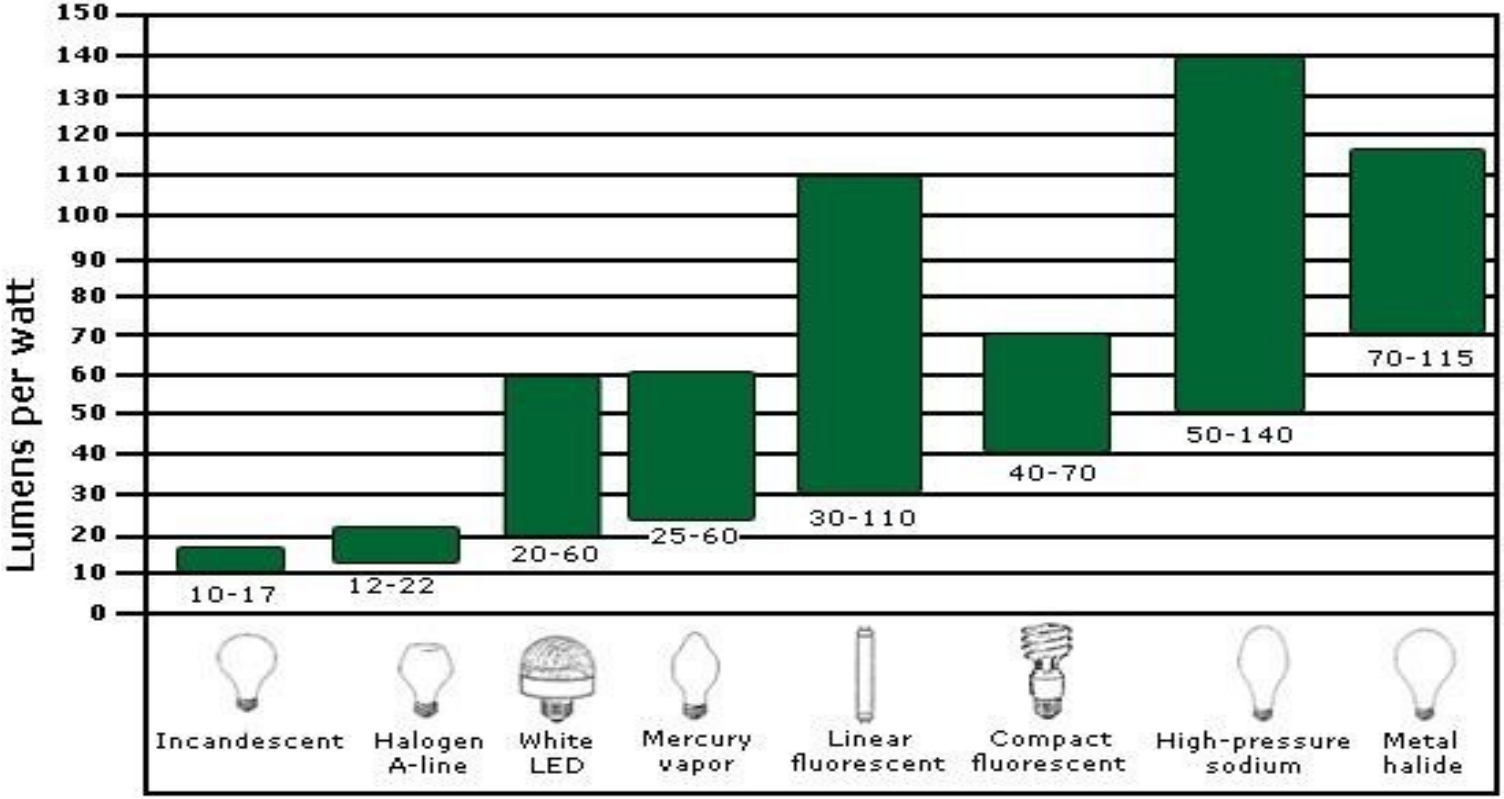


Luminous Flux (Φ) (unit: Lumens)

- Definition: The time rate of light leaving a light source (independent of direction). Basically, we're putting power into a *lamp* and getting lumens out.
- Analogy: The water flow rate out of a shower head.
- The efficiency of a luminaire is called *efficacy*. It has units of Lumens/Watt.

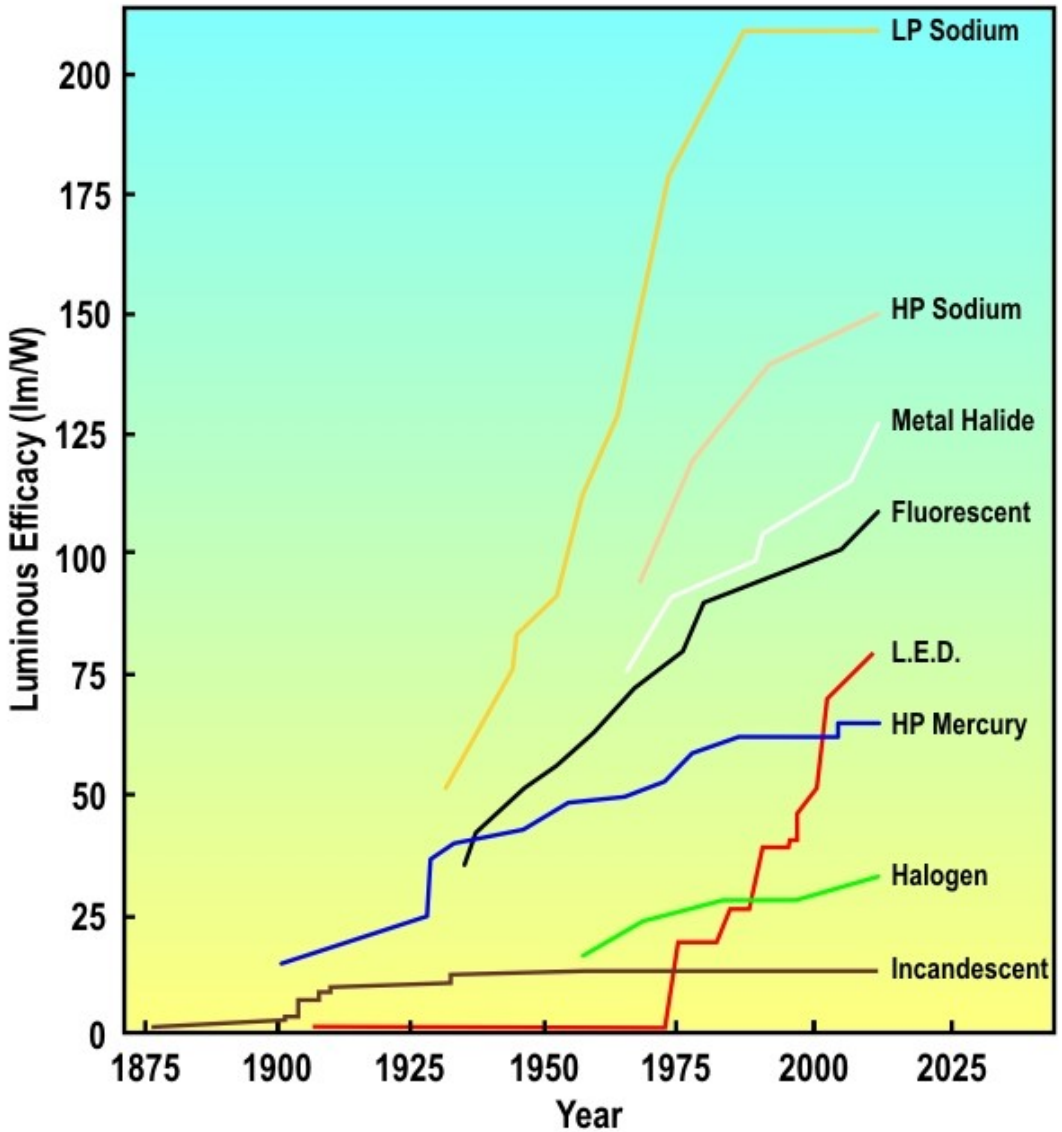
Lighting Units: Lumen

- Rate of <u>visible</u> light being emitted by a source.

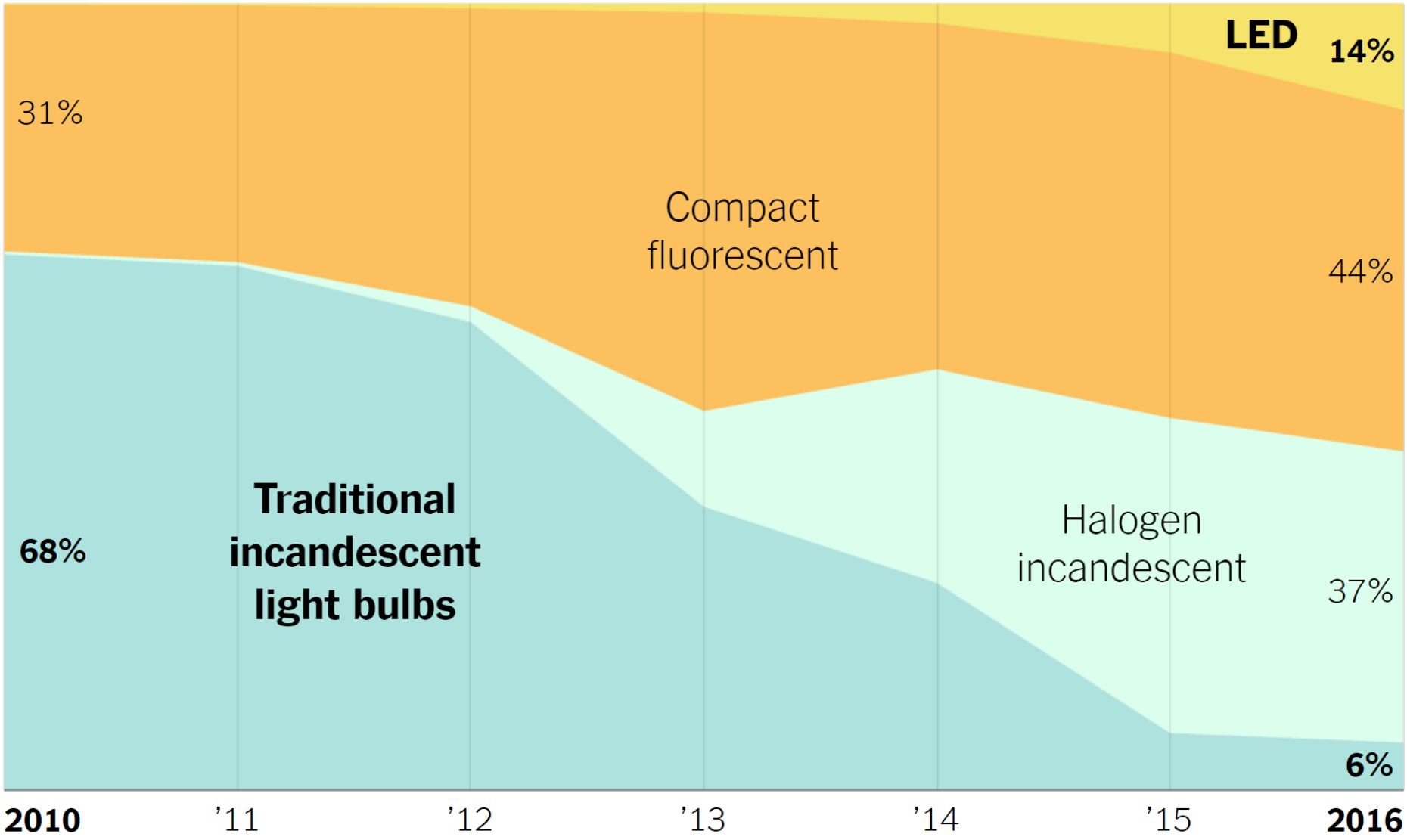


Sun: 93 lumens/Watt
High-effiency LED lamps: 100-170 lm/W
Theoretical limit for white LEDs: 260 – 300 lm/W

Lighting efficacy (lm/W)



Basic Light Bulbs Installed in U.S. Homes



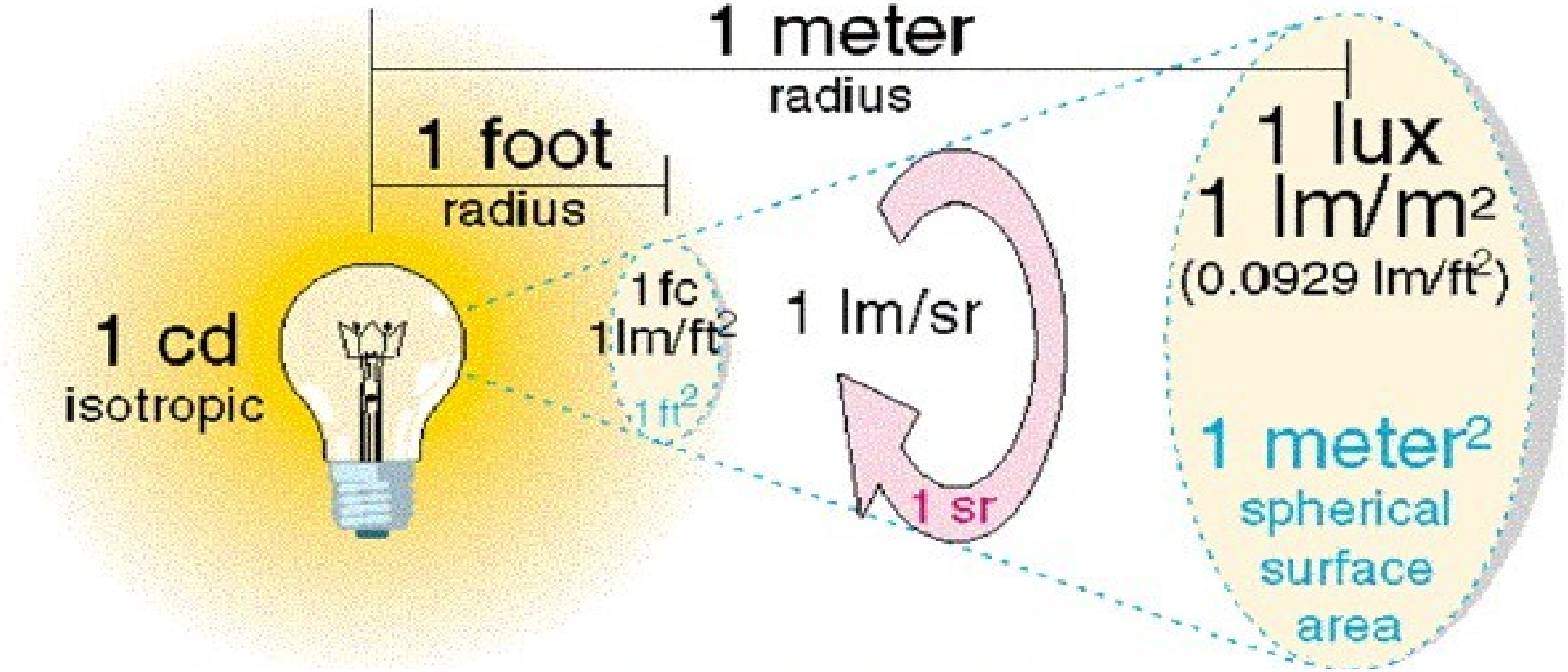
Theory: Illuminance (E) (unit: Lux)

- Definition: The amount of light that hits a surface. It is the key design metric and tells us whether the level of lighting is acceptable.
- Analogy: The rate that a bathtub under a shower head fills up
- We cannot *see* illuminance.

$$E = \frac{\Phi}{A}$$

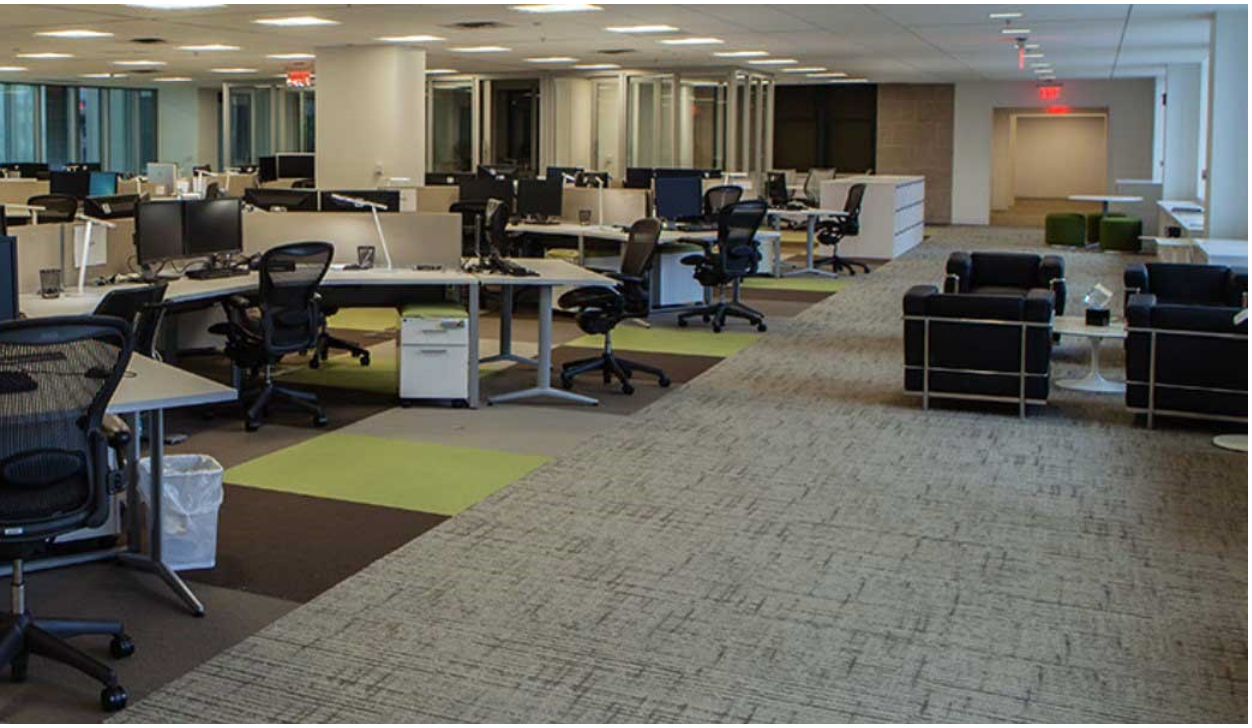
- *A* is the area of the surface receiving light

Illuminance (E)



Illuminance (E)

- Lighting engineers are told to achieve a certain level of illuminance. The value is typically specified for the workplane or other surface of interest.



- Typically, the workplane is 0.8 meters above the floor

Illuminance

Condition	Illumination	
	(ftcd)	(lux)
Sunlight	10,000	107,527
Full Daylight	1,000	10,752.7
Overcast Day	100	1,075.3
Very Dark Day	10	107.53
Twilight	1	10.75
Deep Twilight	.1	1.08
Full Moon	.01	.108
Quarter Moon	.001	.0108
Starlight	.0001	.0011
Overcast Night	.00001	.0001

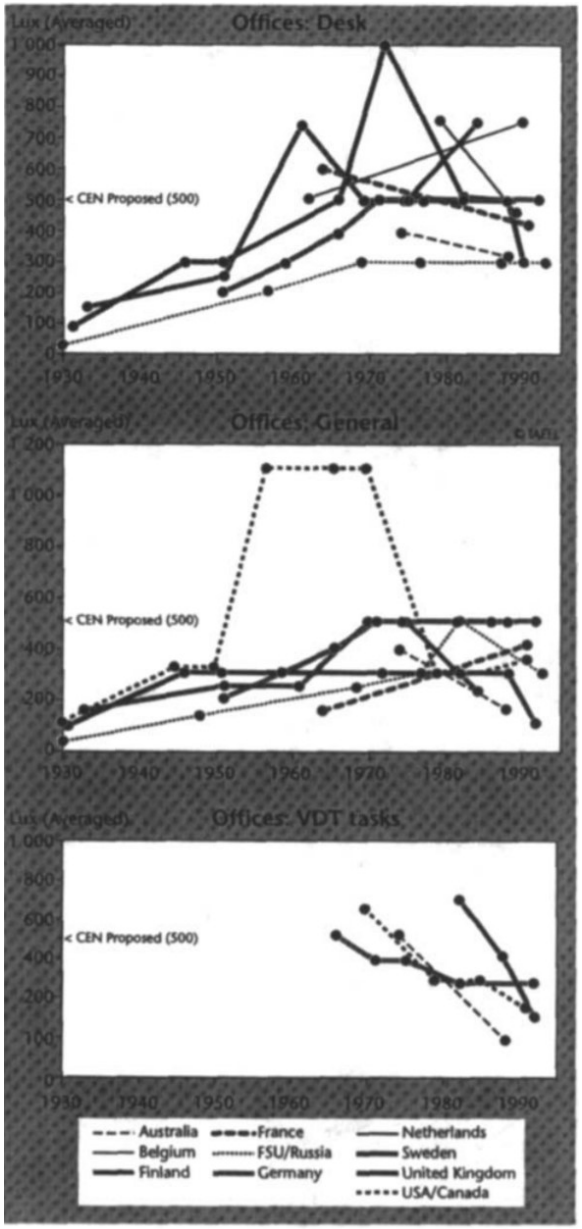
Workplane Illuminance

Activity	Illumination (lux, lumen/m^2)
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1,500 - 2,000

Illuminance standards over time

Table 1— Variation factor between highest and lowest recommendation in 19 countries (based on Table 2)

	19-country Low	19-country High	Variation Factor	CEN/TC-169 Proposed European Guideline
Offices				
General	50	1000	20,1	500
VDT Tasks	150	750	5,1	500
Desk	150	1000	7,1	500
Reading Task	75	1000	13,1	500
Drafting (det)	200	3000	15,1	750
Classrooms				
General	75	750	10,1	400
Chalkboards	250	1500	6,1	500
Retail Stores				
Ambient	50	1500	30,1	300
Tasks/Till Area	100	1500	15,1	500
Hospitals				
Common Area	50	300	6,1	200
Patient Room	30	300	10,1	100
Operating Room	300	2000	7,1	1000
Operating Table	100	1000	10,1	450
Manufacturing				
Fine Knitting,	50	2000	40,1	750
Electronics	200	5000	25,1	1500



Illuminance (E)

Nighttime Workplane Illuminance, [lux]

	Average	Max	Min	Max/Min	LPD
Zone 1	471.3	643.8	319.9	2.0	7.25
Zone 2	489.7	643.8	321.0	2.0	9.67
Total	**479.2**	**643.8**	**319.9**	**2.0**	**8.29**

Light Loss Factor 0.8

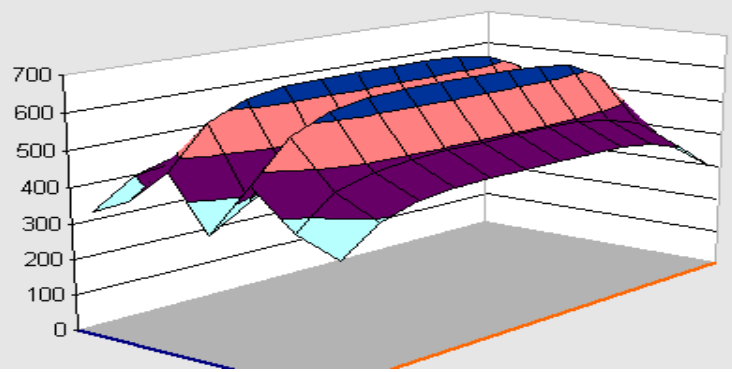
Design Illuminance 300 lux

Width, [m	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
7.0	321	393	424	434	437	440	439	439	434	424	393	321
6.0	368	450	478	491	495	495	495	493	491	480	450	368
5.0	469	578	621	637	640	644	642	640	637	621	578	469
4.0	321	386	431	449	453	455	455	453	449	430	387	320
3.0	469	575	621	637	642	644	642	642	637	624	575	469
2.0	369	450	480	489	495	495	495	495	491	478	449	369
1.0	321	393	424	434	439	439	440	439	434	424	393	320

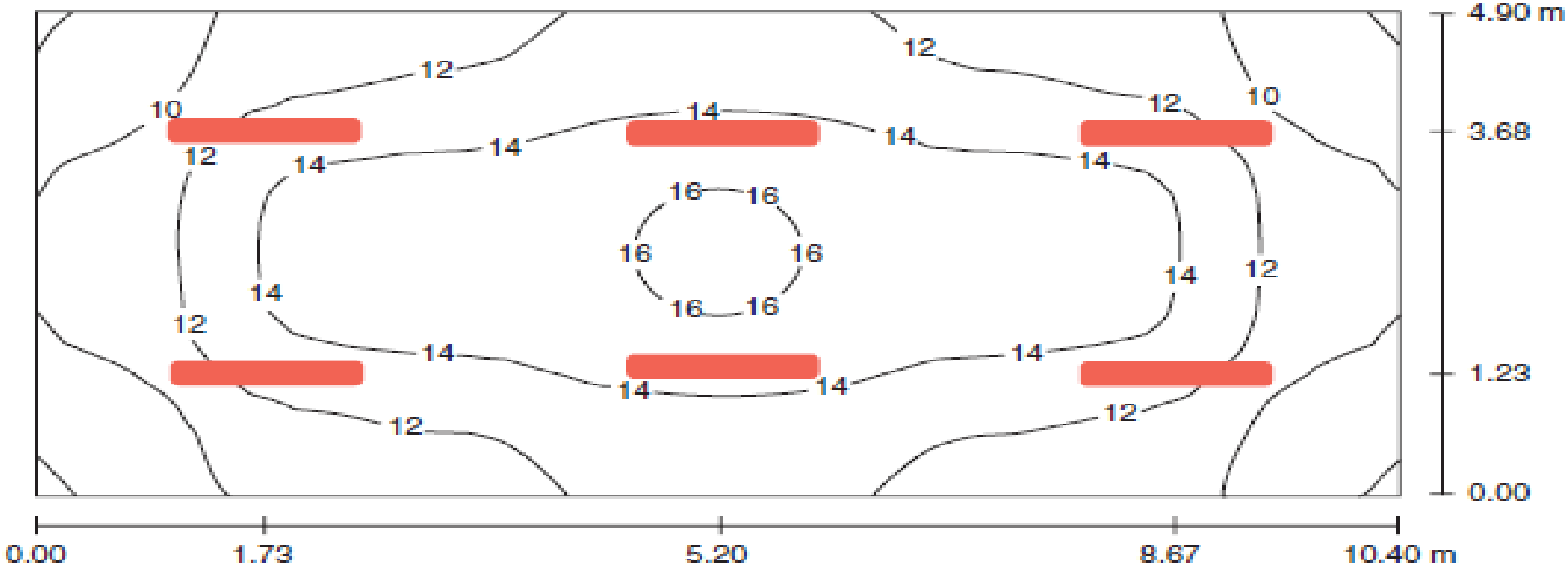
Length, [m]

The data on this sheet represents the electric lighting (nighttime) workplane illumina
Ideally, the nighttime workplane illuminance, scaled by an appropriate Light Loss Fa
will be a good estimate of the intended design illuminance of the space. Workplane
the points on the workplane grid that are dominantly lit by a given electric lighting zo
is automatically determined from the luminaire zone layout.

Workplane Illuminance [lux]



Why can’t we achieve perfectly uniform workplane illuminance? Does it matter?



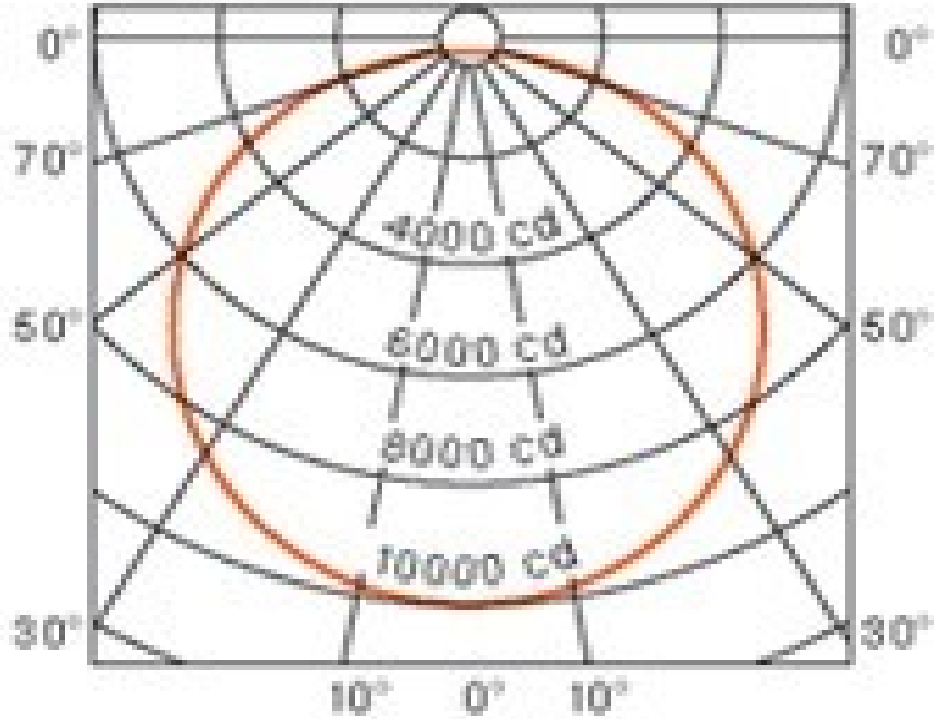
Measuring illuminance

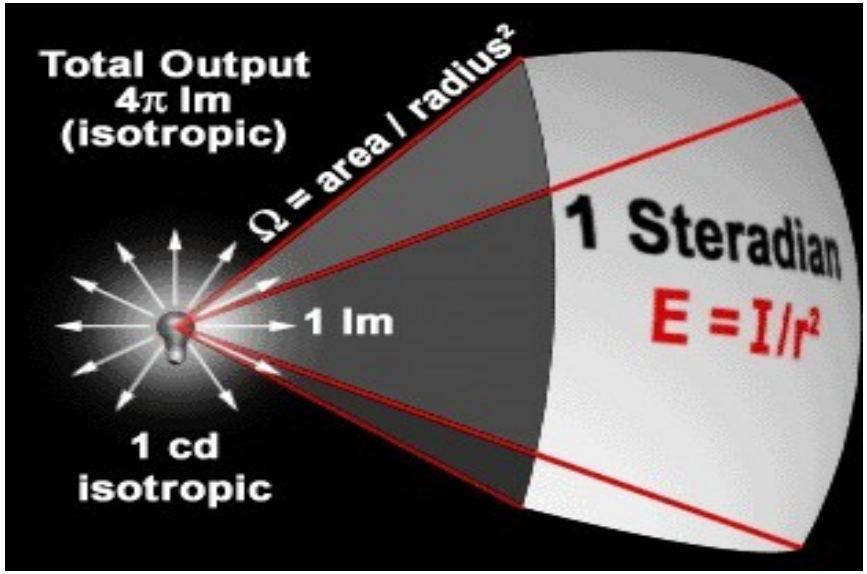
- Illuminance meters are quite cheap ($30 and up) because photographers use them
- Android has a free virtual lux meter (Elixir2) that is *OK*…
- For some reason, illuminance sensors for control applications are very pricey ($200 and up)

Luminous Intensity (I)
(unit: candela or *cd*)

- Definition: Luminous intensity is the force that generates luminous flux. It tells us how intense the light is coming out of a lamp in a given direction.
- Analogy: A shower head lets high-pressure water streams out at some angles and lower pressure water streams out at other angles.

Luminous Intensity (I)

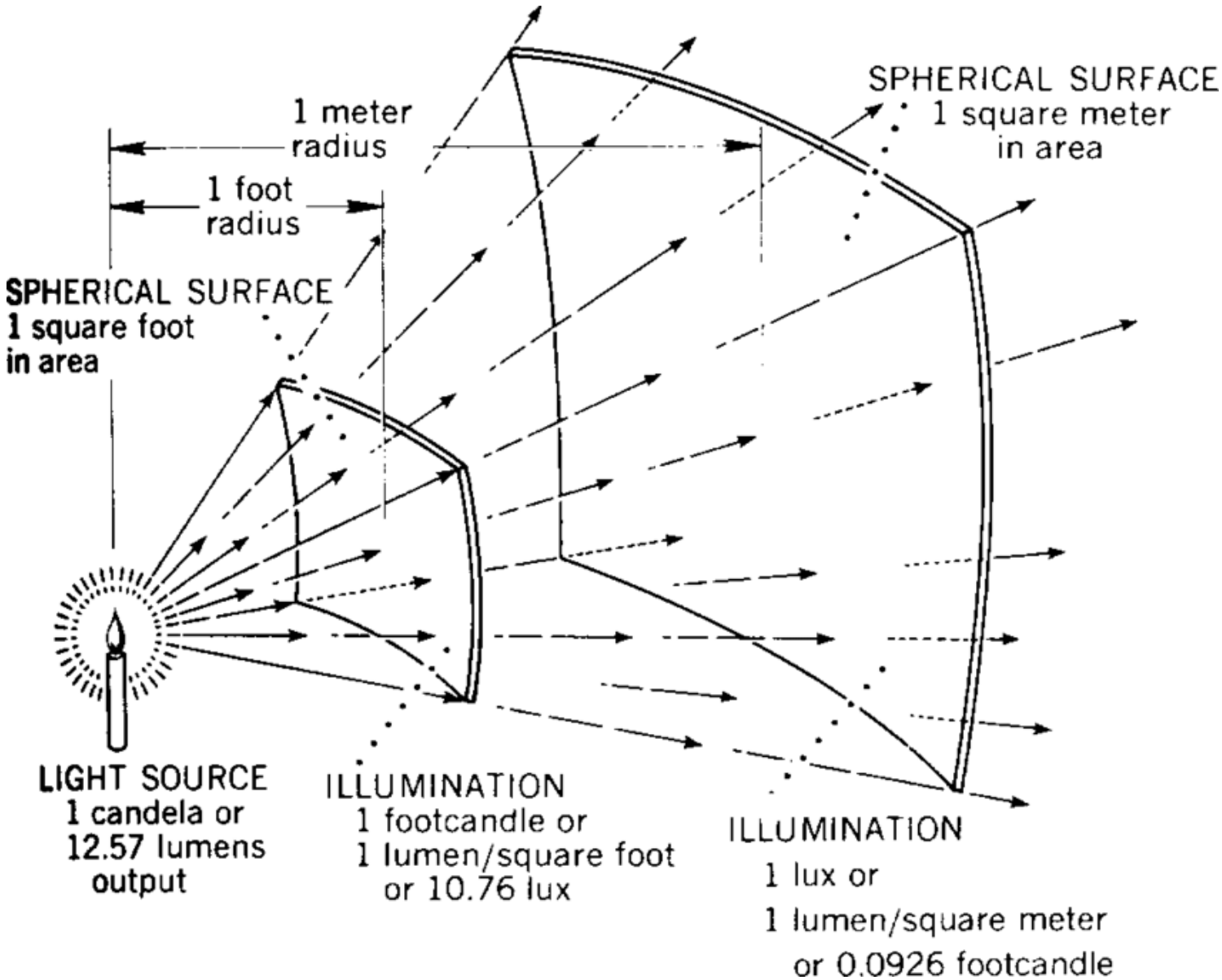




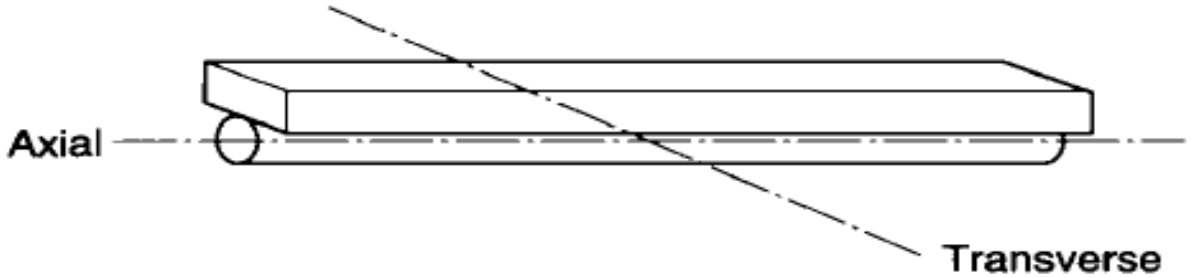
1 steradian (sr) = $A/4\pi r^2$

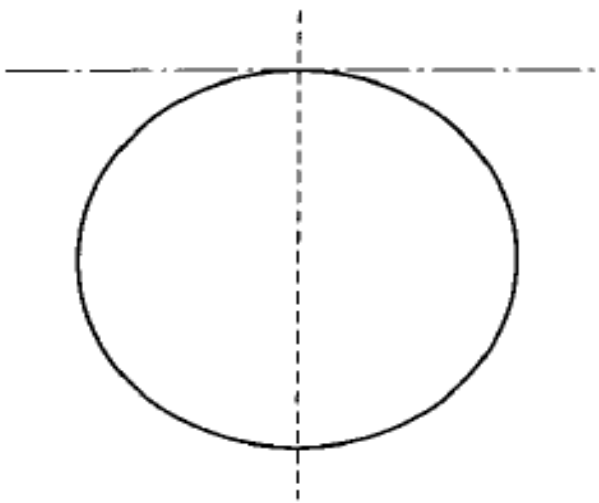
To achieve 1 lux at 1 meter from an isotropic lamp (or other light source), the lamp must give off 4π (12.6) lumens.

Illuminance (lux and foot-candle)

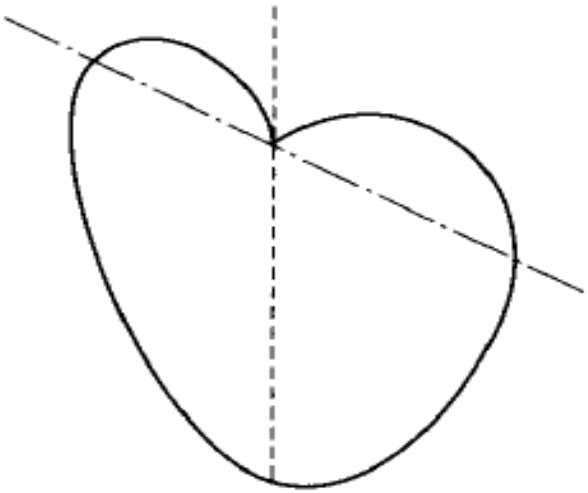


Luminous Intensity Profiles

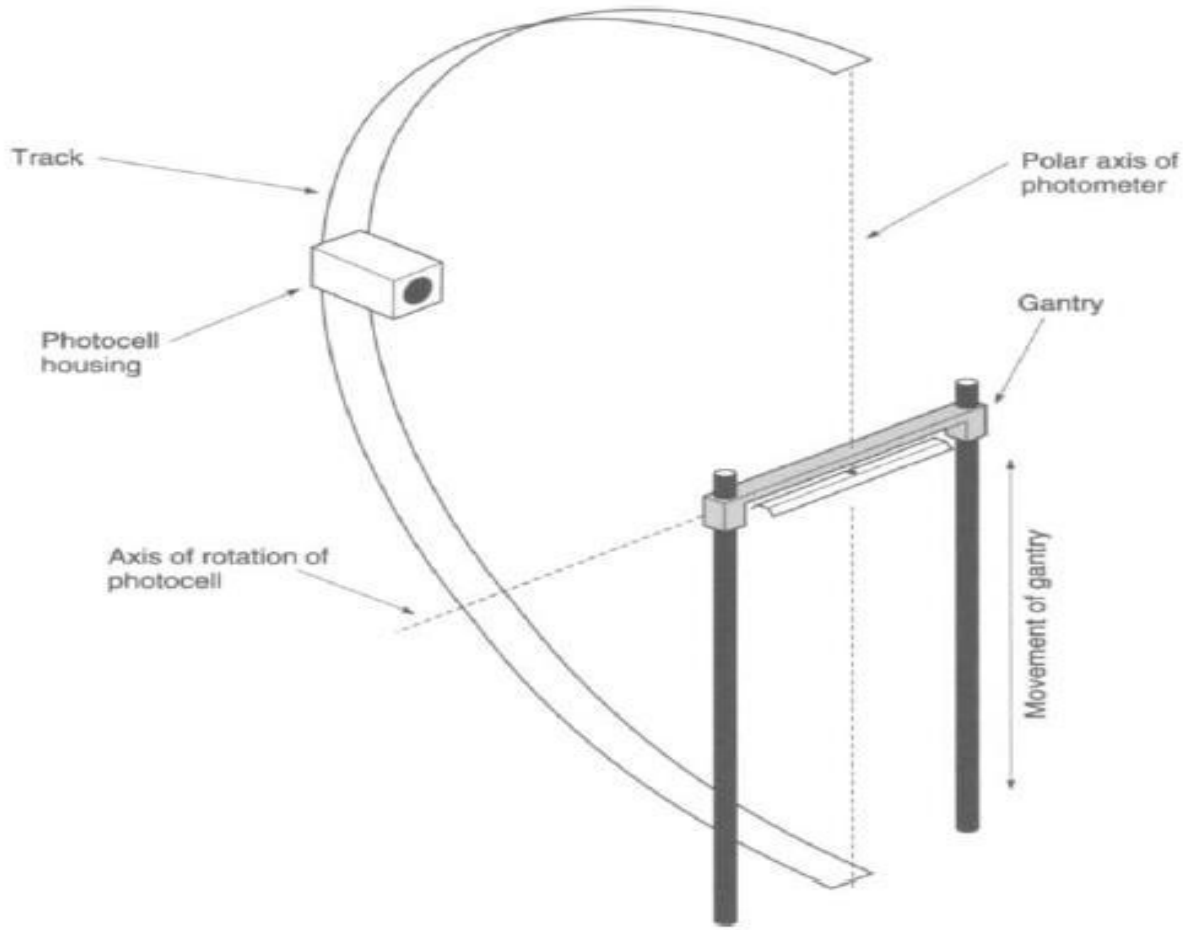




Axial polar curve

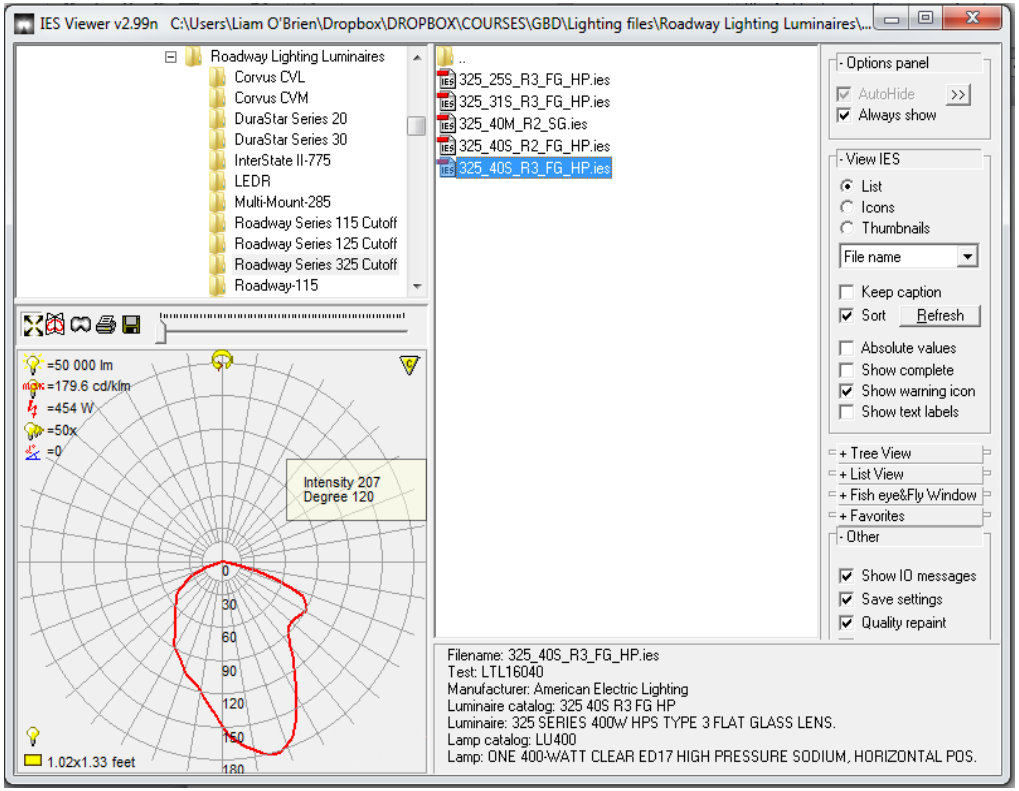


Transverse polar curve


Track
Polar axis of photometer
Gantry
Photocell housing
Axis of rotation of photocell
Movement of gantry

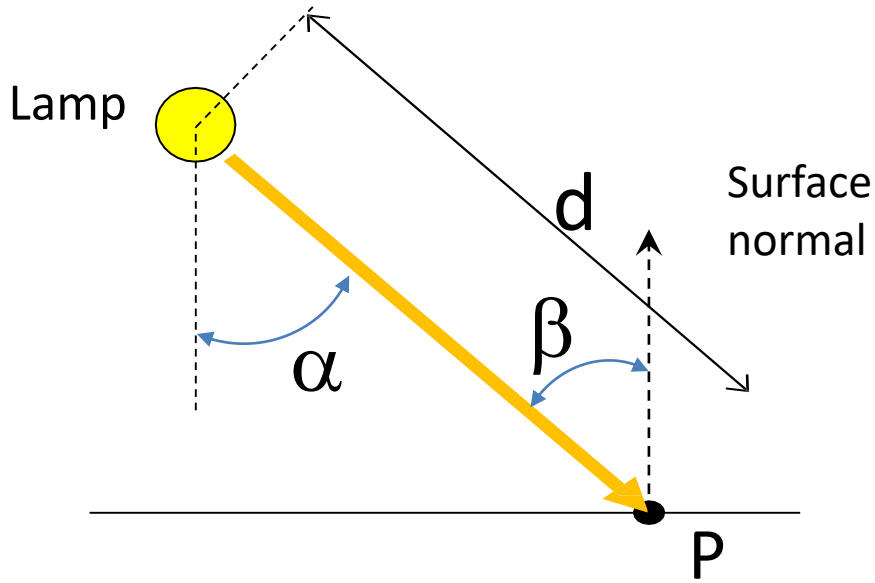
IES Files: Lamp Spec Sheets

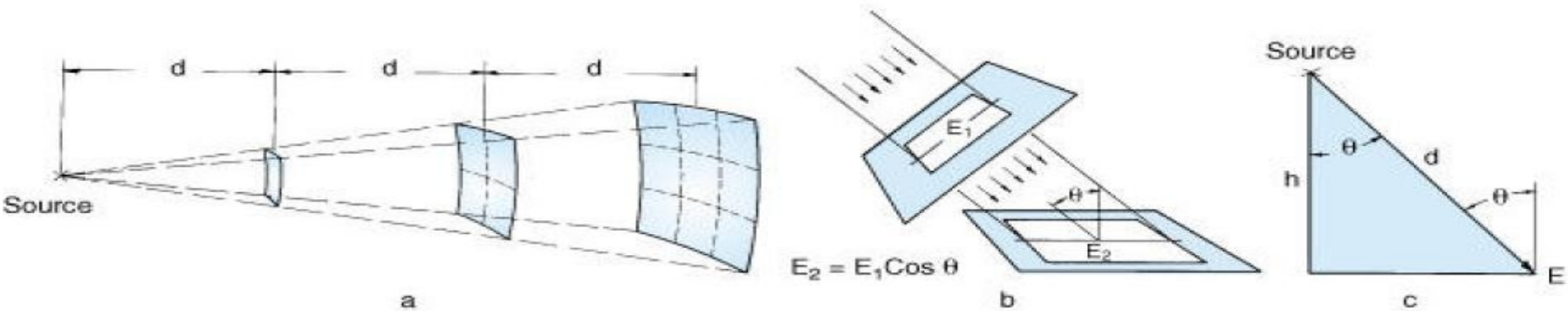
- Freely available from lamp manufacturers.
- The files can be used in lighting design tools or viewed with IES Viewer.
- Diffusers
- Suspended lights



Relationships between E and I
(illuminance, luminance intensity)

$$E = \frac{I \cos \beta}{d^2}$$



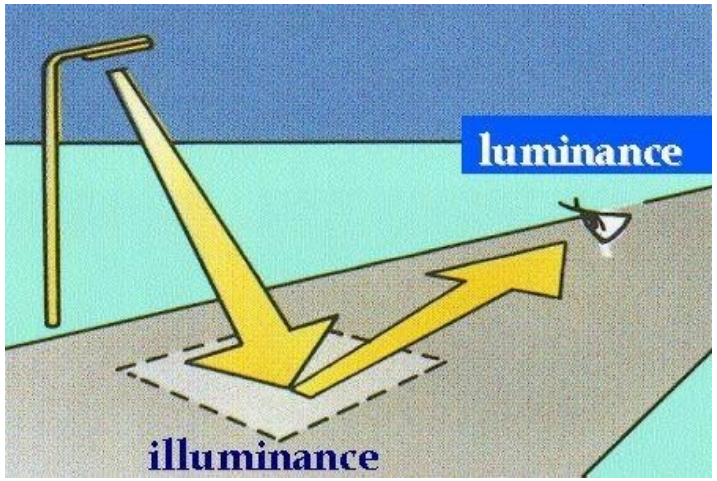


Luminance (L) (unit: *cd/m²*)

- Luminous intensity deals with the direction-dependent brightness of a point light source. Luminance deals with surface light sources.
- Definition: Luminance is the luminous intensity of surface (e.g., outside of a lamp diffuser, sunlit surface, computer screen, or frosted window) <u>in a particular direction</u>.
- It indicates how bright a surface appears to the observer
- Normally, we're interested in luminance in the direction of the observer

Examples:

- Computer monitors emit 50 to 300 cd/m^2 of luminance
- The sun has luminance towards earth of about 1.6 billion cd/m^2



Typical luminance sources

- Non-point light sources give off luminance according to their area.
- Some typical examples of light sources and their luminance:

Fig 4.25 Typical Luminance Values.

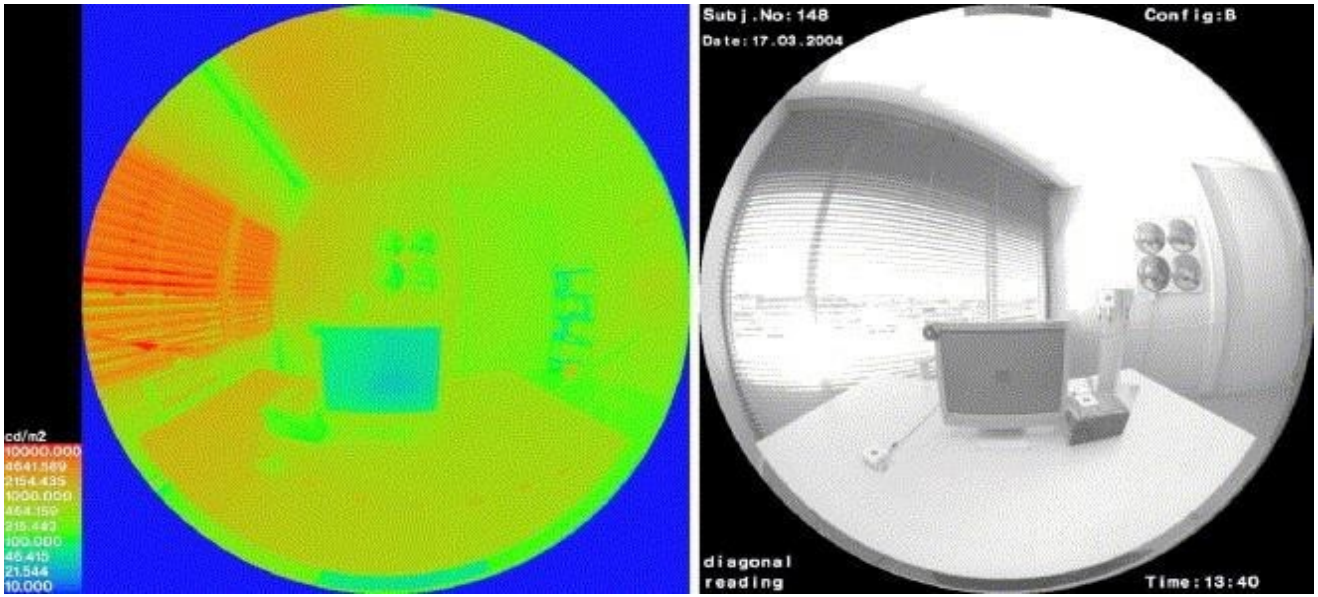
Light Source	Luminance [cd/m²]
Starlight	10^{-6}
Moonlight	10^{-3}
Desk at Night	20
Computer Screen	200
Overcast Winter Sky	3000
Fluorescent Light	7000
Solar disc on a Clear Day	10^{8}

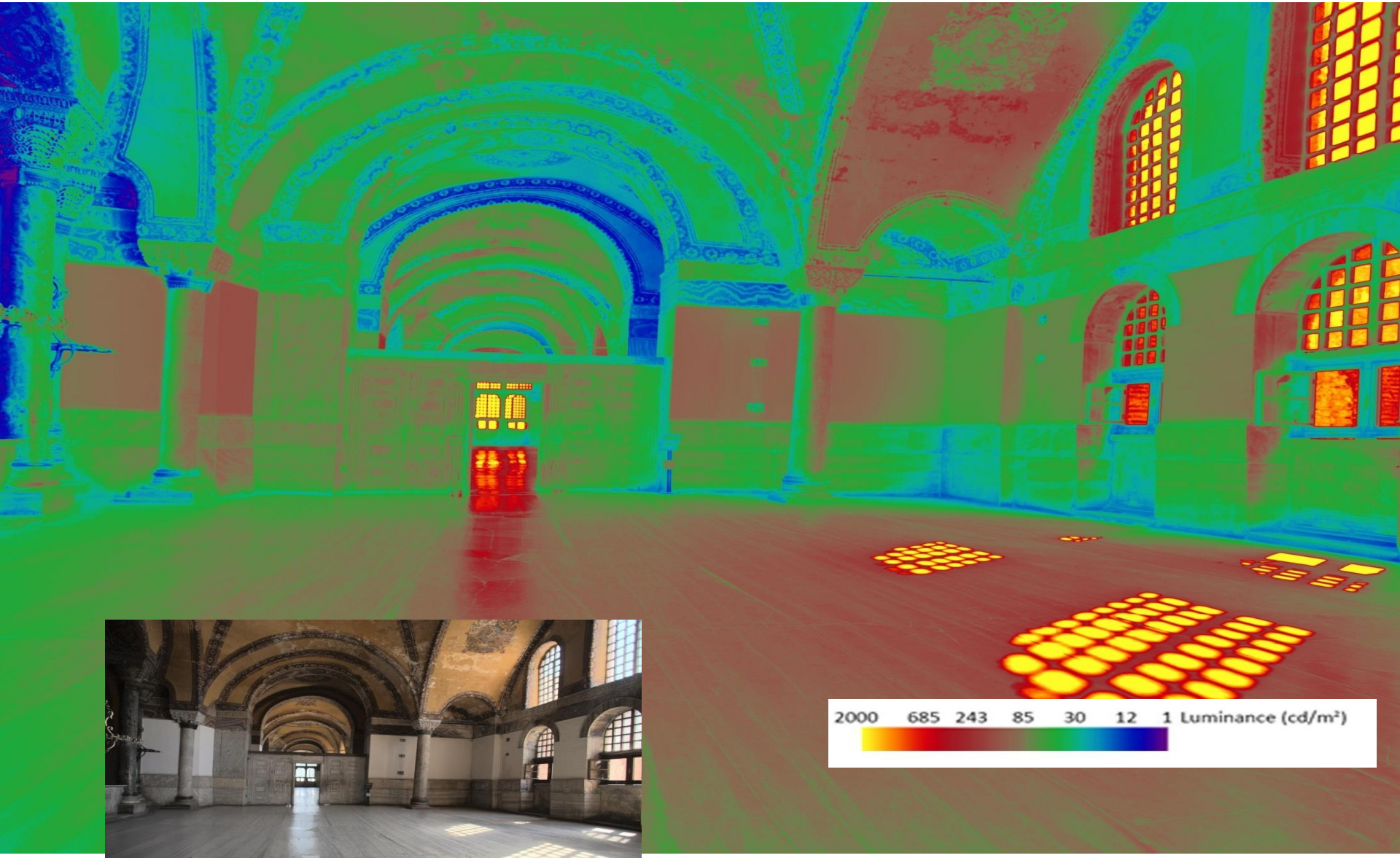
(Reinhart)

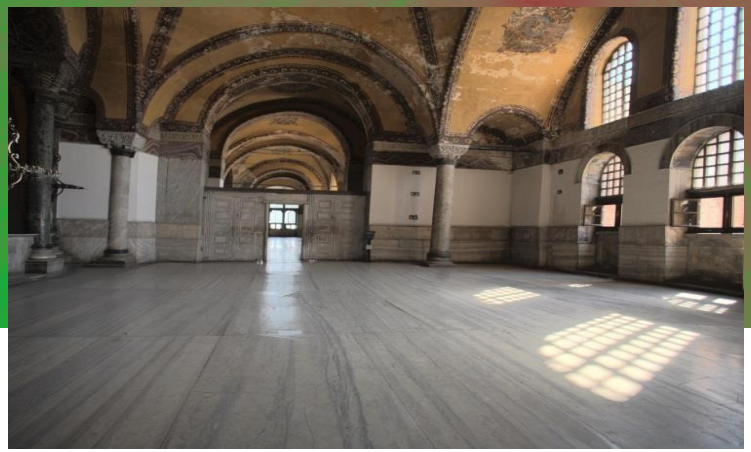
Measuring luminance

Daylight Luminance

- Luminance is frequently used to assess visual comfort because it considers the brightness of surfaces (as seen by the occupant) and their position in the field of view.
- The following false colour image (left side) shows the luminance of surfaces in an office. Normally, we want the ratio of the center of field of view and the surroundings to have a ratio of luminances of no greater than 10.

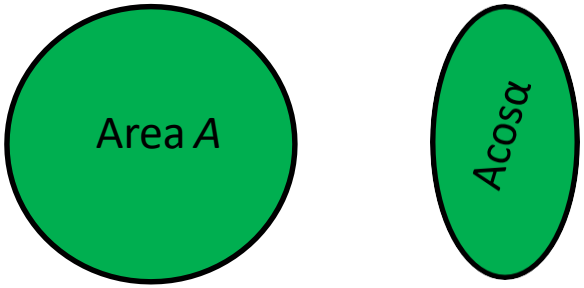



2000 685 243 85 30 12 1 Luminance (cd/m²)

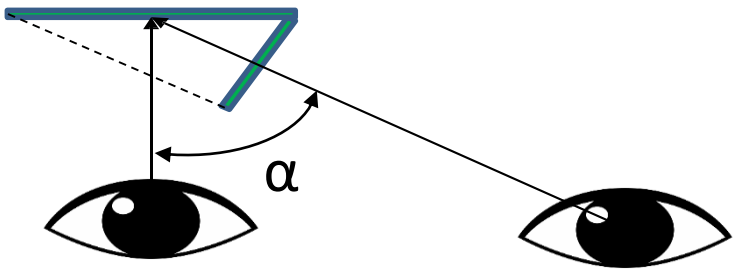


Relationship between luminous intensity (I) and luminance (L)

The luminance and luminous intensity are related as follows:



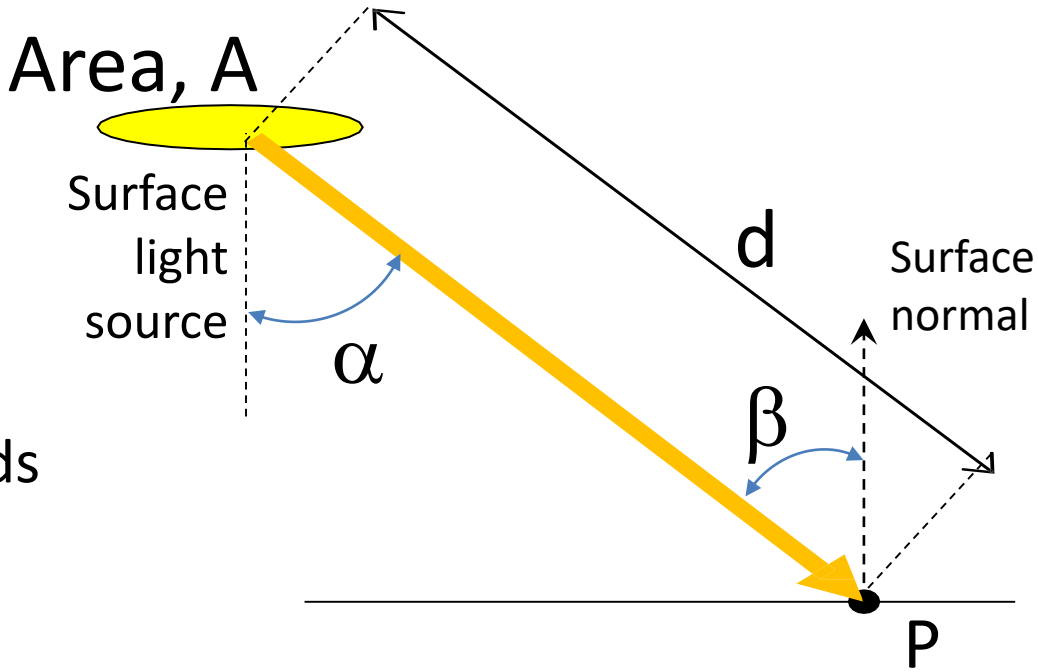
L (luminance) = I (intensity) divided by Acosα (projected area)



L=I/Acosα

Acosα is the projected area of the surface, as seen by the observer.

Relationships between E, I, and L
(illuminance, luminance intensity, luminous flux)



Projected area of source, as viewed from P is:

$$A_P = A\cos\alpha$$

Luminous intensity towards P is:

$$I_P = LA_P = LA\cos\alpha$$

Illuminance at P as a result of the source is:

$$E = \frac{LA\cos\alpha\cos\beta}{d^2}$$

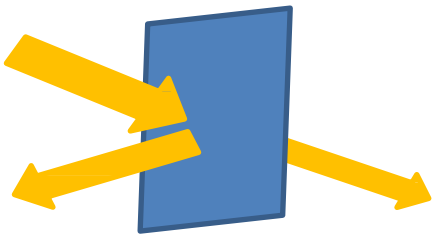
Note that this only applies if the source diameter is much smaller than d. Otherwise, we must integrate over the surface, considering d, α, and β .

Luminous exitance (M) (unit: lumen per area or lm/m^2)

- Definition: the quantity of light leaving a surface – either as reflected or transmitted light from some other incident source.
- The units are lm/m^2, which is essentially the same as for illuminance (lux = lm/m^2)
- Luminous exitance does not imply a particular direction, but see note on Lambertian surfaces.

Luminous exitance (M)

- For reflected light, $M = \rho E$
- For transmitted light, $M = \tau E$
- Recall that ρ is surface reflectance (visible spectrum) and τ is transmittance (visible spectrum)
- These properties are likely angle-dependent, though we do not consider this here.
- It is certainly possible for light to be both reflected and transmitted.

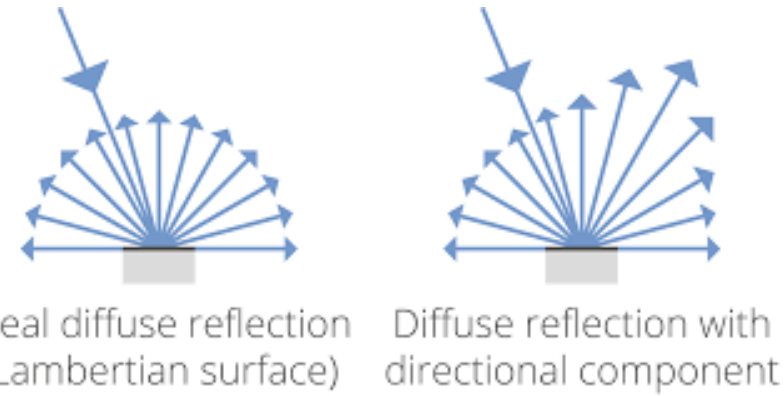


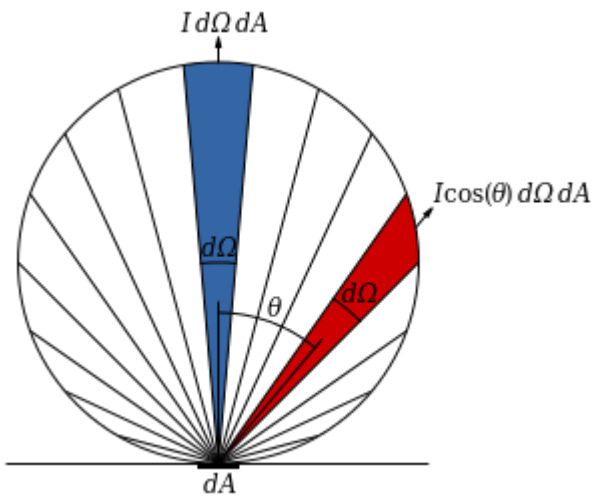
Lambertian surfaces

- Lambertian surfaces are perfectly diffuse
- As a result, emitted luminance (L) is equal in all directions
- But, luminous intensity follows the cosine law:

  $I = L\cos\alpha$

- For Lambertian surfaces only: $M = \pi L$





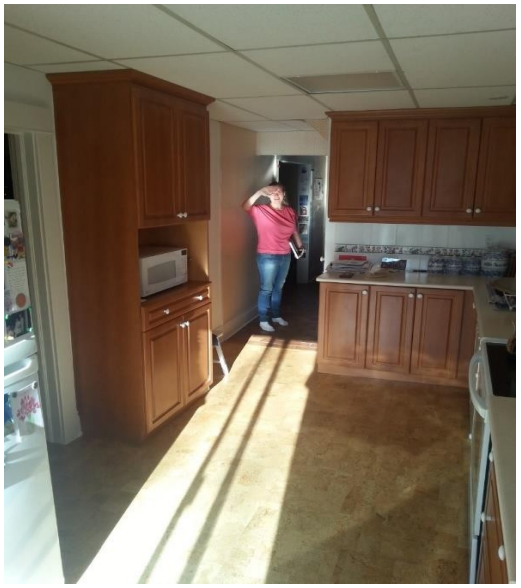
Quantity of light (lm-s)

- Definition: the time integral (cumulative) light hitting a surface.
- This is important for artwork or furniture fading, but does not enter most everyday applications.

"The Book of Kells has had a difficult, even a traumatic life. Some of the pages are missing and others are damaged by wear and exposure to light…"

Quantity of light (lm-s)

Faded cork flooring (about 7 years old)



The finish on this cork flooring is quite specular and causes glare as indicated by the occupants' suffering

The Big 6 Lighting Metrics

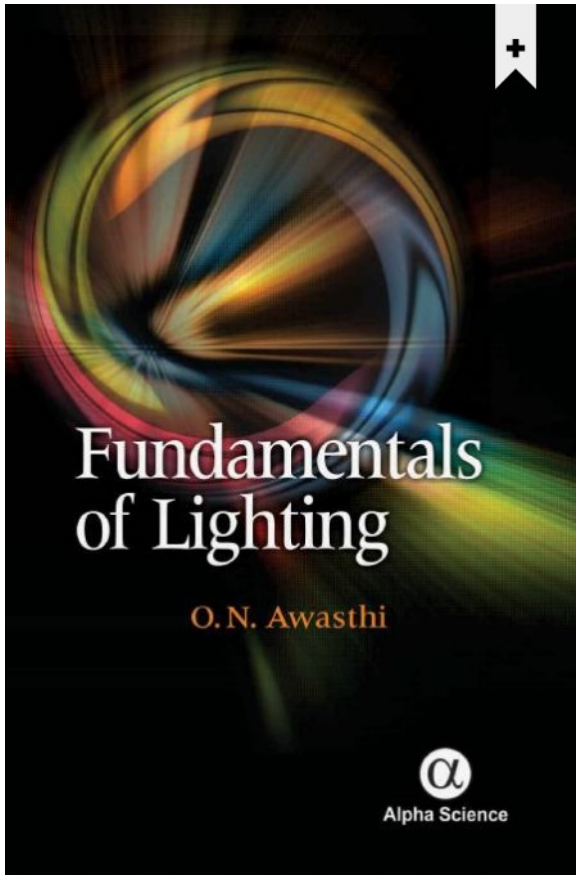
1	Φ	Luminous Flux	Lumen (lm)
2	I	Luminous Intensity	Candela (cd)
3	E	Illuminance	Lux (lx)
4	L	Luminance	Candela/m^2 (cd/m^2)
5	M	Luminous Exitance	Lumen/m^2
6	Q	Quantity of Light	Lumen-second (lm-s)

3B - Visual Comfort Modelling

Dr. Liam O’Brien

Topics

1. Assignment 3: questions?
2. Review of big 6 lighting variables
3. Worked examples
4. Daylight quality and visual comfort metrics
5. Modelling and simulating light for design



The Big 6 Lighting Metrics

1	Φ	Luminous Flux	Lumen (lm)
2	I	Luminous Intensity	Candela (cd)
3	E	Illuminance	Lux (lx)
4	L	Luminance	Candela/m^2 (cd/m^2)
5	M	Luminous Exitance	Lumen/m^2
6	Q	Quantity of Light	Lumen-second (lm-s)

The effectiveness for a light source to provide visible light, known as luminous efficacy, has the units:

A. W/lm
B. lm/W
C. W/lx
D. lx/W
E. lm/m^2

A 100 cd isometric lamp is suspended 2 meters above the floor in a very large room. What is the illuminance on the floor directly below the lamp?

A. 400π lx
B. 100π lx
C. 400 lx
D. 100 lx
E. 25 lx

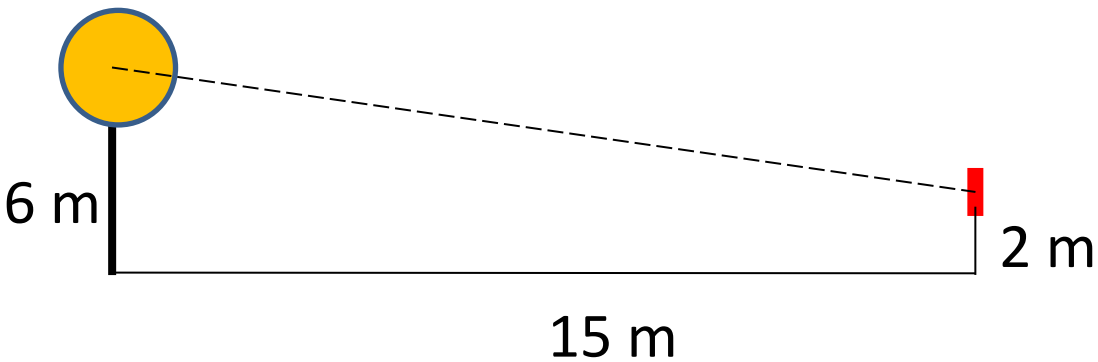
To achieve good visual comfort, appropriate surface visible reflectances for walls, ceiling, and floors, respectively, are:

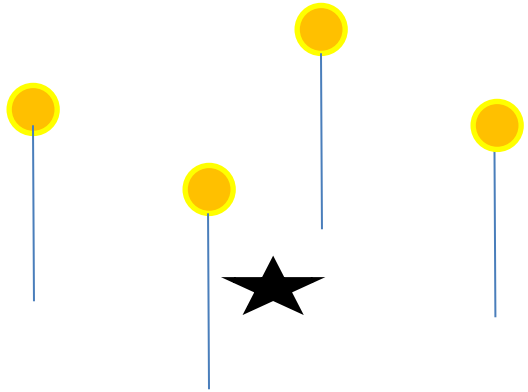
A. 50%, 10%, 80%
B. 50%, 80%, 10%
C. 10%, 80%, 50%
D. 80%, 50%, 10%

Example 1

Find the vertical illuminance from a 2000 cd isotropic lamp on a stop sign as shown in the figure.

Note: vertical illuminance refers to the illuminance that would be measured if the illuminance sensor were positioned flush (flatly) on the stop sign





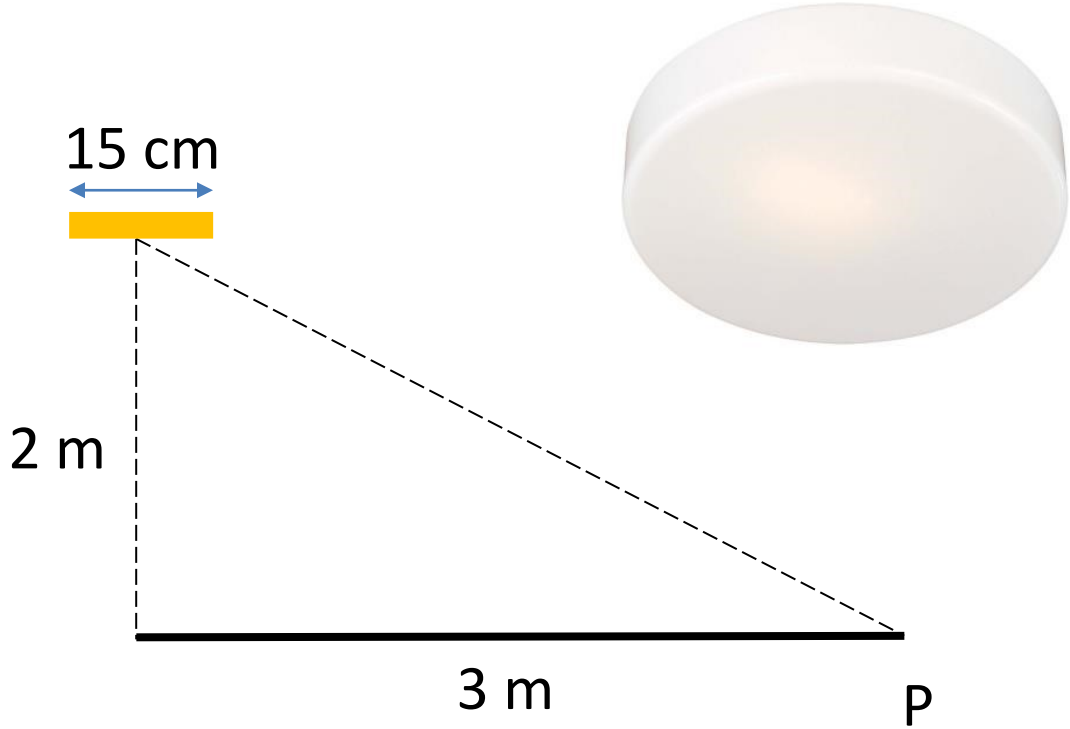
Example 6

- Four 1000 candela isotropic luminaires are 5 meters above the ground and in a square formation with 10 meters on each side. Calculate the illuminance on the ground at the centre of the square.
- Note that light sources play an additive role to illuminance. That is, because the lamps are equidistance to the point of interest, the contribution from one lamp can be multiplied by 4 to solve this problem.

Example 2

A circular, perfectly diffusing 15 cm diameter luminaire has a luminance of 40 cd/cm^2 towards P. Find:

- I towards point P
- E_P



Example 3 (to be done in tutorial)

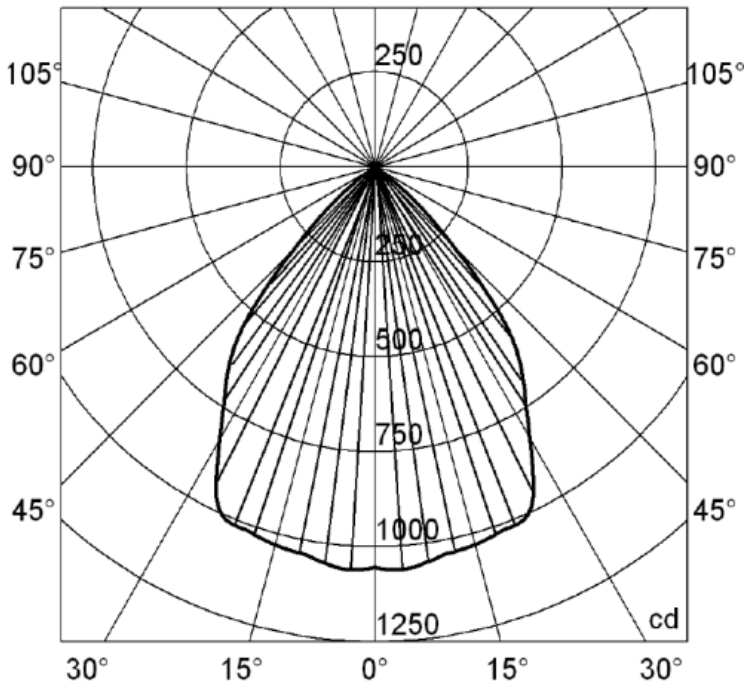
The top half of a 1m diameter globe is silvered with a reflectance of 90%, while the bottom half has an absorbtance of 25% and a transmittance of 75%. At the centre of the globe is a 100 cd isotropic lamp.

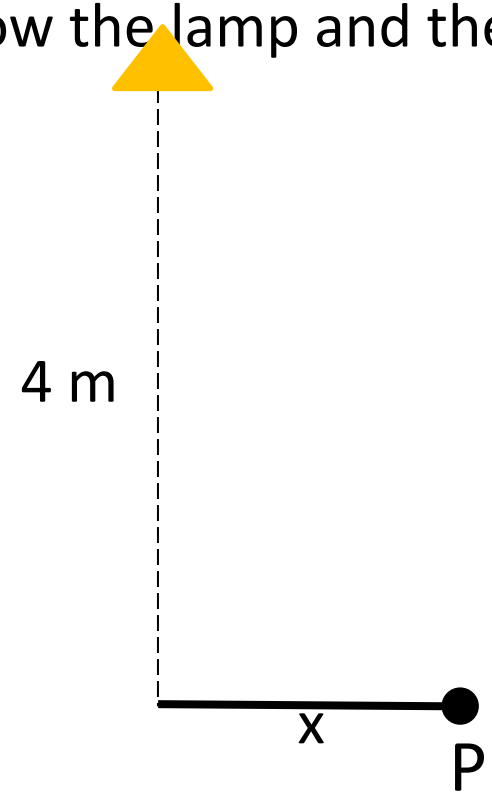
Find:

- E on the inside of the lower hemisphere
- M and L on the outside of the lower hemisphere
- I if the sphere is viewed from far away below it

Example 4 (to be done in tutorial)

For a lamp suspended above a floor of a very big room, the luminous intensity is show in the figure (assume unit is candelas). Determine the location of the highest illuminance (measured as x meters from the point immediately below the lamp and the illuminance magnitude.

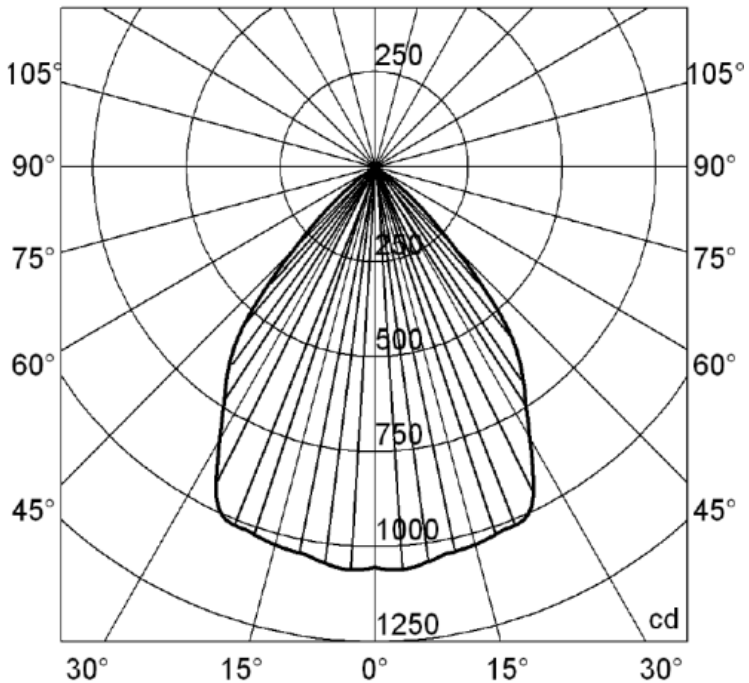


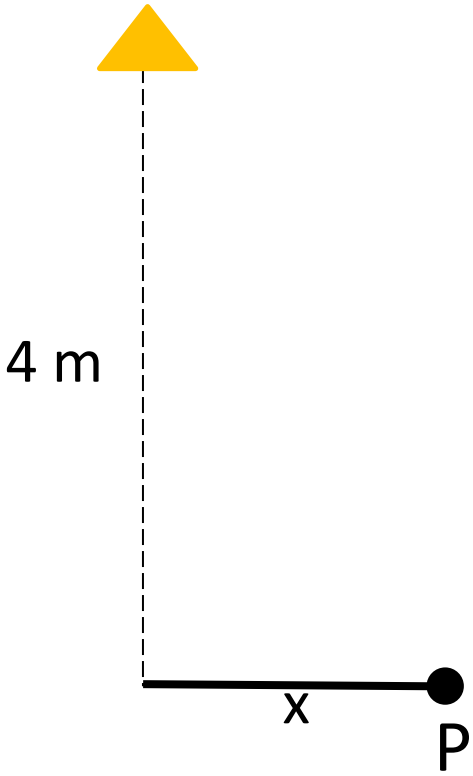


Example 4: solution

The lamp is most intense directly below (as per the diagram, about 1100 cd). In general, the brightest spot will be directly below the lamp because d and beta are minimized here. So x=0.

So, E = 1100 cd/(4m)^2 = 68.8 lux.

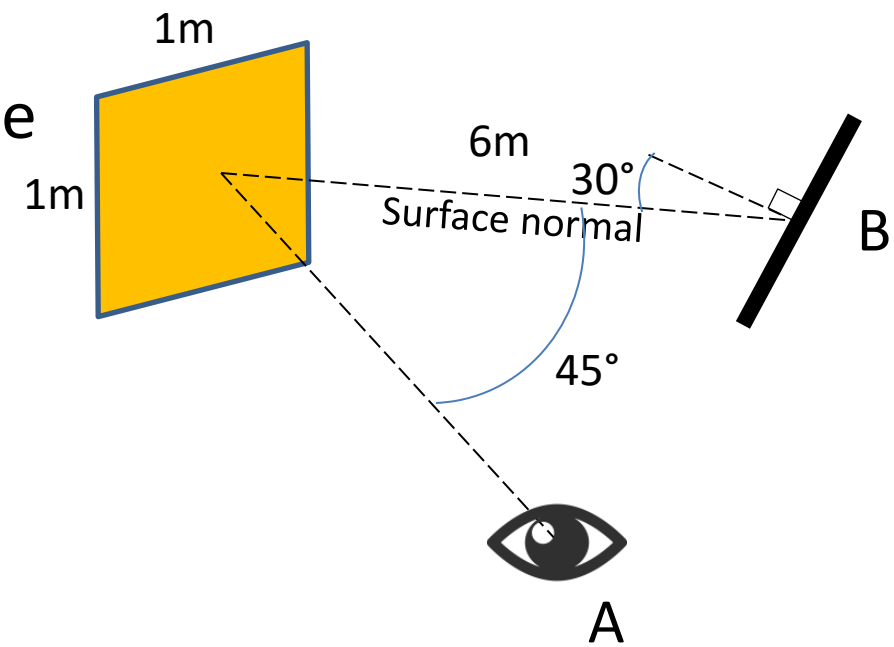




Example 5 (to be done in tutorial)

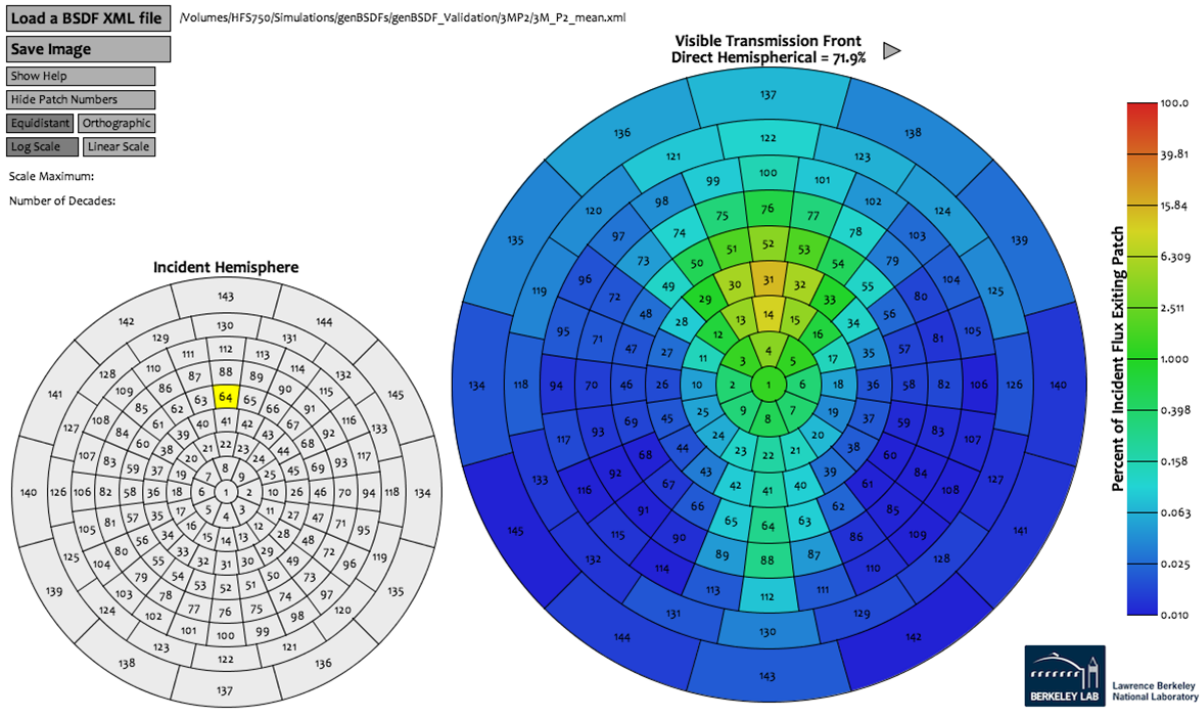
A perfectly diffusing panel for τ=45% is viewed from point A (45 degrees off the surface normal). The luminance of the panel viewed from A is 500 cd/m^2. Find:

a. I (luminous intensity) viewed from A
b. E (illuminance) on the panel's left face
c. ϕ (luminous flux) hitting the (left side) and leaving (right side) the panel
d. E on surface B



Bidirectional Scatter Distribution Function (BSDF)

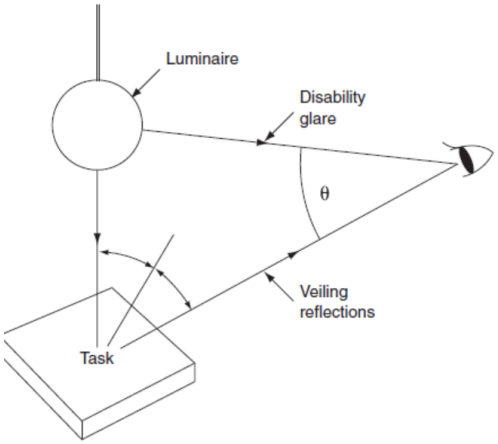
- Non-Lambertian surfaces can be described as BSDFs. These describe transmittance and/or reflectance for any direction of incoming and outgoing light.



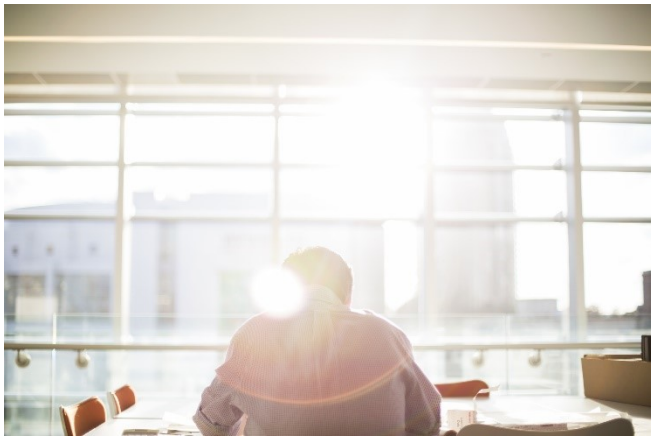
Glare

Glare occurs when luminances (e.g., cd/m^2) is the visual field are significantly higher than the level that the eyes are adapted to.

Types of Glare



- Glare occurs when there is very high contrast between one region of our field of view and others.
- Our eyes have limited ability to adjust to a wide range of luminance levels for a given scene.
- Disability glare: caused by a bright light source in the field of view
- Veiling glare: caused by specular reflections in the main task of a scene

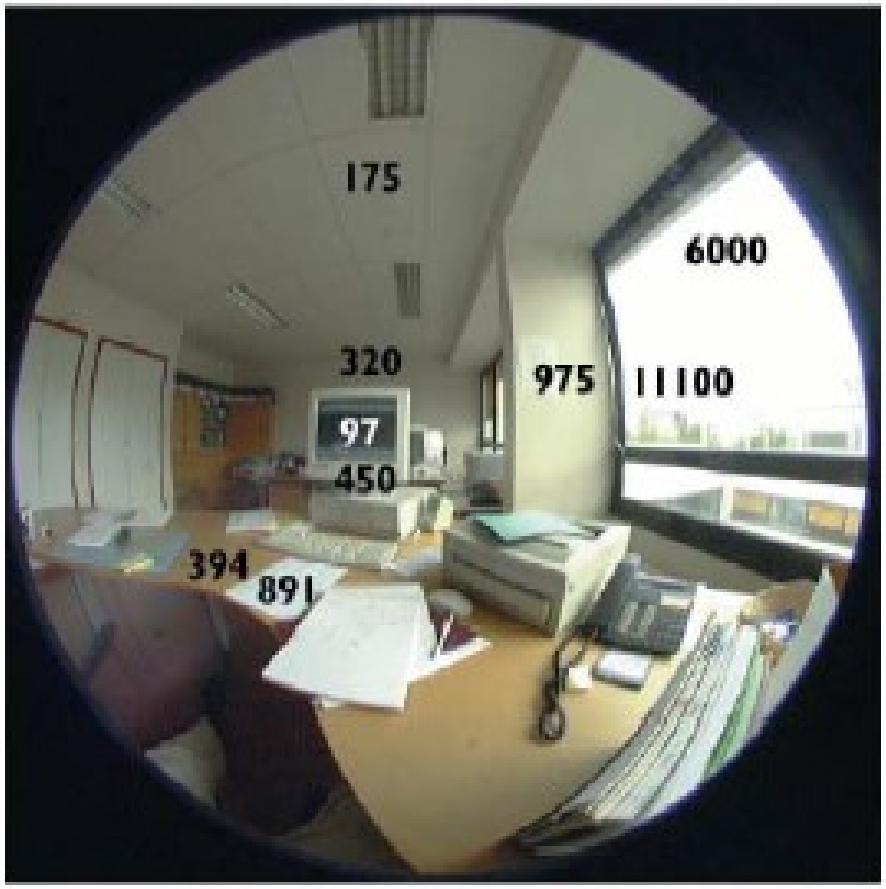


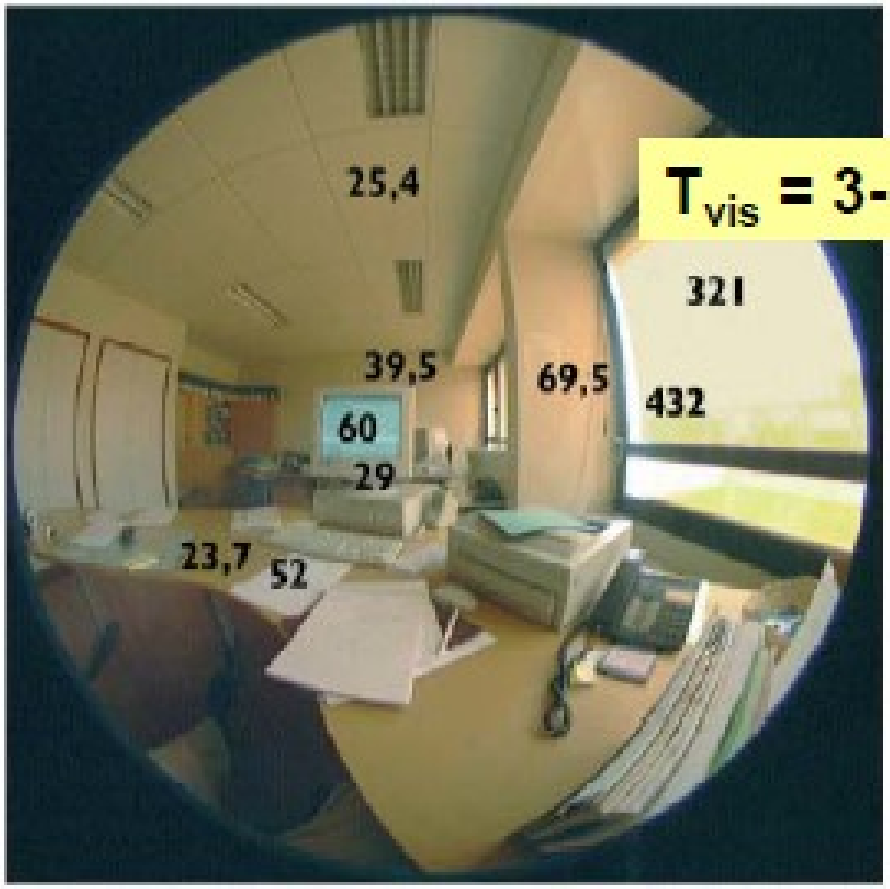
Glare rule of thumb

- Do not exceed luminance ratios of 10:3:1 for

  task: *immediate surroundings* : *remote surroundings*
- Keep maximum luminance below 3000 cd/m^2

Glare

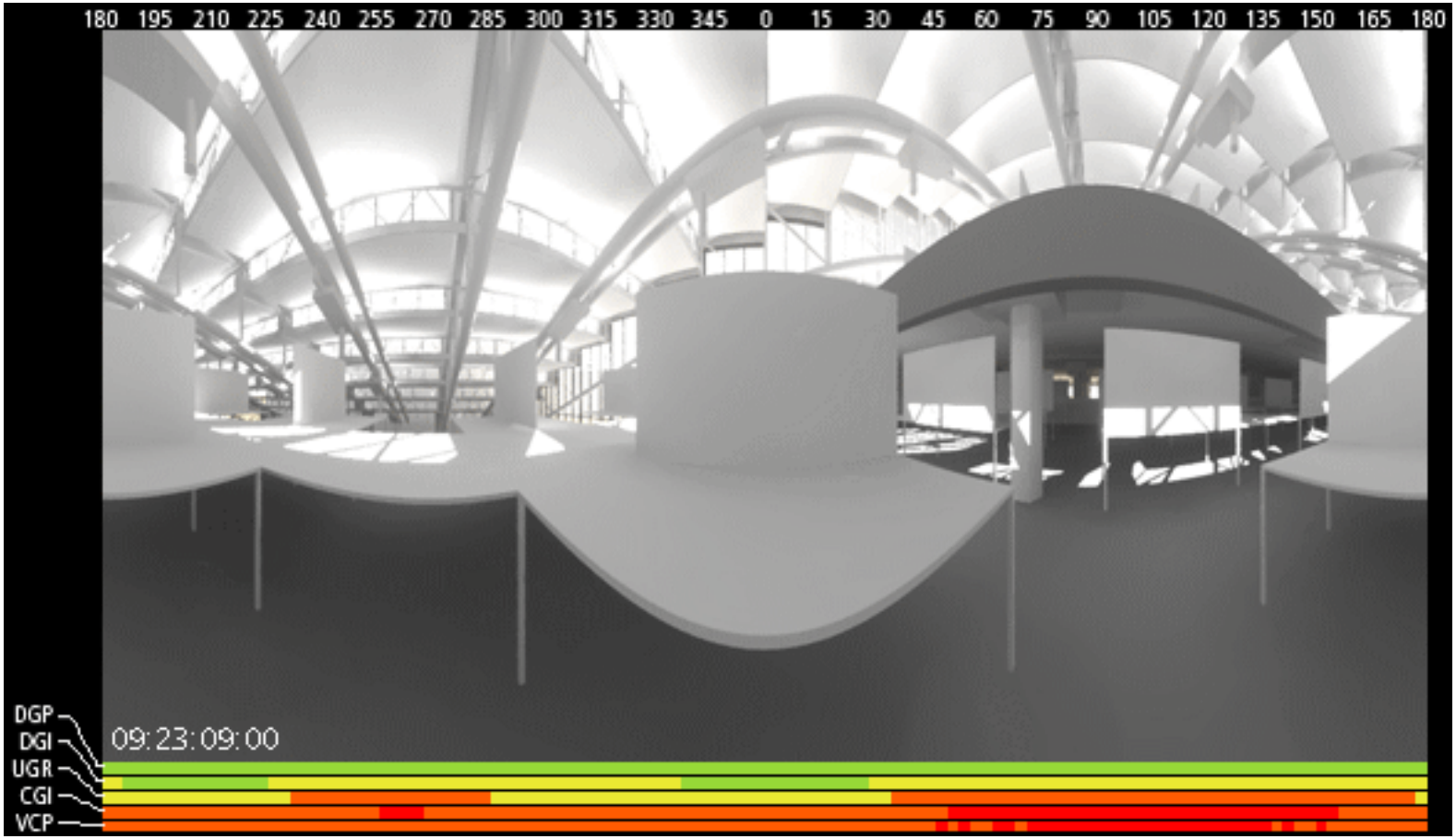

175
6000
320
975
11100
97
450
394
891


25,4
T_{vis} = 3-
321
39,5
69,5
432
60
29
23,7
52

Adaptive Glare

- A flexible workspace provides greater opportunity to avoid glare
- Occupants can rotate or reposition away from glare
- …or can they?

Adaptive Glare



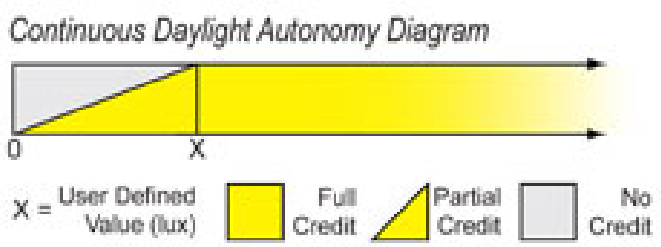
This study showed adaptive glare (use of blinds + flexible seating arrangement) reduced hours with intolerable glare from 735 to 18. (Source: Jakubiec and Reinhart)

“Dynamic” Daylight Metrics

- Daylight autonomy (DA): fraction of occupied hours when daylight, as measured by workplane illuminance (often at centre of room) is adequate (above some illuminance).
- Typical thresholds: 300 or 500 lux
- Technology-independent metric to assess overall annual daylight usefulness
- Most applicable to on/off light controls

“Dynamic” Daylight Metrics

- Continuous daylight autonomy (DA_{cont}): like daylight autonomy but gives credit (linear) to partial daylight availability.
- For example, if full credit requires 500 lux, an hour would 250 lux would receive 50% credit.
- No extra credit for being above threshold.
- DA_{cont} is suitable for daylight-controlled dimmable lighting whereby lights dim if there is some daylight at an inadequate level.



“Dynamic” Daylight Metrics

- Useful Daylight Illuminance (UDI): a measure of fraction of occupied hours when…
  - Daylight is inadequate: $E_{wp} < 100$ lx
  - Daylight is comfortable: 100 lx $< E_{wp} <$ 2000 lx
  - Daylight is likely to cause glare $E_{wp} > 2000$

Daylight metrics example

- Given the following simulated daylight values, find the DA, DA_{cont}, and UDI for the sample data. Assume that the space requires 500 lux (e.g., detailed office work).
- What direction do you think the office faces?

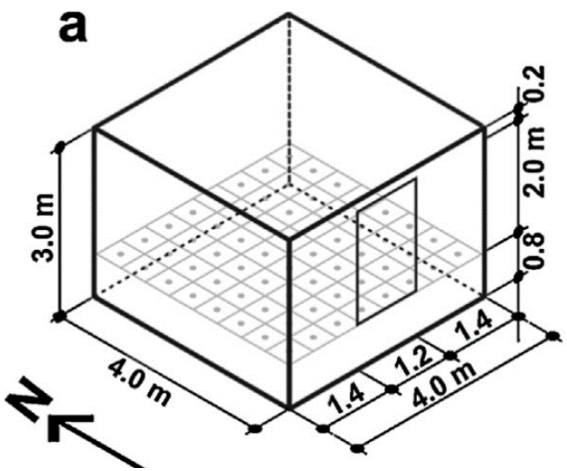
Hour	E_{wp} at centre of room (Lux)
8-9	200
9-10	500
10-11	800
11-12	1200
12-13	3000
13-14	1200
14-15	800
15-16	500
16-17	200
17-18	50

Current daylight metrics: IES LM 83 (referenced by LEED and others)

- DA, DA_{cont}, and UDI are classical dynamic daylight variables, but have some limitations.
  - They don't really consider daylight distribution
  - They nominally assume blinds open.
- Two newer metrics:
  - sDA: Spatial Daylight Autonomy
  - ASE: Annual Sunlight Exposure
- These metrics require more detailed simulation (fairly fine grid of daylight illuminance analysis points) and the ability to "turn off" diffuse daylight and bounces.

Spatial Daylight Autonomy (sDA)

- The fraction of analysis points (grid on workplane), from 8AM to 6PM, that meet or exceed 300 lx.
- $sDA_{300/50\%}$: percent of analysis points that achieve 300 lux for 50% of analysis period (nominally a year).
- Analysis points make up a 0.6 m (2 ft) or finer square grid
- Blinds are closed whenever five analysis points exceed 1000 lux; they reopen immediately after



Spatial Daylight Autonomy (sDA)

- The fraction of analysis points (grid on workplane), from 8AM to 6PM, that meet or exceed 300 lx.
- $sDA_{300/50\%}$: percent of analysis points that achieve 300 lux for 50% of analysis period (nominally a year).
- Analysis points make up a 0.6 m (2 ft) or finer square grid
- Blinds are closed whenever five analysis (10% of) points exceed 1000 lux; they reopen immediately after

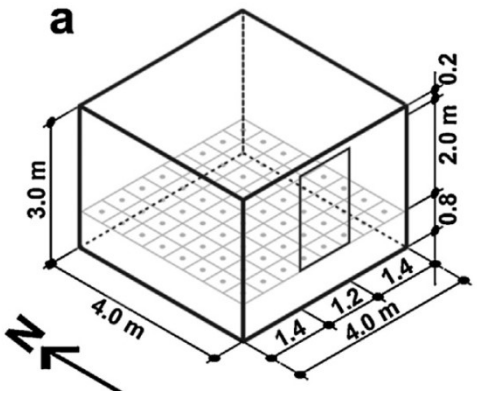
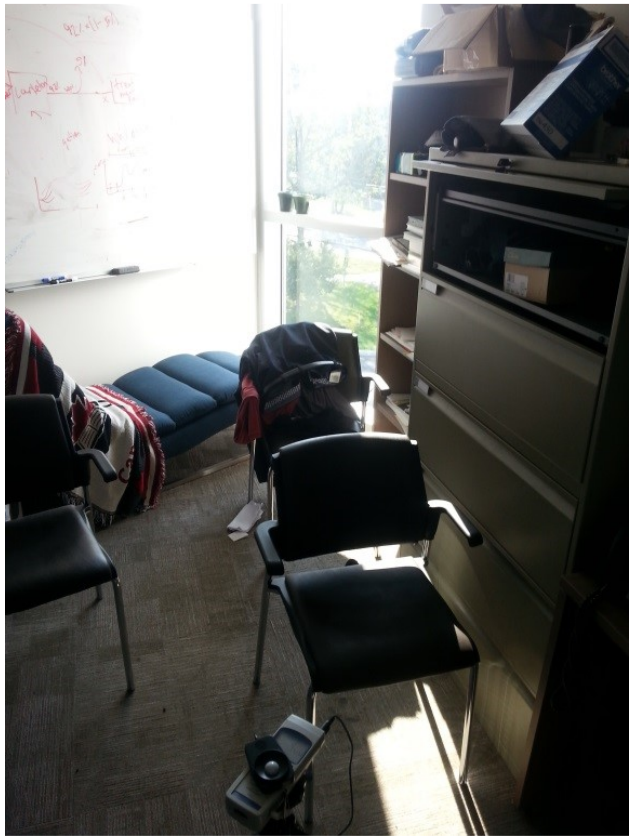


Table 1. Points for daylit floor area: Spatial daylight autonomy

NC, CS, Schools, Retail, Data Centers, Warehouses & Distribution Centers, Hospitality		*Healthcare*	
sDA (for regularly occupied floor area)	*Points*	*sDA (for perimeter floor area)*	*Points*
55%	2	75%	1
75%	3	90%	2

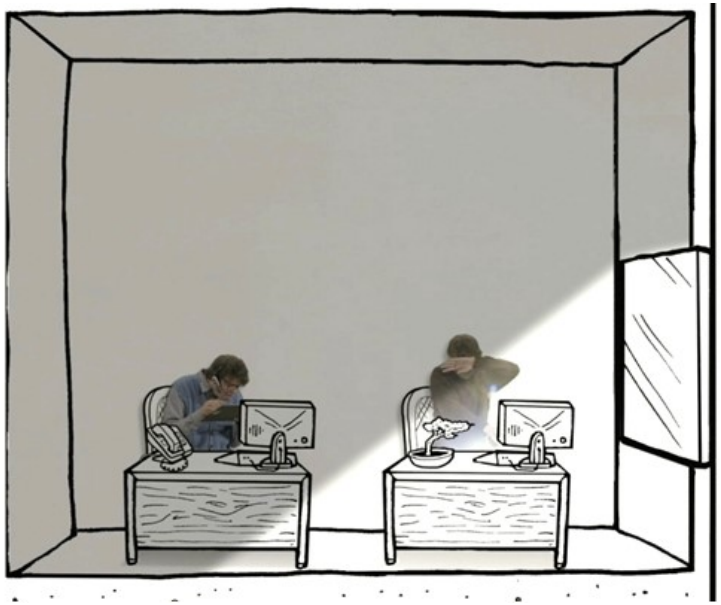
Annual Sunlight Exposure (ASE)

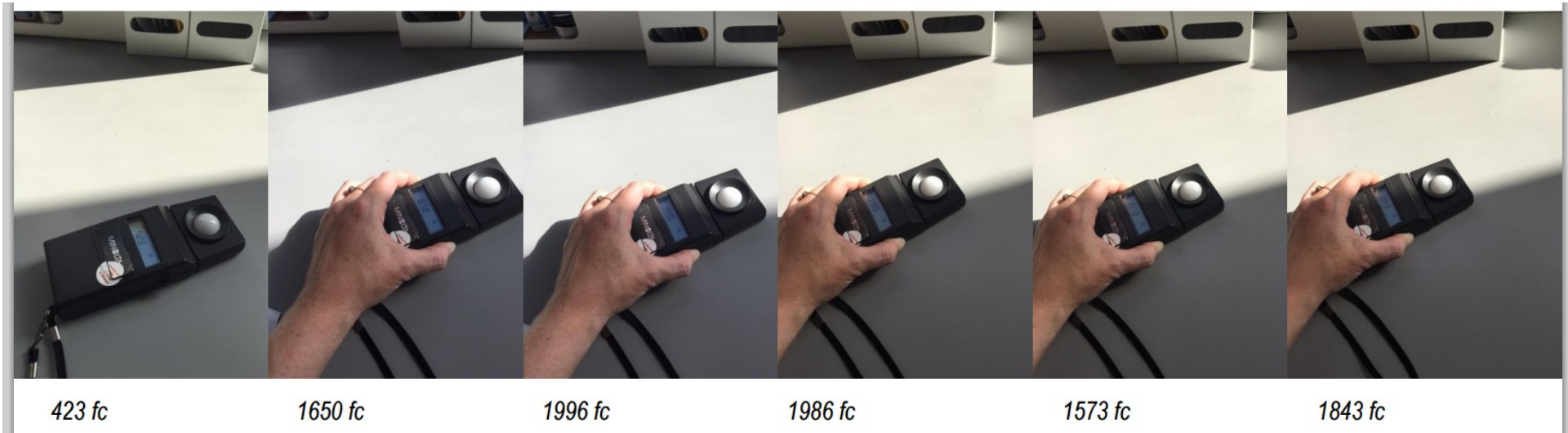
- Fraction of analysis points that exceed the direct sunlight illuminance level for more than a specified number of hours.
- IES LM 83 uses 1000 lx and 250 hours
- $ASE_{1000,250h}$ is the fraction of analysis points that receive more than 1000 lux of <u>direct</u> sunlight for more than 250 hours per year.
- No blinds for ASE simulation



Quantifying daylight glare

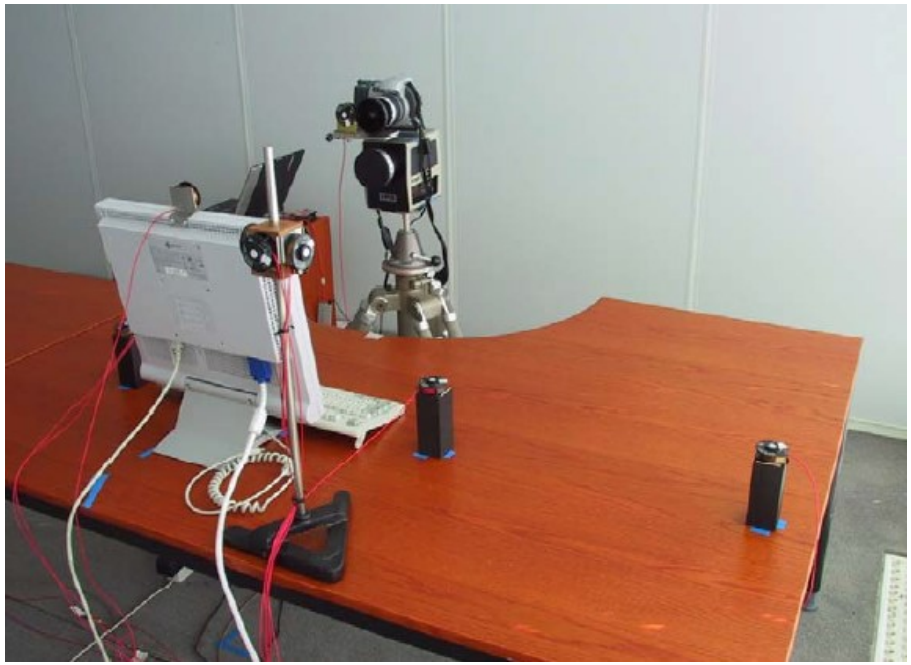
- Over the decades, at least 6-8 glare metrics have been developed that are based on luminance distribution in the field of view.



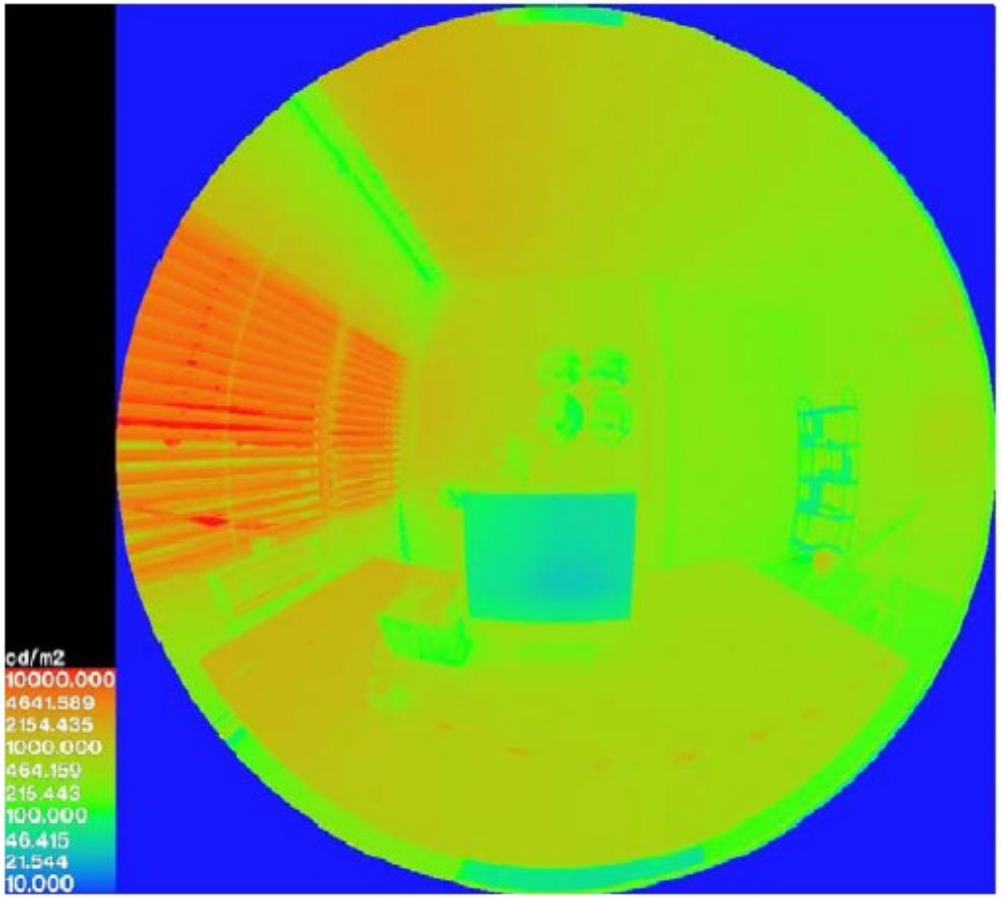


Daylight Glare Probability (DGP)

- DGP was developed in about 2005 by Jan Wienold of the Fraunhofer Institute for Solar Energy Systems.
- It is based on measurements and subjective evaluations of 70 people.



Sample DGP measurement



Daylight glare probability

$$DGP = 5.87 \times 10^{-5} E_v + 9.18\, log_{10}\left(1 + \sum_{i=1}^{n} \frac{(L_{si})^2 \omega_{si}}{\left(E_v\right)^{1.87} (P_i)^2}\right) + 0.16$$

Where,

E_v is the vertical illuminance at the eye (lux)

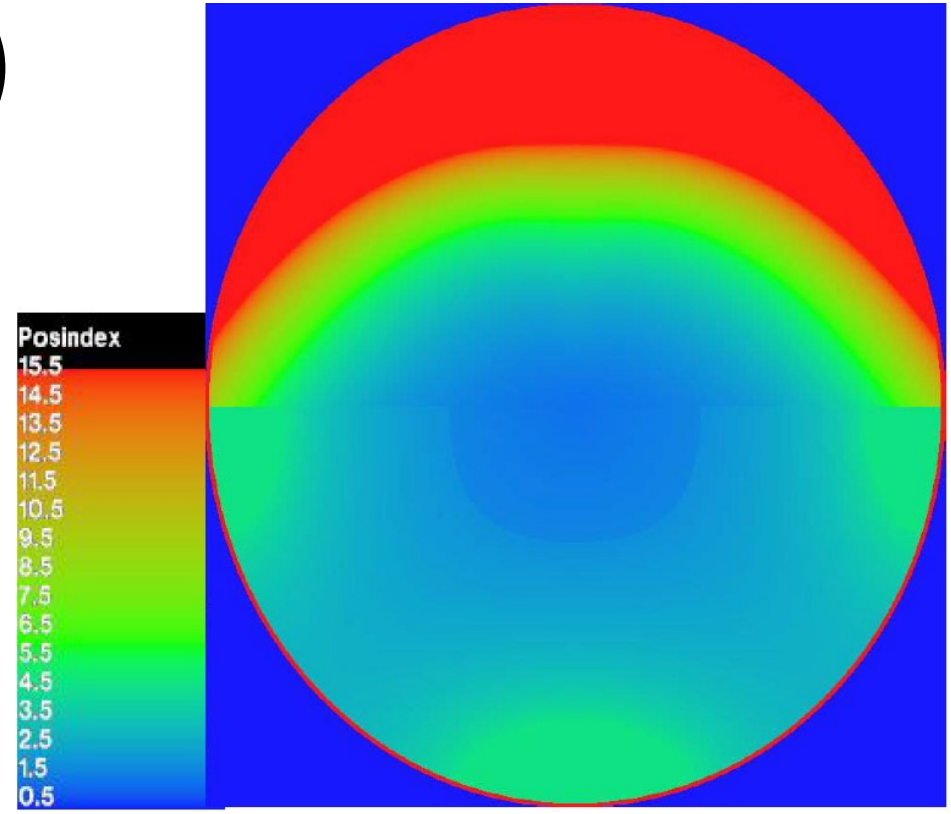
L_{si} is the luminance of surface *i* (cd/m^2)

ω_{si} is the solid angle of surface *i (steradians)*

P_i is the position index of the surface relative to the eyes

Position index (P_i)

- The position index accounts for the direction-dependent sensitivity of the human eye.
- Note that glare depends on $1/P_i$, so high values of P_i mean lower sensitivity.



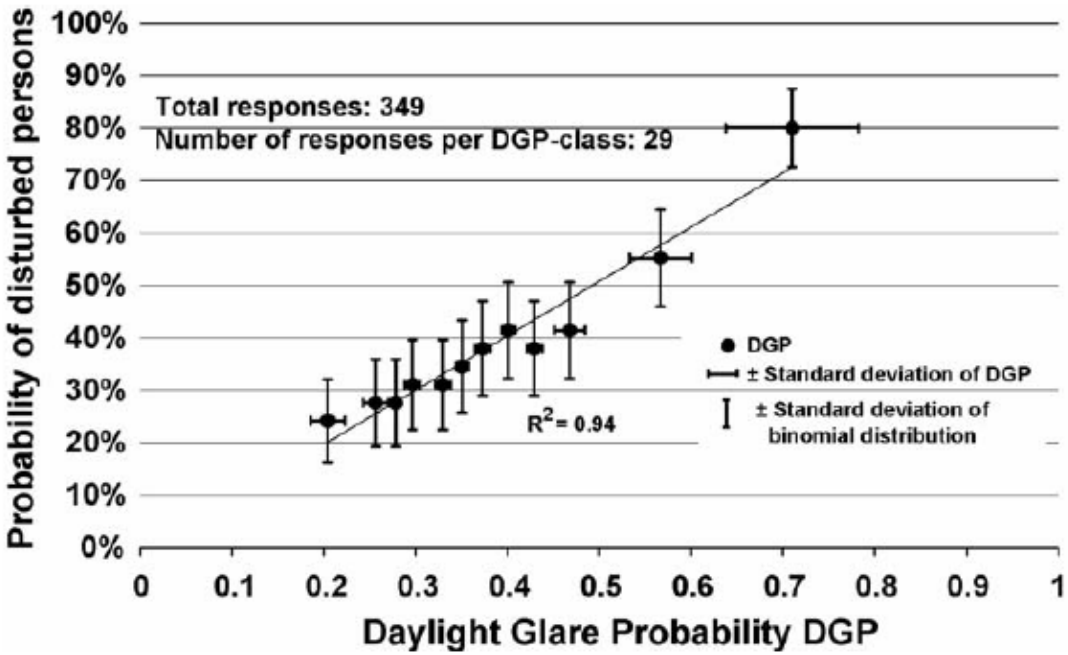
$$P = 1 + 0.8 * R / D \qquad \{R < 0.6D\}$$
$$P = 1 + 1.2 * R / D \qquad \{R >= 0.6D\}$$

$$R = \sqrt{H^2 + Y^2}$$

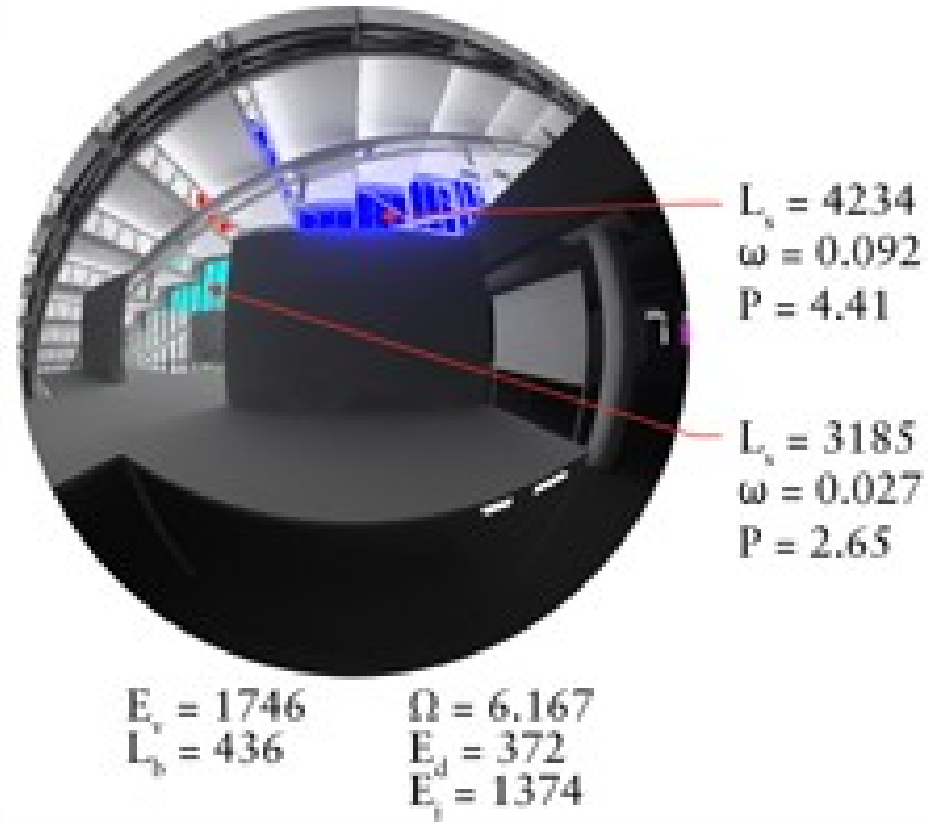
D : distance eye - to plane of source in view direction
H : Vertical distance between source and view direction
Y : Horizontal distance between source and view direction

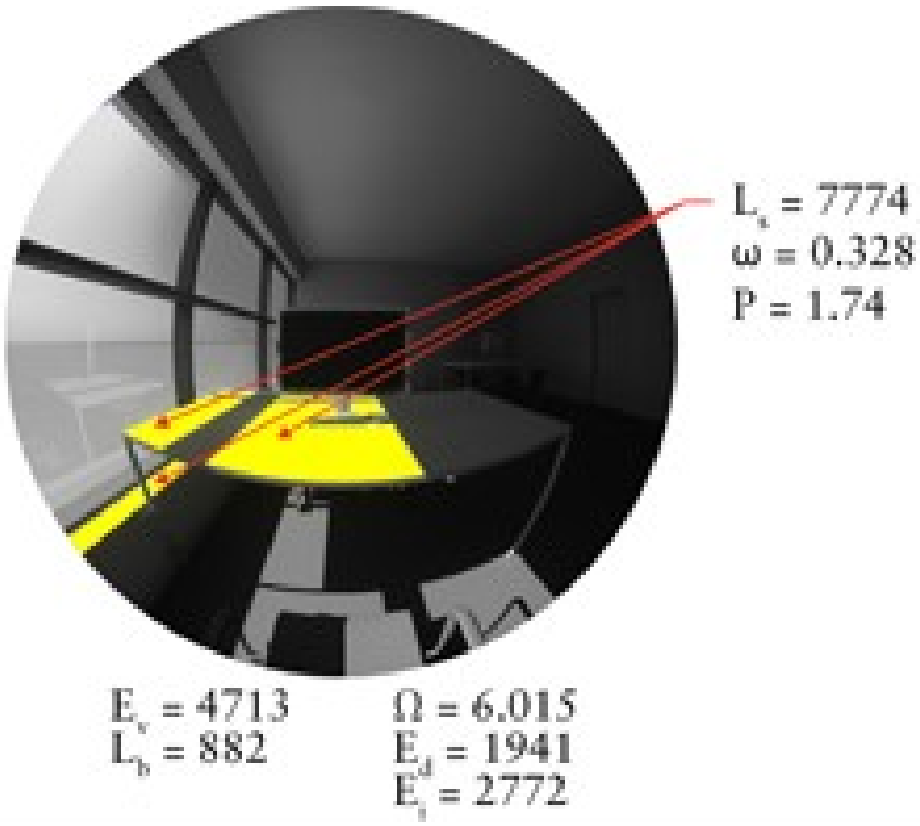
Meaning of DGP values

- Imperceptible glare: DGP < 0.35
- Perceptible glare: 0.35 > DGP > 0.4
- Disturbing glare: 0.4 > DGP > 0.45
- Intolerable glare: DGP > 0.45



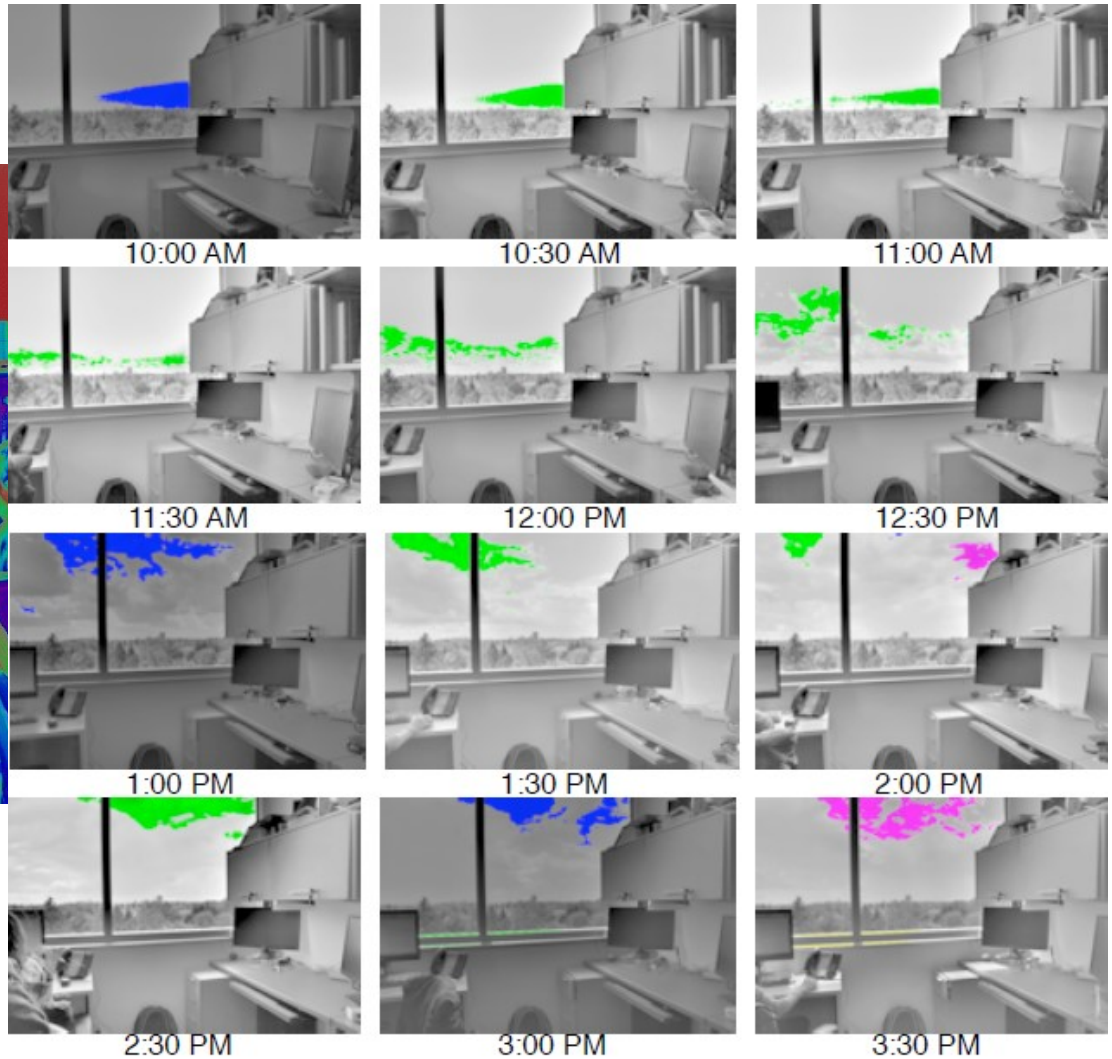
DGP calculation examples





Glare in west-facing Canal Building

Courtesy of Brent Huchuk



DGP pros and cons

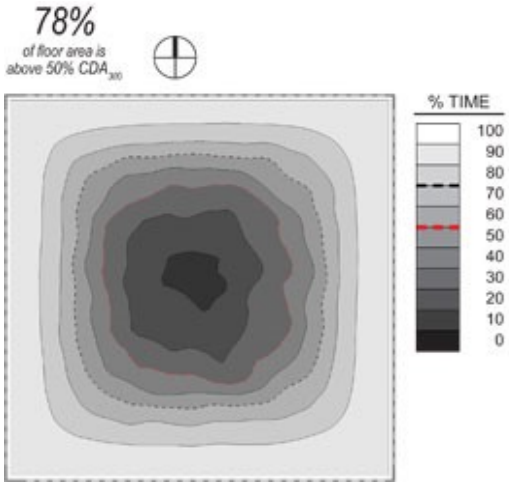
Pros

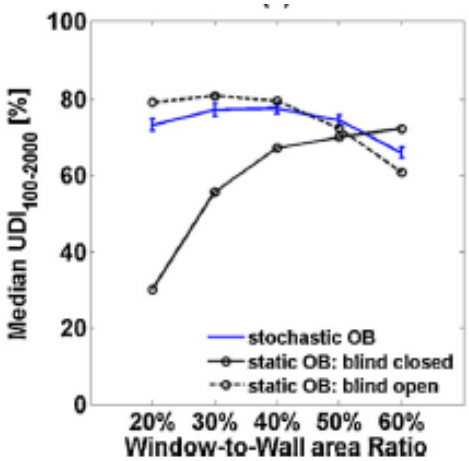
- Better indicator of glare than workplane illuminance (as determined from measurements and subjective responses)
- Considers effect of luminance distribution (vs. simpler metrics like workplane illuminance

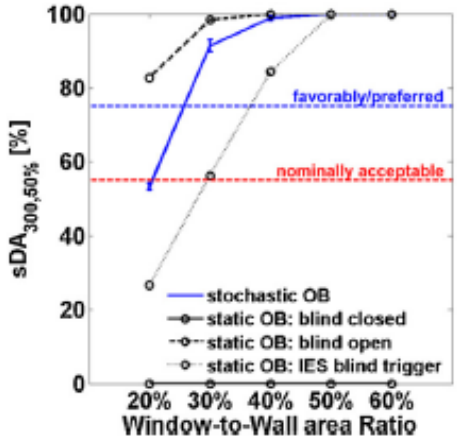
Cons

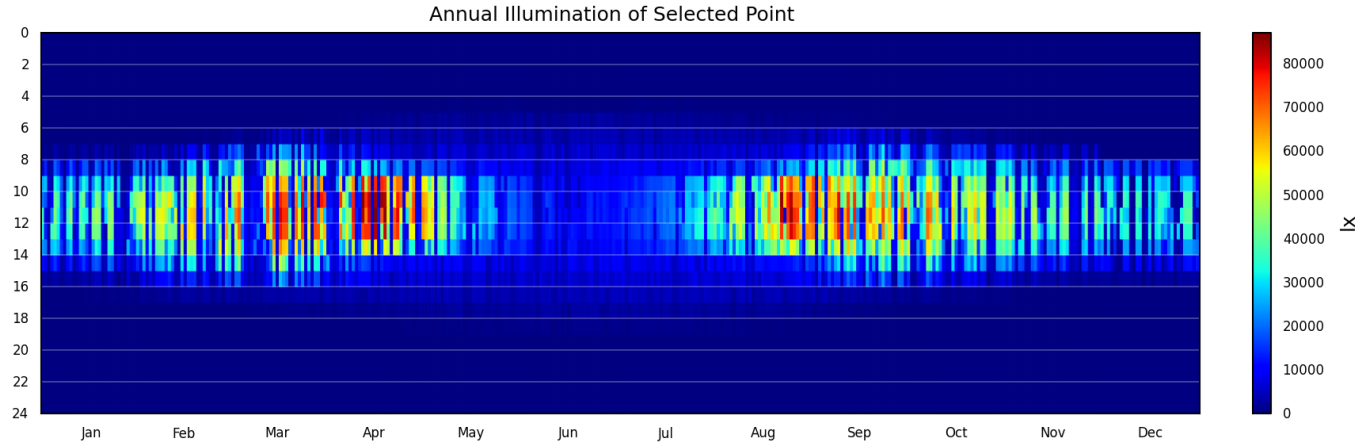
- Requires knowledge of occupant position and orientation
- Relatively expensive and time-consuming to measure

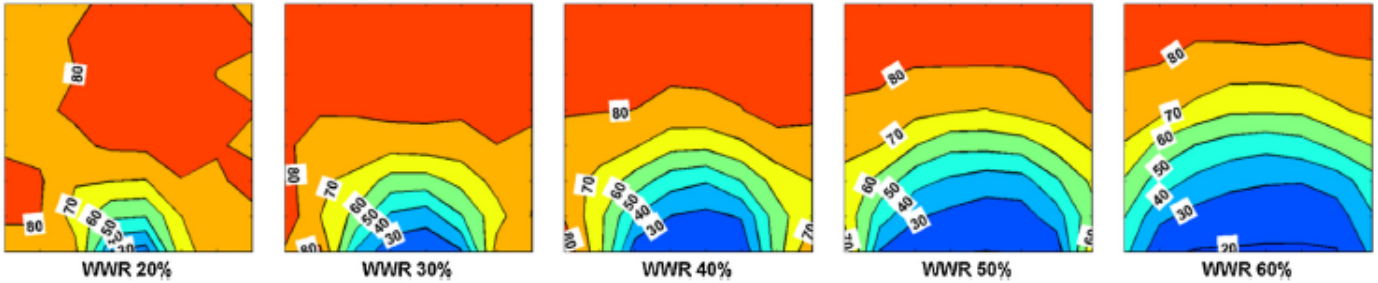
Presenting metrics



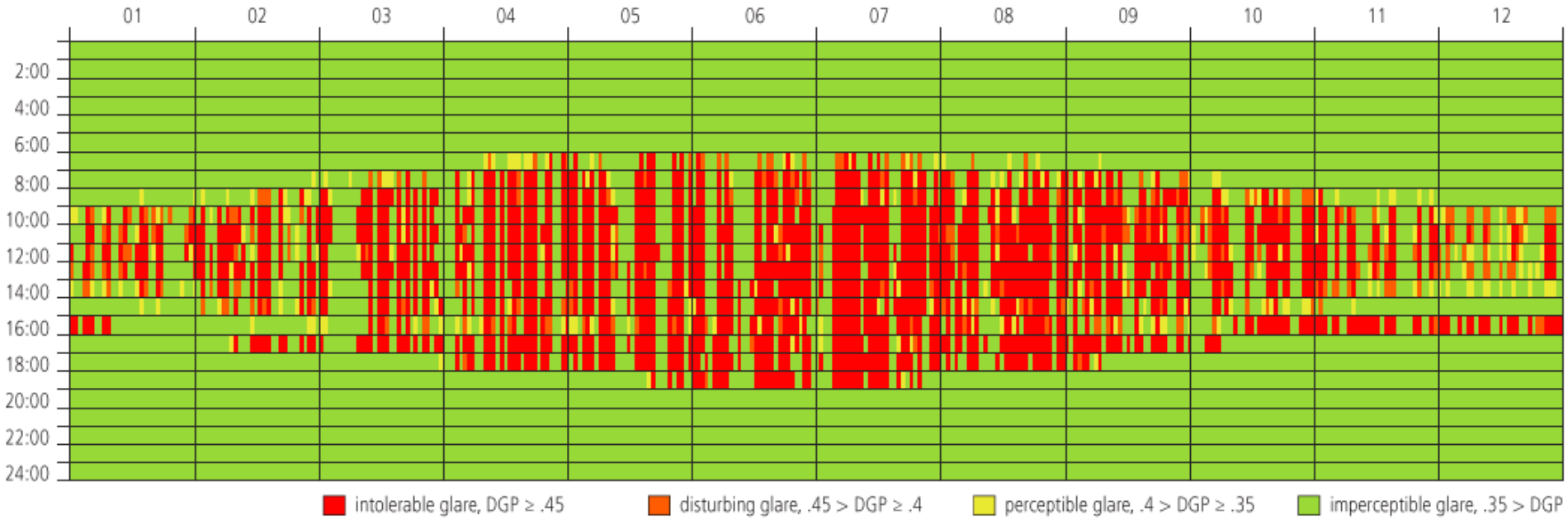






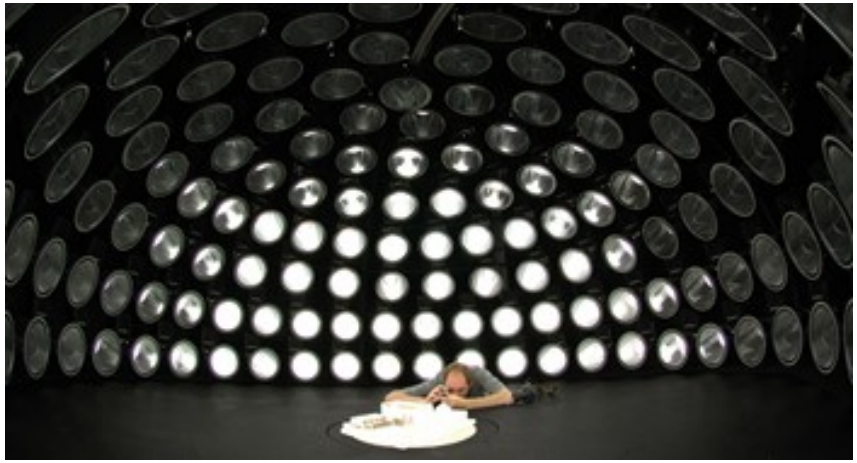


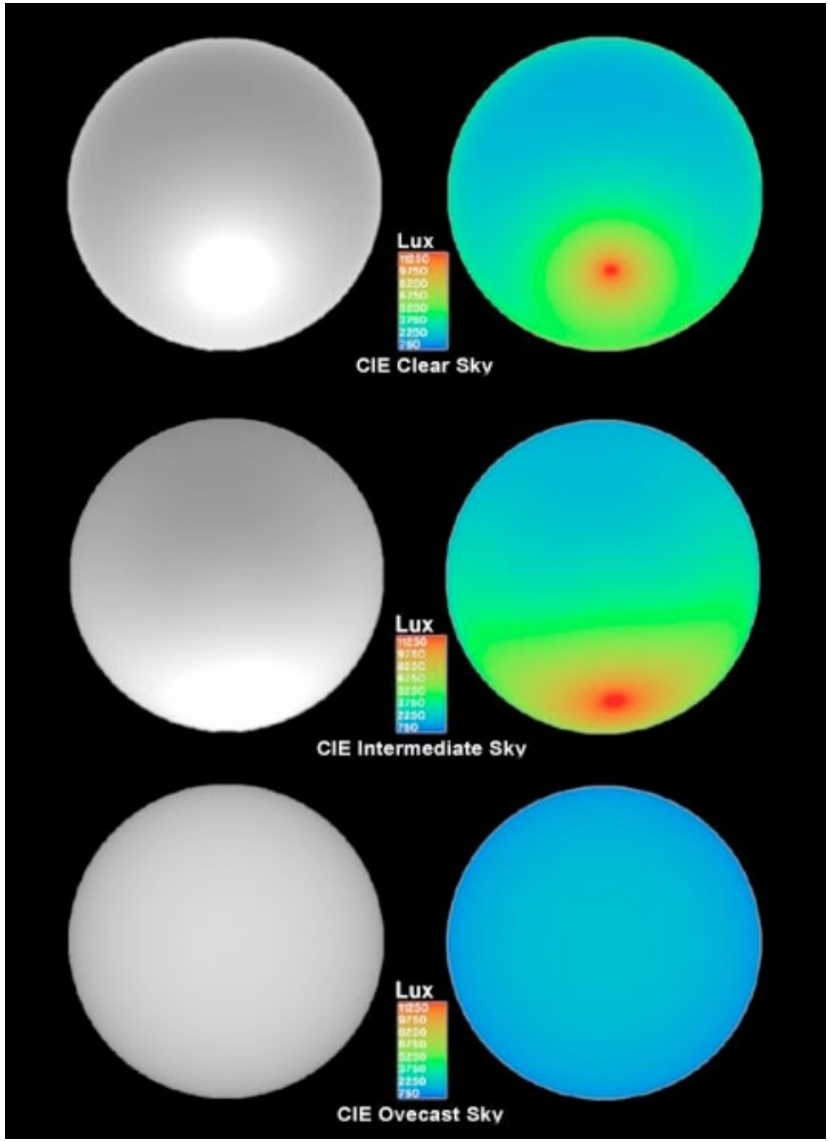
Presenting annual DGP
(source: Reinhart)



Sky modelling

Commission International de l'Eclairage (CIE) established different sky types for modelling daylight

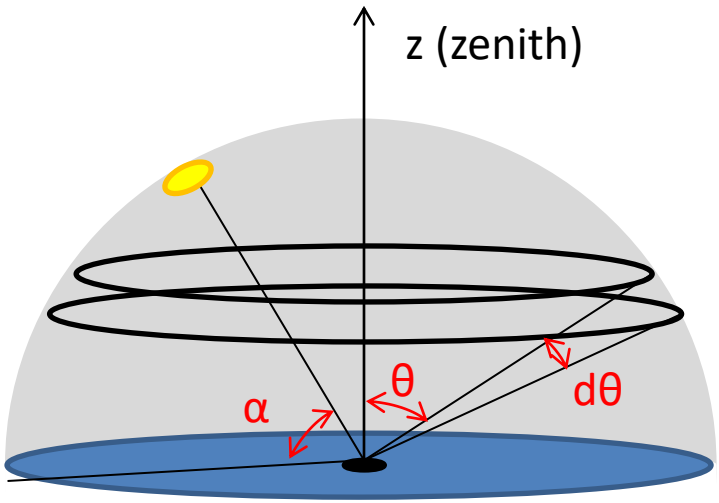




Sky modelling: overcast

- An overcast sky is assumed to have axially symmetrical luminance about Zenith (directly up above the ground).
- Luminance at a given angle θ is modelled as:

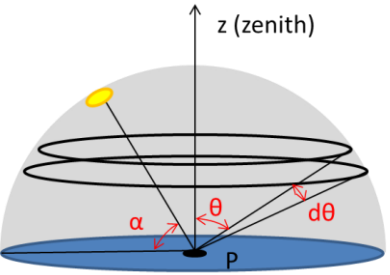
$$L_\theta = \frac{L_z}{3}(1 + 2\cos\theta)$$



CIE Overcast sky:

$L_z = 123 + 8600\sin\alpha$ cd/m^2

α is solar altitude



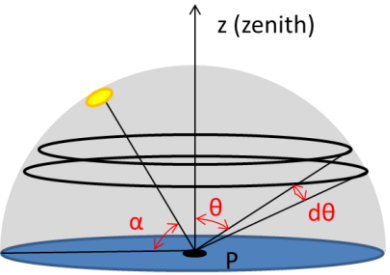
Integrating overcast sky

- To find the contribution of part or all of the sky to the illuminance on the ground, we need to integrate over the entire sky dome.

$dE_{ho} = L\cos\theta d\omega$ …horizontal illuminance at point P from the ring an overcast sky

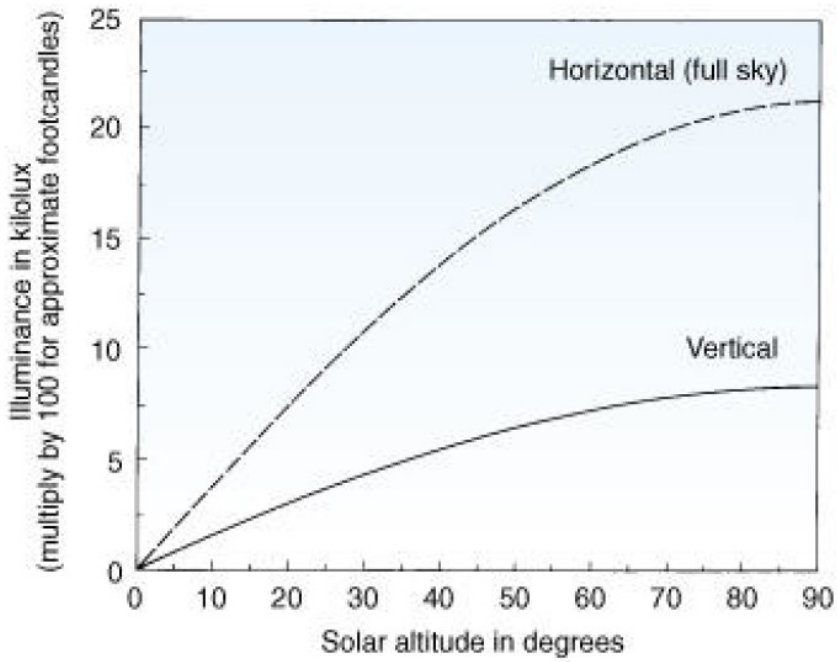
$d\omega = 2\pi\sin\theta d\theta$ …solid angle of ring

- Total illuminance can be calculated by double integrating for a range of θ and azimuth ϕ



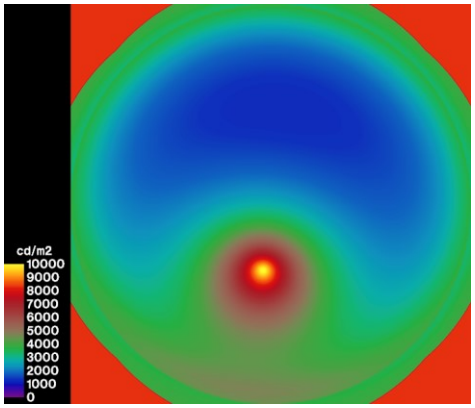
Integrating overcast sky

Integrating over the entire overcast sky dome results in: $E_{ho} = 300 + 21{,}000 \sin\alpha$ lx

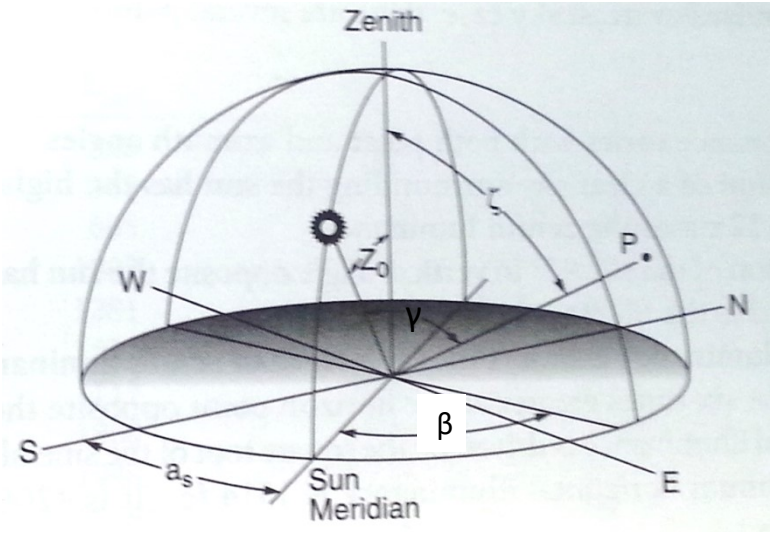


Sky modelling: clear sky

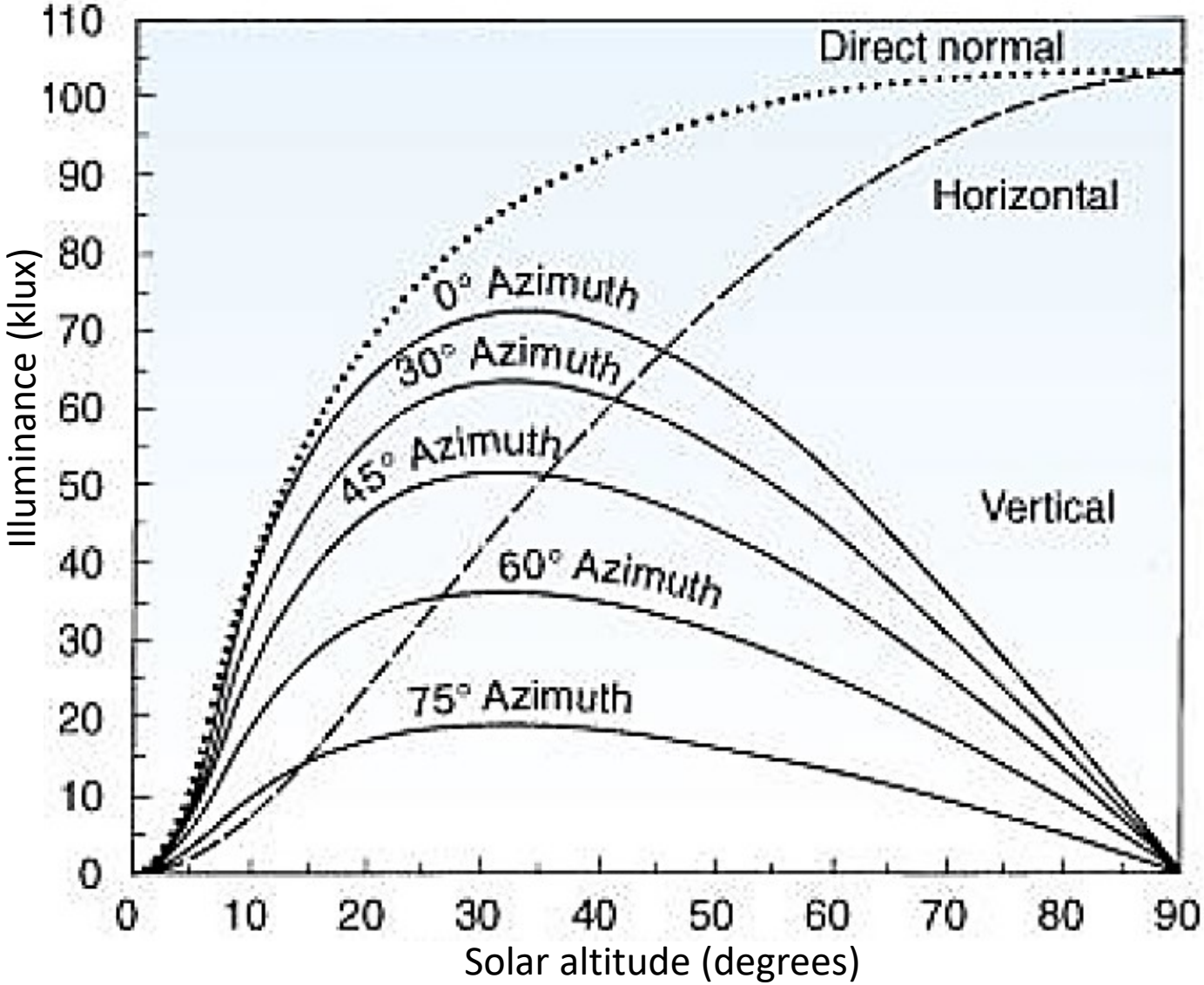
$$L = 3.650 L_z \frac{(0.91 + 10e^{-3\gamma} + 0.45\cos^2\gamma)\left(1 - e^{-0.32\sec(\varsigma)}\right)}{0.91 + 10e^{-z_o} + 0.45\cos^2 Z_o}$$



- *L* is the sky luminance at a given point P in the sky dome
- L_z is the luminance at zenith (directly up); see lookup table
- *γ* is the angle between the sun-observer line and the observer-P line
- *ς* is the angle between zenith and the observer-P line
- *β* is the azimuth angle between the horizontal projections of the solar azimuth and point P
- Z_o = π/2 minus the solar altitude
- $\cos\gamma = \cos Z_o \cos\varsigma + \sin Z_o \sin\varsigma \cos\alpha$



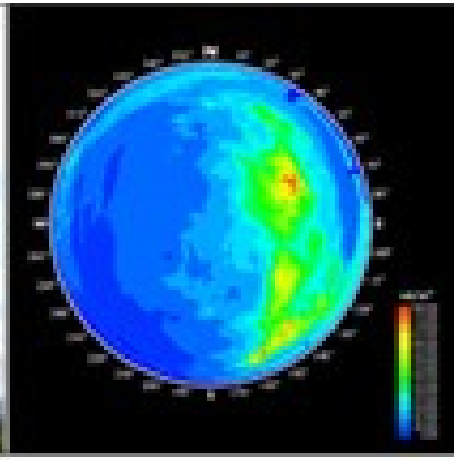
Clear sky illuminance



Sky modelling: partly cloudy sky

$$L = 1.816 L_z \frac{(0.526 + 5e^{-1.5\gamma})\left(1 - e^{-0.80\sec(\varsigma)}\right)}{0.526 + 5e^{-1.5 z_o}}$$

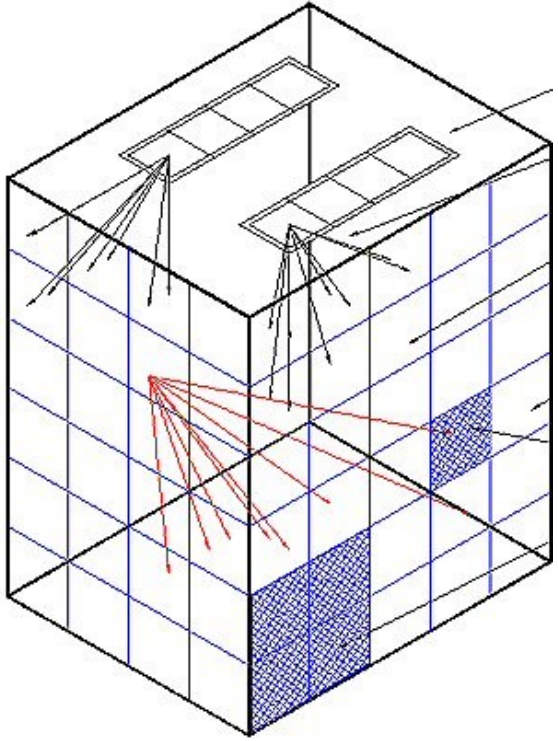
- L is the sky luminance at a given point P in the sky dome
- L_z is the luminance at zenith (directly up); ; see lookup table
- γ is the angle between the sun-observer line and the observer-P line
- ς is the angle between zenith and the observer-P line
- Z_o = π/2 minus the solar altitude
- $\cos\gamma = \cos Z_o \cos\varsigma + \sin Z_o \sin\varsigma \cos\alpha$



Lighting and daylighting modelling and tools

- Basic calculations are still performed but have major limitations with regards to accuracy and visualization
- Two main methods used by software tools:
  - Raytracing (backwards or forwards)
  - Radiosity
- Most daylight modelling originates from computer graphics and video games.

Radiosity



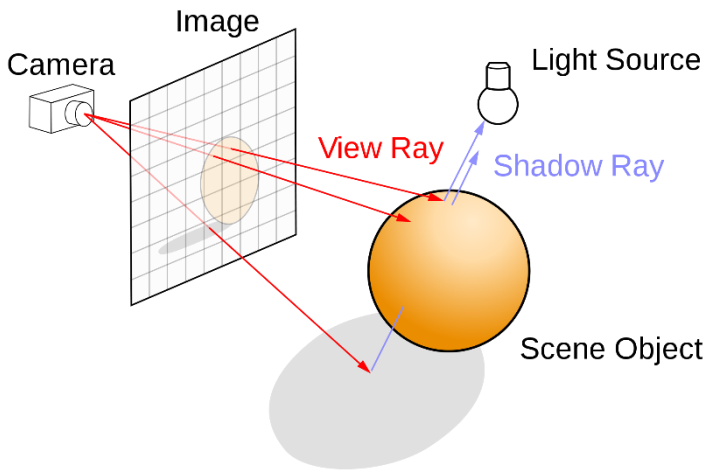
- Space is discretized into mesh for surfaces
- Surfaces are assumed to be Lambertian (perfectly diffuse)
- View factors are calculated for all pairs of surfaces
- A metric system is setup whereby:

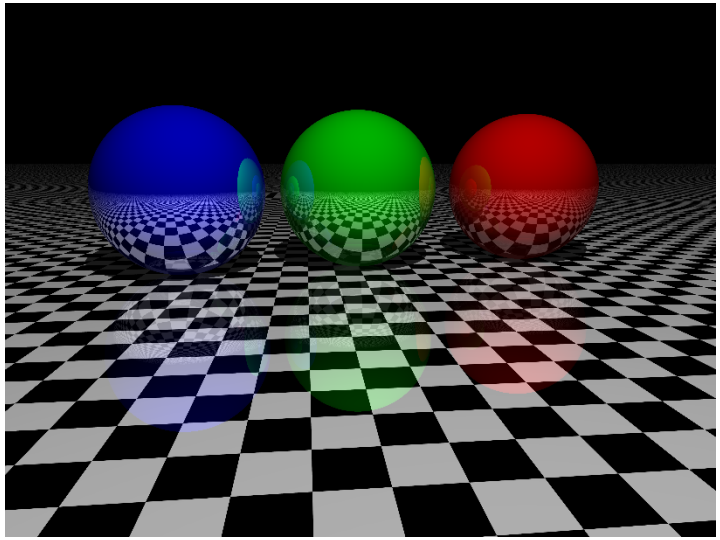
$$M_i = E_i + \rho \sum_{j=1}^{n} F_{ij} B_j$$

- Limited to diffuse surfaces; spaces tend to look very flat.

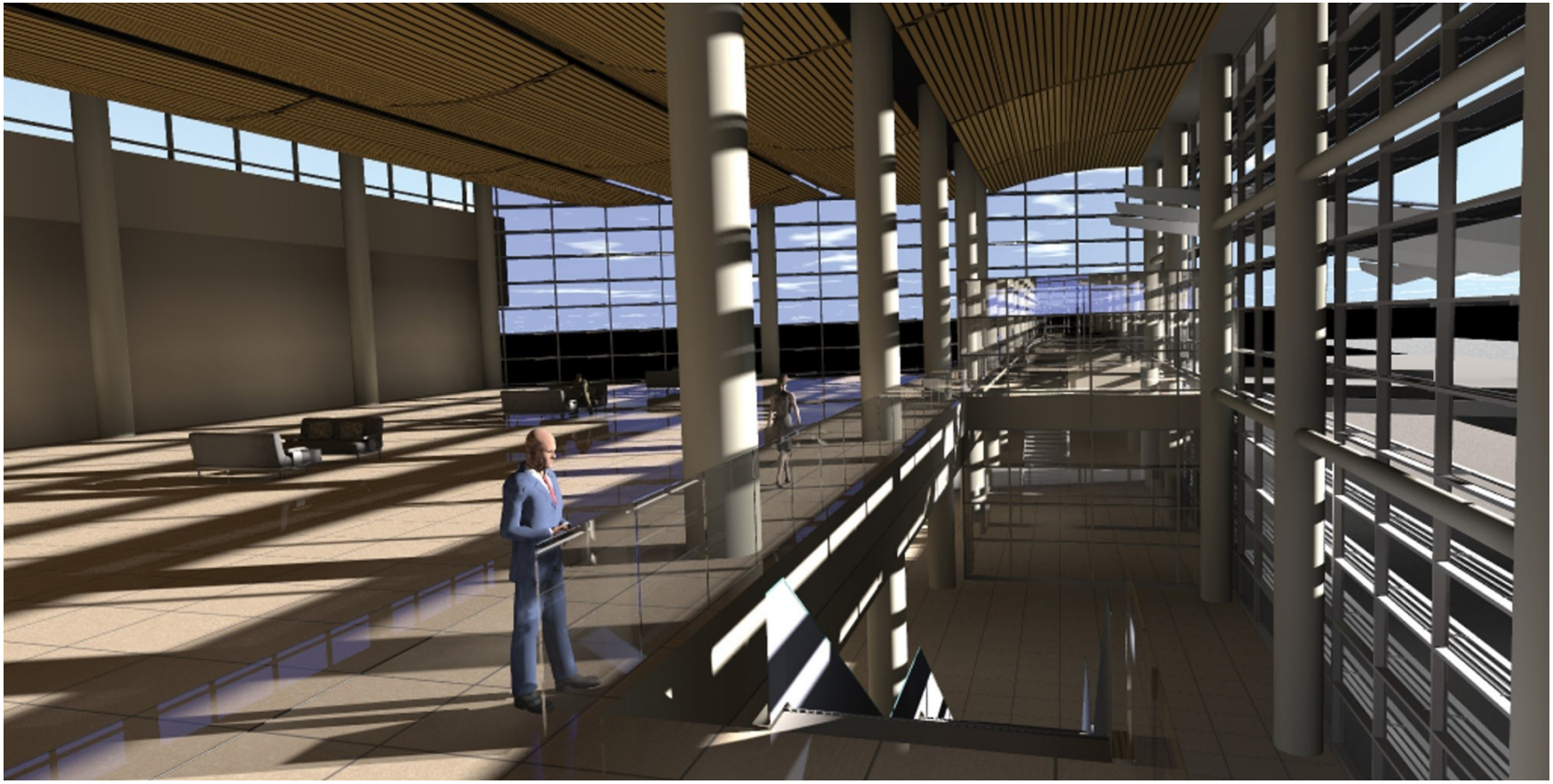
Raytracing

- Rays of light, are followed from light source for some specified number of bounces
- Surfaces can be diffuse or specular
- Backwards raytracing follows light form the analysis point (sensor) to the light source (if any). It's more efficient for when there are only a few analysis points.

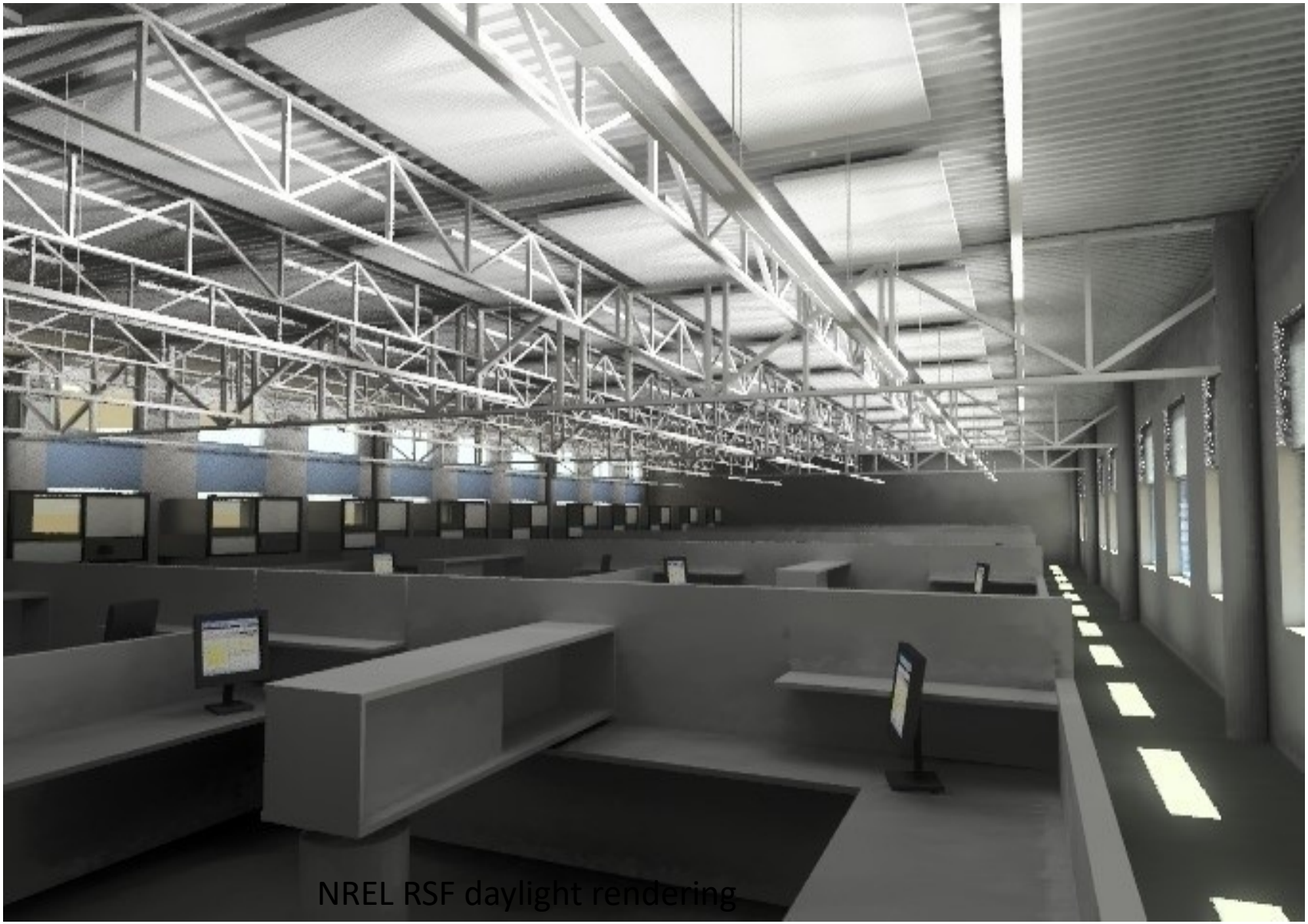




Lighting and daylighting tools: raytracing

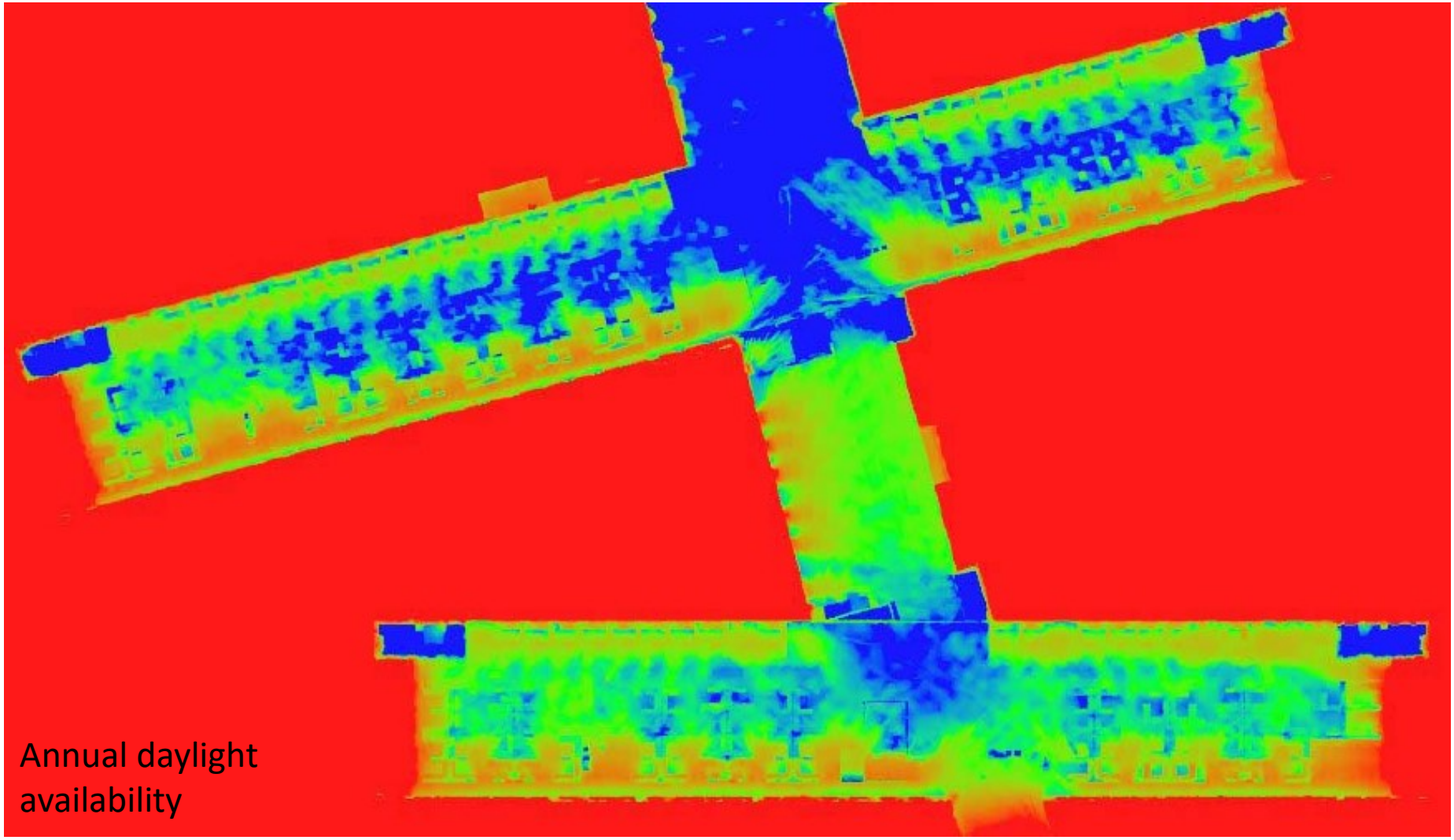


Daylight Simulation

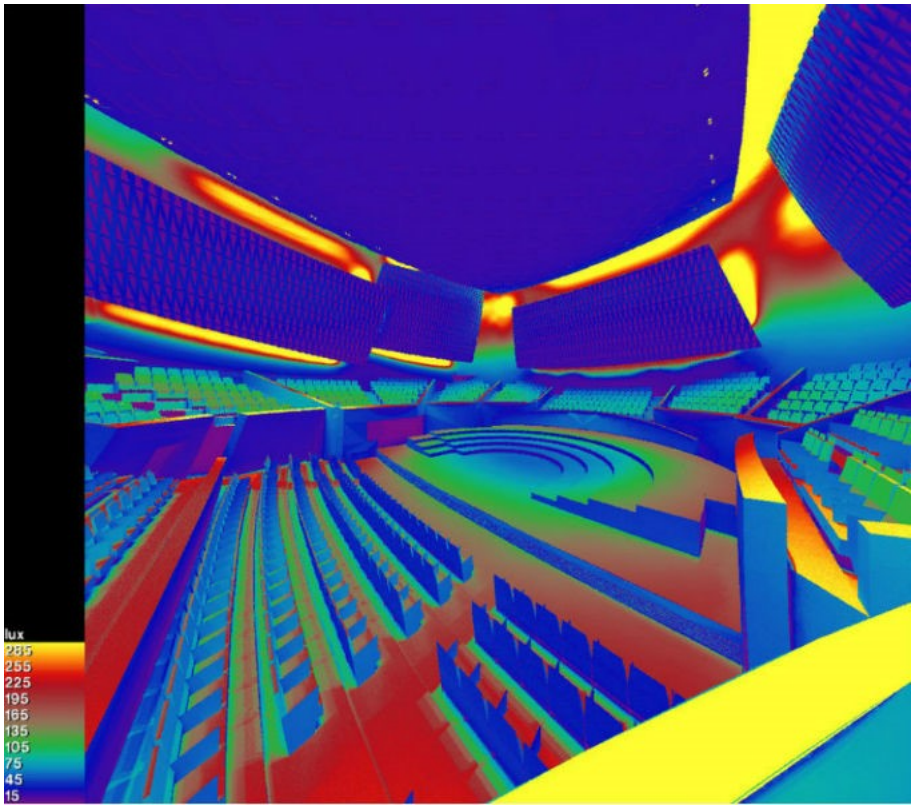


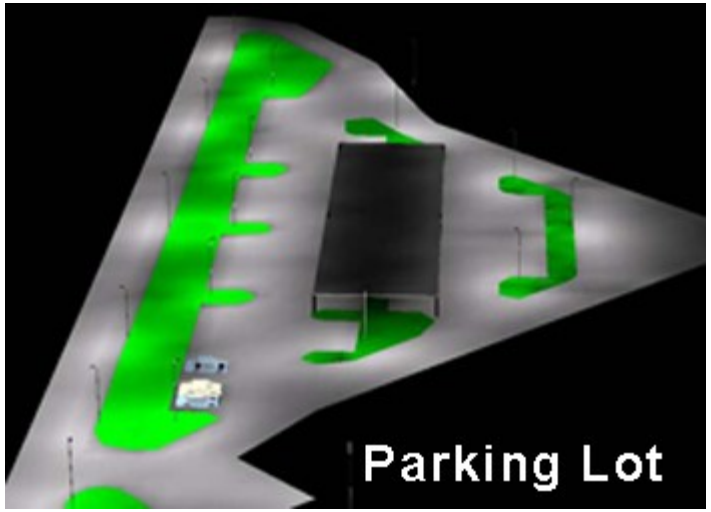
NREL RSF daylight rendering

Daylight Simulation



Lighting Simulation



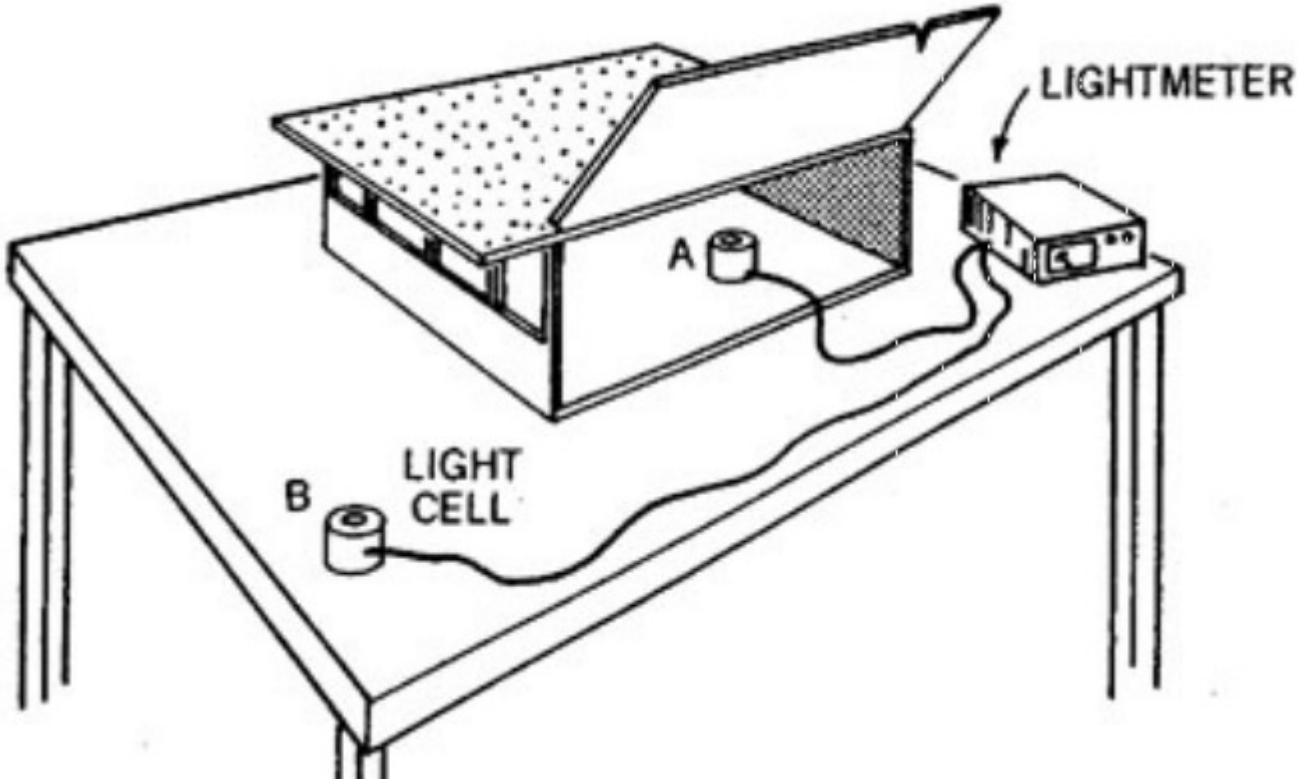


Some good tools

- Daysim (daylight only)
- Diva for Rhino – uses DAYSIM engine and Rhino
- SPOT (free; limited to rectangular rooms)
- Radiance (very advanced but flexible; basis of most daylight simulation tools
- AGI32 (CAD-like and easy to use but not as powerful)
- DIALux
- Lots more here: https://www.buildingenergysoftwaretools.com/software-listing?keywords=&field_catagory_tid%5B%5D=27&field_platform_tid=All&field_price_tid=All&field_last_updated_value%5Bvalue%5D%5Byear%5D=2010&field_language_tid=All&keys=&buildingtype=&sort_by=field_rating_rating&sort_order=DESC&items_per_page=40

Scaled daylight models and heliodons

Scaled daylight models



3C - Visual Comfort and Design

Liam O’Brien

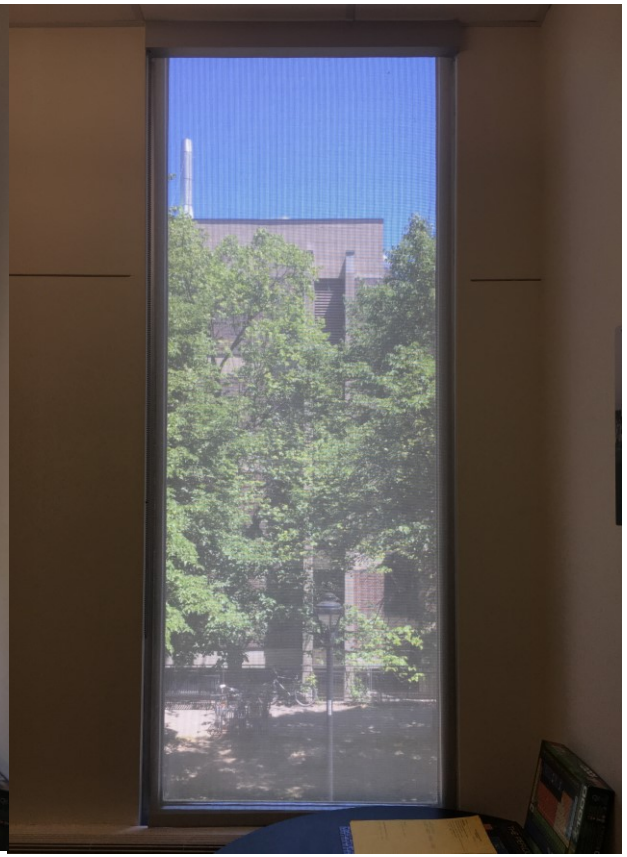
Topics

1. Daylighting design for comfort
2. Lighting design for comfort

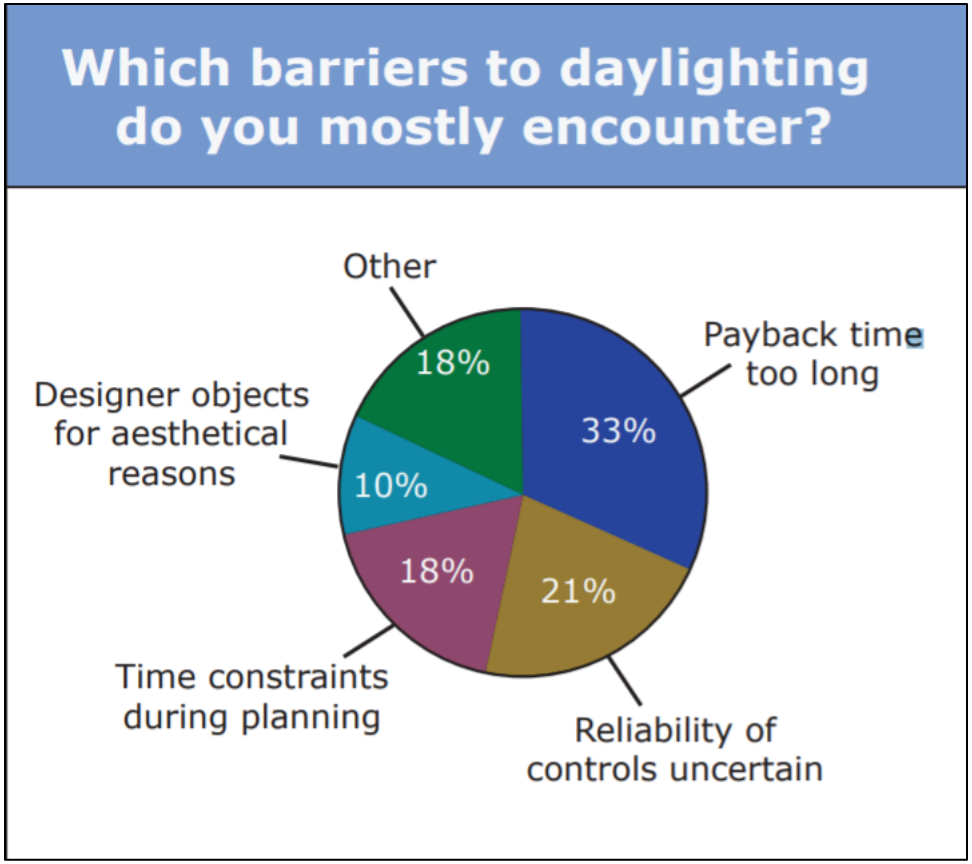
From survey of 170 Carleton employees:“If you had the option to choose any building on campus, which would you choose for your office and why?”

42% of occupants would choose to be in **Richcraft Hall (RH)**

- Primary reasons given for choosing RH:
  - View (59%)
  - New (47%)
  - Natural light (24%)
  - Cleanliness (13%)
  - Operable windows (10%)
  - Proximity to food (10%)



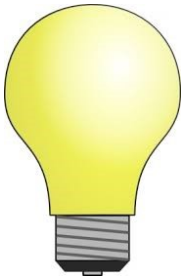
A survey (in 2008) of 177 daylighing designers/architects



Daylight

- Free (but with consequences)
- Efficient and desirable colour (eye is adapted to see daylight)
- Intense
- Good for circadian rhythm
- Mood enhancing
- Variability can be desirable
- Associated with views to/connections with outside (biophilia)
- Vitamin D

- Improve productivity; sales in retail buildings
- Enhance general well-being
- Property value
- Hard to control
- Only available during the day
- Can damage surfaces (e.g., fade, increase off-gassing)
- Too intense (especially at low angles) – glare
- Associated with high solar heat gains (for better or worse)



Electric lighting

- Controllable (intensity, colour, geometry)
- Reliable day and night

- Energy consuming
- Colour can be undesirable
- Not stimulating
- No views
- Produces heat (for better or worse)

Daylighting and lighting goals

- Provide productive, comfortable, and stimulating environment
- Minimize energy (sum of heating, cooling, and lighting), life-cycle costs, and GHG emissions
- (provide views and connection to outdoors)
- Minimize maintenance efforts
- Ensure systems are useable and work with typical occupant behaviour; not against it

What makes for good (day)lighting?

- Relatively even/uniform distribution
- Similar luminances in field of view (or at least not exceeding the 1:3:10 ratio)
- Colour with good CRI (colour rendering index)
- Personalized control (local lighting control, dimmability, local moveable shading)

Best daylighting design

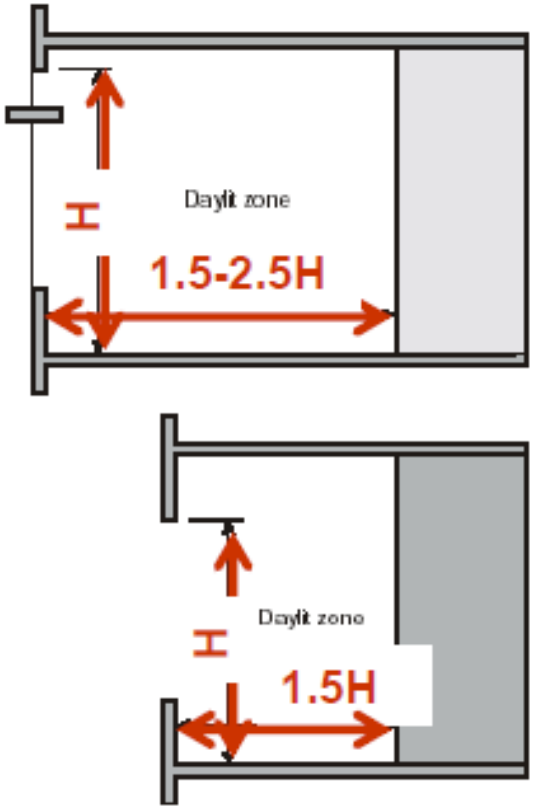
- Provide diffuse (not direct) daylight
- Allow deep penetration (window geometry, wall and furniture geometry, reflective surfaces)
- Minimize glare
- Keep windows above workplane (pretty useless below)
- Shallow building footprint

Fenestration

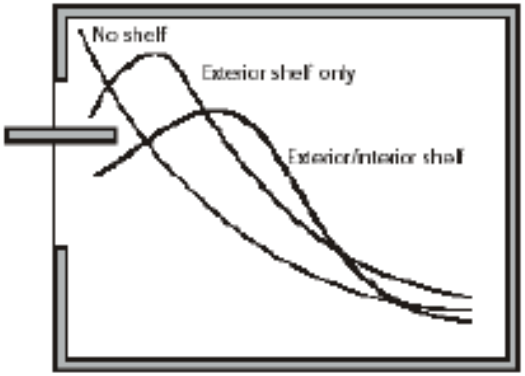
- Sidelighting
- Skylighting
- Clerestories
- Indirect daylighting
  (e.g., light tube)

Daylight Penetration

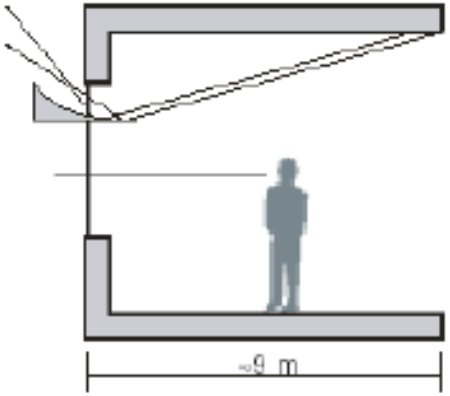
Plan depth



Daylight Depth as a Function of Window Height



Light Distribution with Light Shelves



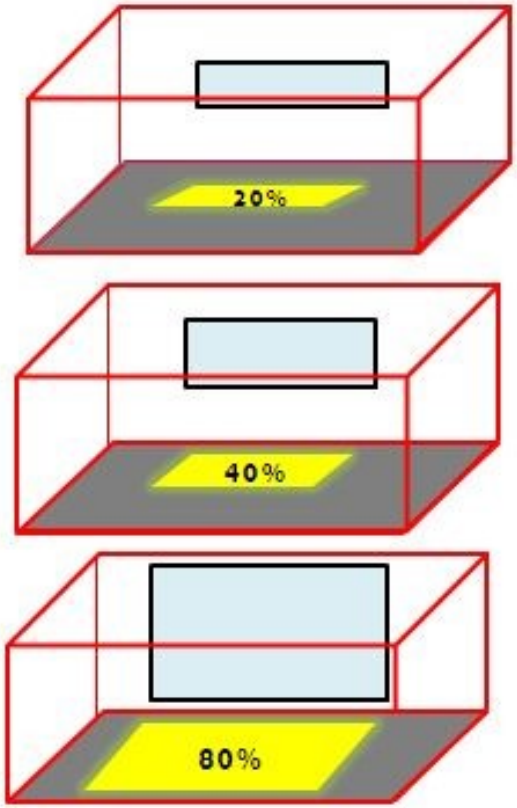
Interior and Exterior Light Shelves

Window to wall ratio

Definition: the window area divided by wall area for a particular façade or the whole building

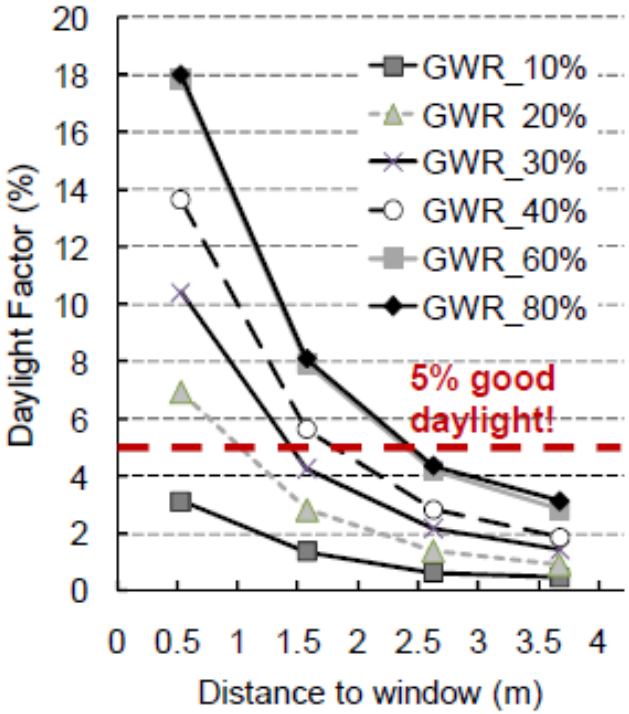
Alternative metric

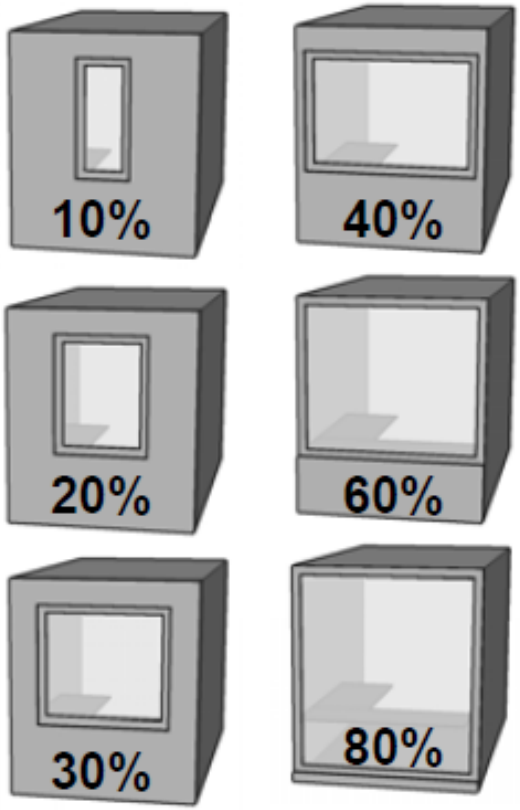
Solar aperture: south-facing window area to gross floor area. (mainly used for passive solar considerations)



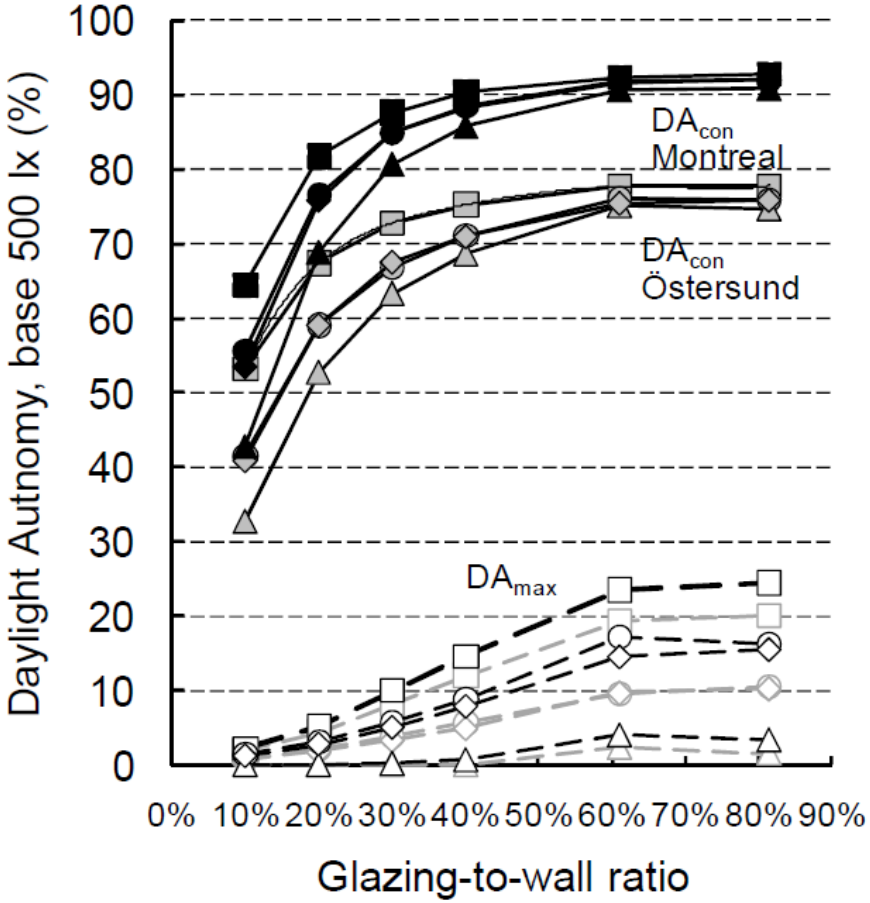
Daylight Penetration

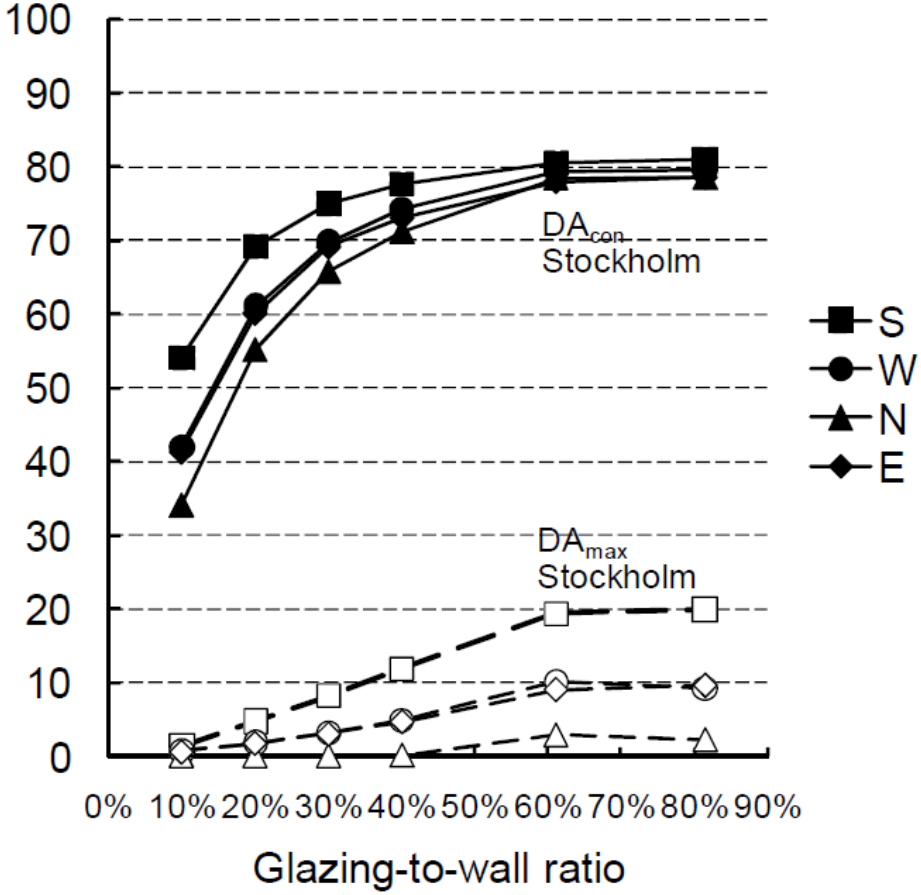
- We don't need massive windows to achieve good daylighting.
- With big windows, when it's bright, it's REALLY bright. When it's dark, it's dark.





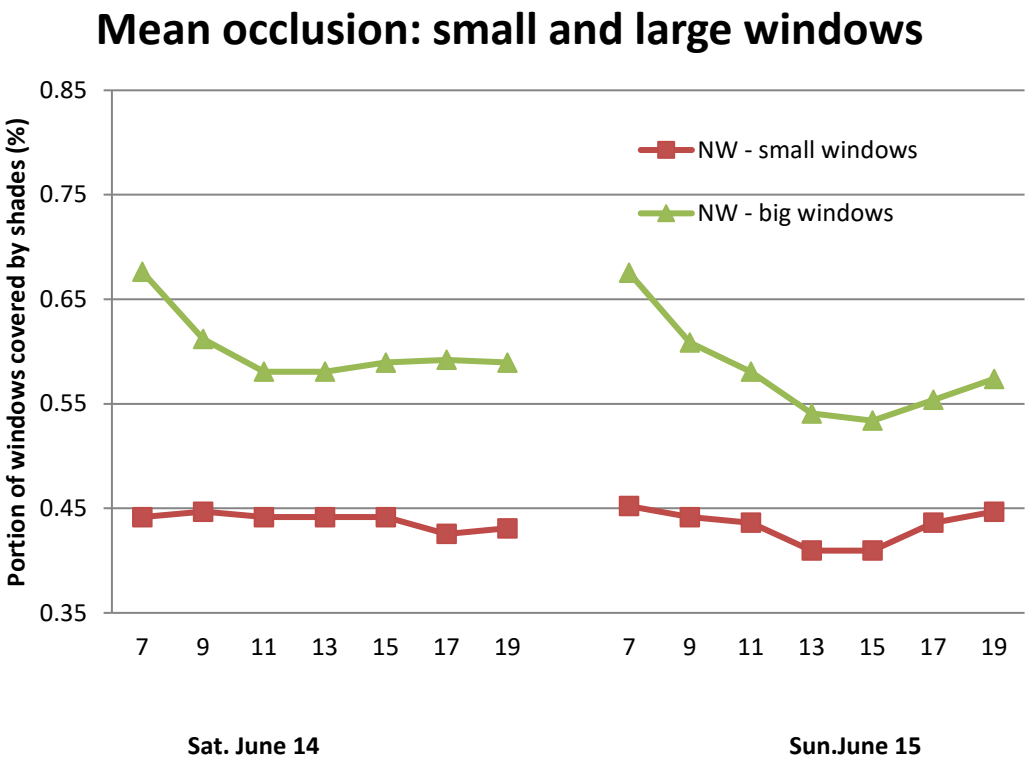
Daylight Autonomy





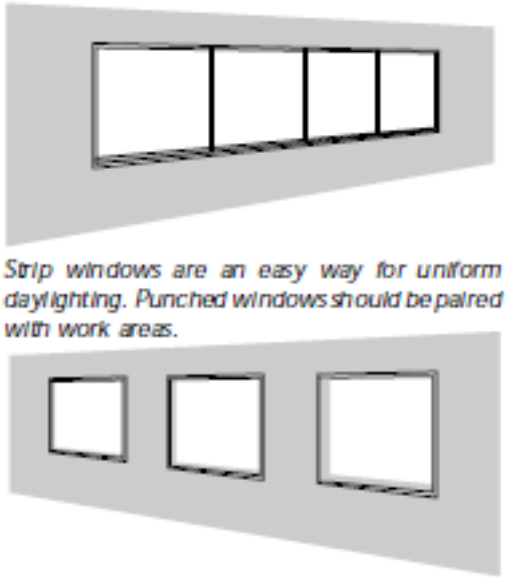
Courtesy: Marie-Claude Dubois

Blind occlusion and window size

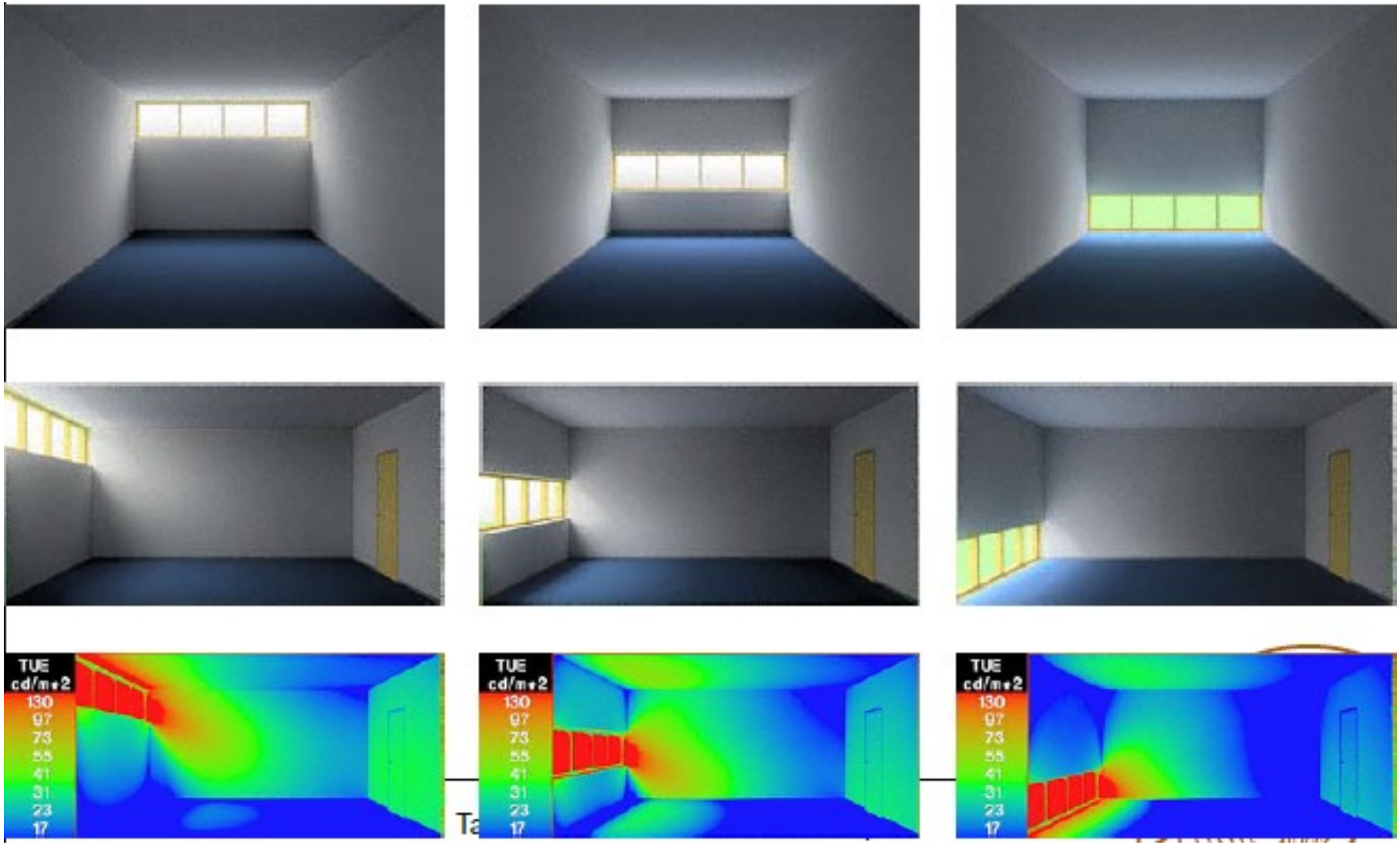


Credit: Isis Bennet

Window layout



- All else equal, better to have continuous windows rather than punched windows
  - Risk of high contrast ratios between glazed and opaque areas
  - Pairing windows with workplaces can partially resolve this.


TUE
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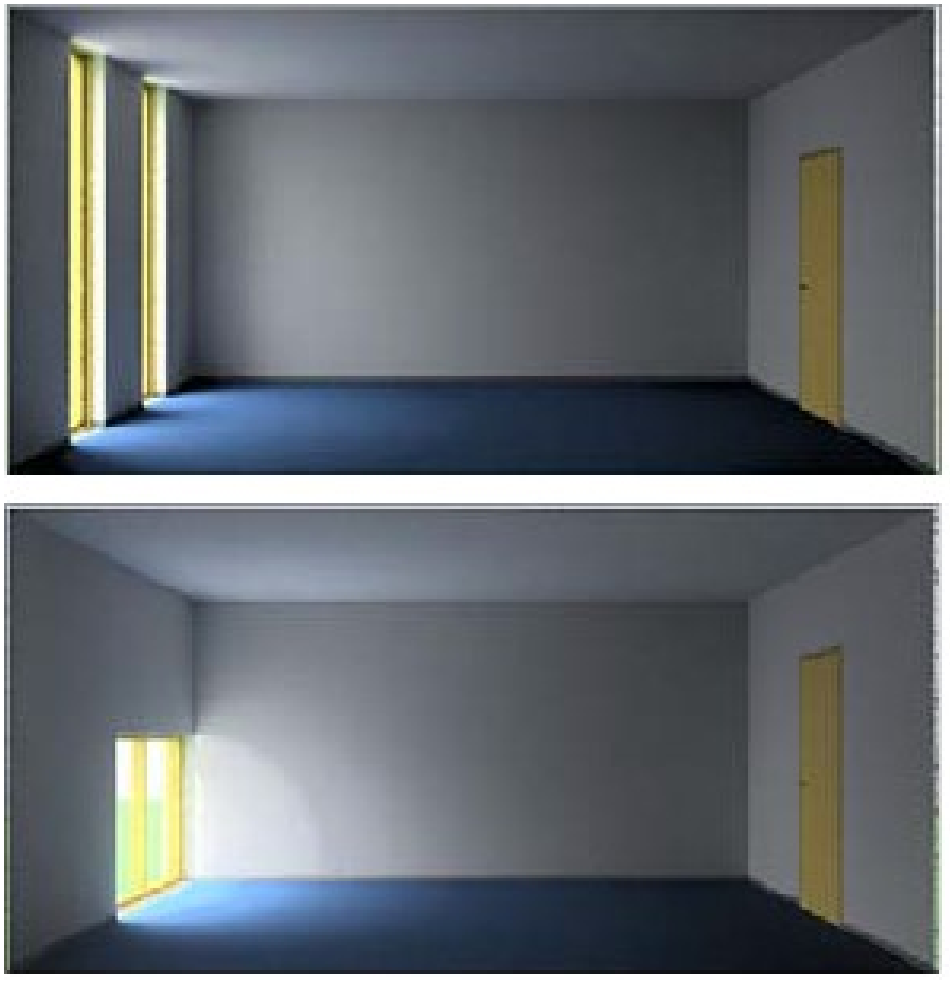
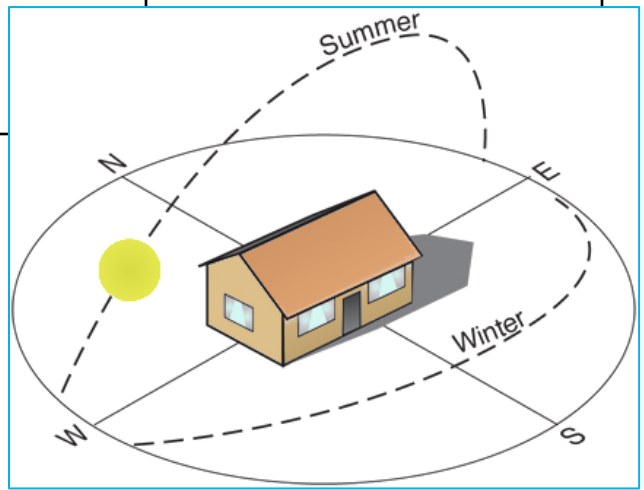


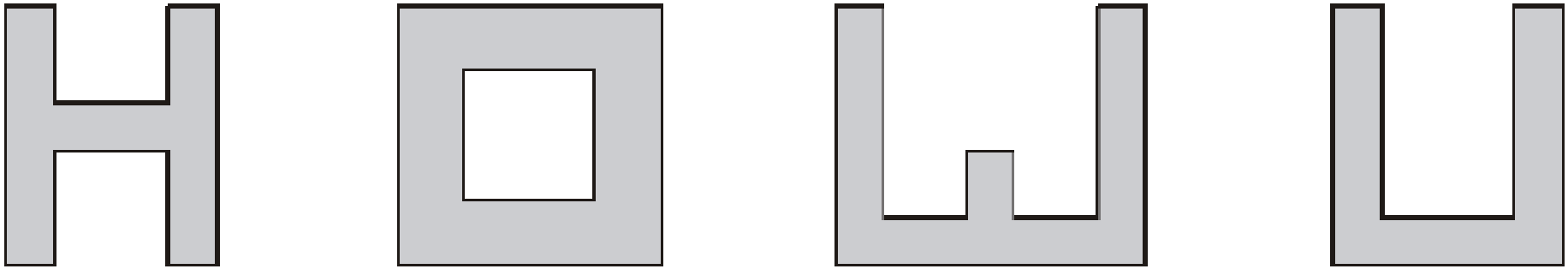
Window orientation and daylighting

	Pros	Cons	Overall
North	Lots of diffuse light	Not as much daylight North-facing windows are net heat losers (could be good or bad)	Excellent
South	Lots of direct light; timing is congruent with working hours; easy to control with fixed shading		Optimal
East/West	Deep daylight penetration	Deep penetration means sun in eyes (glare) High solar gains in summer	Weak



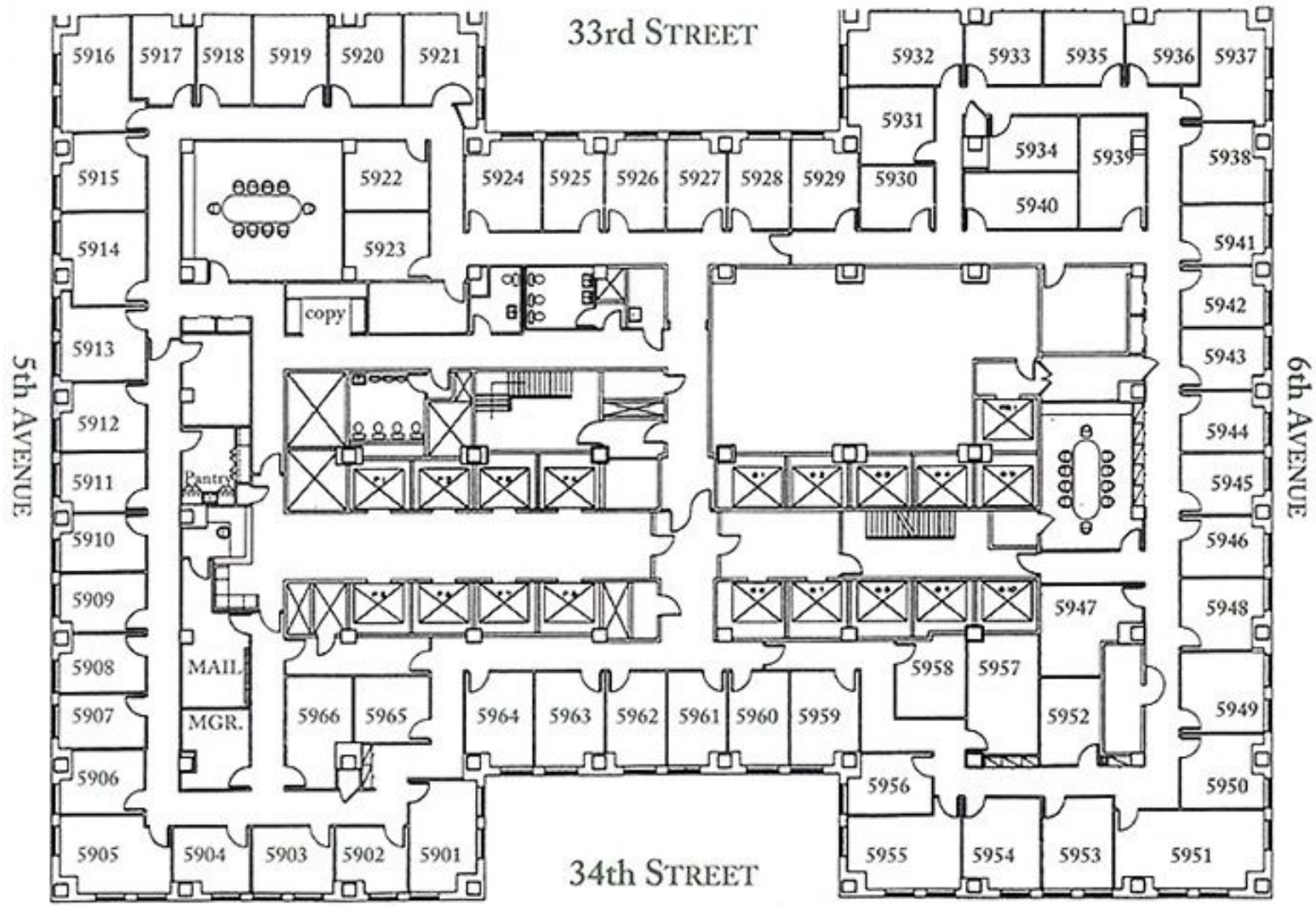
Best daylighting design

- Buildings used to be designed specifically to have ample daylight…then the electric light was invented and cheap energy was made available.



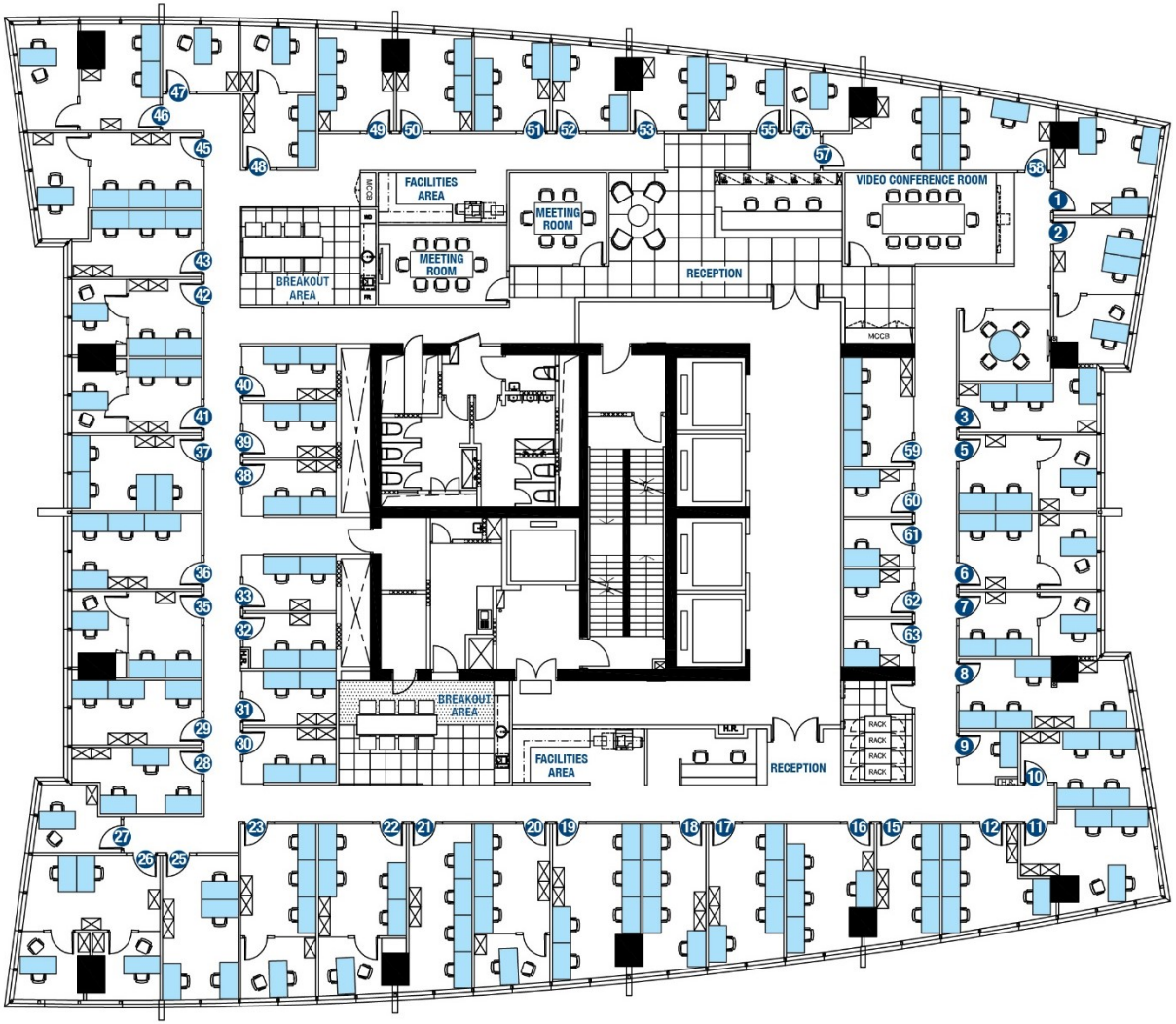
Traditional vs. Modern

Traditional vs. Modern



Empire State Building (1930)

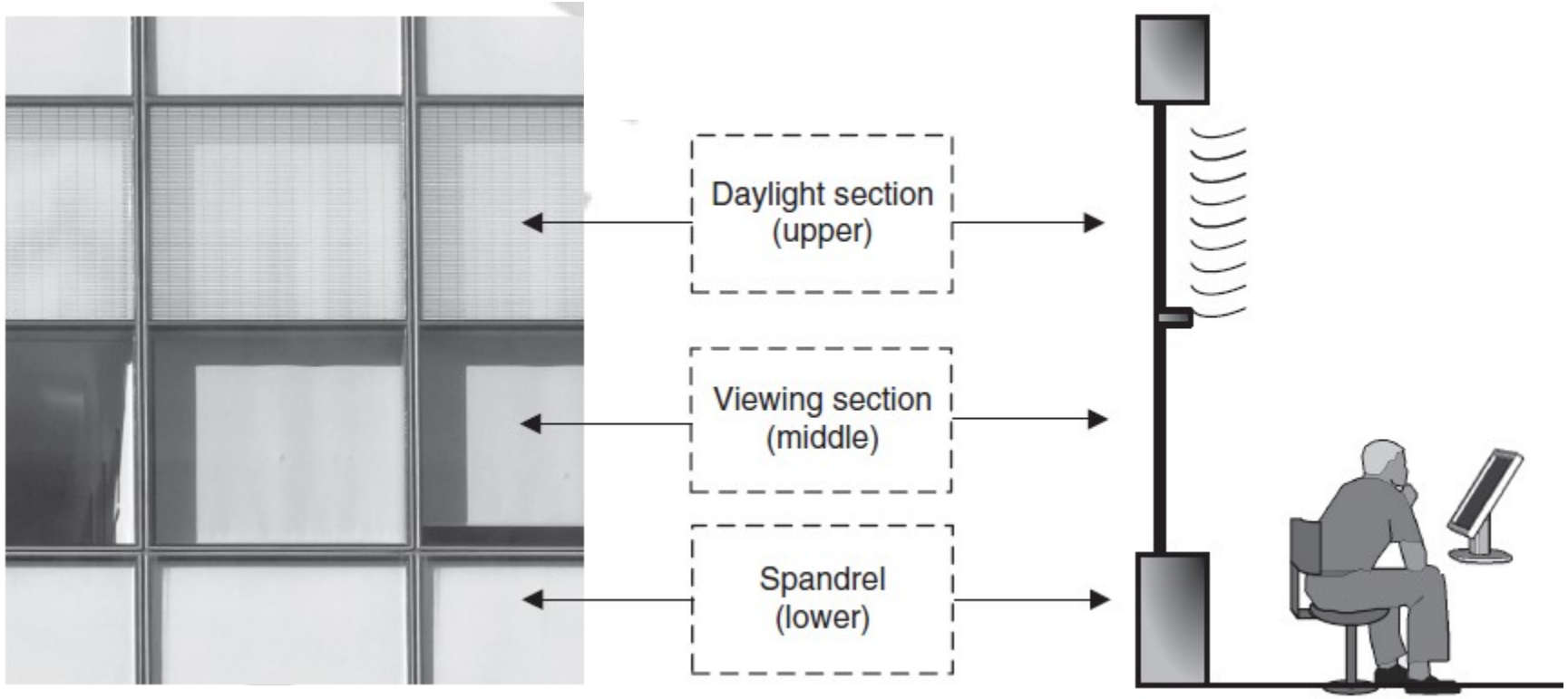
Traditional vs. Modern



Modern office

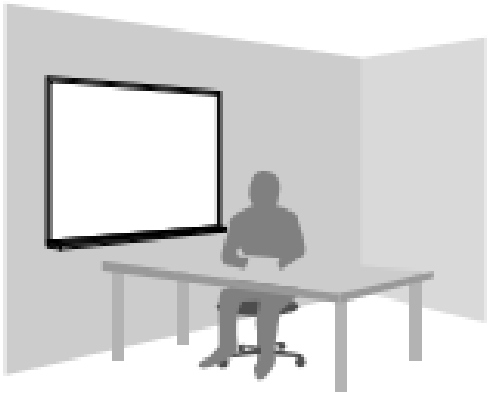
3-section facade

- An optimal façade design is divided into three key components: insulated spandrel, viewing section, and daylighting section.



Interior Furnishing

When the window is behind your back, you may shade your task and make it too dark to see easily. However, your computer screen may be difficult to see if it reflects light from the window.



The most comfortable seating is with the window to the side—task is well illuminated and the source is not in direct line of sight.

Facing the bright window creates a harsh contrast in comparison to your relatively dark task—this is very tiring for the eye to have both in the same field of view.

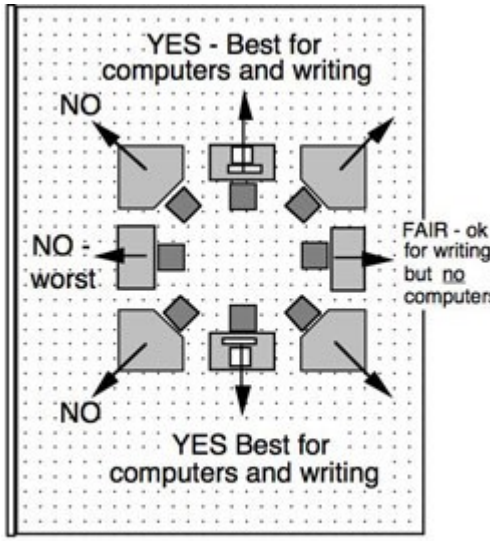
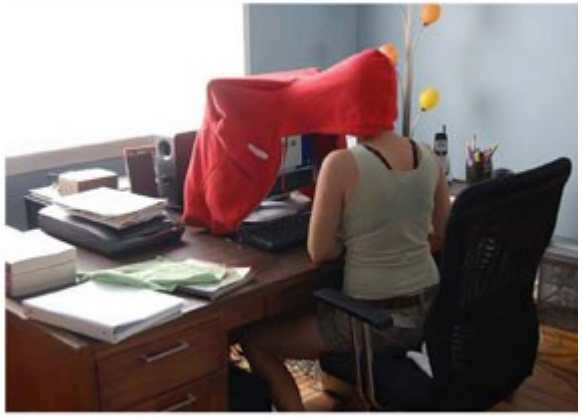
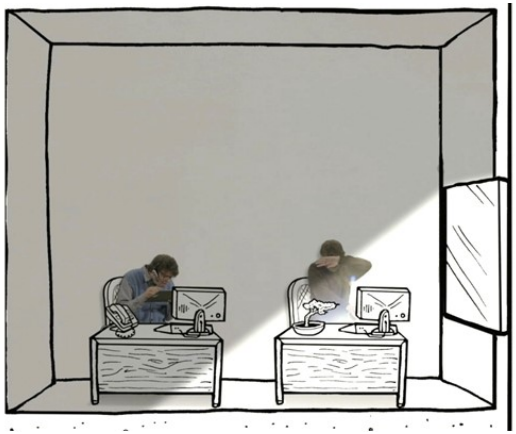
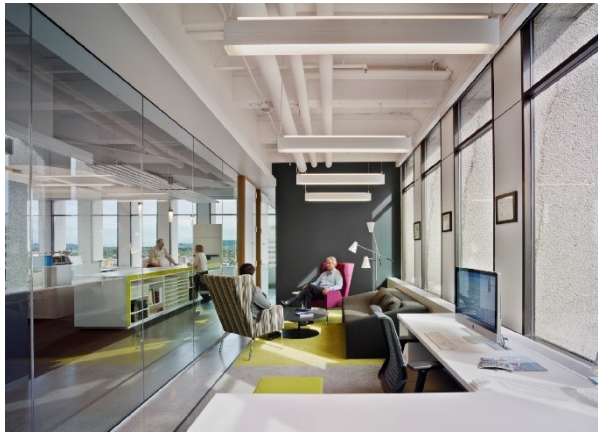


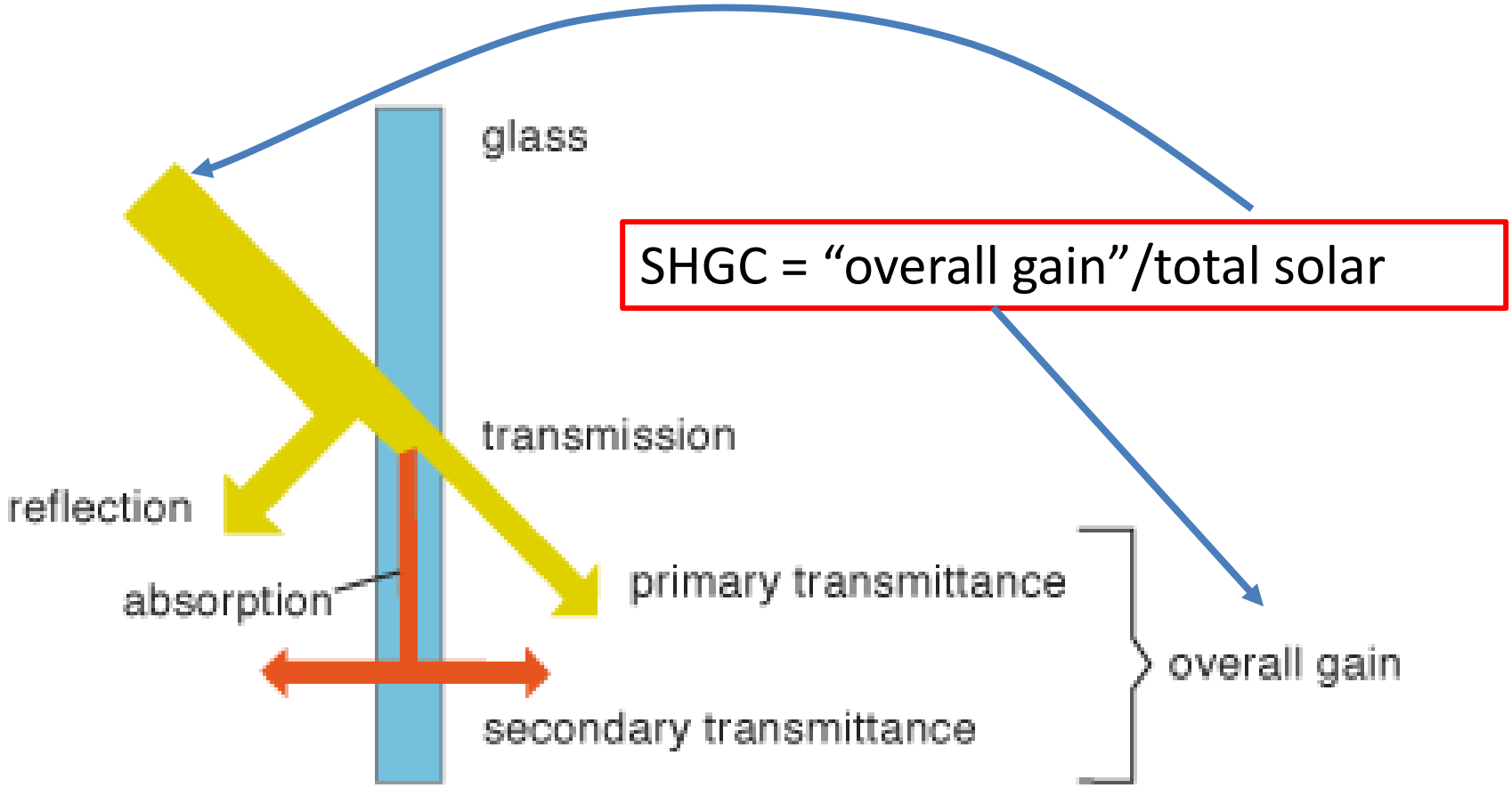
Figure 5







Reflected, Absorbed, Transmitted Solar



Key Window Properties: Visible Transmittance (T_{vis})

- The fraction of <u>visible</u> light that is transmitted by a window
- Higher isn't always better because of glare or if a certain ambiance is sought

Key Window Properties: Solar Heat Gain Coefficient (SHGC)

- Defined as the fraction of solar gains that ultimately make it through the window.
- This includes both directly transmitted solar radiation AND solar radiation that is absorbed by the window that eventually radiates or convects inwards.
- Therefore, SHGC > T_{sol} (solar transmittance)
- Building codes normally limit SHGC. Why?

Key Window Properties: U-value

- The conductance of window assembly or glazing system (be careful to determine which one is quoted)
- Given in W/m^2K (or IP units)
- <u>Note: U-value normally includes the film coefficient unlike walls</u>
- Window U-value is one of the most constrained properties in building codes

Multiple panes/glazing layers

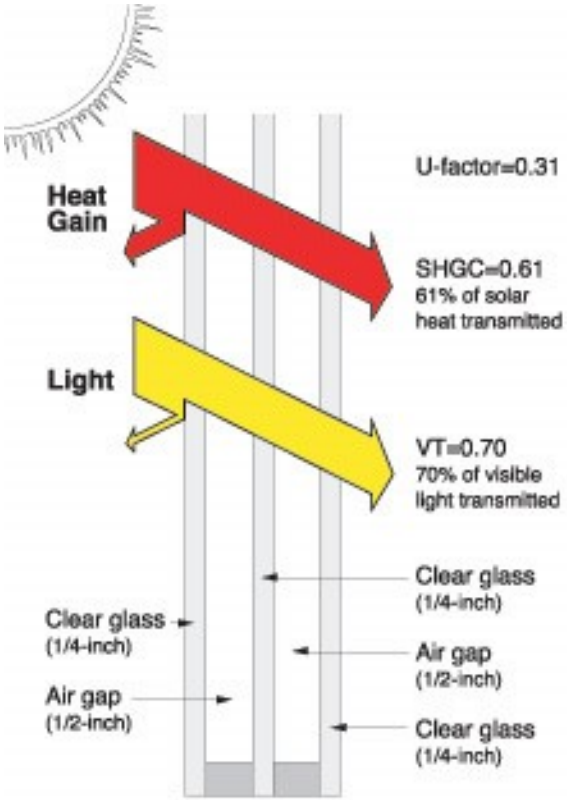


Figure 3-10. Clear triple glazing

All values are for the glazing alone (center-of-glass).
Values for the total window will vary with frame type.
U-factor is in Btu/hr-sf-°F
SHGC=solar heat gain coefficient
VT=visible transmittance

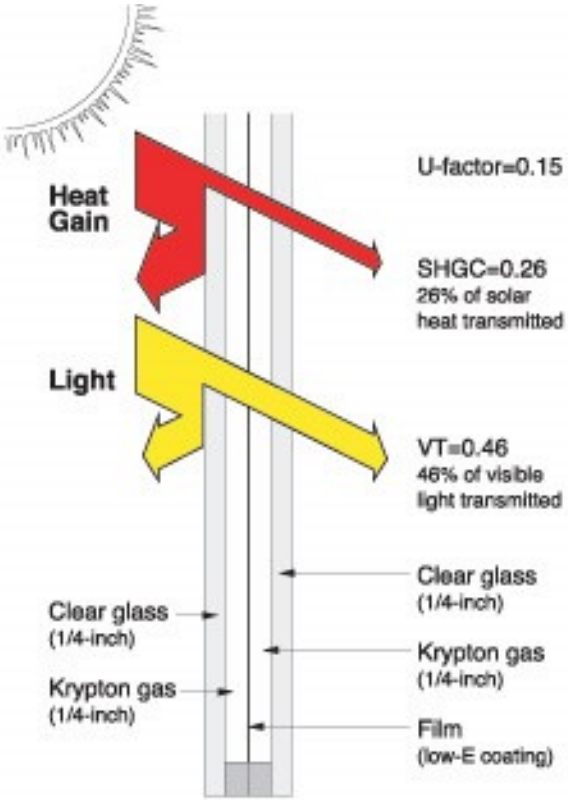


Figure 3-11. Triple glazing with clear glass and a low-E coating on plastic film

All values are for the glazing alone (center-of-glass).
Values for the total window will vary with frame type.
U-factor is in Btu/hr-sf-°F
SHGC=solar heat gain coefficient
VT=visible transmittance

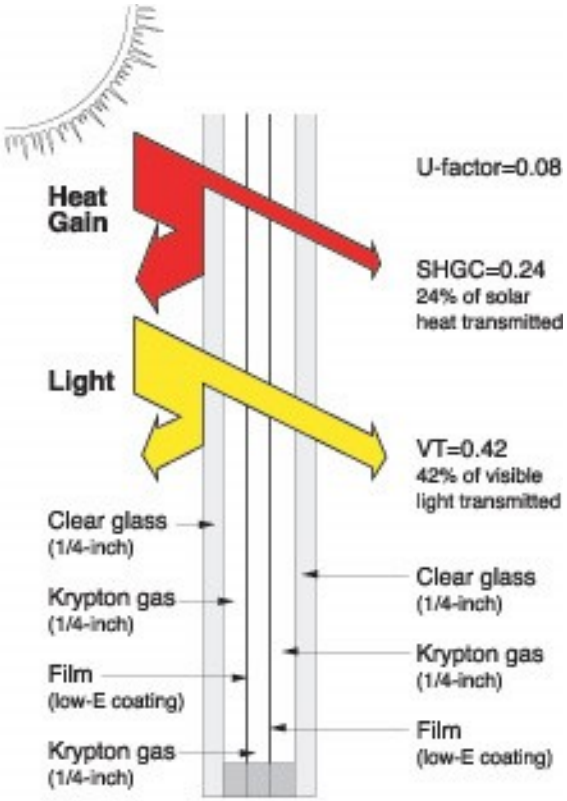
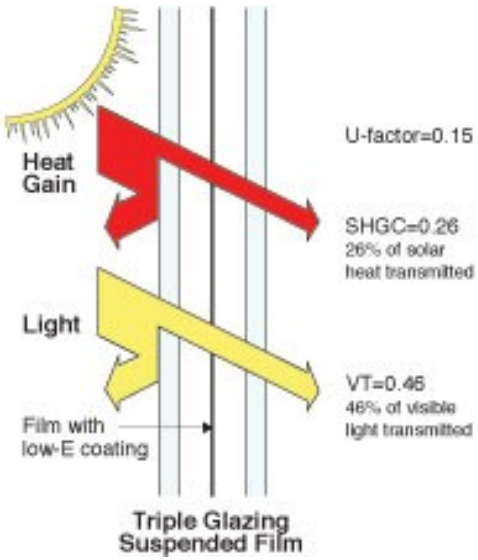


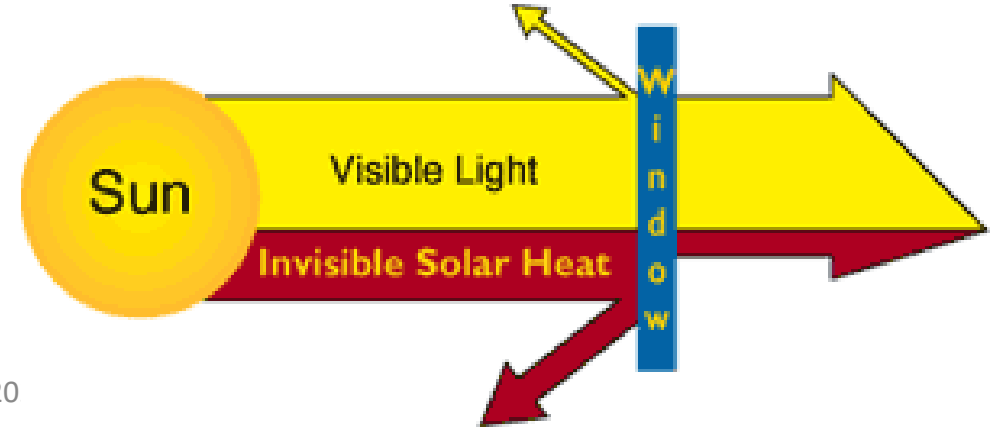
Figure 3-12. Quadruple glazing with clear glass and low-E coatings applied to two suspended plastic films

All values are for the glazing alone (center-of-glass).
Values for the total window will vary with frame type.
U-factor is in Btu/hr-sf-°F
SHGC=solar heat gain coefficient
VT=visible transmittance

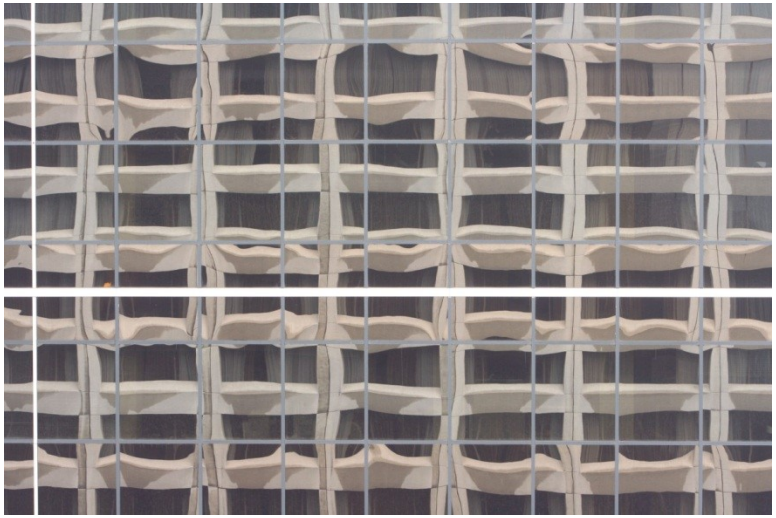
Spectrally-selective glazing

- In commercial buildings (which normally have ample heat gains – even in Canada)), we want to admit just the visible wavelengths of daylight.

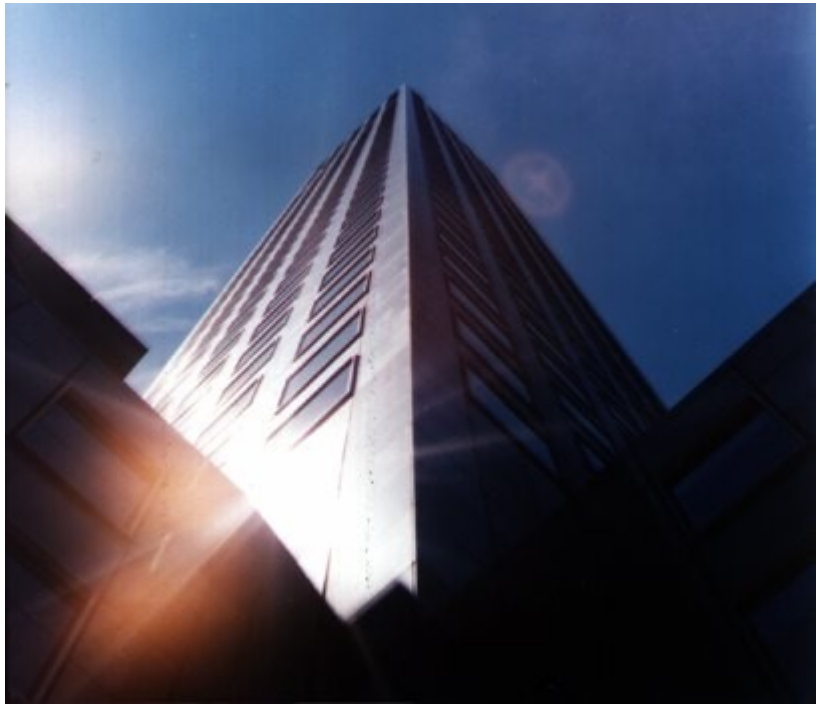


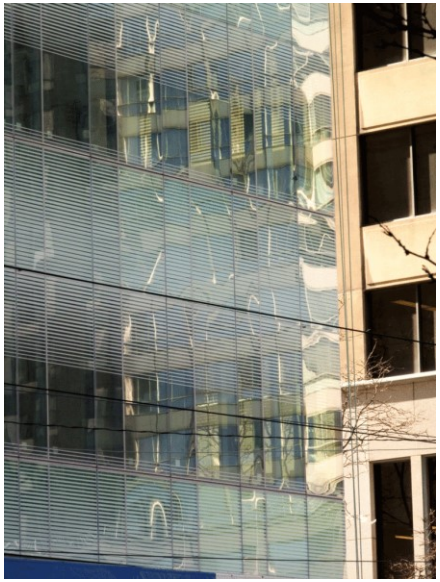


Tints



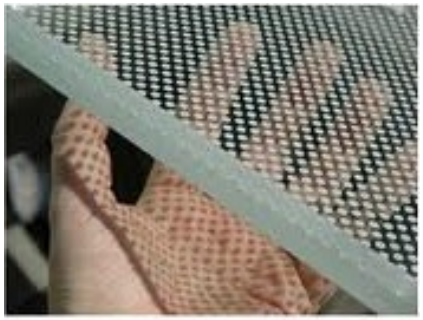
- Reject solar gains
- Covering the root of the problem (glazing area is too high)
- Colour could be unpleasant
- Causes glare for others (could be a safety issue)





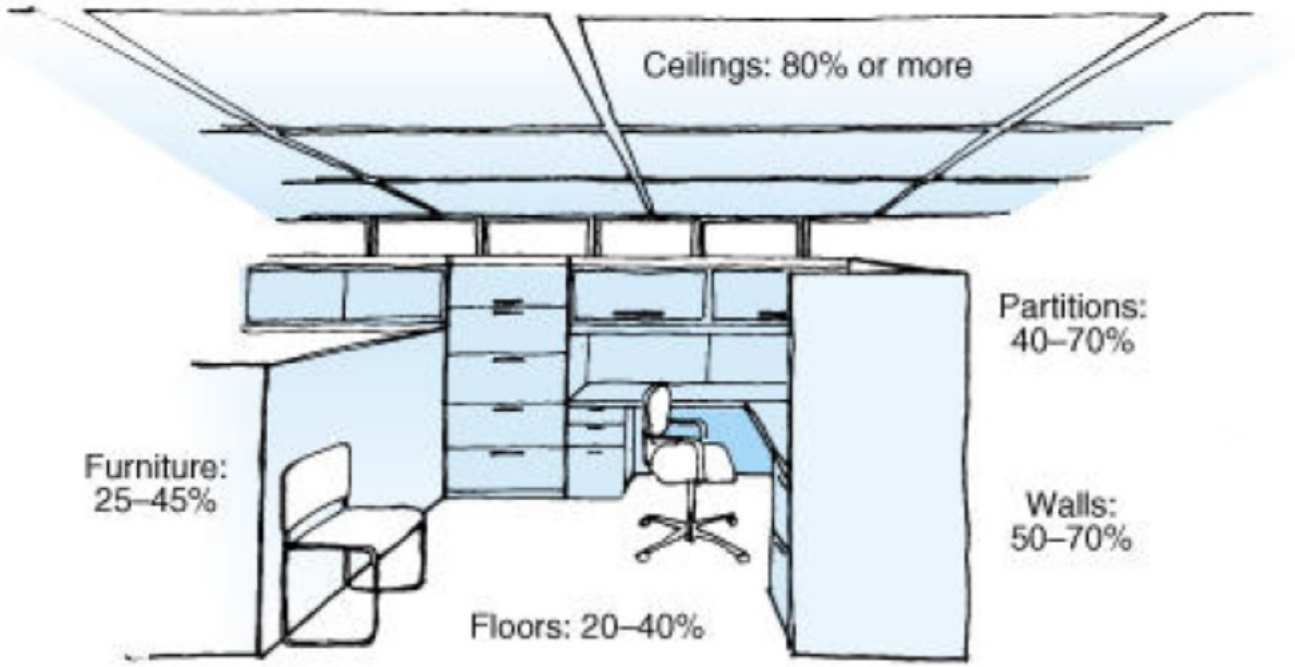
Fritted glass (ceramic coating)

Fritted Glass



Typical Ideally Room Reflectances

- Specularly reflective surfaces should ideally not be in the field of view of occupants. And they must not reflect direct light onto occupants or nearby surfaces.



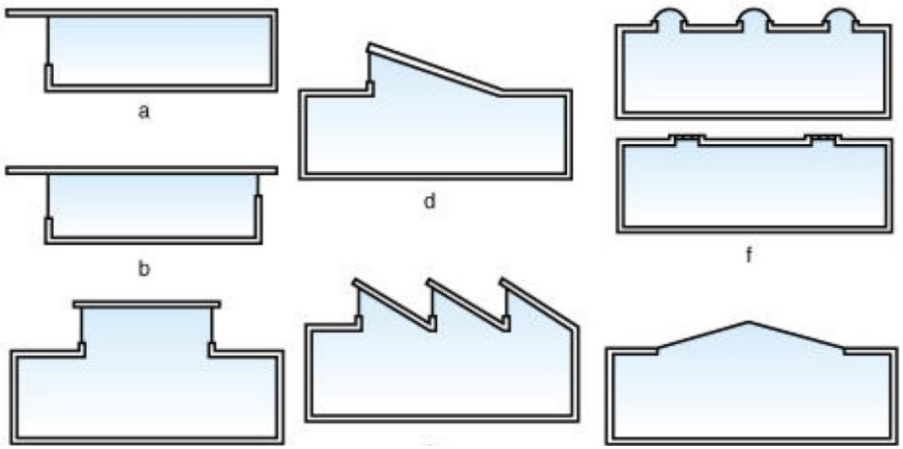
ШТРАФ

Perimeter Daylighting

- Daylight can reach about 1.5 to 2.5 times the height of the top of the window.
- Making the windows massive won't achieve much deeper than this – but they will cause discomfort and excessive solar gains/heat loss.

Daylighting the Core

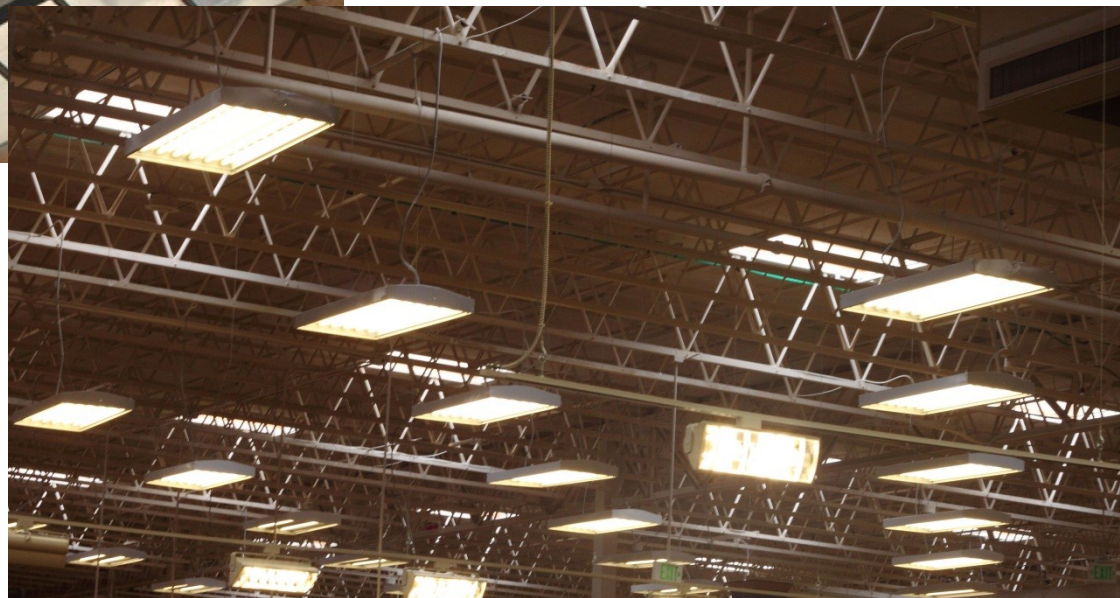
- The tough part is lighting the core in deeper buildings.
- The perimeter can be daylit using windows (sidelighting)
- The top floor can be daylit using skylights.



Skylighting

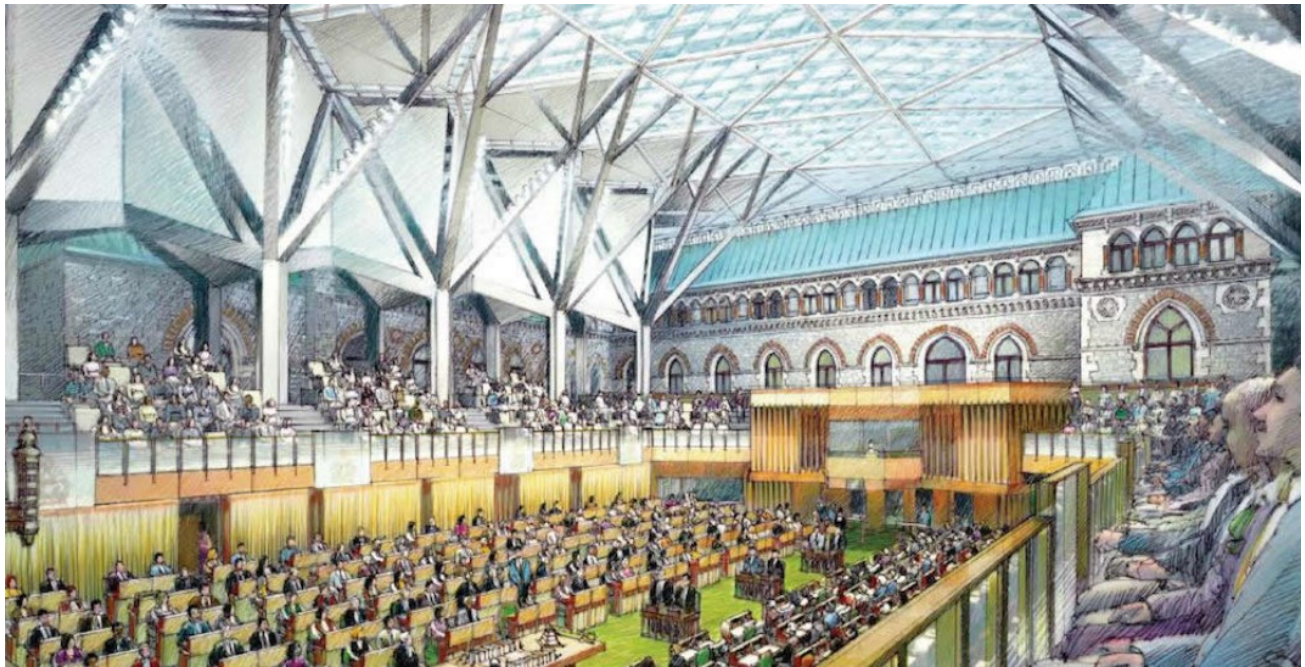
- Very effective at lighting
- Restricted to the top floor (unless open to below - atrium)
- The worst orientations for solar heat gains, so use sparingly
- Code limits to 1% of roof area

Skylighting



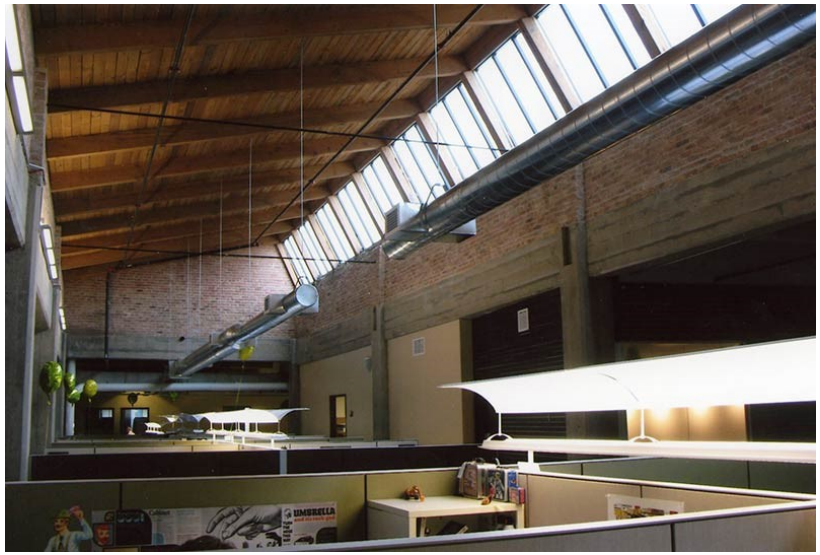
West Block retrofit

- “The glass roof helps keep the chamber cool in the summer and warm in the winter, effectively lowering heating and cooling costs.



Clerestories

- Basically, they're vertical windows that are high up on a wall or dormer
- Do allow core daylighting without the solar gains (if oriented properly)
- Increased complexity of geometry ($$$)
  - Not every space in a large building can have a clerestory

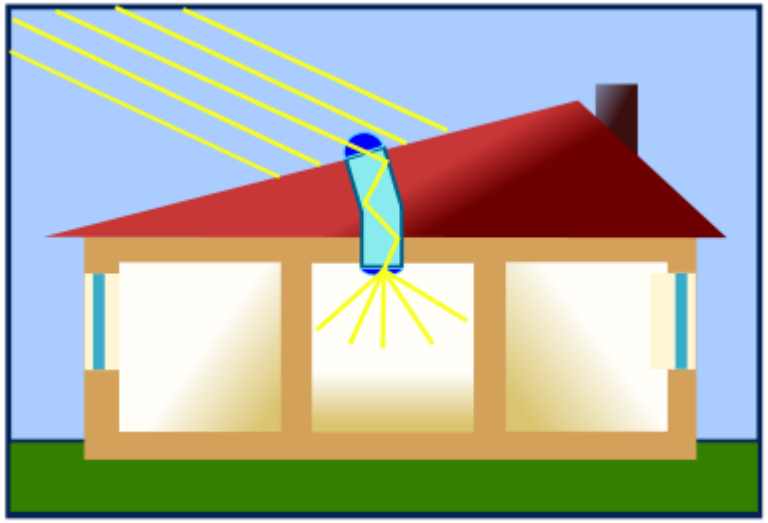


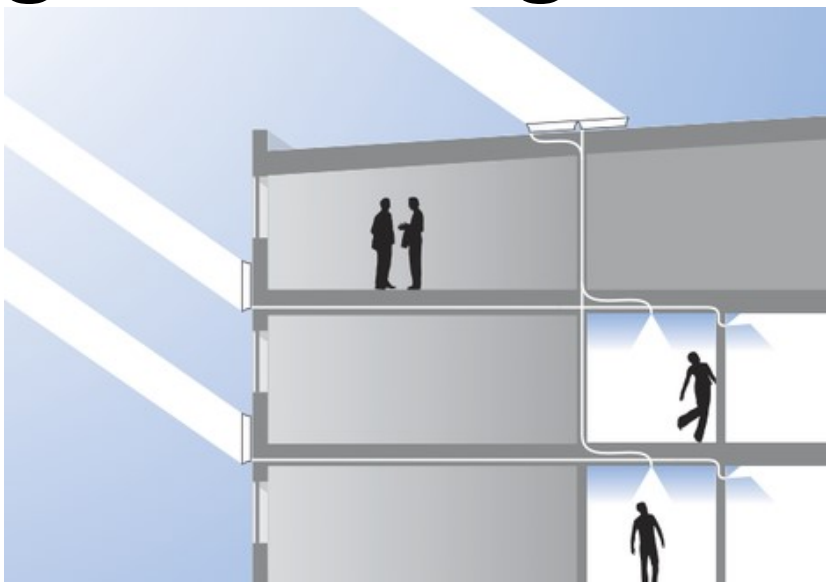
Atria

BCE Place, Toronto

Jazz Cannabis
CITY CENTER

Advanced Daylighting Technologies

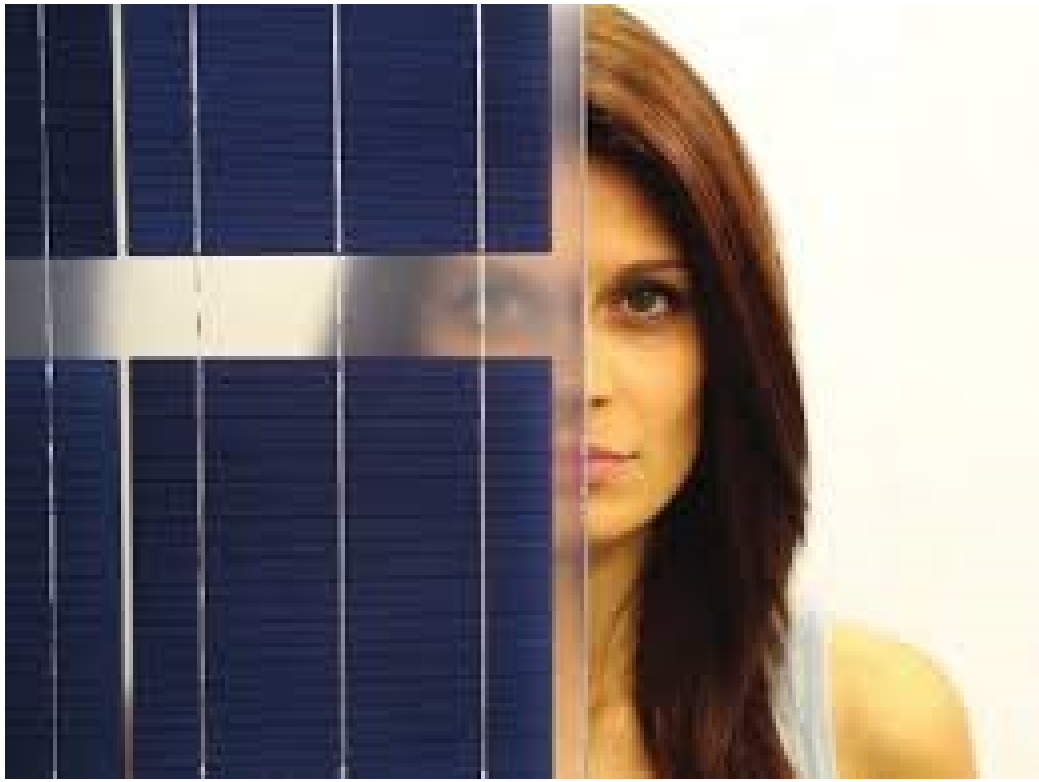




UBC-developed Solar Canopy System

- Can bring daylight 60-80 meters into building from south side on clear day

Semi-transparent photovoltaics (STPV)

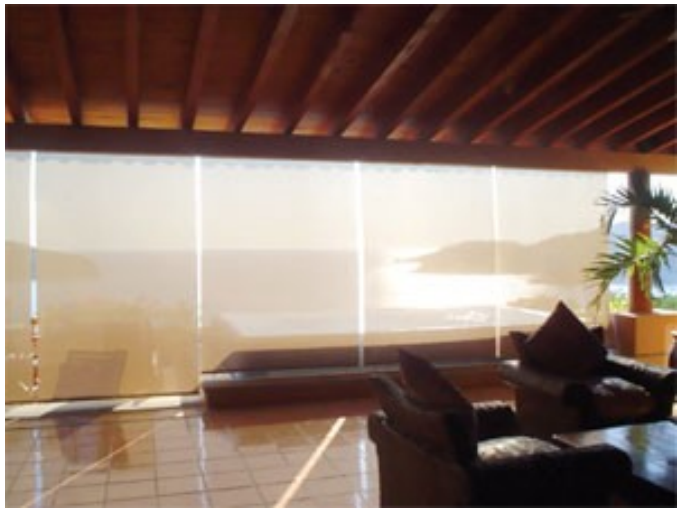


Electrochromic/Thermochromic Windows

- A newer technology exists that allows the optical properties of a window to be changed with the flick of a switch.

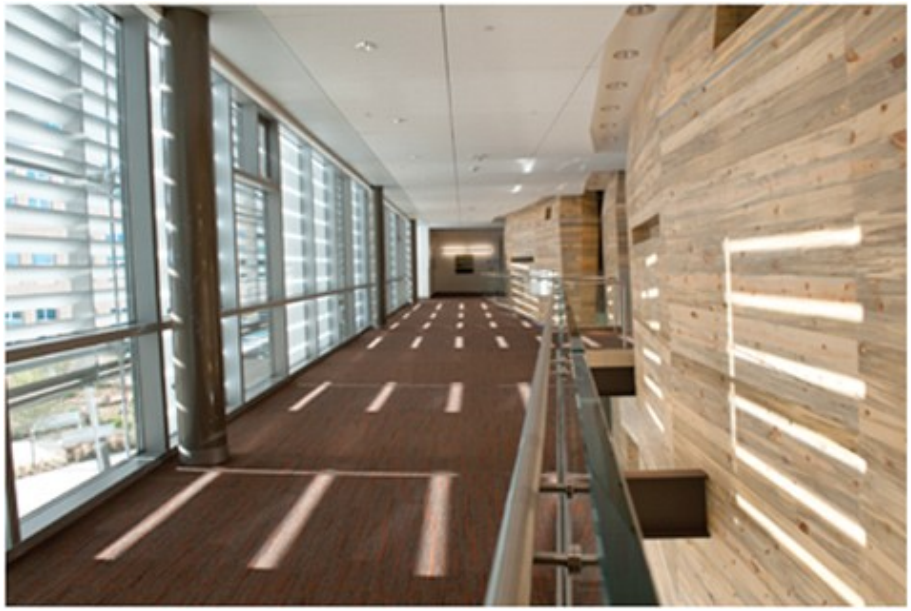
Preventing daylight glare

- The first choice for addressing glare is through passive means (geometry, materials)
- Key window shading devices: roller shades, Venetian blinds, fixed louvers, light shelf.
- Shades with transmittance > 0 cannot perfectly protect against glare from direct sun.



Shading Examples

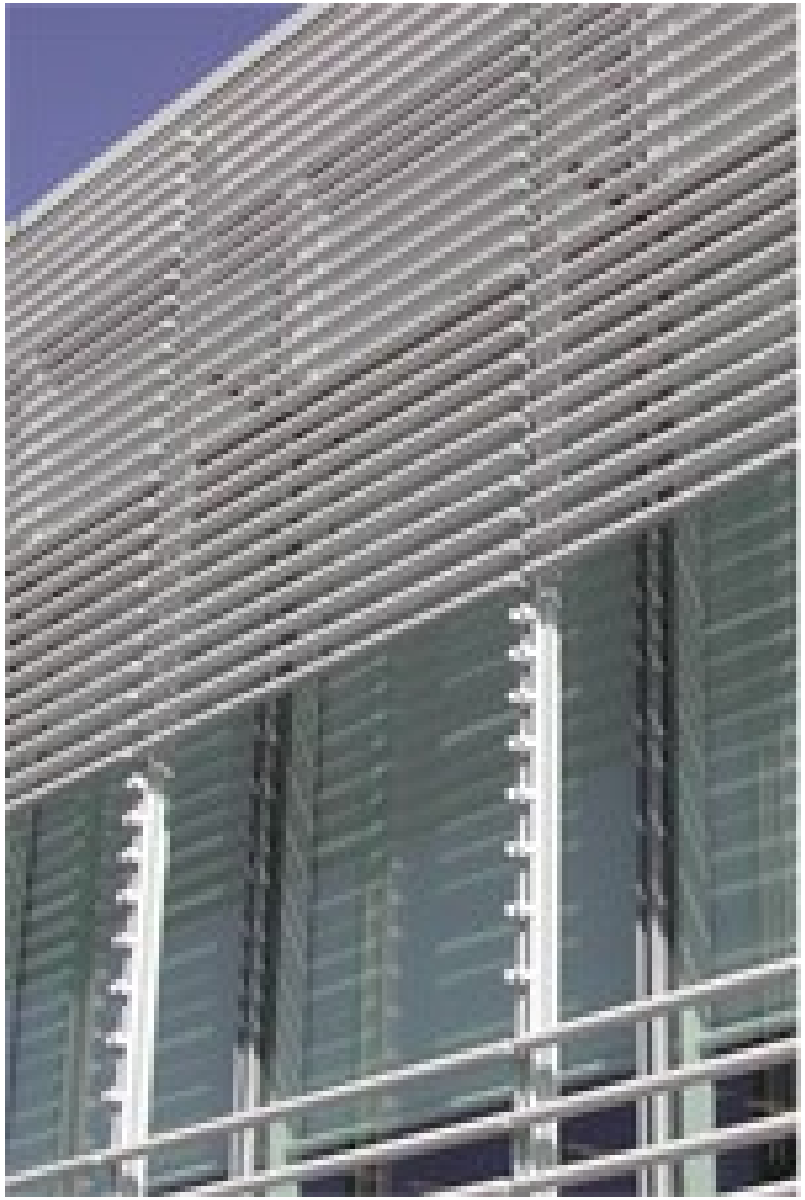
Daylighting Examples



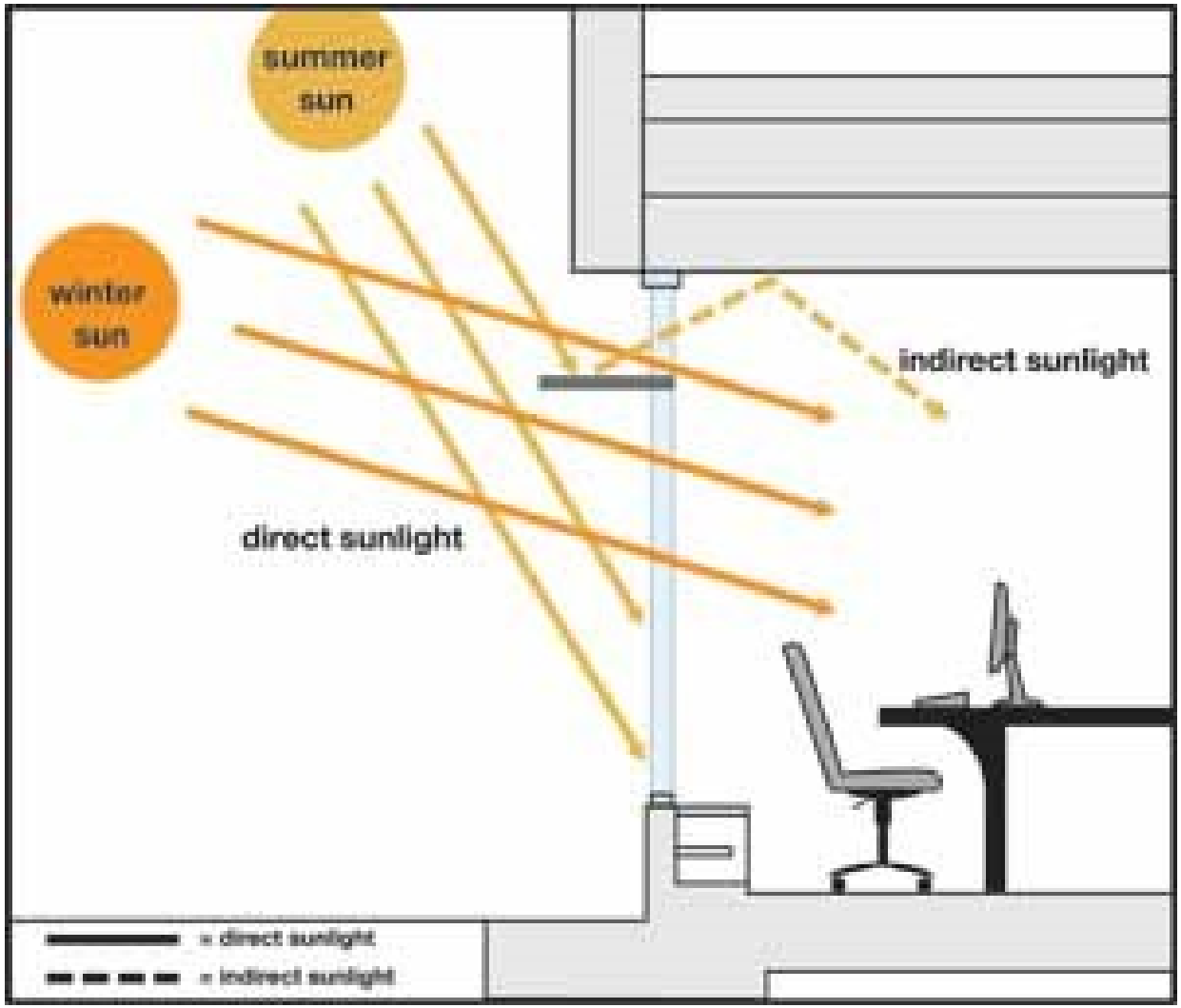
Daylighting Examples

Fixed Shading

- In keeping with our objective of maintaining daylight without glare, fixed shading can be employed to minimize glare.
- If done right, fixed shading prevents occupants from having to take further actions.



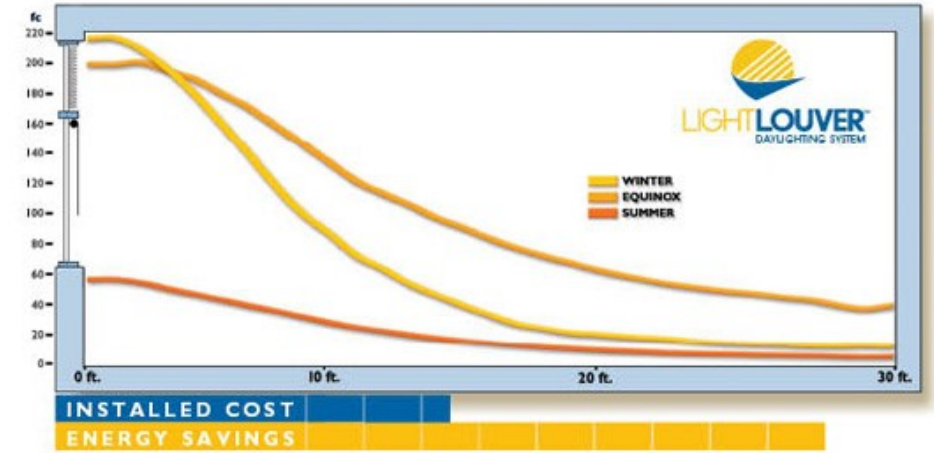
Lightshelves



ARDY
OYS

Fixed Shading/Reflectors

http://lightlouver.com/uploads/Illuminance-edited.jpg

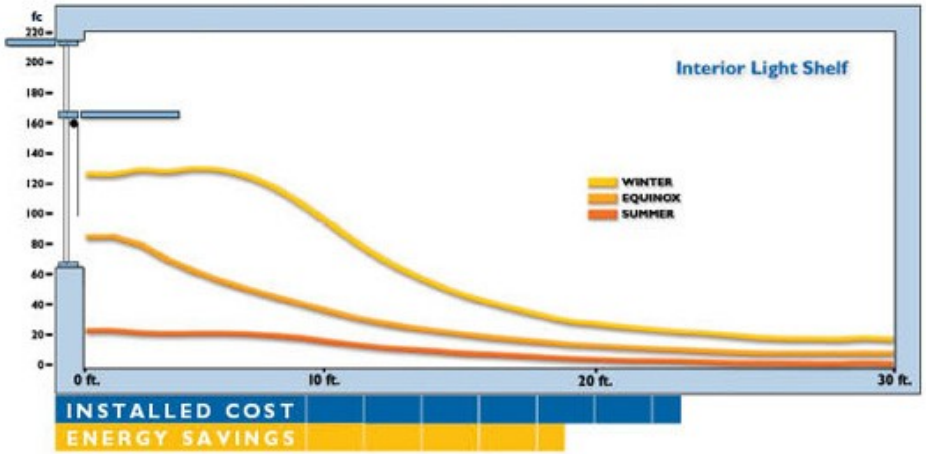


LightLouver units installed in daylight windows; blinds closed 80 percent over vision windows.

Direct Sun Control: Complete*
Daylit Zone: 30 feet**
Energy Savings: High
Visual Comfort: High

* 5 degree cutoff angle inherent in LightLouver unit design

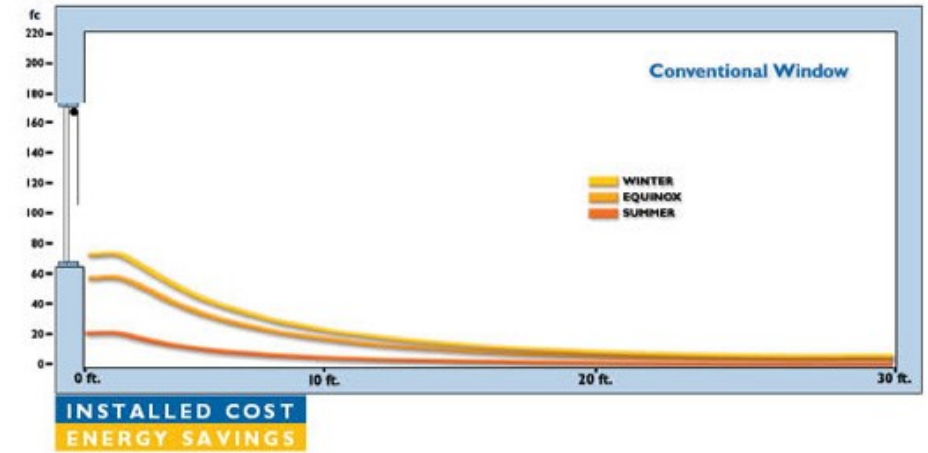
** assumes 2.5 ft. high LightLouver unit



Interior light shelf located under the daylight windows; blinds closed 80 percent over vision windows.

Direct Sun Control: Partial*
Daylit Zone: 15 feet
Energy Savings: Medium
Visual Comfort: Medium

*exterior overhang included to achieve reasonable solar control (15 degree cutoff angle)



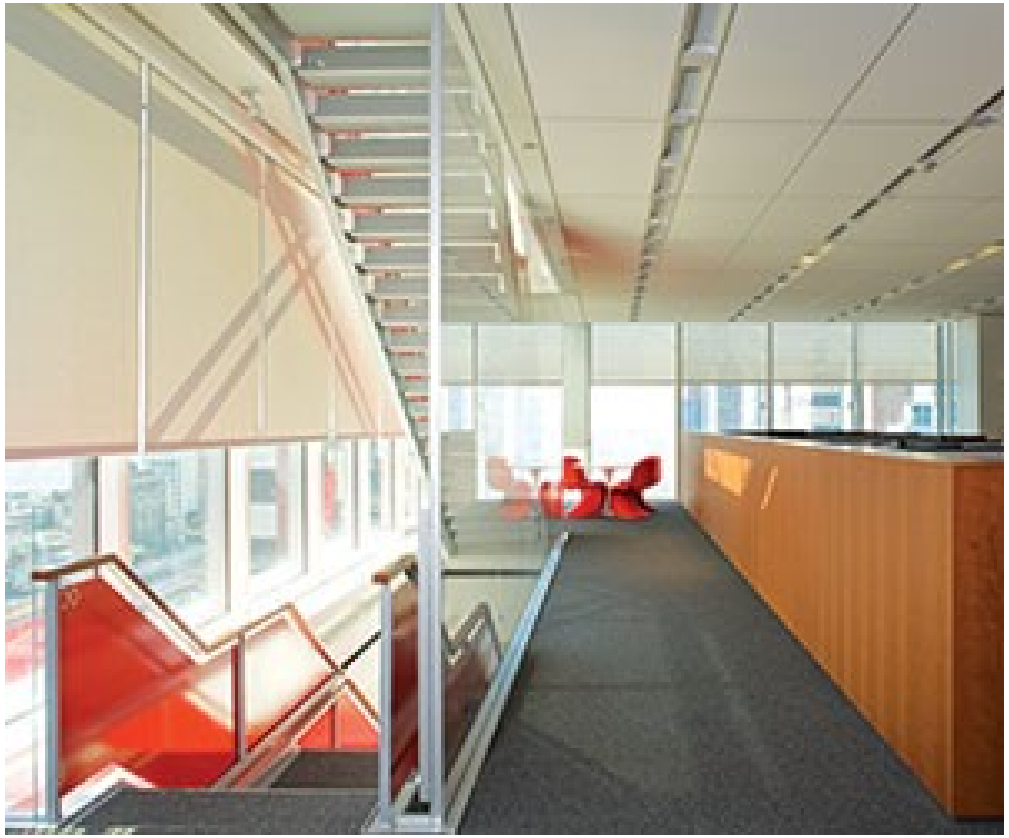
Conventional windows with blinds closed 80 percent over vision windows.

Direct Sun Control: Partial
Daylit Zone: 10 feet
Energy Savings: Low
Visual Comfort: Medium

Moveable Shading

- Offers more control
- But more uncertainty and more moving parts (i.e., potential for failure)
- Tool for material selection:

http://www.performanceshadingadvisor.com/

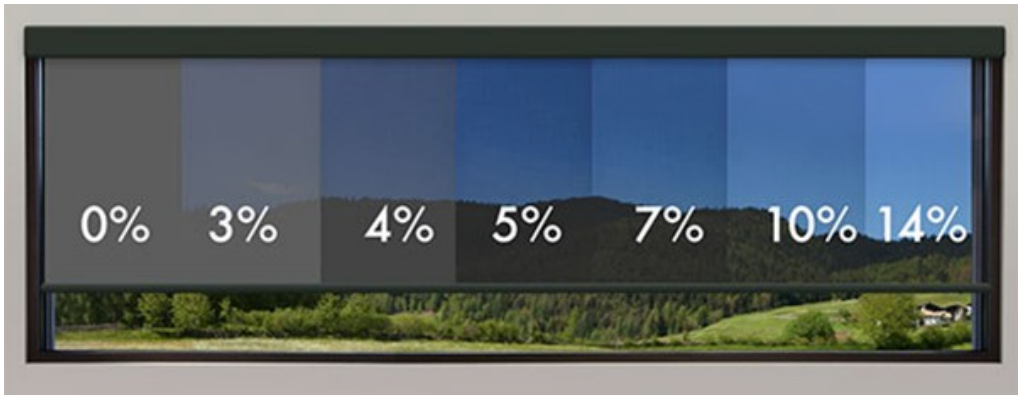


Venetian blind vs. roller shade

- Venetian blinds have two degrees of freedom (up-down and tilt) and can reflect light up on to the ceiling.
  - But they are flimsy and less suitable for spaces that need black-out conditions due to gaps
- Roller shades are more mechanically robust and have less flexibility (only one degree of freedom)
  - Opening is at bottom (where it is worst for daylight penetration)
  - Fabrics properties are main design decision
- Both should ideally be mounted outside – but rarely are in Canada

Key shade properties

- Openness factor: ratio of area without thread (aim for >3% except North)
- Indoor colour/reflectance
- Outdoor colour/reflectance
- Insulating properties, if applicable



(Roller) Shades

- More flexibility on optical properties (especially on the opaque end)
- Doesn’t collect as much dust
- Can seal a window cavity pretty well (better thermal performance)
- Only one degree of freedom
- Normally opens from bottom: not idea for optimizing daylight and glare prevention

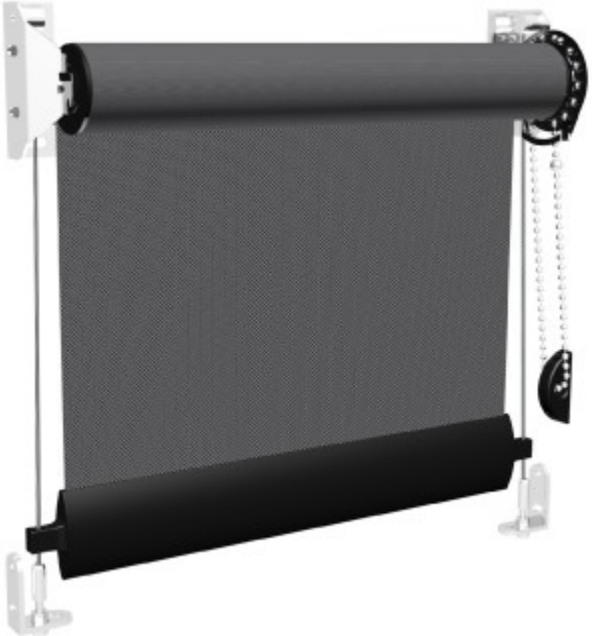
Bottom-up Shades

- Allows deeper daylight penetration
- Protects occupants adjacent to window from glare
- View-killer

Venetian Blinds

- Offers two degrees of freedom: deployment and slat tilt
- Can be used to reflect light upward (horizontal type only) and still offer a view
- Collects dust
- Not very robust to damage/wear and tear
- No prevention of airflow

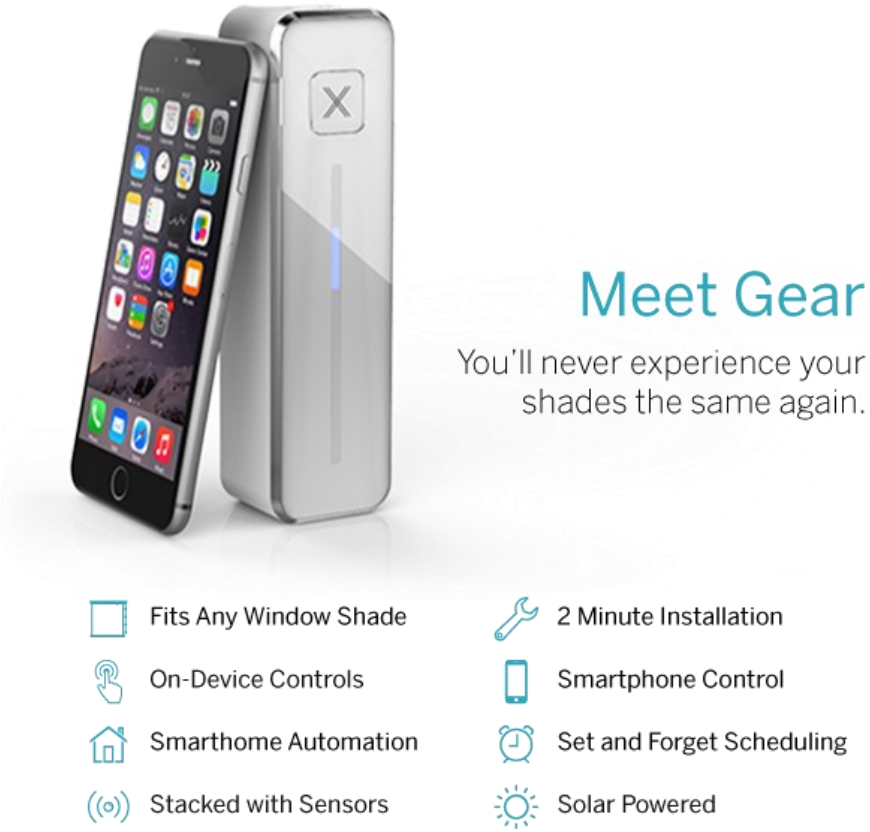
External shades



CHEeR House Shades

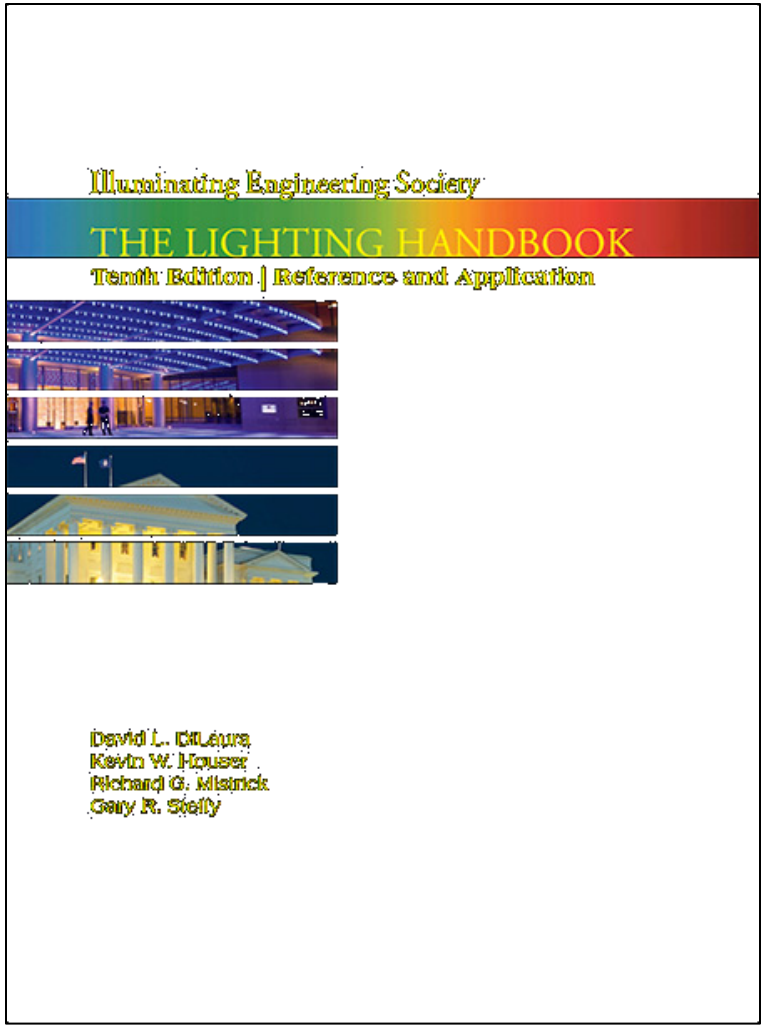
- The CHEeR House at Carleton has 18 motorized blinds
- Passive solar design (WWR_{south} =~ 30%) is prone to overheating
- Model predictive control

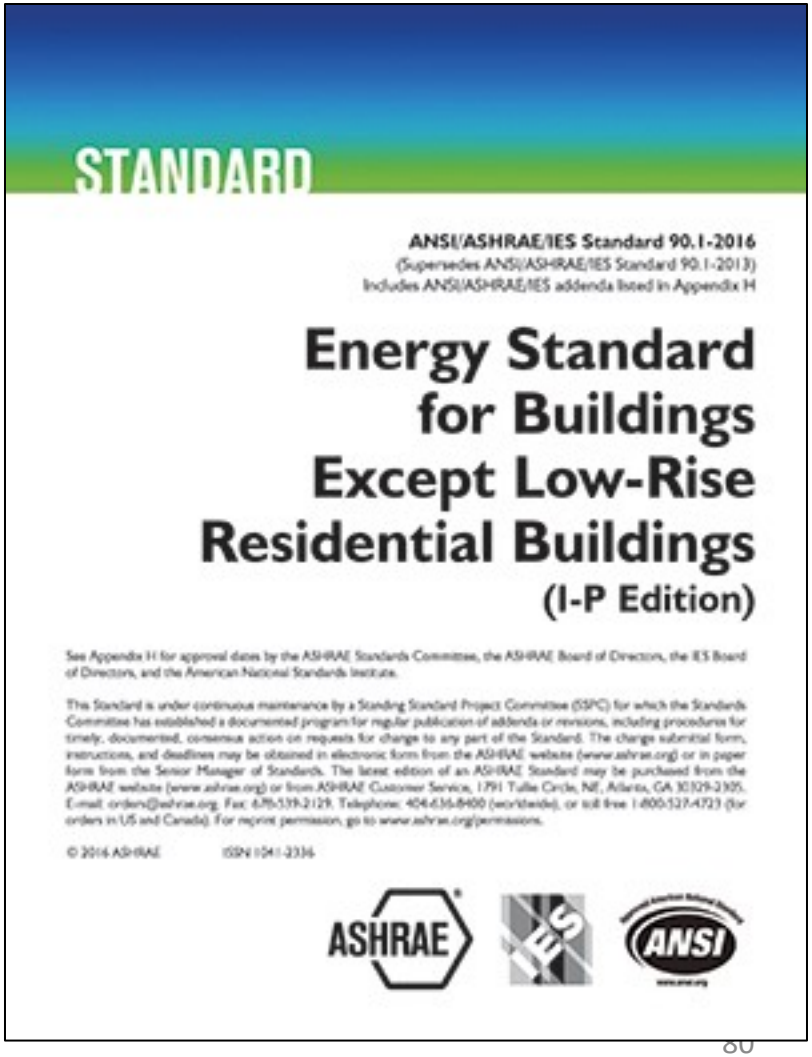
Smart home – motorized blind integration



https://www.youtube.com/watch?v=5PgSF194pDE

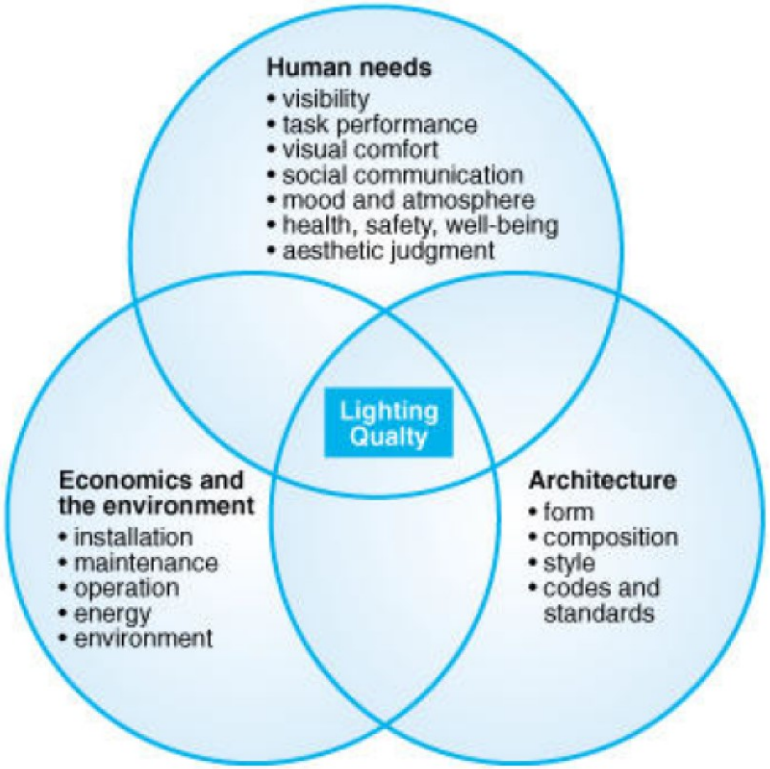
Lighting design





Lighting objectives

- Visibility: general scene visibility
- Task performance, e.g., reading paper on desk)
- Mood and atmosphere, e.g., relaxed soft lighting, bright light for alertness, lots of variation at concerts
- Visual comfort



Characteristic visual tasks (CIBSE, 1994)	*Illuminance (lux)*	*Illuminance category (IESNA, 2000)*
	30	**A** Public spaces
Confined to movement and casual seeing without perception of detail.	50	**B** Simple orientation for short visits
Movement and casual seeing with only limited perception of detail.	100	**C** Working spaces where simple visual tasks are performed
Involving some risk to people, equipment or product.	150	
Requiring some perception of detail.	200	
Moderately easy: i.e. large detail, high contrast.	300	**D** Performance of visual tasks of high contrast and large size
Moderately difficult: i.e. moderate size, may be of low contrast. Colour judgement may be required.	500	**E** Performance of visual tasks of high contrast and small size, or low contrast and large size
Difficult: details to be seen are small and of low contrast. Colour judgements may be important.	750	
Very difficult: very small details which may be of very low contrast. Accurate colour judgements required.	1000	**F** Performance of visual tasks of low contrast and small size
Extremely difficult: details are extremely small and of low contrast. Optical aids may be of advantage.	1500	
Exceptionally difficult: details to be seen are exceptionally small and of low contrast. Optical aids will be of advantage.	2000	
	3000	**G** Performance of visual tasks near threshold

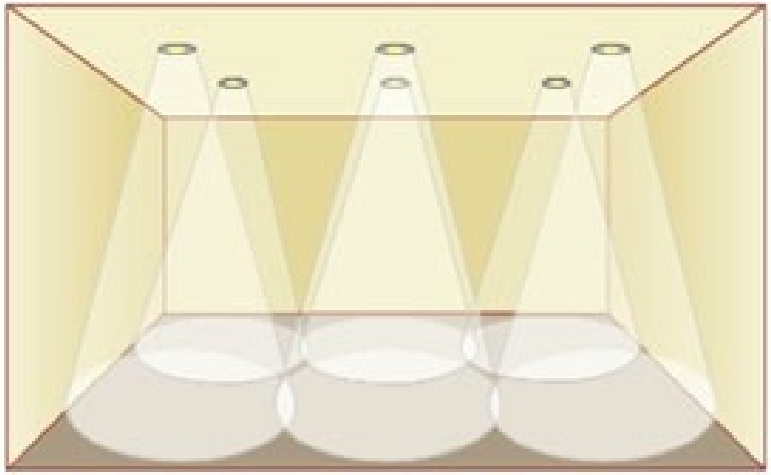
Lighting approaches

- Ceiling-mounted
- Suspended/pendant
- Wall-mounted for accent lighting
- Track luminaires
- Task lamps (desk/floor)
- Furniture-mounted

Vocabulary:

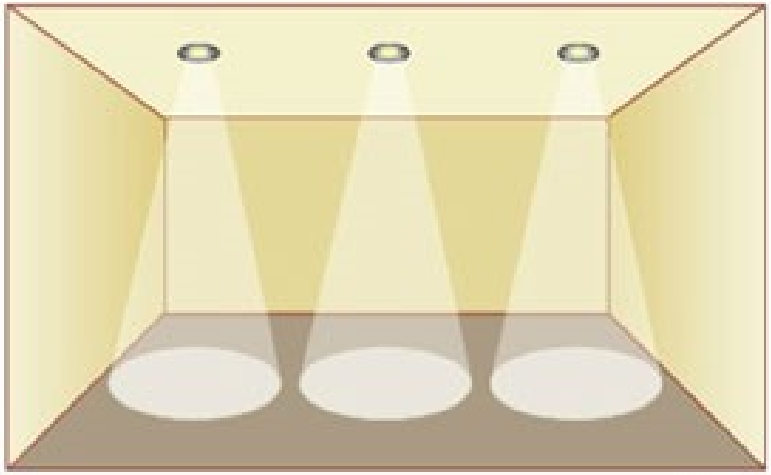
- **Luminaire**: light fixture that contains lamps
- **Lamp**: light bulbs (and LED panels, strips)

Lighting Layout



Uniform Downlighting

Uniform illumination bathes horizontal surfaces in light. Typically a general lighting technique, uniform illumination adds little dramatic impact to a space.



Non-uniform Downlighting

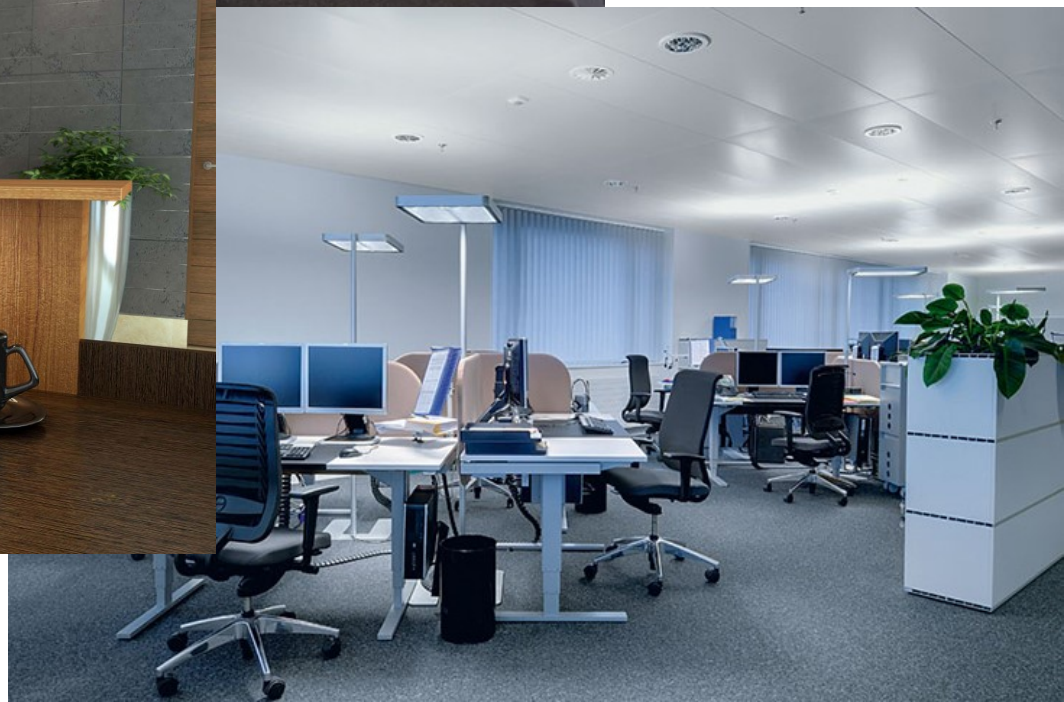
Non-uniform downlighting uses less light sources and delivers a more "individualized" beam spread of light. This lighting technique creates a more interesting visual effect in a space as the beams do not overlap as in general uniform downlighting.

Perceived difference	*Illuminance ratio*
Noticeable	1.5:1
Distinct	3:1
Strong	10:1
Emphatic	40:1

Ceiling-mounted vs. Pendant

Wall accent lighting and track luminaires

Task lamps

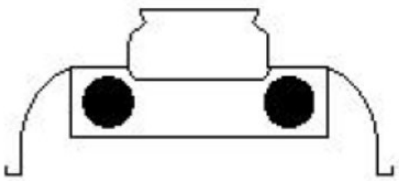
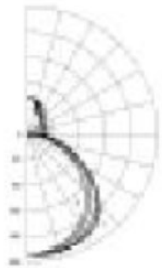


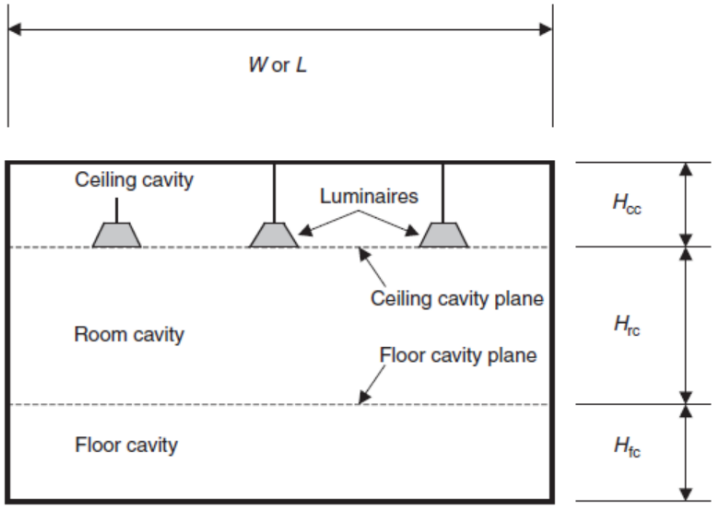
(a)

(b)

Panasonic

Lighting calculations

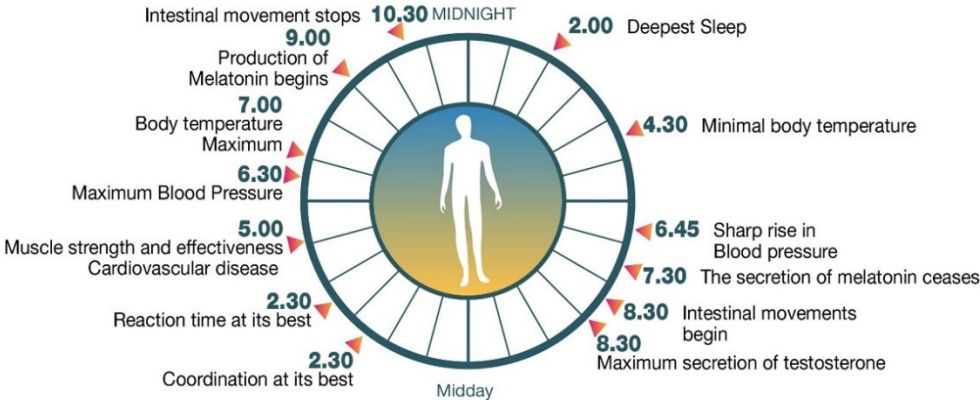
Typical Luminaire	Typical Intensity Distribution	ρcc →	80			70			50			30			10			0
		ρw →	70	50	30	70	50	30	50	30	10	50	30	10	50	30	10	0
		RCR ↓	EFF = 90.5%			% DN = 78.2%			% UP = 21.8%			Lamp = (2) F40T12 SC (along, across, 45°) = 1.3, 1.5, 1.5						
21   Industrial, white enamel reflector, 20% up		0	1.03	1.03	1.03	0.98	0.98	0.98	0.90	0.90	0.90	0.82	0.82	0.82	0.74	0.74	0.74	0.71
		1	0.93	0.89	0.85	0.89	0.85	0.81	0.77	0.74	0.72	0.70	0.68	0.66	0.64	0.62	0.61	0.58
		2	0.84	0.77	0.71	0.80	0.74	0.68	0.67	0.63	0.59	0.61	0.58	0.54	0.56	0.53	0.50	0.47
		3	0.77	0.67	0.60	0.73	0.64	0.58	0.59	0.53	0.49	0.54	0.49	0.45	0.49	0.45	0.42	0.40
		4	0.70	0.59	0.51	0.66	0.57	0.50	0.52	0.46	0.41	0.48	0.43	0.39	0.44	0.39	0.36	0.33
		5	0.64	0.53	0.45	0.61	0.51	0.43	0.46	0.40	0.35	0.43	0.37	0.33	0.39	0.35	0.31	0.29
		6	0.59	0.47	0.39	0.56	0.45	0.38	0.42	0.35	0.31	0.38	0.33	0.29	0.35	0.31	0.27	0.25
		7	0.55	0.43	0.35	0.52	0.41	0.34	0.38	0.32	0.27	0.35	0.30	0.26	0.32	0.28	0.24	0.22
		8	0.51	0.39	0.31	0.48	0.37	0.30	0.34	0.28	0.24	0.32	0.27	0.23	0.29	0.25	0.21	0.19
		9	0.47	0.35	0.28	0.45	0.34	0.27	0.32	0.26	0.21	0.29	0.24	0.20	0.27	0.23	0.19	0.17
		10	0.44	0.33	0.26	0.42	0.31	0.25	0.29	0.23	0.19	0.27	0.22	0.18	0.25	0.21	0.17	0.16



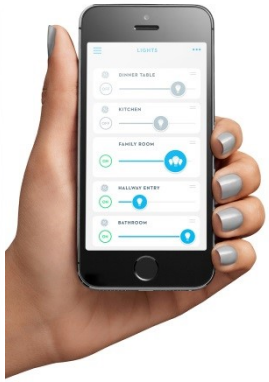
Lighting colour choice

Circadian Rhythm-based lighting

- New products and controls are aimed at providing the optimal light colour and intensity as a function of time of day
- https://www.youtube.com/watch?v=gU-JzVwx-2M



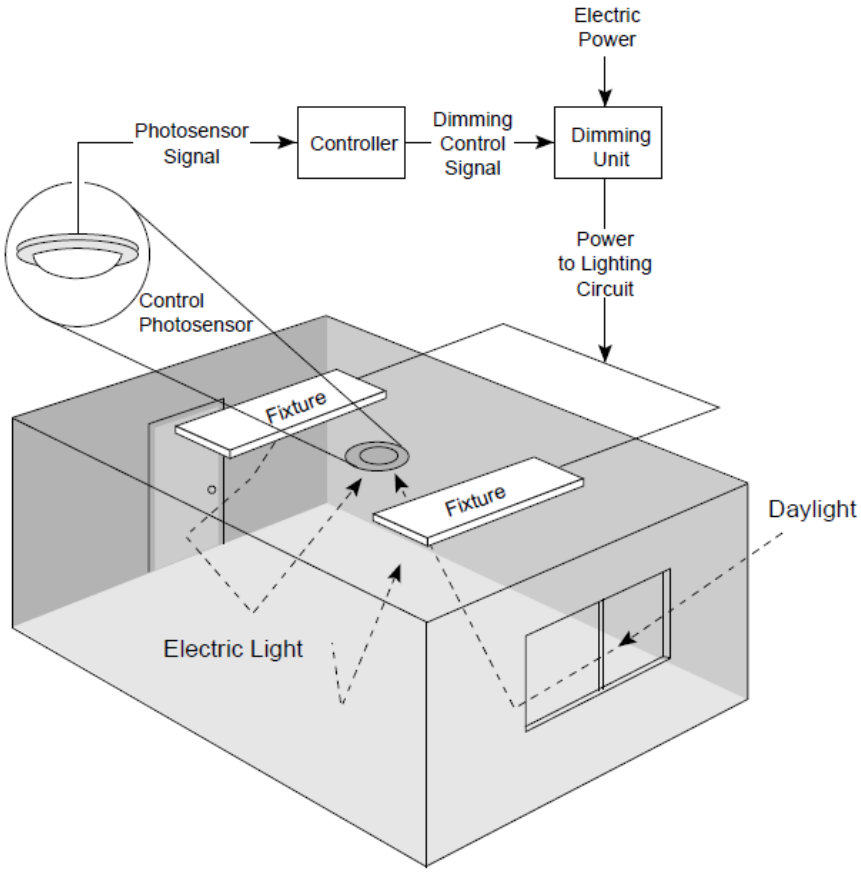
Control of (day)lighting



Lighting Controls

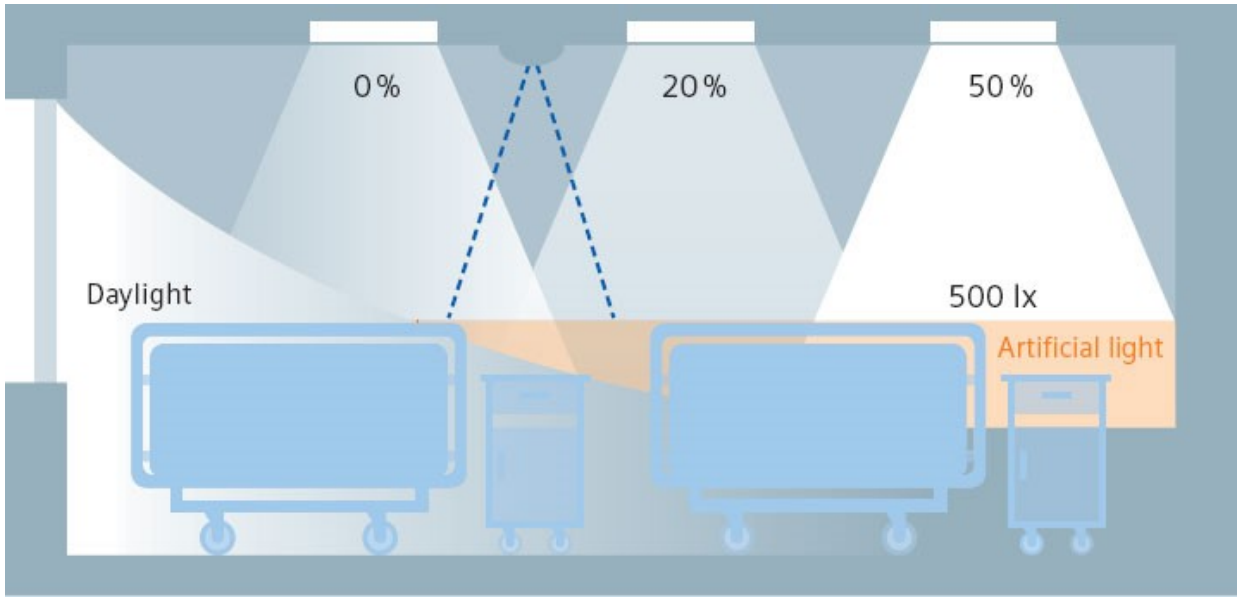
- Objective: Minimize electricity use while maintaining desired lighting
- Involves three components:

1. Light/occupancy sensor
2. Luminaire(s)
3. Control system



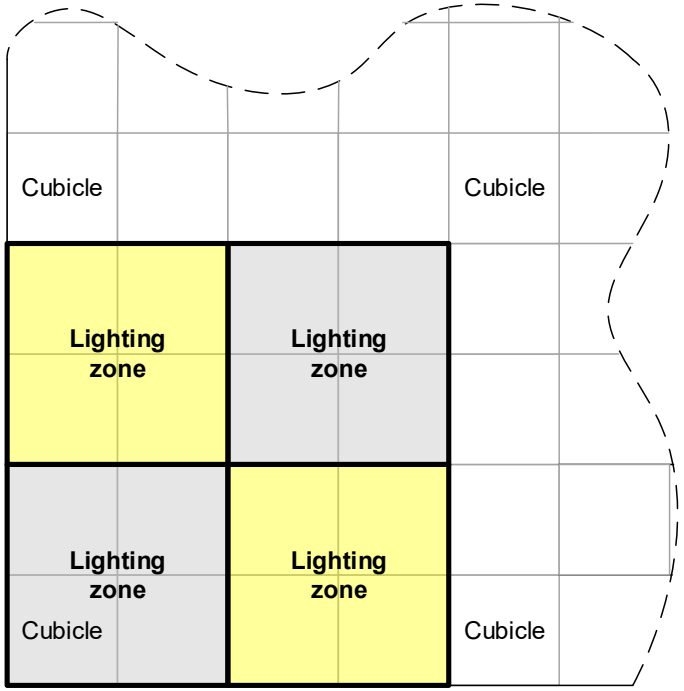
State-of-the-art in Lighting Controls

- Continuous dimming
- Occupancy (absence)
- Integrated sensors in luminaires

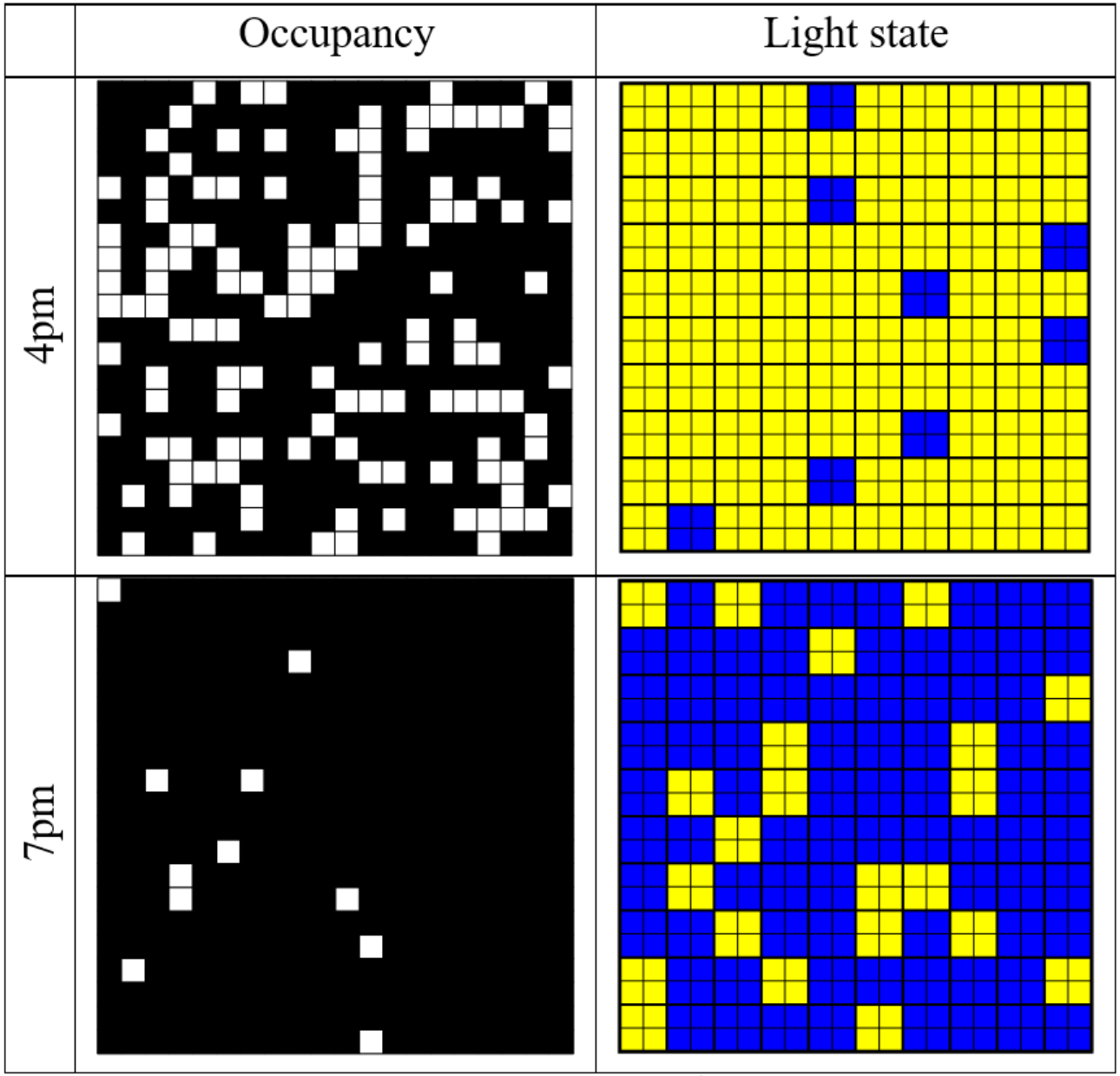


Example simulation: lighting analysis

- Variable lighting control zone size
- Four different occupancy level scenarios
- Stochastic occupancy model to simulate individual occupants/cubicles
- Lights turn on upon arrival
- Lights stay on until all occupants from a given zone have been gone for 20 minutes

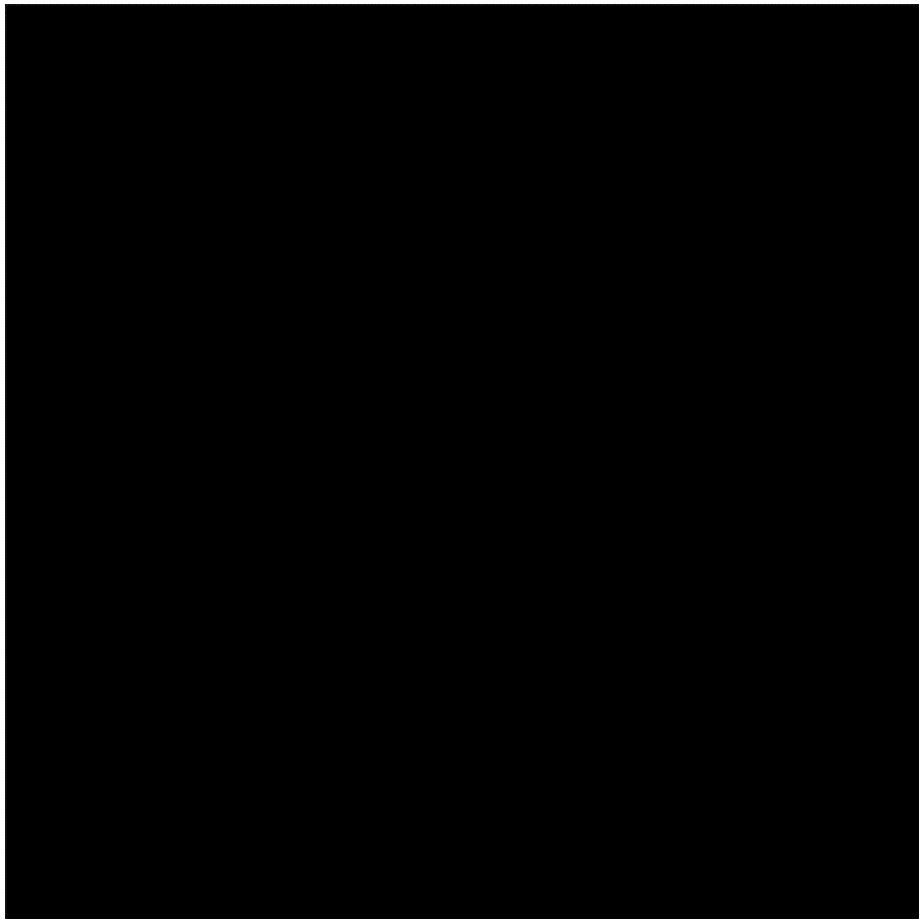


Example: one point in time

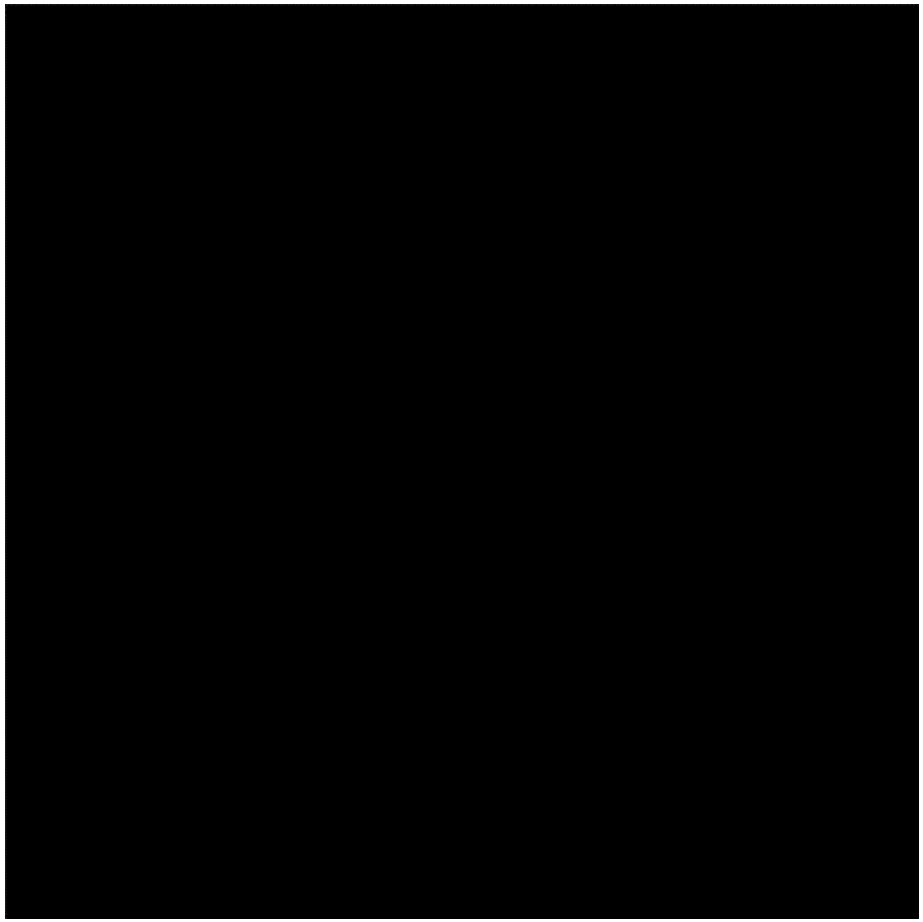


4 cubicles/lighting control zone

Occupancy

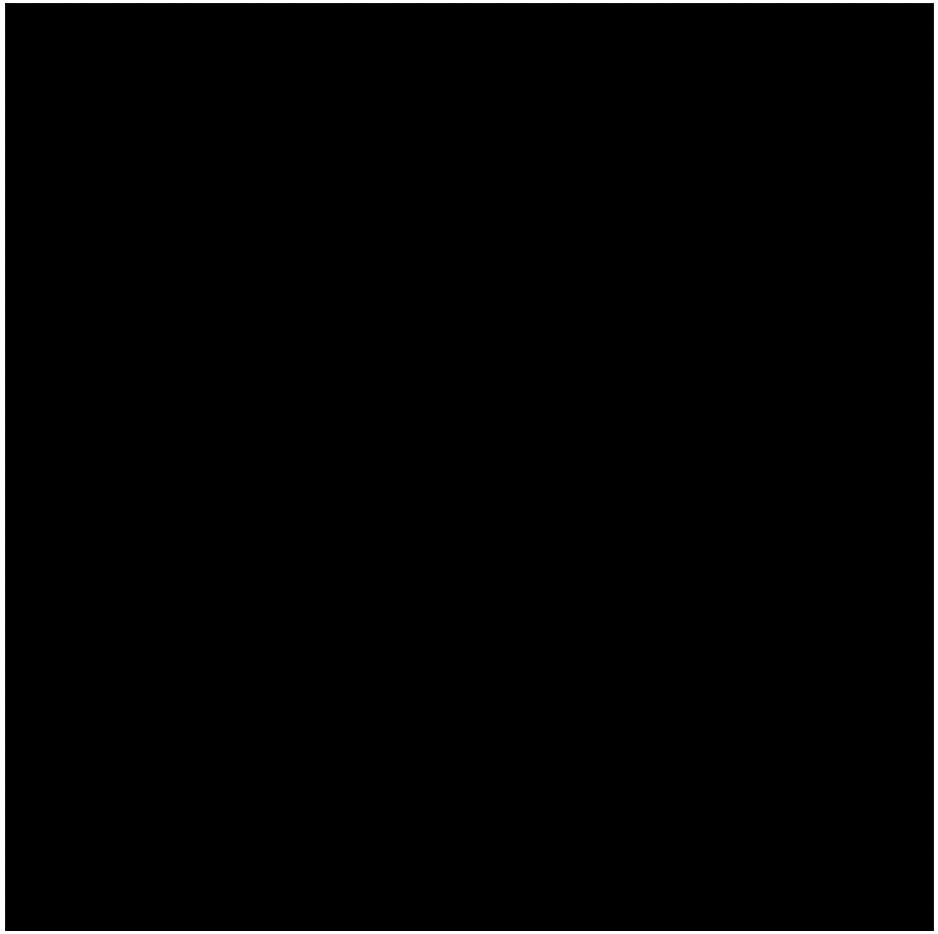


Lighting

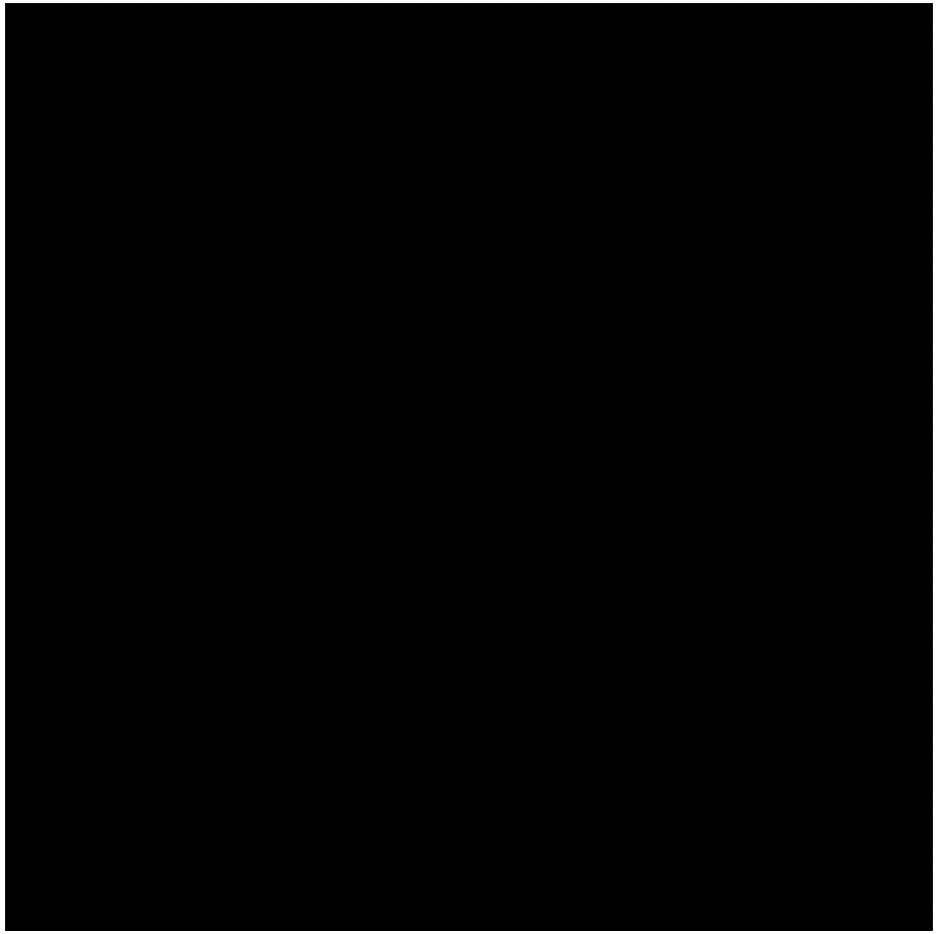


25 cubicles/lighting control zone

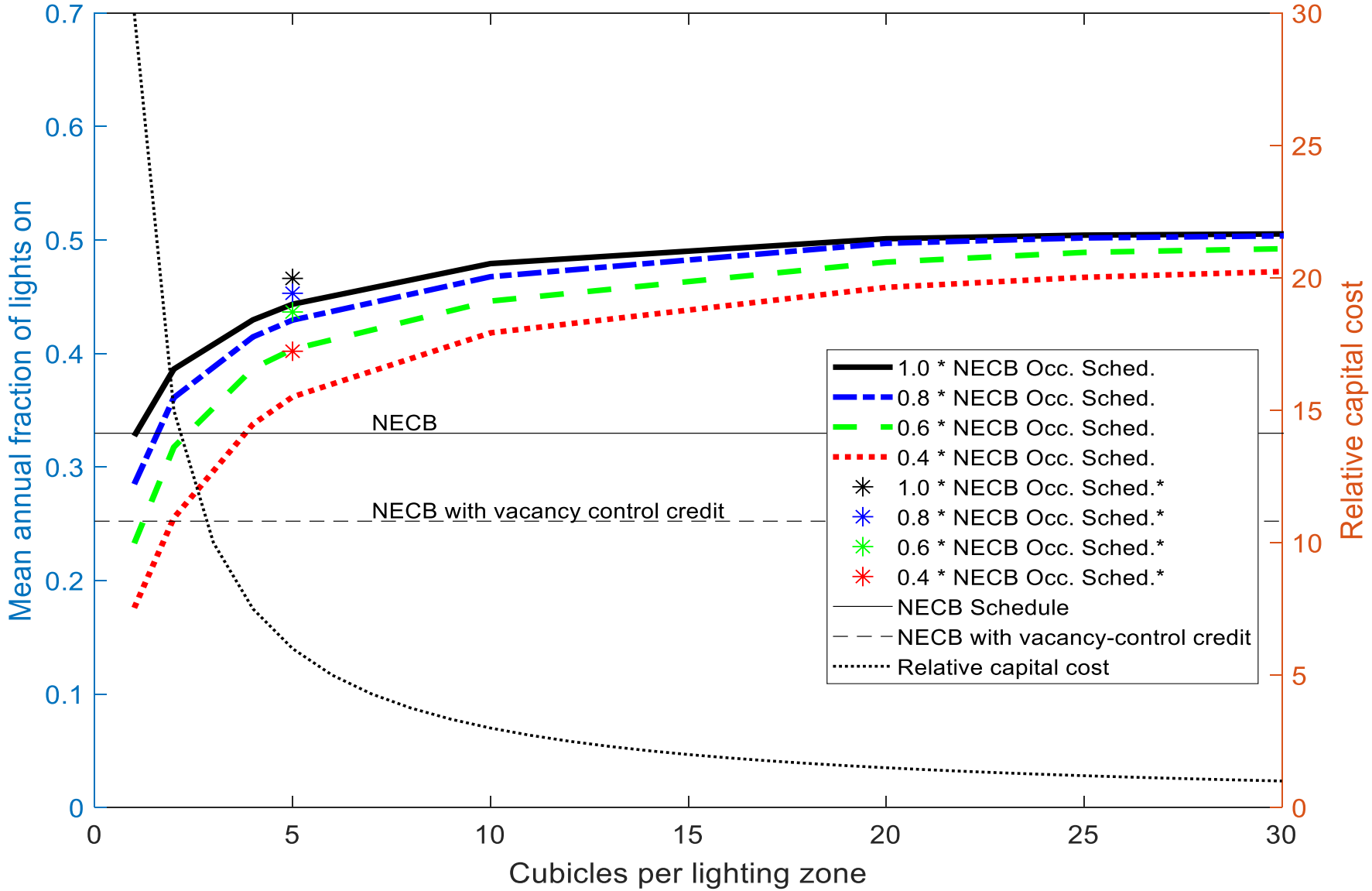
Occupancy



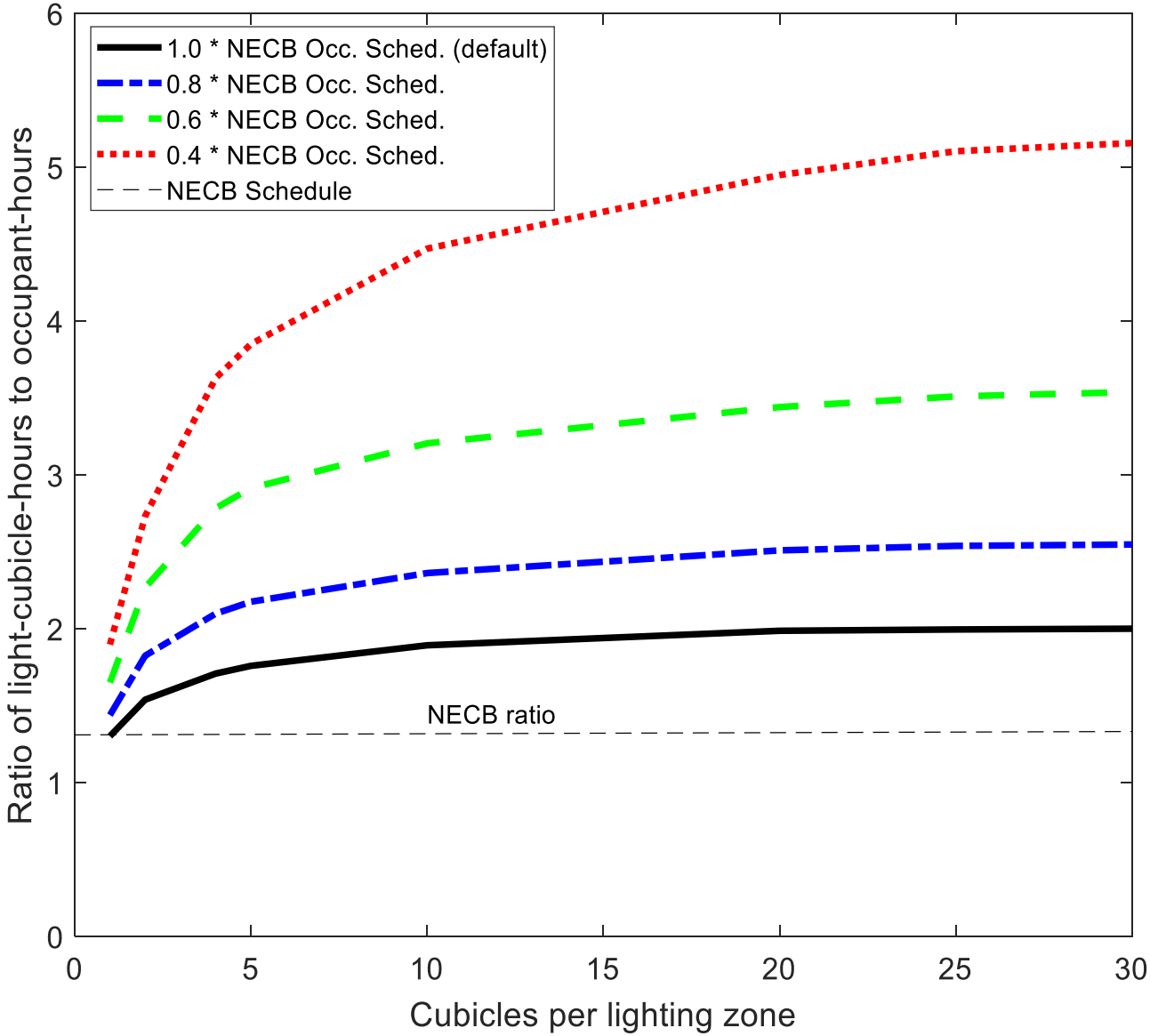
Lighting



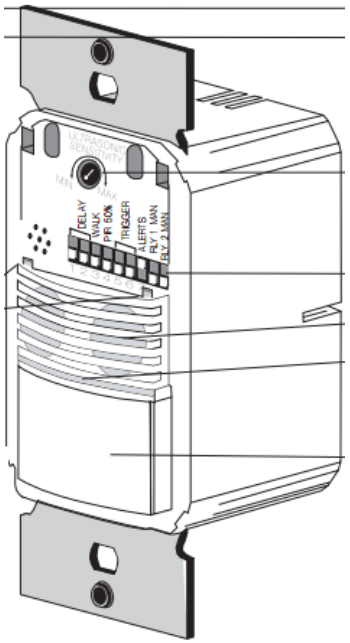
Results of annual simulation

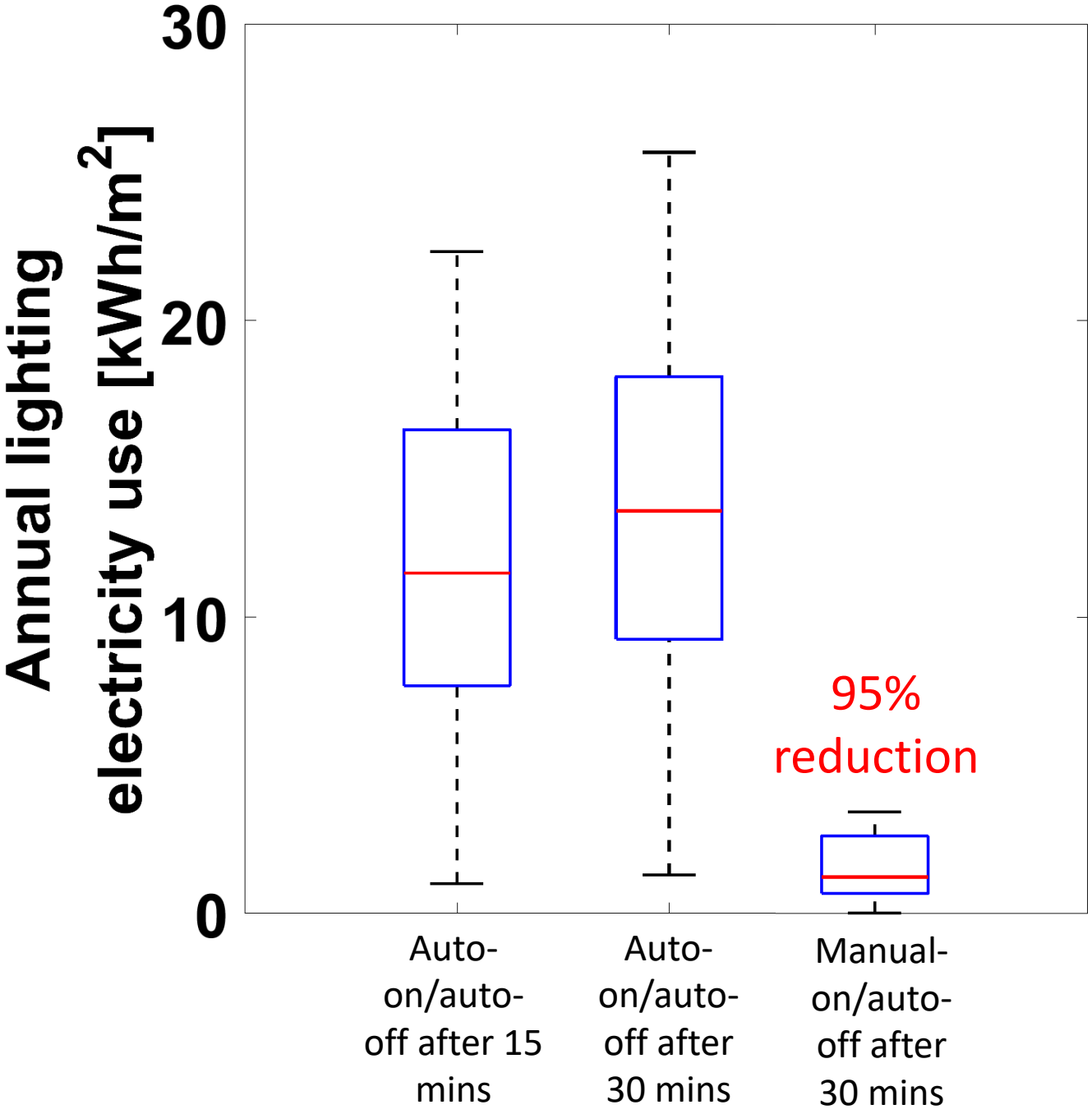


Results of annual simulation



LP-6AD4-7-3


DELAY
WALK
PIR 50%
TRIGGER
OUTPUT S
RLY 1 MAN
RLY 2 MAN


Annual lighting electricity use [kWh/m^2]
30
20
10
0
95% reduction
Auto-on/auto-off after 15 mins
Auto-on/auto-off after 30 mins
Manual-on/auto-off after 30 mins

Lighting in the codes/standards

- NECB/90.1 deal with lighting power and associated control rules
- LEED/WELL/IES focus on visual comfort and energy

Table A-8.4.3.2.(2)-A
Modeling Guidance for Loads, Operating Schedules and Illuminance Levels by Building Type

Building Type	Occupant Density, m²/occupant	Peak Receptacle Load, W/m²	Service Water Heating Load, W/occupant	Operating Schedule from A-8.4.3.2.(1)	Illuminance Levels, lx(1)
Automotive facility	20	5	90	E	400
Convention centre	8	2.5	30	C	300
Courthouse	15	5	60	A	400
Dining					
bar lounge/leisure	10	1	115	B	125
cafeteria/fast food	10	1	115	B	300
family	10	1	115	B	300
Dormitory	30	2.5	500		
Exercise centre	10	1	90		
Fire station	25	2.5	400		
Gymnasium	10	1	90		

Lighting Power Density by Building Type for Use with the Building Area Method
Forming Part of Sentences 4.2.1.5.(1), (4) and (5)

Building Type	Lighting Power Density, W/m²
Automotive facility	8.6
Convention centre	10.9
Courthouse	10.9
Dining:	
bar lounge/leisure	10.9
cafeteria/fast food	9.7
family	10.2
Dormitory	6.1