4.430 Daylighting

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4.430 Electric Lighting

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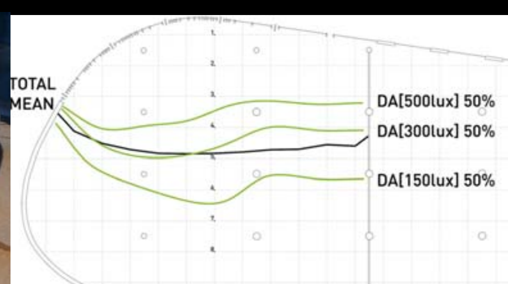
Department of Architecture
Building Technology Program

Daylit Area Study

Carpenter Center Study (2011)

Courtesy of Shelby Doyle. Used with permission.



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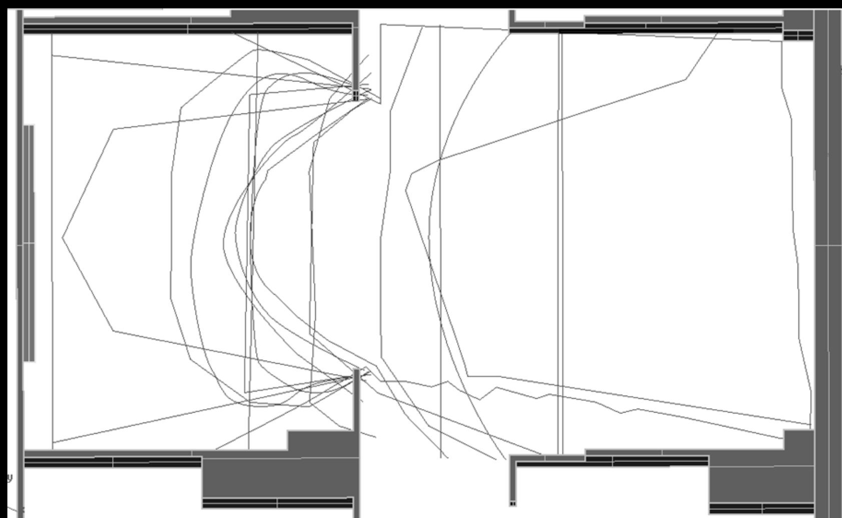
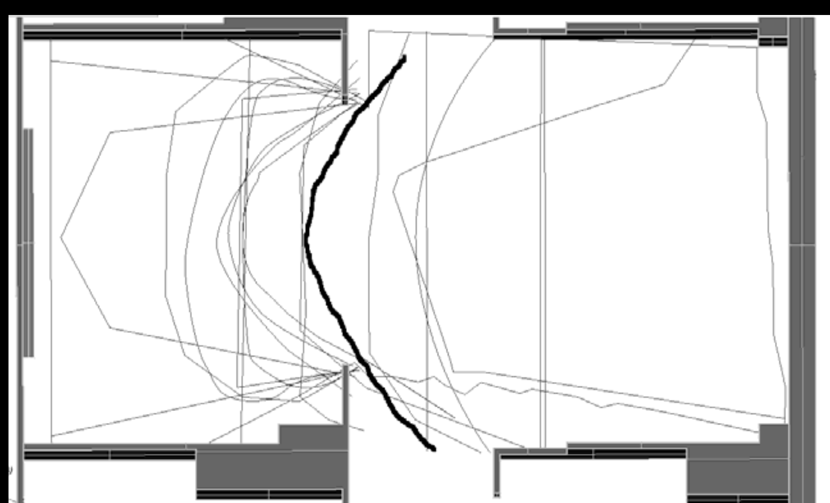
MIT Room 10.485



MIT Room 10.485



MIT Room 10.485

First Results from Gund Glare Survey

2. Did the lighting conditions this semester influence your productivity for the following tasks?

Create Chart Download

	Positive Influence	Did Not Influence	Negative Influence	Response Count
Reading and writing.	16.3% (20)	**63.4% (78)**	20.3% (25)	123
Building physical models.	12.2% (15)	**79.7% (98)**	8.1% (10)	123
Using the computer.	12.2% (15)	**50.4% (62)**	37.4% (46)	123

Annual Glare Map

First Results from Gund Glare Survey

1. Indicate the typical degree of discomfort glare you experienced at your desk during this semester.

Create Chart Download

	Imperceptible	Perceptible	Disturbing	Intolerable	Response Count
Mornings (8:00 - 12:00)	41.6% (52)	40.0% (50)	17.6% (22)	0.8% (1)	125
Lunch (12:00 - 2:00)	51.2% (64)	28.0% (35)	13.6% (17)	7.2% (9)	125
Afternoons (2:00 - 6:00)	55.2% (69)	24.0% (30)	16.0% (20)	4.8% (6)	125
				answered question	125
				skipped question	69

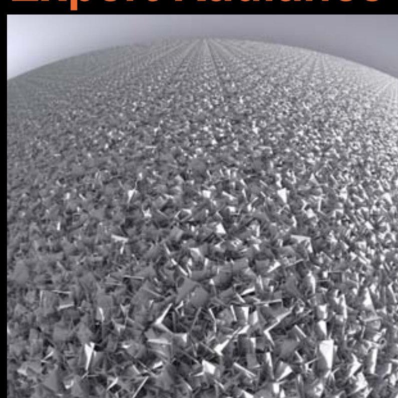
- These results will help us to validate how effective DGP is.

$$DGP = 5.87\times10^{-5}E_v + 9.18\times10^{-5}\log\left(1+\sum_i \frac{L_{s,i}^2\,\omega_{s,i}}{E_v^{1.87}P_i^2}\right)$$

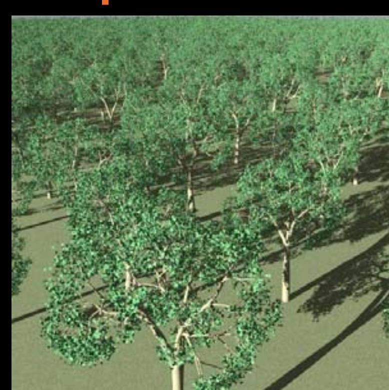
Illuminance-based

Image-based

Expert Radiance Examples



Randomly oriented open boxes across mesh
void plastic def 0 0 5 0.8 0.8 0.8 0 0
3976 polygons per tile turned into frozen octree
xform to make 100x100 array of tiles
vh 100 - vv 100 -vta -aa 0 -ad 16 -ab 2 -as 0 -ps 1 -x 2048 -y 2048
"Mark J. Stock" 2005



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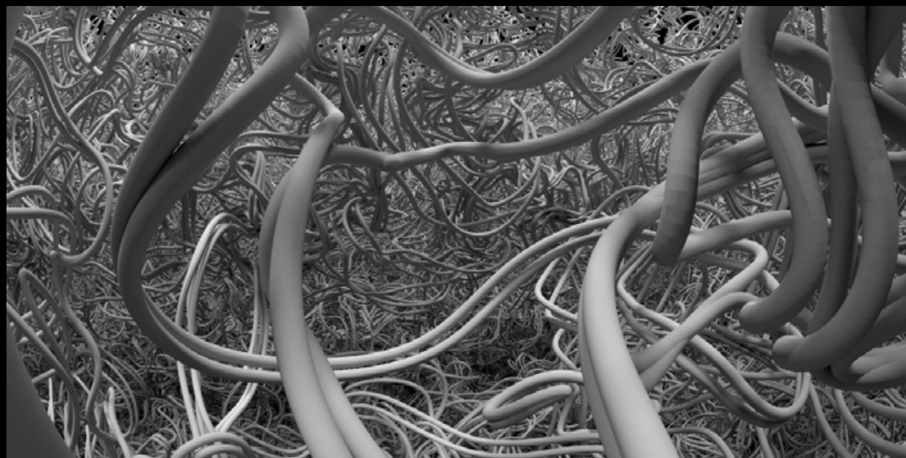
vh 100 -vv-100 vta aa 0 -ad 16 -ab 2 -as 0 -ps 1 -x 2048 -y 2048
"Mark J. Stock" 1998

Expert Radiance Examples



"Turbulence Infinite" "Mark J. Stock" 2003

Mark Stock: “This was the first image that did not use ambient caching (aa 0). While this may look infinite, there are cleverly placed mirrors to make 100k segments look like more.”

Light Sources & Fixtures

Light Direction

Light travels in a straight line…radiates out from the source

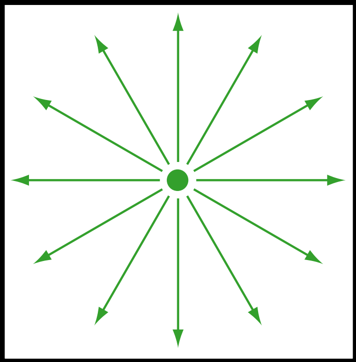
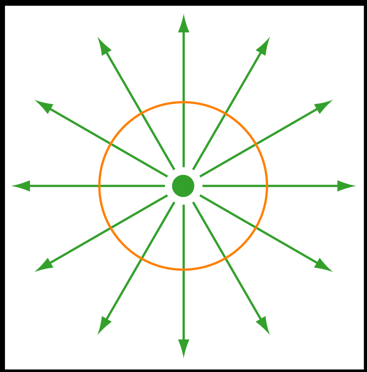


Image by MIT OpenCourseWare.

Light Direction of Clear Lamps

…. add a clear enclosure or envelope around the source, the light will still travel in a straight line.



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Light Direction of Frosted Lamps

Light travels in a straight line…radiates out from the source

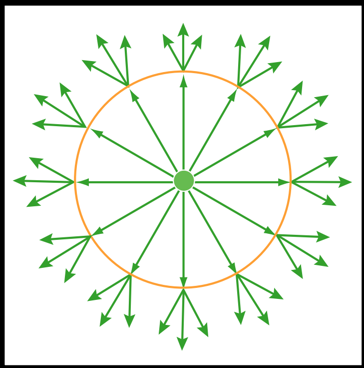
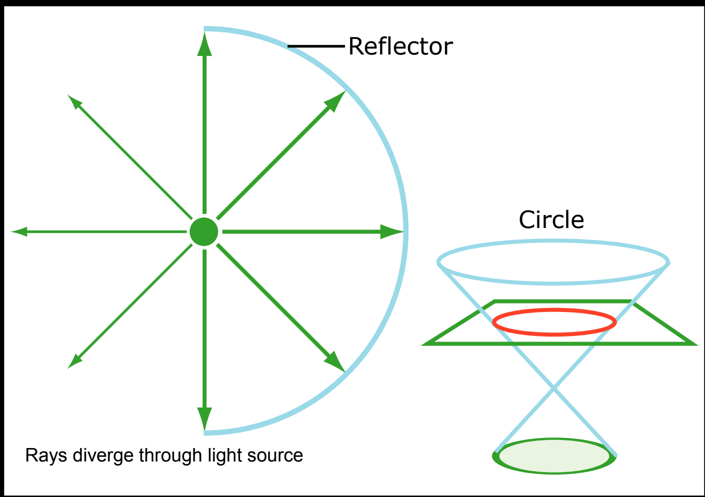


Image by MIT OpenCourseWare.

…. add a coated or frosted enclosure or envelope around the source, the direction of light will bend and radiate from the surface of the enclosure

Reflector Contours



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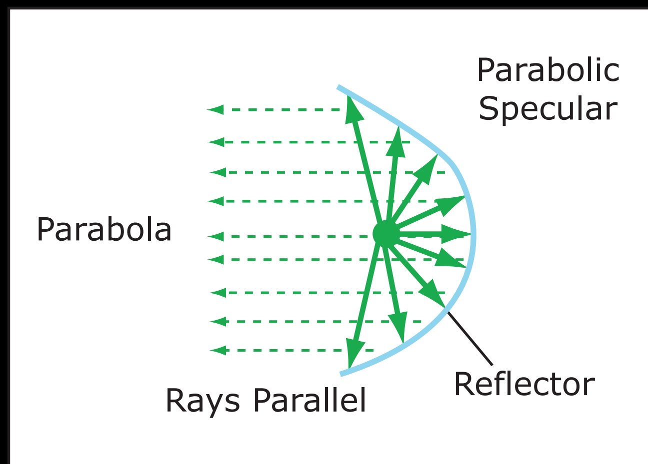
Reflector Contours



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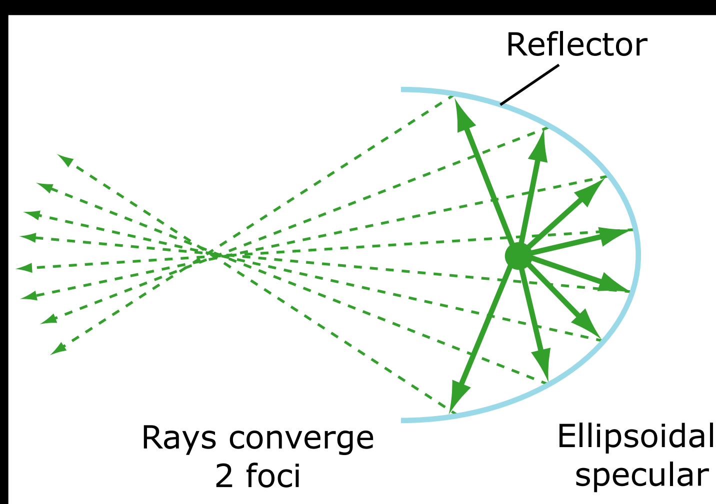
Reflector Contours



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Lamps for General Use

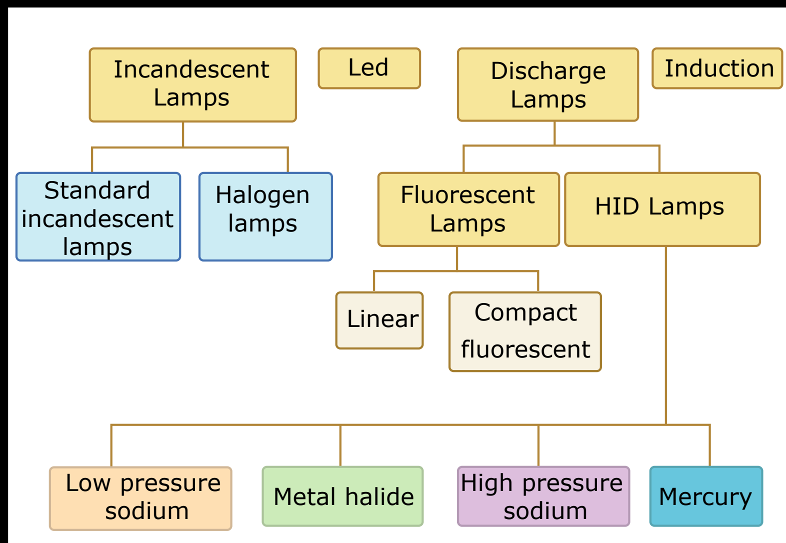


Image by MIT OpenCourseWare.

Burning Temperature

The higher the color temperature (CCT), the "cooler" the color of the lamp is in appearance.

The lower the color temperature (CCT) the "warmer" the color the lamp is in appearance.

This color temperature is measured in Kelvin.

Illustration of color temperatures removed due to copyright restrictions.

Incandescent

- Varied wattages, sizes, shapes, and bases
- Finishes: Clear, Inside Frosted, Coated
- Economical
- Short lamp life
- Warm Light
- Can be dimmed.

Color Spectrum – Daylight & Incandescent

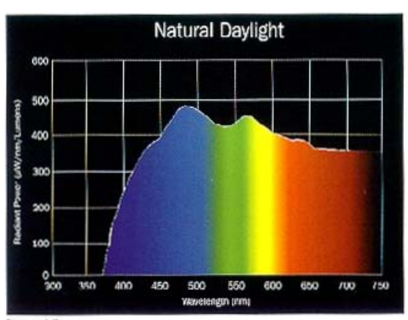


Plate 12

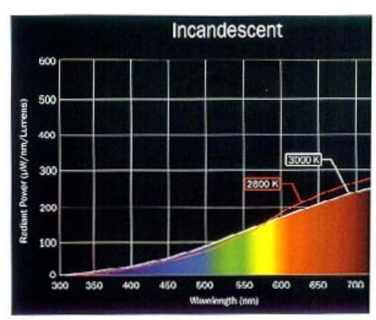


Plate 13

Correlated Color Temperature

Color Temperature	Warm	Neutral	Cool	Daylight
Kelvin Range	3000k	3500k	4100k	5000k
Associated Effects and Moods	Friendly Intimate Personal Exclusive	Friendly Inviting Non-threatening	Neat Clean Efficient	Bright Alert Exacting coloration
Appropriate Applications	Restaurants Hotels lobbies Boutiques Libraries office areas Retail stores	Public reception areas Showrooms Bookstores Office areas	Office areas Conference rooms Classrooms Mass merchandisers Hospitals	Galleries Museums Jewelry stores Medical examination areas Printing companies

Image by MIT OpenCourseWare.

North sky light >10,000 K

Color Rendering Index

Image of color rendering index and examples removed due to copyright restrictions.

Ability of a light source to reproduce color.

Example Correlated Color Temperature

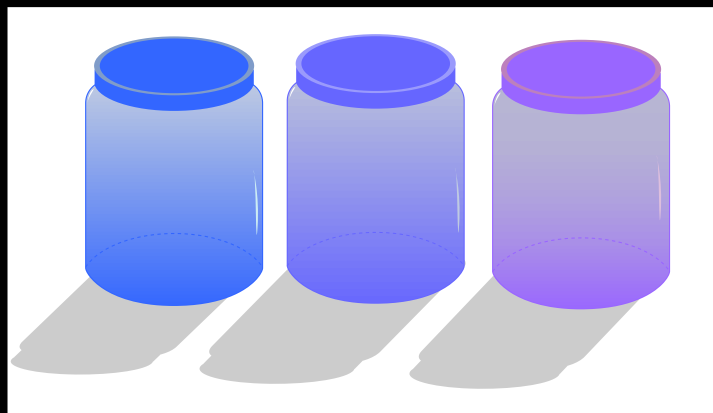


Image by MIT OpenCourseWare.

	COOL	MIDRANGE	WARM
CCT:	4100ºK	3000ºK	2700ºK
CRI:	80CRI	80CRI	80CRI

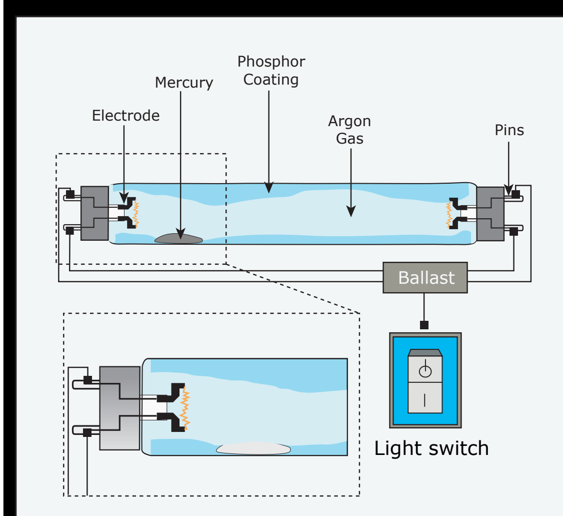
Halogen (also Incandescent)

- ❑ Varied wattages, sizes, shapes, and bases
- ❑ Finishes: Clear, Inside Frosted, Coated
- ❑ Small Sources - Ideal for controlled optics
- ❑ Often low voltage and require transformers
- ❑ White Light
- ❑ Can be dimmed.

Fluorescent

- ❑ Varied wattages, sizes, shapes, and bases
- ❑ Finishes: Coated only ï coating determines color
- ❑ Operates with specific Ballast
- ❑ Long Life
- ❑ Cool Burning
- ❑ Dimming: Yes, with dimming ballast and specific dimmers

Fluorescent Lamp Design



Rapid start and starter switch fluorescent bulbs have two pins that slide against two contact points in an electrical circuit.

Image by MIT OpenCourseWare.

Color Spectrum - Fluorescent

Spectrum graphs of four different types of fluorescent lights removed due to copyright restrictions.

Slide courtesy of Conor Sampson.

Ballasts

Ballasts perform three main functions

- ❑ They start the lamp
- ❑ They take the line voltage (120/240/277/480) and step it up or down as required by the lamp.
- ❑ The make sure that the lamp operates in stable mode by regulating the current.

Ballasts can be electromagnetic (heavy coils) or electronic (lightweight and high frequency).

The Uniqueness Rule

- ❑ Ballast are made specifically for the lamp they are designed to operate. You cannot simply replace a lamp with a different type without changing the ballast. Since it regulates the voltage it is designed for a specific lamp type and wattage.

How LED's Work

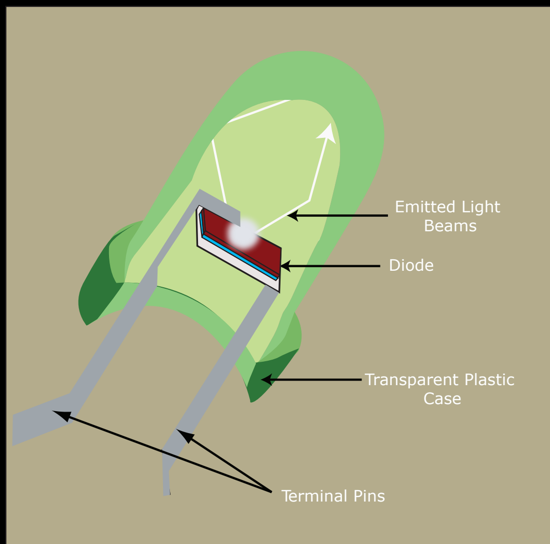


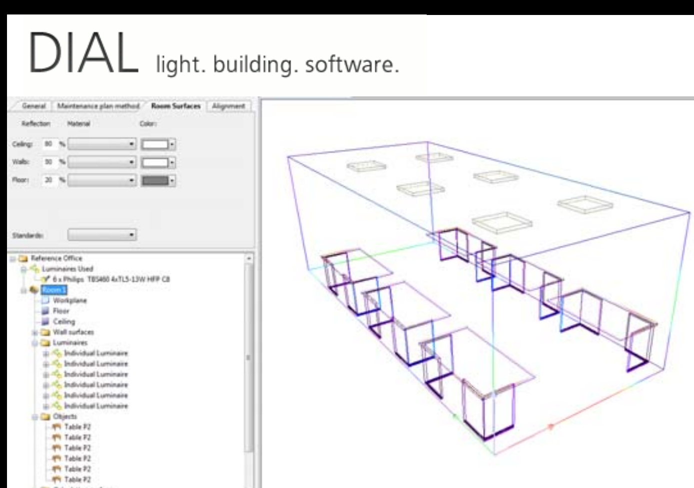
Image by MIT OpenCourseWare.

Table of candlepower distribution and rendering of linear fluorescent uplight removed due to copyright restrictions.

Slide courtesy of Conor Sampson.

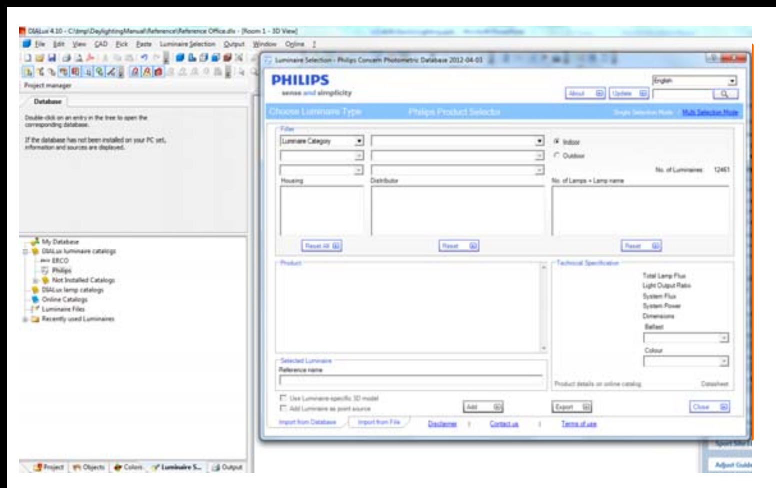
Electric Lighting

Modeling Electric Lighting



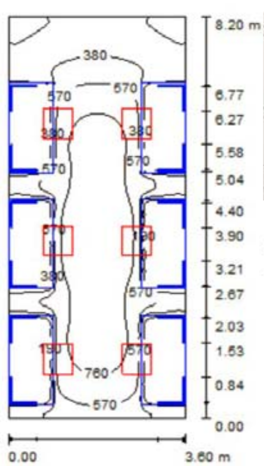
- ❑ Calculations based on POV Ray for Windows
- ❑ Allows to model a simple room with various pieces of furniture.

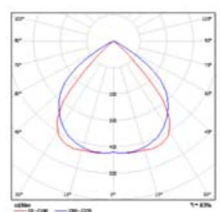
Modeling Electric Lighting



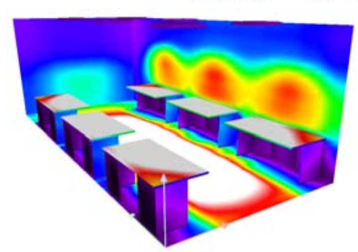
- ❑ Link to multiple luminaire manufacturers.
- ❑ Plug-in allows to actual products to a scene.

Example for Reference Office





No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	6	Philips TBS460 4xTL5-13W HFP C8 (1.000)	3818	4600	59.0
			Total: 22908	Total: 27600	354.0



- ❑ Three rows of offices. Each row consists of two 4xTL5-13W recessed downlights.

Electric Light Source in Radiance

Method 1 – Point Sources

1. Determine Lumens = 860 lm (luminous flux)
2. Convert to Watt: 860 lm / 179 W/lm = 4.8 W
3. Assume a spherical source with a diameter of 0.1m.
4. The resulting surface area of the light source is: $4\pi(0.1\text{m})^2 = 0.126\text{m}^2$
5. The radiosity of the light source is hence $M = 4.8\text{ W}/ 0.126\text{m}^2 = 38.2\text{ W/m}^2$
6. The radiance of a Lambertian source $L = M/\pi = 12.17\text{ W/ster m}^2$
7. The light source in Radiance is

```
void light Bulb
0 0 3 12.17 12.17 12.17
```

```
Bulb sphere LightBulb
0 0 4 x y z 0.1
```

Lighting Controls

Overview of different Lighting Controls

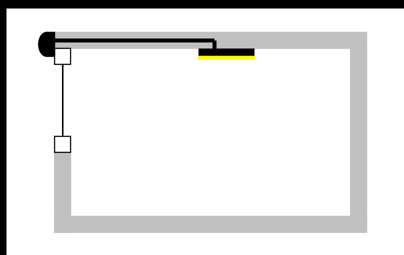
- *Manual*, *automated* and *automated with manual overwrite*
- Bi-level switching.
- Manual dimming
- Photocell–controlled on/off
- Photocell–controlled dimming (specifier report)
- Occupancy sensors (specifier report)

NLPIP Specifier Reports (great documents but out of date by now)

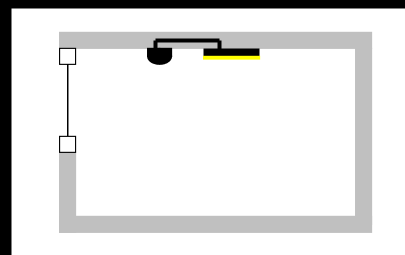
Why Lighting Controls?

- To tailor lighting conditions to occupant’s changing need.
- To raise occupant satisfaction.
- To safe energy.

Photocell Controlled Dimming



open loop



closed loop

- fewer sensors
- less dependant on interior changes
- works well for toplighting or in the
- absence of a shading device

good solution for shared spaces (atria, retail, open plan)

- more sensors but more individualized
- considers blind setting
- suitable for private offices
- requires careful commissioning

Automated Dimming Systems

- ❑ Open loop systems
    - ❑ easier to commission
    - ❑ drawback: system does not respond to blind use
- ❑ Closed loop systems

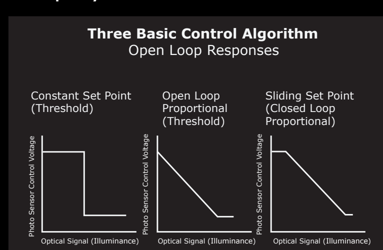


Image by MIT OpenCourseWare.

- ❑ A good tutorial on photo sensors:

http://www.lrc.rpi.edu/programs/nlpip/tutorials/photosensors/feed.asp

Rules of Thumb – Lighting Controls

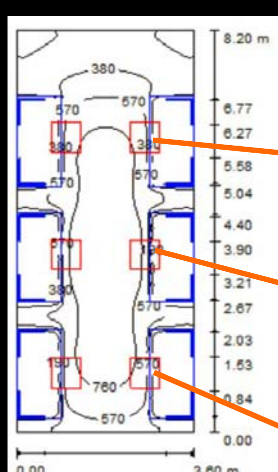
Photographs of occupancy sensor and photocell removed due to copyright restrictions.

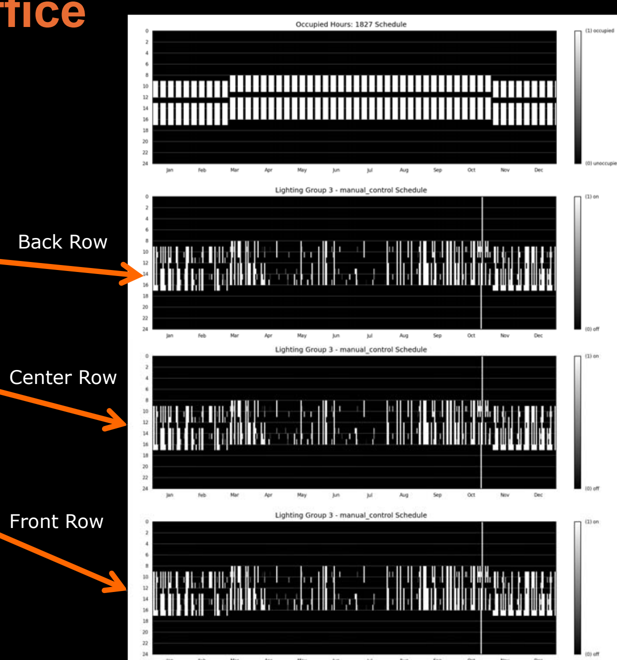
occupancy sensor *occupancy & photocell*

- ❑ occupancy sensors save 25% to 50% lighting energy
- ❑ photocell controlled dimming saves
  - 50-60% in perimeter zone
  - 25-40% in 'second row'
- ❑ commissioning photocells is easier for 'top-lighting' than 'side-lighting'

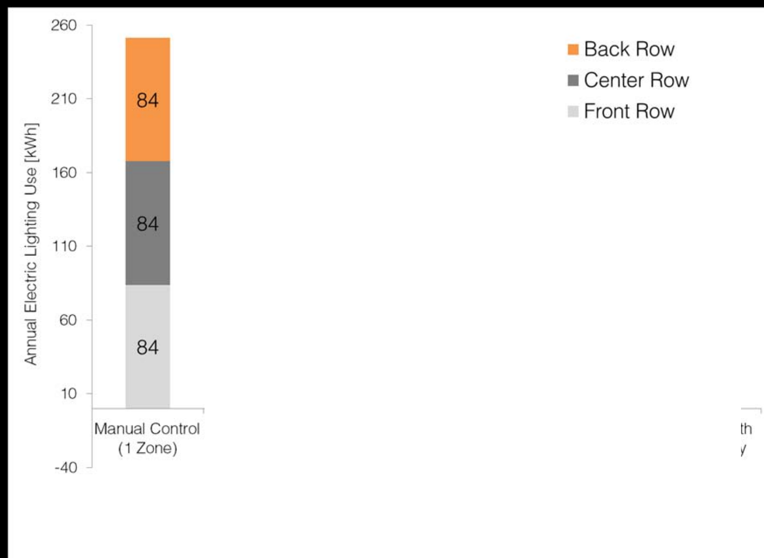
Reference Office

Manual Control 1 Zone





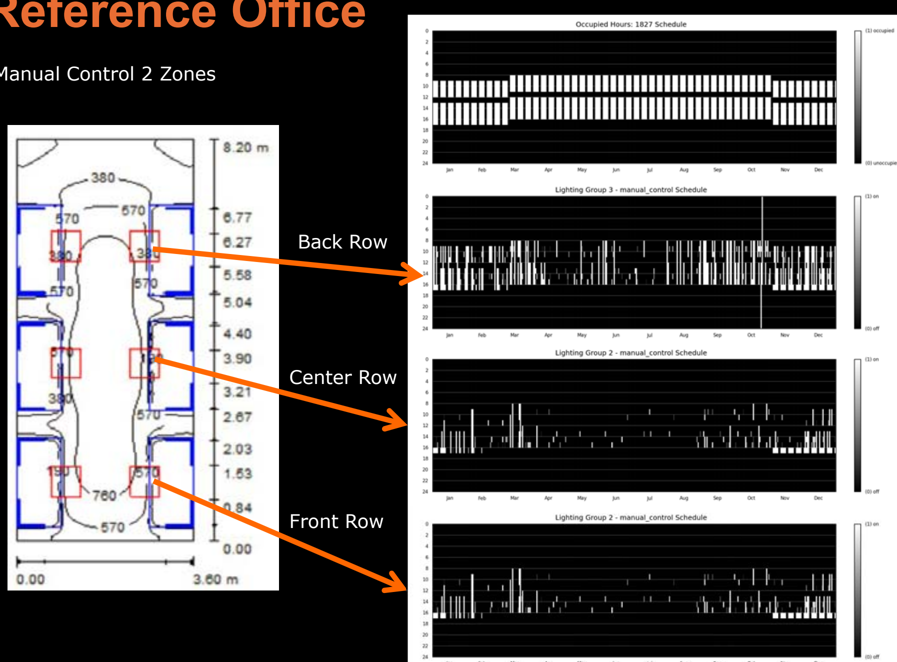
Lighting Use in Reference Office



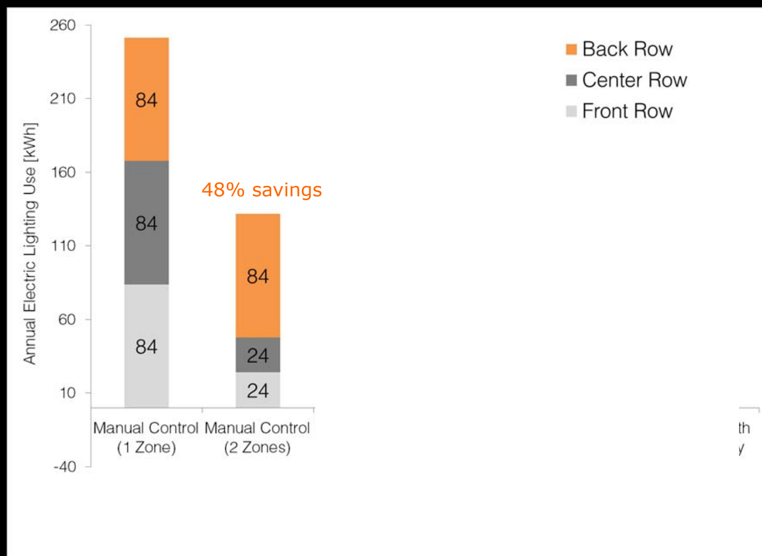
- Base/reference case

Reference Office

Manual Control 2 Zones



Lighting Use in Reference Office



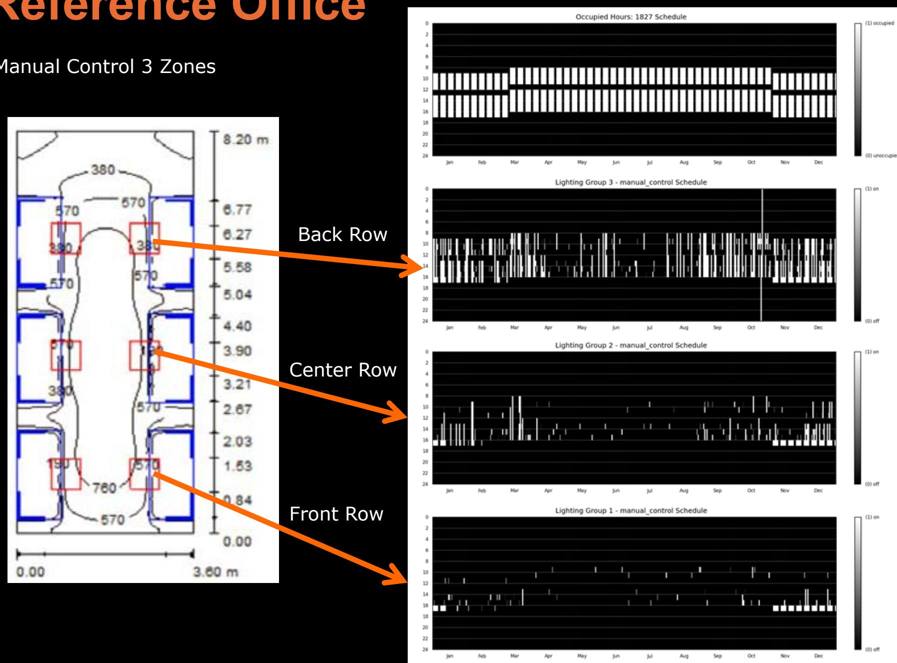
- Clear benefit from zoning.

Simple Payback – Two Zones

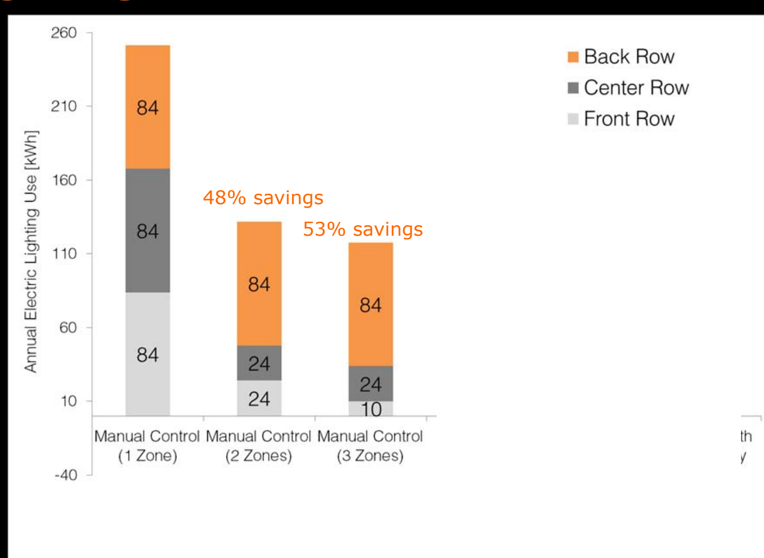
- *assumed price premium $5-20*
- *Absolute annual energy savings: 120 kWh*
- *Assuming a cost of 0.18 W/kWh*
- *Saving: 21$/yr*
- *Simple payback time around < 1 year*

Reference Office

Manual Control 3 Zones



Lighting Use in Reference Office



- ❑ Triple zones, more extreme but may be economic.

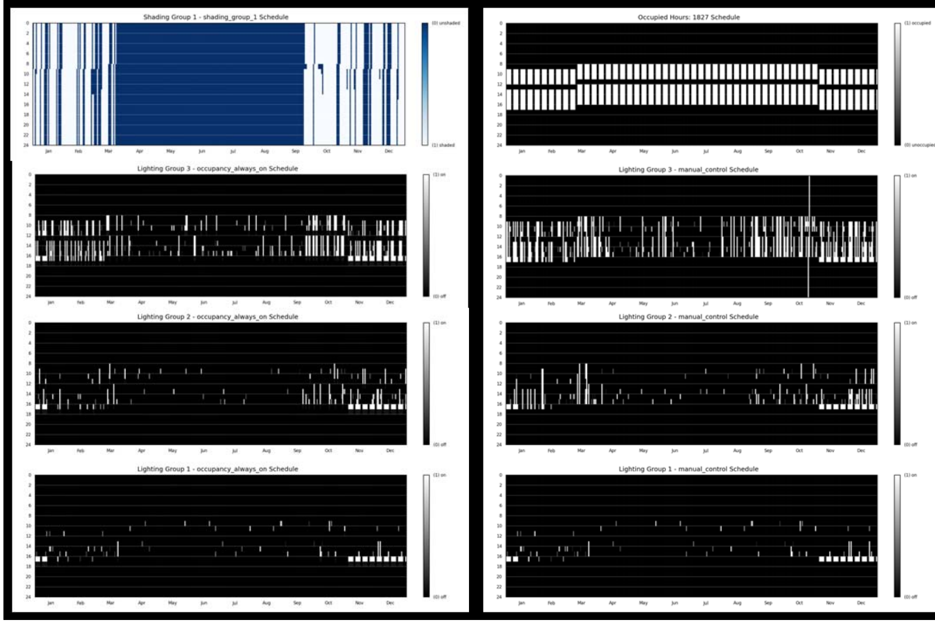
Simple Payback – Three Zones

- *assumed price premium $25*
- *Absolute annual energy savings: 134 kWh*
- *Assuming a cost of 0.18 W/kWh*
- *Saving: 24$/yr*
- *Simple payback time around 1 year*

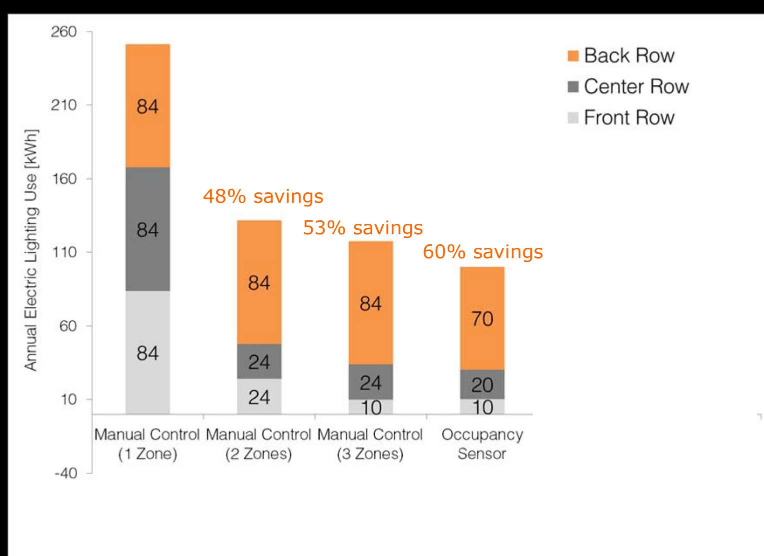
Let's think about automated lighting controls for the space…

Reference Office

Occupancy Sensor | Manual Control (3 Zones)



Lighting Use in Reference Office

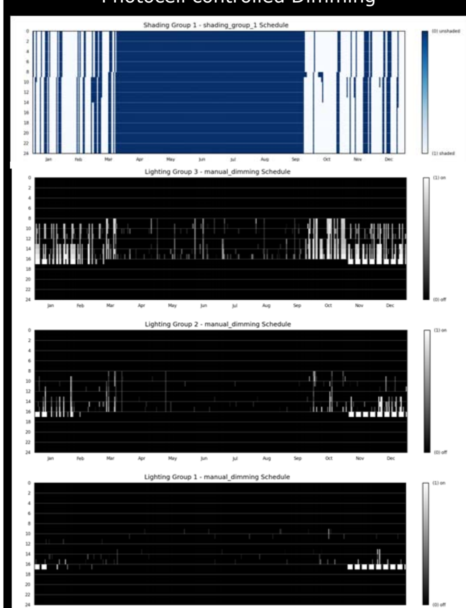


Simple Payback – 3 Zones + Occupancy

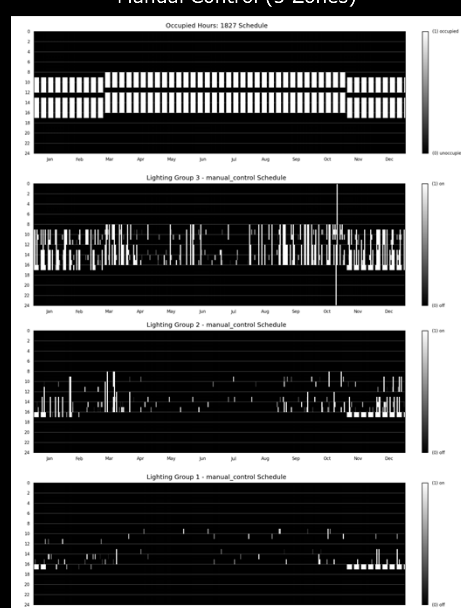
- ❑ *assumed price premium $25 switches + $25 occupancy sensor (low)*
- ❑ *Absolute annual energy savings: 150 kWh*
- ❑ *Assuming a cost of 0.18 W/kWh*
- ❑ *Saving: 27$/yr*
- ❑ *Simple payback time around 2 years*

Reference Office

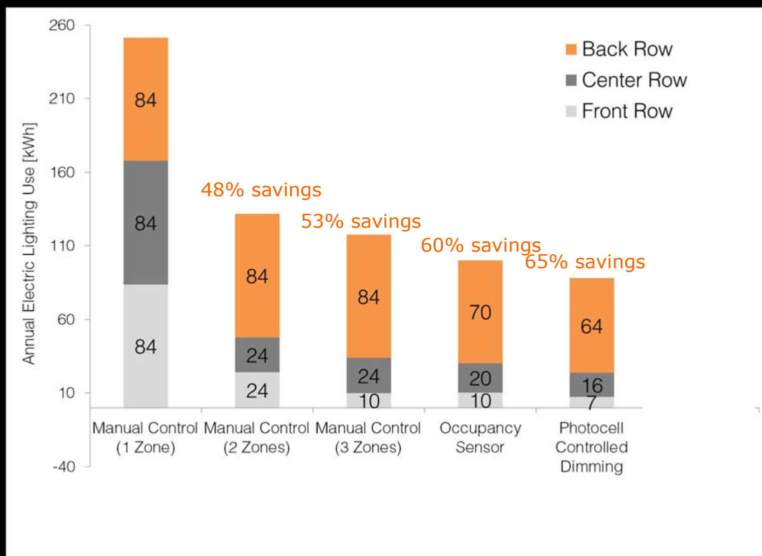
Photocell controlled Dimming



Manual Control (3 Zones)



Lighting Use in Reference Office



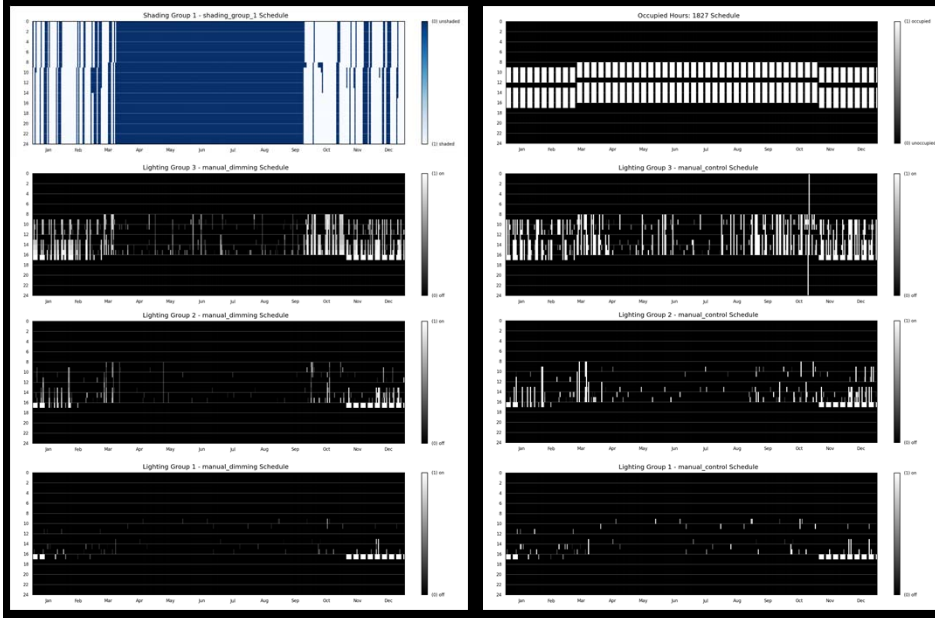
Simple Payback – 3 Zones + Dimming

- *assumed price premium $25 switches + $225 PC (too low!)*
- *Absolute annual energy savings: 163 kWh*
- *Assuming a cost of 0.18 W/kWh*
- *Saving: 29$/yr*
- *Simple payback time around ~8 years*

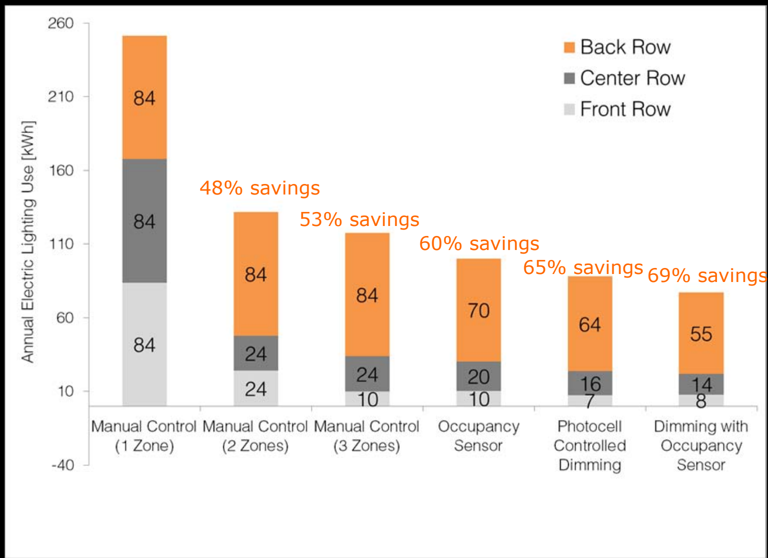
Reference Office

Photocell controlled Dimming & Occupancy

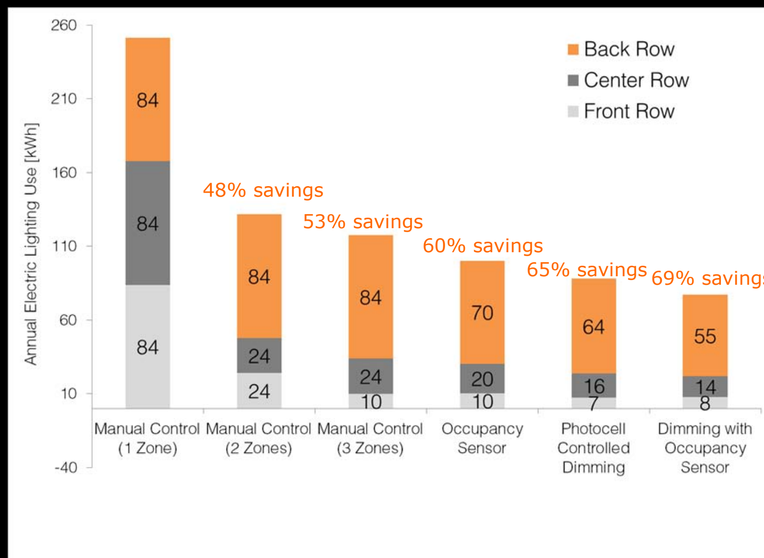
Manual Control (3 Zones)



Lighting Use in Reference Office



Lighting Use in Reference Office



Cost of Lighting Controls

- *cost premium depends on existence of dimmable ballast*
- *installed and calibrated photo sensor control ~ $1000 (~$3/installed watt of lighting capacity)*
- *for a LON system:*
  - *$100 photocell*
  - *$120 0-10V input signal (one per photocell)*
  - *$120 for 0-10 output signal (one per luminare)*
  - *occupancy sensor $100 for a seminar room, $25 for a small office*

Simple Payback - Occupancy Sensor

- *assumed occupancy sensor costs $25 (low)*
- *Absolute annual energy savings: 3.1 kWh*
- *Assuming a cost of 0.18 W/kWh*
- *Saving: 3.1$/yr*
- *Simple payback time around 8 years (long!)*

Frequency of Use

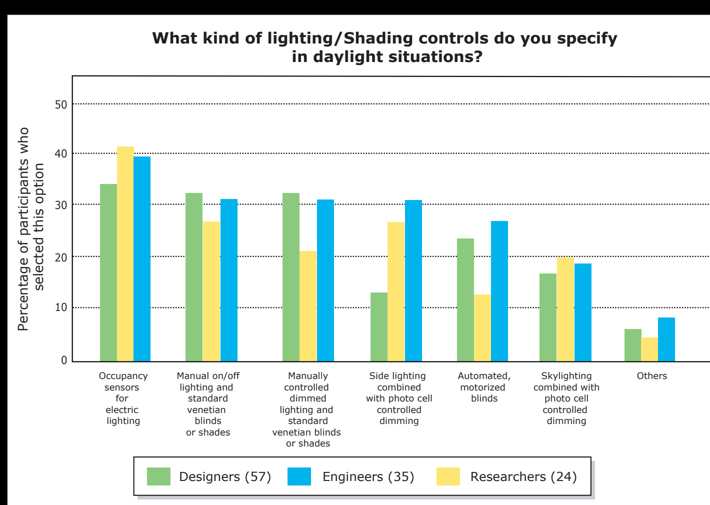
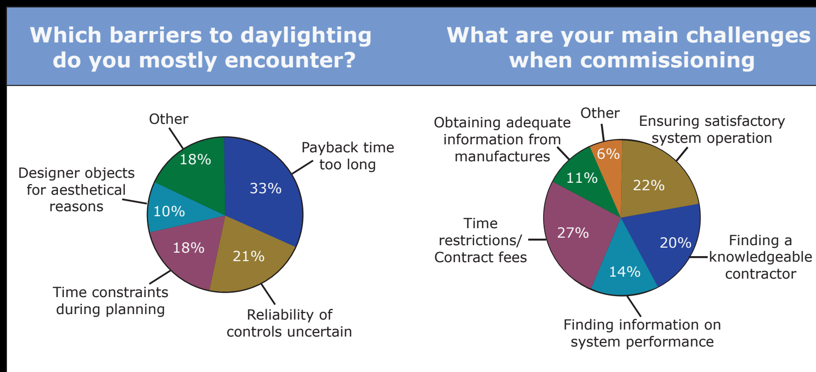


Image by MIT OpenCourseWare.

Source: Galasiu A. D., C. F. Reinhart. "Current Daylighting Design Practice: A Survey." Building Research & Information 36, no. 2 (2008): 159-174.

Commissioning



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