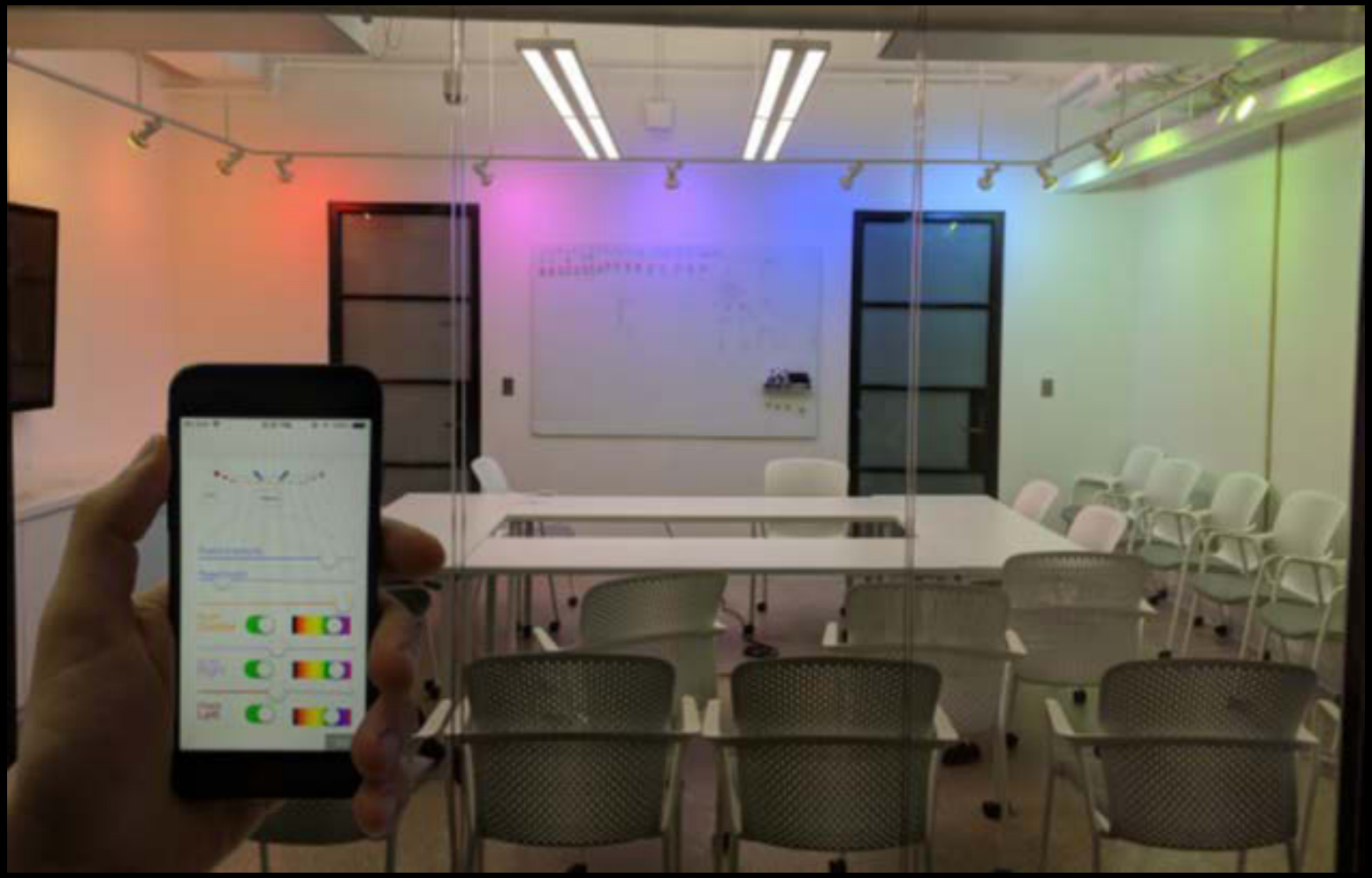
4.401/4.464 Environmental Technologies in Buildings



Party Mode in the BT Lab

Christoph Reinhart

L11 Occupant Behavior + Electric Lighting

Massachusetts Institute of Technology
Department of Architecture
Building Technology Program

Assignment 3 – Thermal Comfort

You were comfortable and the standard...

Predicted Mean Vote

Agreed √

74%

Disagreed ×

26%

Photo courtesy of Rick on Flickr. License: CC BY-NC-SA.

Adaptive Comfort

Agreed √

88%

Disagreed ×

12%

Assignment 3 – Thermal Comfort

You were uncomfortable and the standard...

Predicted Mean Vote

Agreed ✓

76%

Disagreed ×

24%

Photo courtesy of Steven Leckart on Flickr. License: CC BY-NC.

Adaptive Comfort

Agreed ✓

24%

Disagreed ×

76%

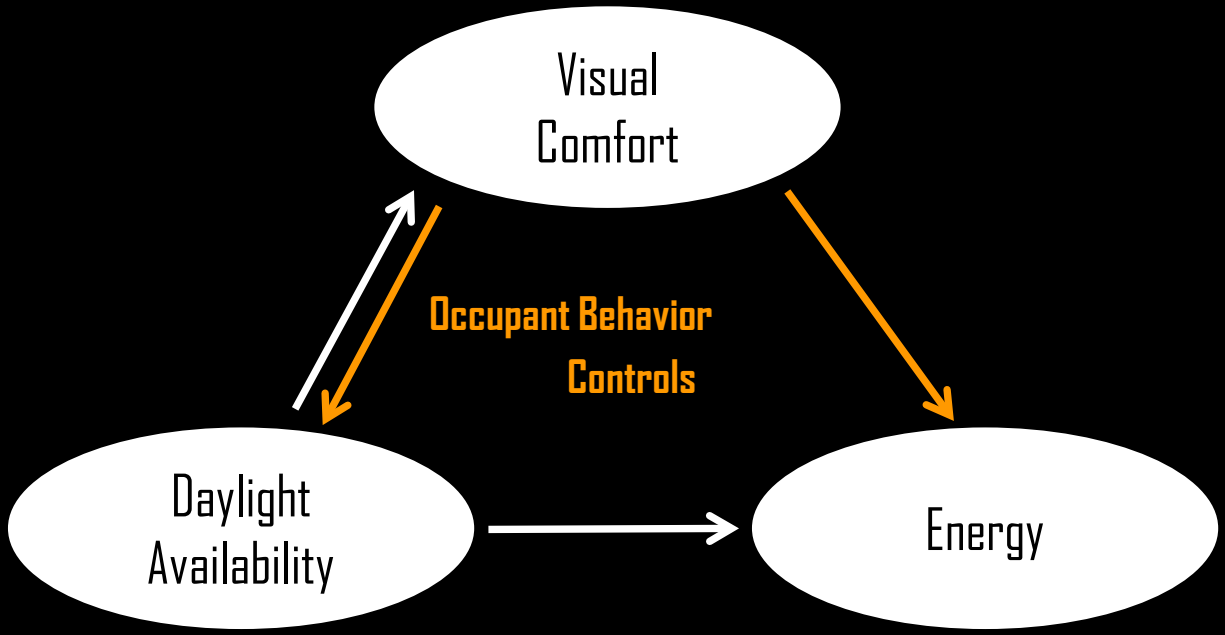
- Applicability of the adaptive comfort standard is not valid in indoor spaces with active cooling.
- Other environmental factors such as noise, poor daylight, and low indoor air quality could influence perception of thermal comfort.
- Thermal history: The climate of the previous city you lived in may set your thermal expectations.

Lighting Module

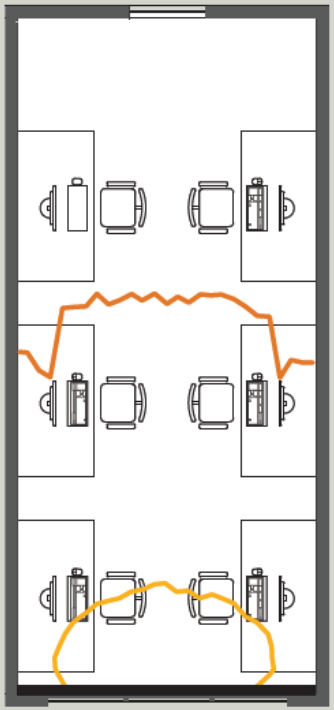
- [x] Light and Human Vision
- [x] Daylighting Design Principles
- [x] Daylight Simulations & Metrics
- [x] Visual Comfort
- [x] Electric Lighting

Occupant Behavior

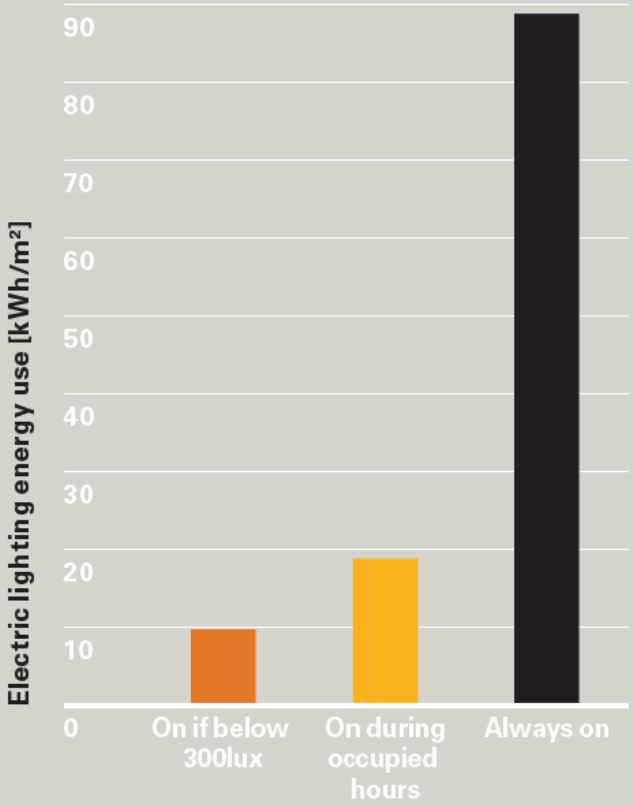
Framework for High-Performance Buildings



Occupant Behavior



- Blinds always up
  $sDA_{300lux}[50\%]=55\%$
- Blinds fully closed (slat angle 45° downwards)
  $sDA_{300lux}[50\%]=9\%$
- Blackout shades
  $sDA_{300lux}[50\%]=0\%$



- ❑ Occupant use of lighting and shading controls matters.
- ❑ Priority one: switch lights off when nobody is present.

Earth at Night

Photo courtesy of NASA. This image is in the public domain.

- Nearly all the light that you see here does not serve any purpose.

Blind & Lighting Use in NYC Classrooms

Image removed due to copyright restrictions.

- 183 teacher surveys, 9 participating schools

Blind & Lighting Use in NYC Classrooms

Image removed due to copyright restrictions.

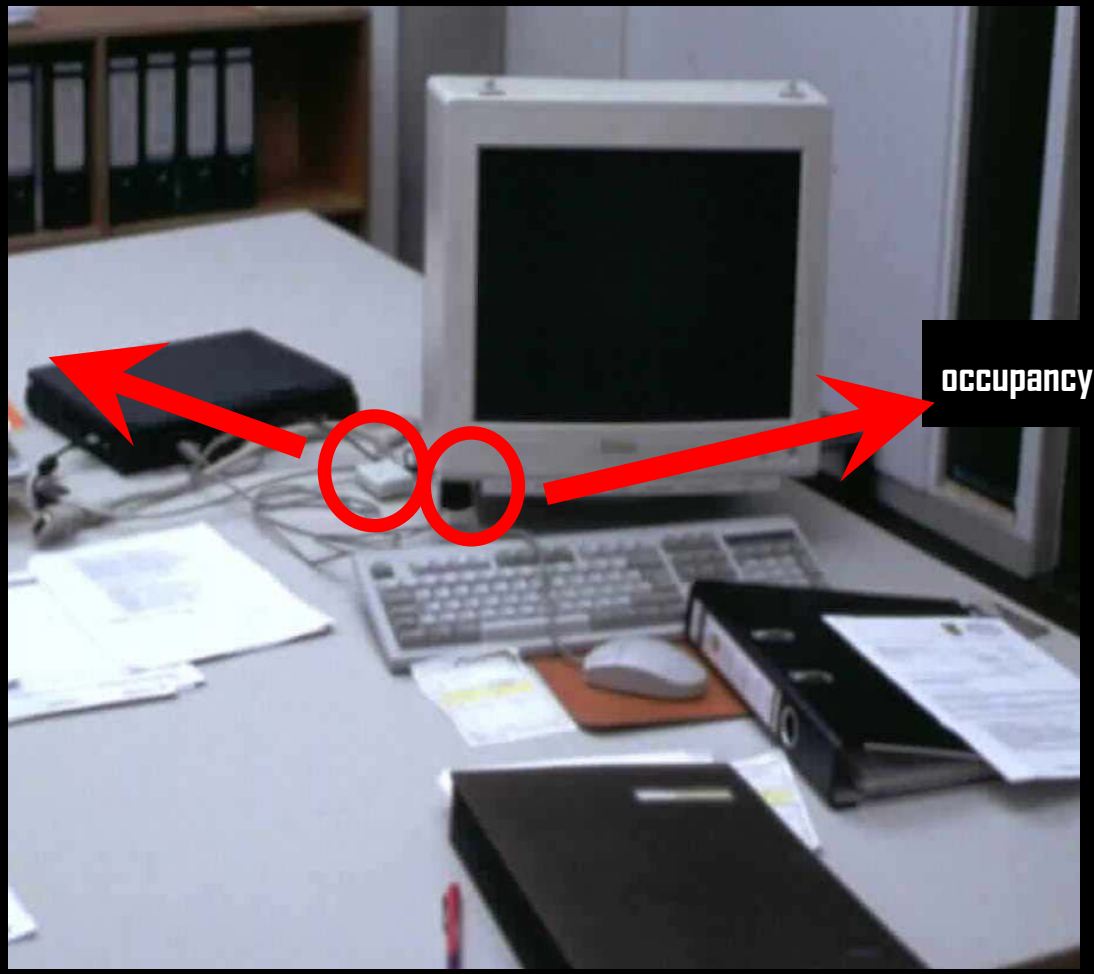
- 183 teacher surveys, 9 participating schools

Monitoring User Behavior

Paper: Reinhart C F, Voss K, "Monitoring manual control of electric lighting and blinds." *Lighting Research & Technology* 35:3, pp. 243-260, 2003.

Monitoring Setup in the Offices

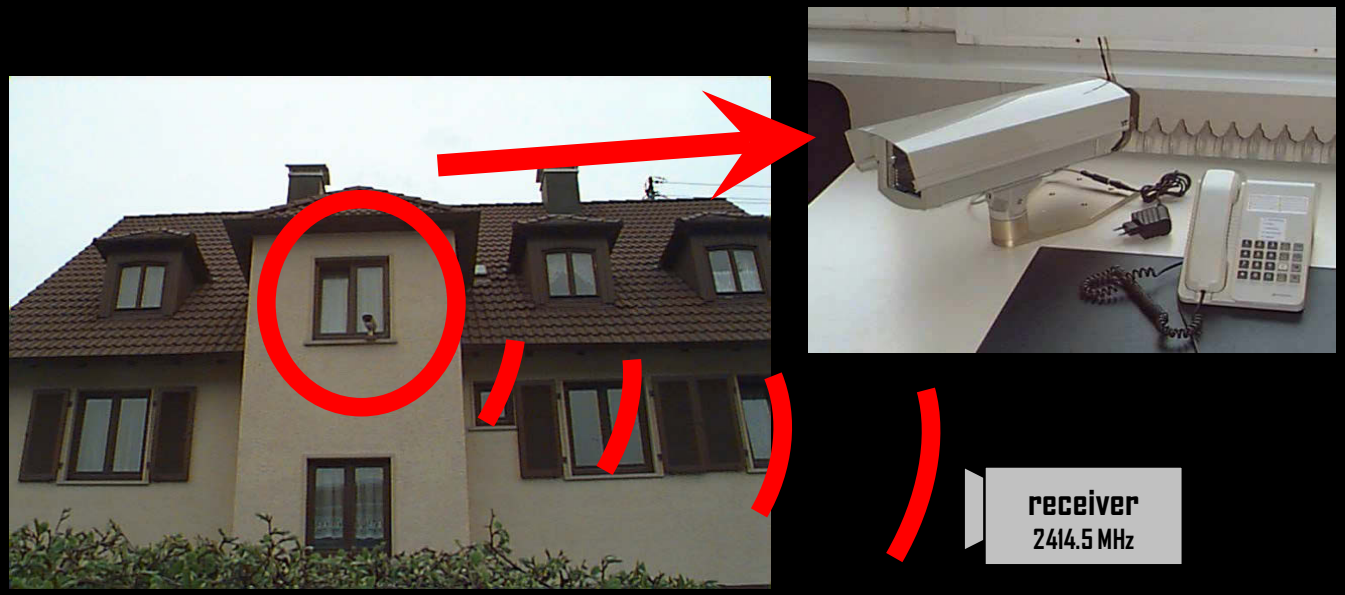
Illuminance
Temperature

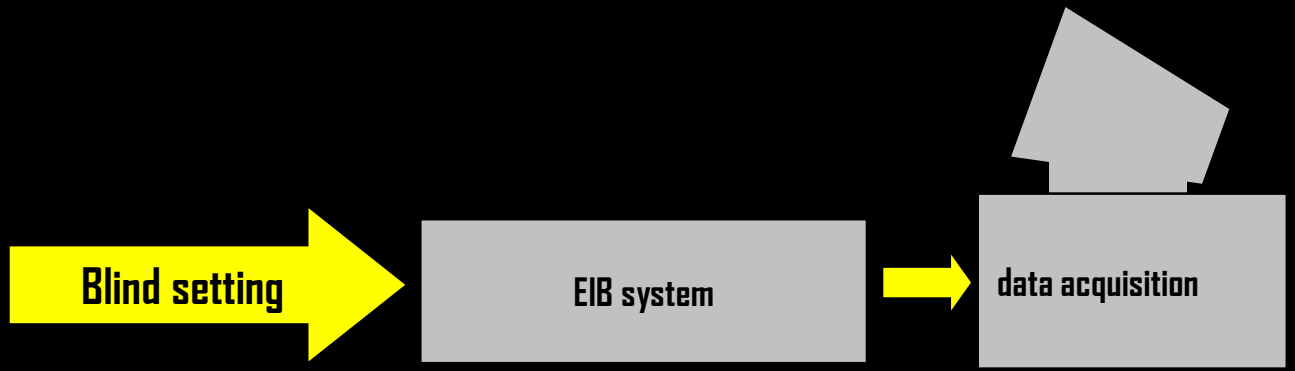


HOBO data logger

Monitoring Blind Usage

video surveillance camera

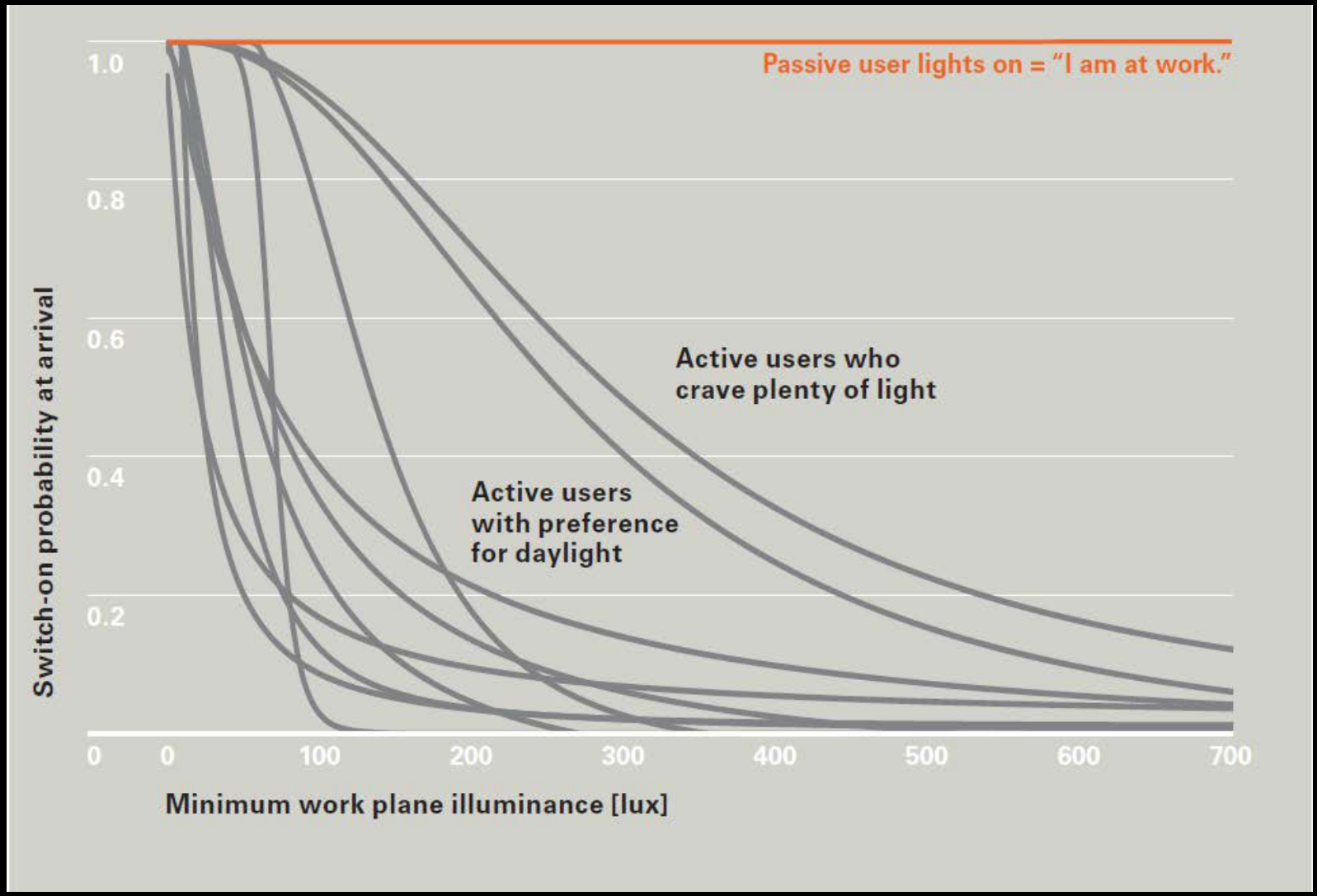




Switch-on Probability

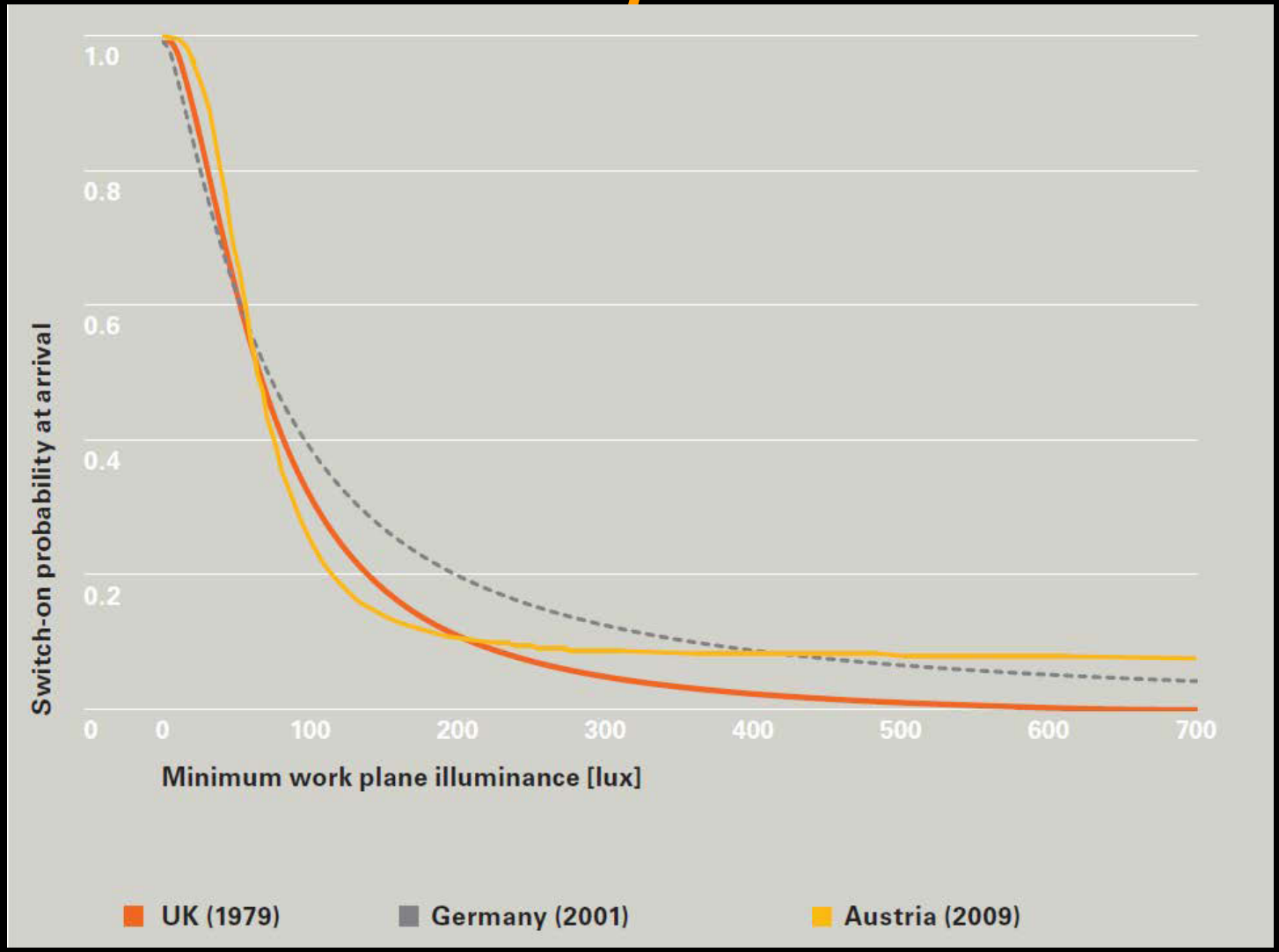
- Electric lighting tends to get switched on when occupants arrive.

People are Consistent but Different



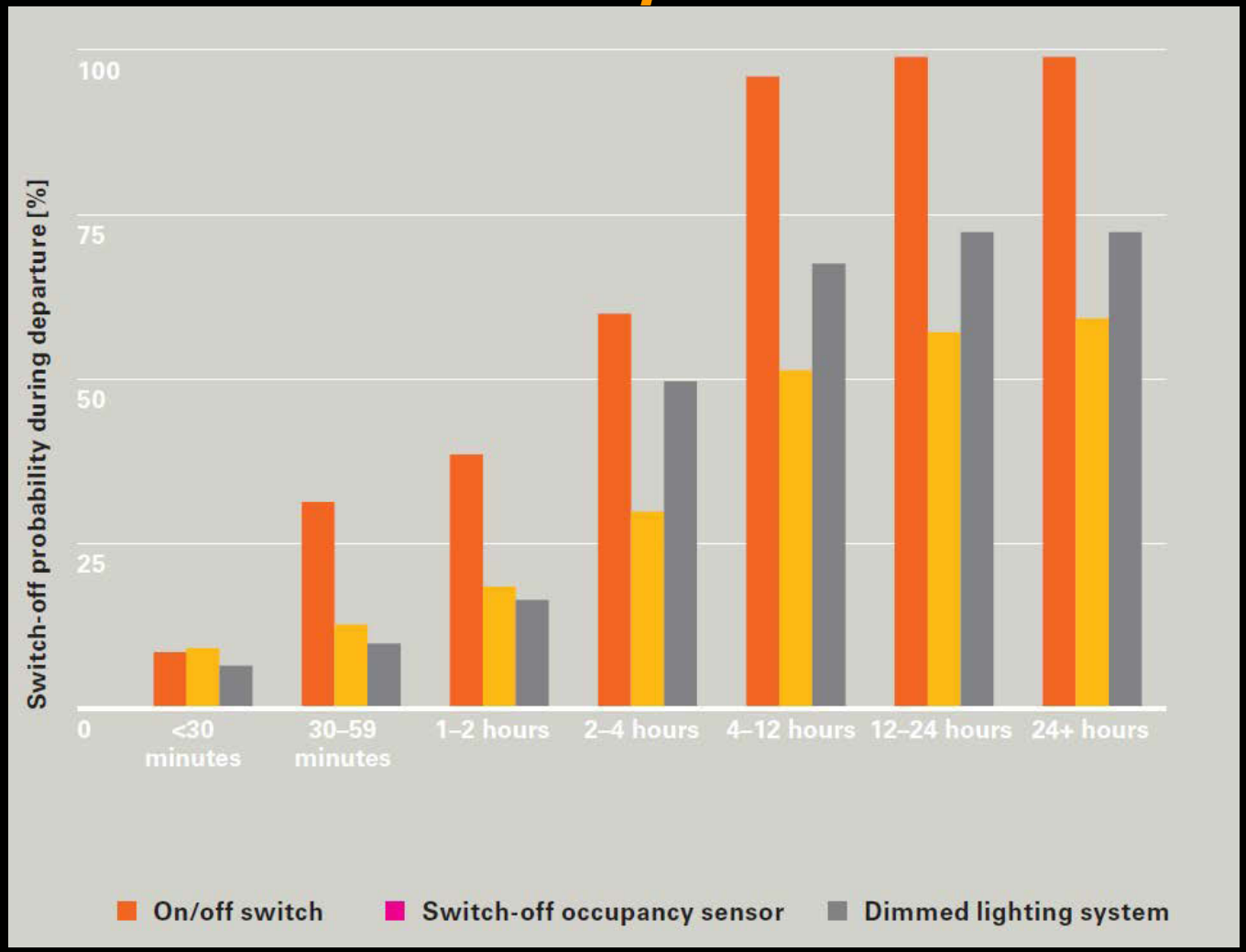
- Two main behavior types, active and passive.

Switch-On Probability



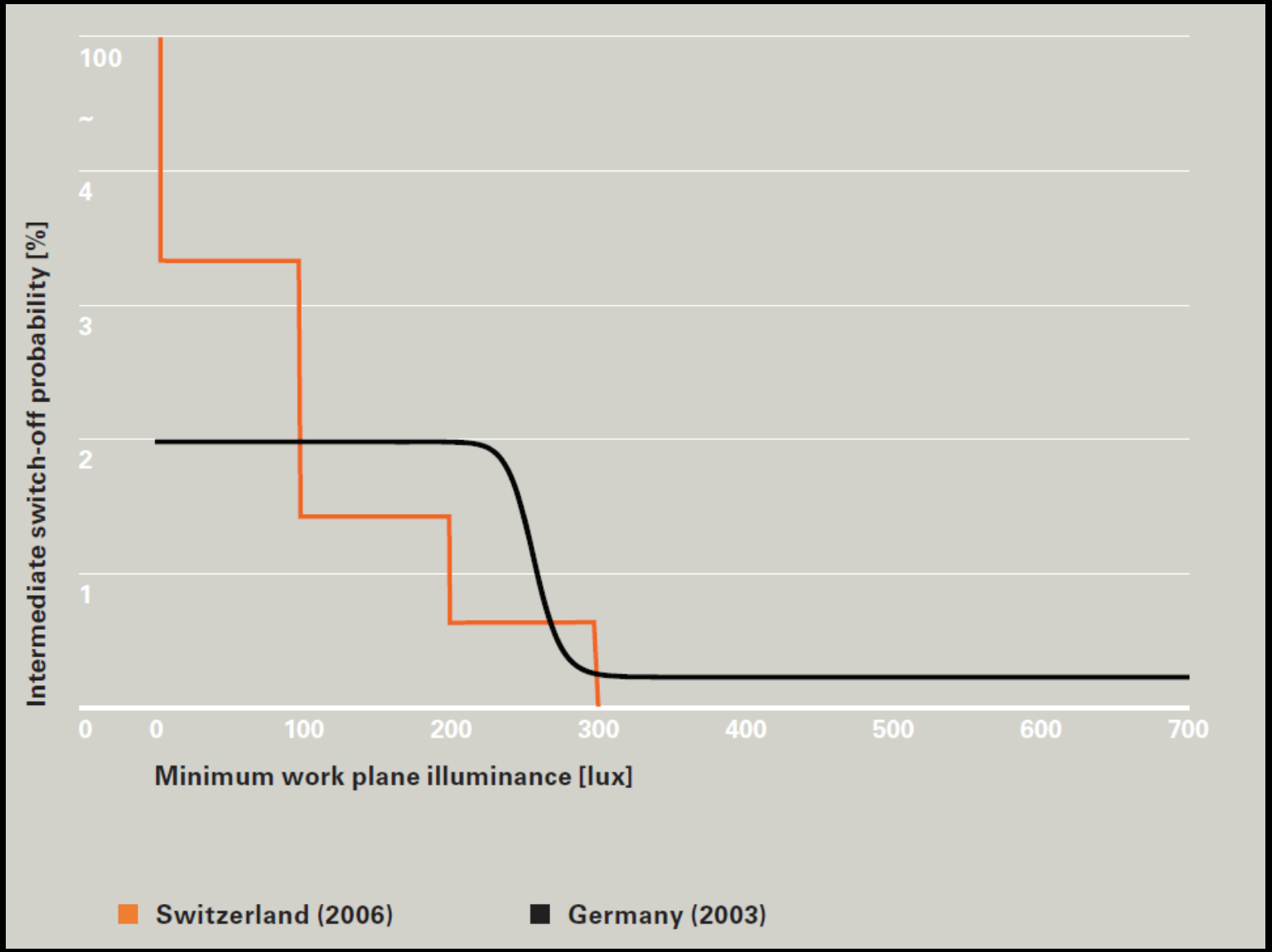
- Surprising consistency at the building level.

Switch-Off Probability

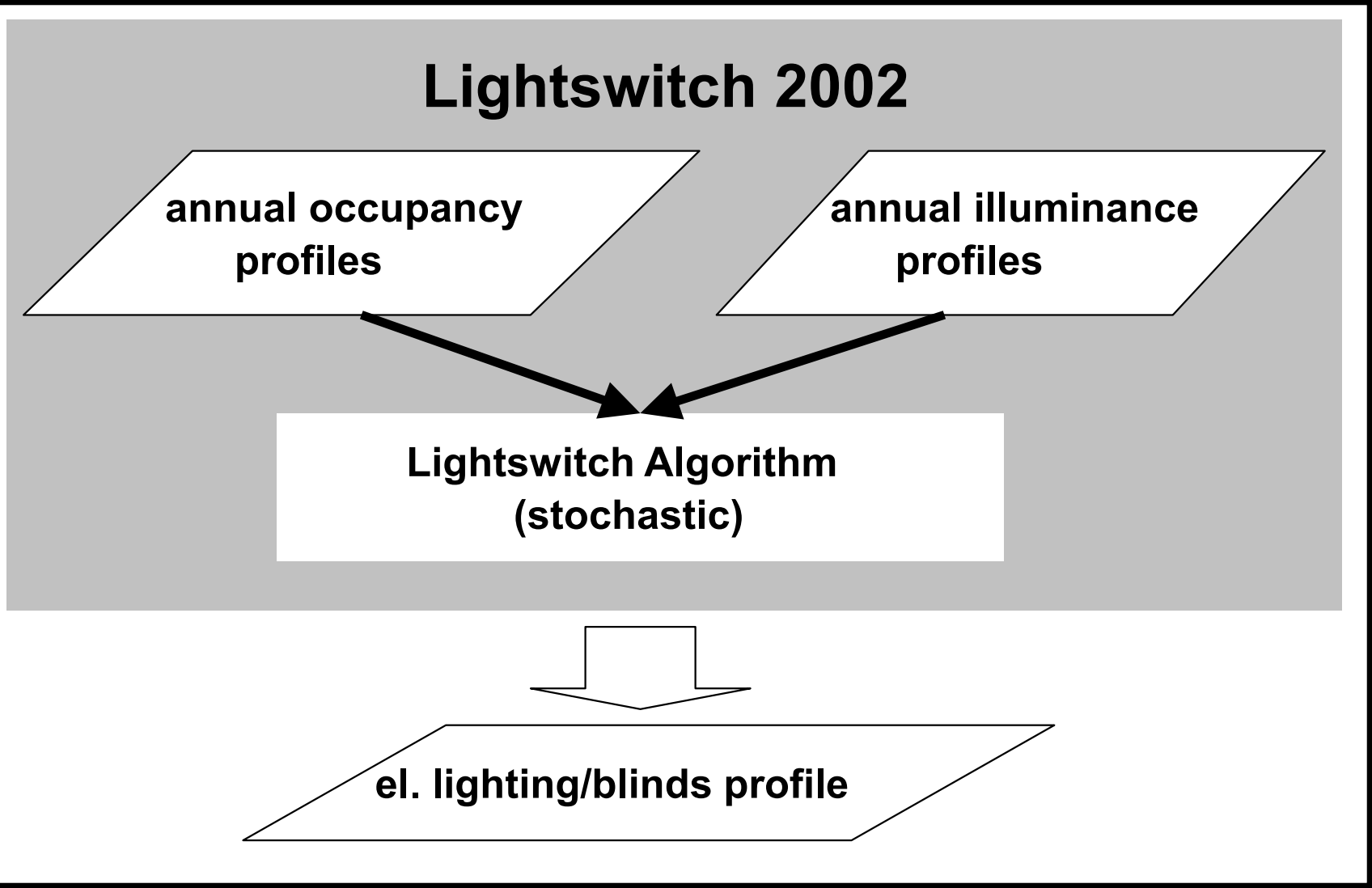


- Behavioral patterns can change in the presence of automated controls

Intermediate Switch-On Probability

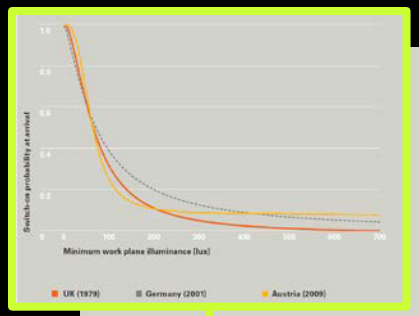


Model Overview



Paper: Reinhart C F, "Lightswitch 2002: A model for manual control of electric lighting and blinds," *Solar Energy* 77:1, pp. 15-28, 2004

Lightswitch - Manual Lighting Control

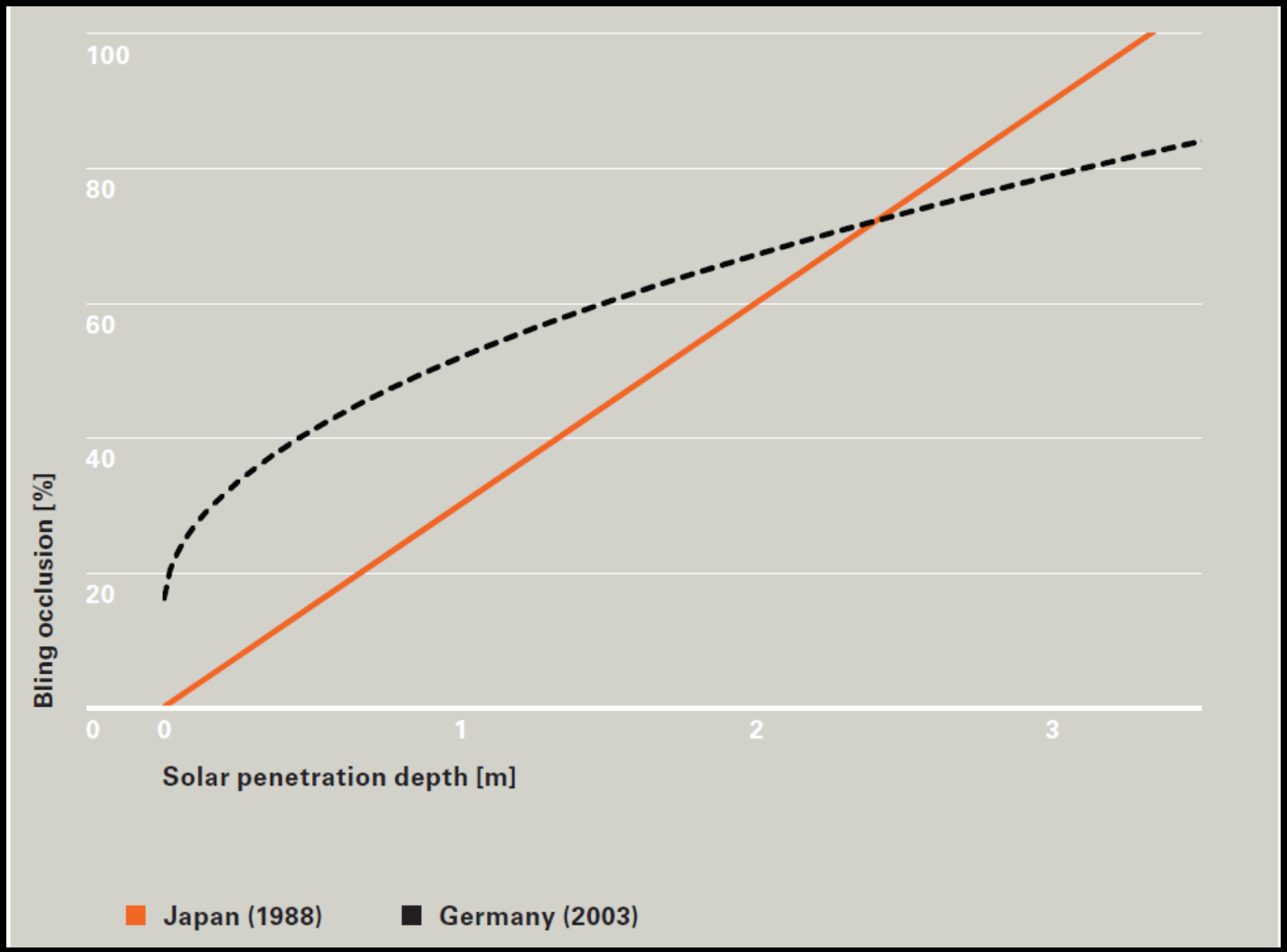


Manual Blind Control

Photo courtesy of Mathias Wambsganss. Used with permission.

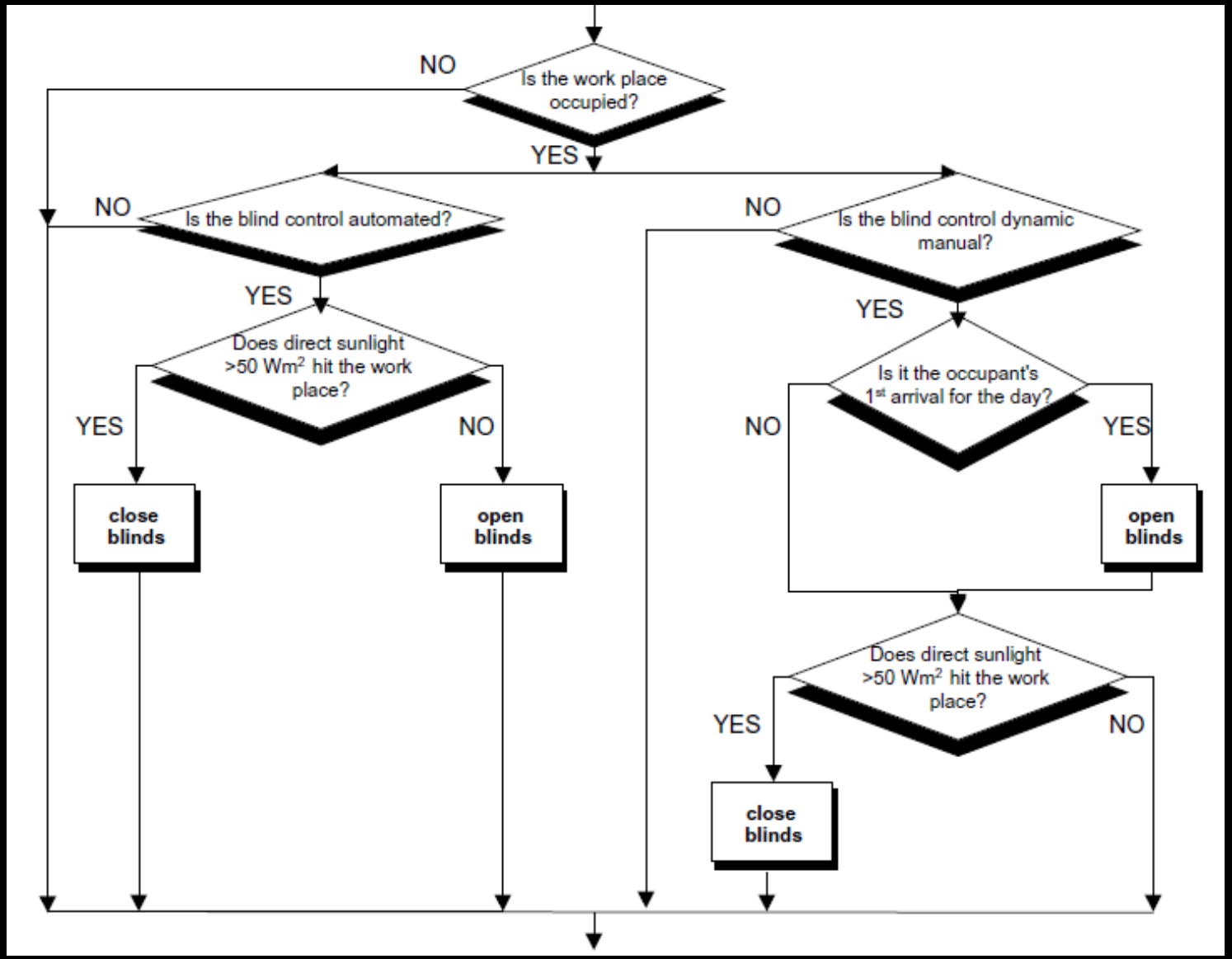
- Occupants tend to avoid direct sunlight stripes like this near the work place.

Manual Blind Control

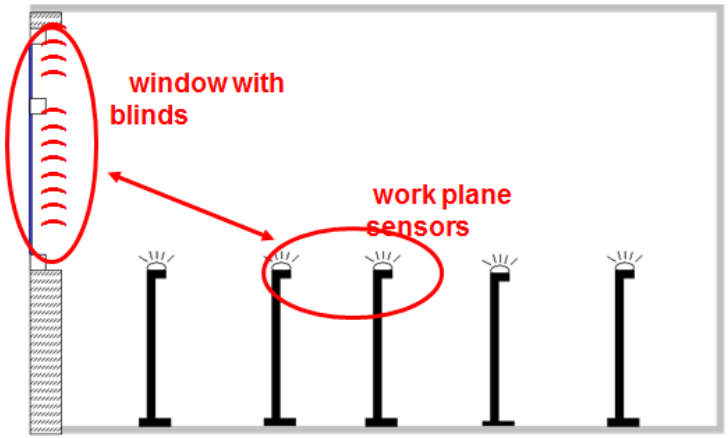


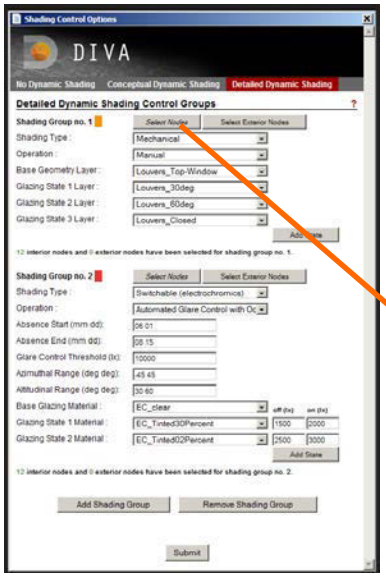
- Blinds get lowered to avoid direct sunlight falling on the work plane.

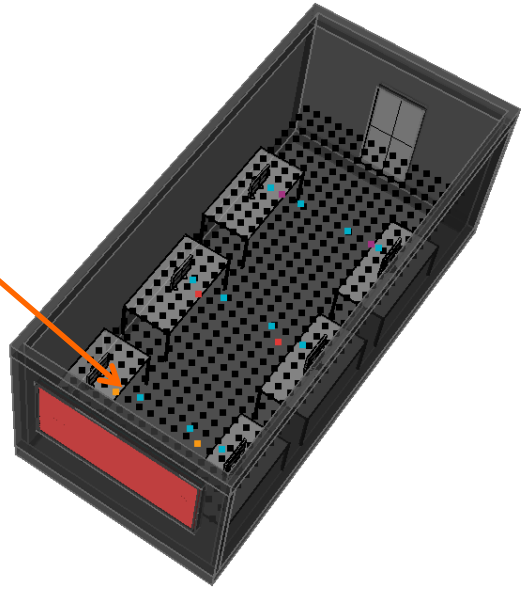
Lightswitch - Manual Blind Control



Lightswitch - Manual Blind Control



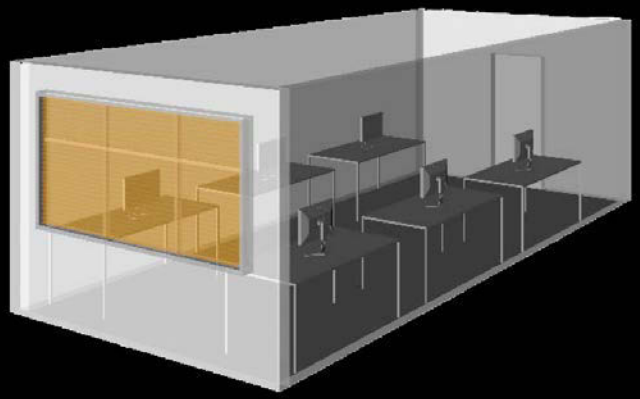




- Define work plane sensors that define where the occupants are usually located.
- Associate sensors with shading groups. A shading group consists of a (set of) blinds that are opened and lowered at the same time.
- Check when direct sunlight (>50 Wm^{-2}) is incident on a work plan sensor.
- Close shading device if yes until occupant is away for more than an hour.

Dashboard

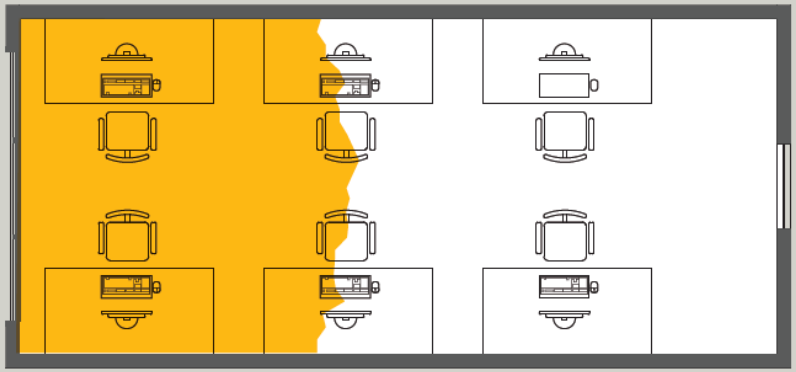
Reference Office



Daylight availability **45% of the space is daylit**

$sDA_{300lux}[50\%]$

Spatial daylight autonomy

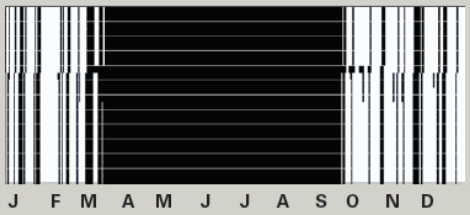


Visual comfort

View outside: 66% of the time
Glare: 0% of occupied hours

Daylight glare probability

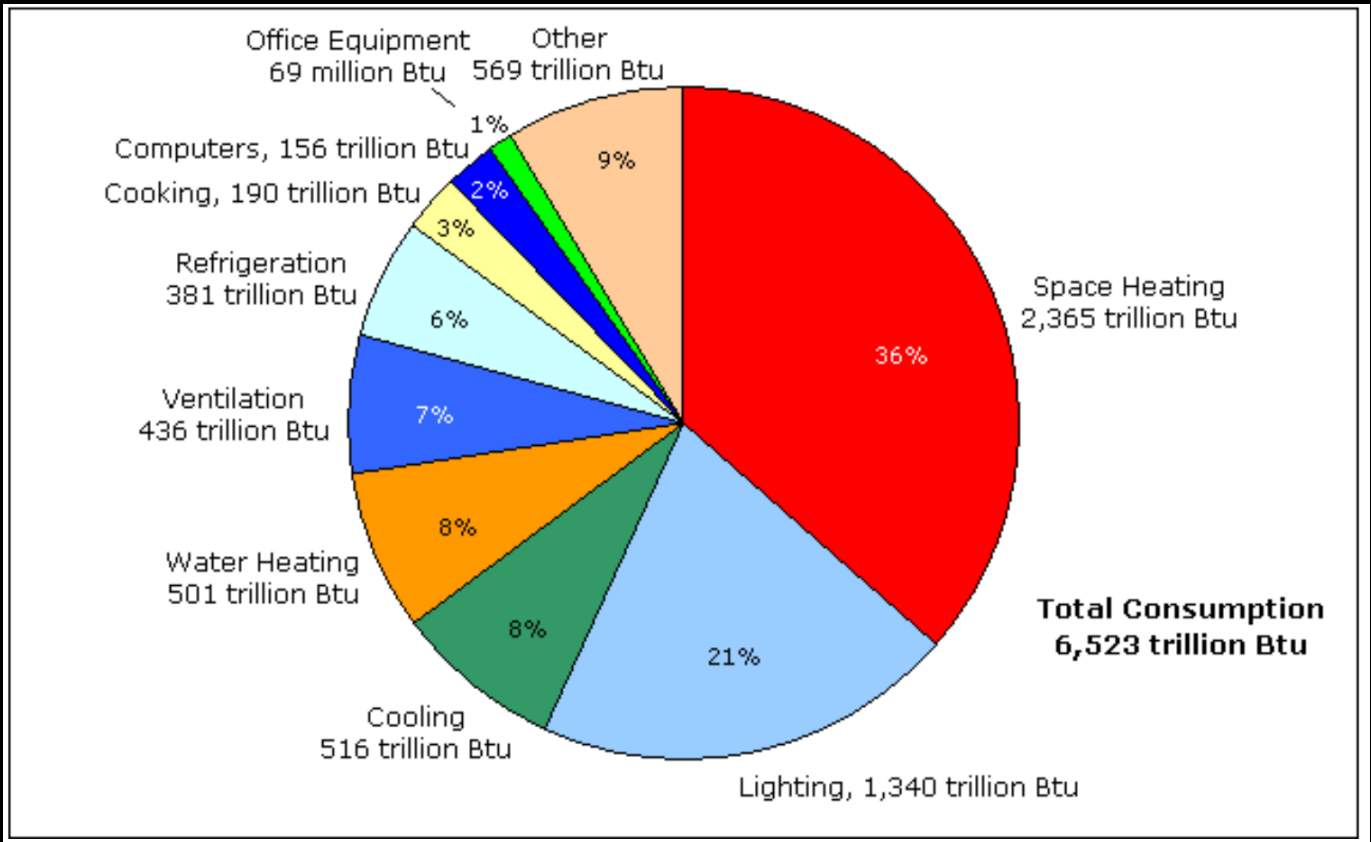
Blinds status (view)



Intolerable
Disturbing
Perceptible
Imperceptible
Blinds closed
Blinds open

Electric Lighting Design

Energy Use in Commercial Buildings



Source: Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Table E1A.

- In 2014 11% of total U.S. electricity consumption was used for lighting by the residential and commercial sectors.
- In residential buildings lighting contributed to 14% of total electricity consumption.
- In the commercial sector (commercial and institutional buildings, public street and highway lighting) the portion was 19%

Lighting Design and LEED

- ASHRAE 90.1: The art of lighting is reduced to lighting power densities (LPD) and power adjustment factors.
- Very simplistic. What actually matters is

Activation Time x LPD

Light Sources & Fixtures

Light Direction

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

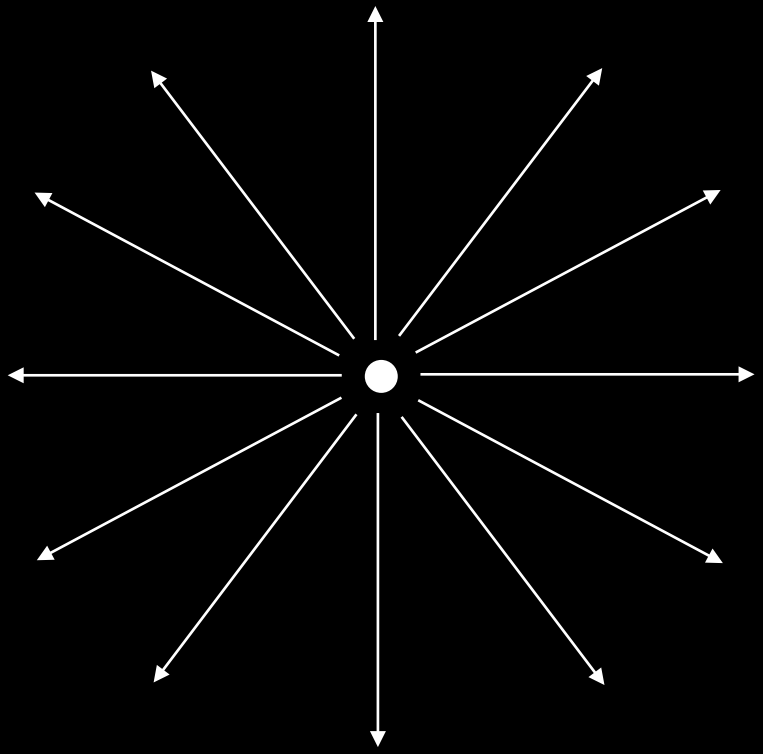


Image by MIT OpenCourseWare.

Light Direction of Clear Lamps

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

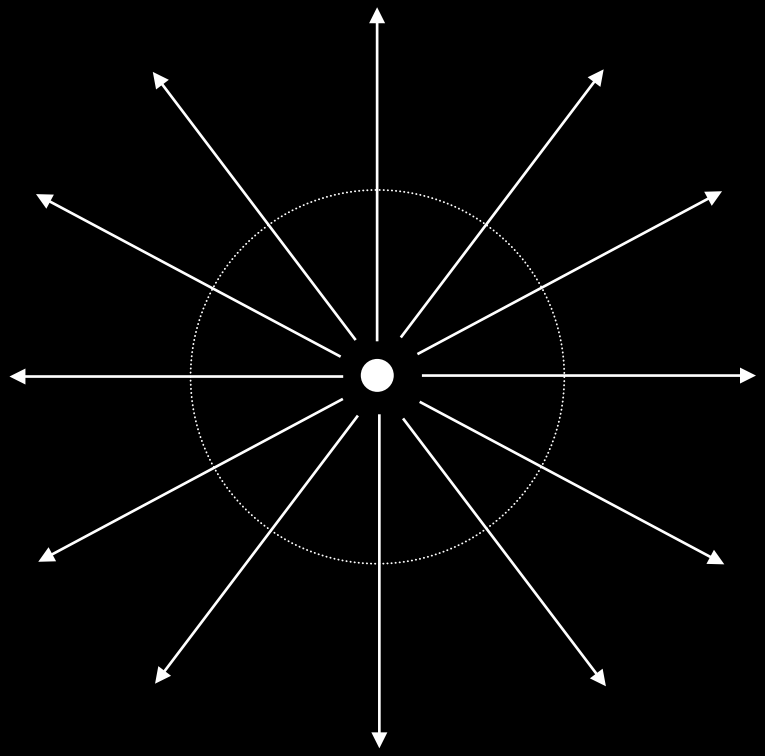
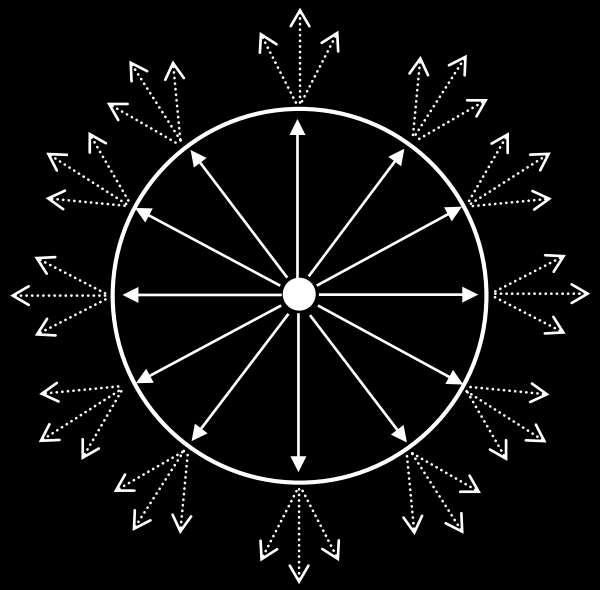


Image by MIT OpenCourseWare.

Light Direction of Frosted Lamps

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



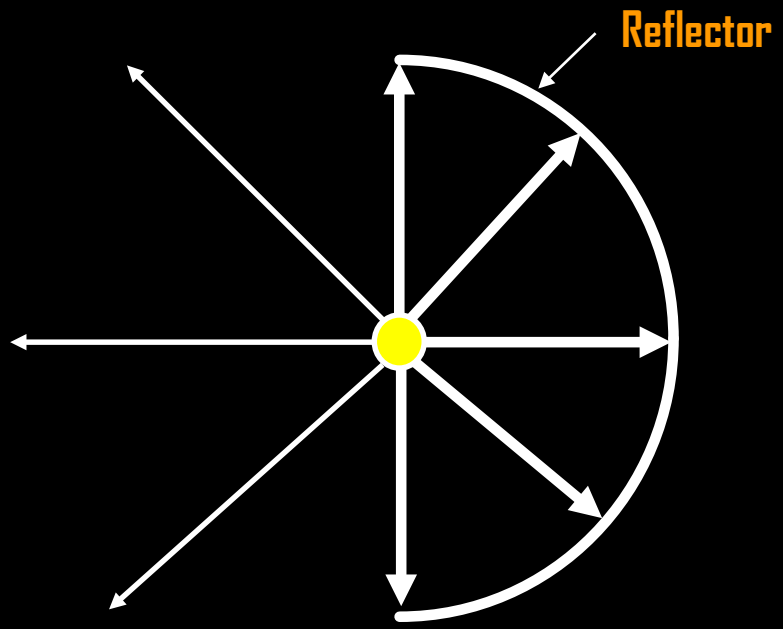
…. add a coated or frosted enclosure or envelope around the source, the direction of light will bend and radiate from the surface of the enclosure

Image by MIT OpenCourseWare.

Reflector Contours

Circular

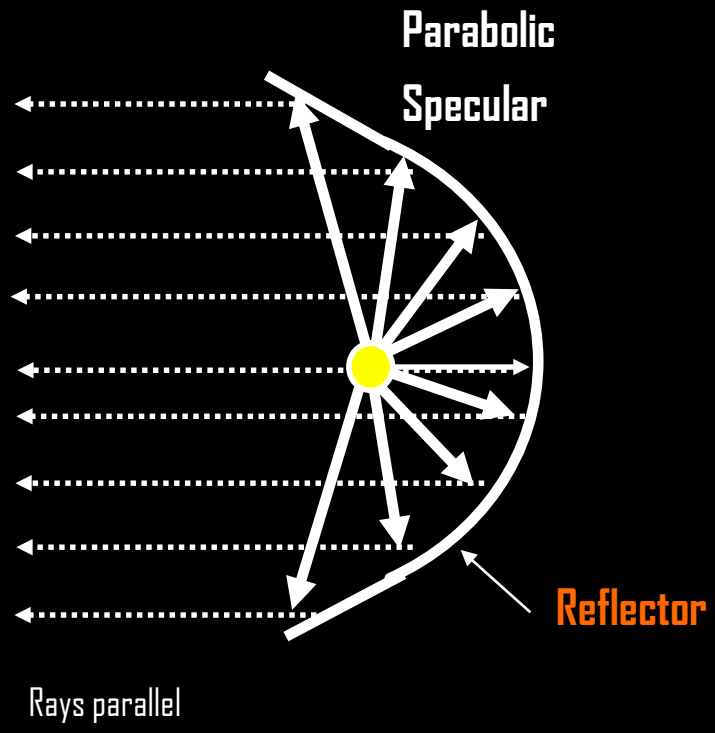
Specular



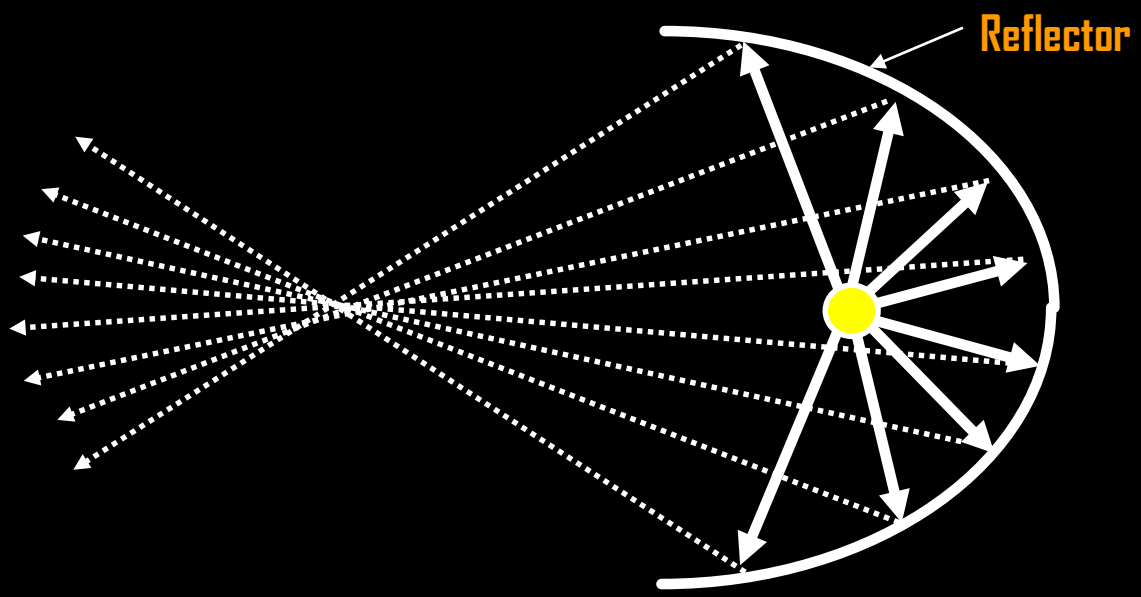
Rays diverge through light source

Image by MIT OpenCourseWare.

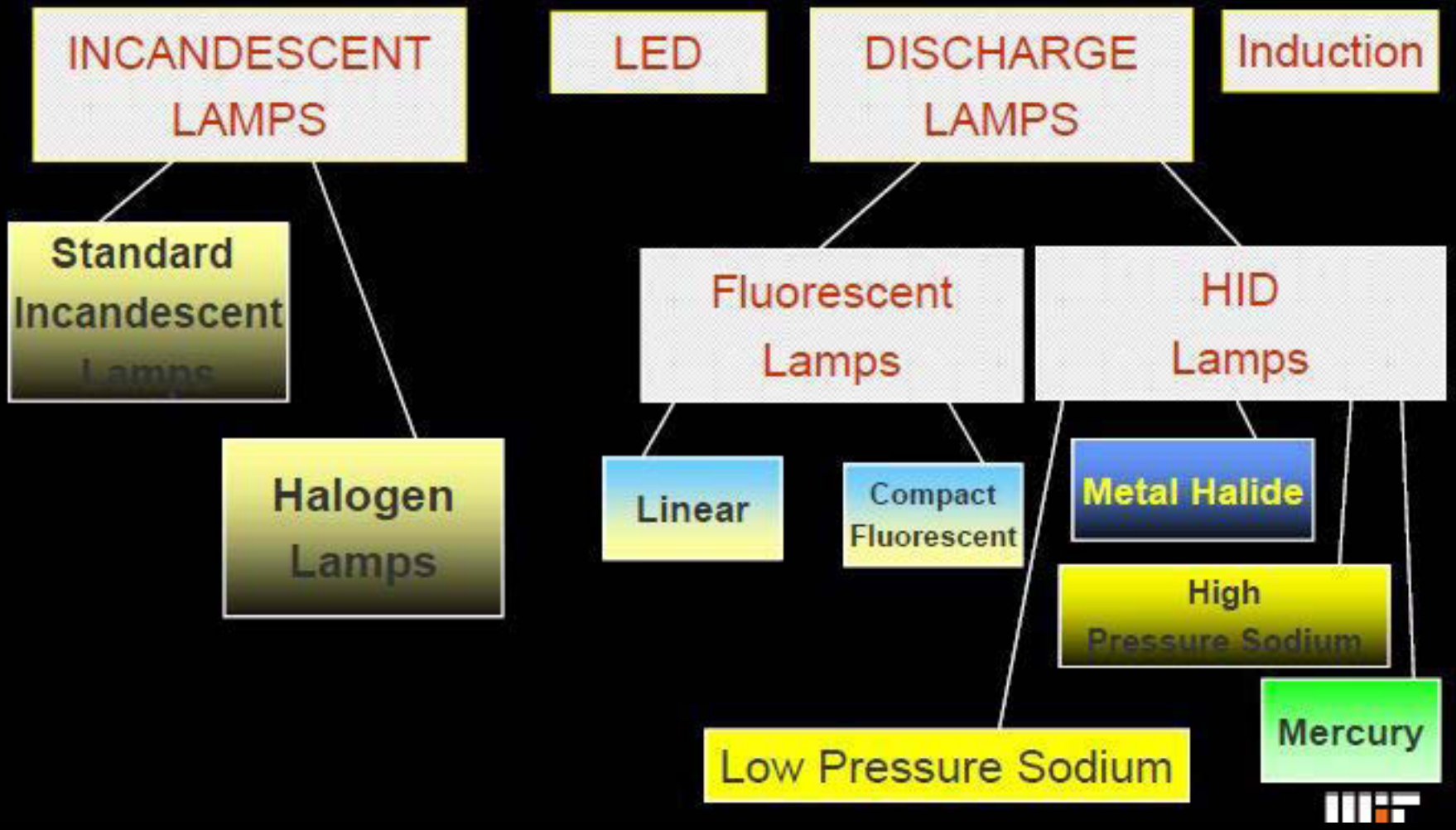
Reflector Contours



Reflector Contours



Lamps for General Use



Lamp Criteria: Color 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.

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

North sky light >10,000 K

Standard Incandescent Lamps

- Varied wattages, sizes, shapes, and bases
- Finishes: clear, inside frosted, coated
- Economical
- Short lamp life
- Warm light
- Can be dimmed

Halogen Lamps (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 Lamp Design

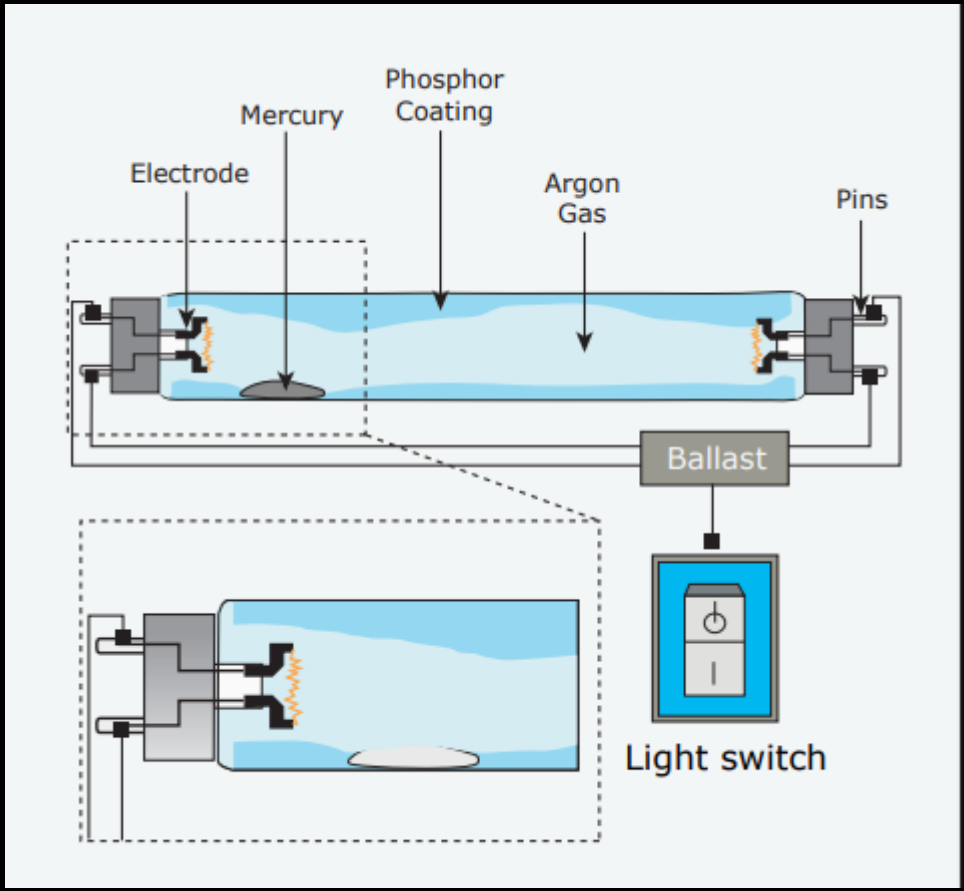


Image by MIT OpenCourseWare.

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

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.
- They 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).

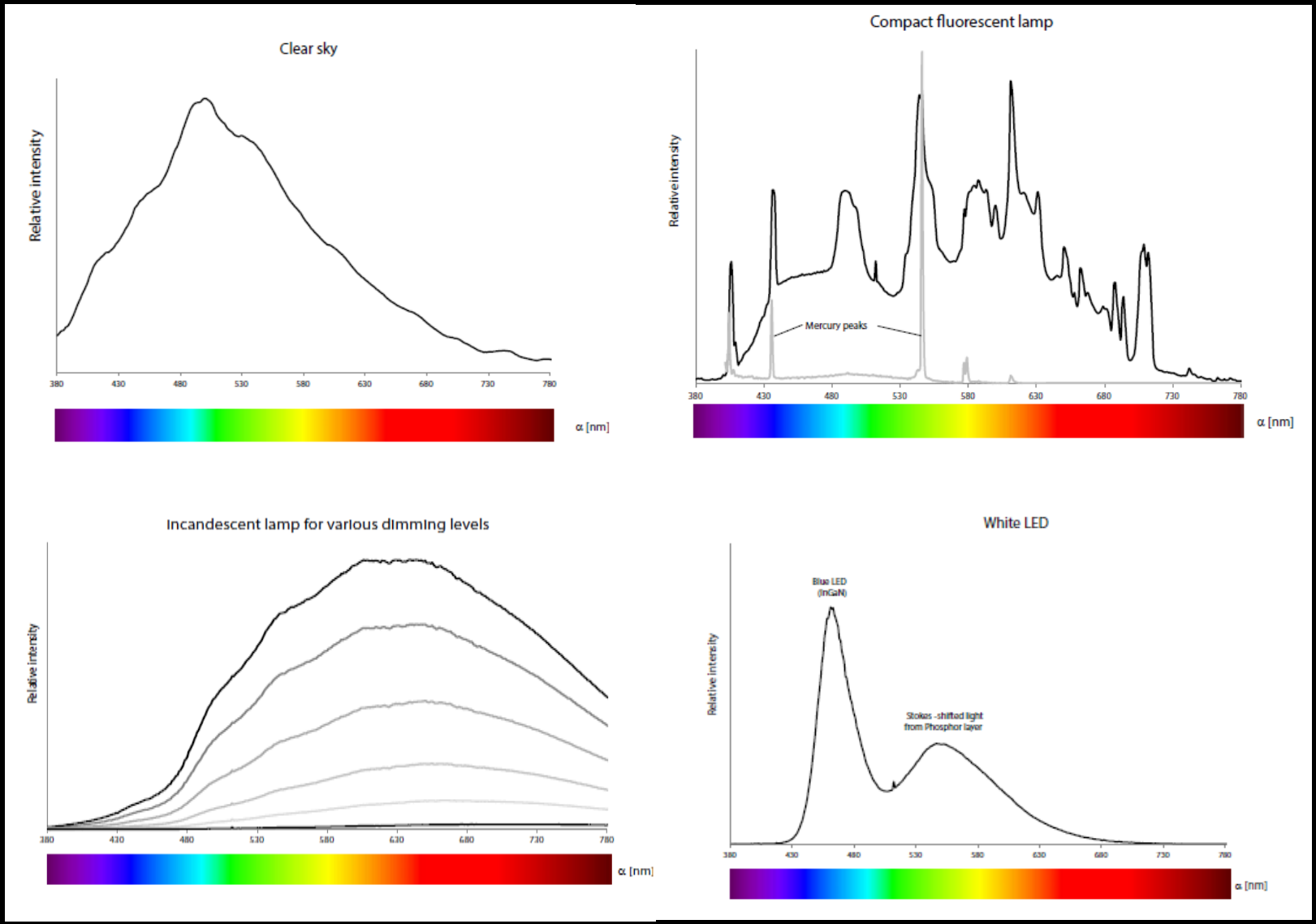
The Uniqueness Rule

- Ballasts 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.

Fluorescent Lamps

- Varied wattages, sizes, shapes, and bases
- Finishes: Coated only – coating determines color
- Operates with specific ballast
- Long life
- Cool burning
- Dimming: Yes, with dimming ballast and specific dimmers

Spectral Intensity of Various Light Sources



How LEDs Work

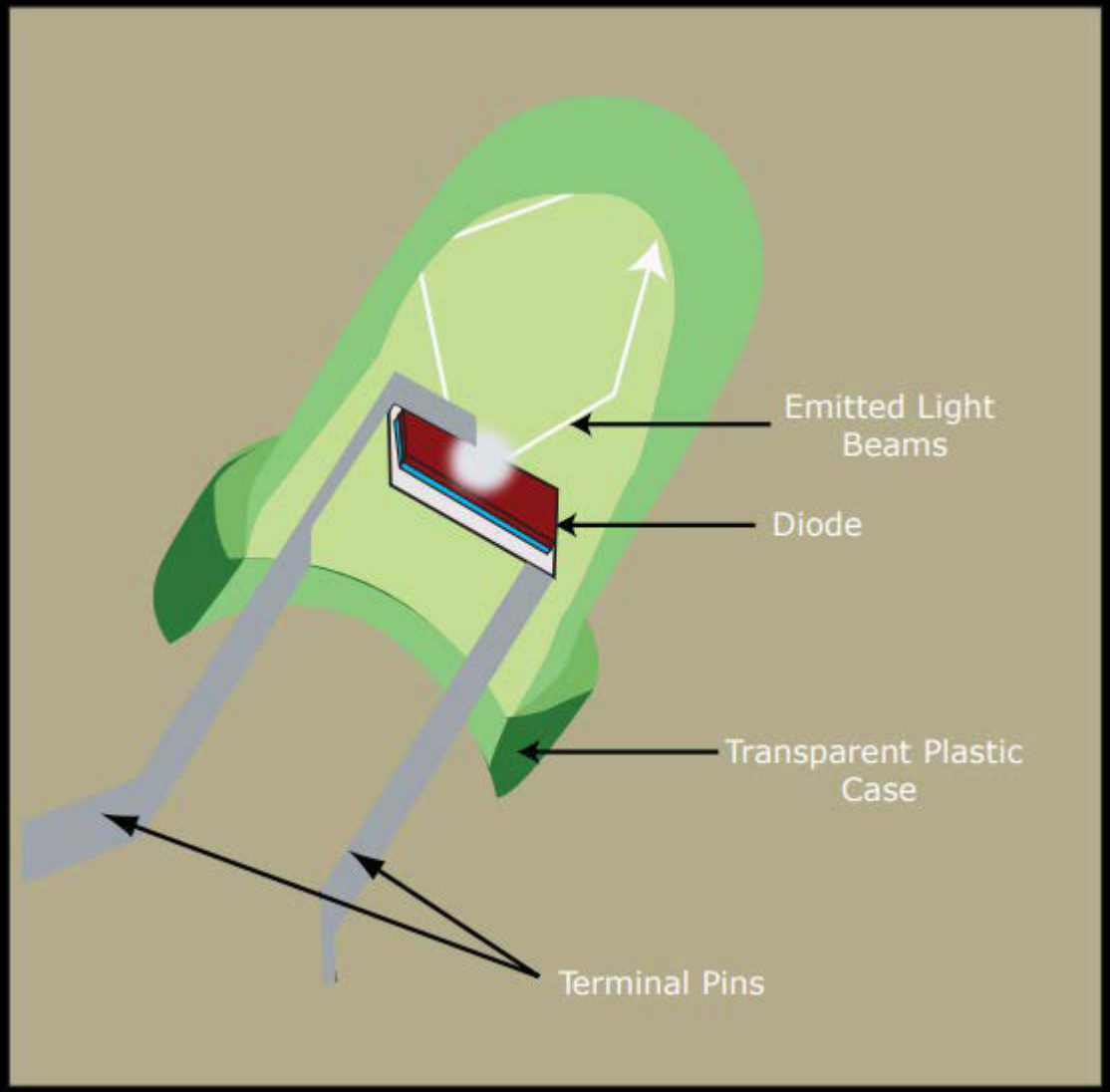


Image by MIT OpenCourseWare.

LED Replacements for Incandescents

6W LED (~40W incandescent)

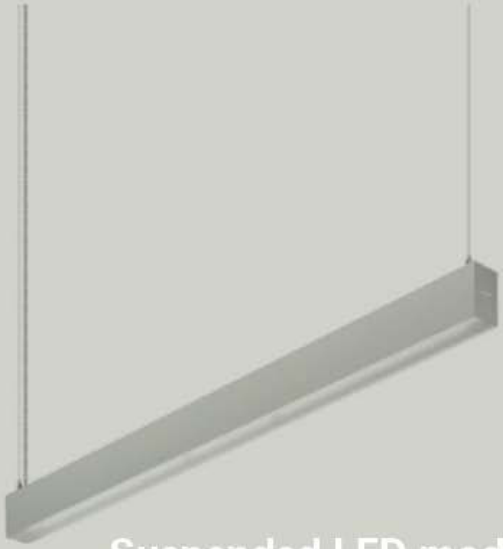
$10 per bulb

Lifetime: 25,000 hours

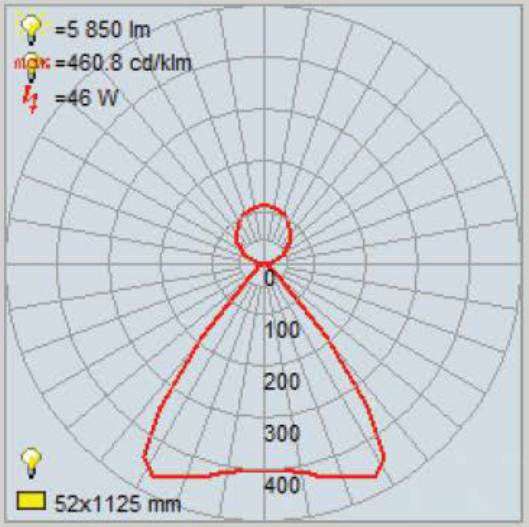
Electric Lighting Design

Lighting Design Step 1

The designer starts by picking a luminaire and downloading the coresponding IES file



Suspended LED module (46W)

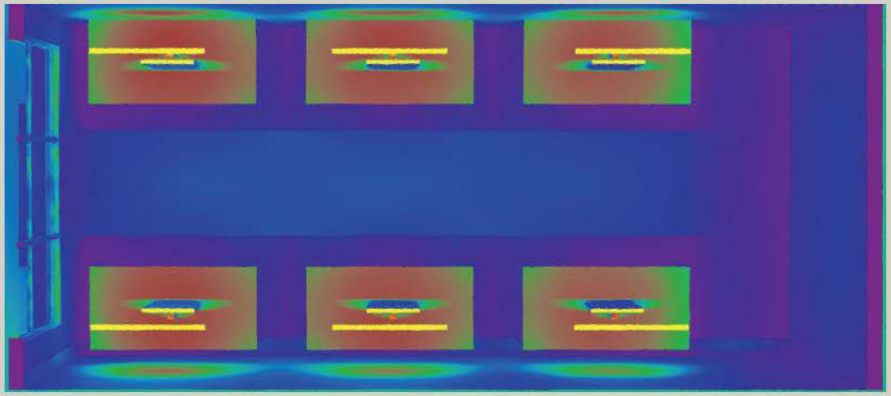


IES file

Lighting Design Step 2

Visualizations at night reveal how the lighting will interact with the space

A cutaway plan determines whether the target illuminance level (300lux) is met



Lighting Design Step 3

A visual comfort analysis yields no glare according to DGP and VCP

DGP = 22% (imperceptible glare)

VCP = 62 (acceptable)

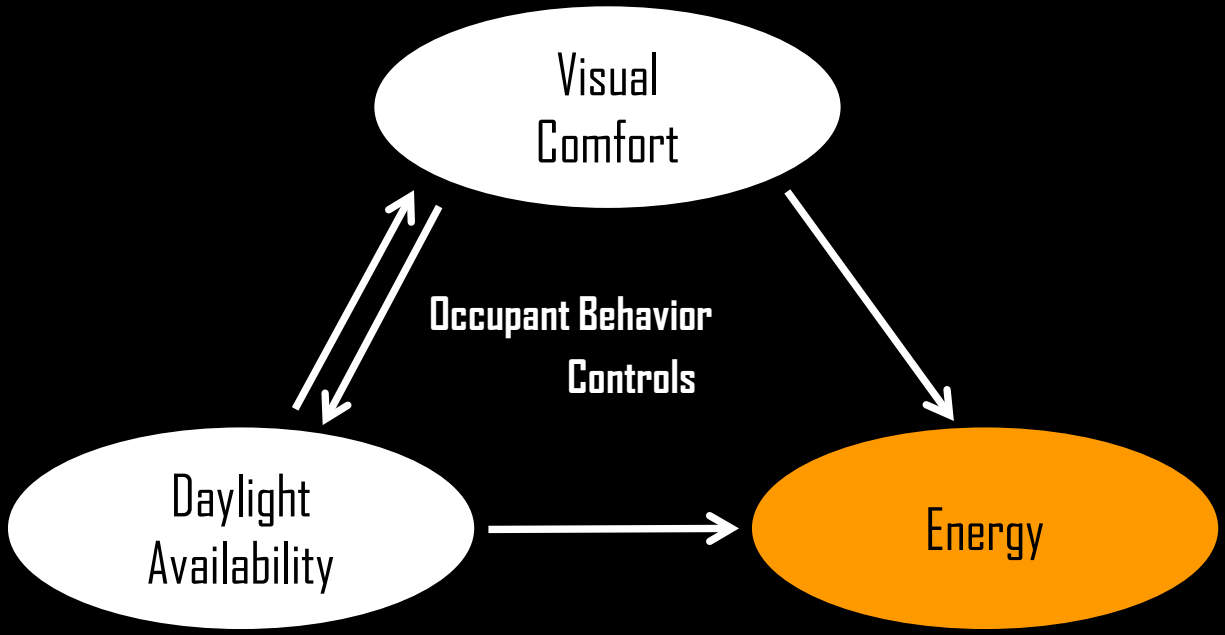
The resulting electric lighting load is 6 × 46W = 276W or 276W/29.52m^2 = 9.3W/m^2

Related Tutorial

- DIVA RH 05: Electric Lighting

Lighting Controls

Framework for High-Performance Buildings



Electric Lighting Energy Use = LPD x Time Activated

Overview of Traditional Lighting Controls

- Manual, automated, and automated with manual override
- Bi-level switching
- Manual dimming
- Photocell–controlled on/off
- Photocell–controlled dimming
- Occupancy sensors

Why Lighting Controls?

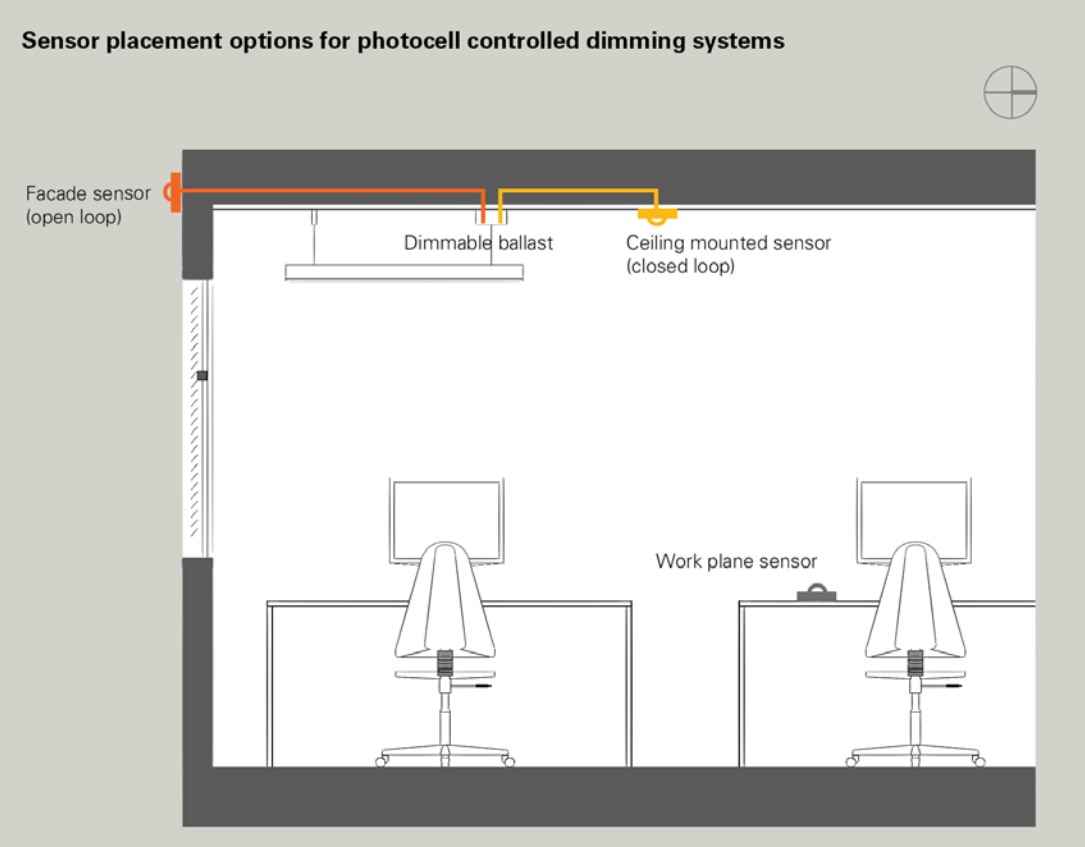
- To tailor lighting conditions to occupant's changing need.
- To raise occupant satisfaction.
- To save energy.

Detecting Occupancy

Ceiling and wall mounted occupancy sensors

- Ceiling mounted (classrooms, open offices)
- Wall mounted (small spaces, single offices)

Photocell Controlled Dimming



- fewer sensors
- less dependent on interior changes
- works well for top lighting 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

New York Times Headquarters

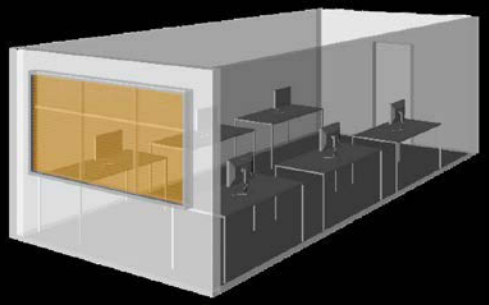
Photo courtesy of Eleanor Lee. Used with permission.

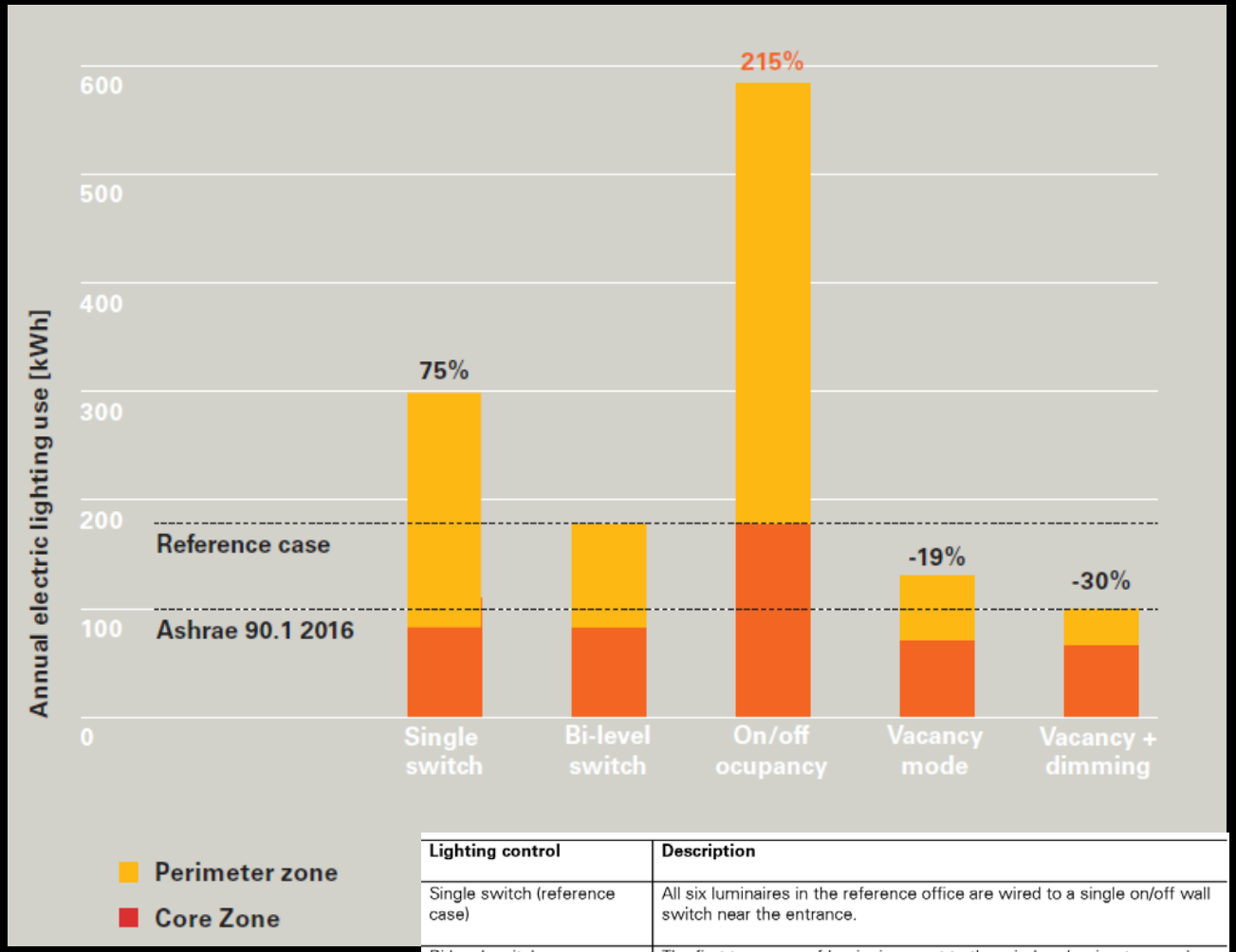
Architects: Renzo Piano, Fox & Fowle
Research Project: Lawrence Berkeley National Laboratory

- At the time (2001), the largest installation of automated lighting and dimming controls in North America. The size of the project halved the price for electronic dimming ballasts.

Electric Lighting

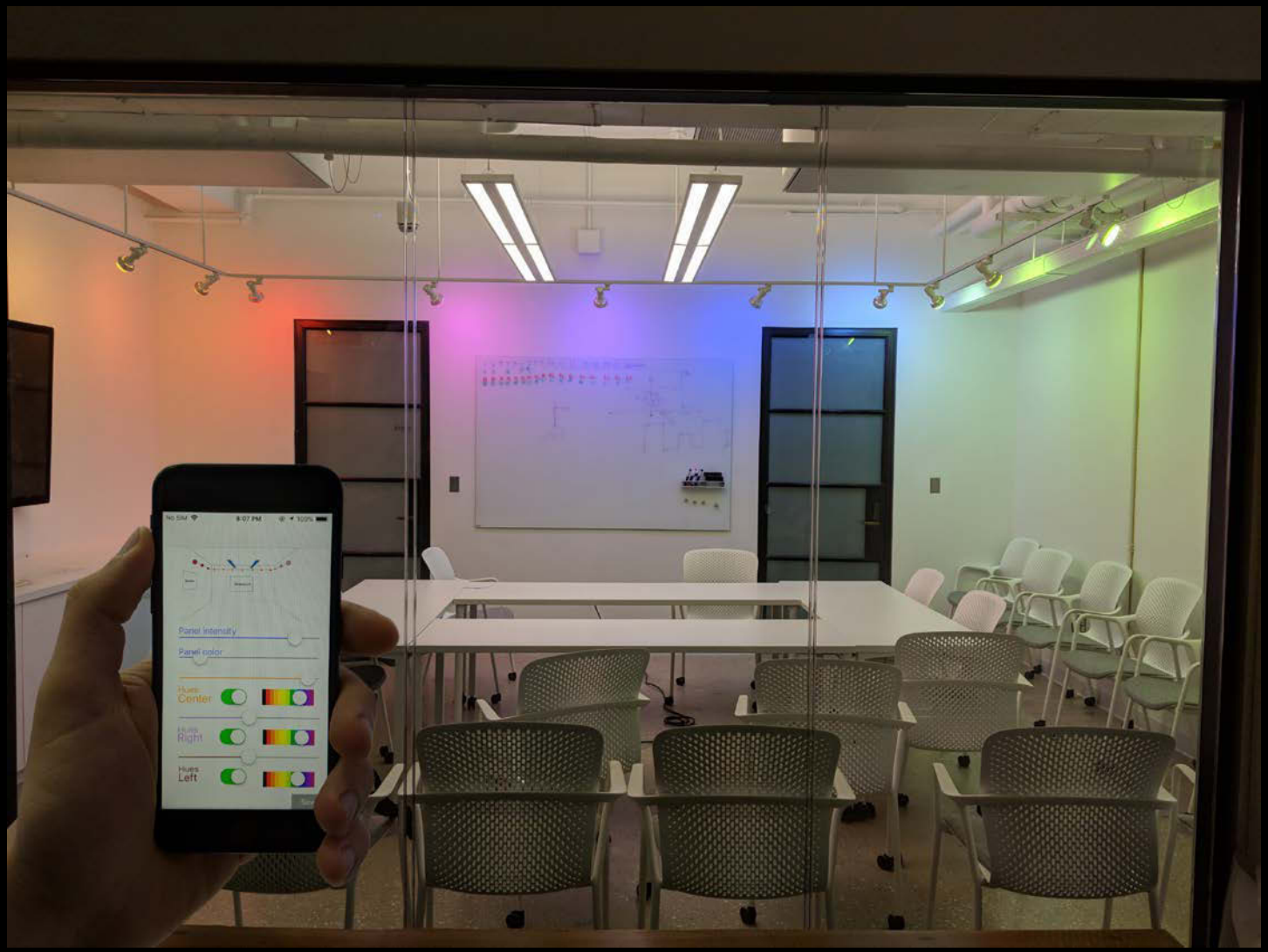
Reference Office





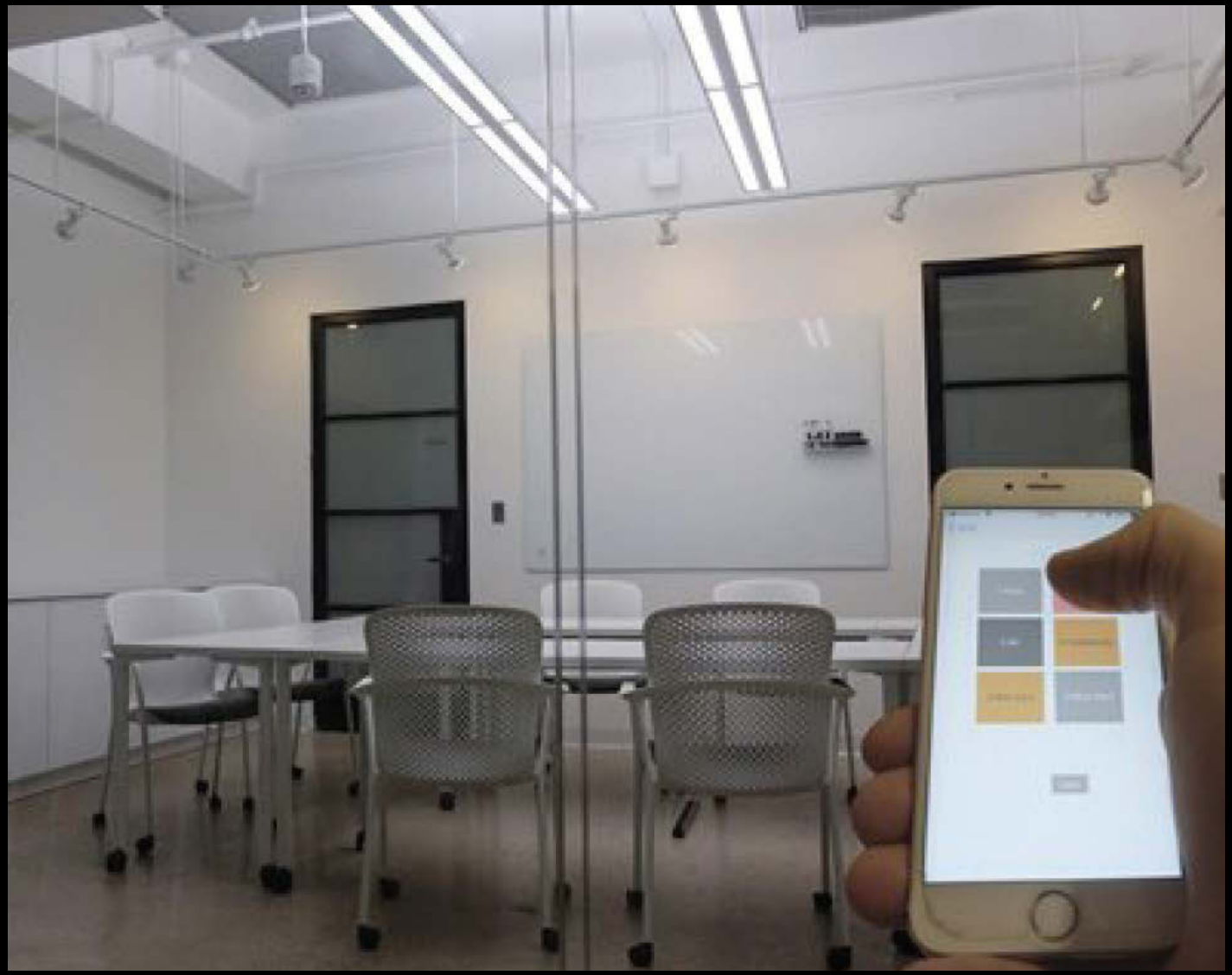
Lighting control	Description
Single switch (reference case)	All six luminaires in the reference office are wired to a single on/off wall switch near the entrance.
Bi-level switch	The first two rows of luminaires next to the window (perimeter zone) are wired to one on/off wall switch. The third-row luminaires (core zone) are wired to a second switch.
On/off occupancy	All six luminaires in the reference office are wired to a single on/off occupancy sensor near the entrance. The sensor controls the lighting without any occupancy intervention.
Vacancy mode	Same wiring as bi-level switching but both switches are replaced with an occupancy sensor in vacancy mode, i.e. occupants have to manually switch on the electric lighting but the sensors switch the lighting off automatically after 20 minutes of vacancy. Occupants may also choose to switch off the lighting manually during departure.
Vacancy mode + dimming	Same vacancy mode but the perimeter zone is also connected to an ideally commissioned photocell controlled dimming system.

Modern Smartphone-Based Lighting



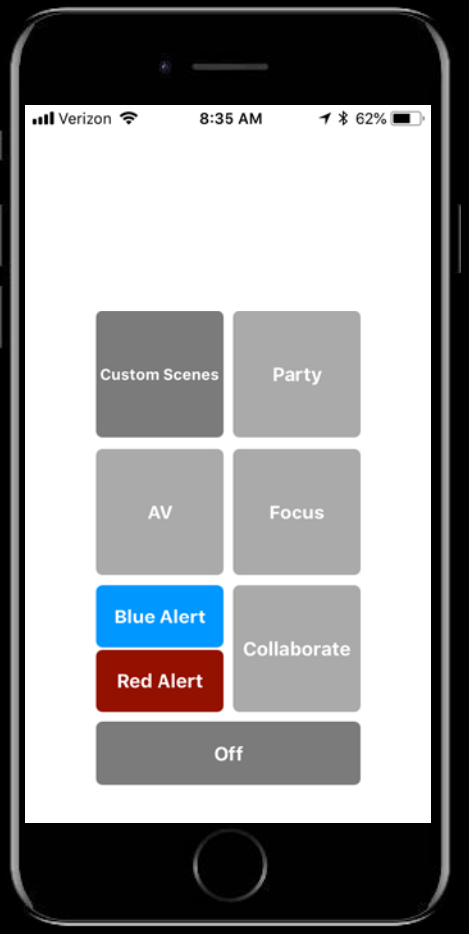
- A room like this has millions of different lighting settings.

Modern Smartphone-Based Lighting

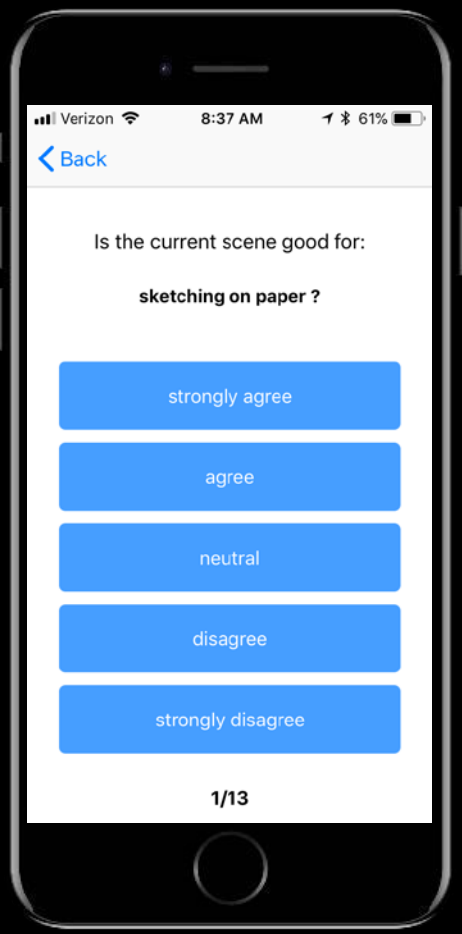


- We are typically reducing the number of settings to a handful.

Lighting Study



Home screen



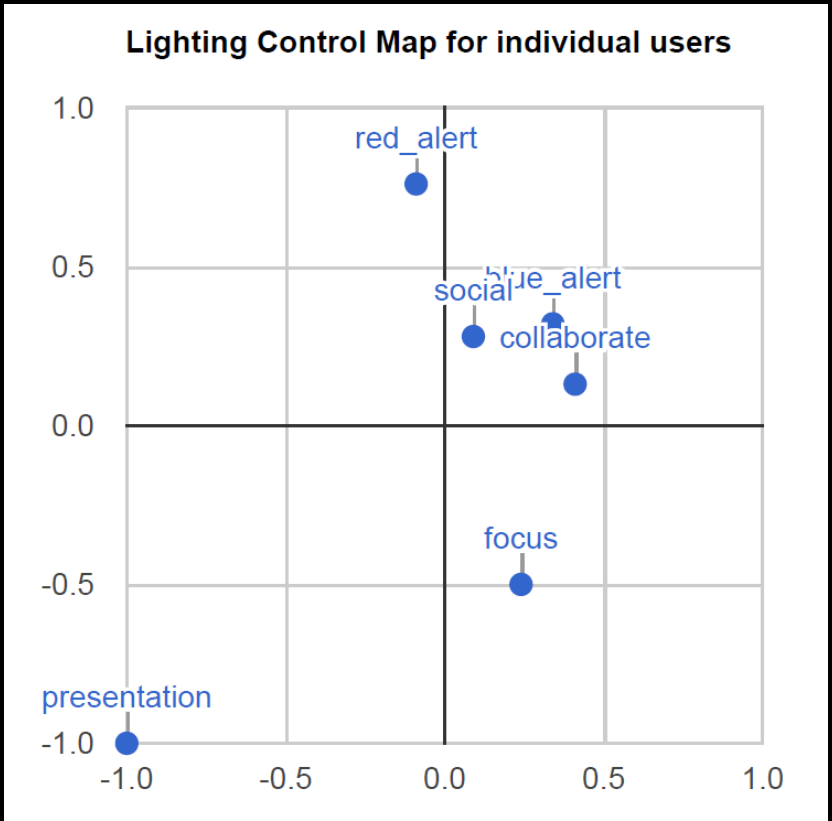
One time survey

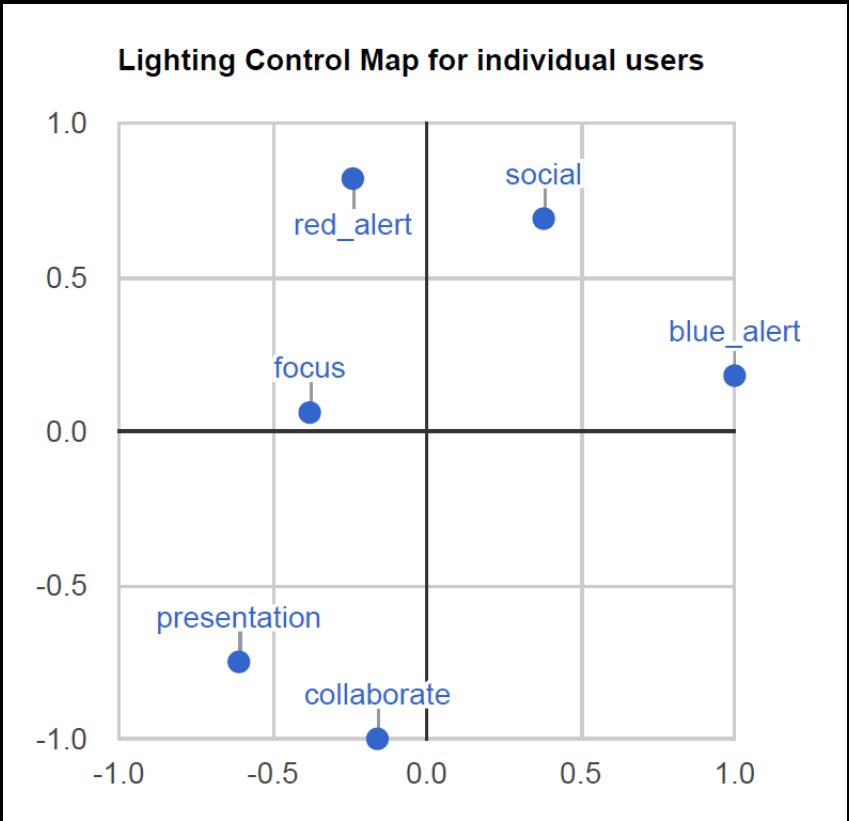
Is the current scene suitable for:

- ❑ sketching on paper
- ❑ informal presentation with slides
- ❑ coffee break
- ❑ brainstorming in a group
- ❑ programming/CAD or video editing on a computer
- ❑ formal presentation with slides
- ❑ creative task using a computer
- ❑ reading a magazine
- ❑ hand-craft
- ❑ informal phone conversation
- ❑ formal phone conversation
- ❑ study/memorization
- ❑ casual conversation with a friend
- ❑ (routine) email on computer

❑ Evaluate occupant preference for different scenes on 13 dimensions.

Lighting Study

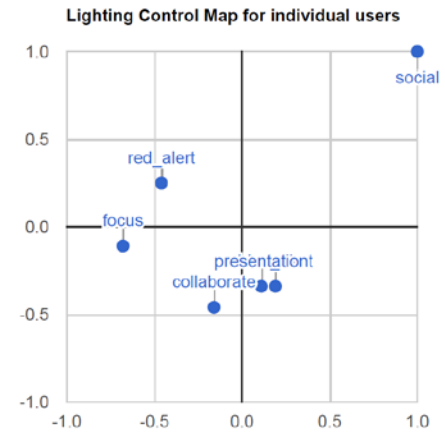


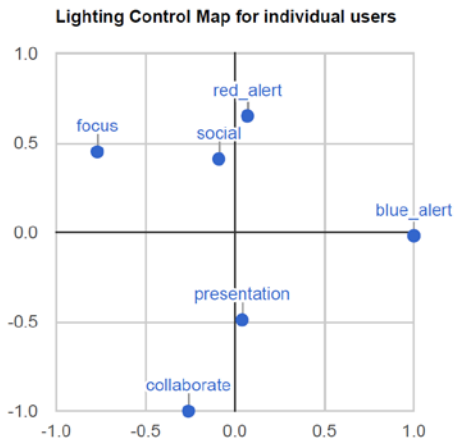


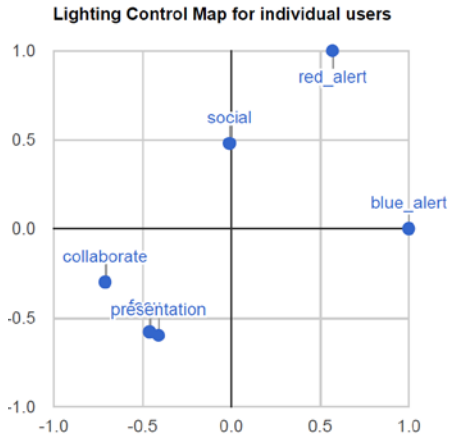
- Using principal component analysis we are mapping/grouping individual survey results on two axes.

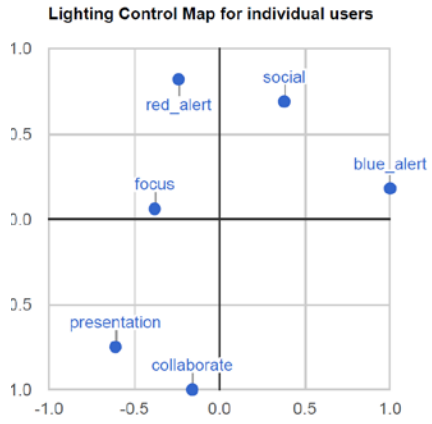
N Zhao, CF Reinhart and JA Paradiso, 2018, "Image-based perceptual analysis of lit environments," *Lighting Research & Technology*, first published July 19, 2018, https://doi.org/10.1177/1477153518786768

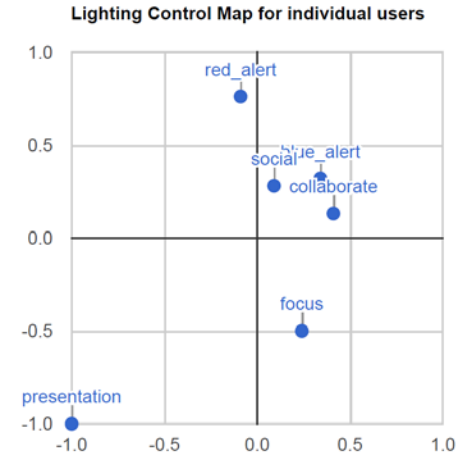
Results for Multiple Users

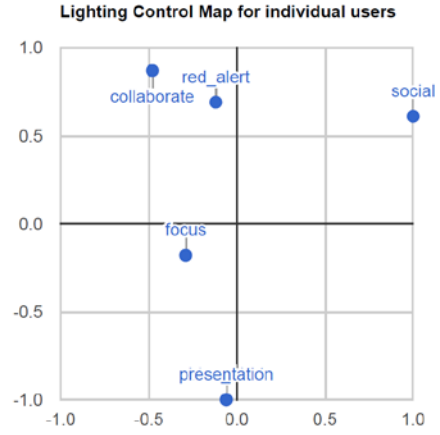


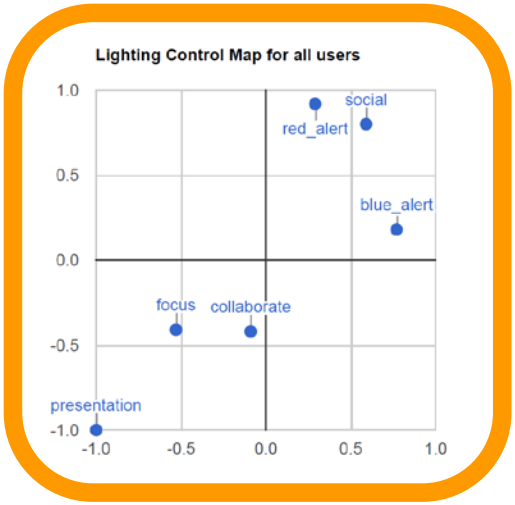






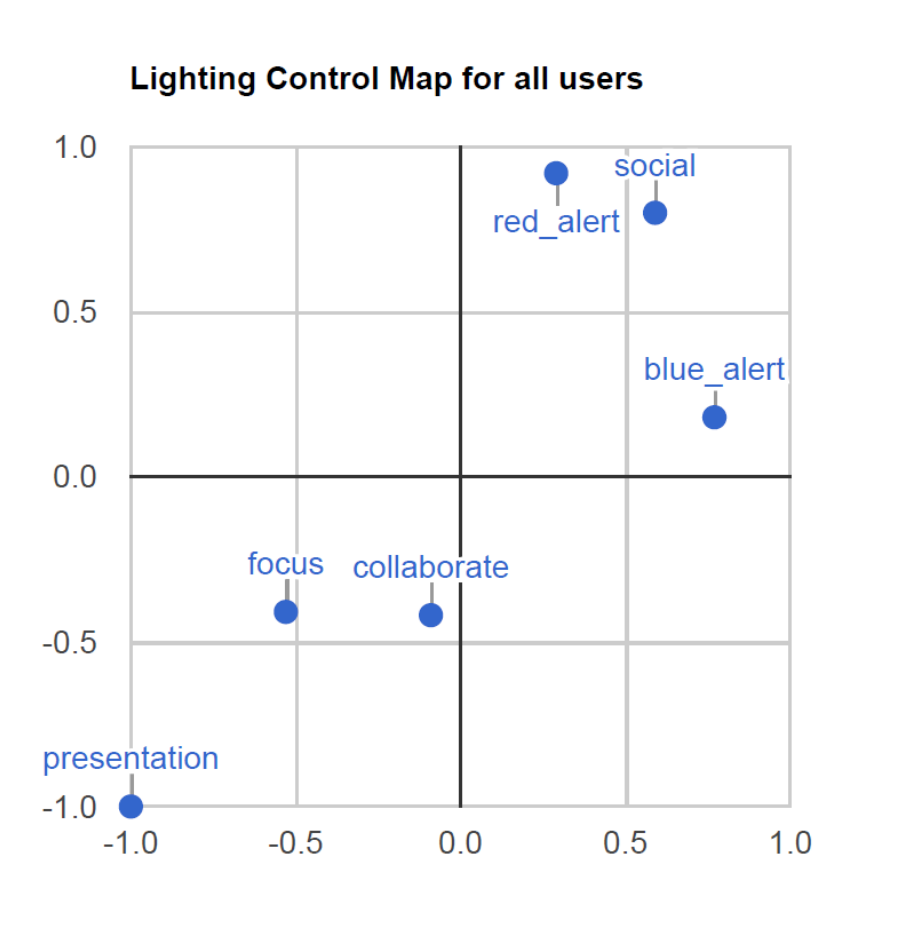


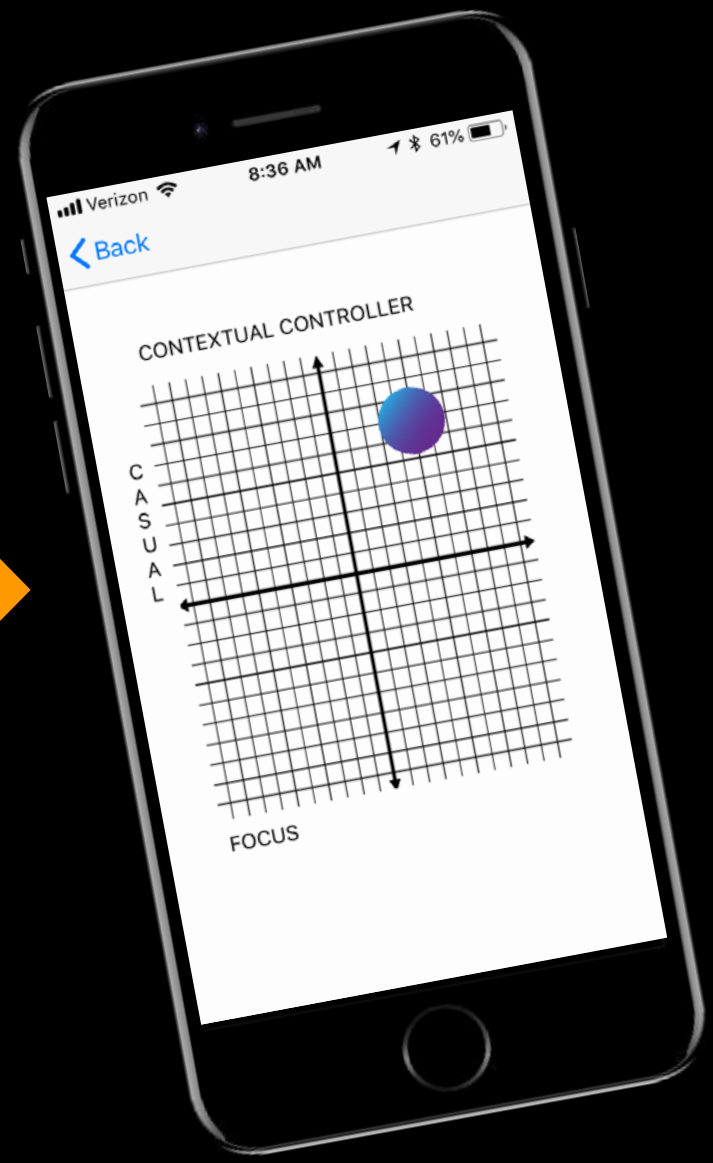




SDLAB

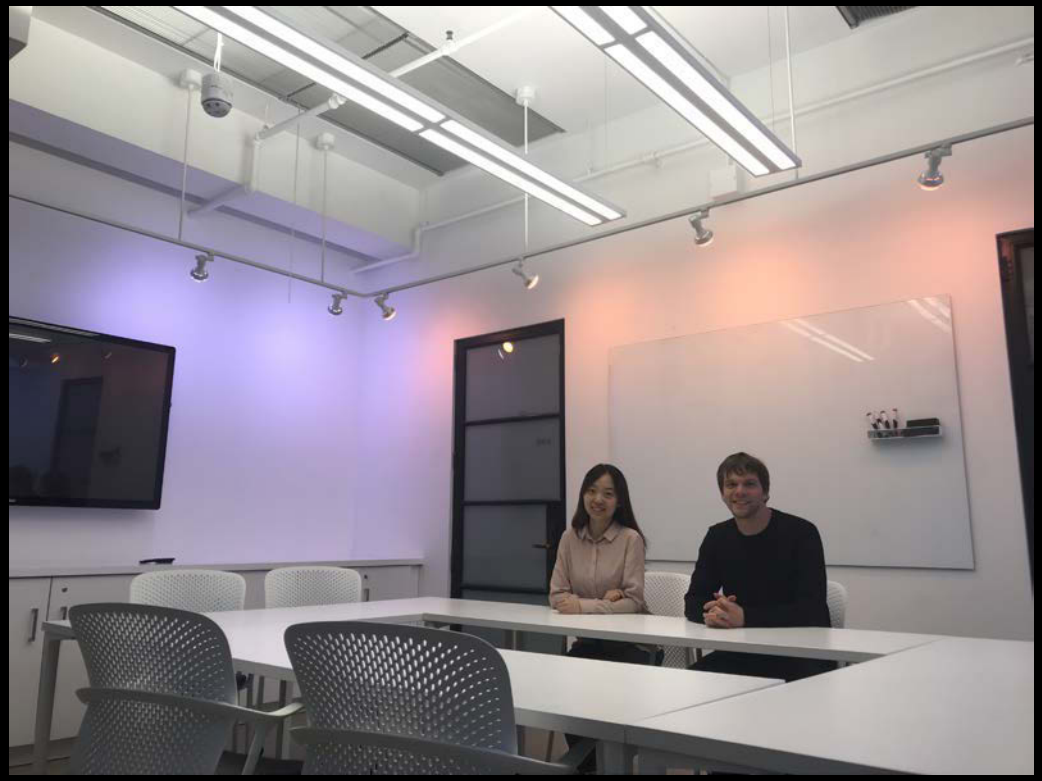
Democratic Map

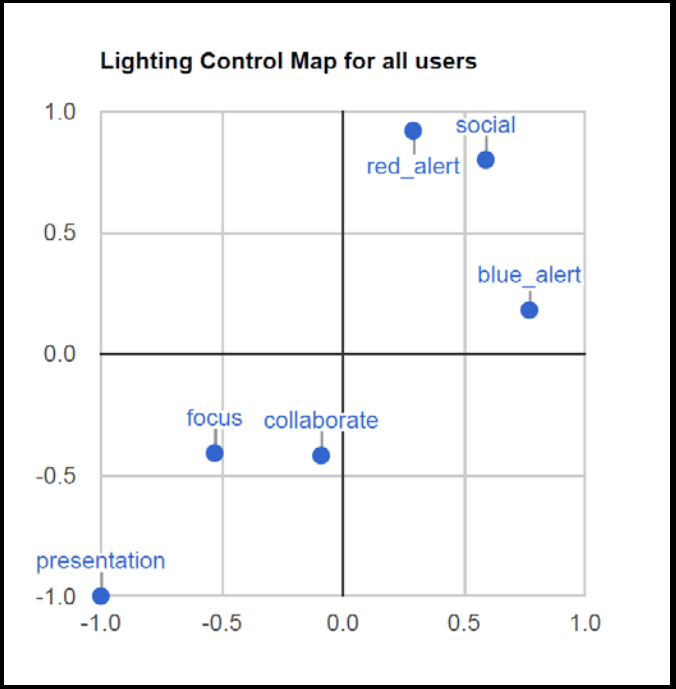




SDLAB

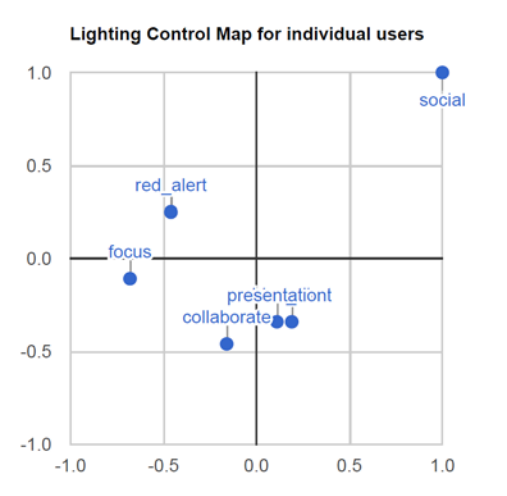
Example





- The lighting preference maps are offered as a complement to traditional scene selectors.
- If no user is present who has defined his or her preferences, use the democratic map.

Example



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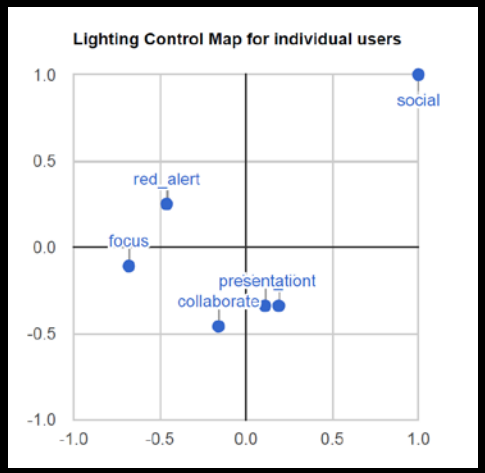
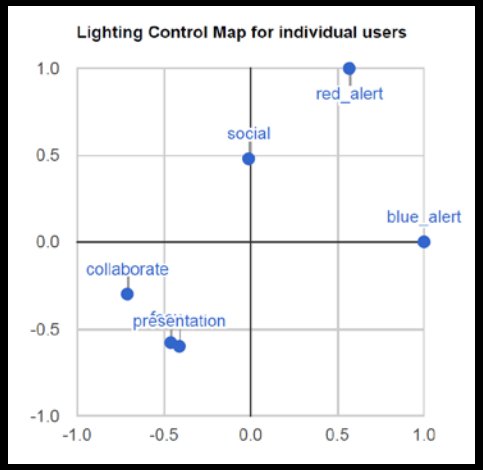
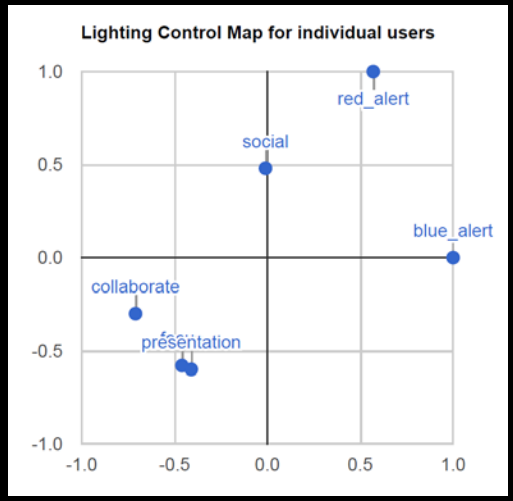
Example







- The lighting preference maps are offered as a complement to traditional scene selectors.
- If no user is present who has defined his or her preferences, use the democratic map.
- If a single user is present with a preference, use his or her individualized preference.
- Otherwise we combine the map for everybody in the room.

Take your map with you...

- People can take their preference with them without sharing their data unless needed.

Questions?

4.401/4.464 Environmental Technologies in Buildings Fall 2018