NRC·CNRC

Lighting for Well-being: The Next Quality Challenge

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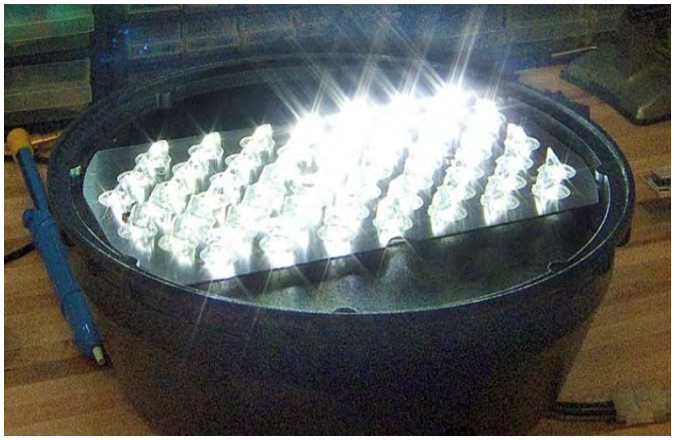
Canada

Outline

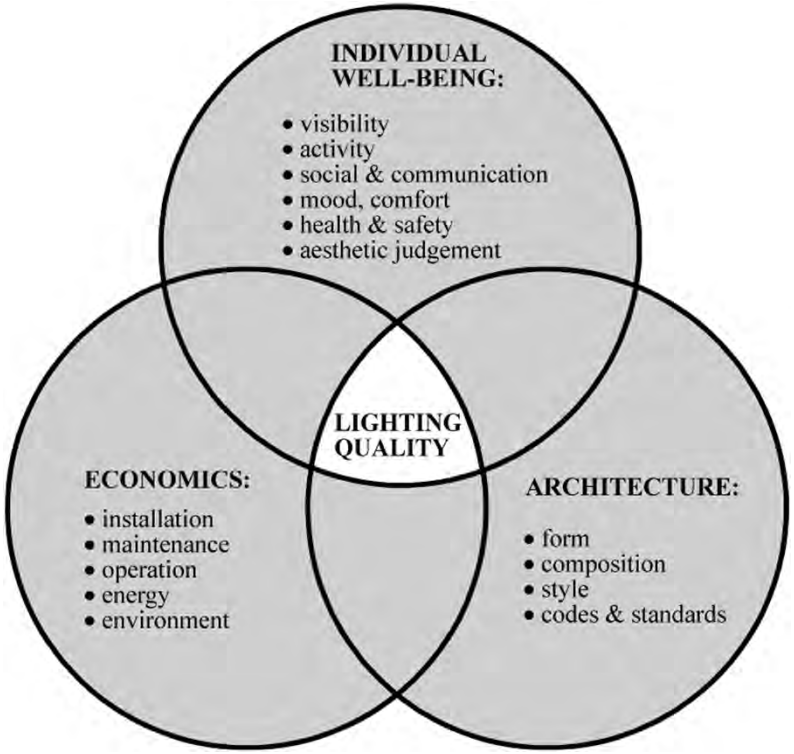
- A vision for the future
- Fostering well-being through lighting:
  - Individual control – level and spectrum
  - Daytime light dose
  - Light at night (not)
  - Colour fidelity
  - Flicker
  - Blue light hazard?
  - Safety & security
- Conclusions – what to watch for

Lighting revolution

- Current general lighting LEDs improve upon fluorescents in lm/W
  - Higher initial cost
  - Greater system complexity
- US DoE predicts 25% reduction in lighting electricity use by 2030 from LED adoption
  - Additional savings from controls
- Smart glazing developments
  - PV integration
  - Thermo- & electrochromic glare control
  - Internal & external shades with automated controls



Lighting knowledge revolution



NRC Lighting Quality model.

- Individual differences
- Value of colour fidelity
- Flicker
- Many effects of ocular light!
  - Circadian regulation
  - Alertness
  - Development

One future vision...

- When all the electric lighting is solid-state and controllable, energy efficiency takes care of itself and the designer can focus on the effects of the light on the occupants.

- But then there is...

  “Can I pay less, even if it’s not so good?”

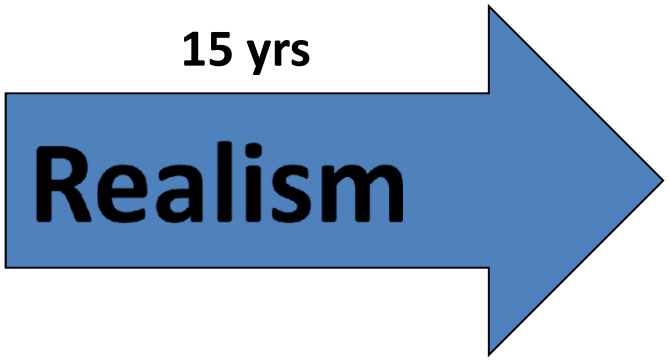
  “It’s so cheap, I can light my sock drawer!”

Lighting quality: Does it matter?

- Can office lighting go beyond providing adequate conditions for seeing?
  - Can it be smart and sustainable?

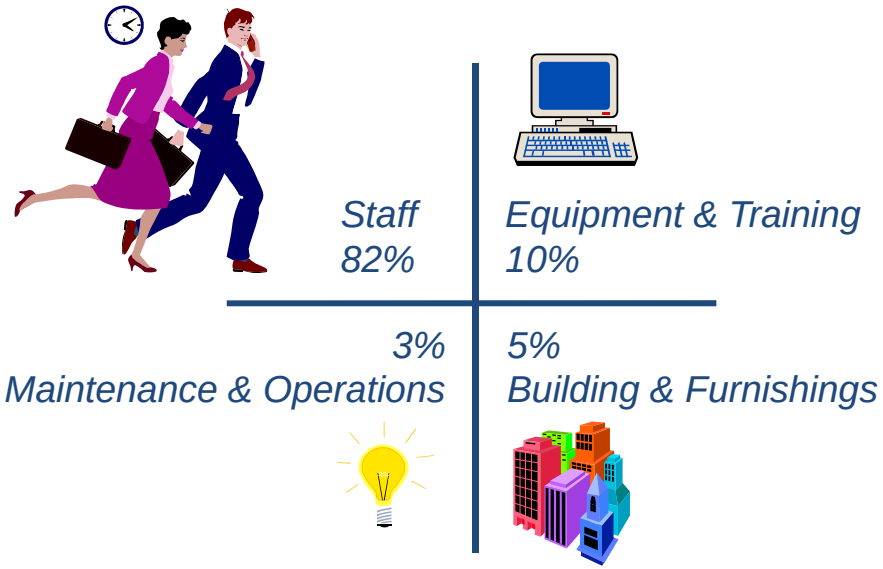
- Evidence for individual dimming and direct/indirect light distribution:
  - Highly-controlled laboratory studies
  - Quasi-realistic laboratory study
  - Field studies

→ ***Yes!***



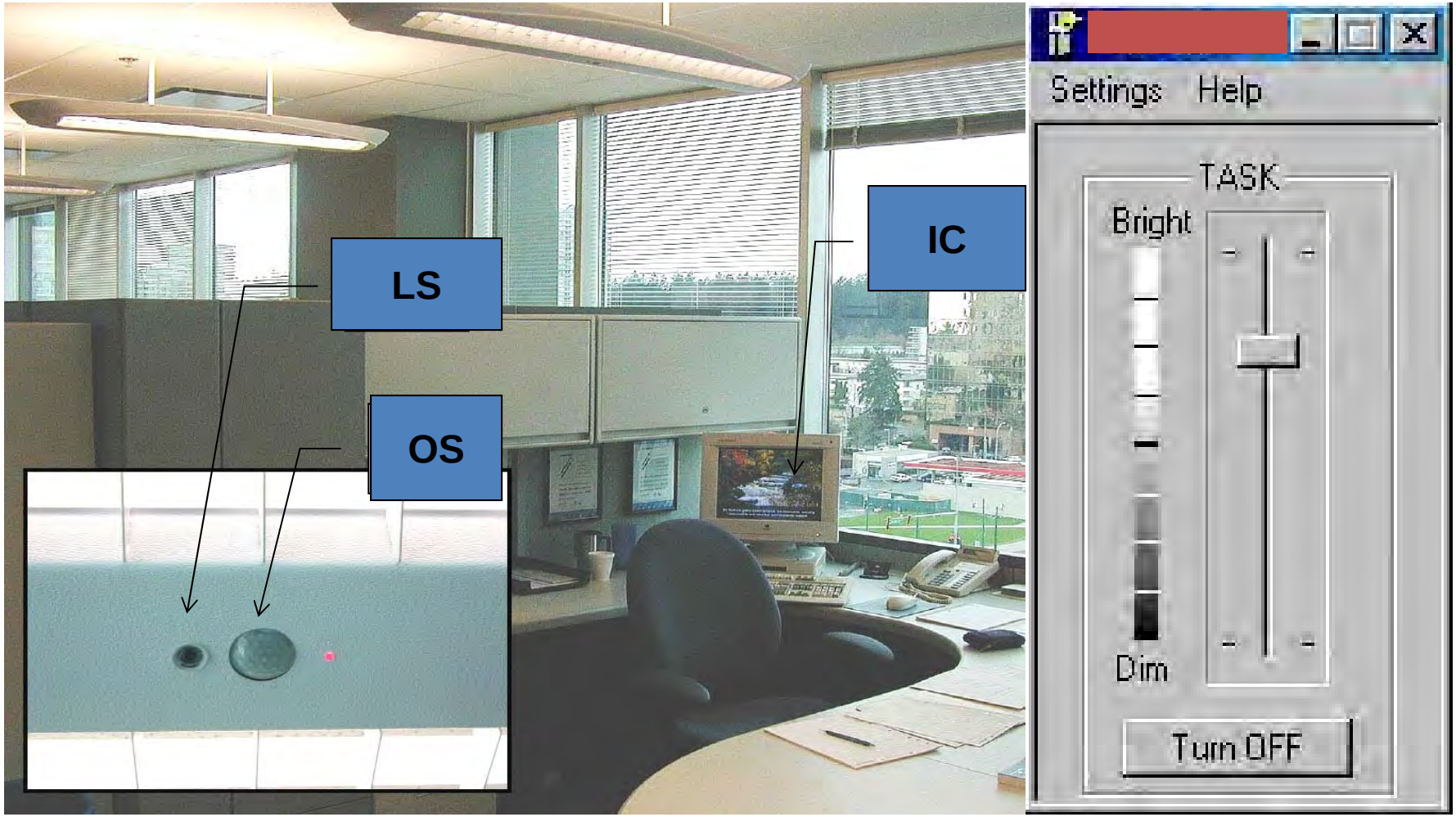
The cost of work

- People cost more than buildings by all estimates

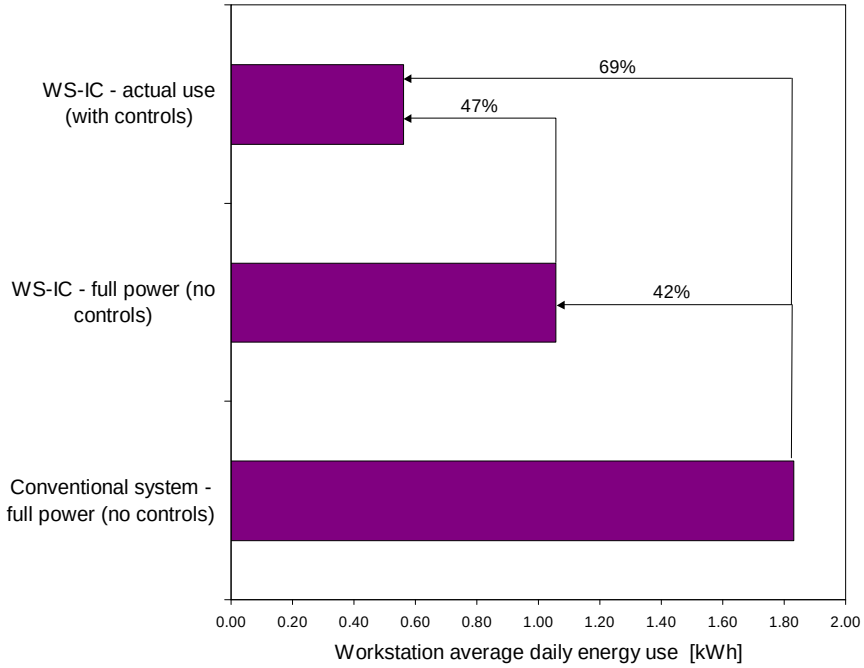


Brill, M., Weidemann, S., & BOSTI Associates. (2001). *Disproving myths about workplace design*. Jasper, IN: Kimball International.

Workstation-specific controls: Field study



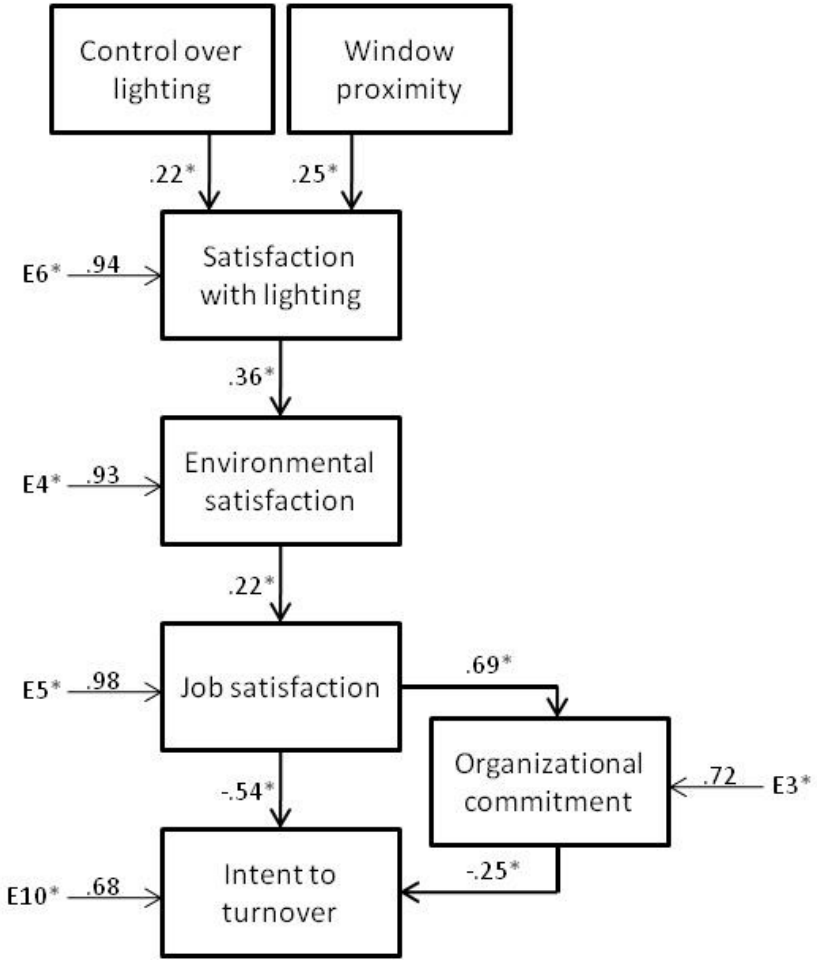
Workstation-specific controls: Energy



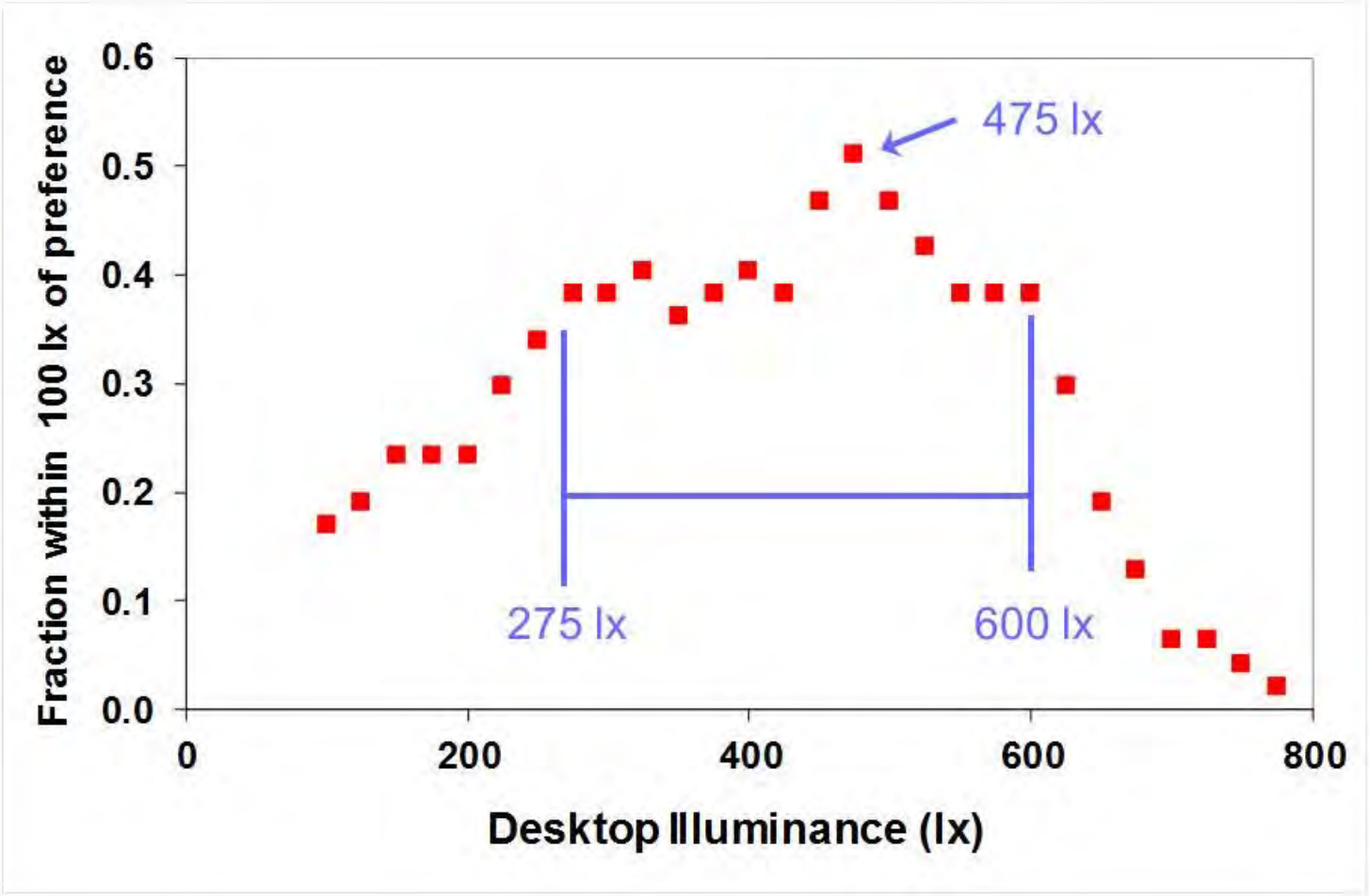
- Lighting power density of installed system is 42% lower than that of a static conventional fluorescent lighting system;
- Average peak daily power demand was reduced by similar amounts

Galasiu, A. D., Newsham, G. R., Suvagau, C., & Sander, D. M. (2007). Energy saving lighting control systems for open-plan offices: a field study. *Leukos, 4*(1), 7-29.

Workstation-specific controls: People and organization

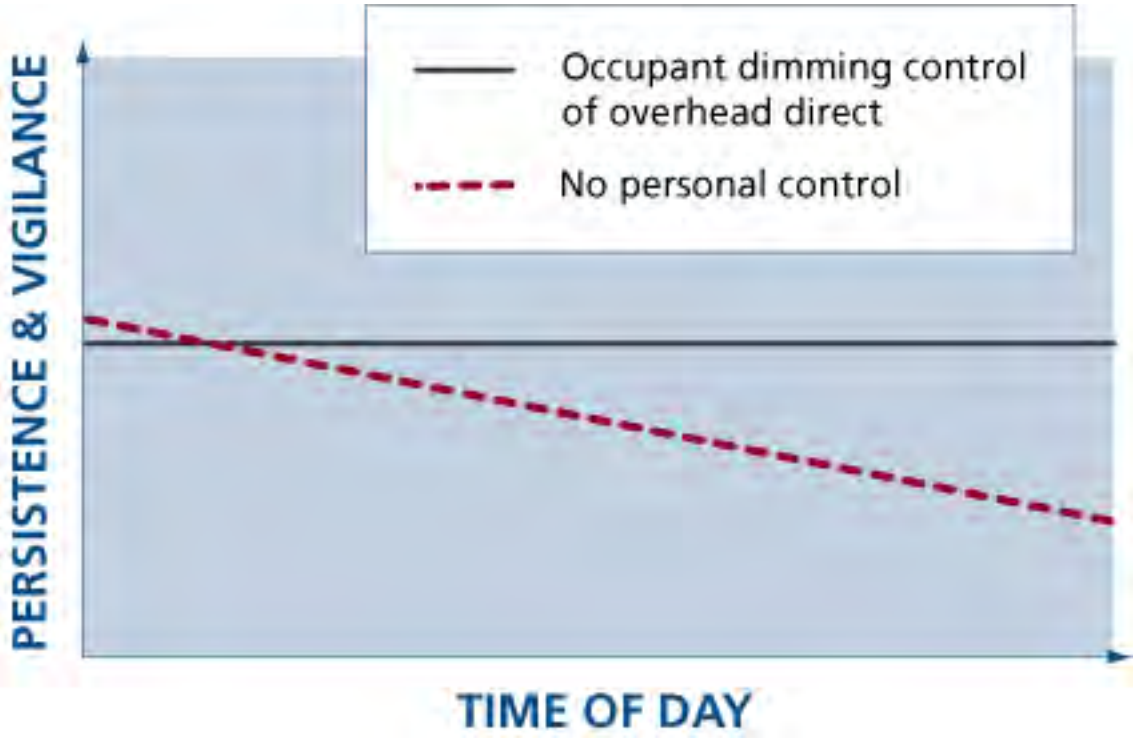


individual differences in preferences



Newsham, G. R., & Veitch, J. A. (2001). Lighting quality recommendations for VDT offices A new method of derivation. *Lighting Research and Technology*, *33*, 97-116.

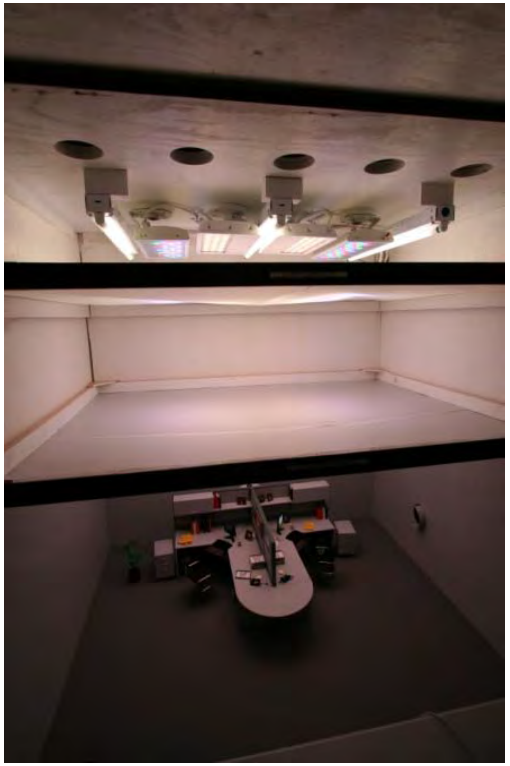
Light Right Albany: Control



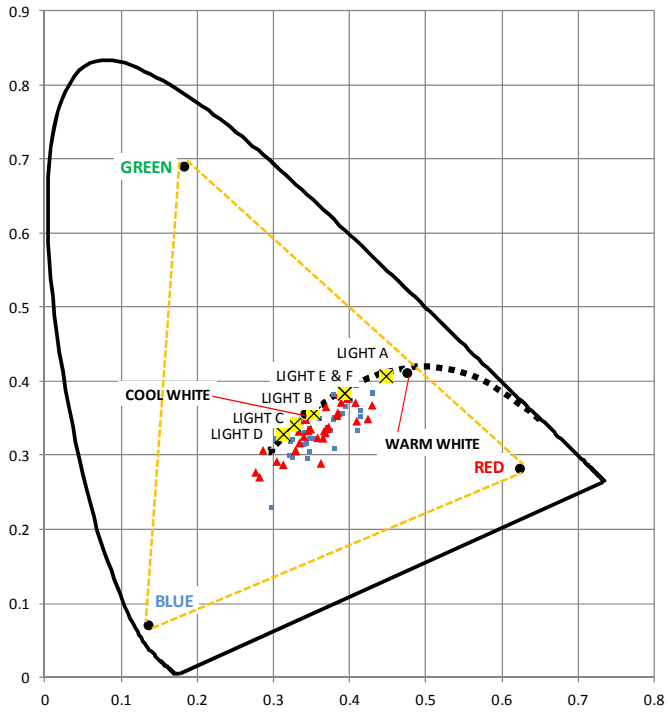
Boyce, P. R., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J. H., Myer, M., & Hunter, C. M. (2006). Lighting quality and office work: Two field simulation experiments. *Lighting Research and Technology, 38*(3), 191-223.

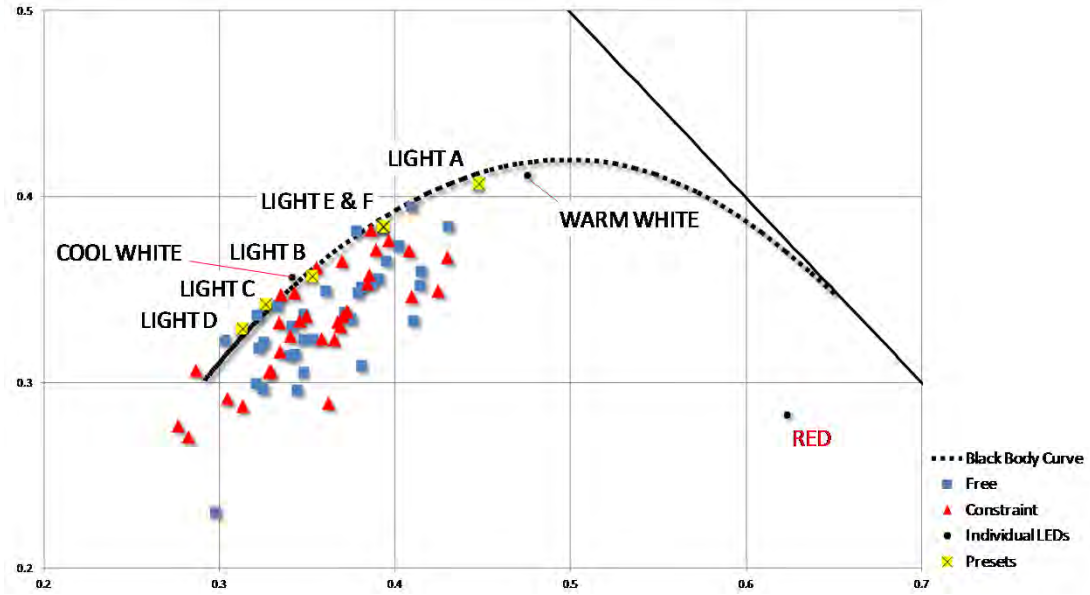
Individual colour tuning control

- Dimming control has benefits for all: What about individual spectrum control?



Tunable colour – scale model choices

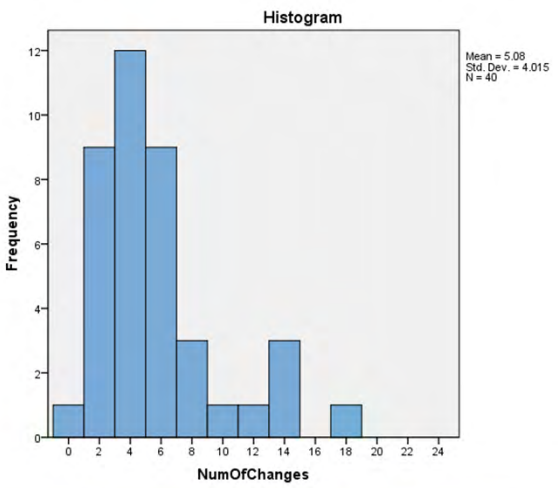


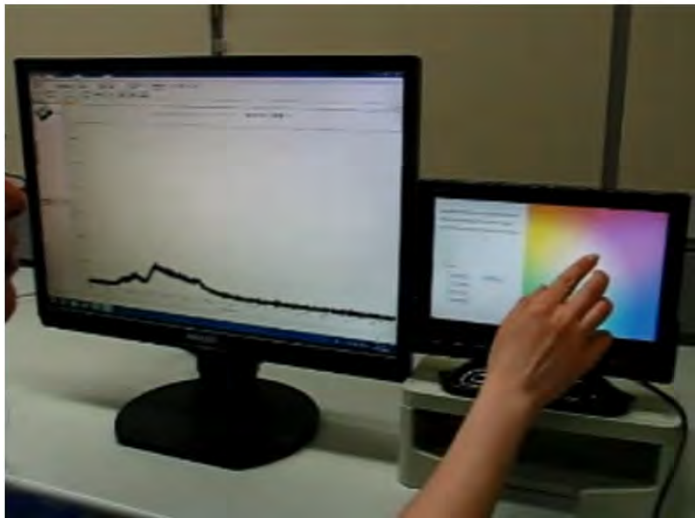


Measure	Condition	Median	Mean	SD	Min	Max
Ave E (lx)	Free	1042	992	391	109	1578
Ave E (lx)	Const.	540	517	50	320	553
CCT (K)	Free	4470	4747	2027	2832	14016
CCT (K)	Const.	4280	5013	2091	2726	11321
CRI	Free	87	82	16	29	95
CRI	Const.	83	82	11	55	96
CQS	Free	91	89	6	70	96
CQS	Const.	91	89	5	76	96
Δuv	Free	-0.0135	-0.0145	0.0109	-0.047	0.005
Δuv	Const.	-0.012	-0.0121	0.0094	-0.042	0.006

Dikel, E. E., Burns, G. J., Veitch, J. A., Mancini, S., & Newsham, G. R. (2014). Preferred chromaticity of color-tunable LED lighting. *Leukos, 10(2), 101-115.*

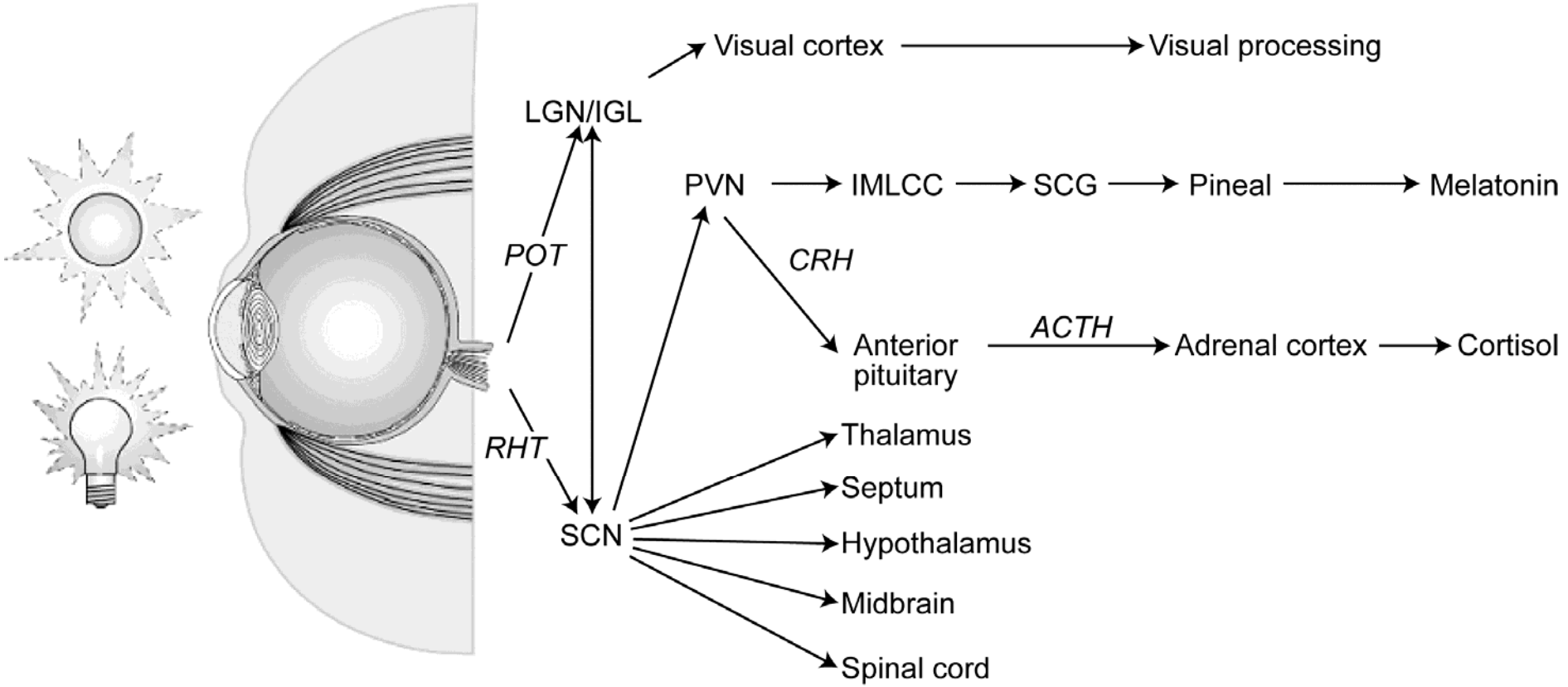
Tunable colour – Full scale



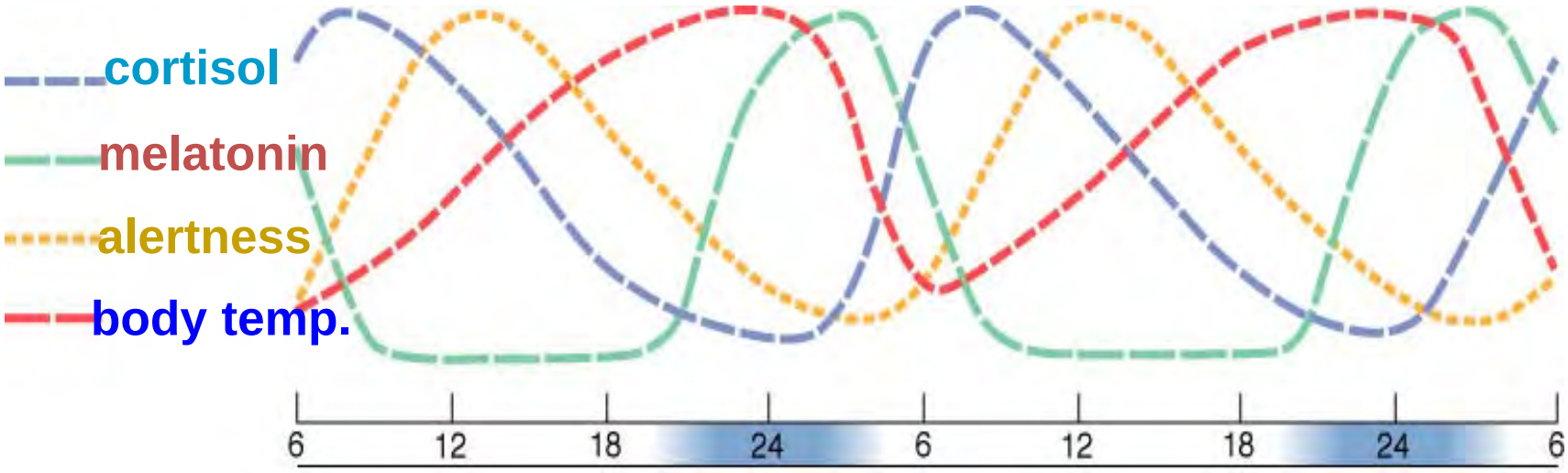


- Full day participation in full-scale office mock-up
- On-screen interface; ½ participants had choice in p.m.
- Histogram above shows frequency of choices – much greater than for dimming control
- Colour-tunable LEDs are on the market now

Light: Not just for vision

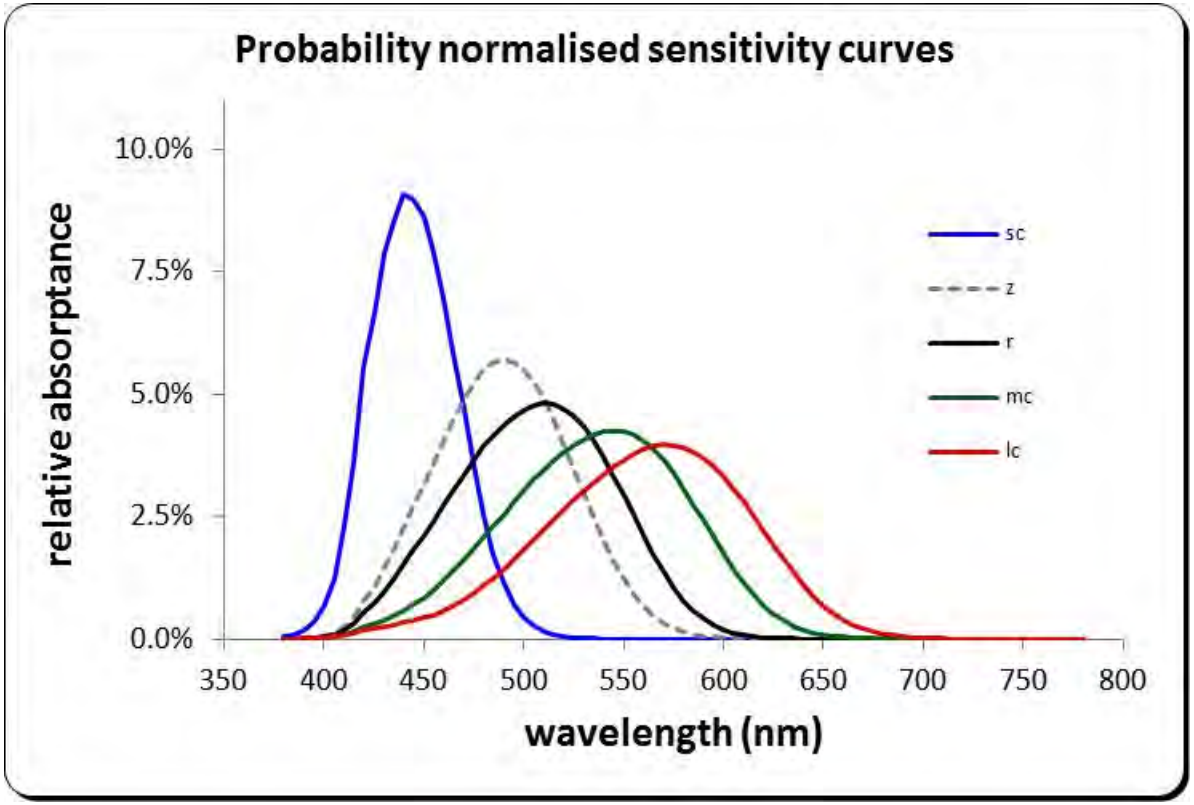


Circadian rhythms



Retinal light detection

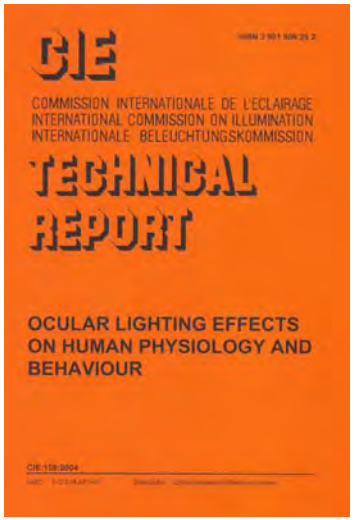
- 5 photoreceptors!
- 3 cones for photopic colour vision
- Rods for scotopic vision
- ipRGCs for irradiance detection
- Cross-connections



Lucas, R. J., Peirson, S. N., Berson, D. M., Brown, T., Cooper, H. M., Czeisler, C. A., . . . Brainard, G. C. (2014). Measuring and using light in the melanopsin age. *Trends in Neurosciences, 37*(1), 1-9.

Principles of healthy lighting

- 1. The daily light dose received by people in Western countries might be too low.
- 2. Healthy light is inextricably linked to healthy darkness.
- 3. Light for biological action should be rich in the regions of the spectrum to which the non-visual system is most sensitive.
- 4. The important consideration in determining light dose is the light received at the eye, both directly from the light source and reflected off surrounding surfaces.
- 5. The timing of light exposure influences the effects of the dose.



How much light?

Average minutes per day while exposed to >1000 lx, by city and season.

	Measurement location	Summer	Autumn	Winter	Spring
Bozeman, MT (46°N)	wrist		36		
Montreal, QC (45°N)	wrist	156		24	
Montreal, QC (45°N)	wrist	91		26	
Montreal, QC (45°N)	wrist				
Morning types		148			
Evening types		94			
Rochester, MN (44°N)	wrist	143		23	
San Diego, CA (33°N)	wrist	130		80	
Zurich, Switzerland (47°N)	spectacles				105

Well-being & light dose

- ~ 90% of time indoors
- Correlational studies associate low daily light exposure with more depressed mood
  - Do more depressed people stay indoors more, or does bright light improve mood?
- Finnish experiments improved mood with higher light doses for healthy adults

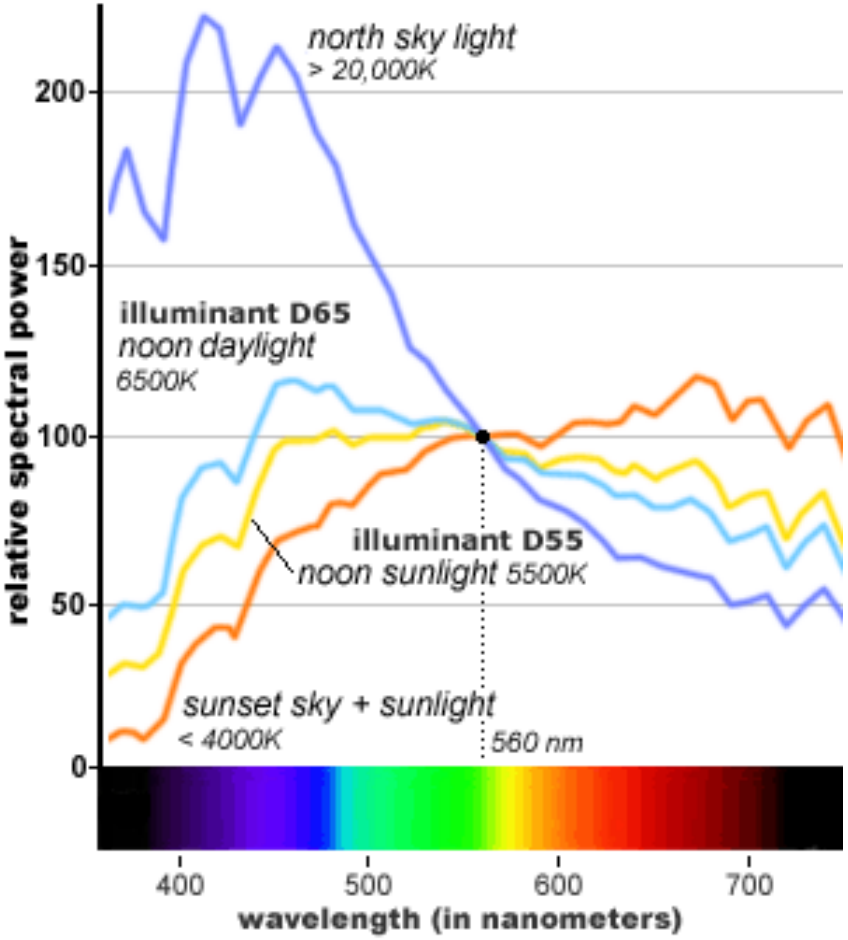
Well-being & light dose

- In mildly seasonal people, bright light exposure…
  - Increased tryptophan uptake (experimental study)
  - Reduced quarrelsome social behaviours (correlational study)
- Hospitalized patients with major depression had shorter stays when in sunny rooms that those in rooms without direct sunshine.
- In a CICU, the sunny side of the space had lower cardiac mortality after controlling for disease severity, age, etc.

Daily light exposure?

- Maybe your teacher was right: Go play outside at recess!
- http://www.fresh-air-and-sunshine.com/

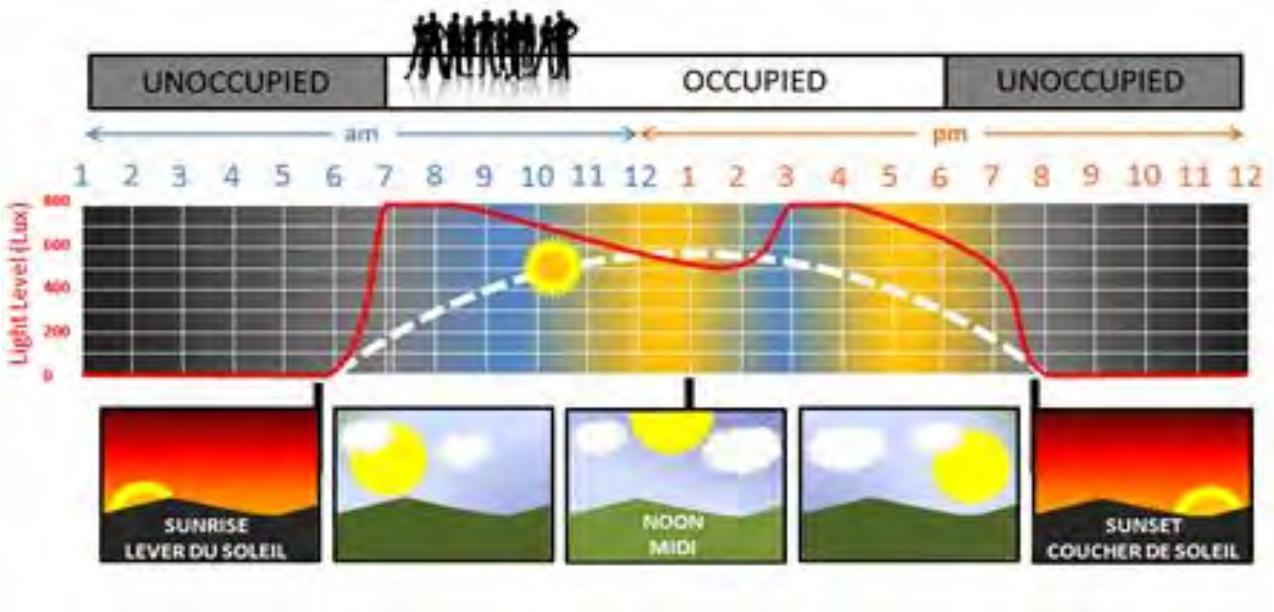
Windows and daylight



- Daylight is variable
  - Intensity
  - Direction
  - Spectral content
- Information provided
- Sometimes, enough is enough
- Glare control

Tunable colour for human well-being

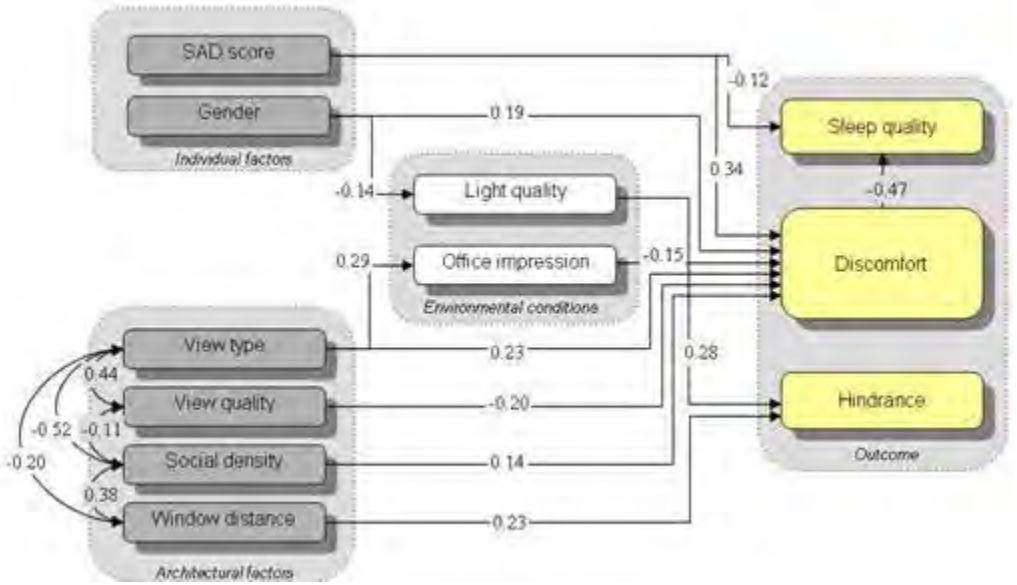
- Automated controls could provide targeted exposures to light intensity or spectrum.
- Jury is still out on how best (if at all) to do this



Bommel, W. J. M. v. (2006). Dynamic lighting at work -- both in level and colour. In *Proceedings of the 2nd CIE Expert Symposium on Lighting and Health* (Vol. CIE x031:2006, pp. 62-67). Vienna, Austria: Commission Internationale de l'Eclairage.

Windows - View & light dose

- Access to nature (images, through view, and in contact) improves well-being by promoting recovery from stress
- More attractive views from offices were linked with reduced discomfort and better sleep quality



Ariës, M. B. C., Veitch, J. A., & Newsham, G. R. (2010). Windows, view, and office characteristics predict physical and psychological discomfort. *Journal of Environmental Psychology, 30*(4), 533-541.

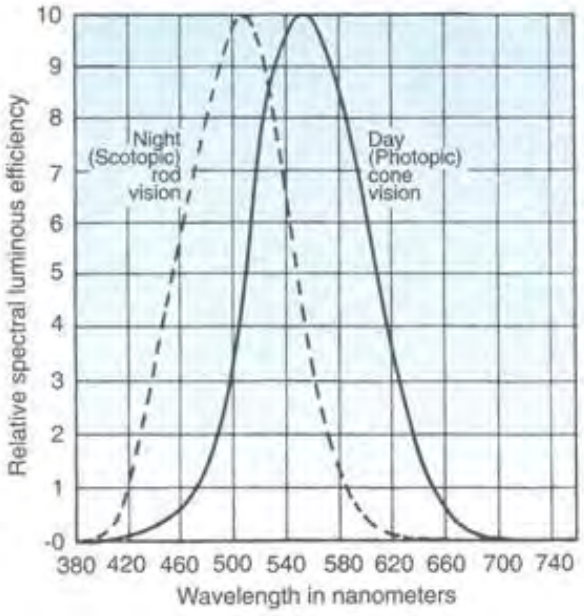
LEDs – Bringing nature indoors

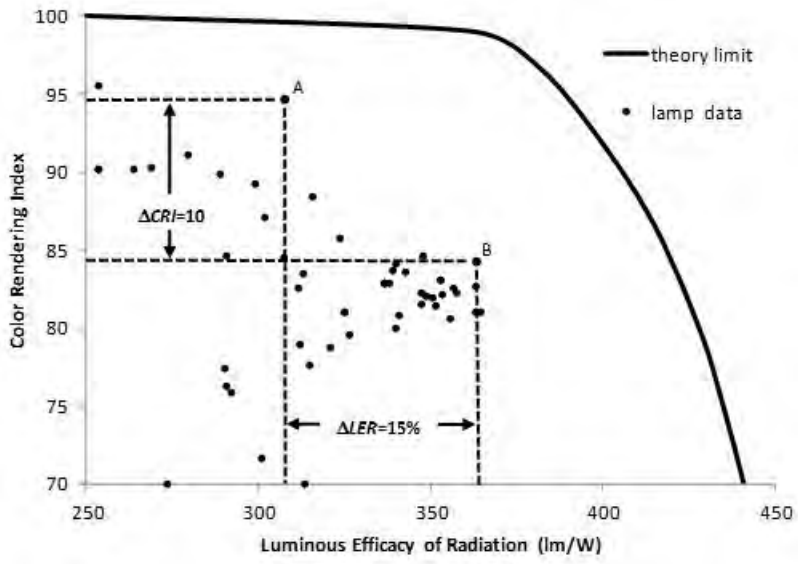
- NRC demo linked to a webcam to provide real-time info
- Artificial skies are on the market now

Light at night

- Cancer risk and shift work?
  - In vitro studies: Melatonin suppresses breast cancer and melanoma cell growth.
  - In vivo studies: Dim light at night suppressed melatonin and increased liver tumour growth.
  - Epidemiology: Separate studies have found night-time light exposure increased breast cancer risk.
- Evidence mounting that light exposure at night disrupts night-time processes, with bad consequences:
  - Sleep quality
  - Disease risk: depression, obesity, cardiovascular health

Light levels, colour fidelity, and energy

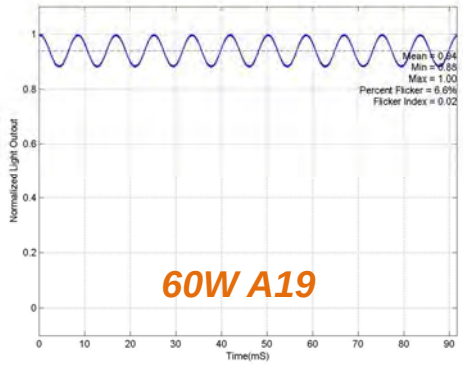


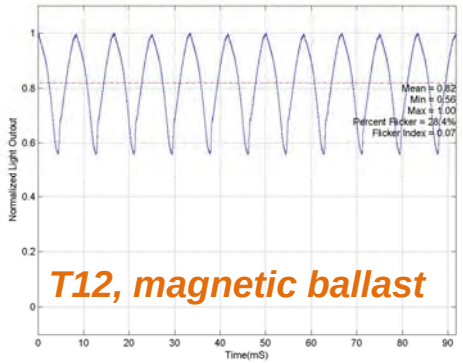


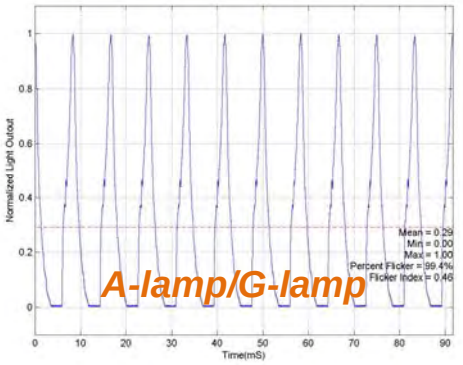
Papamichael, K., Siminovitch, M., Veitch, J. A., & Whitehead, L. (2015). High color rendering can enable better vision without requiring more power. *Leukos, in press*. doi: 10.1080/15502724.2015.1004412.

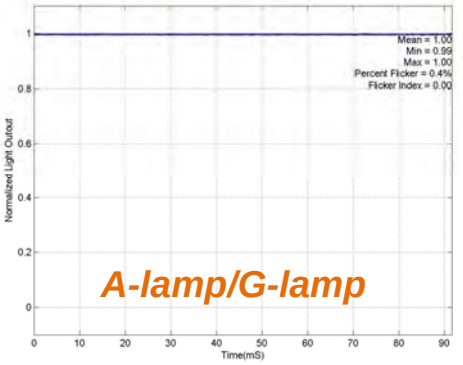
- Luminous efficacy is at odds with colour fidelity
- Reduced light level could let us save energy with good colour

Flicker





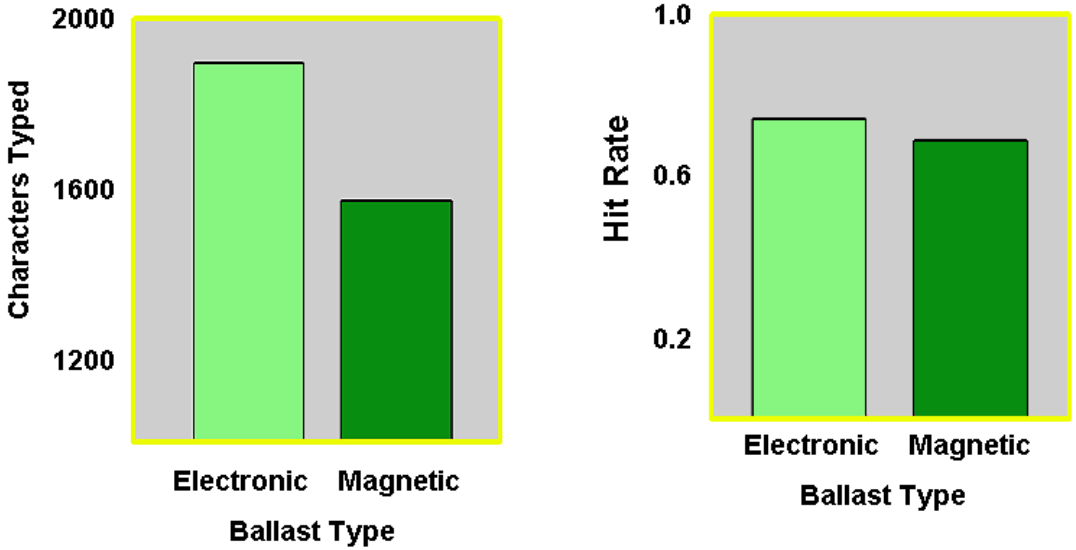




Source: M. Poplawski, PNNL

- LEDs vary widely, depending on driver & system design
- Even when not visible, flicker has neural and behavioural effects
- IEEE PAR1789

Flicker effects - examples



Veitch, J. A., & Newsham, G. R. (1998). Lighting quality and energy-efficiency effects on task performance, mood, health, satisfaction and comfort. *Journal of the Illuminating Engineering Society, 27(1), 107-129.*

- Visual performance:
  - Longer exposures to 100-120 Hz modulation, (i.e., not perceived as flicker) have been shown to reduce group average performance on visual tasks, both when viewed on paper and on CRT screens.
- Headache & eyestrain

Flicker

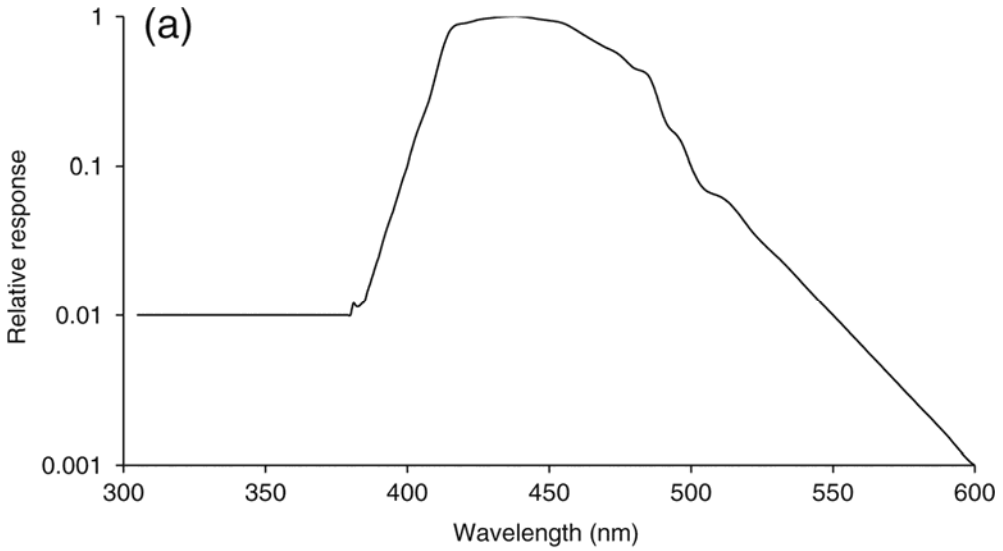
- The characteristics of the physical stimulus matter, not its source:
  - Frequency and amplitude of modulation
  - Spectral (chromatic) variation
  - Adaptation luminance (higher luminance ↑ risk)
  - Contrast
  - Size of retinal area being stimulated
  - Distance to source and its location in the visual field (central stimulation ↑ risk)

Flicker

- Room lighting will cover a larger area of the visual field than some applications
  - …but, consider the nature of the visual task, e.g.,
    - a computer monitor taking up the whole visual field
    - the apparent flicker that arises from moving past a series of point sources (e.g., tunnel)
- Big information gaps:
  - What are the conditions to avoid?
  - New metrics needed
  - At-risk populations
- IEEE P1789 coming soon with recommendations for light sources

Blue light hazard ?

- Intense short-wavelength light can cause retinal damage:
- Blue LEDs and many white LEDs peak in this region
- A 2010 report from France caused a storm…



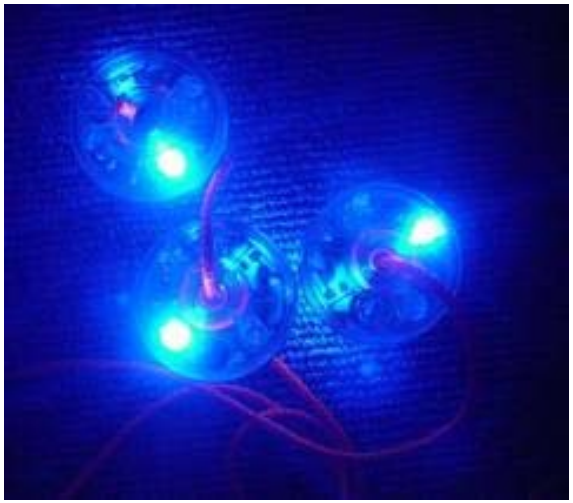
Turnbull D J , Parisi A V Radiation Protection Dosimetry 2011;rpd.ncr251

Blue light hazard – not from general service LEDs

- IEC 62471 test procedure has two measurement approaches: at the distance for 500 lx output for general service lamps, and at 200 mm for other light sources
- At 500 lx, all of the tested LEDs fell into risk group 0 (no blue-light hazard even after 10000 s exposure)
- At 200 mm, some LEDs fell into risk groups 1 (blue-light risk after 100 s) or 2 (blue-light risk within 0.25 s)

Blue light hazard

- Aversion response is protective
- Non-GLS, special populations



LEDs – adding new functionality

- LEDs can add to security signalling, especially if coloured
- Flash when alarm sounds
- Indicate safe exit direction

Conclusions

- Lighting has always been about providing well-being
- New ways to do it:
  - Controls over level and spectrum, individual and automatic
  - Energy savings for long-term sustainability
  - Better daylight integration, higher light dose
  - Affordable high colour fidelity (?)
  - More informative emergency lighting
- Now we know to avoid:
  - Light exposure at night, for people & ecology
  - Flicker (frequencies and modulations in P1789)

Thank you

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