Circadian lighting for health and wellbeing

Thursday 23 April 2020
11:00-12:00 (BST)

Chair - Anastasia Mylona, Head of Research, CIBSE
Speaker - Paul Littlefair, Associate Director, Lighting, BRE

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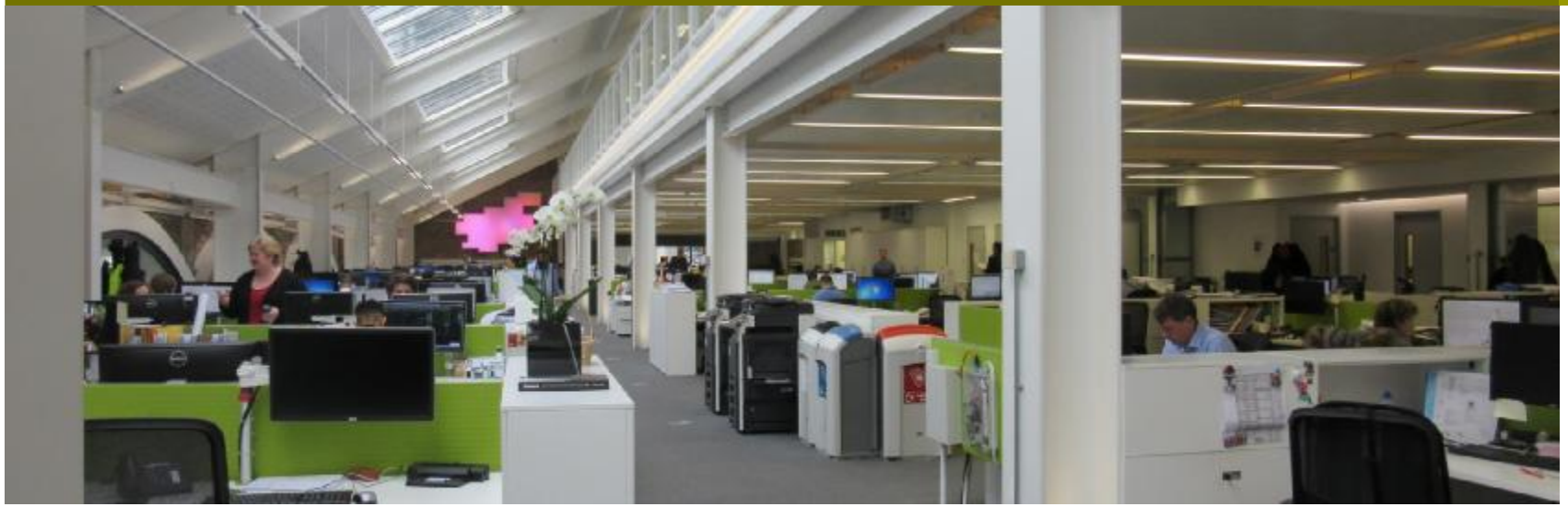
Circadian lighting for health and wellbeing

Dr Paul Littlefair, BRE

Building a better world together

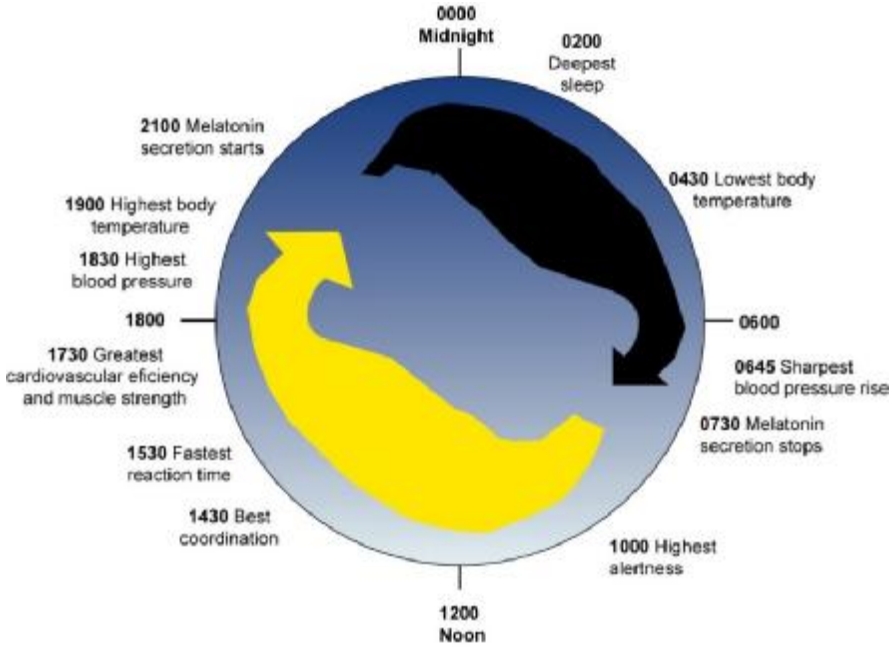


Health implications of poor lighting

- BRE Trust project on Lighting and Health
- Inability to see hazards (low illuminance, disability glare)
- Glare causing headaches, sore eyes, muscle problems
- Flicker causing headaches, eyestrain, epilepsy
- Possible retinal damage from blue light content
- Mercury from fluorescent tubes

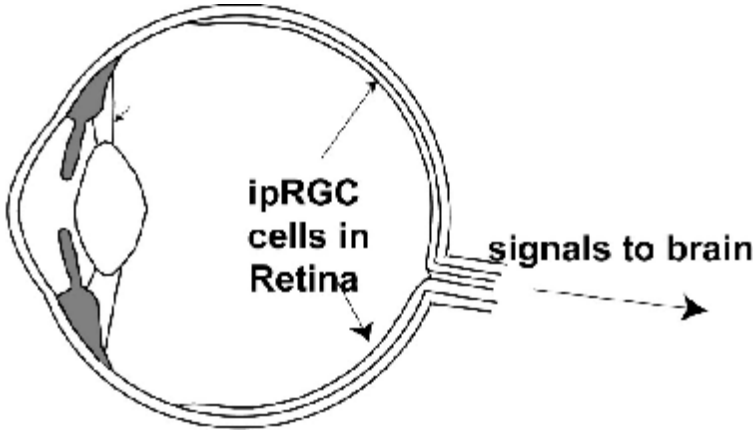
Circadian rhythms

- Our bodies have circadian (daily) rhythms which control our activity
- Light, especially blue light, suppresses melatonin, the hormone that makes us sleepy. Exposure to light at night, can cause lack of sleep.
- Exposure to light during the day helps regulate our daily rhythms of sleep and alertness.
- Lack of light can lead to ‘free running’ rhythms, sometimes with wakefulness at night and sleepiness during the day.



Light and circadian rhythms

- As well as the rod and cone cells which allow normal sight, the retina contains special cells, intrinsically photosensitive retinal ganglion cells (ipRGCs).
- ipRGCs produce a photopigment, melanopsin. This transmits signals to the Suprachiasmatic Nucleus (SCN) which drives the body's circadian clock.
- The ipRGCs are especially sensitive to blue light, at 460 to 480 nm wavelengths.

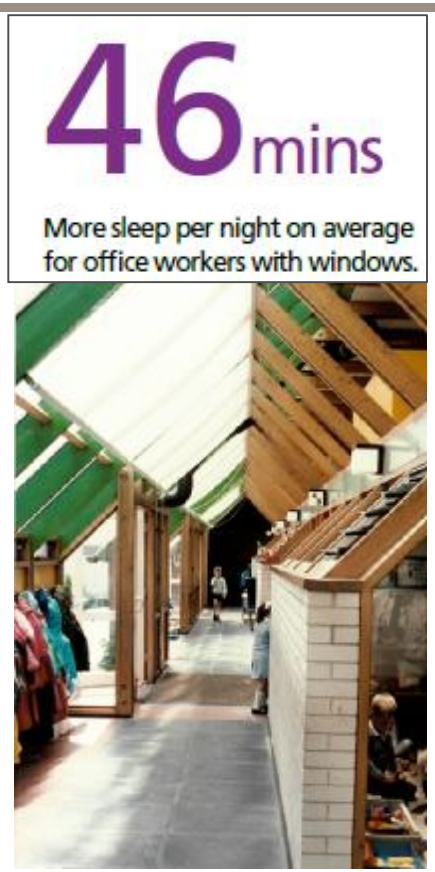


‘Circadian lighting, health and wellbeing’ project

- Daylight helps modulate circadian rhythms, providing bright light during the day, but is not always available in workplaces and homes.
- Electric ‘Circadian’ lighting now widely promoted with bright, bluer light during the day to synchronise circadian rhythms and promote alertness. Light becomes dimmer and redder towards the evening when it is time to relax
- BRE Trust/ CIBSE project to investigate circadian lighting and obtain occupant reactions to a real installation
- Included workshop, literature review, experimental monitoring, producing guidance
- Literature review ‘RLRCL Report describing initial Literature Review on Circadian Lighting’ available at https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q0O00000CF7o9QAD

Daylight- a natural illuminant

- Daylight gives high levels of blue enriched light which are ideal for modulating circadian rhythms, resulting in improved health and mood (Boyce, Hunter & Howlett, 2003; Van Bommel & Van den Beld, 2004; Kaida et al, 2007)
- Several studies have reported healing effects of daylight in healthcare settings (Rashid & Zimring, 2008; Aries et al, 2013; Acosta et al, 2015):
  - Less pain medication, less stress (Walch 2005)
  - Shorter patient average length of stay (Choi et al, 2012; Joarder and Price, 2013)
  - Lower mortality rates in cardiac intensive care unit (Beauchemin & Hays, 1998)
  - Quicker recovery in wards with view out (Ulrich, 1984) or better daylit (Evans & Ferguson, 2011)



Daylight as natural illuminant

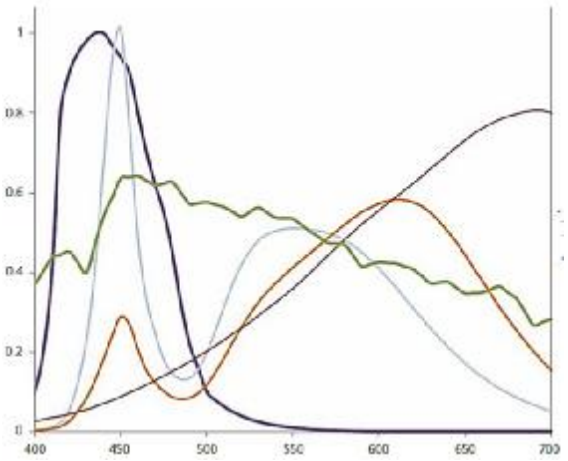
– Exposure to high levels of daylight within buildings can lead to increases in night sleep quantity and quality (Figueiro & Rea, 2016). Workers in offices with windows in Chicago study (Boubekri et al 2014) slept 46 minutes per night more in the work week than similar workers without windows.

– Children in windowless schools have lower levels of cortisol, which reduces the body's resistance to infection and the ability to concentrate or co-operate (Kueller & Lindsten, 1992)

What about electric lighting?

- In principle, exposure to bright electric light at correct times of day may have similar effects
- However electric lighting levels may be:
  - Too low during the day
  - Too high during the evening / at night

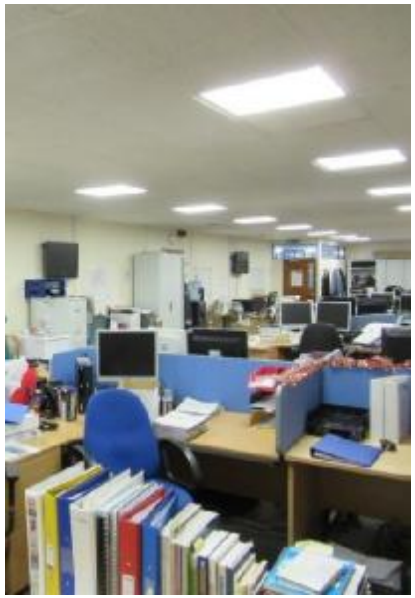
  and/or the light spectrum may not be right
- Increasing use of electric light has paralleled a rise in sleep deficiency (Czeisler, 2013; Sleep Council, 2013; Eisenstein, 2013)
- Exposure to wrong light, particularly at night, is likely to disrupt the circadian system (Cajochen, 2005; Burkhart & Phelps, 2009; Higuchi et al, 2011; Bedrosian et al, 2013; Rahman et al, 2013)



Spectral power distribution of different light sources

Higher illuminance / higher CCT

- Improvements in academic performance at 1000lux / 6500K (Mott et al, 2012; Barkmann, Wessolowski & Schulte-Markwort, 2012; Sleegers et al, 2015) and under blue enriched lighting (Keis et al, 2014)
- No short-wavelength light during the morning → delayed melatonin onset (Figueiro & Rea, 2010)
- Increased subjective alertness at 2500lux / 6500K compared to 500 lux / 6500K (Wilhelm et al, 2011)
- Increased sleep quality & duration, alertness and performance under 17000K compared to 4000K (Viola et al, 2008) and 2900K (Mills et al, 2007)
- Increased alertness & cognitive performance and reduced sleepiness under 6500K compared to 2500-3000K, even at 40lux (Chellappa et al, 2011)



Higher illuminance / higher CCT

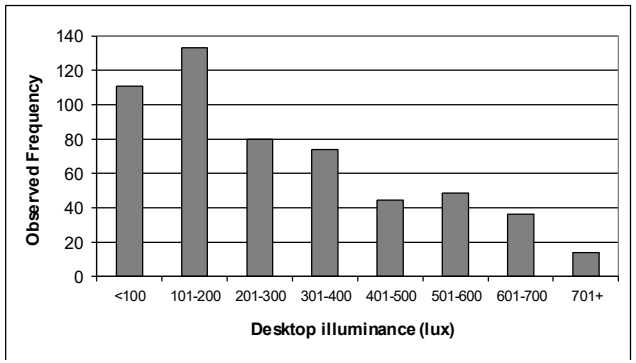
– Studies on variable lighting conditions

- Smolders et al (2012)
  - Baseline exposure of 200lux at the eye for 30mins then 1000lux for 60 mins (4000K, no daylight)
  - 1000lux → More energetic and alert; Better cognitive performance; Increased heart rate and physiological arousal

- De Kort & Smolders (2010)
  - Static lighting 500lux / 3000K vs. dynamic lighting 500-700lux / 3000-4700K
  - Automatic controls; Daylight dimming for luminaires near windows
  - No significant differences on self-reported measures of wellbeing and performance, including sleep quality, but higher satisfaction with dynamic lighting

User preference

- Begemann et al (1997)
  - Dynamic lighting 200-2000lux / 2800-5000K, adjustable by occupants
  - Preference for a daylight cycle as opposed to constant conditions
  - Preference for much higher levels of electric lighting → on average 800lux at desk level was added to incoming daylight
- Zumtobel (2014) study on office lighting (over 2000 participants)
  - Below 40% satisfied with 500lux or less. Over 60% preferred at least 800lux
  - Vast majority preferred 4000K (41%) and 5000K (36%)
  - Tendency towards warm/neutral white (4000K) in individual offices and towards cool white (5000K) in open plan offices
- However in a study by Moore et al (2003) occupants chose a range of lower illuminances
- High illuminance levels can be associated with glare



Light at night – example: shift work

- Light at night in the blue wavelength range is likely to be particularly disruptive to the circadian system (Cajochen, 2005; Burkhart & Phelps, 2009; Higuchi et al, 2011; Bedrosian et al, 2013; Rahman et al, 2013)
- Shift working has been linked to a range of disorders including cancer, heart disease and digestive illness (Schernhammer, 2001; Kantermann & Roenneberg, 2009; Hansen & Lassen, 2012; Knutsson et al, 2013)
- Night workers sleep for over two hours less than day workers
- Light suppresses melatonin, which may result in increased risk of cancer
- Employers can try to reduce night work and shift work
- Rotate shifts quickly, with less light at night, to stop disrupting circadian rhythms

Conclusions of literature review

- Electric lighting can in principle help maintain circadian rhythms
- Building occupants tend to prefer the dynamic nature of daylight as opposed to constant illumination conditions as provided by traditional lighting design
- Variable lighting / higher illuminance / higher CCT / blue-enriched light at the right time of day could help increase alertness, performance and productivity
- Circadian lighting could help synchronise body rhythms
- More research-based evidence required to identify adequate lighting conditions and control schedules so that circadian rhythms are correctly entrained by electric lighting

Circadian lux

- The circadian effects of light are linked to the Equivalent Melanopic Lux (EML), a proposed alternative metric weighted to the response of the ipRGC cells in the eye

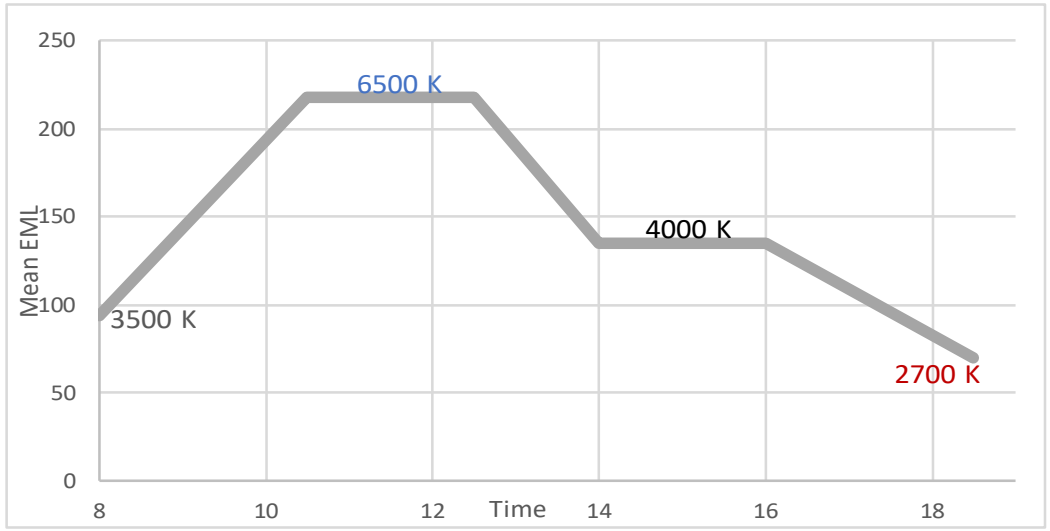
- WELL Building Standard v2 recommends at least 150 EML for electric lighting alone, measured vertically at eye height from 0900-1300 every day of the year. For maximum credits recommends 240 EML.

– <u>150EML equals</u>
- 333lux at 3000K fluorescent
- 258lux at 4000K fluorescent
- 198lux at 4000K LED
- 147lux at 6500K fluorescent
- 136lux at 6500K daylight

- These are vertical illuminances; horizontal lux typically twice this. Normal office horizontal illuminance 300-500 lux.

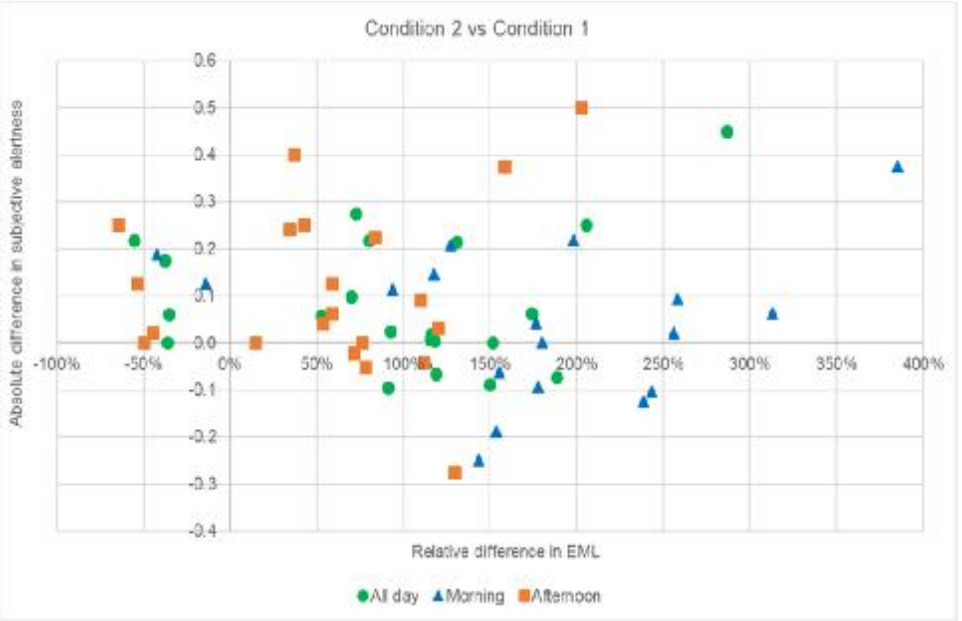
Experimental setup

- An office environment with constant fluorescent light (mean 107 EML) was refitted with variable LED lighting
- LED lighting could vary in colour and intensity



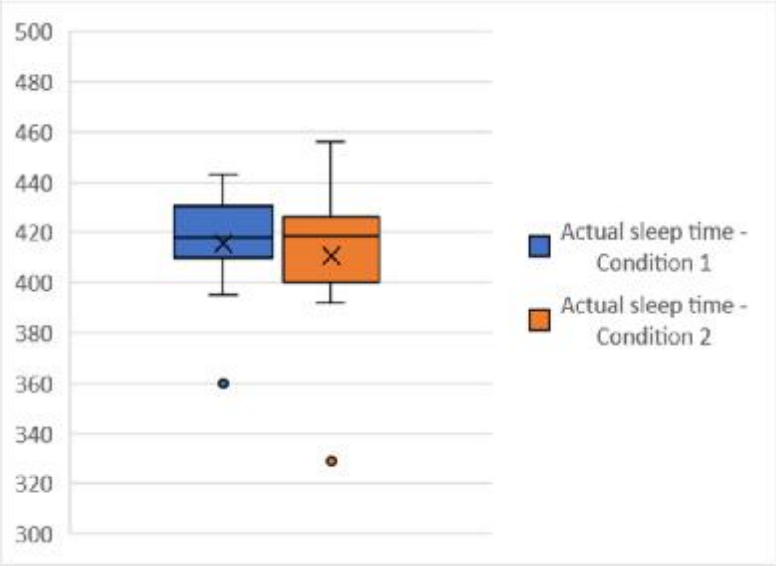
Findings: phase 1

- 23 participants provided subjective assessments of the space and did tests to assess reaction time and concentration.
- With the LED system, the average scores for subjective alertness on the Karolinska Sleepiness Scale, both in the afternoon and averaged across the day, were significantly better. Reaction times were faster too, in the morning and across the day.
- However, there was no statistically significant correlation between the increases in circadian-weighted lighting metrics and the variation in subjective alertness or reaction time.



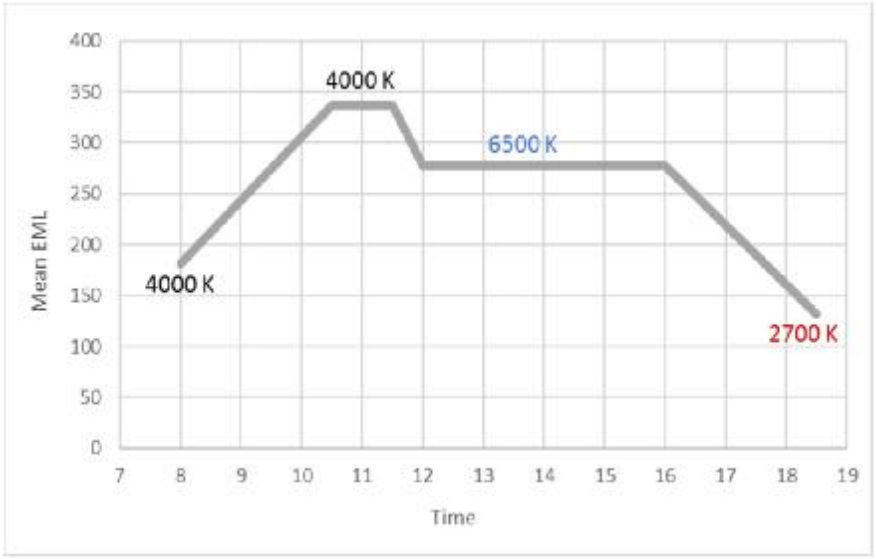
Findings: phase 1

- There were no statistically significant correlations between the increases in circadian-weighted lighting metrics and the variations in concentration.
- 12 of the participants agreed to wear an Actiwatch device to monitor their activity and sleep patterns; there were negligible differences in sleep metrics under the two different lighting conditions.



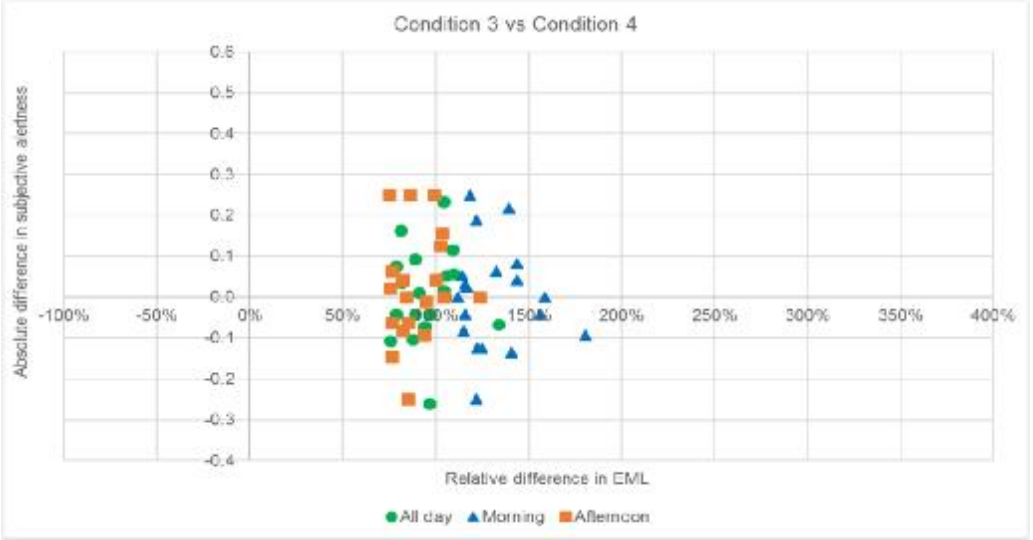
Experimental setup; phase 2

- White office desks changed to wood effect. Varying LED lighting altered to give higher EML (condition 3)
- Compared with condition 4, where LED lighting was retained but operated at constant level (mean 149 EML)



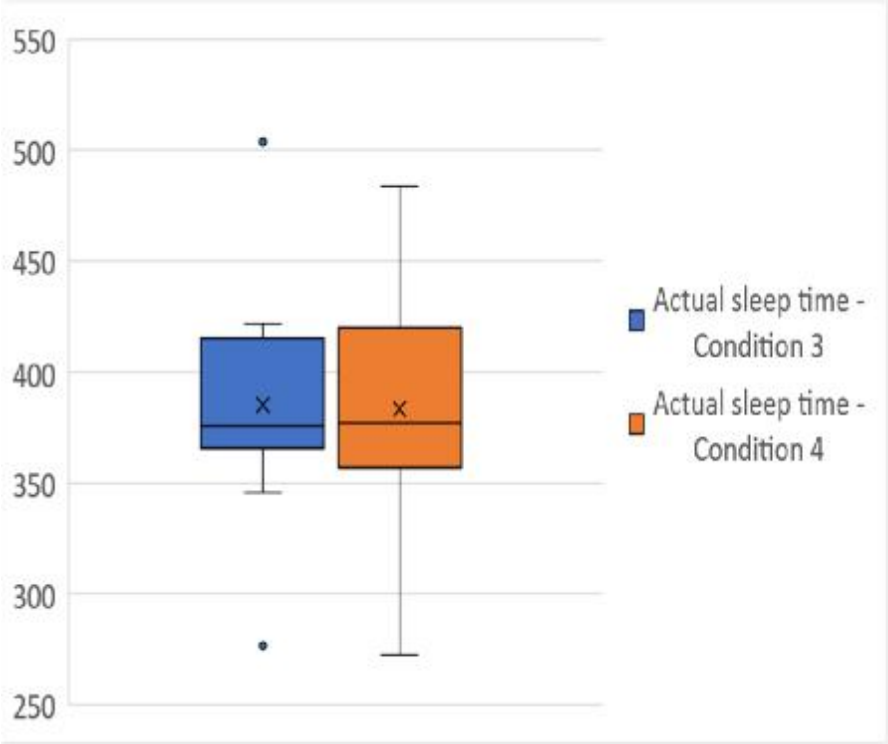
Findings: phase 2

- 20 participants provided subjective assessments of the space and did tests to assess reaction time and concentration.
- Average scores for subjective alertness were very similar with both varying and constant LED lighting.
- There was no statistically significant correlation between the increases in circadian-weighted lighting metrics and the variation in subjective alertness.



Findings: phase 2

- There were no statistically significant correlations between the increases in circadian-weighted lighting metrics and the variations in reaction time and concentration.
- 11 of the participants agreed to wear an Actiwatch device to monitor their activity and sleep patterns; there were negligible differences in sleep metrics under the two different lighting conditions.

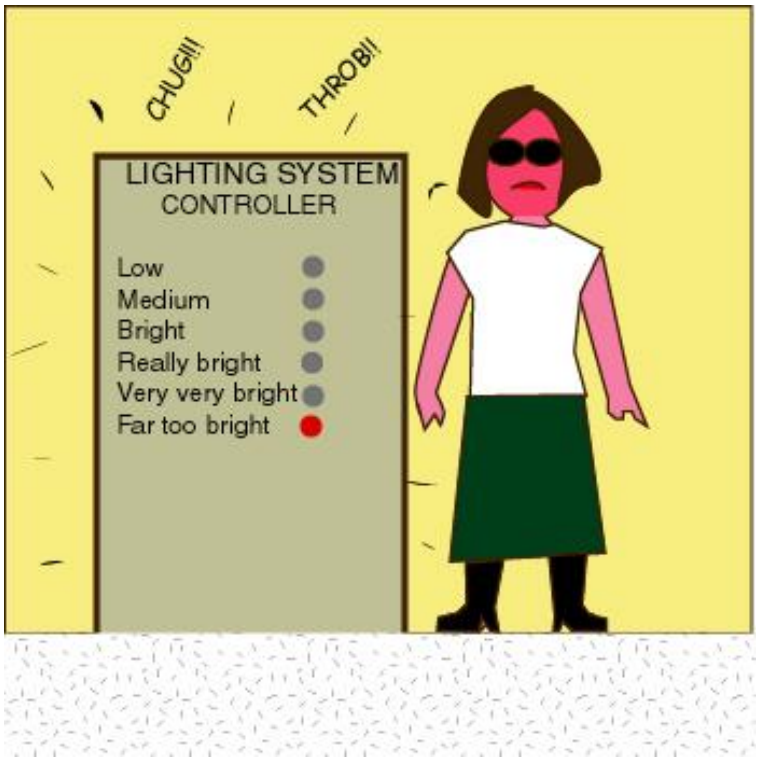


Lesson 1: getting enough circadian light

- Still not clear how much circadian lighting is required. Did our installation provide too little light before and after, or more than enough light before and after? Did the participants get enough light by going outdoors (even though studies were done in Feb/March and Nov/Dec)?
- Further research is required. Until then recommendations in WELL standard and in other documents such as DIN SPEC 67600 need to be viewed with caution.

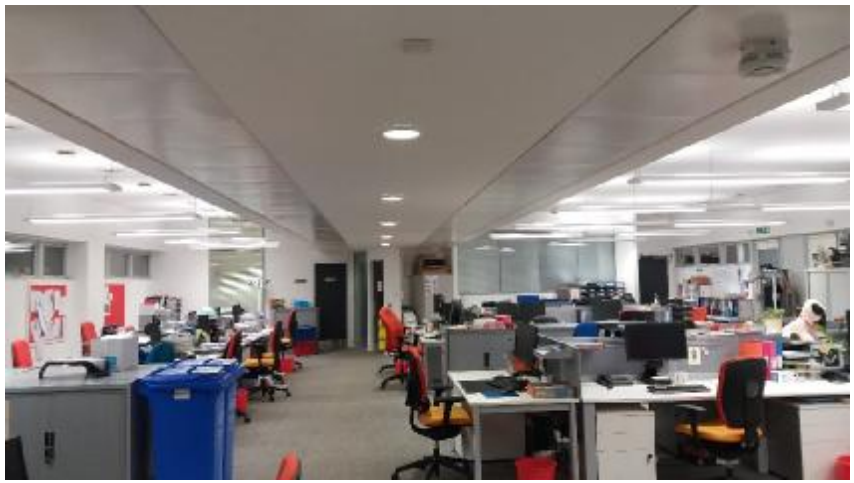
Lesson 2: controls

- Need effective controls that work reliably, and exactly as programmed
- Vary light slowly
- Explain to users what is happening and the purpose of varying the lighting
- People vary in their preferences for lighting; conventional good practice is to offer individual control but this can negate circadian effects



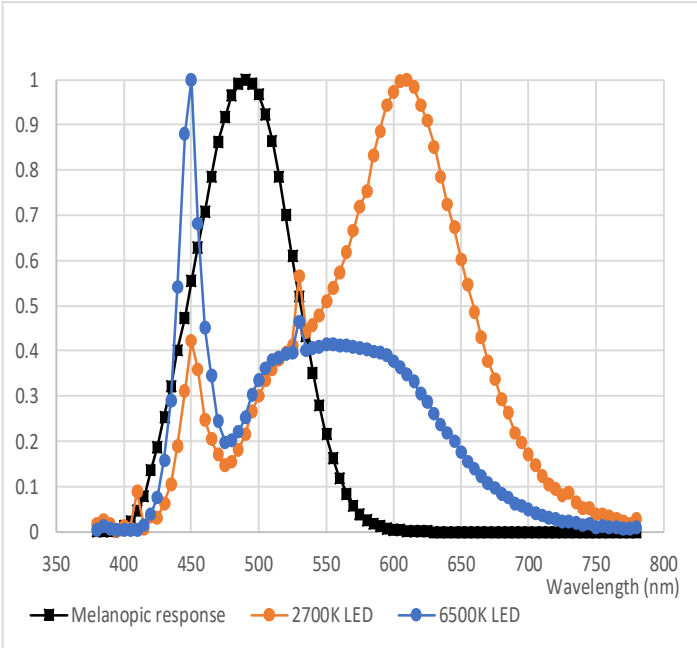
Lesson 3: a good visual environment

- Need a balanced visual environment to avoid over bright surfaces
- Use reflected light to avoid high contrasts and gloom
- Choose low glare luminaires with no flicker
- In the study space, people complained about light reflected from white desks. This limited maximum light that could be provided



Lesson 4: getting enough light late on

- Potential conflict between avoiding circadian stimulus and having enough light to work by
- Solution: use warm white light, typical colour temperature 2700K (domestic light bulb)
- 300 lux horizontal illuminance typically gives 60 EML at the eye with conventional LEDs at 2700K.
- Scope for reducing this EML further in future with tailored spectrum, for example violet LEDs



Lesson 5: Light at eye varies over space

- Even with ‘uniform’ lighting and no daylight, vertical illuminances vary widely over space
- Under peak lighting in condition 2, light falling on eyes varied from 142 EML to 413 EML, in the same space at the same time
- Mean was 218 EML, median 176 EML
- Difficult to ensure consistent ‘dose’ of light for all occupants

Lesson 6: people vary

- Circadian clocks run differently between individuals (Holzman, 2010). Some people (early chronotypes) get up and go to bed earlier than others (late chronotypes) (Roenneberg et al, 2003).
- For late chronotypes, bright light in the morning may help reset circadian rhythms. However this will be less beneficial for early chronotypes.
- People's lifestyle also affects light they receive outside the workplace, especially if they spend time travelling or go outside at lunchtime

Working at home

- Principles also apply at home during lockdown
- Work in daylit room where possible; position screens perpendicular to windows to reduce glare
- Go outside in morning or at lunchtime
- Avoid bright lighting and screen use late in the evening
- Keep to routine, even if on furlough
- US Lighting Research Center video ‘Sleep better and feel better while working from home’

Conclusions

- Lighting can influence circadian rhythms
- Dynamic ‘circadian’ lighting is brighter, bluer during daytime, dimmer and redder in the evening to aid relaxation
- A study in an office space gave inconclusive results
- Individuals vary in how much light they receive, both in workplace and outside, and have different circadian cycles (chronotypes)
- Dynamic lighting needs to meet visual needs both at peak and minimum levels
- Controls must work reliably

Future information

- Final report ‘RI01 Research Insight 01: Circadian lighting’ available at https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q3Y00000HZfg0QAD
- Literature review ‘RLRCL Report describing initial Literature Review on Circadian Lighting’ available at https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q0O00000CF7o9QAD
- Published article ‘Evaluating dynamic lighting’, CIBSE Journal, Health and Wellbeing Special, June 2019, 18-20. Available at https://www.cibsejournal.com/technical/evaluating-dynamic-lighting/
- BRE Information Paper ‘Lighting for circadian rhythms’ https://www.bretrust.org.uk/knowledgehub/wp-content/uploads/sites/20/2019/11/Circadian-Lighting-Trust-report.pdf
- BRE Trust Report ‘Lighting and health’ Priced publication; available from https://www.brebookshop.com/details.jsp?id=327550

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