



Light, health and well-being

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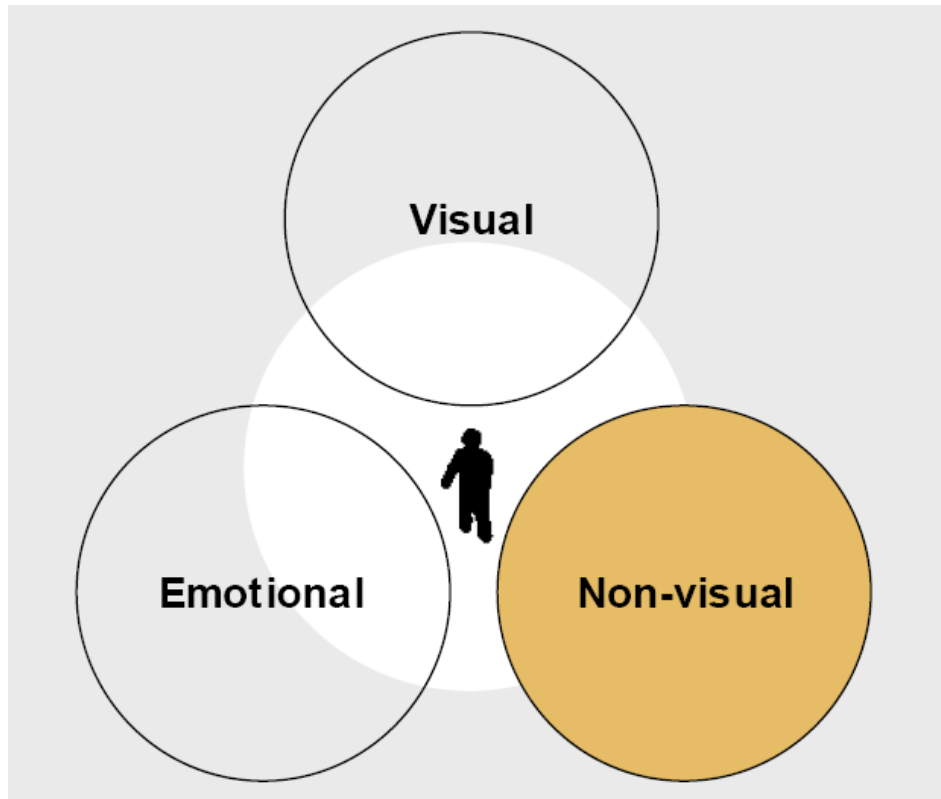
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Department of Energy and Environment

Aalborg University

Next level of lighting design

- Light & well-being - all aspects



Visual aspects of light



*M. Knoop - Dynamic lighting for well-being in work places.
Philips Lighting, LiDAC & TU/e, October 2006*



Visual environment



- 'Good' light improve visual performance and influence the visual impression and atmosphere of the workplace.
- 'Poor' light affect visual performance and may cause eyestrain, excessive tiredness, headaches, discomfort, blurred vision etc.
- Criteria for good lighting
 - Adequate illuminance level in the room and task
 - Luminance distribution within field of view (e.g. contrast, luminance ratio between horizontal and vertical surfaces)
 - Preventing glare
 - Light distribution in the room and task (e.g. direct/diffuse, daylight/artificial light)
 - Colour properties of the light

Codes and standards

Table 1 Visual quality aspects of lighting installations with their quality parameters as specified in the European Norm for the lighting of workplaces¹⁰

Visual quality aspect	Quality parameter
Lighting level	Average illuminance level, E_{av}
Spatial distribution	Uniformity: E_{min}/E_{av} Glare restriction: UGR
Colour rendering	R_a

After van Bommel et al, 2004

Table 4 Vision-and health-related quality aspects of lighting installations

Lighting quality aspects	
Vision related	Health related
Lighting level on the task	lighting level in the eye
Spatial distribution	spatial distribution
Colour rendering	(adaptable) colour appearance
	timing
	duration

After van Bommel et al, 2004



Codes and Standards

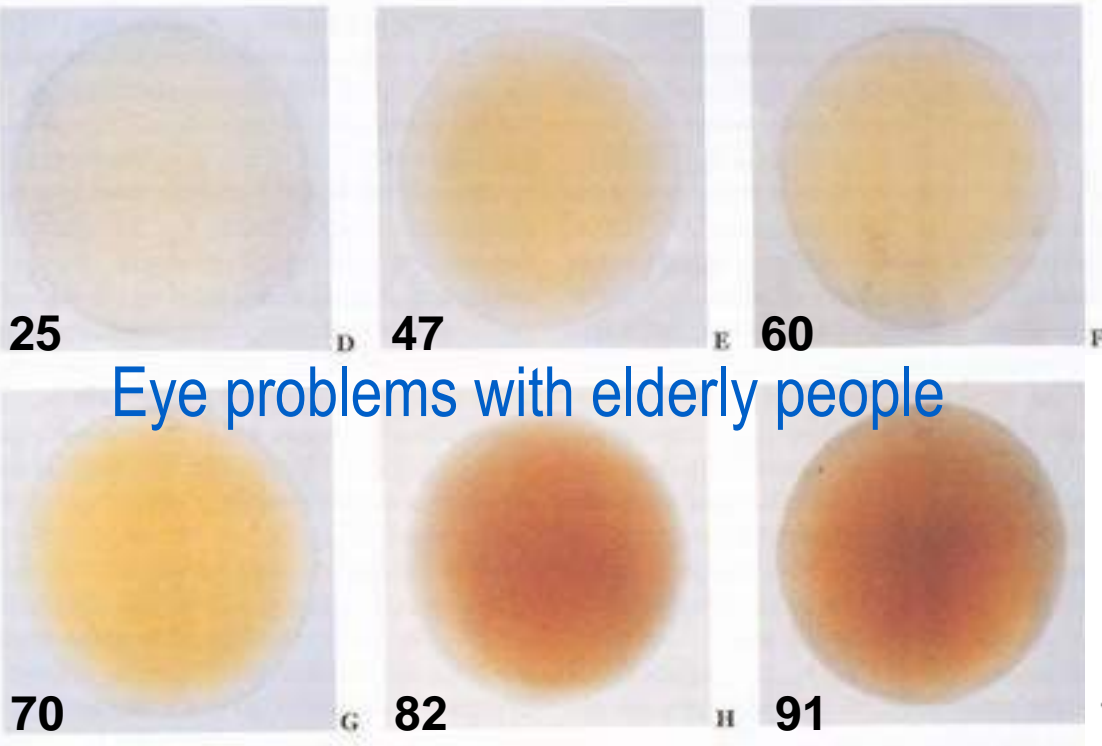
'Recommendations' for horizontal plane

Mainly focus on fovea vision and less on peripheral vision.

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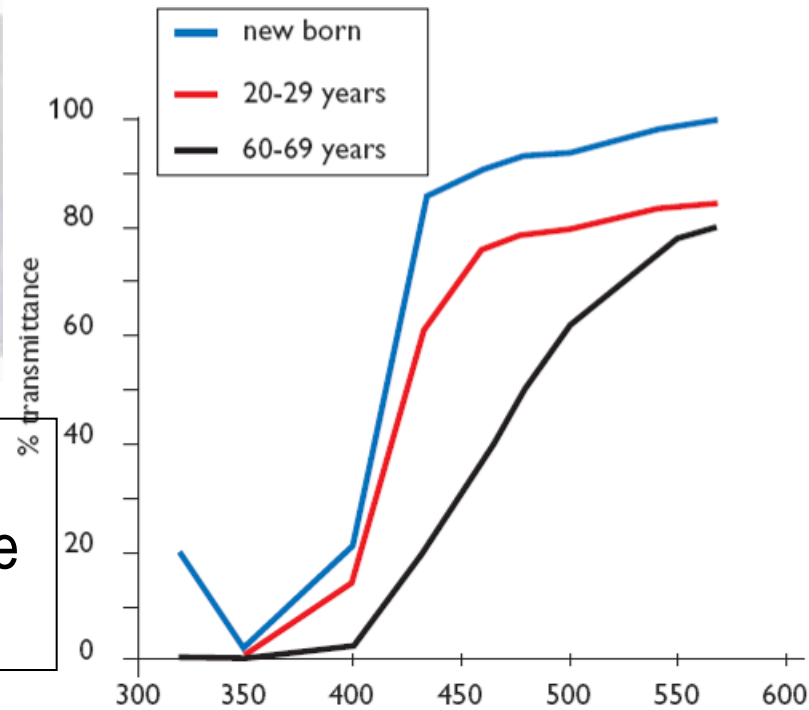
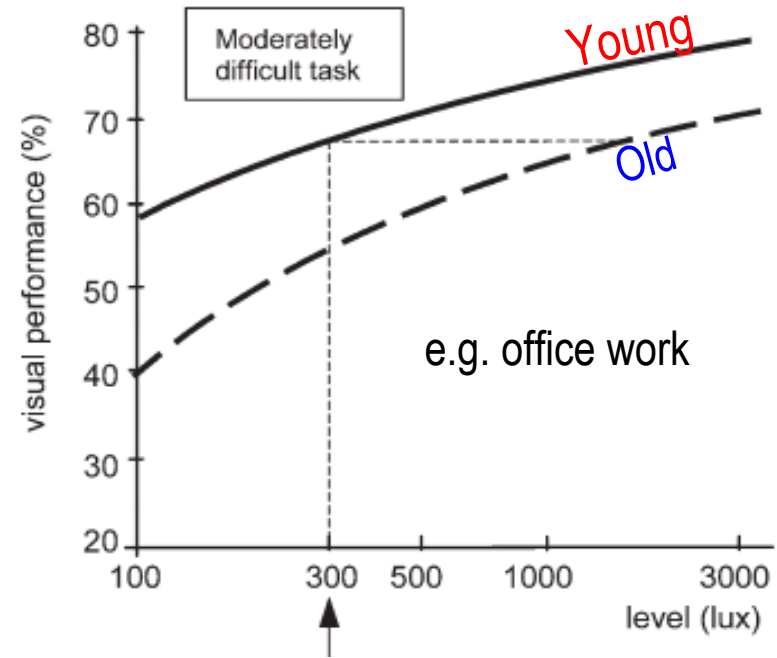
our work tasks are often more in a vertical plane e.g. in plane with the window and visual elements are increasing.

Lighting requirements and age



Eye problems with elderly people

Older people need higher light level to establish similar relative visual performance as young people.



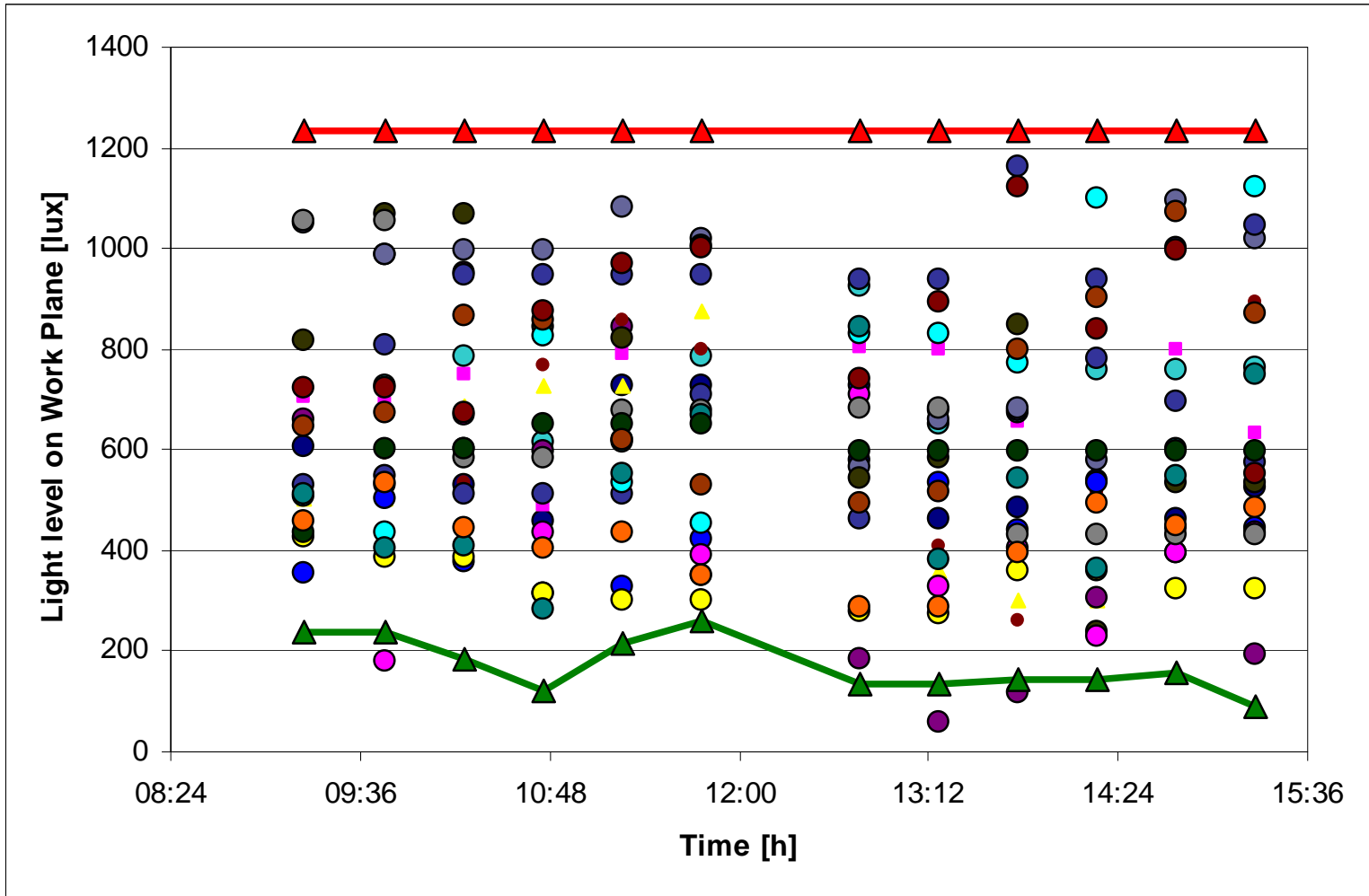
Human variability



Personalization

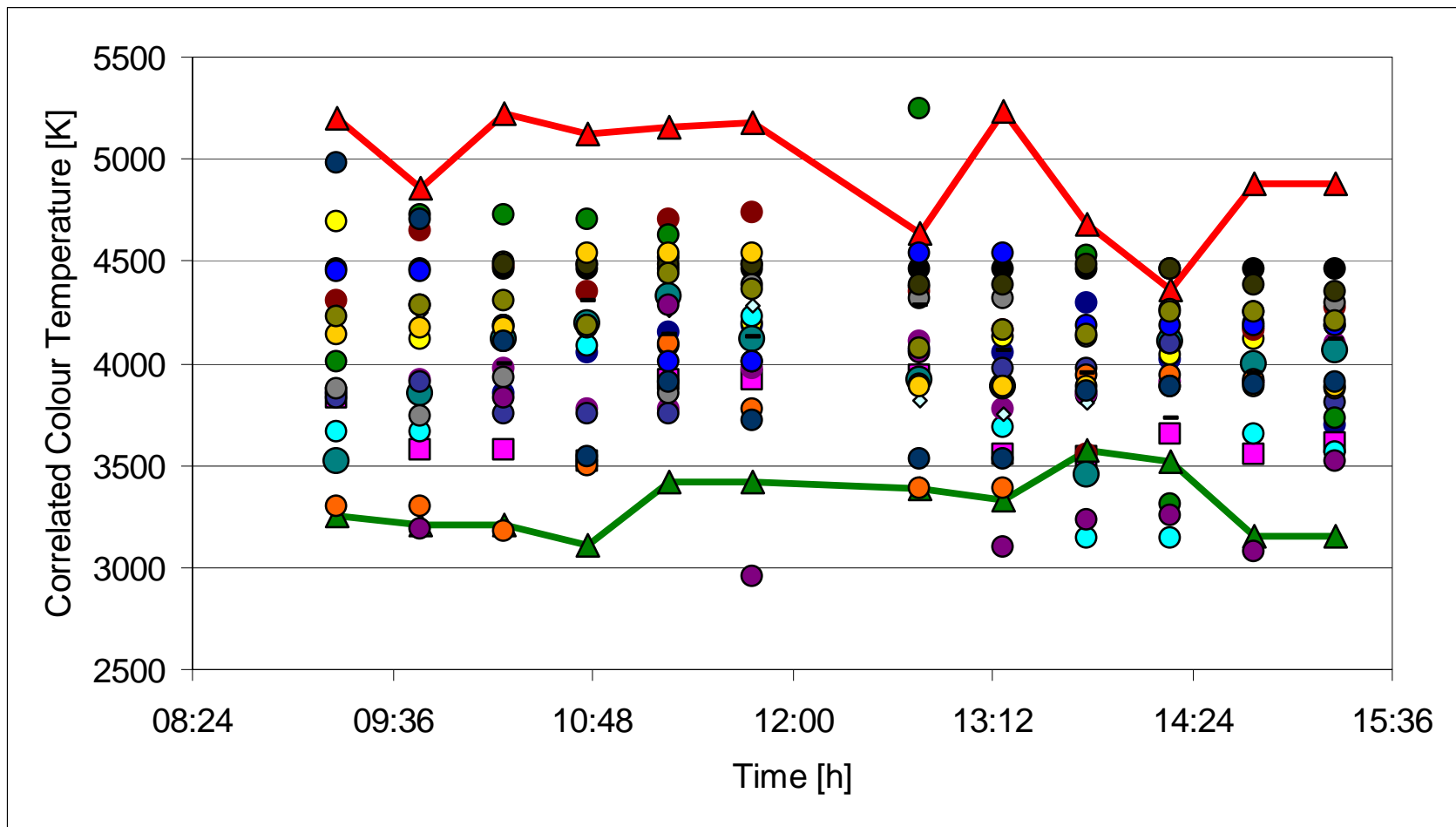


Lighting requirements and office workers



Light level on work plane from electric lighting

Lighting requirements and office workers – individual CCT



CCT from electric lighting

DR2 Viden om det nødvendig dagslys



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Emotional aspects of light



Light and health – an emotional connection?.



- Surveys consistently show that people prefer daylight over electric light and that they believe it to be more healthful (Heerwagen & Heerwagen, 1986; Veitch, Hine, & Gifford, 1993; Veitch & Gifford, 1996).
- The desire for windows and view is well-established (Christoffersen et al., 1999; Butler & Biner, 1989; Cuttle, 1983; Heerwagen & Heerwagen, 1986).
- BUT people in industrialized countries might not be receiving sufficient daily light exposure to maintain optimal health (CIE, 2004)
- The necessary daily light dose is not known
 - but several studies have found that people who receive higher daily light exposures show improved mood, improved quality of social interactions, and greater feelings of vitality (aan het Rot et al., 2007; Espiritu et al., 1994; Kripke et al., 2005; Leppamäki et al., 2004; Leppämäki et al., 2002)

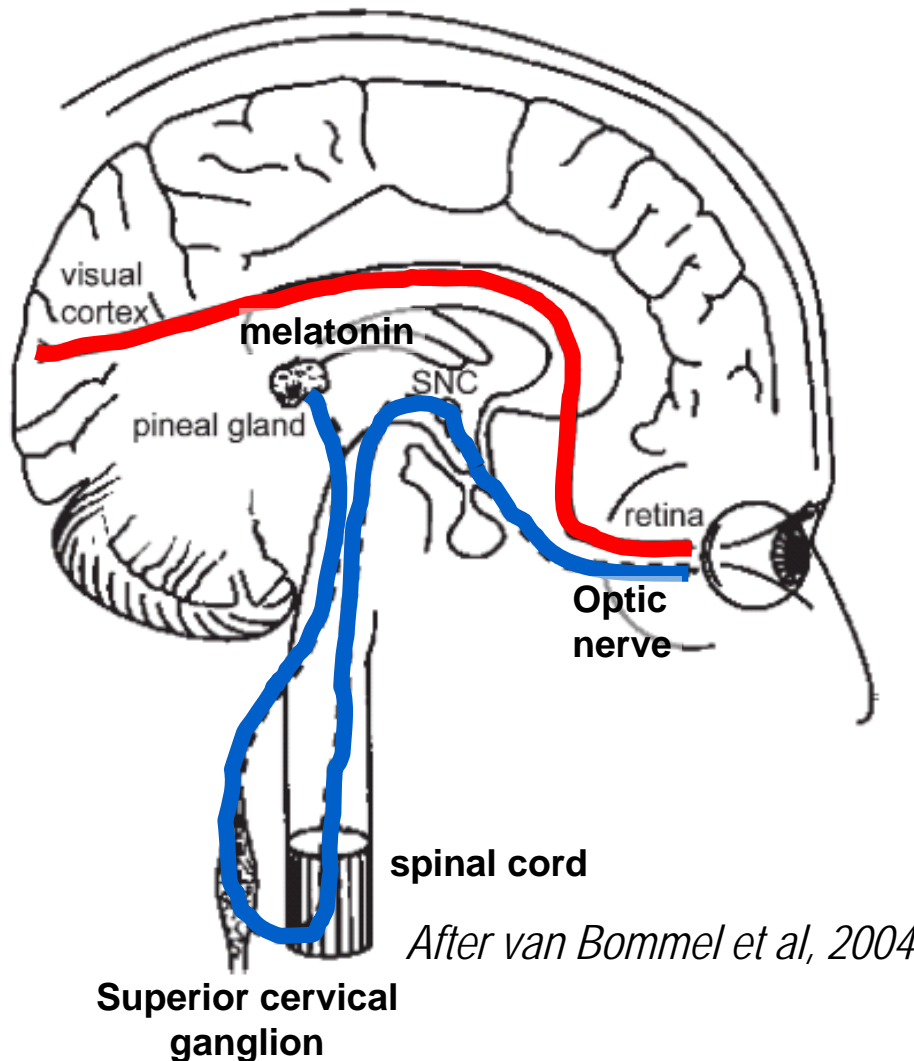
From Veitch, Lysets dage, 2007

Light and health

– a biological pathway



Visual and non-visual pathways in the brain



The visual nerve connections between the retina of the eye (Red), with its cones and rods, and the visual cortex. The non-visual pathways between the retina, body and brain (Blue), with the novel photoreceptor cell, and the suprachiasmatic nucleus (SNC) and the pineal gland.

≈ 80% of the neural fibers transmit signals to the visual cortex for vision.

≈ 20% of the neural fibers send their signals to other areas of the body and brain.

After van Bommel et al, 2004

DR2 Viden om det nødvendig dagslys



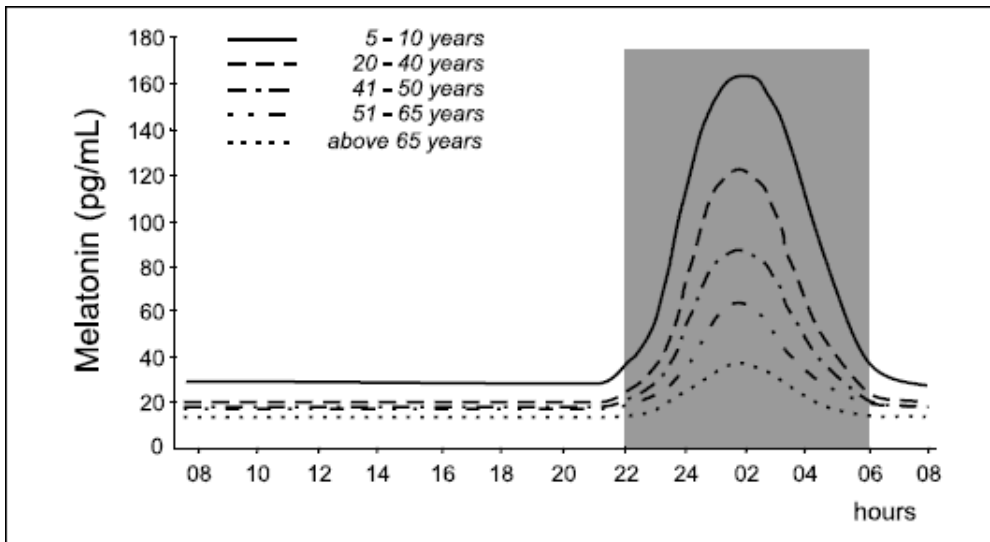
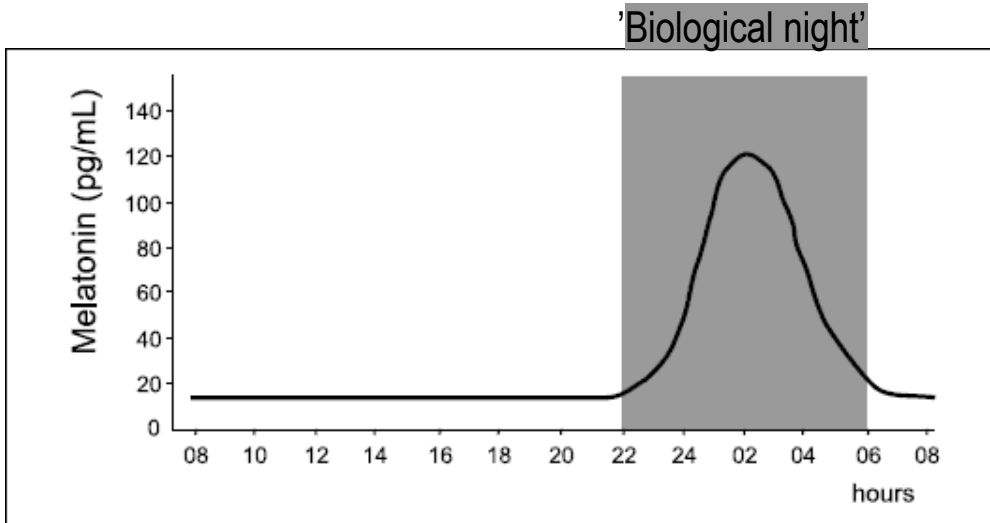
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Light and health – a non-visual connection?.



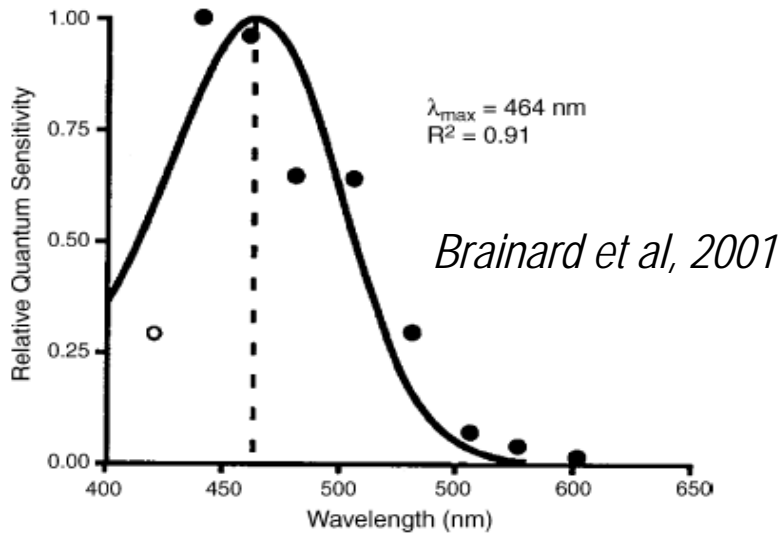
- The ‘melatonin hypothesis’ suggest that disruption of the circadian pattern of melatonin production may be related to some cancers (Stevens & Rea, 2001).
 - Epidemiological studies suggest disruption of the natural light/dark cycle may increase cancer risk, and that blind people have a lower cancer risk.
 - Evidence is mounting that melatonin suppression might increase cancer, and in particular, breast cancer (Hansen, 2001), among women who work at night or who have other light exposure at night – cannot exclude other possible risk factors (e.g. sleep disruption, diet, other toxic exposures).
 - Causal connection remains unknown, regarding intensity, spectrum and timing of light exposure that might lead to higher incidence of breast and other cancers in humans
 - Animal experiments indicate that melatonin suppresses cancer (12:12 light/dark).

Light and health – Melatonin and circadian rhythm

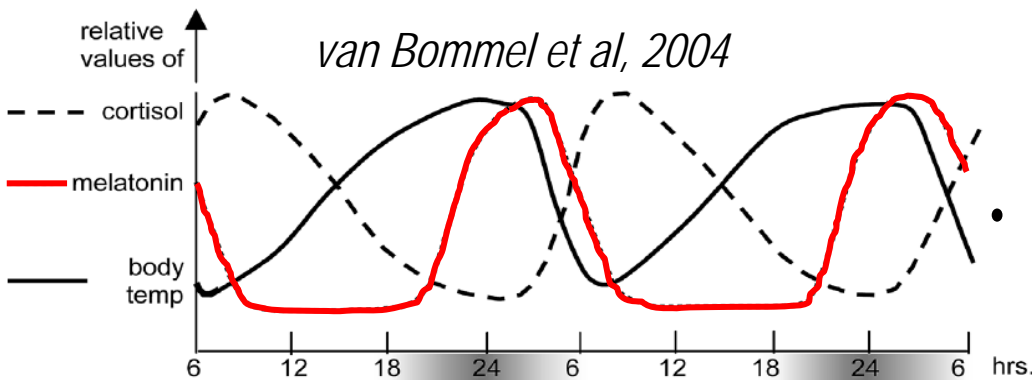


- Melatonin peaks at night, between 2 am and 4 am - levels of melatonin are usually high at night and low during the day.
- Melatonin slightly lowers body temperature.
- Melatonin does not control sleep, but most likely is only one of many factors accounting for the superiority of nighttime sleep.
- Artificial light at night suppress melatonin production, but it takes several minutes for activation.
- The peaks becoming smaller with advancing age after early childhood, and it may explain some of the sleep disturbances seen among elderly.

Light and health – a biological connection?.



Action spectrum for melatonin suppression in humans



Typical daily rhythms (24-h light/dark cycle) of body temperature, melatonin and cortisol in humans

- The retinal ganglion cell (ipRGCs) may be the primary photoreceptors involved in circadian regulation.
- Melatonin suppression has a peak sensitivity between 460 and 480nm (blue-indigo) – Monochromatic lights
- Circadian system is slow responding and requires a prolonged light stimulus to ensure activations
- Light optimised for vision is not necessarily effective for biological effect, and should therefore be rich in that region of the spectrum
- Daylight deliver light that is rich in that spectral region at the times of day when it appears to be most needed (CIE, 2004))

Light and health – a modern lifestyle connection ?.

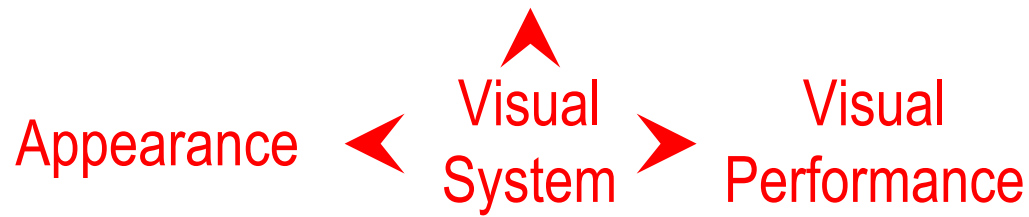


- Abandoned our outdoor agricultural society in favour of spending our days/nights in built environments.
- Electric light has enabled us to abandon lifestyles requiring daylight to perform visual task – it enables us to work 24/7.
 - We spend most of our days indoor with low light exposure, and patterns of light and dark is not recurring at regular intervals
- Transcontinental flight (jet-lag)

Visual and non-visual effects



Intensity Spectrum Distribution Timing Duration



Human performance and health



Intensity Spectrum Distribution Timing Duration

Light for the visual system is different than light for the circadian system

Visual and non-visual effects: Intensity



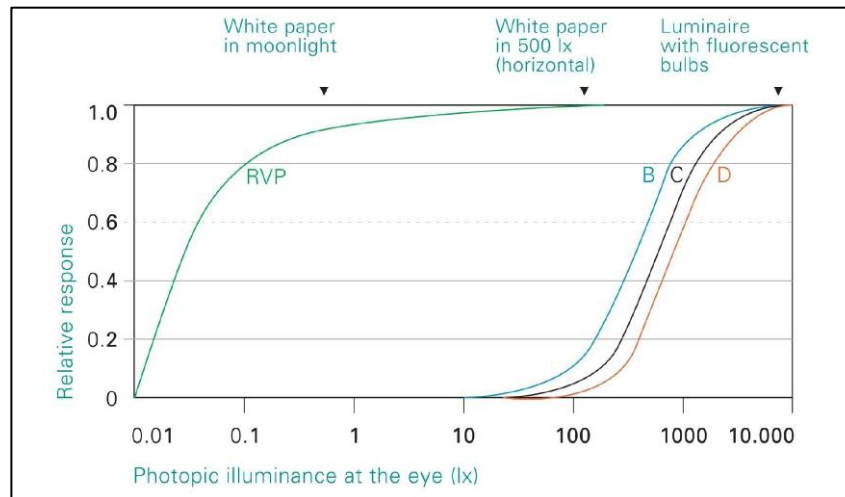
Visual System

- **Intensity:** at light levels of 500 lx (WP), the visual system is processing visual information near its max rate (RVP). Little justification to increase light levels if one only consider visual performance.

Circadian System

- **Intensity:** light levels approaching those found outdoors are sufficient for regulation of the circadian clock and the melatonin cycle (Levy et al., 1980). Light exposure of 500 lx (WP) for 1h is not fully sufficient to stimulate the circadian system – so many indoor light levels are too low. Maybe access to brighter light in the morning can be a supplement, but need more investigation – or a dynamic lighting scenario.

Rea et al 2002, LRT



Relative Visual Performance (RVP), *Rea et al 1991* Max response \approx 100 lx at eye \approx 500 lux WP (Art.)

B, C, D represent the relative sensitivity of the circadian system (1 h.) night time exposure to 6500 K (B), 4100 K (C) and 3000 K (D) fluorescent light

Visual and non-visual effects: Spectrum



Visual System

- **Spectrum:** the portion of the electromagnetic spectrum that is visible to (can be detected by) the human eye. The eye respond to wavelengths from about 380 to 780 nm.

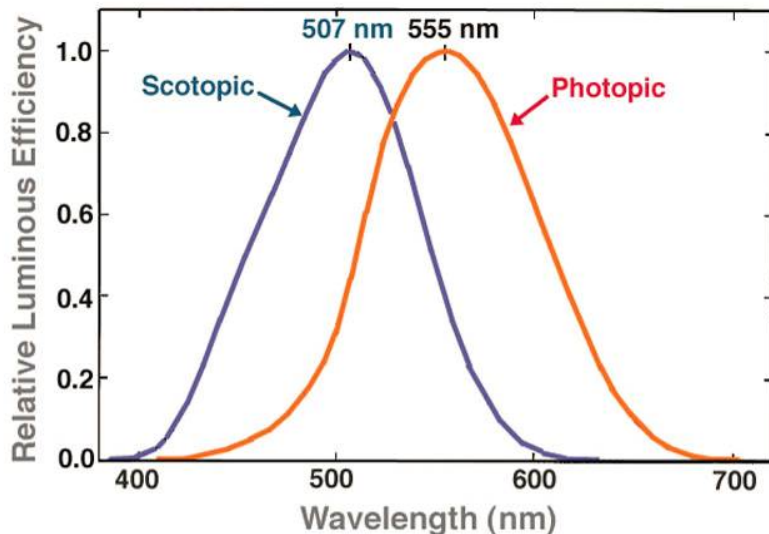
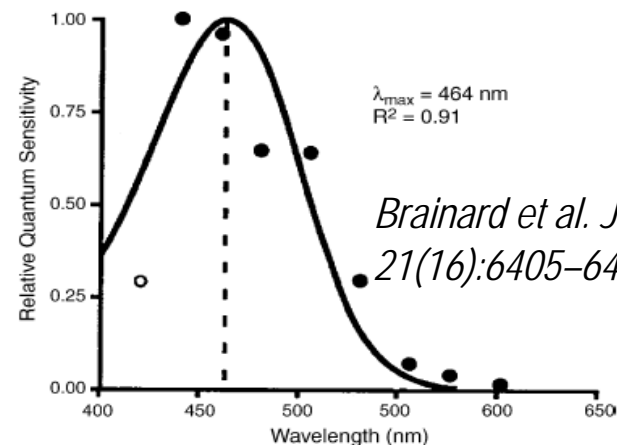


Figure 10. The scotopic and the photopic curves of relative spectral luminous efficiency as specified by the CIE (normalised values).

Circadian System

- **Spectrum:** the melatonin cycle is dominated by the short-wavelength portion of the visible spectrum (Rea et al., 2001, Brainard et al., 2001, Thapan et al., 2001) just as daylight has relatively high output in this portion of the spectrum



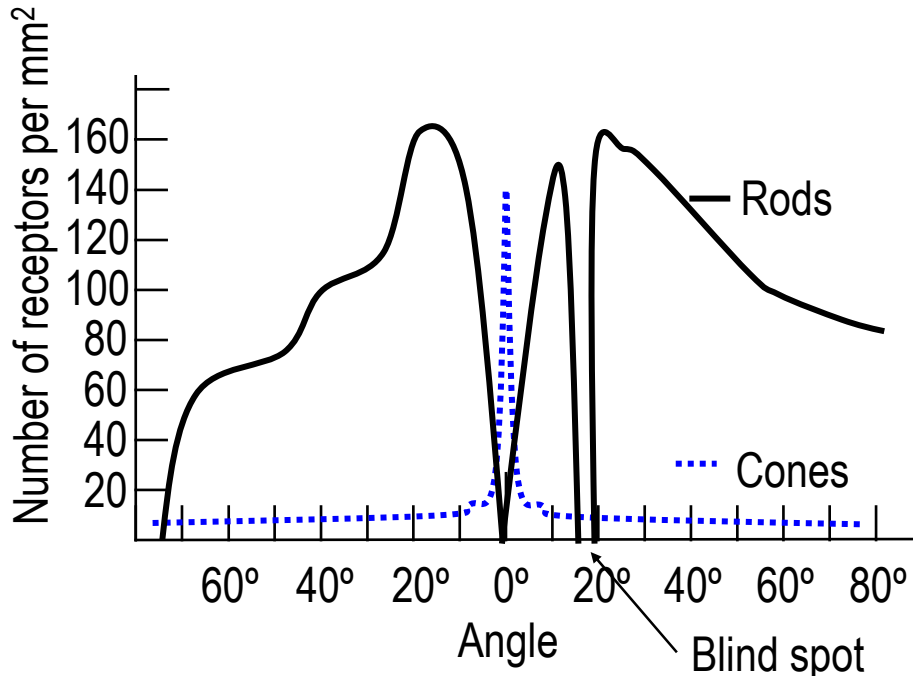
Brainard et al. J. Neurosci., 2001, 21(16):6405-6412

Visual and non-visual effects: Distribution



Visual System

- **Distribution:** Cones are mainly concentrated in the fovea (2°) while rods predominate the periphery. Peripheral vision cover almost 170°



Circadian System

- **Distribution:** the receptors for circadian regulation appear to be randomly distributed throughout the entire retina but some preliminary evidence exists (Lasko et al., 1999, Visser et al. 1999) that the lower part of the retina shows greater sensitivity for circadian regulation than the upper part of the retina, as might be expected given that the sky tends to selectively illuminate the lower part of the retina.
- Indications that rods and cones also provide input to the circadian system

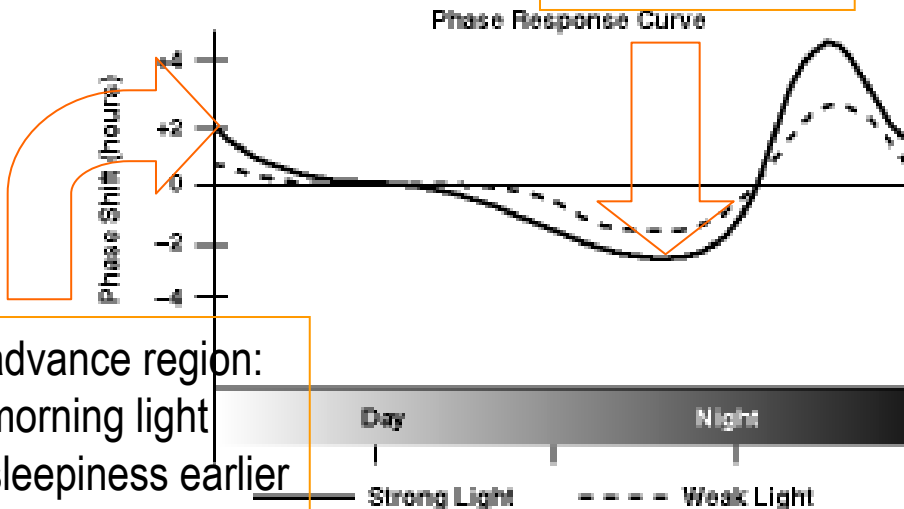
Visual and non-visual effects: Timing



Visual System

- **Timing:** Effects of light on the visual system is measured in fractions of a second, not in minutes/hours as it is for the circadian system

delay region:
evening light
sleepiness later



Phase response curve for core temperature

Circadian System

- **Timing:** light as a cue (Zeitgeber) given at different times of the day will result in either phase advances or delays (Jewett et al, 1997) and the magnitude of these shifts depends upon when light is applied.
 - Early light stimulation will phase advance the master clock – wake up earlier - enable the circadian clock to keep synchrony with daily and seasonal changes in the light–dark cycle.
 - Late light stimulation will phase delay the master clock – wake up later than previous morning
 - Light stimulation in the middle of the day have little effect – daily light exposure have important reinforcing entrainment effect on the master circadian clock.

Visual and non-visual effects: Duration

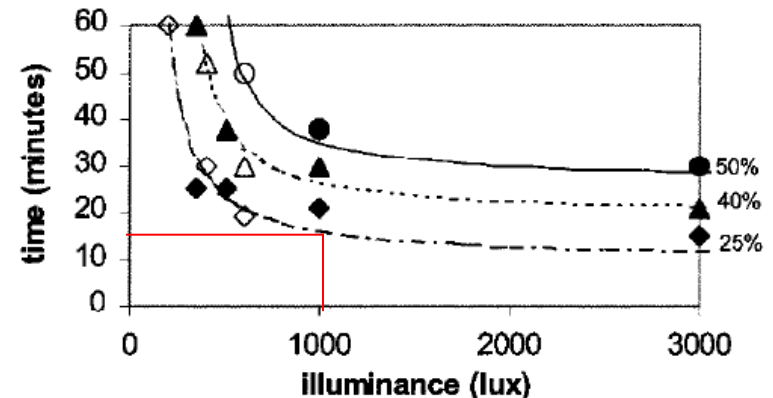


Visual System

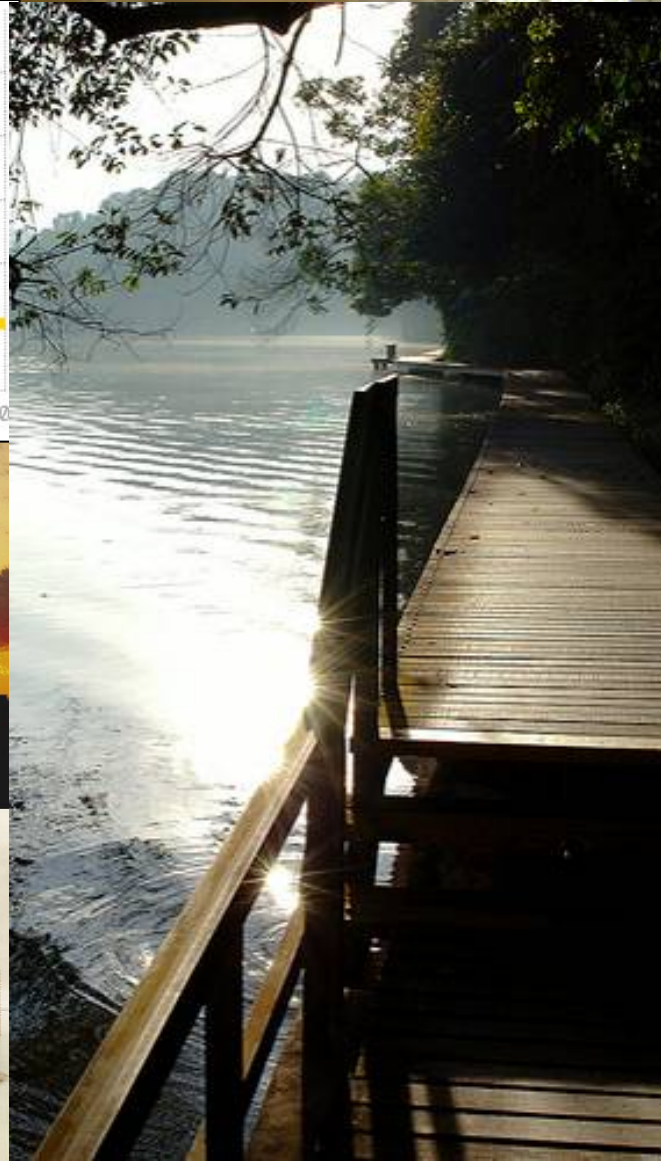
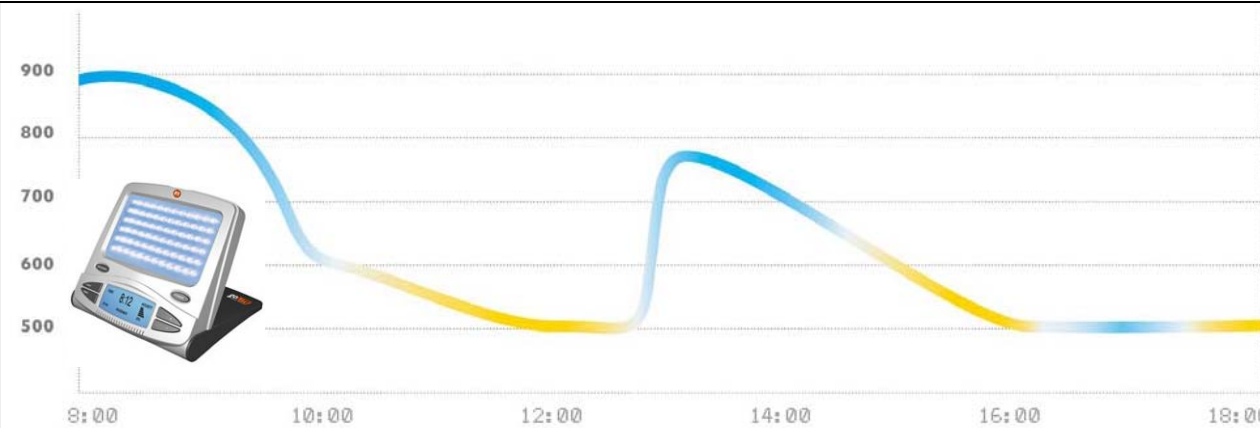
- **Duration:** bright pulses with the same duration of light exposure result in faster suppression of melatonin than pulses of lower intensity. The figure shows three different levels of melatonin suppression (25%, 40% and 50%), and indicates that 25% suppression could be measured in less than 20 min as long as eye-illuminance exceeded 1000 lx. It can also be seen that illuminance of 200 lx would never produce melatonin suppression greater than 25%, no matter the exposure - *McIntyre et al.*

Circadian System

- **Duration:** the melatonin regulation system reduce nocturnal production of melatonin upon exposure to light at night, but resumes upon extinction of the light (Lewy et al., 1980, McIntyre et al., 1989) presumably to minimize the impact of extraneous light stimuli (e.g., lightning flashes).



Non-visual aspects of light: 'Circadian' light



'Circadian' Light – The Role of Daylight



- Daylight has relatively high levels of radiation in the blue-green spectral region, and therefore particularly effective at providing health benefits when compared with electric light.
 - Be aware of select glazing material which maintain high levels of radiation in the blue-green spectral region
- Greater use of daylight in building design, enhance daylit working spaces within the building by giving more workers increased access to windows and daylight may be a primary option for increasing workers' daily light dose, particularly since it uses no energy, but it must be controlled if it is to be used effectively.
 - Accept 'new working rules' according to time-of-day walks, e.g. Wirz-Justice et al. (1996) found that subjects with SAD were treated more successfully by taking a one-hour walk each morning (illuminance ~ 1000 lx) than by 30-minute exposure to bright electric light (illuminance ~ 2800 lx)

'Circadian' Light – The Role of Daylight

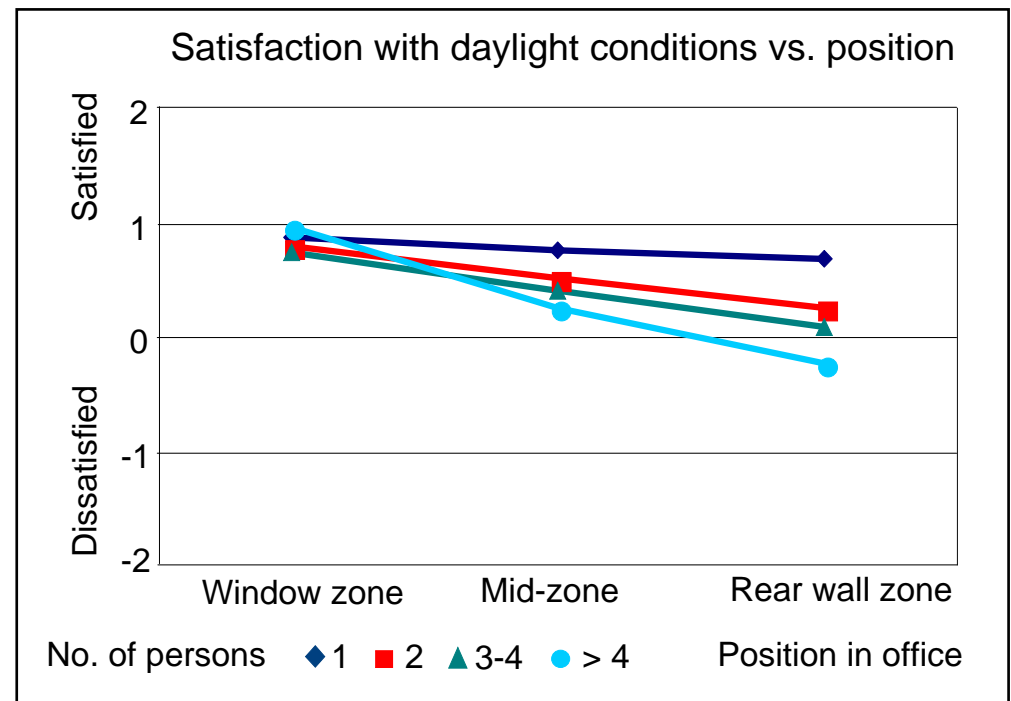


- Research identified benefits of daylight and sunlight as well as view for worker health and well-being
 - Less eyestrain (Cowling et al., 1990), higher productivity (Visher 1989), more effective learning (Heshong et al 1999)
 - Daylight is better for psychological comfort, for office appearance and pleasantness, for general health, for visual health, and for color appearance of people and furnishings (Heerwagen et al., 1986)
 - People believe that working under natural daylight is better for health and well-being than electric light (Veitch et al., 1993/1996)
 - Having a window, or having access to daylight, improves satisfaction with lighting (Veitch et al., 2003), and satisfaction with the view from an office is greater for natural scenes than man-made scenes (Christoffersen et al., 1999)

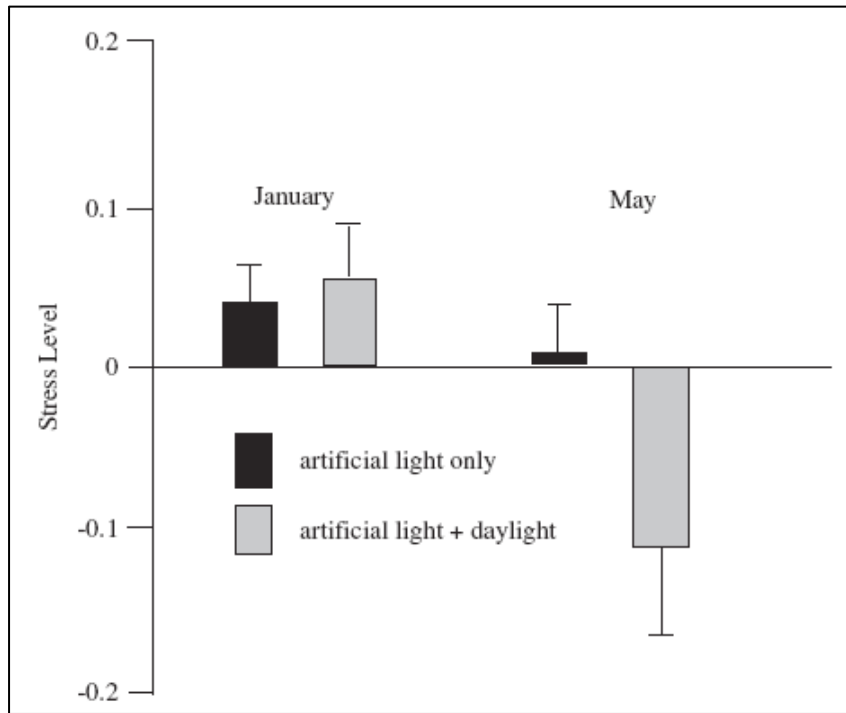
'Circadian' Light – The Role of Daylight

Window seat or aisle ?

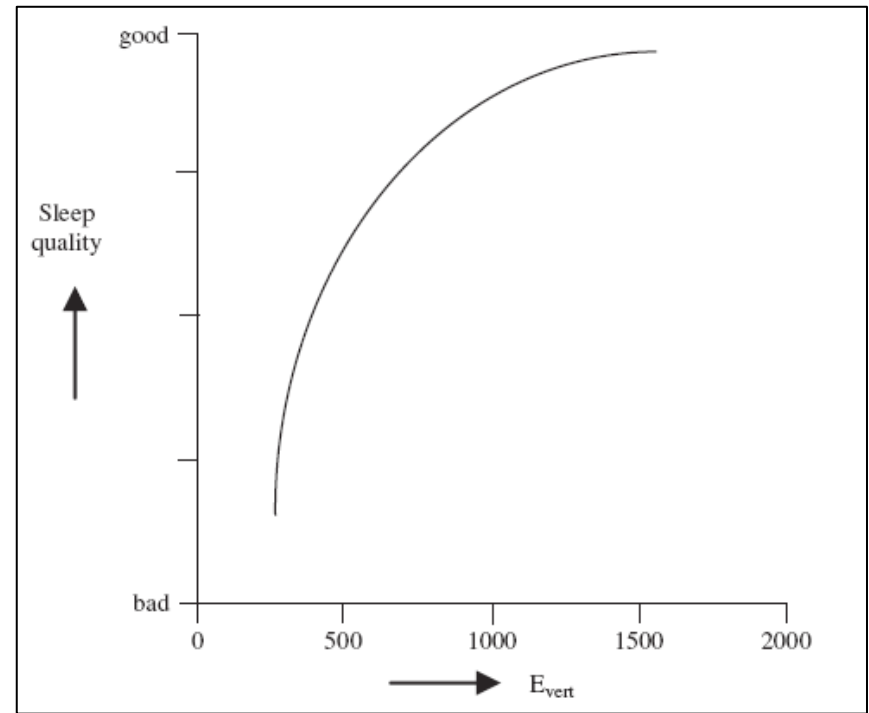
- There is a strong preference for having the workstation near the window - studies in UK and USA support these findings (Collins 1976, Ne'eman 1974)



'Circadian' Light – The Role of Daylight



Indication of the relationship of stress complaint levels in a group of workers working either under artificial light only or under a combination of artificial light and daylight (Kerkhof, 1999).

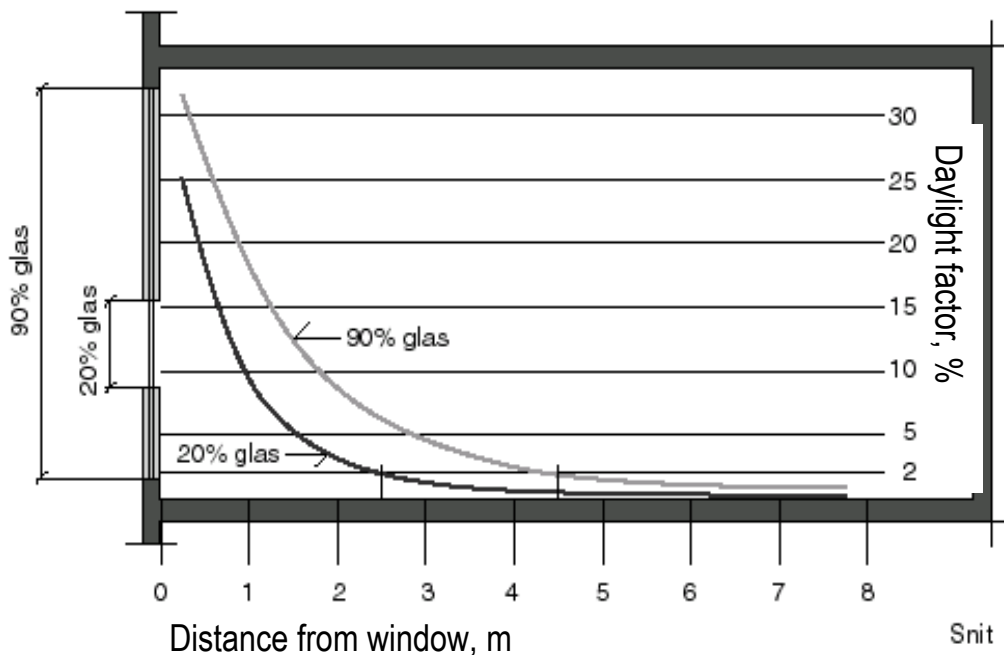


Indication of the relationship of subjective sleep quality as a function of vertical illuminance at the daytime working place (Ariens, 2005).

Size of window



Typical daylight distribution within a room on a horizontal surface. The glazed window area is 20% and 90%.



Light level drops quickly.

The difference in light level between to window areas are large near the window, but modest at the back of the room

Large saving potential in the window perimeter

Position in the room - large building depth ?

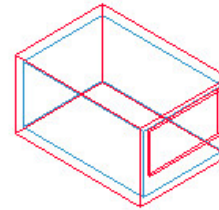


SBi-direction 219

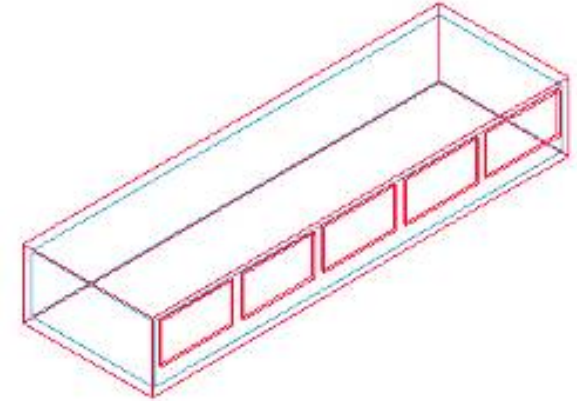
Daylight in room and buildings



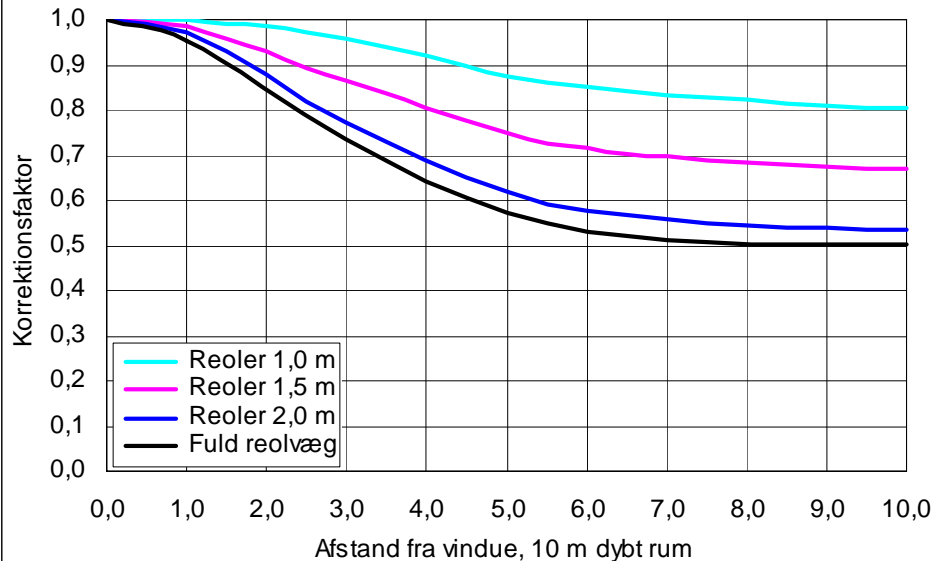
'Correction'
for
bookshelves



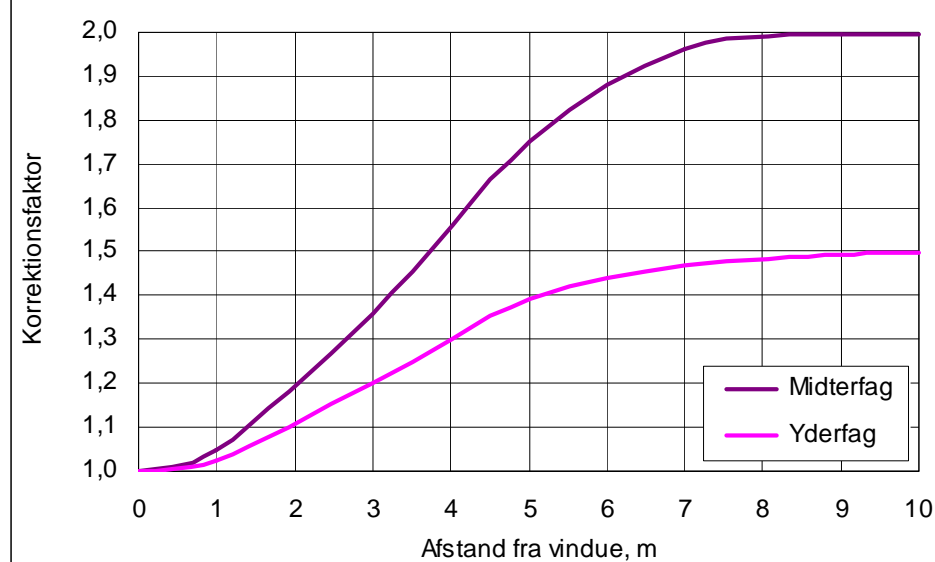
Correction
for multiple
windows



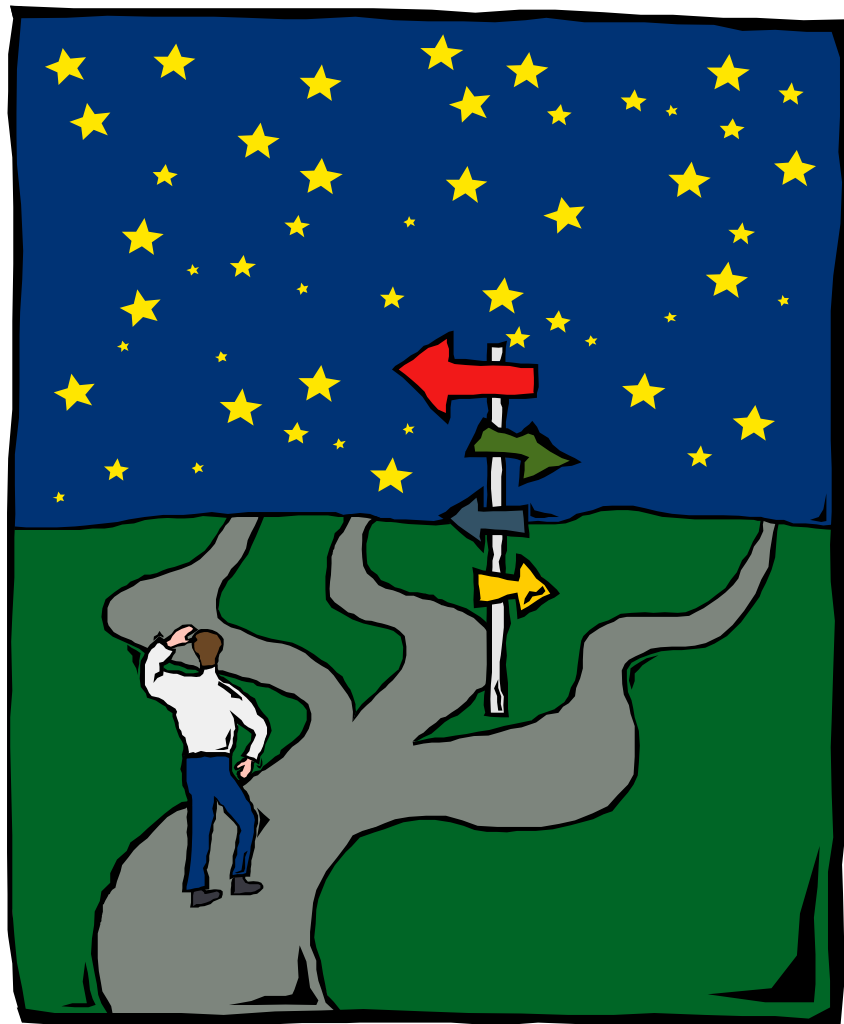
Korrektion for reoler i rum med flere vinduesfag



Korrektion af dagslysfaktor ved flere vinduesfag



Conclusion





Conclusion - Daylight Planning

- Good lighting is tailored to the people in the setting → design the building for the user (inside → out).
- Good lighting is integrated with the architecture → daylight and electric lighting planning should be designed in the early design phase of buildings.
- Good lighting addresses energy, costs, maintenance, and operation → AND QUALITY.

Conclusions - User perspective



- appropriate horizontal & vertical illuminances for tasks and viewers → consider changing task demands.
- control unwanted light (glare), avoid excessive luminance contrast → consider orientation of working area (luminaires), solar shading system, room depth, orientation
- create interest by integrating luminance variability with architecture, highlight important elements, use meaningful luminance patterns, keep vertical surfaces bright → but avoid emphasis on irrelevant cues
- consider individual controls to allow lighting tailored to needs, but don't give more options than occupants need/want

Conclusions - Non-visual effects



- Evidence are circumstantial, and further research will provide more information → but we know that intensity, timing, duration, spectrum and pattern of light exposure influence human physiology and behaviour, but we cannot state what conditions (or combination of conditions) will lead to optimal health and well-being (comments by Veitch in Van Bommel, 2004).
- High needs for multi-discipline research → codes, standards and today's solutions may change in the near future.

How to design of a building fulfilling visual and biological needs



- it's all about finding the right balance



..... and enjoy the exterior light !
- with care!



