Kravspecifikationer til

Lightel

Et forskningsprojekt om døgnrytmelys
i demens- og plejesektoren

ELFORSK

Albertslund Kommune

AALBORG UNIVERSITET

GATE 21 PORTEN TIL GRØN VÆKST

Intervention lighting scheme

For the project intervention, the applied scheme of the electrical lighting is called “circadian lighting”. It is designed to transfer a range of beneficial elements of the daily light-dark cycle of daylight to the electrical lighting system. The following will explain the evidence based motivation for applying it as intervention lighting and outline the principles of the 24-hour lighting scheme itself.

Throughout evolution, human behavior and fundamental body functions have entrained to the daily cycle of light and dark. This cyclical behavior of cognitive and endocrine functions is referred to at the circadian system. This has been known for long, but it was only recently in scientific terms that it was discovered that it is in fact light that is the main entraining element of nature to the human body. Other cues such as activity and food also contributes, but Berson, 2002, finally discovered a novel retinal photoreceptor, the ipRGC, as the main channel of information to the human body for circadian entrainment. More recent studies such as Rea et al, 2005, Güler et al, 2008 and Gooley et al, 2010 reveal that the photo transduction from light incident to the retina through the non-visual photoreceptor (ipRGC) and the visual photoreceptors (rods and cones) is a complex matter that still to this day in 2018 needs more research to be understood in full.

Also, recent studies have shown that immobilization or institutionalization lead to decrease in health conditions and circadian entrainment. That complex is described in West et al, 2017 indicating that lack of exposure to proper amount of daylight and disrupted nighttime conditions regards to sleep and darkness is influencing that health degeneration.

The applied circadian lighting is designed to enhance circadian entrainment by use of electrical lighting such that elderly and demented that stay indoor due to mobility and institutionalization will have proper circadian entrainment as people get with normal access to daylight. Since the photo transduction is not completely understood, the lighting design is imperatively explorative. However, all elements of it is based on proven relations between light and human or mammals and between human circadian rhythm and the light-dark cycle of daylight.

The entrainment has two main components – Circadian phase and circadian strength. The first relates to the synchronization of the sleep/wake cycle of the elderly and the dark/light cycle of daylight (Rea et al, 2005 and Gooley et al, 2010). The latter relates to the amount of diurnal light exposed that leads to increase in sleep drive and immunity to circadian disruption by to nocturnal light exposure (der Lek et al, 2008, Dijk 2009 and Anderson et al, 2012).

To implement this, the 24-hour cycle is divided into four main events, described in principles below:

Morning

A smooth transition from dark to warm white is coordinated with the preferred wake-up time for the elderly. Once the elderly is awoken, the light turns gradually into bright light with colour temperature around 4,000K after approximately 2 hours after waking. The bright light exposure early in the day improves the alertness and has a proven optimal anti-depressive effect. Also, it biologically marks the presence of day (Anderson et al, 2012) such that the human circadian master clock can synchronize all body functions (Dijk, 2009).

Noon

At noon, all areas will have the brightest light. The period with the brightest light is 12.00 - 14.00. Since it is intolerable to attain illuminance levels similar to those of daylight, it is important that the elderly are exposed to

bright light for as long as possible. That is to get the sufficient dose of light to feel alert during the day and in order to build up the circadian sleep pressure to prepare a good night's sleep (Foster & Lockley, 2012). Color temperature around that time tops at 5,500 K approximately correlating to the color temperature of daylight from a clear sky around noon (Williams, 2004). It would be obvious to indicate a reference illuminance level for the light setting at noon, but acknowledging the statement from CIE TN-003:2015, the photometric illuminance metric is inapplicable when it comes to documentation of non-visual response of light. Instead, it is recommended to define the light uniquely by the 5 α-opic illuminance levels that are specific for each of the retinal photoreceptors in the human eye.

Photoreceptor	Cyanopic	Melanopic	Rhodopic	Chloropic	Erythropic
α-opic equivalent illuminance at noon	28 lux	43 lux	52 lux	63 lux	67 lux

Evening

At mid-afternoon it is time to start administering the short-wavelength components of the light, since they have the greatest impact regards to circadian response and sleep disruption (Rea, 2005). At dinnertime, the colour temperature is down to normal indoor levels around 3,000 K and the illuminace levels is reduced to 30% of the daily maximum. From there, the light is gradually dimmed to reach night levels.

Night

During nighttime, the apartments are kept in darkenss unless an event happens. The darkness is important for the elderly to consolidate the sleep and circadian entrainment. The light applied in case of an event as well as in the staff areas are with low illuminance levels and with a novel spectral composition to establish safe and calming visual conditions while ensuring minimal impact of the non-visual system. The spectral composition is a continuous spectrum that resembles an off-black body warm white with correlated colour temperature at 1,850 K and a 2%-of-max bandwidth from 520 – 750 nm

These four daily lighting events are repeated every day in order for the elderly to stabilize around this fixed timing of light and darkness.

In order to ensure the desired effect, all indoor areas are lit with a dynamically controlled lighting system that continuously controls the light of all areas in which the elderly and personnel occupy throughout the day. Also, recognizing the exploratory nature of the lighting design, the lighting scheme is made to be consistent with the basic scheme of daylight: Dark or with low intensity at night and brightest at daytime with long, unnoticeably smooth transitions to optimize the tolerability and experience of daylight. In addition to the circadian lighting, the lighting system also offers the users to turn off the light in the rooms individually and in relevant rooms, some activity based light settings are offered acknowledging that some events require different light than what is optimum for circadian entrainment. Examples of that are dish washing at night, nocturnal patient care or critical events regardless of the time of day.

M. Andersen, J. Mardaljevic, S.W. Lockley, A framework for predicting the non-visual effects of daylight – Part I: photobiology-based model, Lighting Research and Technology, vol 44 (1), pp. 37-53, 2012.

CIE TN-003:2015 Report on the First International Workshop on Circadian and Neurophysiological Photometry, 2013

REA, M., FIGUEIRO, M.G., BULLOUGH, J.D., BIERMAN, A. 2005. A model of phototransduction by the human circadian system. Brain Res Brain Res Rev. 50(2):213-228.

Light, Sleep, and Circadian Rhythms: Together Again
Dijk DJ, Archer SN (2009) Light, Sleep, and Circadian Rhythms: Together Again. PLOS Biology 7(6):

Spectral Responses of the Human Circadian System Depend on the Irradiance and Duration of Exposure to Light, Joshua J. Gooley et al. Sci Transl Med 2, 31ra33 (2010);

A. D. Güler, J. L. Ecker, G. S. Lall, S. Haq, C. M. Altimus, H. W. Liao, A. R. Barnard, H. Cahill, T. C. Badea, H. Zhao, M. W. Hankins, D. M. Berson, R. J. Lucas, K. W. Yau, S. Hattar, Melanopsin cells are the principal conduits for rod–cone input to non-image-forming vision. Nature 453, 102–105 (2008).

Anders West, Poul Jennum, Sofie Amalie Simonsen, Birgit Sander, Milena Pavlova & Helle K. Iversen (2017) Impact of naturalistic lighting on hospitalized stroke patients in a rehabilitation unit: Design and measurement, Chronobiology International, 34:6,687-697, DOI: 10.1080/07420528.2017.1314300

Gooley JJ, Rajaratnam SMW, Brainard GC, Kronauer RE, Czeisler CA, Lockley SW. (2010). Spectral responses of the human circadian system depend on the irradiance and duration of exposure to light. Sci Trans Med. 2:31ra33–31ra33.

Berson DM, Dunn FA, Takao M. Phototransduction by retinal ganglion cells that set the circadian clock. Science. 2002 Feb 8;295(5557):1070-3.

R. F. R.-V. der Lek et al, “Effect of Bright Light and Melatonin on Cognitive and Noncognitive Function in Elderly Residents of Group Care Facilities A Randomized Controlled Trial,” JAMA, June 11, 2008—Vol 299, No. 22., pp. 1–14, May. 2008.

Williams, D. R. (2004). "Sun Fact Sheet". NASA

“Sleep: A Very Short Introduction”, Russell G. Foster and Steven W. Lockley, 2012

Lightel: System specifications for luminaries

The requirements are priorities through the following weight
3 - Minimum requirements
2 - Prioritized requirements
1 - Requirements
I - Information requirement

ID	Requirements	Specification	Weight
Luminaries	Ecolabel Information about Ecolabel must be available	-	I
Luminaries	Failsafe: If no data connection, lights with default light	Warm white LEDs are on	3
Luminaries	High total room illuminance	At max intensity (all LEDS at 100%) <800lux >500lux at any point in a 4mx6m or 3mx5m room	3
Luminaries	No shadows on diffuser / no distinguishable LEDS	-	2
Luminaries	High output of blue light at bed, couch and table area	> 200 lux 355-375 nm	3
Luminaries	Noise / Expected noise	< 5 db	3
Luminaries	Low flicker (50%, 75% and 100%)	Flicker index < 0.1, Flicker percentage < 10%	2
Luminaries	Include warm white LEDS	2000 - 2500 Kelvin	2
Luminaries	Include cold white LEDS	6000 - 7000 Kelvin	2
Luminaries	Include RGB If a tunable white solution is used, an alternative light solution must be available for evening and night. This solution must ensure participants is not exposed to light (wavelengths) disturbing the circadian rhythm.	-	1
Luminaries	For common rooms, be build into 60x60 ceiling	-	1
Luminaries	Energy efficiency	>160lm/watt after system loss (system tab)	1
Luminaries/Software	Disposal of equipment The producer and supplier must meet EU requirements for disposal	-	2
Luminaries/Software	High colour rendering for warm white and cold white LEDS	>90 CRI	1
Luminaries/Software	Lifetime Lifetime of driver corresponds with expected lifetime of the luminaire	>50.000 hours / >L70	1
Luminaries/Software	Dimmable Light	> 200 steps	2
Luminaries/Software	Software based log of user date: when is the lamp on/off and which light scenario is used. i.e. log the following parameters: (roomNo, lightScenario, turnOnDate, turnOnTime, turnOffDate, turnOffTime, duration) Please note that some flats have more than one room.	-	3

Software	Light Scenarios: It must be possible to use one or more light scenarios at the same time in different rooms/on different luminaries. The use of the following two scenarios for research purpose must be possible. 1) Standard light corresponding to typical light composition in elderly homes and nursing homes. 2) Circadian light corresponding to the light curve in Appendix 1 next tab. These scenarios will be controlled by software programming. The use of the following three scenarios for daily use must be possible. 1) Emergency light 2) Very low luminance scenario at night time. These light scenarios will be controlled by a physical switch. 3) The light at night must not be completely red. This will be controlled by software programming	-	3
Software	Usage during intervention: During the intervention only personal must be able to turn off the luminaries and the light must not turn off because of no movement.	-	3
Software	Standard setting The following standard settings must be possible. 1) The light will automatically and slowly turn on in the morning 2) The light will automatically reset after a work shift	-	2
Software	Software compatible with CTS/BMS (e.g. through API)	-	1

Circadian lighting curve

The theoretical basis for the development of the circadian lighting scheme comes from previous chronobiological and cognitive research relating to flicker, illuminance levels and correlated colour temperature (CCT). Firstly, a number of studies have shown the correlation of CCT and illuminance on the circadian rhythm. Research by Figueiro et al. indicates that high circadian stimulation should have an illumination of at least 400 lux at the cornea and a CCT of 6500 K (blue rich light), and suggests this for daytime use. Evening hours are recommended to have an illuminance of 100 lux at the cornea and a colour temperature of 2700K (Figueiro, 2008). In a study on old and demented people, Sust et al. similarly propose a scheme for elderly with a 1200 lux and 6500 K exposure during the daytime, and an 800 lux and 3000 K exposure after three o'clock in the afternoon (Sust et al. 2012). Finally, within a working environment, Van den Beld has proposed a curve which starts at 800 lx and 6000 K at 8.00 in the morning, which gradually decreases to 500 lux and 3000 K by 12.00. This is repeated starting with around 750 lux at 12.30 which again gradually decreases to 500 lux and 3000 K at 16.00 (Van den Beld, 2002). An important aspect of research on the circadian rhythm is the study of the sleep-wake cycle. As an effect of the combination of the circadian rhythm and sleep homeostasis, sleep cycles for humans have been argued to be biphasic, although current society is interrupting this with technology (Ekirch, 2001).

Besides research on the circadian rhythm, there are equally a number of cognitive studies related to emotional response, task performance and alertness with respects to CCT and illuminance levels. Goven et al. have shown that an increase from 3000 K to 4000 K increases alertness (Goven et al. 2007). Similarly, Choi and Suk showed that 6500 K produced the greatest alertness (Choi & Suk, 2016). The same studies indicated that 100 lux produced the best emotional responses (Goven et al, 2007), and that 3500 K was associated with increased relaxation (Choi and Suk, 2016). This is equally reflected by Park et al. who found that a lower CCT of 2766 K increased relaxation (Park et al. 2013).

By using research a dynamic circadian lighting scheme (Figure 1) can be produced with a circadian lighting curve (Figure 2). This scheme would be punctuated by task performance requirements such as dinner, and toilet visits. The light needs to be dynamic, and change illuminance levels and colour temperature in a prescribed sequence depending on the time of day, biological needs and task requirements.

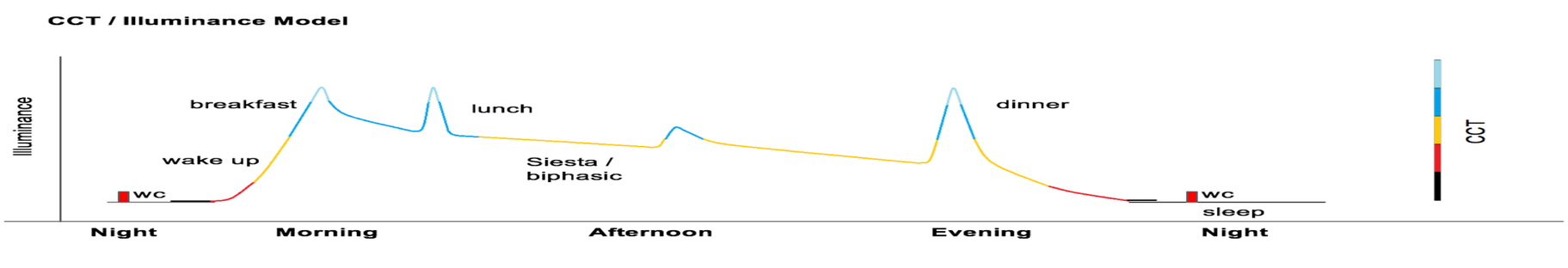
Figure 1. Circadian lighting scheme

		Morning			Afternoon			Evening
		Wake up	Breakfast	Morning activity	Lunch	Afternoon dip	Recovery, afternoon activity	Dinner	Evening activity
Chronobiology	lx	1000 / 600[1]	400[2]			Biphasic[8]			60[1] / 100[2]
	K	6500[2]	6500[2]						2700[2]
Cognitive studies	lx			1000[3]		1000 →500[4]	1000[3]		1000 →500[4]
	K		5000[5]	3000/5000 [3]/ 4000[4]	5000[5]	2700[4]	3000/5000[3]	5000[5]	2700[4]
Standards and recommendations	lx	200[6]	300-500[6]	750-1000[6]	300-500[6]	100 / 5[7]	750-1000[6]	300-500[6]	750-1000[6]
	K								

References in figure:

1 Figueiro, M.G. (2008), A 24 Hour Lighting Scheme for Older adults. http://www.lrc.rpi.edu/programs/lightHealth/LightOlderAdults.asp
2 Figueiro, M.G., Saldo, E., Rea, M., Kubarek, K., Cunningham, J., Rea, M.S. (2008). Developing Architectural Lighting to Improve Sleep in Older Adults, The Open Sleep Journal 1(1):40-51
3 Weitbrecht, W.U., Bäwolff, H., Lischke, A., Jünger, S. (2015), Fortschritte der Neurologie
4 Manav, B. (2007) An experimental study on the appraisal of the visual environment at offices, Building and Environment 42 (2007) 979–983
5 Yamagishi, M., Yamaba, K., Kubo, C., Nokura, K., Nagata, M., (2008), Effects of LED lighting Characteristics on Visual Performance of Elderly People, International Society for Gerontology
6 Terkildsen, M. (2004), Indretning af Plejecentre– for svage ældre og mennesker med demens, Styrelsen for Social Service
7 DS ES 12464-1 2011
8 Kryger et al. (2011), Principles and Practice of Sleep Medicine, Elsevier Saunders

Figure 2. Circadian lighting curve



Medical requirements and recommendations:
Examination room general: 500 lx, 4000-5000 K, Ra 90 (DS EN 12464-1 2011: 5.40.1)
Examination, simple: 300lx (DS EN 12464-1 2011: 5.39.3)
Examination and treatment: 1000lx, Ra 90 (DS EN 12464-1 2011: 5.39.4 / 5.40.2)
Cleaning and examination: 100 - 200 lx (Styrelsen for Social Service, 2004)
Examination and Observation: 500 lx, 5000 K, Ra 90 (Styrelsen for Social Service, 2004)
Emergency lighting: 1500 lx / 5000 K: manual override button.
Toilet:
Daytime: 200 lx (DS EN 12464-1 2011: 5.39.6 / 5.2.4)
Night time: 5 lx, 2700 K, or amber light (Figueiro, A 24 Hour Lighting Scheme for Older Adults, 2008)