Semester: 10th

Title: Exploring light parameters for night shift workers

Aalborg University Copenhagen
Frederikskaj 12,
DK-2450 Copenhagen SV
Semester Coordinator: Georgios Triantafyllidis
Secretary: Lisbeth Nykjær

Project Period:

01-02-2017 to 02-06-2017

Semester Theme:

Master thesis

Supervisor(s):

Jakob Markvart

Project group no.:

N/A

Members:

Victor Suenson &
Anton Flyvholm

Abstract:
Working night shifts is taxing on the human circadian rhythm and a study from 2017 shows that there is 26% increased mortality rate amongst the Danish nurse cohort due to night shift work. The increased mortality rate is thought to be caused by a disruption in the human endocrinology that happens working night shifts. Light can be used as a tool, to help stimulate the hormones melatonin and cortisol, to support the natural circadian rhythm.
The thesis explores the possibilities of finding a lighting condition, for night shift workers, which provides both visual comfort and low circadian stimulation.
The main methods used includes a case analysis of a rehabilitation center with interviews of three night shift workers, a theoretical investigation on how lighting affects the circadian system and a laboratory experiment (n=30) evaluating the performance and preference of three different lighting conditions with varying degrees of circadian stimulation, based on a Circadian Stimulus metric.
Red light is found to have the lowest effect on the circadian rhythm but the experiment shows that it does not provide satisfying visual comfort. A broad spectrum lighting condition, with UV-A (380-420 nm) instead of blue wavelengths, is found to improve visual comfort, while keeping circadian stimulation low.
The thesis ends up by investigating different lighting parameters when designing for night shift workers and finds that there are no lighting conditions, which can fulfill both image forming (visual) and non-image forming (health related) lighting criteria. Although, good compromises can be made, based on the context, to offer visual comfort and at the same time reduce melatonin suppression during the night.

Exploring light parameters for night shift workers

Master Thesis 2017
Lighting Design

By Victor Suenson & Anton Flyvholm

1 Introduction

For many years, it has been a widely-discussed subject, whether there is a relation between working odd hours and an increase in getting various diseases. Both day and night shift workers, accompanied with leading scientists, have undergone investigations regarding work habits, in the pursuit of finding the answers. Some studies, conclude that shift work does not appear to have any unfavourable effect upon mortality (Taylor and Pocock, 1972; Bøggild *et al.*, 1999; Karlsson *et al.*, 2005). Contrary to this, other studies seem to have found that people with rotating night shift work are having enhanced risk of morbidity caused by cardiovascular diseases by 2,7% (Lin *et al.*, 2015), increased morbidity of breast cancer by 8.9% (Lin *et al.*, 2015) and in all-course death. Studies indicate a relation between the increased tendency of cardiovascular diseases and breast cancer and the number of years of night shift work (Gu *et al.*, 2016). Other studies confirm a modest relationship in all-course and cardiovascular diseases mortality and also finds an increase in lung-cancer mortality for night shifts workers working more than 15 years (Knutsson, Hammar and Karlsson, 2004; F. Gu et al, 2016).
In a large Danish study, with roots leading back to 1993 and until 1999, 28731 female nurses were recruited from where 18015 were included in the study (Jørgensen *et al.*, 2016). The aim was to investigate whether shift work is associated with increased all-cause and cause-specific mortality. From the total amount of nurses, the majority (62%) were performing day-work (07:00-15:00). 22% had rotating shift work, 10% evening work (15:00-23:59) and 5.4% had permanent night work (23:00-07:00). Registrations from the Danish Register of Causes of Deaths up to 2013 were used, which is 20 years after the first recruitments started. In this period, 1616 nurses had died. The most common cause of death was cancer with 945 instances, and second came cardiovascular disease with 217 instances. Other causes were Alzheimer's disease, diabetes and psychiatric illnesses. The study was also the first of its kind, to prove that evening (Hazard Ratio (HR) 4.28, 95% CI 1.62-11.3) and rotating shift work (HR 5.39, 95% CI 2.35-12.3) is as strong protagonist for Alzheimer's and dementia mortality. The study concludes that night work increases mortality with 26% (HR 1.26, 95% CI 1.05-1.51) and 29% (HR 1.29, 95% CI 1.11-1.49) for evening work. Furthermore, they found significant association between night shift work

and cardiovascular disease and diabetes but rejected that the overall cancer mortality was carrying any statistical associations with night shift work (Jørgensen *et al.*, 2016).

The result (Jørgensen *et al.*, 2016) has caught attention at The National Research Centre for Working Environment (NRCWE). Prof. Anne Helene Garde, who is researching in the field of night work, has expressed to the news-feed *Ugebrevet A.* that the explanation possibly lies within the body's hormones "*The more night shifts, you have in a row, the greater is the disorder in the circadian rhythms of the various hormones"* (translated by authors)[1]. This statement is presented in a leaflet published in 2012 made by Danish Regions, SHK and KTO (TeamArbejdsliv Aps, 2012). The leaflet presents a set of recommendations for people with night work. The recommendations are to have the least night shifts in a row to avoid the circadian rhythmic disruptions. That is to have fast rotating shifts with 1-2 consecutive nights as opposed to 3 or more consecutive night shifts. They recommend to dim the light in the working area at night but remark that it practically cannot be done without reducing e.g. work safety. The leaflet states that strong light inhibits the melatonin production, and light at night is therefore accused of playing a negative role in health conditions, but clear scientific evidence for this is missing (TeamArbejdsliv Aps, 2012). The leaflet is currently 5 years old and a lot of scientific papers have been published since then. In this context, these recommendations lead to further investigations in terms of finding a better suited lighting design for night shift workers. The knowledge behind the recommendations creates a basis for making a better lighting solution for night shift workers.

[1]http://www.ugebreveta4.dk/ny-dansk-forskning-nattevagter-koster-liv-og-oeger-ri_20790.aspx

2 Approach

This section, serves the purpose of giving the reader an overview of the structure of the entire project. The initial part will give a brief description of the content and relation between the chapters introduced in the project, while the second part will go further into detail of the project plan, which has been used to achieve the final goal.

1. Introduction: What is the problem?
Investigating the problem area and the scale of the problem.
Recent studies conclude that night shift work has an effect on mortality amongst the Danish nurse cohort.
NRCWE provides a guideline for how to deal with night shift work and side effects, includes light as an influencing factor.

2. Approach: How has the project been planned?

3. Methodology: Which tools and methods have been used to investigate this matter?

4. Background: *Why do people get sick from working during the night, and how does light affect this?*
How does the literature explain the correlation between night-shift work and the health-related consequences?
Light influences endocrine hormone production as Melatonin and Cortisol
The Human Centric Lighting concept and qualities.

5. State of the Art: *Which initiatives have been applied in the industry?*
Circadian lighting schedules to support the circadian rhythm
Personalised lighting systems
Projects and validation of these systems

6. Analyse: How is an existing solution working in practice and how can we approach a possible better solution?

Case-study: Albertshøj
Advantages and disadvantages of the current lighting system
Target group interviews

7. Design Criteria: What needs to be done to solve the problems?
Which image forming and non-image forming parameters are required?

8. Laboratory Experiments: How can we test the design criteria to see if they work?
The relationship between low circadian stimulus and visual comfort

9. Design Parameters: What have we discovered and how does it translate to lighting design?
Which spectral compositions are worth pursuing to solve support the guidelines from NRCWE?
The lighting parameters in terms of light intensity, distribution and some additional parameters are included as an implementation guide.

10. Discussion: A discussion of the choice of tools and theory, chosen for the project. And the choice of controversial design elements.
Could we have exploited the opportunity to investigate more research to get a broader understanding of the topic?
Can UV be part of the solution even though it includes both harmful and beneficial properties?

11. Conclusion: What are the findings from the report and can we use it to answer the research question?

12. Future Works: What is the next step from here?

2.1 Project Structure – The Plan Driven Model

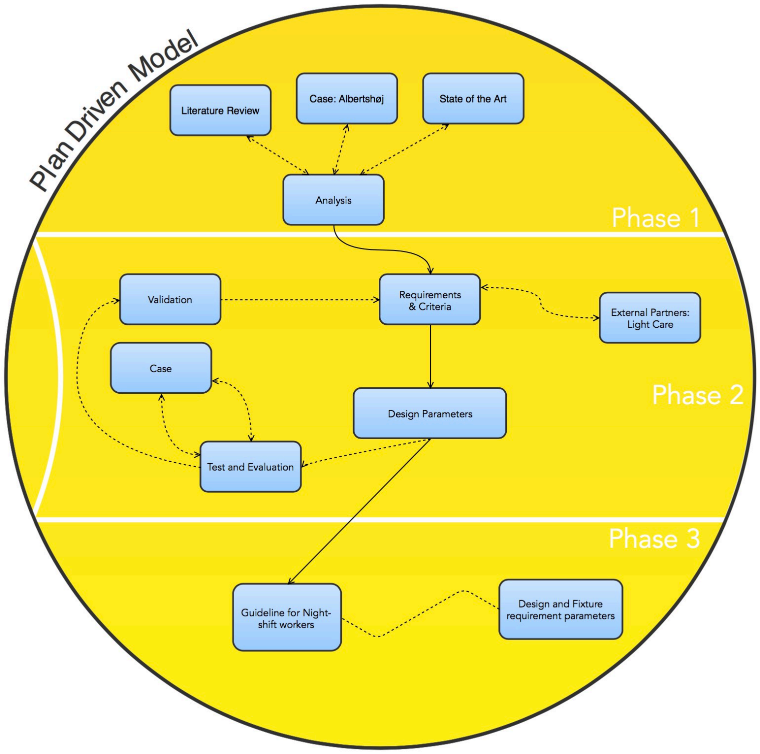


Figure 1 – The plan driven model shows the overall elements of the project and how they relate

The structure of this project has been planned and executed as visualised on the Plan Driven Model figure 1. This figure shows three work phases 1-3, all leading further in the investigation of the final guideline for night shift workers.

Phase 1

This initial phase has consisted of a literature review, providing knowledge regarding the field of human centric lighting and the underlying mechanisms and concepts. The project has taken its basis in a real-life problem, with nurses who have experience working night shifts. Due to the fact that a lighting system had already been installed at the rehabilitation centre, the case has provided knowledge about a system which, generally speaking, was already functioning but had a few issues because it lacked adjustments which were not foreseen at the initial implementation. Finally, the state of the art projects has been elicited and described. This has been part of the foundation, to investigate the newest technologies and implementations regarding personalised and circadian rhythmic lighting systems. Together, these three sections have provided the fundamental knowledge to analyse the different areas and fields.

Phase 2

The second phase has taken its basis in the first phase. On this background, we have been able to elicit some of the important requirements and criteria for the project to be successful. These requirements have been taken into the initial design elements and further tested and validated up against the case scenario in Albertshøj. For validation, we have treated the results from the experiment and applied statistical analytical methods to provide evidence for the outcome. The requirements and criteria phase is then updated together with LIGHTCARE, who provided the lighting system to the case study.

Phase 3

The final phase is the summarizing and concluding phase. This project has aimed to serve as an instructive thesis, to inform the night shift workers, entrepreneurs and architects to be are aware of the consequences and what can be done to change them on the basis of an informed choice. Furthermore, the thesis should function as a guideline for new building owners and providers of employment to take these guidelines into account, when implementing new areas, where night-shift work is a must. Finally, the guidelines can be of help to implement design criteria for specific night-shift work luminaires in the future constructions and workplaces.

3 Methodology

This section describes the scope of the project and general methods which has been used throughout the project. Methods relevant to the specific sections of the report will be described in their respective sections.

3.1 Scope and Delimitation of the report

The project will focus on exploring new design criteria which occur when investigating lighting as a welfare technology. The end result will therefore not be a final lighting design, but a discussion of how the new design criteria influence design parameters in the field of lighting design.

We will mainly focus on the aspect of lighting and how it affects the circadian rhythm in relevance to night shift workers. The paper will make use of current knowledge regarding biological terms to the extent that can be understood by non-specialists. Furthermore, we will look at knowledge within biology, neuroscience etc. on the level on which it becomes relevant for lighting design.

3.1.1 The Cross-disciplinary approach

The education of Lighting Design at Aalborg University Copenhagen, is an education combining the fields of Architecture and design, Media technology and Engineering into a cross-disciplinary field. By combining the knowledge from these three fields, it allows for an academic- and scientific approach with focus on evidence based lighting technologies and applied design aesthetic. In relation to these fields, this project is placed slightly more towards the engineering- and the media technology part than the architectural aspect as illustrated in Figure 2.

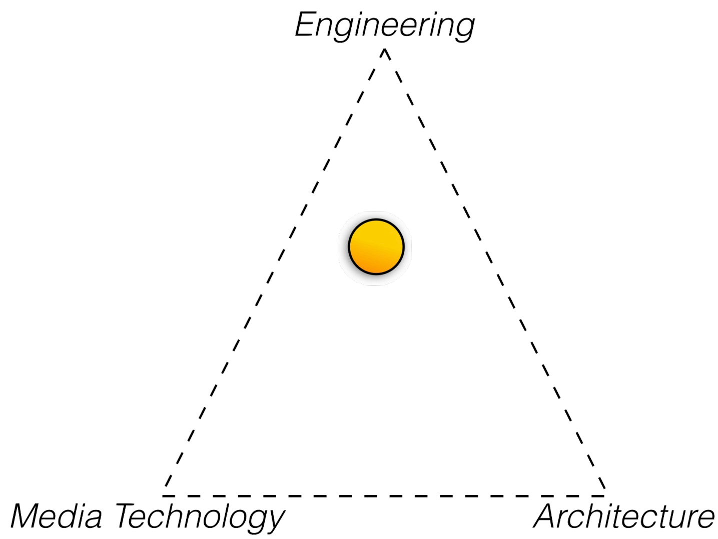


Figure 2 – The figure shows the three fields of the education and how this project is positioned

3.2 Target group

Night time work is a necessity in several businesses. It is required mostly in the industry- and transport and in the healthcare sector. In 2016, there were approximately 320,000 Danish people, who had been working night time jobs within a period of four weeks[2].

Nine percent of the Danish wage earners, between 19-59 years old, are employed in some sort of shift work. Five percent has regular shift work, where the working hours lies partly or totally outside the normal working hours. One percent has fixed evening/night work and three percent has other different working agreements (Arbejdstilsynet, 2004). To delimit the target group concerning the scope for this project, night shift workers can be described in two main categories. The first category of night shift work is where the worker is working in permanent night shifts and is therefore rarely, or not for longer

---

[2] http://www.dst.dk/da/Statistik

periods, returning to a normal diurnal circadian rhythm. This type of job could involve extreme job conditions as on a drilling rig, where disembarkation only occurs at regular intervals with weeks or more in between. Under these circumstances, workers are precluded from any daylight or outside environment for up to several weeks at a time. A permanent night shift worker could have a more common job-description such as a permanent storekeeper at a warehouse. Such job-descriptions require a permanent routine work and it is therefore necessary for the worker to completely turn the circadian rhythm from diurnal to nocturnal.

According to the guidance within the field, these jobs are the most detrimental, and is not recommended by The National Research Centre for the Working Environment (Christensen, 2017). It is furthermore linked to health- and sleep related issues (Pilcher, Lambert and Huffcutt, 2000). Therefore, this type of night workers does not fall within the scope of maintaining a daytime circadian rhythm.

The second category of night shift work includes daytime work with fixed or occasional night work. This category of work is often seen at hospitals, care facilities or emergency call centres, where the employees are having night-shifts in a fixed routine and changes their schedule regularly. The people who are working in fixed night routines with occasional transitions from day to night work and vice versa, are best suited as target group for this project. Only having few night-shifts in a row makes it meaningful to try and keep the circadian rhythm as intact as possible, which is the aim of this lighting design project.

It is required that the work takes place indoor, because the lighting environment is more controllable as opposed to an outdoor environment, where streetlight and other factors have influence. Some jobs, e.g. street policeman, would not be considered within the target group due to the incontrollable working environment.

3.3 Measurement tools

The tools used to measure the lighting conditions were all handheld professional grade equipment with up-to-date calibration.

3.3.1 Hagner - Illuminance meter

Illuminance measurements were made with a digital illuminance meter, model EC1, by Hagner (ID: AAU805339), which features cosine correction, a spectral sensitivity curve which closely resembles the CIE standard observer, and a ±3% accuracy[3].

3.3.2 Asensetek - Spectrometer

The spectral power distribution was measured with a smartphone connected spectrometer model alp-01 by Asensetek (ID: AAU804688), which features a wavelength range of 380-780 nm, a spectral resolution of 8 nm, and an accuracy of ±0.5 nm for wavelength and ±0.002 x,y (at 1000 lux) for the chromaticity coordinate[4].

3.3.3 Minolta - Luminance Meter

The luminance was measured with digital luminance meter, model LS-150, by Konica Minolta (ID: AAU104782), which has an accuracy of Lv ±2%+1digit (above 10cd/m2)[5].

3.4 Calculation of circadian stimulus (CS):

The circadian stimulation metric is a tool used to predict circadian stimulation of a given spectral power distribution from a light source at a given intensity (introduced in the background section 4.3).

All calculations of the CS metric in this report have been made using the freely available tool 'Circadian stimulus calculator'[6] by Lighting Research Center (Rensselaer Polytechnic Institute), which needs two inputs to compute: relative spectral power and vertically measured photopic lux. The spectral power distribution of the light source was measured directly below the given light source, in a controlled environment, using the Asensetek

[3] http://www.hagner.se/illuminance-meters/model-ec1/

[4] http://www.lightingpassport.com/

[5] https://www.konicaminolta.eu/en/measuring-instruments/products/light-display-measurement/luminance-meters/ls-150-ls-160-2/specifications.html

[6] http://www.lrc.rpi.edu/resources/CircadianStimulusCalculator_30Apr2016.xlsx

spectrometer, and data was then converted into radiometric units using the spectrometer's supplied companion software 'Spectrum Genious PC'. The photopic lux on the vertical plane was measured by the Hagner illuminance meter according to the instructions of the calculator by placing an illuminance meter vertically in front of the eyes.

4 Background

The aim of the background section has not been to provide an exhaustive account on all the aspects of how lighting affects the circadian system, but to find the general biological and physiological mechanisms, which are relevant when designing for night shift workers.

The theoretical knowledge was collected through a literature search on different library databases supplied by the royal library of Copenhagen and Aalborg University Copenhagen and Google Scholar[7]. The literature investigation was initialised by searching for a combination of the following general search terms (and semantically related synonyms): night shift workers, circadian rhythm, melatonin production, light.

An iterative search strategy was used, where we explored the references of the initial articles and the articles which cited them, to discover new and more specific search terms, which were of interest for the project.

The knowledge in the background section is based on a mix of both secondary sources from literature reviews and primary sources of empirical studies.

4.1 The Human Circadian Rhythm

As prevailing for most biological organisms, the human body also encounters an endogenous cycle. The daily biological rhythm within humans is referred as the *"circadian rhythm"* that translates from Latin to, *"about a day"-rhythm*. The circadian rhythm describes the sleep/wake cycle, which roughly is around 24 hours but varies slightly (Czeisler *et al.*, 1999). The biological process is based on endocrine mechanisms that regulates the hormone secretion including Melatonin and Cortisol (and Serotonin). These hormones fluctuate the alertness during the day and sleepiness during the evening and throughout the night. The circadian rhythm is affected by external factors, where light is the main influencing factor (Eisenstein, 2013).

During daytime, the bright light from the sun exposure the human eye and skin and ensures a synchronisation of the circadian rhythm. This happens, when the bright light

[7] https://scholar.google.dk/

passes through the eye-lens and reaches the back of the eye, where the retina is located. The retina is a thin inner coat of the eye consistent of photosensitive receptors called Rods, Cones and Retinal Ganglion Cells (RGC). The rods and cones are both responsible for the visual perception. Rods are active in the scotopic vision, when the light exposure is less than 0.005cd/m^2. They are not capable of distinguishing between colours and therefore the surroundings are perceived in nuances of black and white. Cones, on the other hand, are responsible for the photopic vision and are active when the light-conditions are above 5cd/m^2. The cones constitute of three sub-category receptors that are specifically sensitive to a fraction of the visible light spectrum, enabling the coloured vision (Boyce, 2014).

In situations where the light condition lies between the scotopic and photopic vision, the brain uses both rods and cones, called the mesotopic vision. Therefore, the rods and cones are crucial for the image-processing that happens in the visual cortex in the back of our brain. The RGCs are a slightly different type of cell but yet a very important part of the eye, when it comes to entraining the circadian rhythm. The RGC is located just behind the retina, where it is connected to the rods and cones via the bipolar cells. Amongst the RGCs is a rare type of ganglion cells (only ≈ 1-2%) called the intrinsically photosensitive retinal ganglion cells (ipRGC) (Hattar *et al.*, 2002). These cells are in particular sensitive to light at short-waved light around 480nm (Blue light spectrum). The ipRGCs have long axons, feeding directly into several locations of the brain as the Suprachiasmatic Nuclei (SCN) (Hattar *et al.*, 2002). SCN is known as the centre of the brain that synchronizes the circadian rhythm. This is carried out by balancing the hormonal production of melatonin and cortisol.

For a normal person, these hormones are produced in a 24-hour schedule, ensuring quality of sleep and well-being. Melatonin is produced mainly from around 20:00, where the hormones effect the person to feel drowsy and ready for bed. When the melatonin production stops around 4:00, the cortisol level increases. The cortisol peaks at around 08:00 before it decreases slowly during the day (Figueiro and Rea, 2010).

4.2 The Night Shift Worker

The natural light, the sun, follows a fixed and non-alterable cycle. This is the natural light/dark cycle that is the major external stimuli of external factors of entrainment. The bright light, one is exposed to during the day, depends on people's individual habits and activities as well as job-situation, weather conditions and season bright light exposure affects the entrainment, leading to increased melatonin production at night and therefore better quality of sleep (Cajochen, Krauchi and Wirz-Justice, 2003).
In modern society, there is a need for people working throughout both day and night. Policemen, nurses or pilots are jobs, where night-time work is often required. Working throughout the night, compromises the circadian rhythm. This requires activity at night, while the body is in the circadian night state causing a desynchronisation of the circadian determination of the hormones melatonin and cortisol. This leads to people, who work rotating night-shifts, being more prone to a number of health-related issues such as diabetes type 2, as well as shorter sleep durations and quality. A quantity of studies has been made to map the correlation between night-time work and the health-related issues. During a time-period from 1988 to 2008 a study followed a wide number of 69,269 healthy nurses (age 42-67), with a baseline group of 107,915 healthy women (age 25-42). The study was investigating the relation between night-shift work and obesity, metabolic syndrome, and glucose dysregulation. The results of the study suggested that a modest increase was found in people with an extended period of rotating night shift work partly mediated through bodyweight. The increased bodyweight could be explained by the desynchronisation causing the incidence of metabolic syndrome (MetS) (De Bacquer *et al.*, 2009; Pan *et al.*, 2011).

A report made by NRCWE and Institute of Public Health is summarizing and concluding on the final results for a study based on 73 Danish police-officers, working night shifts (Arbejdsmiljøforskningsfonden *et al.*, 2015). The study involved three types of work schedule scenarios with 2+2, 4+4 and 7+7, meaning 2 night shifts and 2 days off, 4 night shifts and 4 days off and finally 7 night shifts in a row with 7 days off. Before the intervention, 49% of the participants preferred the 4 nights in a row, and after the intervention it was 57%, where 26% preferred 2+2 and 26% preferred the 7+7 model. The participants who preferred the 7+7 model, found the night-work less demanding and they were categorised as “night-owls” compared to the people who preferred less nights in a row. None of the participants were fully adapted to the night work even after 7 days of night-work and there was found no significant long-term effect of the circadian rhythms meaning that all hormones were normalized after the last day of recovery. The wake-up was more difficult on the last day independently of the intervention type.

Moreover, the more consecutive night-shifts one test-subject had undertaken, the lower was the melatonin concentration (saliva) during the night. Cortisol was secreted later dependently on the quantity of consecutive night-shifts the test-subjects had undertaken. The more night-shifts, the later the cortisol was secreted as effect of the displaced circadian rhythm. The amounts of consecutive night-shifts, thus have a negative effect on the sleep duration- and quality and results in unnecessary disruptions of the circadian rhythm, and a sleep deficit is built up. Even though the test subjects preferred four consecutive night shifts, NRCWE consider the 4+4 model as the maximum amounts of night shifts in a row which should be used.

4.2.1 Shift work disorder

Shift work disorder (SWD) is long term impairment of waking alertness and insomnia during the habitual sleep and 20-30% of American night shift workers report having these symptoms (Morgenthaler *et al.*, 2007). SWD is the result of having a circadian rhythm which is not synchronized with the sleep-wake cycle caused by the shift work. The disorder has been associated with poor performance, cardiovascular, gastrointestinal and infertility problems, accidents, illness, depression, and excessive sleepiness when at awake (Dodson and Zee, 2010).

Clinical investigation of SWD has been primarily focused on night shift workers, instead of rotational shift workers and treatment and strategies has been aimed at realigning the circadian rhythm with the sleep and work schedule (Dodson and Zee, 2010). Treatments include bright light exposure of 1200-10000 lux for 3-6 hours during the night shift in order to delay the circadian rhythm, avoidance of light at appropriate times of day especially on the commute home, planned napping, taking pharmaceutical melatonin prior to sleep, sleeping pills and stimulants for maintaining alertness such as caffeine (Dodson and Zee, 2010). The pharmaceutical interventions do not alleviate the circadian misalignment but only treats the symptoms of SWD. The treatments also have potential side effects such as headaches, vivid dreams, nausea, and cardiovascular effects and a non-pharmaceutical management of the disorder, such as lighting and structural changes, is favoured to manage the cause of the disorder (Dodson and Zee, 2010). Lighting at the workspace can be used as a welfare technology to alleviate the cause of the circadian misalignment in a non-intrusive way.

4.3 Human Centric Lighting

A new development in the lighting industry promotes electrical lighting with LED technology, to not only provide the basic visual functions for offices, industry or nursing homes. Solutions are today sold with promises of improving work performance, concentration and general well-being. The development of these lighting solutions is scientifically based and is the outcome from years of scientific work. The area combines the interdisciplinary aspects of biology and lighting technology. It opens up for a new way of designing light solutions and lighting fixtures with these purposes. The technological development of LEDs has helped bringing these types of concepts along. The fact that it is now possible to assemble narrowband diodes to optimize the composition of the lighting fixture for supporting fundamental biological functions.
These promising features to optimize on human resources are attractive for employers. One of the key concepts describing these features are developed and described by senior scientist at Philips Lighting Bianca Van der Zande.

The concept of Human Centric Lighting is lighting which considers both the visual and non-visual effects of being exposed to light taking into consideration visual performance, comfort, sleep quality, alertness, mood and behaviour (Boyce, 2016). The elements of the human centric lighting, involves three core elements, the *Functional lighting*, *Biological lighting* and the *Emotional Lighting.* The functional lighting creates an optimum of eye-comfort and can facilitate excellent visual acuity and concentration. The biological element, relates to the circadian rhythm and the light's supporting abilities. This is alertness during the day and the ability to gain quality sleep during the night. The emotional element speaks to the feeling of comfort. To combine these three important elements of a lighting design, it is furthermore, important to understand the human perception of light.

The concept builds upon that the human brain perceives and obtains exposure to light in two ways, the image-forming path and a non-image forming path. Fulfilling the optimal conditions for both paths are correlated and equally important for the overall psychological comfort.

The image forming path consists of two elements. The *Visual performance* is concentrated around the optical system, which is the physical elements of the eye itself and the transmission of signals to the visual cortex. The process is a rather demanding and complex. It is functioning by interpreting the objects, based on reflected electro-magnetic radiation in a limited band of frequencies in the visual frequency span. The visual performance is also correlated with visual comfort and the effort that has to be used to see an object. In this context, the size of the object and the contrast is relevant in order to see the details in the object effortlessly.
Visual Experience is related to the natural way of appearance in a room. If the light appears unnatural or artificial it can compromise orientation and can have an effect on mood and satisfaction (Zande and Rizzo, 2016).

4.3.1 Functional aspects of lighting

Functional lighting is the visual effects of lighting and is primarily about visual acuity – being able to see properly in relation to visual comfort (non-straining lighting conditions), visual performance (task performance), and safety (reducing accidents due to visual issues).
The European Commission have set up a standard (EN-12464-1) for appropriate lighting conditions at workplaces to account for these issues (EN-12464-1;, 2011). The standard takes into account various functional lighting metrics such as glare, luminance contrast, illuminance, uniformity, and colour rendering.
However, the lighting standard solely account for lighting which is appropriate on a functional level and does not (yet) include biological and emotional effects of the lighting. This means that the standard proposes the same lighting for night- and daytime except

for corridors, which can be reduced to 50% at night time to conserve energy (EN-12464-1;, 2011).
Furthermore, the standard has been developed with a relatively young target group in mind. Vision deteriorates as a function of age, where more and more light is required as we grow older due to an age-related yellowing of the lens reducing light transmittance, and especially the short wavelengths of the light (blue) is filtered away (van Bommel and van den Beld, 2004). This calls for adaptable lighting which goes beyond the EN lighting standard to take into account the different populations.

4.3.2 Light and the acute system

Alertness is important for work efficiency and reducing errors, and alertness levels are especially important to manage for night shift workers since they have to be awake during the biological night and perform at a time, where they their body tells them to feel sleepy (Boyce, 2014). The stress hormone cortisol and sleep hormone melatonin plays a role in determining alertness and sleepiness. A high concentration of cortisol increases blood sugar and gives the body energy. A low concentration of melatonin increases core body temperature thereby reducing sleepiness making you more alert (van Bommel and van den Beld, 2004). Both of these hormones is part of the circadian rhythm and should not be disrupted too much to ensure long term health. Cortisol levels cannot be maintained in high levels throughout sustained amount time or the system becomes exhausted and inefficient (van Bommel and van den Beld, 2004).

Light affects alertness during night time, by both supressing melatonin at appropriate light levels and increasing cortisol. There is currently no model describing the spectral sensitivity of cortisol, but both short wavelength and long wavelength light exposure have been shown to increase cortisol levels although there are a lot of uncertainty as to what intensity of light is needed to affect the production (Boyce, 2014). Light has been shown to increase alertness in daytime at bright light levels (Sahin and Figueiro, 2013), but most research on alertness has been conducted at night time (van Bommel and van den Beld, 2004). Doing so provided the biggest results because one would be both reducing melatonin levels and increasing cortisol levels (van Bommel and van den Beld, 2004).

A laboratory study by Figueiro et al. (2016) a showed that a red lighting condition (213 lux, 630 nm) enhance brain activity during the day and night without suppressing melatonin production when compared to a dim lighting condition (<5 lux, 3500 K). The red lighting condition had a weaker effect on alertness, than a warm white lighting condition (361 lux, 2568 K) (Figueiro *et al.*, 2016), showing that even though red light affects alertness, the impact might be rather low. However this finding shows that it is possible to increase alertness levels to some degree during the night without influencing melatonin production by the use of long wavelength (red) light (Sahin and Figueiro, 2013; Figueiro *et al.*, 2016).

4.3.3 Light and the circadian system

With the discovery of the intrinsically photosensitive retinal ganglion cells (ipRGCs) in 2002 the theoretical link was finally made between the retinal light input and the circadian pacemaker suprachiasmatic nucleus (SCN) of the brain, without the use of the photoreceptors rods and cones (Berson, Dunn and Takao, 2002). Light is the strongest entrainment agent for the circadian clock (Morgenthaler *et al.*, 2007), and at the same time light is a non-invasive way to control the circadian rhythm without the use of medication. Exposure to appropriate light in the morning can be used to advance the circadian rhythm, while exposure to appropriate light in the evening can delay it based on chronotype (Wright *et al.*, 2013)

How light affects the circadian system is a complicated matter and not every detail is currently known (Boyce, 2014), but there are two major characteristics of the light which determine how the circadian system is affected: Spectral composition and intensity. The following sub-sections will go into how these parameters affect the circadian system in terms of melatonin suppression relevant to shift work.

Spectral composition

The colour of the light determined by spectral composition (radiant power per unit wavelength) has an impact on the circadian system since the photo pigment melanopsin of the ipRGCs are more sensitive to light at 460 nm, with a 110 nm band around the peak being 50% effective at supressing melatonin levels (Rea and Figueiro, 2016). In comparison the cones of the photopic vision has a peak sensitivity around 555 nm (Rea *et al.*,

2012) meaning that the circadian and the visual system is sensitive to different parts of the visual spectrum.

Previously studies have mainly been dealing with white light (chromaticity following the planckian locus) and mainly focused on how different CCT's affect the circadian system and found that higher CCT supresses melatonin better and lower CCT supresses melatonin less (van Bommel and van den Beld, 2004). However, CCT is only a limited indicator of spectral composition and with the prevalence of new lighting technologies, such as LED and fluorescent lights, which have SPD's characterized by peaks instead of a continuous spectrum, such incandescent lights, the metric is a poor indicator for predicting how the lighting will affect the circadian system.

The ipRGCs are not the sole circadian photo-transductor and also the rods and cones play a role when determining the impact of light on the circadian system. The addition of the rods and cones in the process complicates the model for circadian stimulation since the circadian spectral sensitivity is also determined by the relative distribution of colours (spectral opponency) in the spectrum (Rea *et al.*, 2010). This model for circadian spectral sensitivity is based on nocturnal melatonin suppression studies and surpass other models by being able to predict the effect of polychromatic light exposure opposed to narrowband light exposure by taking into account the relative number of different wavelengths. The model shows a peak sensitivity to blue light (460 nm) and no sensitivity to ultra violet light (<400 nm) and red light (>600 nm) (Rea *et al.*, 2012). Therefore, according to the model ultra violet and red light does not affect the circadian system (does not supress melatonin production).

Intensity

Intensity is dealing with the amplitude of the optical radiation. Intensity has an impact on the circadian rhythm simply due to the fact that it is the sum of absolute power of each wavelength in the visual spectrum. The general relationship is that higher light intensity means a higher suppression of melatonin and vice versa since the visual spectrum and the circadian sensitivity spectrum overlap. Therefore, given the same light condition except for a change in intensity, 200 lux will supress the melatonin production more than that of 50 lux.

For bright white light, intensity has been shown to be the main parameter for suppressing melatonin, and the impact of CCT on melatonin suppression becomes less significant as the intensity levels go up (Figueiro, Rea and Bullough, 2006).

Additional parameters

Other parameters worth mentioning in relation to the circadian stimulation are (1) the exposure history of the individual meaning that the impact of any given light intervention is determined by much light the individual has been exposed to recently, where people who are exposed to more light throughout a week are less sensitive to night time melatonin suppression (Hébert *et al.*, 2002) (2) the duration of light exposure determines the magnitude of entrainment and that e.g. a light exposure of 1000 lux for 10 minutes has the same circadian stimulation as 500 lux for 20 minutes (Schlangen, Lang and Novotny, 2014), (3) the exposure area also plays a role, where bigger exposure areas have bigger effects of the circadian stimulation than smaller exposure areas (Schlangen, Lang and Novotny, 2014), (4) also the angle of incidence of the exposure area plays a role where we are more sensitive to light coming from above than below our visual field (Glickman *et al.*, 2003), however peripheral contra central light exposure showed no significant changes in sensitivity (Adler *et al.*, 1992).

4.3.4 Metric for circadian stimulation

Intensity and spectral composition are interrelated parameters when describing how lighting stimulates the circadian system and it makes sense to look at these factors in in combination. This renders conventional lighting metrics inadequate, such as illuminance (lux) and correlated colour temperature (CCT), used in general lighting practice. Instead a more complex metric is needed which takes into account both the relative spectral power and the intensity to provide an indication, of how much the light stimulates the circadian rhythm in terms of melatonin suppression in percentage (Rea and Figueiro, 2016).

To describe this phenomenon, the Circadian Stimulation metric (CS metric) can be used. It was originally described by (Rea *et al.*, 2010) and later updated *(Rea et al.*, 2012; Rea and Figueiro, 2016). The metric deals with circadian lighting (CL_a) as opposed to the conventional photopic luminous efficiency function [V(λ)], as it acknowledges that the circadian system, by help of the ipRGC's, has a luminous efficiency function which is different from the visual system (Rea *et al.*, 2012). CL_a is spectrally weighted irradiance for the circadian system and is therefore comparable to illuminance which is spectrally weighted irradiance for the visual system (Rea *et al.*, 2010). To make this comparison easier 1000 CL_a has been normalised to a CIE standard illuminant A - incandescent light source at 1000 lux and 2856 K (Rea and Figueiro, 2016).

Circadian Stimulation (CS) is based on CL_a and is an indicator which describes how much the given lighting supresses melatonin production in percentage, where CS=0.0 is no melatonin suppression, and CS=0.7 is 70% melatonin suppression which is the theoretical maximum (Rea and Figueiro, 2016).

The metric does not account for the additional parameters (exposure history, duration, distribution, timing) (Rea and Figueiro, 2016), and these parameters needs to be accounted for separately to accurately determine circadian stimulation of light.

The CS metric has not yet been adopted as a metric in the conventional lighting design practice (Boyce and Smet, 2014), but the model has been validated through experiments as a predictor of melatonin suppression (Rea and Figueiro, 2016).

Another contesting metric describing light in terms of impact on the human circadian system is melanopic illuminance, which is a measure of the melanopsin response curve of the ipRGC photoreceptors (Lucas *et al.*, 2014). This measure relies on the response of a single photoreceptor (ipRGC), and does not take into account indirect input from other photoreceptors (Cones and Rods) (Rea and Figueiro, 2016). Because the CS metric seems to be the most accurate measure of circadian stimuli, it is the metric used in this project.

5 State of the art

The topic regarding specific light for night shift work, was rather limited in a Danish coherency due to the relatively limited amount of people who are working night shifts. By conducting a search, it was possible to find and investigate the state of the art companies and their solutions. The search technique has focused mostly on companies and systems that has provided scientific knowledge and understanding for the circadian rhythm and how the light can support that functionality. The research has resulted in only a few companies, operating in Denmark who are selling these lighting solutions with this aim.

5.1 The Circadian Light with Therapy and Boost

In recent years, the lighting industry has developed full-dynamic light systems based on the circadian rhythm. Such solution has especially been designed with an aim for optimizing the healthcare sector by incorporating full-dynamic electrical lighting on a schedule based on the diurnal circadian rhythm. The full dynamicity is used to describe the fixture's capabilities, with full range within the visible light spectrum in terms of both colours and intensity. This combines complex compounds of LED technology with the know-how of the effect on the human centric aspect.
One of the latest and largest implementation of such a system, is installed at the new health-care facilitation in the municipality of Silkeborg, where 120 sheltered houses has been constructed.

Technical description:
The design example is taken from the company LIGHTCARE[8], to demonstrate the architectural possibilities. The solution consists of a Central Management System (CMS) that form the software and hardware connection. The communication is based on Digital Multiplexing (DMX) / Remote Device Management (RDM) technology and can individually be controlled in zones to support individual usage in the residential apartments with

[8] www.LIGHTCARE.dk/

local switches in every room. The implementation is scalable and can contain multiple sensors, switches and wireless communication links to the fixtures.
The lighting fixtures itself consists of up to seven-channels but is normally implemented with RGB-WW-A. This is a combination of Red, Green and Blue diodes in addition to Warm-White, Cold-White and a yellow/orange looking Amber facility. The combination of these diodes creates a smooth distribution of representatives in the visible spectrum, even though these diodes are limited to the specific peak and bandwidth, they are produced for.

5.2 Personalised Intelligent Lighting Control System

In the pursuit of creating a method for providing individual light preferences and perception, concepts as the Danish company, LIGHTEN has taken form. These concepts functions by taking dynamic electrical lighting scenarios and controlling them, for optimizing daily performance and alertness. The dynamic light levels and colour temperature is scheduled based on personalised profiles, containing preferences, gender, chronotype- and or mental/medical condition. Such a system could take basis in the mobile or wearable software that contains the information for the individual and adapts the lighting surroundings accordingly via a hardware module in the lighting control unit. The concept is cloud based and is automatically adjusting over time to adjust the preferred settings at preferred times a day. Thereby the solution always provides a personalized lighting condition when turning on the lighting with the mobile application.

The concept does not appear to have any proof of concept implemented currently. Even though it appears to include a certain functional aspect by approaching the personalized lighting conditions

5.3 Computer Screens and the effects on the Circadian Rhythm

There is no doubt that screens as phones and computers are indispensable necessities for most work situations, whether it is writing notes checking emails or updating the social media. During night work, the sharp illuminance from screens has great impact on the circadian rhythm and blocks the melatonin production. Therefore, software developers have as part of the operating systems or add-on applications, implemented software that will decrease the amount of blue light on screens at certain point in time[9].

5.4 Applied Lighting design

A study carried out by Dr. Katharina Wulff from Oxford University, London, has investigated an installation from the Ceres Centre (Horsens, Denmark). The installation involves a project, where the effect of the light has been measured on 16 severe patients with dementia in 16 apartments, hallways, living rooms, orangery, staff rooms and offices.
Here it was observed that the patients in the care-facilities felt it easier to calm down during the evening and they showed a more stable sleep pattern. The personnel felt less headache during the day-hours and they were also easier to calm down during the evening and also during night shifts.

The essential aspect of this concept lies in the removal of the blue wavelengths in the spectrum from luminaires in the functional lighting. This happens during the early morning hours, late afternoon and evening hours. This is creating a more comforting awakening and makes it easier to fall asleep during the evening for both residents and personnel. When changing to night shift in the evening, the light turns into a night light scenario, where a red light is applied. This is to intervene least possible with the personnel's circadian rhythm. In the morning, blue wavelengths are used actively in (cold) white light with high intensity to entrain the internal clock (SCN) to the natural light/dark cycle.

[9] https://justgetflux.com

6 Case Study – Analysis

This section provides an analysis of the case, involved this project. The section will include a brief analysis of the functional area of the space together with a description of the implemented lighting design. Additionally, semi-structured interviews have been undertaken to investigate the functionalities and get an overview of the night shift workers' tasks, routines and experiences regarding the lighting.

6.1 Case: Albertshøj – Rehabilitation Center

The rehabilitation center, Albertshøj in Albertslund, agreed to participate in our investigation to improve their current lighting facilities. Albertshøj is a bed-unit for rehabilitation of primarily old people, who have been undergoing surgery or are recovering from another form of illness. The rehabilitation center is often functioning as an extension to the hospitals and the patients are often hospitalized at the care unit for periods of up to three weeks. The care unit is a part of the health-care sector that also includes a doctor's unit, assisted living and training facilities located in the same health facility building.

The building was inaugurated in January 2016 and is therefore up-to-date technology wise. The rehabilitation unit is located at the third floor, with a large east-facing roof top terrace and large panoramic windows, bathing the hallway in morning sun. From the hallway, there is access to 4 west-facing one-room bays. The entrance is located north of the hallway and the staff room and day room are located in the south-facing part.

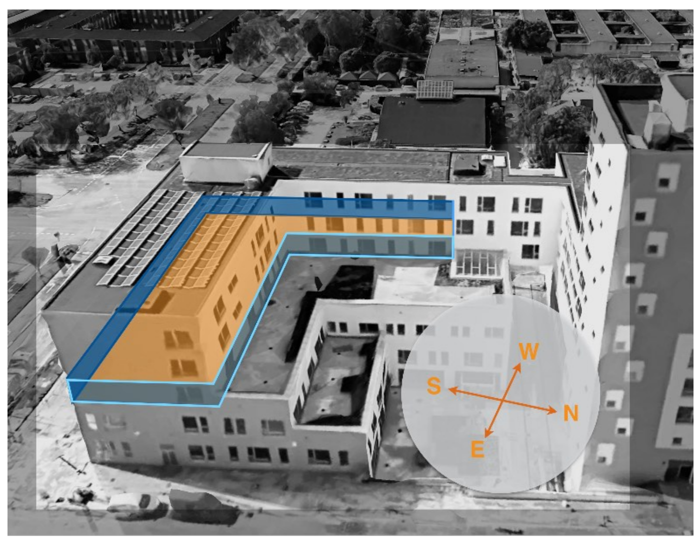


Figure 3 - Albertshøj Location

Google, Data SIO, NOAA, U.S. Navy NGA, GEBCO, Landsat / Copernicus, Kortdata ©2017 Google.

The department of the existing rehabilitation centre was initially supposed to be a care centre instead of providing a fixed residency. Due to the fact that patients are only hospitalized in short intervals of approximately three weeks before returning to their private homes, the patients are not considered to benefit from the therapeutically lighting design as implemented. Hence, the focus of the lighting is on the staff working there.

6.1.1 The current lighting design

The following section will describe the current lighting installation, installed at Albertshøj. This is carried out in order to analyse the work space lighting conditions for the night shift workers. The current lighting installation is programmed to boost the circadian rhythm by adding a rich short waved light in a white light composition during the morning, while extracting the short-wavelengths in the afternoon, to support the natural circadian rhythm. It is built upon the results from an OPI project in Albertslund concerning better lighting for elderly people (Plan-C, 2013). It has been developed with the focus to support both patients and staff during the hospitalization and working hours.[10]

Luminaires

The general illumination in the common-area, is based upon a recessed Basic M8 fixture from Luminex. The fixture serves as the functional lighting, providing a maximum luminous flux of 6740 lm. The installed Basic M8 fixtures are installed with RGB-W. In the day-room an additional set of Caravaggio pendants are placed above the dining tables to provide additional food and mood lighting.

Inside the one-room bays there are three main fixtures. One large LED fixture is placed centrally on the ceiling and above the bed (Basis LED A1, Ø950). The fixture is installed as a therapy lamp and is capable of providing up to 9000 lm and has been installed with an opal diffusing material, providing a diffused downlight distribution to avoid the sensation of glare. The second fixture is placed on the wall across the footboard of the bed (Basis LED A1 Wall, Ø300), providing up to 2312lm. This fixture is wall mounted. The third fixture is located next to the bed over the sink in the kitchen area. The kitchen and ceiling fixtures are installed with RGB-W and is following the full dynamicity of the

[10] http://lightcare.dk/cases/bedre-lys-til-ældre/

schedule specially programmed to the implementation at a care home for elderly people. The wall-mounted fixture is installed with only R-W as a semi-dynamic installation but can be used for the night scenario as well as daytime. In the bathroom, there are two types of fixtures installed. One fixture is a Cubic LED A3, mounted on the ceiling with a direct light distribution. The second type is two wall-mounted Matric LED A3 fixtures that also provide a direct light distribution. Both types of fixtures are installed with RGB-W for the full-dynamic installation schemes (See Table 1).

	Luminous Flux (lm)	**Setting**	**Diffusion**
General Illumination	*Hallway & Common area*		
Basic LED M8, L 597	6740	RGB-W: DMX	Opal
Caravaggio, Pendant	≈ 800	2700-3000 K	Opal
One-room Bay	*Livingroom*		
Basis LED A1 Wall, Ø300mm	2312	R-W: DMX	Opal
Basis LED A1, Ø950mm	9000	RGB-W: DMX	Opal
Matric LED A3, L 1760mm	N/A	RGB-W: DMX	Opal
	Bathroom (Sensor Triggered)		
Cubic LED A3,	4907	RGB-W: DMX	Opal
Travis LED A3	N/A	RGB-W: DMX	Opal

Table 1 - Fixtures in the one-room bays at Albertshøj

The installed fixtures are all made with a direct light distribution, creating a high contrast in the corners of the rooms. Therefore, when the sun is not sufficient, the experience of the space seems a bit tight and does not fulfil the room's potential. By installing luminaires with an indirect light distribution, it would create a better light distribution in the room. This does not seem to have been in focus, when designing the ward.

6.1.2 Interview with three night workers from Albertshøj

Staff is working during the night period in the rehabilitation unit taking care of practical situations and journal keeping. This is currently set up as a 7+7 work load, where the staff is working 7 night shifts in a row and afterwards is having 7 days fully off or as-

	Team 1	Team 2
Common tasks:	- Emptying urinal catheter - Turning patients (to avoid pressure soreness)	- Journal keeping - Giving personal care - Pill apportion
Working inside the bays	Using sink light or no light at all	Turning on Night light at 25%
General light adjustments	Night light is dimmed to 10% or Off	Night light is dimmed to 25-50%
When no alarms triggered	Watching TV	Watching TV/Book reading
Working on computers	Surrounding light is off or 10% (Enough light from the computer screens)	Increasing light to 50% or white light
Visits from e.g. doctors	-	Increasing light to 50%

Table 2 – Overview of the interviews with three night shift workers at Albertshøj.

sisted with day-shifts in addition to that. The staff works in two teams of two persons, where one team is working even weeks and the other team is working uneven weeks. The workers are currently part of the persistent night worker category, who are working only night shifts followed by days off. This could preferably be changed, to follow the recommendations from NRCWE. Three out of the four possible night-shift workers from Albertshøj took part in an interview concerning the current lighting installation and their experience and usage of it. The night shift workers were interviewed in the teams that they work in (see appendix 14.1 for full interview notes).

Interview with Team 1, (Including Night Worker 1.1 and Night Worker 1.2): In the room was Sofie Seeman and Key Account Manager from LIGHTCARE, Thomas Feldborg.

Night Worker 1.2 is protagonist for turning off the lighting in the night, but Night Worker 1.1 is sometimes having troubles finding what she needs.
Night Worker 1.2 is aware that the field she is working in, makes her more exposed and is not very healthy in the long run, yet she continues to do so. She has an interest in reading about the latest research in newspapers, trade union publications or scientific papers. She is also very structured in her way of planning her schedule before and after she has been working night shifts. Even though Night Worker 1.2 is good at scheduling her time, she frequently takes additional melatonin in pill-form, to sleep when she gets home from work. Generally, she experiences no problems staying awake at night but if she gets tired, she takes a caffeine pill.

Interview with Team 2 (Including Night Worker 2.1): Only Night Worker 2.1 is present for this interview. The other colleague had cancelled due to sickness.

Night Worker 2.1 and her colleague have problems working in the red light at night. She has troubles adapting her eyes to it. Especially when she has to prepare the pills and medication for the patients. Her colleague is visually impaired and they have to adapt the lighting to that. Therefore, she adjusts the night lighting to 25% as opposed to 10%, which is the dim night light. At 25% light intensity, the green colour appears slightly more dominant helping the visual perception says Night Worker 2.1.
When Night Worker 2.1 is nursing the patients, she often turns on the white light opposed to her colleagues. She says that it is often also requested from the patients when they have to use the restroom during the night. The patients ask Night Worker 2.1 to turn on the light, even though the night-light scene is already on.
Night Worker 2.1 has 12 years of experience, working in night-shifts. She explains that she has been working at Albertshøj with the current lighting installation for 1½ year and she does not have headache as she used to from her old job. She is worried about her health, due to prone genetics for breast cancer that lies in the family genes. She is therefore very cautious and goes to routine checks with regular intervals.

6.1.3 Mapping routines and sleep habits:

To gain an insight in the night workers routines and work habits, we asked them to fill out a schedule of their sleep habits. The model will allow us to investigate and compare if and how the workers are preparing themselves before a night shift, in between the night shifts and how they return to their natural circadian rhythm.

Figure 4 shows a 24-hour clock-schedule. The schedule can be used to describe when the night worker is working, sleeping or having leisure time. These routines can be held up against the maximum and minimum amount of sun hours from a Danish seasonal sun-perspective. The maximum of sun hours is found close to Midsummer Day the 23rd of June, whereas the minimum number of possible sun-hours is found on Solstice the 22nd of December. This is important because the sun influences the circadian entrainment and can therefore help synchronize the circadian rhythm. Another factor, which is equally important, is to compare their schedules and routines with the metabolic cyclises. The hormones are visually expressed through the green and purple line showing the normalised values based on a saliva-measured study relative to one another (Figueiro and Rea, 2010). The distribution of the hormone balance can give an indication on how the diurnal circadian rhythm is functioning. The cortisol is predominantly from around 06:00 in the morning and builds up until 08:00. From here it drops slowly until melatonin takes over from around 18:00. The melatonin increases to about 75% at 23:30 and further to 100% until 04:30, before it decreases and cortisol is again predominant. The figure repeats itself and expresses how a normal circadian rhythm is working.

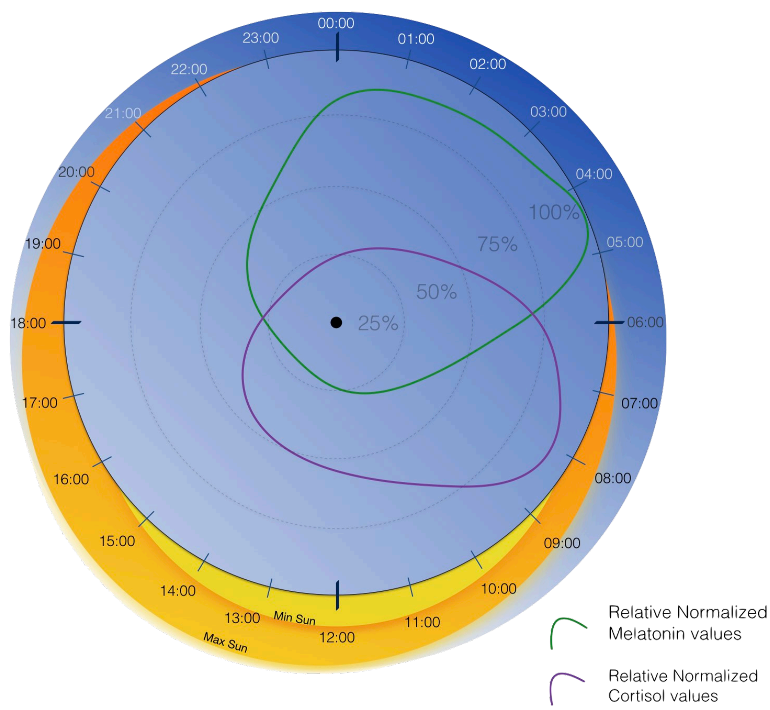


Figure 4 – 24-hour clock with daily normalised hormone levels

Night worker 1

The first night worker explained that the day she will have her first night shift, she wakes up at 08:00 and is enjoying some leisure time before she is trying to get some sleep in the afternoon from around 16:00-17:00. She is awake until she gets to work and is then awake for at least 8 hours until her watch ends 07:15. At this point, she has been awake for approximately 24 hours (Figure 5).

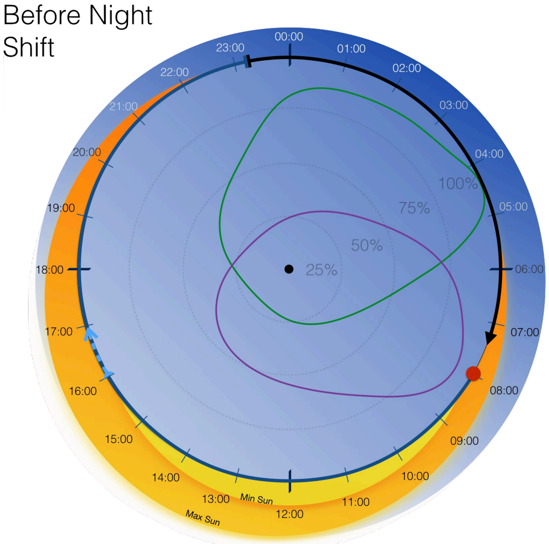


Figure 5 – Overview of night worker 1, before night shifts

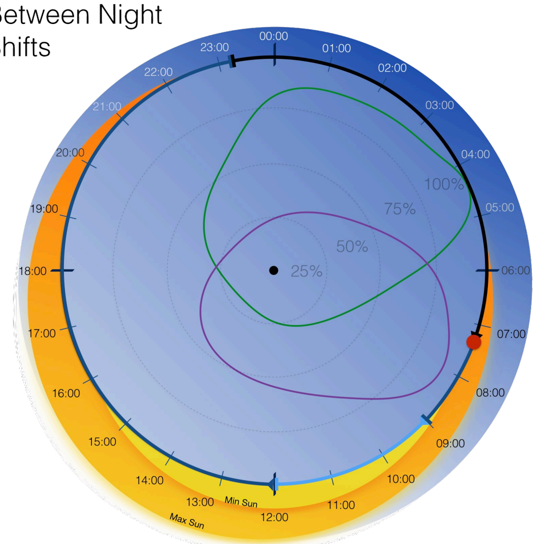


Figure 6 - Overview of night worker 1, between night shifts

In between the shifts, the night worker gets off work in the morning at 07:15. It takes an additional two hours before the night worker is sleeping. She sleeps until 12:00 and is from there-on having leisure time until she goes to work again from 23:15-07:15. At this time she has been up for 19 hours continuously (Figure 6).

When the night worker is getting off at 07:15 she tries to return to bed as fast as possible. Here she sleeps already at 08:00 and until 13:00. When she gets up she has leisure time until she gets to bed again. The first nights she is having troubles sleeping early and does not sleep until approximately 01:30 (Figure 7).

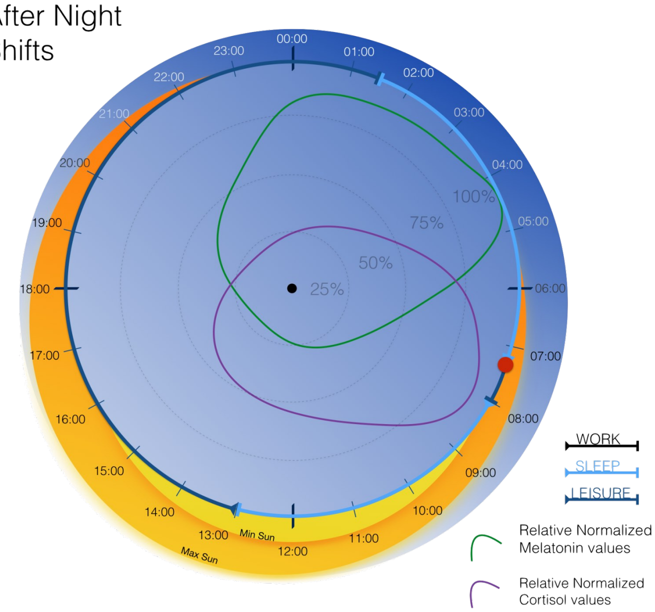


Figure 7 - Overview of night worker 1, after night shifts

Night worker 2

The second night worker from Albertshøj is getting up at approximately 09:30, the morning before getting to work in the evening. She tries to get some sleep from around 20:00-21:30 if possible. This sleep can be abrupt or non-existing. She then gets to work at 23:15-07:15, where she gets off (Figure 8).

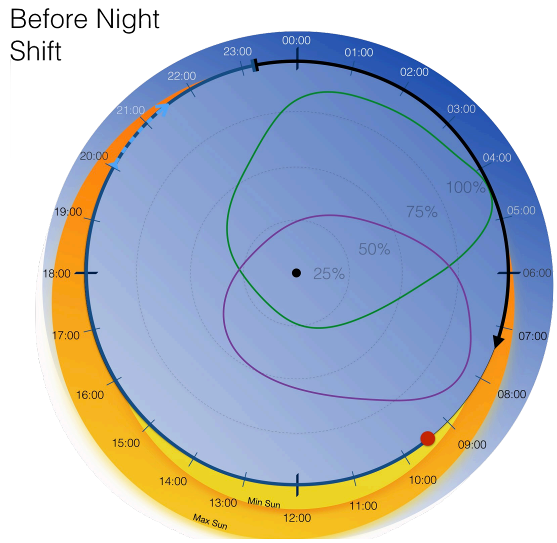


Figure 8 - Overview of night worker 2, before night shifts

It takes her only 45 minutes for her to get to bed and is already sleeping at 08:00.

During the first couple of days of her night shift week, sleep is very abrupt. Therefore, she takes melatonin or sleeping pills if she cannot sleep and sleeps through until 17:00. She is then having leisure time from 17:00 until she gets to work from 23:15 to 07:15 (Figure 9).

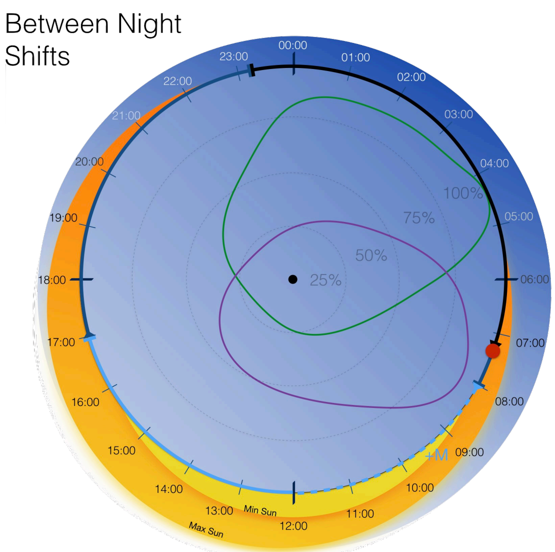


Figure 9 - Overview of night worker 2 between night shifts

When she tries to fall back to her regular diurnal schedule, she has her starting point at 07:15, when she gets off her watch and gets to bed at 08:00. Then she sleeps until 12, where she tries to stay awake until she goes to bed around 23:00. The first two nights are very difficult for her to sleep and she often takes additional melatonin in this transition period (Figure 10).

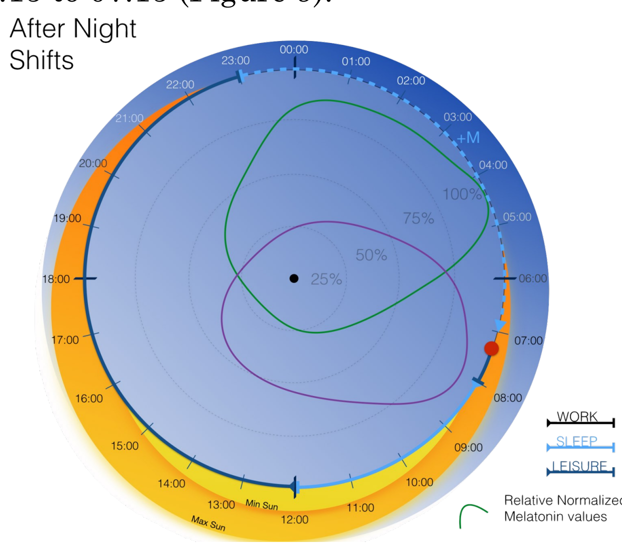


Figure 10 – Overview of night worker 2, after night shifts

Night worker 3

Before Night Shift

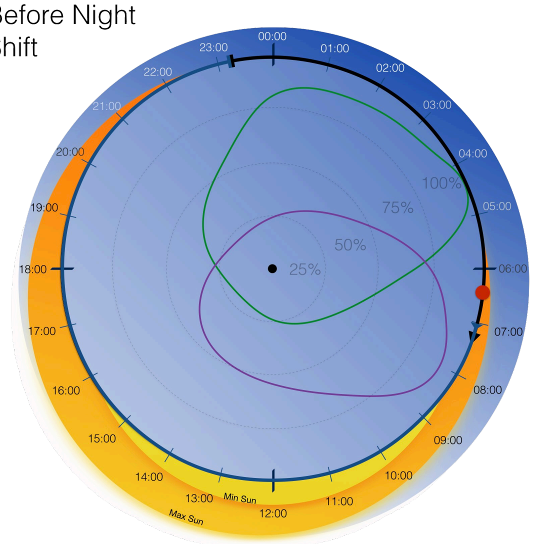


Figure 11 - Overview of night worker 3, before night shifts

The third night worker gets up early at 06:30, the day she starts her night-shift period. This night worker is fully awake throughout the day and during the working period from 23:15-07:15. At this time she has been awake for 26 hours before she gets to bed (Figure 11).

She gets to bed at approximately 08:30 and sleeps until 14:00, where she is having leisure time until early evening. At 19:00-20:00 she tries to get a short rest before going to night work from 23:30-07:15 (Figure 12).

Between Night Shifts

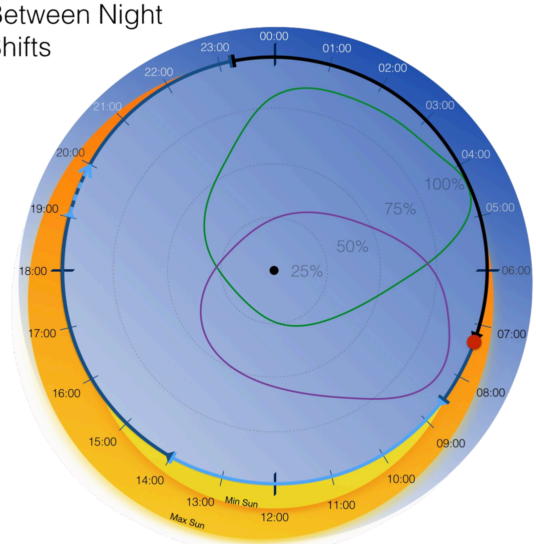


Figure 12 - Overview of night worker 3, between night shifts

After Night Shifts

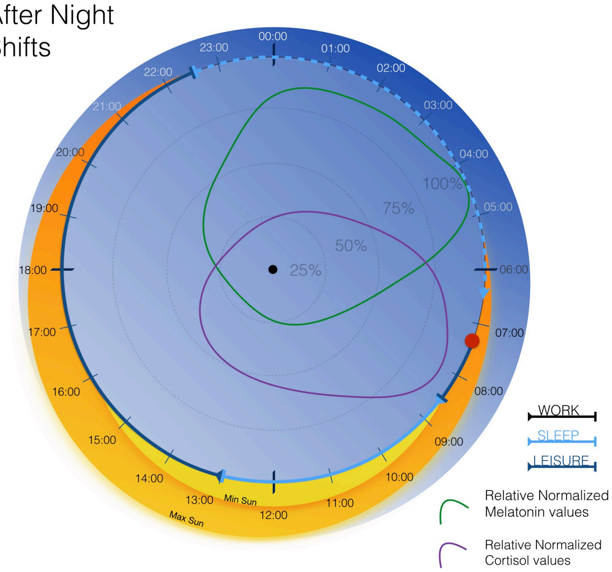


Figure 13 - Overview of night worker 3, after night shifts

The last day of her night work schedule, she gets off work at 07:15 and goes to sleep at 08:30. She sleeps until 13:00 and is then awake until she goes to sleep again approximately 22:30. The night can be abrupt and not very consistent the first night.(Figure 13).

From the previous schemes (Figures 5-13), it seems that the three night workers are having diverse schedules and there is a big difference in the amount of sleep, each night worker is getting. They all express that the first nights are the toughest to get through, which seems clear, inasmuch they are all awake for approximately 24 hours before the first night shift. When they get home from their night shift, they are having a peak of cortisol in their blood due to their natural diurnal circadian rhythm, which indicates that it must be difficult, to get a good quality sleep in the morning hours.
They all seem to have a common structure, by sleeping after their night shifts. This seems contradictory, compared to the lighting design that is installed in the rehabilitation centre. The purpose of the lighting design, is to support the natural circadian cycle, while reducing melatonin-suppression during the night and boost the cortisol hormone in the morning. When the shift workers are sleeping in the morning, their body is not suited for that and they are therefore not sleeping well. To accommodate for that, one of the workers are taking additional melatonin and thereby shifts the circadian rhythm. Furthermore, the schemes reveal that the hours, where the night workers are sleeping, are also the daylight hours of the day, which is important for the circadian entrainment. Therefore, it will be difficult during winter, for the night workers to experience the effect of the sun that can lead to an insufficient entrainment and- or SAD (Rosenthal and Sack, 1985).

6.2 The lighting dilemma to solve

The current lighting installation is designed with the aim for fixed residents, which would imply that both staff and the patients would get benefit from the installation. Currently the installation benefits mostly the staff in the unit. The installation is designed to let the melatonin produce under the best conditions by using red light during the night and boost the cortisol in the morning, using intense blue/cold-white with a colour temperature towards (12000 K). If the night workers are exposed to the blue light in the morning or on the computers during the night, the melatonin is swiftly oppressed from the stimuli resulting in a decrease and shift in the circadian rhythm. It is important that the lighting design supports the natural circadian system and the workers are planning their routines after that. Because the workers are having troubles being situated in the dim red light during the night, it could indicate that the visual comfort is something worth investigating further.

6.3 Final research question

From the background section and case study we have found a discrepancy between state of the art lighting, which is beneficial for the health of night shift workers and their visual comfort. Therefore, because of a conflict between the literature and case, it is relevant for us to investigate the following:

How can lighting, during the night, support shift-workers' circadian cycle by reducing melatonin suppression, while maintaining visual comfort?

7 Design Criteria

This section presents a set of success criteria for the lighting to fulfil the research question. To design and implement a prime lighting design, it is worth to strive against taking the most relevant parameters into account and to find good solutions to solve them. The fundamentals in the human centric lighting concept creates a good frame for setting up these requirements. This allows for taking both the non-image forming and image-forming perceptions into account and describe the criteria to be solved.

7.1 Non-image forming

Circadian system:

1. *Melatonin production should be suppressed minimally during the night.*

Acute System:

2. Support of high degree of alertness to sustain work performance.

7.2 Image forming

Visual performance

3. Personnel should be able to perform visual tasks during their night shift.

Visual experience

4. The lighting should support visual comfort and the perception of space.

For the non-image forming lighting criteria the literature investigation (background) provides a several options for how to solve these issues. However, findings from the Albertshøj case emphasised the problems of comfort and visibility when exposed to these lighting conditions. What is lacking is therefore knowledge about how implementing the lighting conditions needed to fulfil the non-image forming criteria affects the ability to fulfil the image forming lighting criteria. Therefore, we set up an experiment to investigate this relationship further.

8 Laboratory Experiment

The findings from the literature suggests a monochromatic red light to be the least disruptive lighting condition for the circadian rhythm at night, by having low effect on melatonin suppression (Figueiro *et al.*, 2016). For health reasons this light is the most beneficial for night shift workers, who wants to maintain a diurnal circadian rhythm. The use of monochromatic red light is at the same time rather controversial, in terms of the lacking colour rendering, where the surroundings will appear in shades of red or no colour at all (shades of grey). This will affect both visual comfort and work performance.
To investigate the work performance and preferences for the lighting conditions, which affects the circadian rhythm the least, we set up an experiment. We included a selected group of people and different lighting conditions for a simulated work task in an office setting.

8.1 Hypotheses:

Hyp 1: Participants who are informed about health benefits of red lighting will rate this scenario differently than people who have not been given this information.
Hyp 2: Visual comfort and the CS value do not have a linear relationship.
Hyp 3: Visual acuity performance is worse for lighting conditions with a low CS value.

Explanations:
Hyp 1: The case study provided insights that communicating the lighting benefits is of great importance for the evaluation of night shift lighting.
Hyp 2: We want to investigate if it is possible to design lighting, which is both beneficial for the circadian rhythm of night shift workers and visually comfortable at the same time.
Hyp 3: A lower colour rendition will be worse for work performance and therefore scenarios with low CS values will have lower levels of visual acuity since this lighting scenario does not include the full spectrum of light. Therefore, it will be interesting to see how a compromise scenario, will perform in terms of visual performance.

8.2 Method:

8.2.1 Experimental design

The experiment is a hybrid design being both an independent measures design and a repeated measures design. The repeated measures were balanced, meaning that all participants went through all of the conditions.

There were two independent variables: the lighting scenarios (red, 2700 K, compromise) and whether information about health benefits of light was given or not (information, control).

Dependant variables: Visual acuity (performance/time) and subjective ratings.

8.2.2 Participants

The sample for the study included 30 people (17 male and 13 female), who were between 22 and 51 years old with a mean age of 29.7 years (SD=6.8). The study used nonprobability sampling and participants consisted of undergraduate students and staff recruited by availability at Aalborg University Copenhagen campus. 16 out of 30 participants reported to have prior experience working night shifts between 23:00-07:00 hours.

Exclusion criteria:

The experiment dealt with coloured light and therefore normal colour vision was required to participate in the experiment. A colour vision test was performed at the beginning of the experiment, where the participants had to read out the numbers of a two plate Ishihara test (plate 4 and 7) to check for red-green deficiency and total colour blindness (Ishihara, 1972). One participant (ID: 7) failed the colour blindness test and was excluded from the dataset and further analysis.

8.2.3 Lighting scenarios

The lighting scenarios were chosen in relation to how much they supress melatonin. Three lighting scenarios were created for the experiment (SPD: Figure 14, Picture: Figure 15)

Scenario 1 is a *red* scenario consisting of narrowband red light (λp=634, which represents a minimum suppression of melatonin (CS=0.3% at 124 lux at the vertical plane).

Scenario 2 is a *2700 K* scenario consisting of a mix of RGBWA which represents a warm white light with a moderately high suppression of melatonin (CS=13.9% at 128 lux at the vertical plane). The specific composition of light was created with the aim to have good colour rendering (CRI=91, TM-30: Rf=86, Rg=97).

Scenario 3 is a *compromise* scenario consisting of a mix of RGA-UV, which represents warm white light but with an ultra violet (UV) component to compensate for the lack of blue wavelengths resulting in a 47% lower melatonin suppression (CS=7.3% at 129 lux at the vertical plane) with almost half the CS value of Scenario 2, and a decent colour appearance.

Scenario 3 was created with the aim to have the lowest possible CS value while resembling white light maintaining a high degree of visual comfort. The scenario was based on a combination of (1) knowledge from the spectral sensitivity of the circadian system as described by Rea et. Al. 2012 showing that near UV-A light around and below 400 nm and red light above 600 nm have little to no effect on the circadian system (Rea *et al.*, 2012) and (2) a visual assessment of how colours appeared in the light in terms of having a broad range of colour rendering. Since the lack of blue wavelengths caused the chromaticity coordinate to divert too much from the planckian locus, and what is considered white light, CRI could not be used as a measure of colour rendering. Instead the visual assessment was made of how skin and paper was represented in the light.

The UV component had contrary to the theoretical knowledge an effect on the CS value, resulting in a small but unwanted increase in circadian stimulation when UV was added. This increase might have been caused by the fact that the spectral power distribution of the UV led was not entirely constricted to the <400 nm range recommended (λp=400 nm), and bled into the 420 nm range. But the UV component (and a bit of green) provided a critical component in altering the appearance of the otherwise yellowish and reddish lighting condition, which would make the skin look pale and unnatural.

A reference lighting scenario (4000 K) was created to be used between the tested lighting scenarios in order to reduce adaption bias of going from one scenario to another. A 4000 K light was chosen as a reference to appear cooler than all of the scenarios
since previous studies have shown that the anchor point plays a big role when evaluating lighting (Logadóttir *et al.*, 2013).

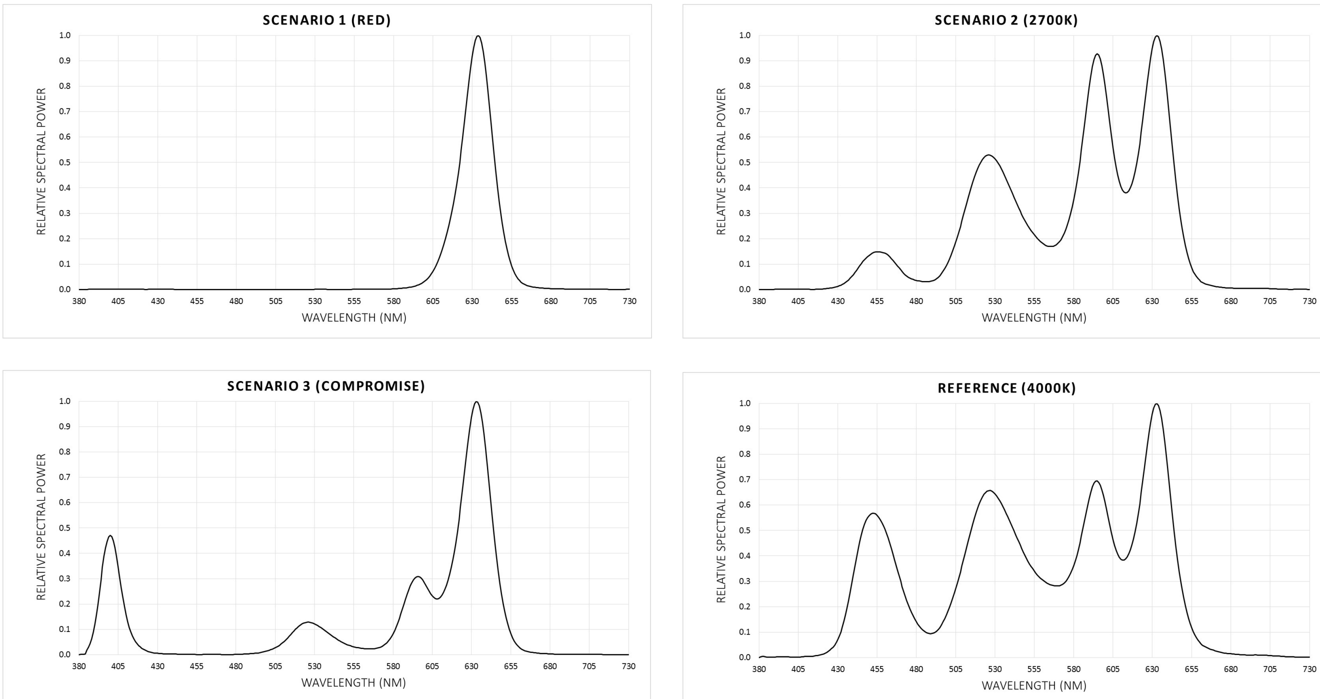


Figure 14 – shows the relative spectral power distributions of the four lighting scenarios.

The three lighting scenarios (and the 4000 K reference) were all calibrated to approximately 500 horizontal lux (mean=504.6, SD= 1.69), measured at the task plane, in order to ensure minimum bias of brightness. Luminance measurements were likewise similar across the lighting scenarios 60-66 cd/m2 (M=63.13, SD=2.60).

8.2.4 Setting and apparatus

The experiment took place in a windowless room at Aalborg University Copenhagen, and a small work station was set up. The setting had no objects in the scene, except for a varnished wooden table, a white A-4 paper (the evaluation sheet), and a black office chair.

The light came from two fixtures, one downlight placed in the ceiling in front of the chair providing indirect illuminance for task light in the form of a directional wall wash. The other fixture was an up-light placed behind the chair, which was used as a fill light to provide additional ambient illuminance in the room and reduce contrast.

Figure 15 – Fish eye lens depiction of the four lighting scenarios

Apparatus

The fixtures used were two Cameo Studio Par 64, which is a LED fixture with 6 channels (RGBWA+UV) and a 25° beam angle, providing up to 5000 lux at 1 meter distance. The fixture was mainly chosen for the UV component, high range colour mixing and powerful intensity. Both fixtures were controlled using DMXIS software by Entec, which granted full control of the different channels of the fixtures.

There was a mobile ventilator on during the experiment which was noisy and one participant reported being distracted by the noise it made.

8.2.5 Procedure

When the participant entered the room the reference (4000 K) lighting scenario illuminated the room (See Table 3 for an overview of the procedure). The participant was then asked to sit down at the desk and was informed about the details of the experiment and to fill out demographic data and the colour blindness test. All participants were asked to: "*Imagine you are working night shift and you will be working in this lighting scenario*" and then half of the participants were allocated by ID number to be briefly informed about beneficial effects of red lighting for night shift workers (even id numbers got info).

Activity	Intro	1 min Adapt	Landolt test	Evaluation	10 secs	1 min Adapt	Landolt test	Evaluation	10 secs	1 min adaption	Landolt test	Evaluation
Lighting	Ref	Condition 1			Ref	Condition 2			Ref	Condition 3		

Table 3 – Procedure timeline by activity and lighting condition

To evaluate the three lighting scenarios the experimenter changed to the first scenario. A five second dimming profile made a smooth transition from one lighting scenario to another, and then the participants waited for a full minute to adapt their eyes to the new environment. Colour appearance studies have shown an immediate chromatic adaption of approximately 80-90% after one minute of exposure if the change is not accompanied by a luminance change (Fotios *et al.*, 2006), which was the case for this experiment. Participants then evaluated the lighting scenario by doing a visual acuity test followed by a subjective rating of the lighting scenarios.

The visual acuity test was a Landolt ring chart, which was used as a simulated work task, where the participants were timed counting a total number of rings with the critical detail (opening) in the left side of the ring. The total time and reported ring count was documented by the experimenter.

The subjective rating was based on observer-based environmental assessment (OBEA) which uses human perception to define the environmental quality (Johansson *et al.*, 2014) and included four 7-point semantic differential ratings: Pleasant-Unpleasant, Dim-Bright, Interesting-Boring, Unnatural-Natural, and two 5-point Likert scales concerning the impression of visual comfort in the space, and the impression of colour appearance in the space, spanning from 'Very satisfied' to 'Very unsatisfied'. The scales were inspired by a lighting preference study by Dikel et al. 2014 (Dikel *et al.*, 2014).

When the participant had successfully evaluated the lighting scenario, the lighting was briefly returned to the reference lighting (4000 K) for five seconds and then changed to the next lighting scenario. The adaption and evaluation was then repeated for each of the lighting scenarios.
The order of how the three lighting scenarios were exposed to the participants was randomised in a non-balanced order (Table 4).
Participants undertook the experiment one at a time and each test lasted between 9 and 15 minutes with a mean of 10.8 minutes (SD=1.4).

Randomisation	
Scenario order	Frequency
1-2-3	7
1-3-2	2
2-1-3	6
2-3-1	6
3-1-2	6
3-2-1	4
Total	**30**

Table 4 – Showing the frequency of scenario orders

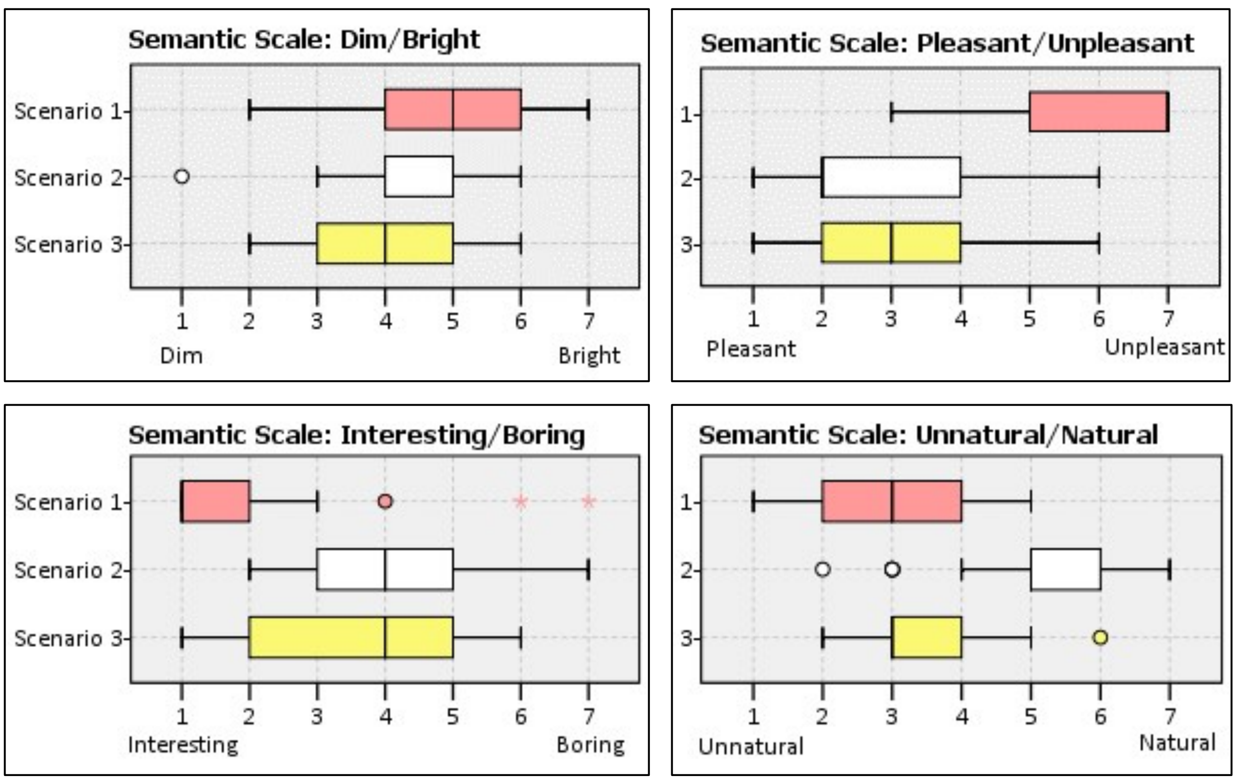


Figure 16 – Boxplots showing min-max, median and upper- and lower quartile for the four different semantic scales: Dim/Bright, Pleasant/Unpleasant, Interesting/Boring, Unnatural/Natural. Outliers (circles and stars) are defined as 3 times the width of the boxes.

8.3 Results:

8.3.1 Repeated measures

The distribution of results for the evaluation of the different lighting conditions is visually represented in boxplots (Figure 16 and Figure 17).

Friedman's Anova test for non-parametric data was used for analysis of the ordinal dependent parameters of the semantic and Likert scales. By using nonparametric tests, we are more likely to make a type II error since these tests are less powerful, than the parametric tests. This means that there is a higher chance of accepting that there is no relationship, even though there actually is one in the population (Field and Hole, 2003). The significance values are adjusted by the Bonferonni correction for multiple tests. A confidence level of 95% was assumed for the statistical analysis.

Friedman's test showed that the semantic 'pleasant/unpleasant' rating was significantly affected by the lighting scenario ($x^2(2)=43.35$, $p=.001$). Follow-up pairwise comparisons showed that there was a significant difference of ranks between Scenario 1 and 3

(Z=5.035, *p*=.001) and 1 and 2 (Z=6.003, *p*=.001) but not between Scenario 2 and 3 (Z=-.968, *p*=.999).

The semantic ‘dim/bright’ rating was not significantly affected by lighting scenario, $x^2(2)=3.98$, p=.137. The semantic ‘Interesting/Boring’ rating was significantly affected by the lighting scenario $x^2(2)=29.85$, p=.001. Follow-up pairwise comparisons showed that there was a significant difference of ranks between Scenario 1 and 3 (Z=-4.196, *p*=.001) and 1 and 2 (Z=4.906, *p*=.001) but not between Scenario 2 and 3 (Z=-.968, *p*=1.00). The semantic ‘Natural/Unnatural’ rating was significantly affected by the lighting scenario $x^2(2)=25.70$, p=.001. Follow-up pairwise comparisons showed that there was a significant difference of ranks between Scenario 2 and 3 (Z=4.002, *p*=.001) and 1 and 2 (Z=4.131, *p*=.001) but not between Scenario 1 and 3 (Z=-.129, *p*=1.00).

Semantic scale descriptive statistics

Scenario - Variable	N	Minimum	Maximum	Mean	Std. Deviation
1. Pleasant/Unpleasant	30	3	7	6.03	1.245
2. Pleasant/Unpleasant	30	1	6	2.63	1.474
3. Pleasant/Unpleasant	30	1	6	3.13	1.432
1. Interesting/Boring	30	1	7	1.80	1.495
2. Interesting/Boring	30	2	7	4.27	1.363
3. Interesting/Boring	30	1	6	3.80	1.584
1. Dim/Bright	30	2	7	4.80	1.495
2. Dim/Bright	30	1	6	4.50	1.253
3. Dim/Bright	30	2	6	4.10	1.269
1. Unnatural/Natural	30	1	5	3.13	1.008
2. Unnatural/Natural	30	2	7	5.03	1.217
3. Unnatural/Natural	30	2	6	3.33	1.028

Table 5 – Semantic scale descriptive statistics for each of the lighting scenarios.

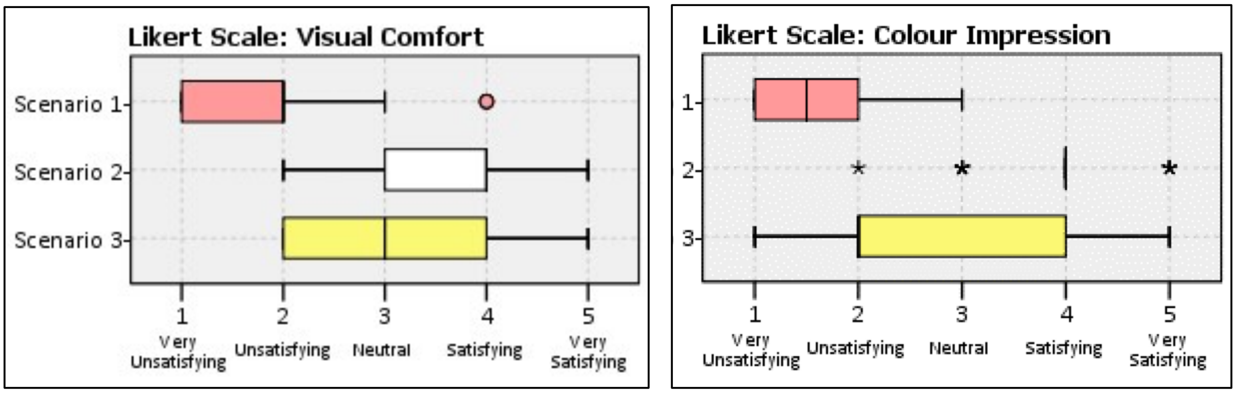


Figure 17 - Boxplots showing min-max, median and upper- and lower quartile for the two different likert scales: Visual comfort and Colour impression. Outliers (circles and stars) are defined as 3 times the width of the boxes.

The Likert scale 'Visual Comfort' was significantly affected by the lighting scenario ($x^2(2)=32.85$, *p=.001)*. Follow-up pairwise comparisons showed that there was a significant difference of ranks between Scenario 1 and 3 (Z=-3.744, *p*=.001) and 1 and 2 (Z=-5.164, *p*=.001) but not between Scenario 2 and 3 (Z=1.420, *p*=.467). The means for visual comfort were higher for Scenario 2 (M=3.60) and Scenario 3 (M=3.13) than Scenario 1 (M=1.80) (Table 7). Figure 18 shows the relationship between the Likert scale: Visual Comfort, and the lighting scenarios in terms of how much it supresses melatonin production. The curve shows that visual comfort is considered higher, when the CS value of the scenario increases, but that there is only a small difference in visual comfort between Scenario 2 and 3 even though the CS value is almost cut in half (13.9 and 7.3 respectively).

The Likert scale 'Colour appearance' was significantly affected by the lighting scenario ($x^2(2)=40.75$, *p=.001)*. Follow-up pairwise comparisons showed that there was a significant

Likert scale: Descriptive Statistics

Scenario - Variable	N	Minimum (1=Very unsatisfying)	Maximum (5=Very satisfying)	Mean	Std. Deviation
1. Visual comfort	30	1	4	1,80	0,961
2. Visual comfort	30	2	5	3,60	0,814
3. Visual comfort	30	2	5	3,13	0,973
1. Colour appearance	30	1	3	1,57	0,626
2. Colour appearance	30	2	5	3,87	0,681
3. Colour appearance	30	1	5	2,70	1,055

Table 6 – Likert scale descriptive statistics for each of the lighting scenarios.

difference of ranks between all scenarios: 1 and 3 (Z=-3.421, *p*=.002), 1 and 2 (Z=-6.068, *p*=.001), and 2 and 3 (Z=2.647, *p*=.024).

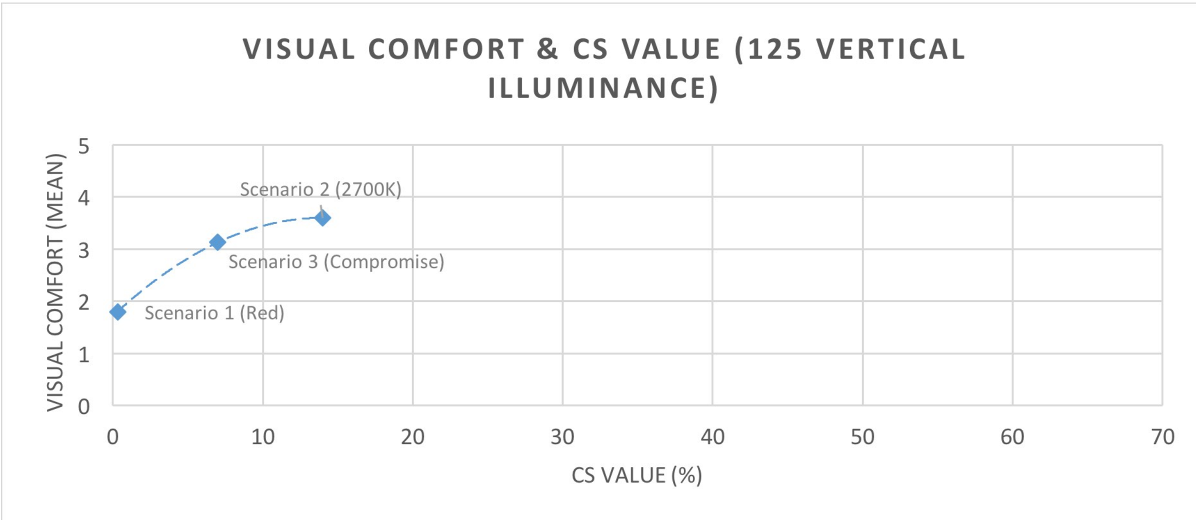


Figure 18 – Graph showing the relationship between the Likert scale: Visual comfort, and the lighting scenario based on how much it suppresses melatonin (CS value)

Figure 19 shows a histogram of the distribution of errors for the visual acuity test. The graph shows that the amount of errors in counting were similar across all three lighting scenarios with only small differences between 2 and 3 errors, where Scenario 2 (2700 K) performed better. A repeated measures Anova, with Greenhouse-Gisser correction (sphericity not assumed), supported this by showing no significant difference between lighting scenarios for the amount of errors made in the visual performance test (F(.851), p=.422) (Appendix 14.4-A3). Counting time was also similar across the scenarios (M=30.7-32.0 secs) but has not been included in

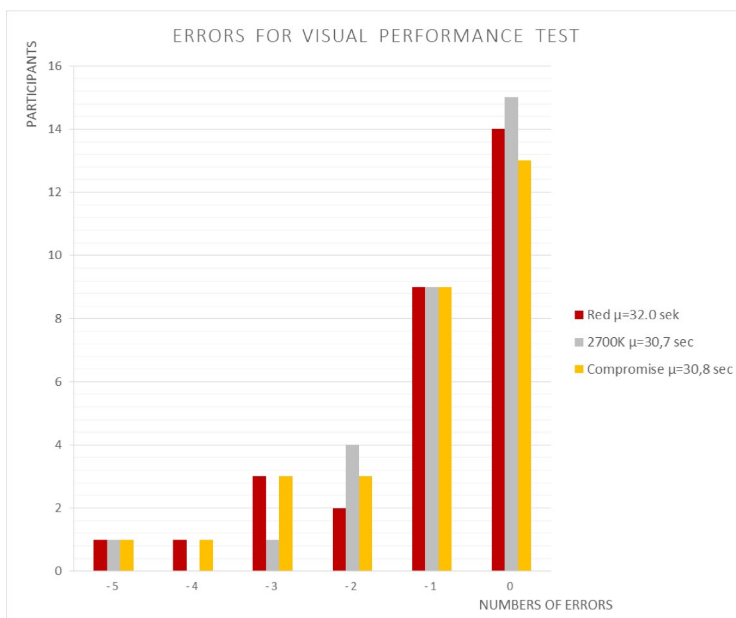


Figure 19 – Histogram graph showing a frequency of participants based on how many errors they made in the in the Landolt test

the statistical tests due to weak methodological reliability of measuring of time taken during the experiment.

8.3.2 Independent measures

An independent samples-test Mann Whitney, was used to account for differences among the groups of the experiment with only two levels (Information, Gender & Night shift experience). The test showed no significant differences between the group of participants who were given information about the health benefits of the light (n=15), and the participants who were given no information (n=15) for the semantic and Likert scale variables (Appendix 14.4-A0). There was no significant difference between men (n=17) and women (n=13) for any of the dependent variables except for the semantic pleasant scale for Scenario 2 (p=.17) and the Unnatural/Natural scale for Scenario 3 (p=.01) (Appendix 14.4-A1) Between the groups who had previous experience working night shifts (n=16) and the ones with no previous experience (N=14) there was a difference between the pleasant/unpleasant semantic scale for Scenario 1 (p=.019), the impression of visual comfort in the space for Scenario 2 (p=.017), and the time counting for Scenario 1 (p=.038), Scenario 2 (p=.019) and Scenario 3 (p=.012) (Appendix 14.4-A2).
The Kruskal-Wallis test was used to investigate differences between the 6 different randomisations and found that there was only a significant difference between the randomisations for the evaluation of dim/brightness of Scenario 3 (p=.041) (Appendix 14.4-A3).

8.4 Experiment discussion

The statistical analysis showed that there was only a significant difference between the different randomisations (orders) for the dim/brightness scale of Scenario 3, meaning that the order of how the scenarios were presented to the participants, did not play a big role in the evaluation of the scenarios.
However, some participants reported that the particular ordering had influence on their answers, with some reporting that they were forced to put the same answer for two different scenarios. Even though they found them to be a lot different, due to limited choices in the Likert/semantic scales and there was no reference of comparison between the sce-

narios before the evaluation. The order of how the scenarios were presented was randomised for each participant, however not all randomisations were equally frequent (Table 4). Order effect might be increasingly an issue since the adoption time was rather low and the difference in chromaticity was rather high. For the visual performance test, some participants verbally reported that they found new strategies for completing the test, e.g. counting vertically instead of horizontally.

The statistical analysis showed no significant difference between the two groups (Information, Control) for any of the variables (Appendix 14.4-A0). This means that hypothesis 1 (information resulting in higher evaluation for Scenario 1) was rejected for this experiment. Because there were no differences between the groups they were treated as one group for the remainder of the data analysis.

However, by including the independent variable of giving half of the participant's information about the benefits of red light for night shift workers, we might have partly revealed the aim of the experiment. Doing so can be a risk for the validity of an experiment since the participant's evaluations can be influenced by demand characteristics, where participants e.g. try do comply with what they think the experimenters wants them to do.

The experiment showed no significant difference between the three different lighting scenarios for the visual performance test ($F=.851$, $p=.422$) meaning that the visual performance investigated in this experiment is not influenced by the spectral composition of the different lighting scenarios. Explanations might be that the critical detail (ring opening) of the test was too big to be of relevance in the lighting conditions in the experiment, and the disparity in errors might have been caused by internal reliability. Yet the experiment reject hypothesis 3 concluding that the visual performance tested is the same for all scenarios. For practical use this means that the chromaticity tested does not influence immediate number of errors and time spent for a short visual task with moderately sized critical detail. The test does, however not account for visual tasks with smaller critical details, e.g. reading the small text on the back of a medicine container.

The data analysis showed that scenario 2 (2700 K) and 3 (compromise) were similar for the Pleasant/Unpleasant scale, Interesting/Boring scale, and the visual comfort scale, where they were evaluated as more pleasant, less interesting and more visually comfortable than Scenario 1 (red), which was considered as having both unsatisfying visual comfort and being unpleasant. Both scenario 1 and 3 were considered unnatural. For colour impression, all the scenarios differed, where the colour impression of Scenario 1 was considered unsatisfying, Scenario 2 was considered satisfying and Scenario 3 was considered neutral. This is the expected finding and reflects the span of wavelengths of the lighting scenarios. However, the results of colour impression are limited by the evaluation setting, not having a lot of objects in the space, which could be used as a reference for evaluation. The setting only included table, chair, paper and the participants because it was difficult to choose what colour the objects should have, in order to avoid bias towards one scenario over the others since the scenarios were very different. Some participants did use their own skin and clothes as a reference for colour impression, and including e.g. a colour chart in the setting would have improved the validity of the colour impression evaluation.

Comparing the evaluation of visual comfort to the amount of circadian stimulation of the 3 scenarios (Figure 18) shows the relationship between CS value and visual comfort, where a lower circadian stimulation results in a lower evaluation of the lighting condition. But this relationship is not necessarily linear, since both scenario 2 and 3 have a similar and moderately high visual comfort, even though scenario 2 have approximately double the CS value (CS=13.9%) of scenario 3 (CS=7.3%). This confirms hypothesis 2 that the relationship between CS value and visual comfort is not a linear relationship, which means that it is possible, to a certain degree, to design lighting, which is both beneficial for the circadian system (by having low circadian stimulation) while at the same time being visually comfortable. One way of designing such light is by the use of UV wavelengths as a substitute for blue wavelengths. Using UV lighting has certain trade-offs such as being considered unnatural similarly to monochromatic red light, but makes up for it in pleasantness and visual comfort, which makes this lighting worth pursuing further for night shift workers.

9 Design Parameters

In this section, we try to synthesise the knowledge gained from the investigation of the project in order to provide insights about the design criteria, which should be considered when designing lighting for night shift workers, and how they can be fulfilled in terms of lighting parameters. Designing lighting for night shift workers, with the assumption of minimal impact on the circadian clock, opens up for a whole new category of lighting design criteria: non-visual effect of lighting (e.g. health and performance) opposed to the conventional visual effects of lighting (e.g. function and comfort). Meanwhile the parameters used to fulfil the nonvisual criteria can have great impact on the capacity to fulfil the visual criteria. This section will primarily focus on the new category of lighting criteria and how it affects the established lighting criteria, with the aim to afford informed decision making, when designing for night shift workers.

For the night shift worker, the non-visual design criteria will always be second priority firstly due to the fact that the shift worker needs lighting to be able to perform their job, and secondly, because the perfect healthy lighting condition would be complete absence of light at night. Including non-visual effects in the design of lighting will therefore, for night shift work, always rely on compromises.
The needs for functional lighting is highly dependent on the task, which is being performed by the shift worker and therefore the first step should be to analyse the specific site one is designing for. This will in terms decide what type of non-visual designs can be employed, e.g. in terms of colour rendering and what can be practically implemented.

Red and amber light is the least disrupting light for the night shift worker and both have very low CS values due to consisting of narrowband wavelengths at nanometres, which lie outside the spectral sensitivity of the circadian system. However, these lighting conditions are limited in terms of colour rendering, general acceptance and visual comfort as shown by the experiment conducted. This lighting condition therefore only fulfil the requirement of minimal suppression of melatonin, and not the requirement of being comfortable as a lighting condition which is why this lighting condition is only recommended, where the health aspects is of very high priority.

Another approach is creating a compromise scenario which has both a moderately low circadian stimulation while at the same time being comfortable for the users of the space. The experiment showed that it is possible to have such lighting which is evaluated well relatively to how little it supresses melatonin production, solely when it comes to the spectral composition of the light.

Dynamic light is considered healthy in its way to replicate the natural daylight. Currently (See State of the art section 5.0), the dynamic aspects of the light are for many cases reduced to a change in colour temperature and intensity throughout the day. However, daylight has other qualities which can be beneficial for night shift workers both in terms of visual experience and the response of the circadian system.

9.1 Spectral composition of the light

We know from the CS metric-calculations that Scenario 1 has the least circadian stimulation with being only 0.3%, followed by Scenario 3 with 7.3% and then Scenario 2 with 13.9%. This means that the *Circadian System,* is the least disrupted. Regarding the *Acute System*, studies have shown that red light has some effect on the alertness during the night, though warm white light is even more effective (See Background section 4.3). This means that the Scenario 2 is better at providing alertness to the night workers than Scenario 1. It is currently known that blue wavelengths are the most beneficial for the acute system, and since there are none of these in the scenario we cannot say. However, the UV light might provide increase in alertness but is currently unknown.
The visual part of the design criteria is evaluated based on both the laboratory test and the interview with the night workers. The laboratory test found no statistical significant differences in *Visual Performance* in relation to Scenario 1-3. Though we got the impression the night workers at Albertshøj found it difficult to work in a red light similar to Scenario 1. Scenario 3 has not been implemented and tested on night workers and we can only rely on the performance results in the Landolt ring-chart test. The *Visual Experience* was accordingly to the laboratory test, significantly similar in both Scenario 2 and 3, whereas Scenario 1 was experienced much worse. An evaluation of the compared scenarios, compared to the effect on the design criteria can be seen on table 8.

Design Criteria	Non-Visual		Visual	
	Circadian System	Acute System	Visual Performance	Visual Experience
Scenario 1 “Red”	High	Medium	Low	Low
Scenario 2 “2700 K”	Low	High	High	High
Scenario 3 “Compromise”	Medium	N/A	High	High

Table 7 - Design Criteria and Scenario comparison

9.1.1 Validation with CS metric

The CS metric has been useful in the project to help choose the specifications needed for a fixture and creating the optimal scenario and provided powerful in evaluating the scenarios in terms of impact on the circadian system.

As the Table 8 from the previous section (9.1) visualises, there is a trade-off between good visual comfort and a low circadian stimulus. This is obvious, as a good circadian stimulus requires the absence of blue light and the light composition represent the full spectrum. The CS-value has enabled us to evaluate a compromise scenario, which can work as a trade-off, where the CS-value is relatively good, while still achieving a good visual comfort, as validated in the experiment.

9.1.2 UV and its capabilities

A quality of daylight is that it contains radiance within the non-visual part of the electromagnetic spectrum, more specifically short wavelength ultra violet light and long wavelength infrared lighting. The ultra violet part of the spectrum has certain properties which influence health, both negatively (e.g. risk of skin cancer) and positively (e.g. D-vitamin production). Uncertainties for the health aspects have resulted in UV not being used for conventional lighting fixtures, and mainly as black-light for event lighting for its fluorescent effects (Scenihr, 2012).

In the experiment, near UV-A light (380-420 nm) was used in the compromise scenario (Scenario 3) to avoid using the spectrum from 400-600 nm. UV-A light in the visual spectrum (380-400 nm) has limited effectiveness for erythema and skin cancers (Boyce, 2014), and due to the limited intensities when dealing with night time lighting, the risk of detrimental health effects of including a small amount of UV-A light in interior lighting is considered low.
Instead the focus of using UV light for night shift workers was to reduce the lights impact on the circadian system and including this unconventional part of the spectrum resulted in a good subjective evaluation of pleasantness and comfort, which was nearly on par with the 2700 K lighting scenario (Scenario 2). The main difference was that the compromise scenario was considered more unnatural than the 2700 K lighting scenario. The use of UV-A can therefore be a key component in creating a lighting scenario for night shift workers which has both a low impact on the circadian rhythm and a high visual comfort.

9.2 Intensity

Intensity has an impact on the circadian system depending on the spectral composition of the lighting: Conferring with the CS metric, red lighting has almost no stimulation across a wide range of intensities meaning that you can have a lot of light when dealing with this spectral composition. When using 'white light', intensity plays a big role for the outcome of the CS value and intensity should therefore be kept low to minimise circadian stimulation, which can result in a lighting condition with low light levels, which might affect the *Visual experience* and *Visual performance* negatively. When designing with a compromise scenario the light has a moderately low impact on the *Circadian system*, the benefit being that it is possible to design spaces with a higher general brightness than using white light, which can ensure visual performance of being able to perform work related tasks.
The lighting standard (EN-12464) does not include the aspect of non-image forming effects of the light and thereby does not differentiate between daytime and night-time lighting. This means a relatively high light intensity is suggested during night time.

However, we were informed by one of the shift workers from Albertshøj (and other undocumented sources from the health sector) that the night shift workers dimmed down the lights or even switched them off completely at night time. The argument was that they did not need the additional light, especially when they were working on the computer since it supplied sufficient light on its own. When working on self-illuminating devices such a computer monitors, additional luminance in the space reduces the visibility of the screens (Boyce, 2014), and since more and more work is done using this technology less light is needed for *visual performance* in the workspace.

This both accounts to the fact that the current lighting standards should not be adhered to when designing for night shift workers both in terms of how it negatively affects the *circadian system*, and how much light is needed for *visual performance*.

9.3 Light Distribution

9.3.1 Height

Sunlight has additional dynamic qualities, one being changing direction and height of the light throughout the day, which affects the way we perceive objects. One example is that we can estimate the time of day just by looking at shadows (Descottes and Ramos, 2013). One way of including this quality is by altering the height of the lighting throughout the day, so that the light comes from above at daytime where spatial elements in the top of the visual field is illuminated (e.g. ceiling and upper wall) but is lowered in the evening, through night time, where mainly the spatial elements in the bottom of the visual field is illuminated (e.g. floor, table, lower wall). Including the quality of dynamic directionality in the electrical lighting solutions would be beneficial for both the *circadian system* and the *visual experience*.

It would optimise the impact on the *circadian system* at both daytime and night time since the eye is more sensible to light coming from above than below the visual field (Glickman *et al.*, 2003). Drawing from principles of lighting design the dynamic movement would also be beneficial for the *visual experience* because it stimulates a sense of time and lowering the height of the light can create a sense of intimacy (Descottes and Ramos, 2013). A study of workspace illuminance showed that people prefer different light settings at different times throughout the day in terms of illuminance (Newsham *et al.*, 2008), meaning that there is expectations to how the space should appear throughout the day.

However, *visual performance* should be considered if altering the position of the light sources since disability and discomfort glare is more prone to occur, when the light source is positioned at a lower angle from our visual field (Boyce, 2014) and appropriate shielding and luminance uniformity should be enforced.

Implementing dynamic directionality requires new ways of lighting up the work space, which is currently dominated by 60x60 cm ceiling mounted luminaires where it is difficult to change the height and direction of the light throughout the day.

A lot has happened within the field of LED optics in the past few years and an option to implement this effect could be to change the optics of wall washers throughout the day and thereby change the focus of the light to be predominantly on the bottom of the space at night time (see example Appendix 14.5).

9.3.2 Direct/indirect

At day- and night time vertical objects and architectural features are illuminated even if they are not within the immediate task area. Night time lighting should have similar features as daytime or evening lighting, when it comes to how light is distributed in the space. Emphasis should be put on surrounding areas of the work space since surroundings determines the general perception of the space, and whether it is found gloomy or cosy (Descottes and Ramos, 2013). The solution of focusing illumination (intensity or spectral composition) more on the surroundings than the immediate task area, to improve psychological wellbeing, corresponds well with the criterion of minimising circadian stimulation. Since the design strategy increases the distance from the shift worker to the light thereby reducing personal light exposure. One such lighting strategy would be to design lighting with a mean exitance strategy (Boyce and Smet, 2014), where focus is on illuminating vertical elements in the space instead of the mean illuminance strategy, where the focus is on illuminating, which is most often being used to fulfil the effective lighting standards.

9.3.3 Intelligent control

A note on energy consumption: The scope of this project has not been to reduce the energy consumption of lighting for night shift workers.

On the other hand, we were informed in the Albertshøj case study that both the shift workers and patients were displeased by how the lighting installation autonomously attempted to reduce energy consumption by dimming down unoccupied zones. This seems like an intelligent solution, which harmlessly reduces energy consumption at night, but due to a zone control with too many and too small zones, the shift workers described situations, where they were sitting in one end of a common room and the other end of the room would be dimmed down, prompting the employee to go to the specific area to activate the sensors.

This example testifies to the importance of designing for the spatial expression of the space making sure that efforts to reduce energy does not have a negative impact on how people perceive their spaces.

9.4 Timing

9.4.1 Proposed schedule for routines and habits

From the interviews, (described in section 6.1) we have identified, how the night shift workers are sleeping after their night shifts, which is not very optimal, when taking their current hormonal state into account. To accommodate this problem, an attempt has been made to optimise the workers' schedule, to synchronise their biological needs to the rhythms of the sun. Getting sufficient light exposure during the day is especially important for night shift workers as it can reduce their melanopic sensitivity to light exposure at night (Hébert *et al.*, 2002).

Practically it would be beneficial for the night shift workers to get some sleep during the evening before they are going on a night shift. As seen on Figure 20 (Into Night Schedule), the sleeping hours are planned for the worker to sleep at 15:00 and as late as possible before the night shift starts. This can probably, be the most difficult part of the routine, because at that time, the worker would be rested and refreshed. Though it would be very important to get some rest before the night shift. A physical training session could be used, to tiring the body before getting to rest again and sleep better.

When the first night shift has passed, it would be beneficial for the worker to stay awake and get the most out of the day and the possible sun-hours.

By following these recommendations, it would be easier for the worker to follow the natural circadian rhythm, and not shift it by going to sleep after the night shift. This imply that the lighting during their night shift is not disturbing their circadian rhythm and they will therefore get a cortisol boost in the morning, allowing the body to be feel fresh. As shown on Figure 21, it is important for the night worker to get a quality sleep and therefore it is necessary that they can sleep at around 15:00 to get around 7 hours of sleep. By sleeping at 15:00 their cortisol level is lower than if they had to sleep in the morning as they currently do. It is crucial for the

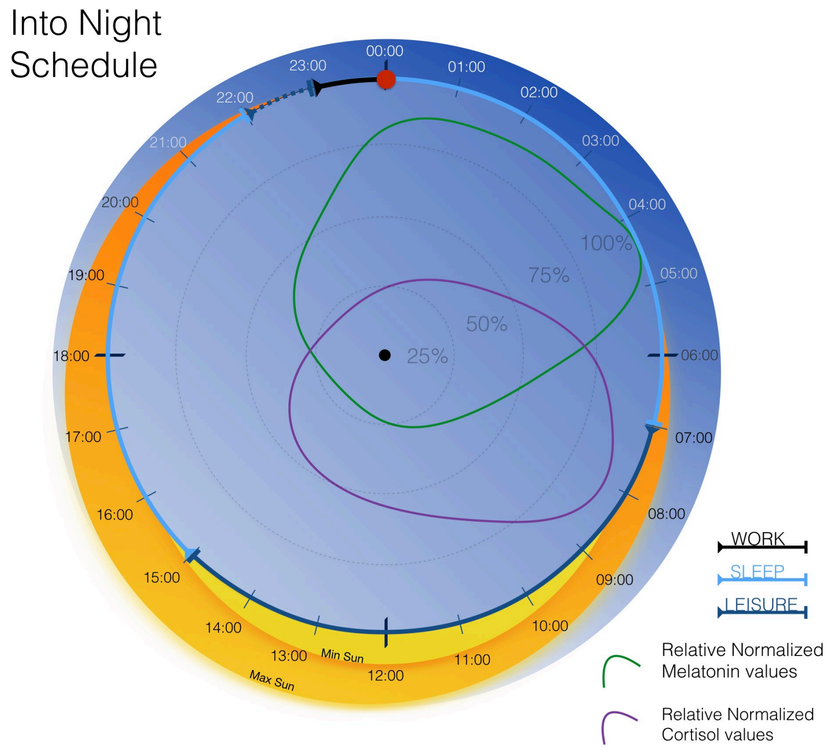


Figure 20 - Proposed schedule going into a night shift

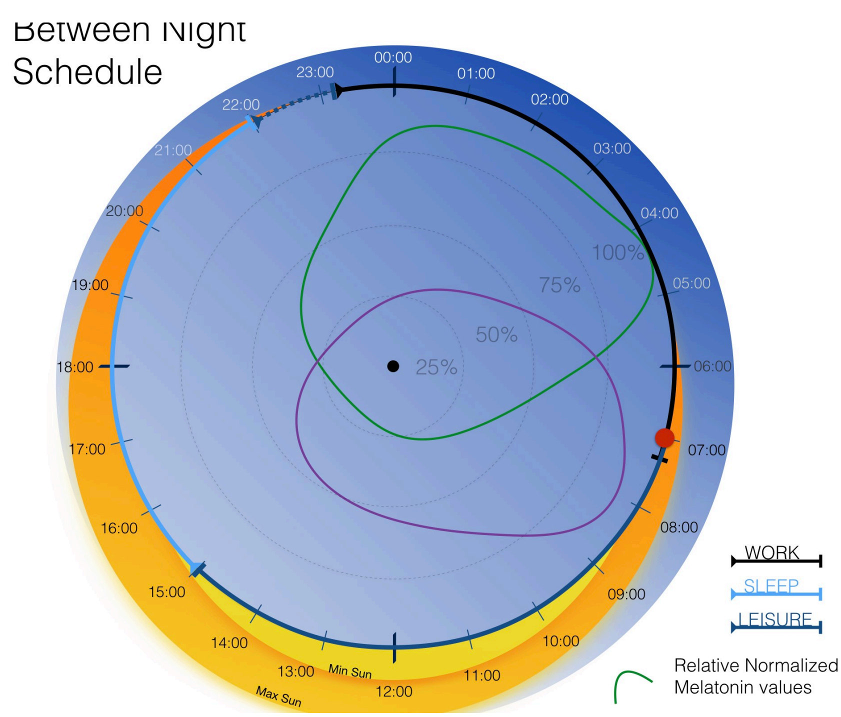


Figure 21 – Proposed schedule between night shifts

workers to be able to work again at 23:15.

When the night workers are stepping out of the night shift phase again, they will have to stay awake as long as possible, even though they are tired. They should go to sleep at their regular diurnal bedtime as visualised in Figure 22.

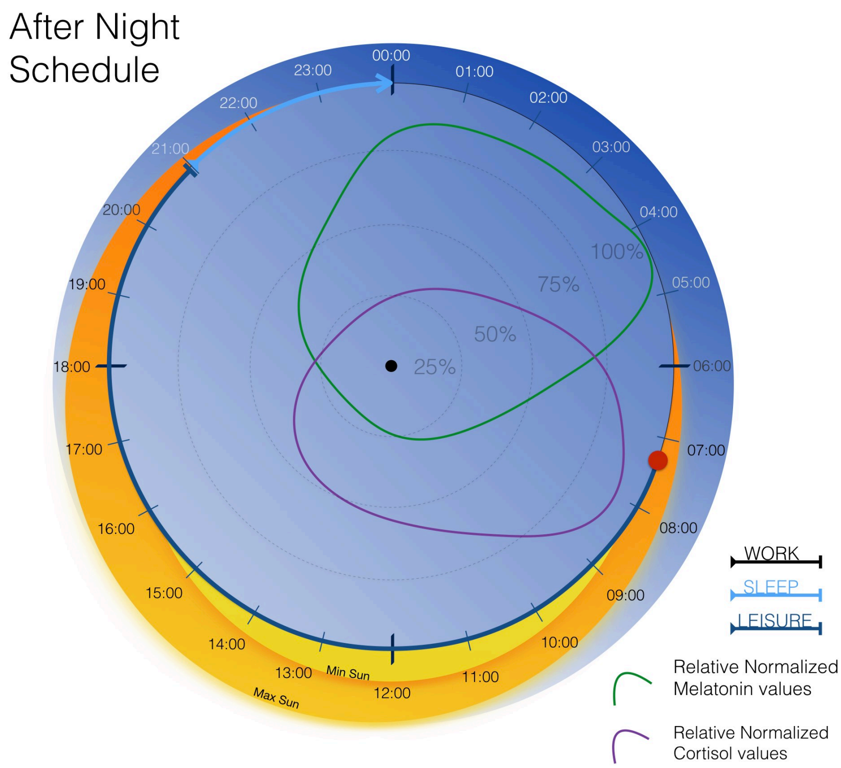


Figure 22 - Proposed schedule after the last night shift

This schedule proposal is based solely upon the hormone distribution and with a reference to the sun-hours that are available during the day. Since the recommendations from NRCWE are to disrupt the circadian rhythm the least possible, the proposed schedule complies with that statement.

While this proposed schedule is desirable, there is also a social aspect to consider. The night workers might have children and- or a partner. It can be difficult for the night worker to socially interact with these people if they ought to sleep, when they return from job or school. Even though this suggestion proposes a more optimal schedule, there can be contradictories with the regular schedules and surroundings that society is built upon.

9.4.2 *Additional Lighting Schedules*

The night shift workers are ought to be kept in a diurnal schedule, with focus to maintain their biological rhythms. Therefore, it is desirable to try and keep the melatonin production intact and high as possible at the regular diurnal time. This imply that the night shift workers must attempt to avoid strong non-circadian lighting from when the melatonin production starts, which happens already from around 18:00 (as seen on the Figures 20-22). Already at this time the night and evening scenario should start and evolve until sunset, where the night light should end. From here, the night light should function as the main light and be fully activated until sunrise. Alternatively, the light can be turned off fully in this period as well. From around sunrise, it is desirable to lower the melatonin and boost the cortisol levels with natural sunlight or by supportive additional electrical light, including full spectrum in high intensity. This will increase the production of cortisol and give the night shift workers a good foundation to go home and feel fresh before going to bed, when most of the cortisol is gone in the afternoon.

9.5 Additional design aspects

9.5.1 *RGB and TW Comparison*

To help in the decision of choosing the best type of fixtures for designing light for night shift work, we have taken measurements of the different scenarios on an RGB vs a Tunable White (TW) fixture. Figure 23 shows the different measurements of the scenarios and its relation between illuminance and the impact on the CS-value. The measurements have been executed with increasing intensity from 10-1000 lux. The Scenarios *Therapy Boost*, *Night Light* and *Red Light* is based on the Basic A1 fixture that is also used at Albertshøj rehabilitation center. Scenario *TW3000 K* and *TW6000 K* is based on the Zumtobel Ondaria TW-Fixture and represents measurements at CCT 3000 K and 6000 K.

It is clear that the monochromatic *Red Light* has the least effect on the CS-value almost independently on the illuminance. The *Night Light* is the scenario used currently at Albertshøj Rehabilitation center compared to the Compromise Scenario used in the laboratory experiment (section 8.2) shows similar results but the *Night Light* scenario has a slightly higher impact on the CS-value. Both *TW3000 K* and *TW6000 K* TW fixtures have higher CS-values compared to the Night Light and Compromise scenario in the high illuminance spectrum. The *Therapy Boost* is a 20.000 Kelvin scenario, used in the morning, to boost the circadian rhythm, used at the Albertshøj rehabilitation centre. (Appendix 14.5) shows the SPD of the five scenarios).

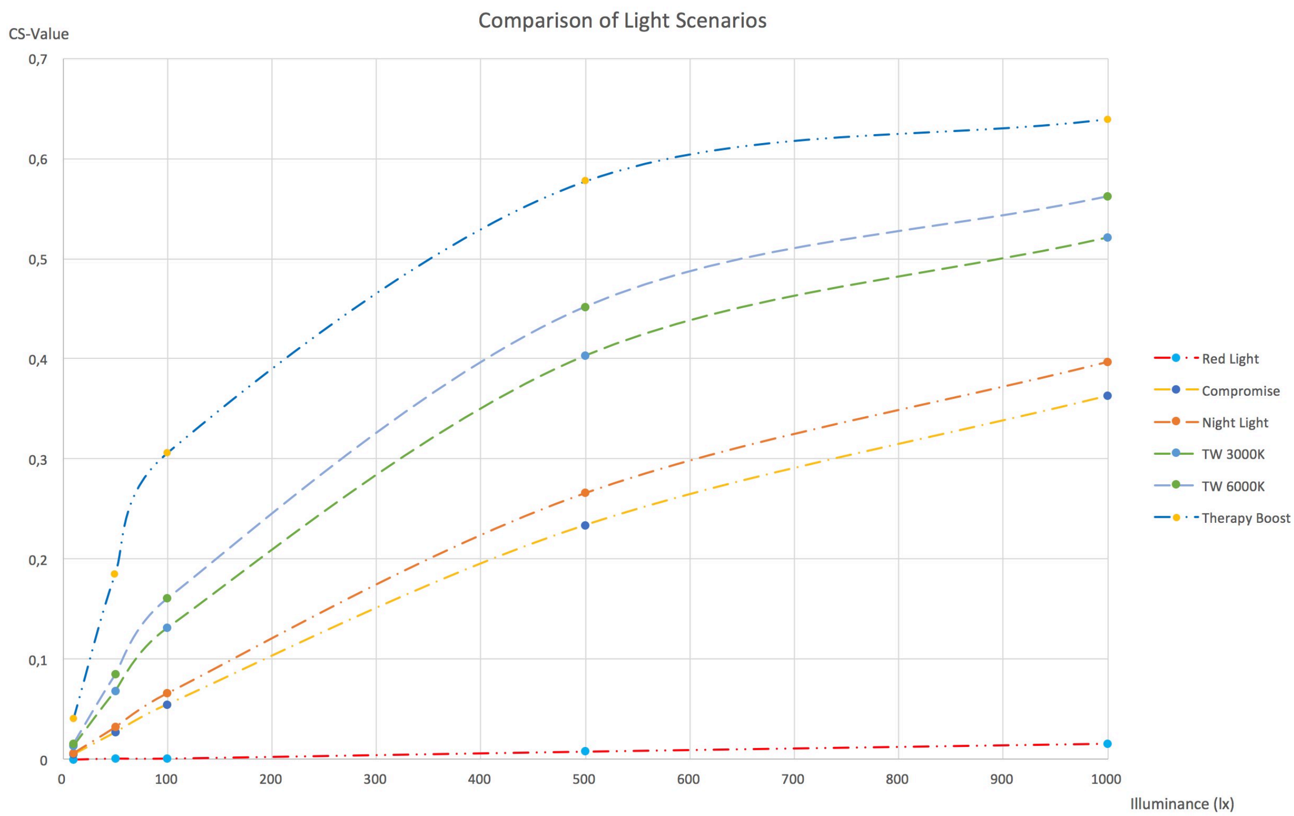


Figure 23 - Shows the CS value of 6 different SPD's (scenarios) by illuminance calculated for 5 different lux levels

The CS calculation measurements of a Tunable White (3000 K-6000 K) fixture against the multichannel (RGB) fixture showed that the RGB fixture was able to cover a much wider range of circadian stimulation than the TW fixtures, where the spectral changes of warm to cool accounted to very little in terms of health benefits at a fixed illuminance level. The TW fixture tested had limited boundaries (3000 K-6000 K), which might not be representative of all TW fixtures used for dynamic lighting, but the test serves to give insights of how the different technologies should be employed.

The results have implications when designing dynamic lighting: A TW fixture can reach the same levels of circadian stimulation as an RGB fixture but to do so it is highly reliant on changes in intensity, whereas the RGB fixture can maintain a certain required illuminance and alter circadian stimulation only by changing the spectral distribution of the light. Consequently, a space where very low levels of illuminance is viable and permitted then a TW fixture might be sufficient, but when dealing with a vulnerable population then a multichannel fixture is needed to accommodate the needs of the group.

9.5.2 Colourimetry

As the colour of objects can only reflect the colours that the lighting consists of, it is important to implement this knowledge, when designing with light. Especially when the electric lighting is the only light source during evening and night at the work site. Coloured light should be strived to look as natural as possible i.e. a good colour rendering and as close to the reference. The colour rendering is measured in a Colour Rendering Index (CRI), where 100 CRI equals a light source contains all wavelengths represented in the visible spectrum. The result is white light (See Figure 24).

When building a lighting design with other purposes for instance during night shifts, where the wavelengths are purposely avoided in a spectrum from 400-600 nm, it is an important design aspect, to try not to include blue or objects in the room (Figure 24). These objects would appear dark and- or distorted, when they are seen in a red light composition. Including red objects can also cause problems, as they will appear oversaturated and non-natural either. Therefore, is the best solution to design with neutral colours in the room i.e. grey and white paints on walls and floor. Alternatively, artistic paintings could be made with an eye to form different pictures in red, blue and white light as different colours are prominent in each setting (See figure 24). Having the room change expression throughout the day. Using the colour change (Blue-White-Yellow) to one's advantage and create value for the users.

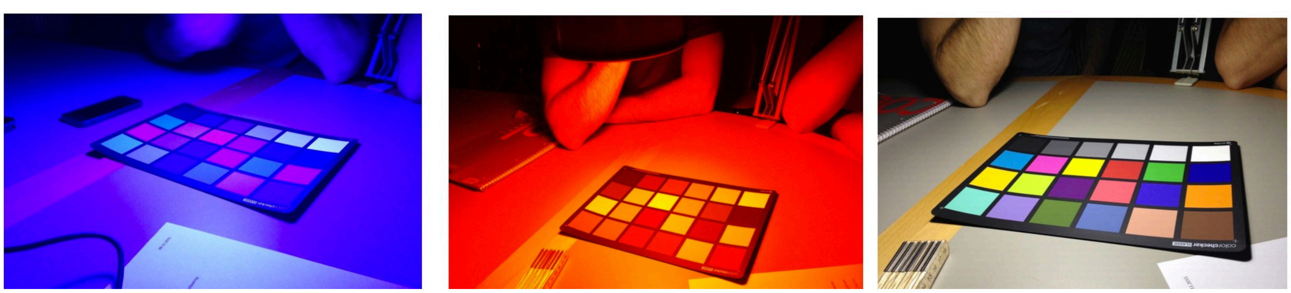


Figure 24 – The three pictures show how colours (pigments) appear under three different lighting conditions (Blue, Red, White)

9.5.3 Self-illuminating screens

For night lighting, any light is of relevance. Figure 23 shows that even low intensities with the wrong coloured lighting can have big impact on melatonin suppression. Change in colour temperature and intensity should also include the screens of the workplace to make sure that the effort put in creating a dynamic general lighting is not disrupted by the often blue light, which is emitted from monitors. Such software is already readily available, which automatically changes the brightness and colour temperature of the screen throughout the day, in relation to the sun.

10 Discussion

In this section, we will discuss the validity of the CS metric as experienced and the prospects of using UV in the future of health-related lighting designs.

10.1 The CS metric

In essence what the CS metrics does is that it interprets the spectral composition and intensity of the light and gives an account of how the lighting affects the circadian rhythm. The metric is largely built upon a mix of empirical studies, and relies largely on theoretical assumptions. As mentioned in the introduction of the CS metric (CS Metric section) the metric does currently not account for the impact of exposure history, timing, duration and light distribution (Rea and Figueiro, 2016). This is the case despite the fact that the metric itself was termed in 2010 (Rea *et al.*, 2010), the ipRGCs have been discovered since 2002 (Berson, Dunn and Takao, 2002), and that the impact of light on melatonin production was known long before that (e.g. Adle*r et al*, 1992). The fact that there after so many years are uncertainties and different elements, which does not fit into a single metric accounts to the vast complexity of the circadian system, which is not easy to understand, and should not be easily interpreted. One example of the complexity is the two different luminous efficiency functions of the CS metric, where the given SPD is either calculated as warm or cool and the CS value is then calculated according to that. For the cool luminous efficiency, part of the visual spectrum (approx. 525-650 nm) becomes sub additive, where the radiant power in the region subtracts from the overall response of the system (Rea and Figueiro, 2016). This becomes relevant in the crossover point from warm to cool and was observed when calculating the CS value for a 3000 K light source and a 4000 K light source which resulted in the 4000 K light source having a lower CS value than the otherwise warmer light. When designing the compromise scenario for the experiment we found that CCT is a very inaccurate way of describing light, when it comes to circadian stimulation. Due to the distance allowed from the plankcian locus (duv), what is considered white light in terms of CCT, but that duv has big impact on the CS value.

The CS metric is not a complete measure of circadian stimulation, which accurately describes all lighting conditions, but it is a big step onwards from only describing light in terms of intensity and CCT.

We see potential that the CS metric can be used in the design phase, for the lighting designer, when designing new lighting for night shift workers. The metric can also be used to make adjustments which fulfils the needs of the specific target group.
The metric is also especially relevant when evaluating already existing lighting designs. The metric can then serve as an instrument to show and communicate the trade-offs between different types of lighting scenarios for night shift work and how they affect visual comfort and health aspects. The current lighting standard (EN-12464) could benefit from including a metric such as the CS metric in a way to quantify and standardise the health impact of the lighting.
However there are a lot of obstacles for new lighting metrics to be adopted (Boyce and Smet, 2014). In terms of adoption of metrics which takes the health aspects of the lighting into consideration, F.lux (which is the name of a software providing dynamic lighting for computer monitors) launched a feature in June 2015[11], which integrates Melanopsin and the CS value in the effort to communicate the impact of self-illuminating monitors on the circadian system.

10.2 Literature search

By utilising the type of literature search strategy, we were able to discover the important studies in the fields, but the strategy was also limited given authors referencing themselves. An example of the latter is that the theoretical background to a high degree has relied on the works of Mariana G. Figueiro which is referenced often throughout the paper. The reason is that she has conducted a lot of the research within the field of light and its effect on nocturnal melatonin production and how lighting affects night shift

[11] https://forum.justgetflux.com/topic/16/introducing-f-luxometer

workers. Her work is of great relevance for the project since she has attempted to operationalize theoretical knowledge and make it applicable for architecture and designing with light.

10.3 The social aspect of working during the night

One of the consequences of working during the night have an adverse effect on the social aspect. This is of course due to the surrounding environment that is based on a diurnal schedule. Simple and daily tasks as grocery shopping, being social with friends and family, are situations that has to be closely planned but should be highly prioritized, to avoid loneliness and isolation. Therefore, it is also possible that conflicts can occur between the most optimal sleeping schedule and social events. The optimal schedule is solely based on the individual night worker and his/her's circadian rhythm and it is not suited for vast alternations. To make the schedule able to comply with the social activities, it is therefore, another reason, why it is desirable that the night shift worker's shifts are no longer than three days in a row, to make it easier to fit appointments and dates into the calendar.

10.4 UV

In the analysis of sleep habits and routines we mapped how the shift workers at Albertshøj managed their time. We found that they slept after work hours meaning that, in winter time, they would not be exposed a lot of daylight.

Considering other non-circadian health impacts of UV light, it might also be beneficial for production of vitamin D, to make up for possible vitamin D deficiency caused by sleeping at daytime in the winter period. The production, happens when exposed to UV light in the 290-330 nm range but overlaps with the action spectrum of erythema (sunburn), which has an aging effect on the skin and an increased risk of cancer (Boyce, 2014). Additional care should therefore be taken if using light from this part of the spectrum. On the other hand, deficiency of vitamin D can also lead to depression, anxiety or schizophrenia, which might be a concern to the Danish night workers. The vitamin D is

besides, essential for regulating the calcium uptake, which is vital for strong bones and teeth and also for the immune-system capabilities.
Living on the northern hemisphere, spending most of the daytime indoors, exposure to the sunlight is low, also limiting the amount of UV exposure. Because the vitamin D is produced, when UV touches the skin, the component could be included as part of the bathroom environment in a low but sufficient manner, where the exposed time is limited to the same time of taking a shower. It should be stressed that further investigations should be performed under controlled conditions, to avoid skin and tissue damage that is the precursor for cancer.
It could be interesting to include UV in the indoor lighting environment both for its visual properties and also for its non-visual aspects if a healthy balance can be found.

11 Conclusion

From a literature investigation, it was found that red lighting is the least disrupting lighting condition for night shift workers. However, the lighting is controversial in terms of colour rendering (since it contains narrowband wavelengths only), and interviews with shift workers from Albertshøj informed that the red lighting provided problems when performing work tasks. This led to the following problem statement:

How can lighting, during the night, support shift-workers' circadian cycle by reducing melatonin suppression, while maintaining visual comfort?

By using knowledge from the complex sensitivity of the circadian system it was possible to create a lighting scenario, which was an alternative to full spectrum white light, but with UV (in the visual spectrum 380-420 nm) instead of using blue wavelengths near the peak of the ipRGC (peak 460 nm). The lighting scenario was more disrupting than using red lighting, but caused a considerably lower melatonin suppression than using warm white light (2700 K) as measured by the Circadian Stimulus metric (CS), making it a compromise scenario.
The scenarios were evaluated in an experiment, concerning a simulated work task (n=30). The experiment confirmed the initial findings that red lighting was considered unpleasant with low visual comfort and found the compromise scenario to be pleasant with medium-high visual comfort comparable to the warm white scenario.

The report then discussed other efforts and opportunities within lighting parameters which could optimise the health benefits of the lighting, such as the benefits of using a multi-channel fixture instead of tuneable white, the interaction between coloured lighting and materials in the space, and the benefits of including more qualities of daylight such as including UV and a change of direction of the light.

The thesis concludes that there is no lighting condition which can fulfil all the lighting criteria when designing for night shift workers, although good compromises can be made to provide good visual comfort and at the same time reduce melatonin suppression during the night.

12 Future Works

The idea of using UV light for night shift workers is based on a theoretical model of the response of the circadian system and theoretically the near UV light should not suppress melatonin suppression. However, the methods of using UV for functional lighting needs to be tested in empirical studies to make sure that humans really do respond to the light as intended. Because of the vast complexity of the response sensitivity of humans (e.g. relativity and colour opponency) it is relevant to test how the lighting affects the hormones of people in a real-life setting.

13 Bibliography

Adler, J. S. *et al.* (1992) 'Peripheral vision suppression of melatonin', *Journal of Pineal Research*, 12(1), pp. 49–52. doi: 10.1111/j.1600-079X.1992.tb00025.x.

Arbejdsmiljøforskningsfonden, S. *et al.* (2015) 'MIDT om NATTEN', (december 2015), pp. 1–15.

Arbejdstilsynet (2004) *Håndbog om psykisk arbejdsmiljø*. Available at: https://www.arbejdstilsynet.dk/~/media/AT/at/06-Emneord/Psykisk arbejdsmiljoe/Psykisk-haandbog-2004 pdf.pdf.

De Bacquer, D. *et al.* (2009) 'Rotating shift work and the metabolic syndrome: a prospective study.', *Int J Epidemiol*, 38(3), pp. 848–854. doi: 10.1093/ije/dyn360.

Berson, D. M., Dunn, F. A. and Takao, M. (2002) 'Phototransduction By Retinal Ganglion Cells That Set The Circadian Clock', *Science*, 295(5557), pp. 1070–1073. doi: 10.1126/science.1067262.

van Bommel, W. and van den Beld, G. (2004) 'Lighting for work: a review of visual and biological effects', *Lighting Research and Technology*, 36(4), pp. 255–269. doi: 10.1191/1365782804li122oa.

Boyce, P. R. (2014) *Human Factors in Lighting, Second Edition*. doi: 10.1201/9780203426340.

Boyce, P. R. (2016) 'Editorial : Exploring human-centric lighting', *Lighting Research and Technology*, 48(2), p. 1.

Boyce, P. R. and Smet, K. A. G. (2014) 'LRT symposium "Better metrics for better lighting" – a summary', *Lighting Research and Technology*, 46(6), pp. 619–636. doi: 10.1177/1477153514558161.

Bøggild, H. *et al.* (1999) 'Shift work, social class, and ischaemic heart disease in middle aged and elderly men; a 22 year follow up in the Copenhagen Male Study', *Occupational and environmental medicine*, 56(table 1), pp. 640–645. doi: 10.1136/oem.56.9.640.

Cajochen, C., Krauchi, K. and Wirz-Justice, A. (2003) 'Role of melatonin in the regulation of human circadian rhythms and sleep.', *Journal of neuroendocrinology*, 15(4), pp. 432–437. doi: 989 [pii].

Christensen, B. (2017) *No Title*, *arbejdsmiljoviden.dk*. Available at: http://www.arbejdsmiljoviden.dk/Emner/Psykosocialt-arbejdsmiljo/Arbejdstider/Saadan-planlaegger-du-bedst-nat-og-skiftearbejde.

Czeisler, C. A. *et al.* (1999) 'Stability , Precision , and Near-24-Hour Period of the Human Circadian Pacemaker', 284(5423), pp. 2177–2181.

Descottes, H. and Ramos, C. . (2013) *Architectural lighting: Designing with Light and Space*. Princeton Architectural Press.

Dikel, E. E. *et al.* (2014) 'Preferred chromaticity of color-tunable LED lighting', *Leukos*, 10(2), pp. 101–115. doi: 10.1080/15502724.2013.855614.

Dodson, E. R. and Zee, P. C. (2010) 'Therapeutics for Circadian Rhythm Sleep Disorders', *Sleep Medicine*, 5(4), pp. 701–715. doi: 10.1016/j.jsmc.2010.08.001.Therapeutics.

Eisenstein, M. (2013) 'Stepping out of time', *Nature*, 497, pp. S10–S12. doi: 10.1038/497S10a.

EN-12464-1; (2011) 'Lys og belysning – Belysning ved arbejdspladser – Del 1 : Indendørs arbejdspladser Light and lighting – Lighting of work places – Part 1 : Indoor work places', *European Standard*, pp. 1–63.

Field, A. P. and Hole, G. (2003) *How to design and report experiments*, *Control*. doi: 10.1016/B978-0-12-384727-0.00002-1.

Figueiro, M. G. *et al.* (2016) 'Light at Night and Measures of Alertness and Performance', *Biological Research For Nursing*, 18(1), pp. 90–100. doi: 10.1177/1099800415572873.

Figueiro, M. G. and Rea, M. S. (2010) 'The effects of red and blue lights on circadian variations in cortisol, alpha amylase, and melatonin', *International Journal of Endocrinology*, 2010. doi: 10.1155/2010/829351.

Figueiro, M. G., Rea, M. S. and Bullough, J. D. (2006) 'Circadian effectiveness of two polychromatic lights in suppressing human nocturnal melatonin', *Neuroscience Letters*, 406(3), pp. 293–297. doi: 10.1016/j.neulet.2006.07.069.

Fotios, S. A. *et al.* (2006) 'Chromatic adaptation and the relationship between lamp spectrum and brightness', *Lighting Research and Technology*, 38(1), pp. 3–14. doi: 10.1191/1365782806li149oa.

Glickman, G. *et al.* (2003) 'Inferior retinal light exposure is more effective than superior retinal exposure in suppressing melatonin in humans.', *Journal of biological rhythms*, 18(1), pp. 71–79. doi: 10.1177/0748730402239678.

Gu, F. *et al.* (2016) 'Total and Cause-Specific Mortality of U.S. Nurses Working Rotating Night Shifts', 48(3), pp. 241–252. doi: 10.1016/j.amepre.2014.10.018.Total.

Hattar, S. *et al.* (2002) 'Melanopsin-Containing Retinal Ganglion Cells: Architecture, Projections and Intrinsic Photosensitivity', *American Association for the Adavncement of Science*, 295, pp. 1065–1070.

Hébert, M. *et al.* (2002) 'The effects of prior light history on the suppression of melatonin by light in humans.', *Journal of pineal research*, 33(4), pp. 198–203. doi: 1o885 [pii].

Ishihara, S. (1972) 'The Series of Plates Designed as a Tests for Colour-Blindness', *Nature*, p. 24 plates edition. Available at: http://adsabs.harvard.edu/abs/1910Natur..82Q.429E.

Johansson, M. *et al.* (2014) 'Perceived outdoor lighting quality (POLQ): A lighting assessment tool', *Journal of Environmental Psychology*. Elsevier Ltd, 39, pp. 14–21. doi: 10.1016/j.jenvp.2013.12.002.

Jørgensen, J. T. *et al.* (2016) 'Shift work and overall and cause-specific mortality in the Danish nurse cohort', *Scandinavian Journal of Work, Environment & Health*, 43(2), pp. 117–126. doi: 10.5271/sjweh.3612.

Karlsson, B. *et al.* (2005) 'Total mortality and cause-specific mortality of Swedish shift- and dayworkers in the pulp and paper industry in 1952-2001', *Scandinavian Journal of Work, Environment and Health*, 31(1), pp. 30–35. doi: 10.5271/sjweh.845.

Knutsson, A., Hammar, N. and Karlsson, B. (2004) 'Shift workers' mortality scrutinized.', *Chronobiology international*, 21(January), pp. 1049–53. doi: 10.1081/LCBI-200035942.

Lin, X. *et al.* (2015) 'Night-shift work increases morbidity of breast cancer and all-cause mortality: A meta-analysis of 16 prospective cohort studies', *Sleep Medicine*. Elsevier B.V., 16(11), pp. 1381–1387. doi: 10.1016/j.sleep.2015.02.543.

Logadóttir, Á. *et al.* (2013) 'Investigating the use of an adjustment task to set preferred colour of ambient illumination', *Color Research and Application*, 38(1), pp. 46–57. doi: 10.1002/col.20714.

Lucas, R. J. *et al.* (2014) 'Measuring and using light in the melanopsin age', *Trends in Neurosciences*. Elsevier Ltd, 37(1), pp. 1–9. doi: 10.1016/j.tins.2013.10.004.

Morgenthaler, T. I. *et al.* (2007) 'Practice parameters for the clinical evaluation and treatment of circadian rhythm sleep disorders. An American Academy of Sleep Medicine report.', *Sleep*, 30(11), pp. 1445–1459.

Newsham, G. R. *et al.* (2008) 'Individual control of electric lighting in a daylit space', *Lighting Research and Technology*, 40(1), pp. 25–41. doi: 10.1177/1477153507081560.

Pan, A. *et al.* (2011) 'Rotating night shift work and risk of type 2 diabetes: Two prospective cohort studies in women', *PLoS Medicine*, 8(12). doi: 10.1371/journal.pmed.1001141.

Pilcher, J. J., Lambert, B. J. and Huffcutt, a I. (2000) 'Differential effects of permanent and rotating shifts on self-report sleep length: a meta-analytic review.', *Sleep*, 23(2), pp. 155–163.

Plan-C (2013) *Bedre lys til ældre borgere*.

Rea, M. *et al.* (2012) 'Modelling the spectral sensitivity of the human circadian system', *Lighting Research and Technology*, 44(4), pp. 386–396. doi:

10.1177/1477153511430474.

Rea, M. and Figueiro, M. (2016) 'Light as a circadian stimulus for architectural lighting', *Lighting Research and Technology*. SAGE PublicationsSage UK: London, England. doi: 10.1177/1477153516682368.

Rea, M. S. *et al.* (2010) 'Circadian light.', *Journal of circadian rhythms*, 8(1), pp. 1–10. doi: 10.1186/1740-3391-8-2.

Rosenthal, N. and Sack, D. (1985) 'Antidepressant effects of light in seasonal affective disorder', *Am J* …, pp. 163–170. Available at: http://ajp.psychiatryonline.org/doi/pdf/10.1176/ajp.142.2.163.

Sahin, L. and Figueiro, M. G. (2013) 'Alerting effects of short-wavelength (blue) and long-wavelength (red) lights in the afternoon', *Physiology and Behavior*. Elsevier Inc., 116–117, pp. 1–7. doi: 10.1016/j.physbeh.2013.03.014.

Scenihr (2012) 'Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR Health Effects of Artificial Light', *Report*, (January), pp. 1–118. doi: 10.2772/8624.

Schlangen, L., Lang, D. and Novotny, P. (2014) 'Lighting for health and wellbeing'.

Taylor, P. J. and Pocock, S. J. (1972) 'Mortality of shift and day workers 1956-68', *British journal of industrial medicine*, 29, pp. 201–207. doi: 10.1136/oem.29.2.201.

TeamArbejdsliv Aps, K. / V. A. (2012) 'Natarbejde med færre gener', p. 16. Available at: http://vpt.dk/sites/default/files/Natarbejde_med_faerre_gener_0.pdf.

Wright, K. P. *et al.* (2013) 'Entrainment of the human circadian clock to the natural light-dark cycle', *Current Biology*. Elsevier Ltd, 23(16), pp. 1554–1558. doi: 10.1016/j.cub.2013.06.039.

Zande, B. Van Der and Rizzo, P. (2016) *Human Centric Lighting (Bianca van der Zande & Patricia Rizzo).* Youtube. Available at: https://www.youtube.com/watch?v=qonekBGvpeM&t=519s.

14 The Appendix

14.1 Interview Summary

Interview with Night Worker 1 and Night Worker 2: In the room was Sofie Seeman and Key Account Manager from LIGHTCARE, Thomas Feldborg.
During the night shift, Night Worker 1 and Night Worker 2 are carrying out various tasks, as emptying the patient's catheter from urine, giving personal care or turning the patients around to avoid pressure soreness. When they operate inside the patient's rooms, they are using the fixture above the sink and or no light at all, depending on the task. Late in their night shift (between 05:00 and 06:00), they are working on computers, where they log the patient's journals. The rest of the time they are watching television and answering alarms from troubled patients.
The ambient lighting fixtures in the day room are dimmed to 10% or turned off by Night Worker 2 or Night Worker 1, during the night time. In that timespan, the lighting is red with slightly green. Night Worker 2 is protagonist for turning off the lighting in the night, but Night Worker 1 is sometimes having troubles finding what she needs.
Night Worker 2 is very aware that the field she is working in, makes her more exposed and is not very healthy in, yet she continues to do so. She has an interest in reading about the latest research in newspapers, trade union publications or scientific papers. She is also very structured in her way of planning her schedule before and after she has been working night shifts. Even though Night Worker 2 is good at scheduling her time, she frequently takes additional melatonin in pill-form, to sleep when she gets home from work. If she has troubles staying awake at night, she is not troubled to take a caffeine pill.

Interview with Night Worker 3: Only Night Worker 3 is present for this interview. The other colleague had cancelled due to sickness.

Night Worker 3 explains that she and her colleague are mostly watching TV during the night. It occurs that Night Worker 3 sometimes reads a book, when it is quiet on the shift. Night Worker 3 and her colleague have problems working in the red light at night.

Especially when she has to prepare the pills and medication for the patients. Her colleague is visually impaired and they both have to adapt the lighting to that. She has troubles adapting her eyes to it. Therefore, she adjusts the night lighting to 25% as opposed to 10%, which is the dim night light. The red light-setting is especially challenging for Night Worker 3. At 25%, the green colour appears slightly more dominant. When they are having visits from doctors during the night, they adjust the lighting to 50% in the office and sometimes when they are working on the computers too.
When Night Worker 3 is nursing the patients, she often turns on the white light opposed to her colleagues. She says that it is often also requested from the patients when they have to use the restroom during the night. The patients ask Night Worker 3 to turn on the light, even though the night-light scene is already on. The bathroom light is activated by movements.
Night Worker 3 has 12 years of experience, working in night-shifts. She explains that the 1½ year she has been working at Albertshøj with the current lighting installation she does not have headache as she used to, from her old job. She is worried about her health status, due to prone genetics for breast cancer lies in the family. She is therefore very cautious and goes to routine checks with regular intervals.

14.2 Data analysis

A0)

Table 8 – Group comparison (Info-Control)

Group comparison: Information-No information

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. [2*(1-tailed Sig.)]
1. Pleasant/Unpleasant	109.000	229.000	-.159	.874	.902[b]
1. Dim/Bright	94.500	214.500	-.764	.445	.461[b]
1. Interesting/Boring	78.000	198.000	-1.665	.096	.161[b]
1. Unnatural/Natural	101.500	221.500	-.485	.628	.653[b]
1. What is your impression of the visual comfort in the space?	104.500	224.500	-.360	.719	.744[b]
1. What is your impression of how colours appear in the space?	91.500	211.500	-.977	.328	.389[b]
2. Pleasant/Unpleasant	96.500	216.500	-.705	.481	.512[b]
2. Dim/Bright	109.000	229.000	-.150	.881	.902[b]
2. Interesting/Boring	75.000	195.000	-1.594	.111	.126[b]
2. Unnatural/Natural	87.000	207.000	-1.117	.264	.305[b]
2. What is your impression of the visual comfort in the space?	105.000	225.000	-.338	.735	.775[b]
2. What is your impression of how colours appear in the space?	104.500	224.500	-.387	.699	.744[b]
3. Pleasant/Unpleasant	110.000	230.000	-.109	.913	.935[b]
3. Dim/Bright	83.500	203.500	-1.242	.214	.233[b]
3. Interesting/Boring	108.500	228.500	-.170	.865	.870[b]
3. Unnatural/Natural	110.500	230.500	-.087	.931	.935[b]
3. What is your impression of the visual comfort in the space?	97.500	217.500	-.653	.514	.539[b]
3. What is your impression of how colours appear in the space?	106.500	226.500	-.277	.782	.806[b]

a. Grouping Variable: Information

b. Not corrected for ties.

A1

Gender	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. [2*(1-tailed Sig.)]
1. Pleasant/Unpleasant	66,000	219,000	-2,040	0,041	0,065[b]
1. Dim/Bright	102,500	193,500	-0,342	0,732	0,742[b]
1. Interesting/Boring	86,000	177,000	-1,193	0,233	0,320[b]
1. Unnatural/Natural	92,500	245,500	-0,801	0,423	0,457[b]
1. What is your impression of the visual comfort in the space?	65,500	156,500	-2,044	0,041	0,059[b]
1. What is your impression of how colours appear in the space?	90,500	181,500	-0,939	0,348	0,408[b]
2. Pleasant/Unpleasant	54,000	207,000	-2,511	0,012	0,017[b]
2. Dim/Bright	93,500	246,500	-0,736	0,462	0,483[b]
2. Interesting/Boring	87,500	240,500	-0,987	0,324	0,341[b]
2. Unnatural/Natural	105,500	258,500	-0,221	0,825	0,837[b]
2. What is your impression of the visual comfort in the space?	82,000	173,000	-1,296	0,195	0,245[b]
2. What is your impression of how colours appear in the space?	99,500	190,500	-0,536	0,592	0,650[b]
3. Pleasant/Unpleasant	90,000	243,000	-0,901	0,368	0,408[b]
3. Dim/Bright	74,000	227,000	-1,577	0,115	0,133[b]
3. Interesting/Boring	108,000	261,000	-0,107	0,915	0,934[b]
3. Unnatural/Natural	50,500	141,500	-2,627	0,009	0,010[b]
3. What is your impression of the visual comfort in the space?	99,500	252,500	-0,483	0,629	0,650[b]
3. What is your impression of how colours appear in the space?	74,500	227,500	-1,676	0,094	0,133[b]
Scenario 1 time	90,500	243,500	-0,840	0,401	0,408[b]
Scenario 1 count	109,500	200,500	-0,045	0,964	0,967[b]
Scenario 2 time	82,000	235,000	-1,196	0,232	0,245[b]
Scenario 2 Count	96,000	187,000	-0,659	0,510	0,563[b]
Scenario 3 Time	99,000	252,000	-0,482	0,630	0,650[b]
Scenario 3 Count	83,000	174,000	-1,220	0,223	0,263[b]

a. Grouping Variable: Gender (1 Male)

b. Not corrected for ties.

A1

Experience working night shifts	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. [2*(1-tailed Sig.)]
1. Pleasant/Unpleasant	56,500	161,500	-2,527	0,012	0,019[b]
1. Dim/Bright	80,000	216,000	-1,361	0,174	0,193[b]
1. Interesting/Boring	74,500	210,500	-1,814	0,070	0,120[b]
1. Unnatural/Natural	93,500	198,500	-0,818	0,414	0,448[b]
1. What is your impression of the visual comfort in the space?	81,000	217,000	-1,399	0,162	0,208[b]
1. What is your impression of how colours appear in the space?	76,000	212,000	-1,679	0,093	0,142[b]
2. Pleasant/Unpleasant	102,000	207,000	-0,442	0,659	0,697[b]
2. Dim/Bright	100,000	205,000	-0,516	0,606	0,637[b]
2. Interesting/Boring	106,000	211,000	-0,256	0,798	0,822[b]
2. Unnatural/Natural	84,500	189,500	-1,207	0,227	0,257[b]
2. What is your impression of the visual comfort in the space?	55,000	191,000	-2,575	0,010	0,017[b]
2. What is your impression of how colours appear in the space?	106,000	211,000	-0,291	0,771	0,822[b]
3. Pleasant/Unpleasant	88,000	193,000	-1,047	0,295	0,334[b]
3. Dim/Bright	78,500	214,500	-1,438	0,151	0,166[b]
3. Interesting/Boring	68,000	204,000	-1,874	0,061	0,070[b]
3. Unnatural/Natural	86,000	191,000	-1,131	0,258	0,294[b]
3. What is your impression of the visual comfort in the space?	93,000	229,000	-0,829	0,407	0,448[b]
3. What is your impression of how colours appear in the space?	76,000	212,000	-1,665	0,096	0,142[b]
Scenario 1 time	62,000	167,000	-2,087	0,037	0,038[b]
Scenario 1 count	85,500	221,500	-1,180	0,238	0,275[b]
Scenario 2 time	56,500	161,500	-2,314	0,021	0,019[b]
Scenario 2 Count	74,000	179,000	-1,716	0,086	0,120[b]
Scenario 3 Time	52,500	157,500	-2,479	0,013	0,012[b]
Scenario 3 Count	102,000	207,000	-0,441	0,660	0,697[b]

a. Grouping Variable: Do you have any experience working night shifts? (Between 23:00-07:00)

b. Not corrected for ties.

A2

Randomisations	Chi-Square	df	Asymp. Sig.
1. Pleasant/Unpleasant	5,073	5	0,407
1. Dim/Bright	5,478	5	0,360
1. Interesting/Boring	2,895	5	0,716
1. Unnatural/Natural	3,338	5	0,648
1. What is your impression of the visual comfort in the space?	5,837	5	0,322
1. What is your impression of how colours appear in the space?	3,064	5	0,690
2. Pleasant/Unpleasant	0,970	5	0,965
2. Dim/Bright	3,046	5	0,693
2. Interesting/Boring	7,763	5	0,170
2. Unnatural/Natural	5,922	5	0,314
2. What is your impression of the visual comfort in the space?	3,062	5	0,690
2. What is your impression of how colours appear in the space?	3,344	5	0,647
3. Pleasant/Unpleasant	6,797	5	0,236
3. Dim/Bright	11,597	5	0,041
3. Interesting/Boring	7,484	5	0,187
3. Unnatural/Natural	3,568	5	0,613
3. What is your impression of the visual comfort in the space?	10,118	5	0,072
3. What is your impression of how colours appear in the space?	8,988	5	0,110
Scenario 1 time	9,233	5	0,100
Scenario 1 count	2,394	5	0,792
Scenario 2 time	7,226	5	0,204
Scenario 2 Count	3,490	5	0,625
Scenario 3 Time	6,374	5	0,272
Scenario 3 Count	6,940	5	0,225

a. Kruskal Wallis Test

b. Grouping Variable: Randomisation

A3

Errors counting – One way Anova

Measure: CountError

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Scenario	Sphericity Assumed	2.756	2	1.378	.851	.432	.029
	Greenhouse-Geisser	2.756	1.791	1.538	.851	.422	.029
	Huynh-Feldt	2.756	1.902	1.449	.851	.427	.029
	Lower-bound	2.756	1.000	2.756	.851	.364	.029
Error(Scenario)	Sphericity Assumed	93.911	58	1.619			
	Greenhouse-Geisser	93.911	51.947	1.808			
	Huynh-Feldt	93.911	55.145	1.703			
	Lower-bound	93.911	29.000	3.238			

14.3 Experiment protocol

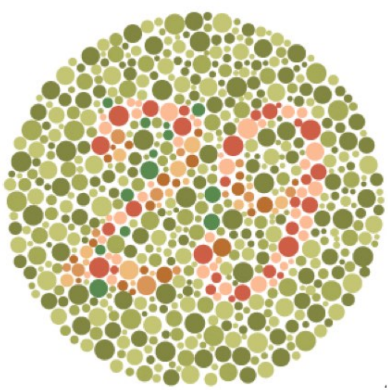
1. **ID (1-100)**

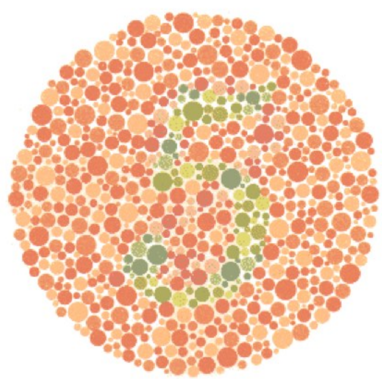
2. **Gender**
Markér kun ét felt.
 - Male
 - Female

3. **Age**

4. **Do you have any experience working night shifts? (Between 23:00-07:00)**
Markér kun ét felt.
 - Yes
 - No

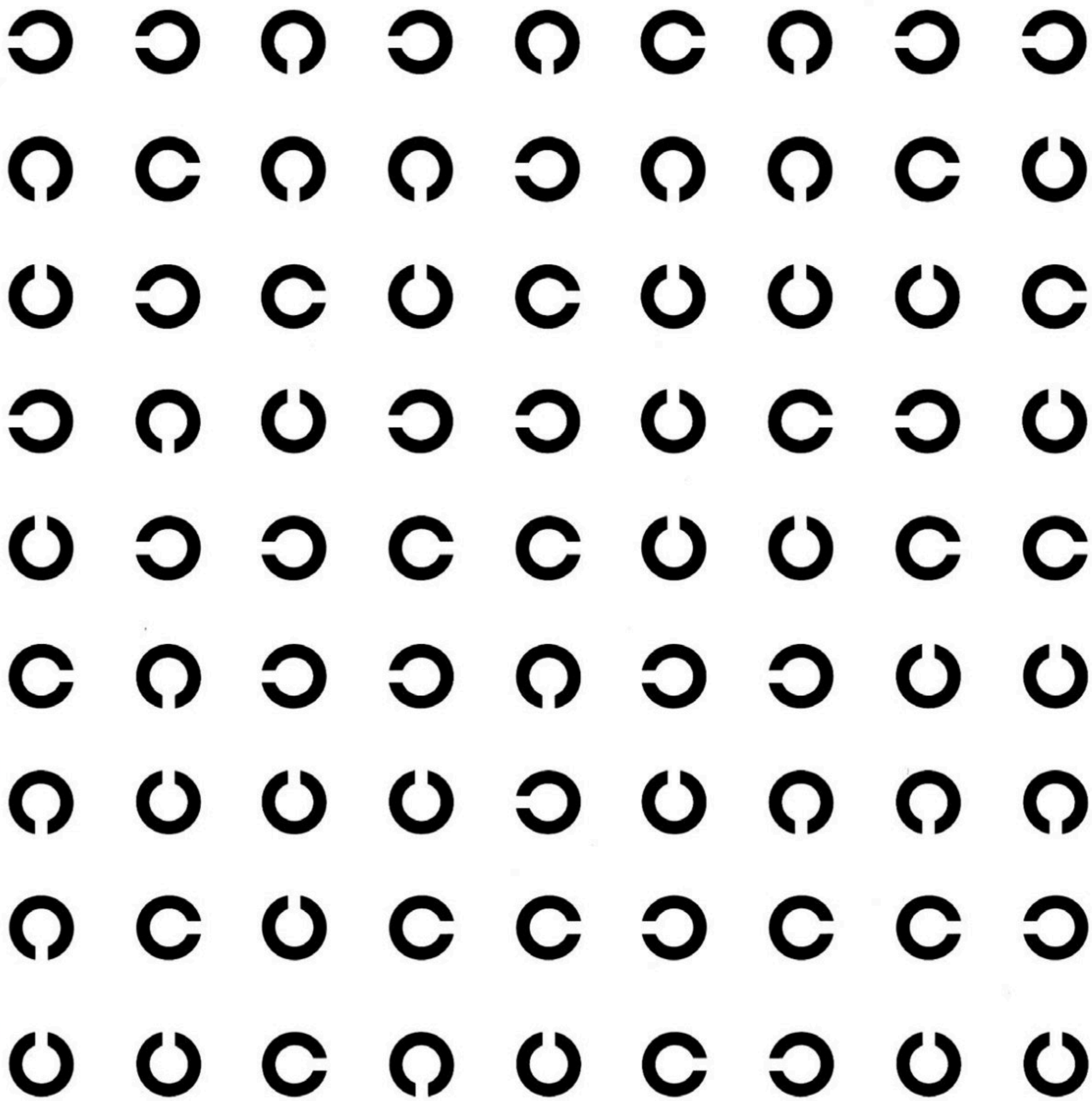
Colour vision - Report the number shown inside the circle





Scenario 1

Count the number of rings with the opening
in the left side and report the number to the surveyor



Scenarie 1

5. **How do you perceive the lighting in the space?**
Markér kun ét felt.

	1	2	3	4	5	6	7	
Pleasant	◯	◯	◯	◯	◯	◯	◯	Unpleasant

6. *Markér kun ét felt.*

	1	2	3	4	5	6	7	
Dim	◯	◯	◯	◯	◯	◯	◯	Bright

7. *Markér kun ét felt.*

	1	2	3	4	5	6	7	
Unnatural	◯	◯	◯	◯	◯	◯	◯	Natural

8. *Markér kun ét felt.*

	1	2	3	4	5	6	7	
Interesting	◯	◯	◯	◯	◯	◯	◯	Boring

9. **What is your impression of the visual comfort in the space?**
Markér kun ét felt.

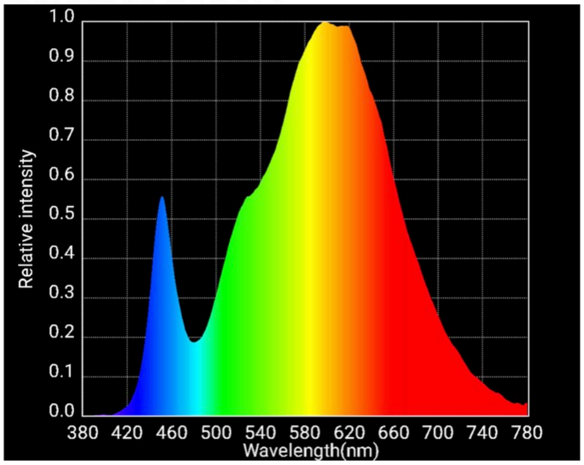
- ◯ Very satisfying
- ◯ Satisfying
- ◯ Neutral
- ◯ Unsatisfying
- ◯ Very unsatisfying

10. **What is your impression of how colours appear in the space?**
Markér kun ét felt.

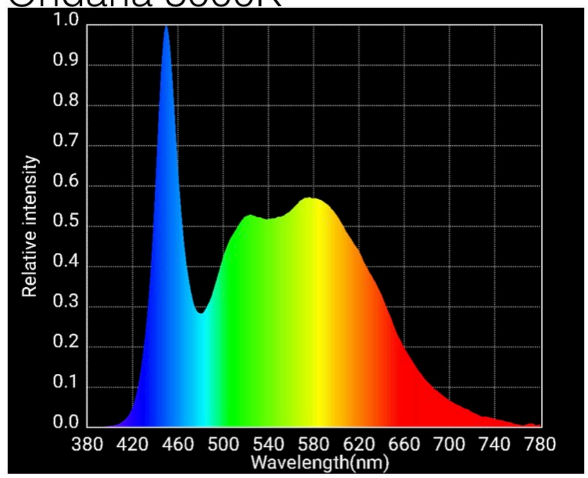
- ◯ Very satisfying
- ◯ Satisfying
- ◯ Neutral
- ◯ Unsatisfying
- ◯ Very unsatisfying

14.4 RGB vs TW - Spectral composition

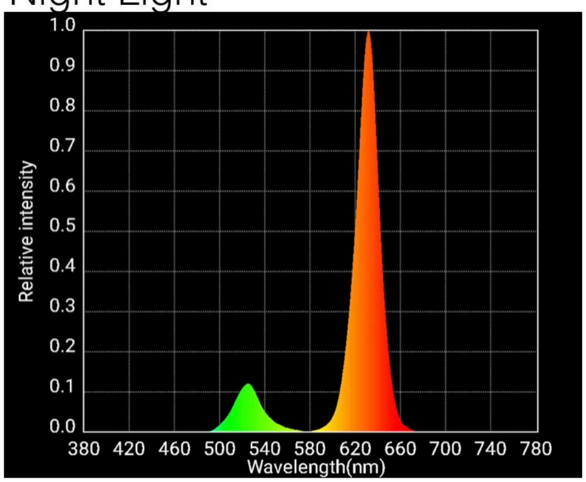
Ondaria 6000K



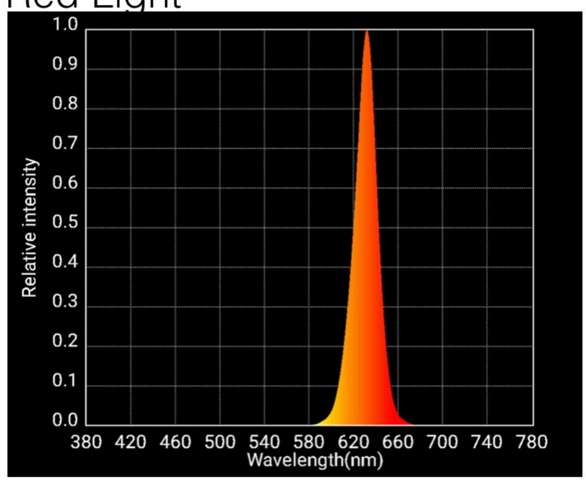
Ondaria 3000K



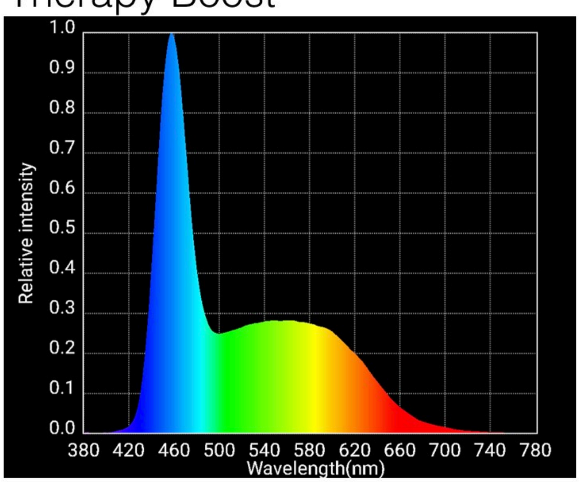
Night Light



Red Light



Therapy Boost



14.5 Distribution example pictures