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Lighting Design for Eldercare homes:
A lighting design proposal for the common areas of Albertshøj eldercare home.

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ABSTRACT:

This thesis aims to identify the critical parameters for lighting design in the context of an eldercare home, having as a case study the communal areas of Albertshøj eldercare home.

Focus is given on how light can improve the everyday living conditions of residents, respecting their needs and routines in their practice of home, and at the same time improve lighting conditions to ensure an efficient work environment for staff. The role and contribution of daylight and natural elements in the built environment are also highlighted as an effective way to enhance users' physiological and psychological well being. Additionally, the non-visual effects of light on humans' health are in the center of attention, with the goal of providing lighting conditions that support all users' circadian rhythm.

Success criteria for the lighting design of communal areas of an eldercare home are determined based on the findings of theoretical work (literature review, case study analysis, and state of the art). Lastly, a design concept is developed that incorporates a customized 24-hour lighting scheme, and a design proposal that supports the sensory, physical and functional needs of residents and staff.

This thesis emphasizes the importance of providing flexible lighting conditions to meet the functional needs of an eldercare home, while providing residents with the ability to orchestrate the atmosphere of home, and ensuring the entrainment of all users' biological rhythms. Finally, an exploration of a lighting element that simulates a biophilic view is introduced as a means of enhancing users' connection with nature, resulting in a pleasant and stimulating environment, suitable for both home and work environment.

Lighting design for eldercare homes

A lighting design proposal for the common areas of Albertshøj eldercare home

LiD10_Master Thesis_Spring 2020
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Abstract

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Contents

1
Introduction 6

2
Methodology 8

3
Literature Review 10

1. Introduction 10
2. "Healing Architecture" 11
3. Light shapes atmospheres 11
4. The restorative effects of nature 12
5. Natural views 13
6. Daylight 14
7. Biophilic patterns related to well-being & spatial appraisal 15
8. The essence of feeling at "home" 16
9. How does light affect human 17
10. Circadian Stimulus Metric 19
11. The effect of light on work performance 20
12. Night-shift workers 21
13. Optical changes with age - the role of lighting 22
14. Human-Centric lighting / Circadian Lighting 24
15. Literature Review Summary 24

4
Case Study Analysis 26

1. Introduction 26
2. Albertshøj eldercare home 27
3. Focus Area 28
4. Electric Lighting 29
5. Daylight 33
6.Users 36

5
State of the art 38

1. Introduction 38
2. LIGHTEL 39

6
Research Question 42

7
Success Criteria 43

8
Design Concept 44

1. Introduction 44
2. 24-hour lighting scheme 45
3. Lighting Design Proposal 49
4. Additional design components 72

9
Evaluation 73

10
Discussion 76

11
Conclusion 79

12
References 81

13
Appendix 88

1

Introduction

During my quite recent experience as a lighting designer, I found myself being impressed by how light, natural or artificial, is able to affect mood, experience, perception of the space, and especially health. Ever since, I have been very keen on studying and researching in more depth, the ways light affects human well-being, physically and psychologically, ideally so that the relevant knowledge can be applied to a lighting design proposal.

It is a well supported fact that we are facing a big demographic change. The ageing population is rapidly growing and this surfaces the need for high-quality elderly care. A larger elderly population will increase the number of people who live with decreased visual capabilities, and dementia, a common geriatric condition where people lose their cognitive ability. Luckily, in an effort to cope with this challenge, there is a vast number of researches focused on ways to improve elderly's quality of life. Lighting design plays a significant role in improving the living conditions of the elderly, based on the findings that directly correlate qualities of light with increased levels of health and comfort.

Along these lines, I decided to focus on how the lighting design in an eldercare home can support users' sensory, physical, and functional needs.

Eldercare homes are multifunctional spaces. A professional environment for the staff, a home for the elderly people, and concurrently, due to their role of promoting well-being for them all, a healing environment.

Richard Ryan and Edward Deci, articulate the meaning of well-being based on two main approaches: "the hedonic approach, which focuses on happiness and defines well-being in terms of pleasure attainment [...] and the eudaimonic approach, which[...] defines well-being in terms of the degree to which a person is fully functioning" (Ryan and Deci, 2001, p.141). In their study, it is mentioned that according to Cowen (1991), well-being can be described as "an array of positive aspects of functioning that are promoted by attainment of strong attachment relationships, acquisition of age-appropriate cognitive, interpersonal, and coping skills, and exposure to environments that empower the person" (Ryan and Deci, 2001, p.161). In other words, the accomplishment of wellness is not only based on humans' good physical and psychological state but also on social interactions and personal parameters that define a good experience according to cultural issues and individual preferences. It is, thus, a necessity for this project to take into consideration the findings of both quantitative and qualitative methods. The measurements and data indicating the physical reaction of the human body to light, together with findings regarding the way users experience the space from a more phenomenological approach will finally provide the whole picture of what is needed to promote well-being.

A lot of times the design of such spaces is focused on the fulfillment of residents' needs and expectations. However, in order to ensure the efficient operation of a healthcare system, the needs of all users, including the care providers, must be met at the same time. The challenge is to balance and meet the different needs under a coherent lighting design and at the same time create an overall pleasant and inspiring atmosphere for residents to live in and staff to work at.

2

Methodology

The thesis uses a mixed-method approach. It starts with an in-depth literature review that examines all related to light parameters, in the context of an eldercare home, that can affect users' physio-psychological state. The literature review leads to valuable findings regarding the way that light should be used in such a context, taking into account all key users, namely residents and staff.

The thesis continues with the case study analysis, that is the common areas on the third floor of Albertshøj eldercare home. Due to the restrictions imposed during the COVID-19 pandemic, no actual observations or measurements were made possible. Therefore, the electric lighting & daylight analysis was made through 3D simulations and visualizations (using Velux and Dialux software), based on data retrieved from Aalborg university's archive of LIGHTEL project, and the architectural and electrical plans of the space. For a better understanding of the space layout and environment, photos of the space were analyzed, and also an interview that was conducted via telephone with a staff member provided knowledge regarding users' daily routines, daily schedule, and staff's tasks.

The anthropological part of LIGHTEL project is used as a state of the art as it reveals how the Circadian Lighting affects users' well-being, practice of home, and daily routines in an eldercare home.

The findings of the literature review combined with the case study analysis and state of the art, built a path towards the identification of the research question and the success criteria.

The thesis continues with an exploration of moodboards that qualify the design concept and then the design concept is developed. It includes a customized 24-hour lighting scheme (according to the daily schedule of the eldercare home) and a lighting design proposal for the space. Dialux software, the Circadian stimulus calculator and Adobe After Effects were used to examine and finally specify the attributes of the design concept.

The aforementioned design concept is being furthermore evaluated in order to determine if the success criteria are fulfilled, compared to the overall findings of the thesis. Finally, in the discussion part, a number of aspects that need to be tested or taken into account, are listed, to be used in future steps of the project.

3

Literature Review

1. Introduction

An eldercare home is by nature a multifunctional space with various needs and limitations, which when combined, can define it as a framework of great complexity. The purpose of the literature review is to build a solid and holistic knowledge foundation on the subject, by exploring every key aspect of lighting for such a framework, focusing both separately and collectively, on residents and staff.

The literature review firstly introduces the role of architecture and of lighting as an architectural element in shaping atmospheres that enhance the healing process and support users' well-being. The chapter continues with a research presentation, regarding the restorative effect of nature and the positive impact that daylight, natural views, and biophilic patterns, can have in built environments. The essence of feeling at home is then analyzed, highlighting the most crucial aspects for cultivating this feeling for the residents. In-depth research is then presented regarding the way light affects humans, including both its visual and non-visual effects. Later on, emphasis is placed on lighting factors that create a good professional environment, but also on those that create optimal visual conditions for the elderly. Lastly, the Circadian stimulation metric and the contribution of circadian lighting in well-being are introduced. The literature review concludes, emphasizing the most critical findings that will be taken into account for the lighting design of an eldercare home.

2. “Healing Architecture”

There are more and more studies examining the impact of the architectural environment of a healing space that may have on health by influencing behaviors, actions and interactions of patients, their families and the staff members. The context of the physical environment has an essential impact on the experience of well-being (Rogers, 1970). Daylight, art, acoustics, pleasant views and colors are elements that have a positive effect on the treatment of the patients/residents while at the same time on both patients’/residents’ and staffs’ experience (Schweitzer et al., 2004).

The Center for Health Design and other researchers have gathered a substantial amount of evidence, claiming for the way the different elements of the physical environment in healthcare systems affect their users. This accumulated knowledge aims to improve the healthcare systems following the Evidence-Based Design in a way that all the design decisions will be informed “...by the best available evidence concerning how the physical environment can interfere with or support activities by patients, families, and staff, and how the setting provides experiences that provide a caring, effective, safe, patient-centered environment” (Ulrich et al., 2004, p.26).

3. Light shapes atmospheres

But how can we affect the way users experience a space? The German philosopher Germot Böhme says that the first thing one perceives in a space is the atmosphere.“What is the first and immediately perceived is neither sensations nor shapes or objects or their constellations [...] but atmospheres” (Böhme, 1993, p.23). He argues that light shapes atmospheres. Depending on the way it is used, it is able to transform the whole spatial context and reveal new atmospherical feelings and moods. “Lighting is one of the few environmental parameters that can have an instant effect both on perception and appraisal of a space” (De Vries et al., 2018, p.535). That being said, light is considered as an effective element of the physical environment, that can affect humans’ experience towards well-being.

Richard Kelly in his essay “Light as an Integral Part of Architecture” (1952) presents the importance of combining three different layers of light in order to create a stimulating environment that will effectively engage its users. He writes that there are “three kinds of light: (1) Focal glow, (2) ambient luminescence and (3) play of brilliants, respectively (1) make it easier to see (2) make surroundings safe and reassuring and (3) stimulate the spirit” (Kelly, 1952, p.26). These three principles of illumination serve different purposes and it is necessary to satisfy each one of them in order to create an atmosphere that satisfies the user physically and mentally.

Nevertheless, the way one translates and experiences an atmosphere is highly subjective. Humans subliminally search for visual clues to connect what they experience with their prior knowledge.

As Pallasmaa states in his book “The eyes of the skin”, our emotions when experiencing a space or an atmosphere are an outcome of our past accumulated experiences, knowledge, memories and senses. (Pallasmaa, 1996).

Concerning humans’ relation and experience of light, it is highly associated with the relation and experience of daylight. Different geographical locations and cultures affect humans’ association with daylight, contributing to different experiences and therefore expectations from the way a space is lit naturally or artificially. Therefore it is necessary to understand how Danish people interpret light. In Denmark, from a cultural point of view, a quite dimmed and warm light placed on a relatively lower level (reminiscing the sense and the effect of candlelight) is connected to a cozy, relaxing and welcoming atmosphere called “Hygge”. It can be confidently assumed that this warm and dimmed lighting scenario would be perceived as an intimate, positive and relaxing experience for most of the Danish people in a home-like context. However, the perception of such an atmosphere would be different for humans from a different cultural and geographical context.

4. The restorative effects of nature

Individuals’ inherent inclination to affiliate with nature, known as biophilia, can be considered as a commonality among the human species. This notion has led a lot of researchers to investigate the role and the contribution of natural elements, in the architectural context, on humans’ mood and well-being in general.

“The idea of intense exposure to nature as a cure for illness found built form in many countries from about 1885 to 1950 in response to the tuberculosis crisis...sparked new healthcare typologies, like sanatoria...as well as therapeutic architectural features such as roof decks and cure porches” (Peters, 2017, p.26) (Figure 1).

Figure 1: Paimio Sanatorium, Alvar Aalto, 1993

A great number of researches show that the experience of daylight, a natural view and in general natural elements have a positive effect on humans' physiological and psychological state. Humans' connection with nature has been proven to have beneficial effects in anxiety levels, pain relief, hospitalization duration, concentration, and overall satisfaction (Frandsen et al., 2009). "Stressful or negative emotions such as fear or anger diminish while levels of pleasant feelings increase" (Ulrich et al., 2004, p.21)

5. Natural views

Ulrich in his study "A theory of supportive design for healthcare facilities", emphasizes the role of the natural views as a medium of "positive distraction" that contributes to mood elevation and stress reduction. He also argues that views of nature can have a restorative effect on both patients and staff (Ulrich, 1997). A relevant research conducted in a Swedish hospital to heart-surgery patients shows that the subjects who had a view of an image of a natural landscape of trees and water experienced less stress and needed less meditation to cope with the pain than the ones who did not see the image (Ulrich, 1991).

There are additional researches that are claiming that there is a link between access to a natural view and work motivation and productivity. Clay presents that office workers are more productive and satisfied with their work environment when they have access to daylight and a natural view (Clay, 2001).

The window as an architectural element provides a view to the outside world, gives contextual clues regarding the time of the day and the weather conditions, while supports eye muscle relaxation. "The view from a window can affect several aspects of physical and mental well-being. It can, for example, support restorative processes, relieve stress or increase job satisfaction…views into a deep space can relieve the eye and the muscle tonus, and free the cerebral cortex from processing information, leading to cognitive relaxation. Looking at a view speeds-up physiological recovery from a stressful experience" (Knoop et al., 2019, p.10-11).

	STRESS REDUCTION	COGNITIVE PERFORMANCE	EMOTION, MOOD & PREFERENCE
Visual Connection with Nature	Lowered blood pressure and heart rate	Improved mental engagement /attentiveness	Positively impacted attitude and overall happiness

Table 1: A summary of the positive effects of the visual connection with nature on humans' well-being

6. Daylight

A number of laboratory and clinical studies are here to prove the importance of daylight, the ways it stimulates human senses and its therapeutic effects. Patients in a bright daylit room have a shorter hospitalization than others in dull rooms (Beauchemin and Hays,1996). Additional research indicates the beneficial effect of daylight in the treatment of depression, agitation and sleep disorders (Ulrich et al., 2004).

Other studies with a focus on the effect of daylight in work environments, present that the workers who are exposed to higher amounts of daylight are more alert, satisfied and they report a better sleep quality than the workers that have no access to daylight (Boubekri et al., 2014). Van Bommel et al. argue that the variable lighting conditions that daylight offers in an office environment affect positively users' level of alertness and in the occasions where there is no efficient amount of daylight, the experience of dynamic artificial light will be also effective (van Bommel, 2004).

Daylight constantly changes and this characteristic is believed to affect dominantly humans' senses. "People like daylight…There has not been enough research to be certain why we have this desire for daylight. Strong but circumstantial evidence implies that changeability is crucial: the continual variation of brightness in a daylight room is literally, stimulating because our senses respond to change, not to unvarying conditions…natural light, by its spatial and temporal variability, carries information, and this information is at least as important for us as the energy of radiation"(Tregenza and Wilson, 2011, p.5). Tregenza argues that the dynamic nature of daylight, both temporal and seasonal, which results in the movement of light and the variation of intensities and tonalities (Figure 2), is one of the most important driving forces for the activation of body and mind.

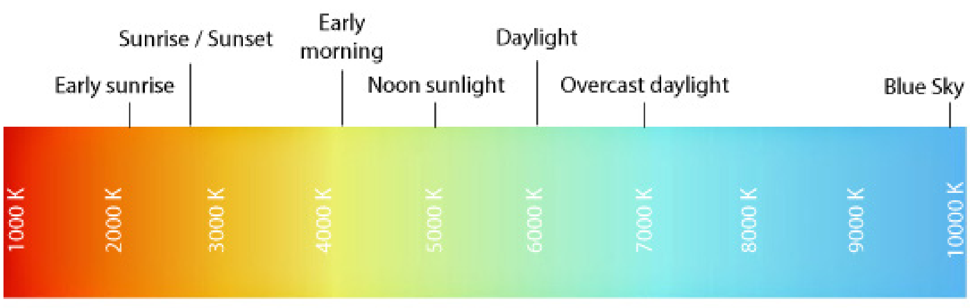


Figure 2: Daylight CCT variations during the day

By experiencing the changeability of daylight, humans consciously and subconsciously receive information that supports the need for orientation, time orientation, contact with nature and the weather. According to William Lam, those needs are characterized as "biological needs" and lighting designers should consider them as very crucial since they affect users' appraisal and spatial perception, as well as well-being (Lam, 1977).

7. Biophilic patterns related to well-being & spatial appraisal

Except for the contribution of natural views and daylight in humans' psychophysiological state, there is overwhelming evidence to argue for the therapeutic effect that biophilic designs, natural and artificial, have on humans' health (Salingaros, 2015). The term biophilic design refers to the direct or indirect incorporation of natural elements in the built environment as a way to connect users with nature and thus to enhance their well-being.

Browning, Ryan & Clancy present some biophilic patterns in order to "articulate connections between aspects of the built and natural environments and how people react to and benefit from them" (Browning et al., 2014, p.21). Each of those patterns has been analyzed according to their effect on users' spatial appraisal and health state. It seems useful to have a look at the ones related to lighting design:

-The combination of "dynamic and diffuse light" creates the sense of a naturally lit environment. Using varying light intensities and shadows, result in a relaxing and inspiring atmosphere that increases users' visual comfort, sense of safety, time orientation and connection with nature (Browning et al., 2014).

Figure 3: The experience of dynamic and diffuse light. "Visionaire, New York, NY. Pelli Clarke Pelli Architects" (Browning et al., 2014, p.36)

-The "non-rhythmic sensory stimuli" refer to ephemeral effects that most of the time occur unpredictably (as happens naturally), creating a fresh and stimulating environment. They are considered as a positive distraction since they lead to physiological restorative effects supporting eye muscle relaxation (Browning et al., 2014).

Figure 4: Non-rhythmic sensory stimuli. "Kinetic membrane of the Brisbane Domestic Terminal Airport Carpark by Ned Kahn" (Browning et al., 2014, p.30)

-“Biomorphic forms & patterns” are used as an effective way to create natural representations indoors that enhance users’ connection with nature. Researches on humans’ view preferences show that natural forms or their representations decrease stress and boost concentration levels (Browning et al., 2014).

Figure 5: Biomorphic forms & patterns. “Facade of Manuel Gea González Hospital, Mexico” (Browning et al., 2014, p.38)

8. The essence of feeling at “home”

When dealing with the context of an eldercare home, it is necessary to bear in mind that this space should not create an institutional hospital-like feeling to its residents. It is very important to consider the fact that elderly residents are often fragile and have experienced a profound change from living in their own homes to moving into a care facility. It is therefore of utmost importance the general atmosphere and consequently the lighting design to create a home-like feeling, facilitating their relaxation, comfort, and safety.

As Percival argues, architecture and architectural elements (including lighting) are able to support and positively affect ageing, by taking into account the use of the space, including social relations, habits, and routines (Percival, 2002).

Mark Vacher, through an anthropological analysis, articulates the notion of home for Danish people. He makes a distinction between the term house, as being the description of just the physical environment-the building, and the term home as the expression of an overall experience one is living in a space where specific activities, social relations and perceptions have been established (Vacher, 2010). These personal routines and relations are the ones that ground the relationship of the individuals with their space and contribute to eventually feel it “home”.

Starks and Trinidad disclose the interrelated relationship between light and home pointing out that humans unconsciously experience this correlation in their everyday life, therefore every shift in this relationship is immediately apparent and affects the experience of home (Starks & Trinidad, 2007). Giving the residents the freedom to control and adjust the ambient of the space, according to their needs, contributes to the establishment of an intimate and cozy relationship among them and their physical environment (Percival, 2002). Following this idea, it is necessary to consider and support residents’ daily routines and activities (eg.knitting, reading, handmade constructions, chatting with friends, etc) through lighting design. In this way, residents will build their own experiences and eventually they will develop the feeling of relaxation, warmth, and safety of being at home.

9. How does light affect human

9.1 Image forming system

The obvious effect of light entering the eyes is to enable vision. Light enters the human eye via the cornea and the pupil, it approaches the lens and then it is projected on the retina. There are two kinds of photoreceptors in the retina that once they are exposed to the light energy, they send the information to the brain through the optic nerve. The two types of photoreceptors are called cones and rods. Cones are located on the retina's center, called fovea, having a 5-degree focus. Cones are able to discern small details and they are the ones responsible for the color discrimination since they are able to process red, green and blue light. Cones are active during the photopic vision (>5cd/m^2). Rods, on the other hand, are considered more light-sensitive, allowing for mesopic and scotopic vision (<0.005cd/m^2). Rods are located on the edges of the retina, ruling peripheral vision. While peripheral vision gives no information regarding color, it is very effective in detecting the change in brightness and contrast, thus it is very sensitive to motion (Tregenza and Loe, 2014).

9.2 Non-image forming system

Except for vision, there are a lot many other physiological aspects that are affected through light. The non-image forming system is the one responsible for these effects on human physiology.

All living species, including humans, have been adapted to the natural day-night cycle by creating biological rhythms, called circadian rhythms. Circadian rhythms are regulated by the biological clock resulting in an approximately 24h sleep/wake cycle, hormones productions, mood stimulation, and other important functions for human health. Humans' exposure to daylight, during the morning hours, ensures the entrainment of the circadian rhythm.

In the past two decades, there has been great progress in research regarding the correlation between light and humans physiology. In 2002 a huge step forward was made when Berson et al. identified a new form of photoreceptor in the human retina. The new photoreceptor is called the intrinsically photosensitive retinal ganglion cell (ipRGC), contains a photopigment called melanopsin, and is the one that involves/leads to circadian phototransduction (Figueiro et al., 2018). The ipRGC passes the signals through the retino-hypothalamic tract (RHT) which leads to the suprachiasmatic nuclei (SCN). The SCN is considered as the master clock in mammals, including humans (Klein et al., 1991), therefore is the one responsible for the synchronization of circadian rhythm and several human physiological events. Finally, the signal is transmitted to the pineal gland, where the synthesis of the hormone melatonin occurs during the dark hours. The hormone melatonin carries the message of darkness, as SCN determined (Figure 6).

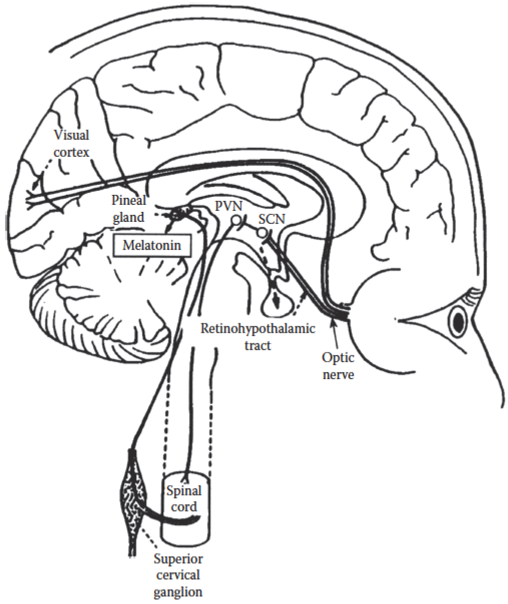


Figure 6: Illustration of the retinohypothalamic tract (Boyce, 2014, p.94)

The normal rhythm of melatonin secretion is to have high levels during night time and low during the daytime. The suppression of melatonin occurs with the presence of light at night and that leads to the disruption of the circadian rhythm. The spectral distribution of the light, the duration of exposure, and the amount of light reaching the retina determine the degree of melatonin suppression (Wood et al., 2013). It has been proven that melatonin suppression is highly influenced by short-wavelength radiation at about 460 nm, meaning that circadian spectral sensitivity is different from CIE standard photopic luminosity function - Vλ that peaks at 555nm (Berson, 2007) (Figure 7).

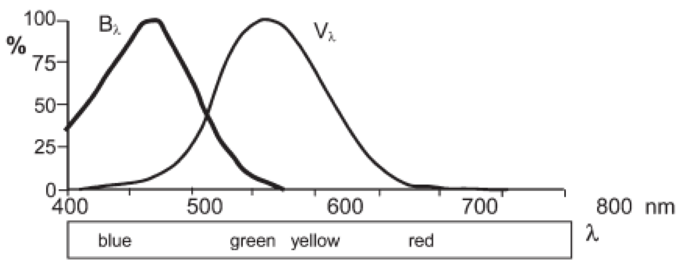


Figure 7: “Spectral biological action curve Bl (based on melatonin suppression), bold line, and the visual eye sensitivity curve Vl, thin line” (van Bommel, 2004, p.257)

It is not yet possible to accurately measure the required amount of light in order to suppress the melatonin in a given degree. The lighting research community still needs more efficient ways to calculate the light incident on the retina, while it is also very crucial to take into consideration the subject’s prior light exposure (Smith et al. 2004). It has been proven that if a subject has been exposed to daylight for at least 4 hours every day for one week, the amount of light that is needed for the suppression of melatonin during night time is increased. Lastly, each individual secrets a different amount of melatonin, therefore we cannot be sure whether there is a different sensitivity to melatonin suppression (Waldhauser and Dietzel, 1985).

Except for the circadian timing system, the "awakening system" (Boyce, 2014) is also a part of the non-image forming system, which is highly affected by exposure to light. More specifically, the production of the hormone cortisol, which releases the energy our body needs to go from an inactive to an active situation or as a response to a stressful condition, is affected by exposure to light. Cortisol itself has a circadian rhythm, which peaks the first hours after awakening and then fades away until the early night. The cortisol rhythm has been proven to have a phase delay with exposure to light at specific times. However, unlike the melatonin suppression, cortisol concentration seems to be increased with exposure on both short-wavelength (blue) and long-wavelength (red) irradiation (Figueiro and Rea, 2010) (Figure 8).

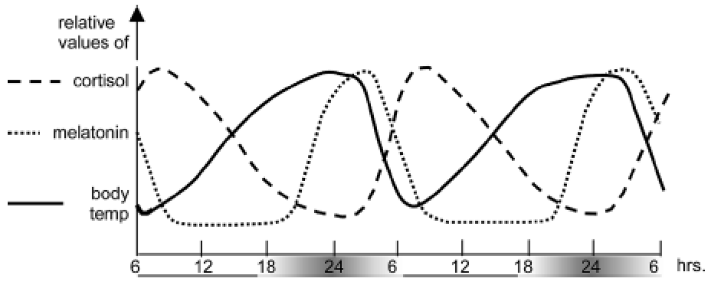


Figure 8: "Double plot (2 x24 h) of typical daily rhythms, between their relative minimum and maximum values, of body temperature, melatonin, and cortisol in humans for a natural 24-h light/dark cycle" (van Bommel, 2004 p.261)

Summing up, the non-image forming system is affected by the lighting conditions, contributing to the regulation or the disruption of the circadian rhythm. The circadian rhythm is responsible for several very essential body functions for humans health, such as sleep-wake cycles, hormones' production, etc. The modern lifestyle demands most of the day to be spent in the built environment, having minimum contact with nature and therefore with the natural light. Additionally, during the evening a great number of people of all ages are exposed to blue-enriched light, emitted from shelf-luminous LED screens (televisions, smartphones, tablets, etc) or from indoors and outdoors electrical lights. Both lack of exposure to daylight or intense blue electrical light during morning hours, and evening exposure to blue light, affects negatively humans' circadian rhythm. Circadian rhythm disruptions have been proven to be linked to sleep disorders, depression, seasonal affected disorders (SAD), decreased task performance, obesity, diabetes, etc.(Figueiro et al., 2018).

10. Circadian Stimulus Metric

The Lighting Research Center of the Rensselaer Polytechnic Institute has proposed a new metric called Circadian Stimulus (CS) that aims to measure the effects of artificial light on humans' circadian rhythm, having as an indicator the melatonin suppression that occurs from light exposure. The CS gets values from 0.0 for no suppression to 0.7 for maximum melatonin suppression.

The Circadian Stimulus does not take into account additional parameters that are necessary to determine the circadian stimulation of light. That is, the exposure history of the subject in a 24h cycle, the duration, the distribution, and the timing of exposure (Rea and Figueiro, 2016). Therefore those parameters need to be calculated alongside the CS metric.

The Lighting Research Center created an online Circadian Stimulus calculator for all possible combinations of light sources (commercial or custom ones) and intensity levels, which is available for free on the following website: http://www.lrc.rpi.edu/programs/lightHealth/index.asp. In this way, the calculation of the Circadian stimulus is an easy procedure that can be done using regular photometric tools to measure the spectral power distribution and the intensity of the light (using spectrometer and illuminance meter respectively) and then by just inserting the values in the calculator.

Experimental researches that use this metric, prove that it can be considered as one of the most efficient predictors of melatonin suppression. The Lighting Research Center has proven that a light exposure with a CS value of at least 0.3, for at least one hour in the (early) morning, has a positive impact on the regulation of the circadian system and consequently on sleep quality and mood (Rea and Figueiro, 2016).

11. The effect of light on work performance

Peter Boyce in his book “Human factors in lighting” presents that lighting can affect work performance through three different ways:

a. the visual system
b. the circadian system
c. mood and motivation

The visual system (a) is affected by the technical characteristics of light (illuminance, light distribution, color temperature), in regards to the nature of the certain task and its characteristics (size, contrast, amount of details). On the other hand, the effect of the lighting conditions on the circadian system (b) depends on the illuminance level, the duration of subject’s exposure, the timing, the spectrum of light, and subject’s light history. Daylight or intense blue light during daytime is an effective entraining stimulus resulting in better performance. Exposure to light during nighttime may disrupt the circadian system that leads to an inability of task fulfillment, feeling of fatigue, and reduced health conditions. The final path through which lighting can affect work performance is mood and motivation (c). Undoubtedly, light can be used to change one’s mood, at least for a short time period (Baron et al., 1992). Lighting attributes as the illuminance and the correlated color temperature have been shown to affect humans’ psychology and therefore behavioral state (McCloughan et al., 1999). Boyce et al. argue that the primitive way to ensure humans’ satisfaction and positive mood in their work environment is by providing them with a sufficient lighting system in regards to their task and also some level of control over the lighting on their workplace (Boyce et al., 2006).

12. Night-shift workers

Humans' physiological rhythm is to be active during the daytime and inactive during night time. Therefore, when someone needs to be active during the hours that their system should actually be sleeping, experiences some difficulties. Firstly, an immediate effect occurs on their ability to perform effectively their tasks and secondly more serious issues arise regarding the disruption of their circadian timing system. The longstanding condition of insomnia during night time and excessive sleepiness during daytime has been characterized as "Shift work disorder" since it affects the majority of the night shift workers (Morgenthaler et al., 2017). The Shift work disorder has been correlated with the feeling of fatigue, malfunctions to the metabolic system, cardiovascular diseases and other chronic disorders (Jensen et al., 2016).

Some experiments have been made that aim to find the proper lighting condition that the night shift workers should be exposed to, in order to overcome the feeling of fatigue and give a boost on their levels of alertness, without disrupting melatonin's secretion. Light exposure during the night time has a profound impact on alertness, either by suppressing melatonin or by increasing cortisol. Cortisol has been shown to increase levels under the exposure of both short and long wavelengths (Boyce, 2014). Taking into consideration this fact, Figueiro et al. compared the effect of monochromatic red light (213 lux, 630nm) and dim light (<5lux,3500K) on the brain's activity. The red one had a greater effect without suppressing melatonin. However, when they compared the red light with a warm light (361lux, 2568K) they saw that the warm one was more effective on increasing alertness. Although the red one has a smaller effect on alertness, it is still a piece of evidence that it is possible to boost alertness during the night without influencing melatonin (Figueiro et al., 2016).

An additional fact worth to take into consideration is subjects' history exposure to light. In a relevant study Hébert et al. prove that when a subject is exposed to the morning daylight for a sufficient amount of time, then their circadian timing system sensitivity appears lower levels. That is, night shift workers' exposure to morning daylight (or intense blue light) is of great relevance in order for their melatonin production to not be disrupted so easily from the light exposure during the nighttime (Hébert et al., 2002).

There are other researches trying to figure out ways to successfully create a phase shift on the circadian timing system of night shift workers. This phase shift is necessary in order for them to be able to sleep the morning hours when they end their work. In order to guarantee a phase shift, it is mandatory to control subjects' 24h exposure to light. That being said, it is necessary to be aware and somehow control subjects' exposure to daylight on their way back home. Additionally, it has been proven that humans' system needs about 15 days in order to make a total phase shift (Monk et al., 1978), that means that situations where the rotation of the shift system is very fast, do not allow for an effective phase adaptation.

Smith et al. have demonstrated a protocol where they expose the night-shift workers on an intermittent bright light (4100 lux, 5095 K) emitted by fluorescent lightboxes for 15 minutes every hour, while the general illumination has an intensity of < 50 lux and CCT of 4100K. In this way, they partially entrain night-shift workers' circadian rhythm in a way that the time of maximum melatonin concentration is shifted to 10:00 am (when the night-shift workers return to their homes). Using this light pattern schedule seems to have also a positive effect on their mood, alertness, task performance, and feel of fatigue. Taking into consideration the importance of the subject's 24h light history, they argue that it is necessary for the subjects to wear sunglasses when they are outdoors during the day and also to sleep in a completely dark room (Smith et al., 2009). The aforementioned study is focused on permanent night shift workers (having 3-5 night shift in a row and 2 days off), that being said the humans' system slow phase adaptation does not act as a deterrent on this occasion. However, it is not proven whether this light pattern schedule would be equally effective in rotating night shift workers.

13. Optical changes with age-the role of lighting

As time passes, the functional abilities of the human eye fade. This has an impact on both image-forming and non-image forming systems. Eye lenses gradually develop a yellow pigment, that leads to the increase of the amount of scattered light, to the reduction of image quality and visual acuity, to the increase of the sensitivity on discomfort glare, and to the reduction of contrast sensitivity and color discrimination. Additionally, the older the eyes the less the transmittance of the visible spectrum, especially for short-wavelength light. The absorbance of shorter wavelength light can cause the fluorescent effect on older eyes, but this does not affect the quality of the retinal image. On the other hand, this has a great impact on the non-image forming system and specifically on the circadian timing system. The overall result is the reduction of the ability of the circadian timing system adjustment to the 24h day-night cycle, which can lead to a lot of critical physiological and psychological malfunctions such as the decrease of alertness, mood, cognitive functioning and sleep disorders (Knutsson et al, 2004).

Lighting can be used as an effective tool to overcome both the difficulties in visual performance and the disruption of the circadian timing system. Undoubtedly higher illuminance benefits the elderly's visual performance. However, it is necessary to be very careful with the way the high-intensity light will be provided, in terms of distribution and directionality, in order to avoid any possibility of discomfort or disability glare. An additional way that accounts for the improvement of visual performance is to increase the luminous contrast of the salient parts of the surrounding environment. For example, a high-luminance contrast between door and door-handle or door-frame would be a very effective way for elder people with some sort of sight loss or visual difficulty to easily navigate and feel safe and confident to move (Boyce, 2014). High importance should also be given to the transitions from a brighter to a darker environment, due to the elderly's decreased dark adaptation.

Hence, the transition should be smooth without big and fast differences in light intensities (De Lepeleire et al., 2007).

Danish regulations do not include enough specifications in regard to artificial light and especially to account for elderly people or people with impaired vision. One of the most relevant guidelines the Danish Standard DS700 includes regarding visually impaired people, is that the contrast in the reflectance of the surfaces between the walls, the doors, and the door frames should be at minimum 0,4 and for areas like staircases that are more dangerous, the difference of the reflectances should be 0,75 (Frandsen and Mathiasen, 2017).The "SBi guidelines 230" introduce some specifications that are very beneficial for this particular target group. According to them, artificial light must provide guidance, emphasize important architectural elements or spaces such as entrances or crossroads, and should not create any glare issue (Frandsen and Mathiasen, 2017). All in all in order to provide an efficient visual environment to elderly people or visually impaired people, the lighting design should provide " directional light which highlights important entrances or intersections of shared access routes; light which describes the boundaries and shapes of rooms etc.; light which offers well-balanced contrasts without glare (concerning the reflectance from surfaces); and light which entails a shadow pattern that enhances form and distance" (Frandsen and Mathiasen, 2017, p.244).

Regarding the ways lighting can help with the regulation of the circadian timing system, it has been proven that increasing the subject's light exposure during day time and by diminishing it during night times has a positive effect. Ideally, the subject should be exposed to sunlight (indoors or outdoors), but on the occasions that this is not possible Mishima et al. (2001) have shown that the exposure to a full-spectrum fluorescent light source of 2500lx at the eye for two hours two times per day, can regulate melatonin and circadian rhythm and diminish insomnia in elderly people (Mishima et al., 2001). It is known that the short-wavelength light is the one that suppresses melatonin's production, thus the light therapy using a lower illuminance light (400lux) enriched with short-wavelengths visible radiation (blue light) is able to produce respectively positive results (Figueiro et al., 2014). In a more recent study Figueiro et al. demonstrate the effectiveness of a lighting scheme that provides CS of >0.3 during daytime and CS <0.1 during nighttime, in regards to sleep quality and duration, and levels of depression and agitation in demented people and their caregivers (Figueiro et al., 2015).

The ideal scenario is a lighting design to support both visual performance and circadian rhythm. In this regard, Figueiro (2008) proposes a lighting design that provides high-quality visual conditions during the daytime while enhancing circadian rhythm stimulation and provides a low-level illumination during the night that creates a safe environment to move while maintaining a low circadian stimulation. The proposed lighting scheme recommends "at least 400 lx of circadian-effective light at the cornea during the day, no more than 100 lx of circadian-ineffective light at the cornea during the evening and no more than 5 lx of circadian-ineffective light at the cornea during the night.

Circadian-effective light is rich in short-wavelength power, circadian-ineffective light is not" (Boyce, 2014, p.516-517). To ensure the best possible visual performance, the recommended light intensities should be delivered taking into consideration the light distribution and directionality in order to avoid any glare issues and to be sure that there will be a sufficient amount of light on the task areas with good color rendering.

14. Human-Centric lighting / Circadian Lighting

Following the evidence-based knowledge regarding the way light affects human health, the lighting industry has been reinforced around design and health. Known as circadian lighting or human-centric lighting, these lighting design systems follow the dynamic character of daylight, in order to entrain humans' circadian rhythm and generally empower all the positive effects daylight has on humans' physical and mental state.

The circadian lighting systems use various software and control systems, combined with LED - light-emitting diodes technologies in order to reproduce daylight's changing spectra.

The existing circadian lighting systems, so far, achieve this dynamic element either by tuning the illuminance (brightness) following the time of the day, or by simultaneously changing brightness and tonality (CCT) to emit bright cool light during daytime and dimmed warmer light during evening and nighttime, or by adjusting light's wavelength to exclude/reduce the short wavelengths during evening and nighttime.

15. Literature Review Summary

- The physical environment in a healthcare context plays a significant role in users' well-being.

- Light as an architectural element and as a medium of creating atmospheres can affect humans' experience towards well-being.

- It is of great importance, as Richard Kelly suggests, to combine the three layers of light: "focal glow", "ambient luminescence" and "play of brilliants", in order to create an atmosphere that supports users' both physical and emotional needs (Kelly, 1952).

- Humans' geographical and cultural environment affects their expectations and preferences regarding light. Danes associate the feeling of relaxation and coziness with a warm dimmed light placed on a lower level.

- Access to daylight, natural views and natural elements, in general, have a profound effect on humans' psychophysiological state, even when they are just artificial representations.

- It is crucial, as Lam states, the lighting design to account for users' both activity and biological needs, thus taking into consideration the need of orientation, time orientation, relaxations, connection with nature and weather (Lam, 1977).

- The notion of home grows with the establishment of social relations and activities between the residents and space (Vacher, 2010). So lighting design in eldercare homes must support the routines and needs of residents in order for them to develop a sense of security and relaxation.

- The exposure to short-wavelength light (blue light) has an acute effect on melatonin suppression (Berson, 2007).

- Exposure to long-wavelength light (red light) has been shown to affect alertness without disrupting the circadian rhythm (Figueiro et al., 2016).

- Circadian stimulus metric measures the effect of artificial light on humans' circadian rhythm. Rea and Figueiro argue that light exposure with a CS value higher than 0.3 for a minimum of one hour in the morning, has beneficial effects on the entrainment of the circadian rhythm and therefore on sleep quality and mood (Rea and Figueiro, 2016).

- Exposure to morning daylight for a sufficient amount of time lowers the impact of blue light on melatonins' production during nighttime (Hébert et al., 2002).

- To ensure a good work performance it is needed that the light fulfills the needs of the visual system, the circadian system and enhances mood and motivation.

- Providing flexible solutions and a sense of control leads to a positive experience for both residents and staff.

- Ageing contributes to the malfunction of vision. Well-balanced contrasts and directional lighting that points out architectural forms or silhouettes ensure a good visual environment for visually impaired people (Frandsen and Mathiasen, 2017).

- Elderly people need illumination of higher lux levels for efficient visual performance and circadian entrainment. For the implementation of such high levels of intensity, attention is needed due to their glare sensitivity.

- Figueiro et al. have proven that exposure to light with a CS higher than 0.3 during daytime and lower than 0.1 during nighttime is very beneficial for both residents' and staff's health (Figueiro et al., 2015).

- Circadian lighting follows the dynamism of daylight and it has been proven to control sleep-wake cycles and improve humans' mental and physical state.

4

Case Study Analysis

1. Introduction

Case study analysis introduces Albertshøj eldercare home. It identifies the focal area of this project, the different spaces within this area and their individual characteristics, all linked to the actual use of them throughout the day. The chapter continues with a combination of qualitative and quantitative analysis which, through photographic material, architectural and electrical drawings, and 3D simulations, examines the conditions of daylight and electric lighting in the defined area. Emphasis is given on how natural and artificial light affect the illuminance levels, the functionality and the atmosphere of the space. The chapter concludes by analyzing the users of the space, their attributes, schedules and needs.

2. Albertshøj eldercare home

Figure 9: Albertshøj eldercare home

Albertshøj eldercare home is located in Albertslund Municipality, 15km west from central Copenhagen. It is built in 2016 and is a part of Albertslund's healthcare center. Albertshøj consists of 81 homes for one or two residents, staff's offices and common areas such as shared living rooms, kitchens, dining rooms and a roof garden.

The project will focus on the 3rd floor of Albertshøj. The 3rd floor has 21 rooms and it is divided into two groups, one smaller with nine residents and one larger group with twelve residents. There is a big hallway connecting the private rooms the communal areas, the offices, and the shared toilets (Figure 10).

Figure 10: Floor plan - space analysis

All of the private rooms are spacious and have their own toilet. In each of them, big windows allow daylight to penetrate the space, providing mainly urban views. The residents are allowed to bring their furniture and decorate their private space using their objects, including luminaires.

The anthropological part of the LIGHTEL project (see more in the "State of the art" chapter, 5.2) provides insights regarding the way residents use their private rooms and ways that their personal luminaires help them set the atmosphere and the desired conditions in their practice of home. The findings of the project indicate that residents have linked the use of their luminaires with previous experiences and therefore they have created an emotional connection with them (Schledermann et al., 2020). Taking this fact into consideration, it is decided that the lighting design proposal will not include residents' private rooms since in these areas it is not feasible to have absolute control of the light. However, as it will be shown in the "State of the art" chapter, it is very important to keep in mind the ways that residents use light and shape their atmosphere according to their activities and the time of day, in order to understand how the use of light enhances intimacy and leads users to create a home-like feeling.

3. Focus Area

The lighting design proposal will be focused on the common areas of the third floor of Albertshøj eldercare home.

The common areas consist of the hallways, the kitchen/dining room, and the living rooms (Figure 11). The hallways are transitory spaces that connect all the other spaces. There are 2 living rooms that are used throughout the whole day. Living rooms are the spaces where residents meet each other, socialize, discuss and carry out their daily activities such as reading, knitting, watch television, etc. The kitchen/dining room consists of two sections that are fully equipped with electrical appliances (oven, refrigerator, hood) and the rest kitchen equipment (sink, cupboard, etc.), and a large hall with dining tables, which can be divided in half creating two identical spaces. The kitchens are used mainly by the staff for the preparation of meals and less often by the residents. The dining room is used primarily for meals, but also as a gathering area or a place where residents carry out activities mainly in the morning and early afternoon. Albertshøj's intention is the communal areas to act as an extension of residents' private space.

The kitchen/dining room has big East facing windows allowing the morning sun to enter the space. The living rooms are located on the other side of the building, having big westward facing windows and thus allowing sunlight to enter the area during sunset. There are no tall buildings in the surrounding area of the building, so natural light intake is as high as possible.

Figure 11: Floor plan - focus area

4. Electric Lighting

The existing electric lighting in the 3rd floor is a regular lighting system that emits static light with specific intensity and color temperature throughout the day. Albertshøj's intention is to replace the existing lighting with the circadian lighting system that is already implemented on the 5th floor. Therefore the electric lighting analysis is focused on the attributes of the lighting system of the 5th floor with the aim of highlighting its strengths and weaknesses.

Due to the restrictions imposed during COVID-19 pandemic, it was not possible to conduct any observations or measurements in the eldercare home. Therefore all the necessary information regarding the electric lighting and the operation of the space, in general, were retrieved from the architectural and electrical drawings of the space, and LIGHTEL project data folder in Aalborg university's archive (see more about LIGHTEL project in the "State of the art" chapter, 5.2).

For the general illumination in the common areas, recessed ceiling LED fixtures have been used providing a uniform illumination throughout the whole space. The selected fixtures have an opal covering avoiding any glare issue. They emit a maximum luminous flux of 6600 lumens, they are 0,1-100% dimmable and emit varying CCT from 1800K to 6500K.

In the dining room, some additional fixtures have been placed on the top of the dining tables (Figure 12). Those fixtures are LED pendants that are also covered with an opal surface to avoid any glare issues. They provide a maximum luminous flux of 800 lumens and they have a stable color temperature of 3000K.

In the living room, a floor lamp is placed in between two armchairs creating a cozy spot, there is also a functional articulated wall luminaire that can either be used for reading or for other activities and finally, some sparse candles are placed in the space (Figure 13). The floor lamp emits a maximum luminous flux of 1100 lumens, providing a warm illumination of 2700K. Finally, the wall luminaire has a luminous flux of 700 lumens and a color temperature of 2800K.

Figure 12: Albertshøj's dining area

Figure 13: Albertshøj's living room

Figure 14 illustrates the location of the different lighting fixtures throughout the space.

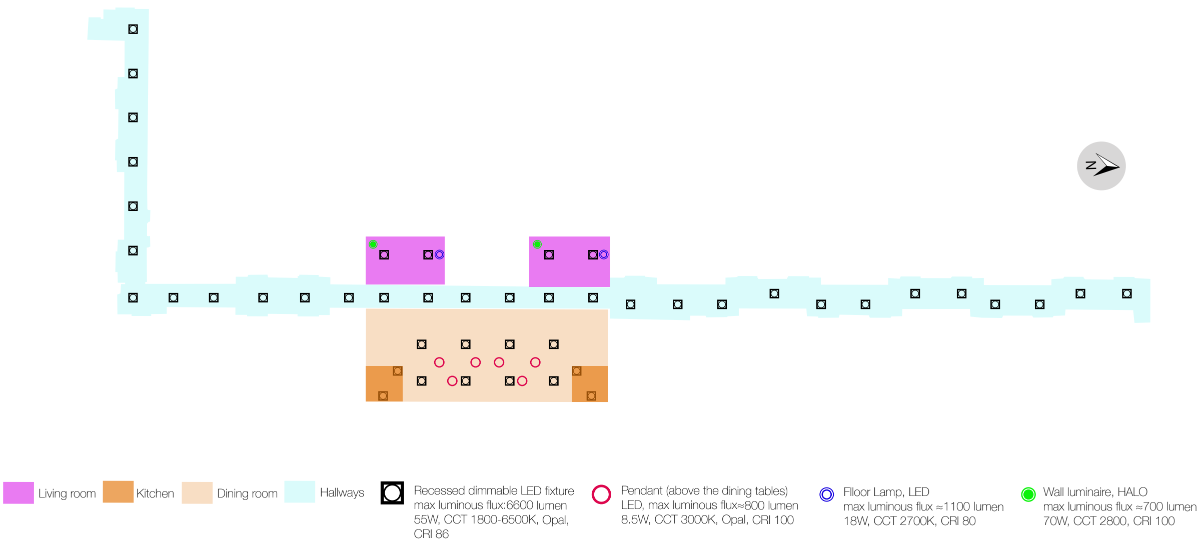


Figure 14: Electric lighting layout

The variations of the intensity and the color temperature of the light during the day are intended to enhance the circadian rhythm of both residents and staff, following the principle of providing intense blue-enriched light in the morning and warm low-intensity light during evening and nighttime.

Particularly, during the awakening time (around 7:30 am) the light has transformed from dark to warm white, and over the next two hours (around 9:30 am) it gradually becomes brighter with a color temperature of 4000K. The brightest and coolest light, with a CCT of 5500K, is emitted between 12:00 and 14:00. During the evening time, the light starts to become warmer by excluding the blue component of its spectrum. At dinner time (around 17:30), 70% of the maximum intensity is emitted with a CCT of 3000K, and from that moment the light gradually decreases to reach the night scenario. During the night, the common areas are illuminated with a very subtle and warm light that does not include any short-wavelength in its spectral composition. In this way, minimal circadian disruption is ensured for both residents and staff while creating a safe and relaxing environment.

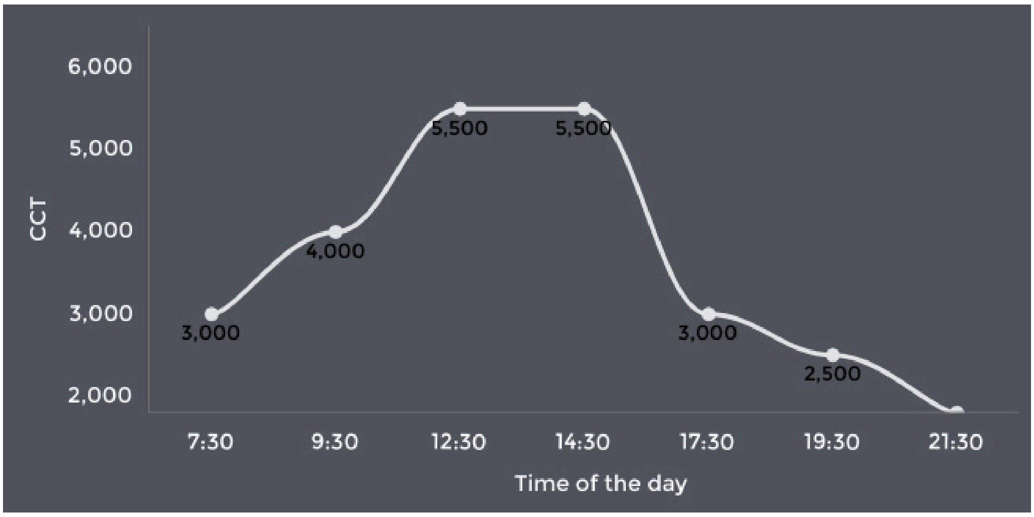


Figure 15: Electric lighting CCT variations during the day

Figure 16 is a false-color illuminance map, created in Dialux software, showing the maximum illuminance levels that the existing luminaires provide to the space. The illuminance calculations conducted on a horizontal plane at a height of 0.9m (table level). The overall result is a fairly uniform illumination of the common areas with an average of 500 lux in hallways and living rooms, and a slightly higher illuminance levels in the kitchen/dining rooms ranging from 500-750 lux.

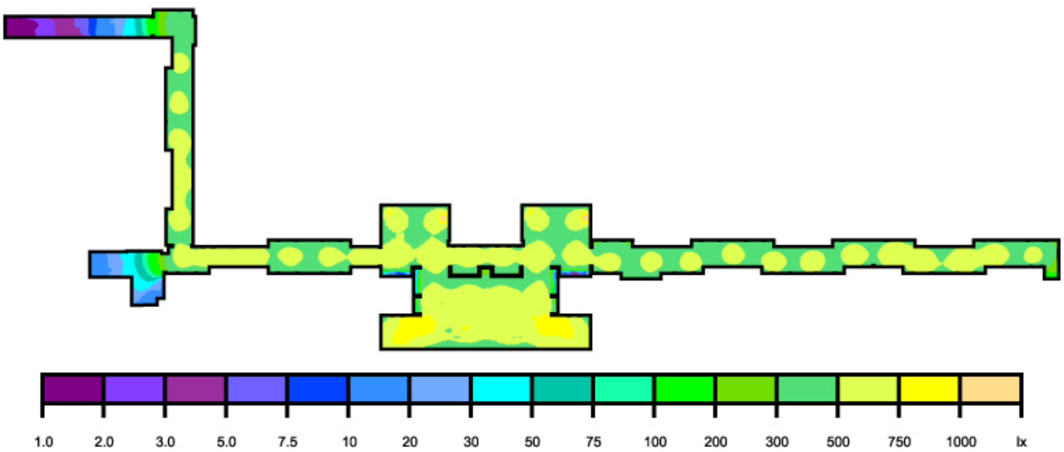


Figure 16: False-color illuminance map of electric lighting (maximum intensity)

Regarding the illumination in the hallways, the rather uniform illumination is efficient, however, there are no additional lighting elements that could increase the sense of orientation. It is important to note that some interior design elements are used to facilitate wayfinding; the walls adjacent to the entrances of residents' private rooms are painted with varying green colors, while all the other walls and doors are white (Figure 17). The difference of the reflectances is considered to be an effective way of enhancing the visual performance and orientation of the elderly, however, the placement and use of light, especially in the evening/nighttime scenario is not effectively used in the direction of this goal.

Figure 17: Albertshøj's hallways

As for the kitchen/dining area, attention has been given on creating a warmer atmosphere focused on the tables that seems to satisfy not only the functional needs of the space but also the atmospheric ones.

In the living room, the use of the wall-mounted spotlight supports functional needs for reading or other activities. Additionally, the use of the floor lamp effectively creates a warm and relaxing spot. However, apart from the general lighting, there are only two additional lights in the room and in combination with the choice of their location, in an evening or nighttime scenario they are not able to allow more than one user to perform activities, such as reading or knitting, or more than two users to experience the relaxing atmosphere created by the floor lamp.

Considering the overall electric lighting situation in the communal areas, it would be reasonable to argue that the placement of the general lighting fixtures (that are placed mainly in a row), their design (big ceiling recessed circular shape fixtures with a diameter of 600mm), the fact that only one type of fixtures is used and finally the uniform distribution of the light seems to create a rather institutionalized feeling.

Further, the existing lighting does not provide any additional visual stimuli that could excite the users' senses. That being said, if we consider Richard Kelly's three layers of light, the existing lighting system fulfills only the first two ones; the "ambient luminescence" with the use of the ceiling fixtures and the "focal glow" with the use of the pendants in the dining room and the functional lights in the living room. There is no lighting element representing Kelly's "play of brilliants". This third layer of light is the one aiming to stimulate users' senses and finally, the combination of all three layers of light is able to create an atmosphere that satisfies users both physically and mentally (Kelly, 1952).

All in all, the main weaknesses that “electric light” analysis reveals are:

- The fairly institutionalized atmosphere produced by the general lighting.

- The lack of lighting elements that stimulate users’ senses (except for the dynamism of general lighting).

- In the hallway, there is a lack of lighting elements that enhance user’s orientation and sense of safety.

- In the living rooms, there are very few functional or low-height lights that could support users’ activities and “hygge” atmosphere.

5. Daylight

Ideally, the analysis of daylight includes on-site observations. These would allow an in-depth understanding of how the different dynamics of daylight affect the illumination of the space and thus the experience of it throughout the day. Unfortunately, privacy issues and others related to the operation of the nursing home due to restrictions imposed during the COVID-19 pandemic, do not allow for these observations to occur. Therefore, the daylight analysis is based on 3d simulations and visualizations made in Velux and Dialux software.

The experience of daylight
An annual analysis of the way daylight penetrates the dining room and living room is made for a time span from 6:30 am to 7:30 pm for a clear sky weather condition with direct sunlight (Appendix 1 & Appendix 2).

The dining room has big windows facing east, therefore direct sunlight enters the space during the first morning hours (6:00-10:00 am) creating distinctive shadows out of the window frame that travel throughout the whole space (Figure 18). The movement of the sunlight effect in the space creates a rather intense atmosphere that can lead to a direct correlation with the passage of time. A high amount of daylight penetrates the dining room, mainly during the spring and summer months (March until September) for the morning hours until late noon. As the sun starts to set, the overall amount of daylight declines gradually and eventually no daylight enters the space.

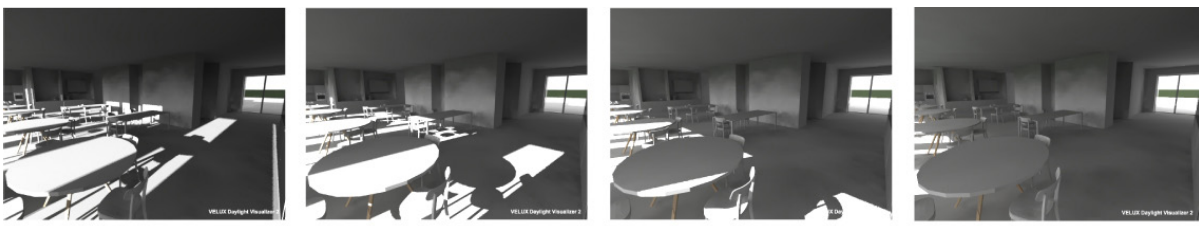


Figure 18: Sunlight effect_Dining room | April | Sunny | 6:30-9:30 am

The living rooms have big windows facing west. The depth of the living room is relatively small (≈3.8m) and, as it is mentioned, the size of the window is big (4,5 m width, 2,5 m height), allowing daylight to penetrate the space almost during the whole day. The illumination of natural light is becoming rather intense once the sun starts to culminate. Almost throughout the whole year, in clear sky weather conditions, during the early afternoon (around 13:00) direct sunlight starts entering the space creating intense shadows out of the frame of the windows (Figure 19). In the same way with the sunlight effect in the dining room, the window frame shadows create linear geometries that alongside with the change of the seasons and the time, they move throughout the space. The climax of the sunlight effect takes place during the summer months, where the light shadows move all over the place creating a spectacular scene depicting the entire course of the sun leading to the end of the day (Figure 19).

Figure 19: Sunlight effect_Living room | April | Sunny | 6:30-9:30 am

Considering the color variations of daylight, it is reasonable to conclude that unlike the morning sunlight effect where the light is cool and refreshing, this, in turn, creates a warm and relaxing atmosphere.

During the spring and summer months that the sunlight effect occurs in its greater performance, the users of the space are able to experience it regardless of their position. The architecture of the communal spaces is such that one sitting on some spots of either living or dining room is able to look through the other space. Thereby, not only the users of the living room but also the ones of the dining room are experiencing the sunlight effect during sunset or respectively during sunrise (Figure 20).

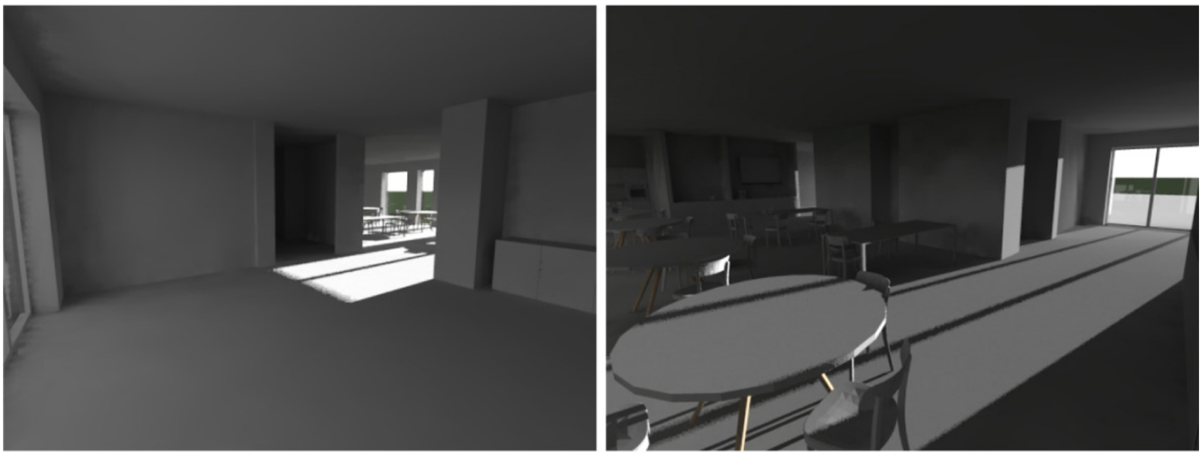


Figure 20: Sunlight effect_Living room during sunrise & Dining room during sunset | August | Sunny

All in all, when the sunlight enters the space, it creates an ever-changing experience of light, space and time. It connects users with Earth's rotation and thereby the seasonal and day passage while also accentuates the spatial depth and architectural attributes resulting in an overall stimulating and pleasant experience of the space.

Unfortunately, the weather conditions in Denmark and in northern climates in general, do not allow sunshine to occur very often though. The average daily sunshine hours in Copenhagen from October until March are very minimal (1-4 hours) (Appendix 3), and therefore the users most likely are able to experience the aforementioned effect mainly during summer months.

Taking into consideration the beneficial effects of daylight in humans' well-being (as it has been analyzed in the literature review chapter, 3.6), it is reasonable the lighting design to focus on ways that could supplement daylight or even recreate the feeling of daylight in the space to balance its absence during the dark days of the year.

The illuminance of daylight

Visualizations in Velux software are made to provide information regarding the maximum illuminance levels that daylight provides during the year and specifically the spring equinox, summer solstice, fall equinox and winter solstice in four different times of the day (Appendix 4). Figure 21 depicts the highest daylight illuminances during four different times of the year, at the time that the sun is at its highest point. The living room seems to be the brightest space, having an average illumination of 400 lux during June and September, ≈300 lux in March and ≈200 lux in December. The dining room seems to be similarly bright but only in the areas next to the windows, while as the distance from the window increases, the daylight intake decreases accordingly.

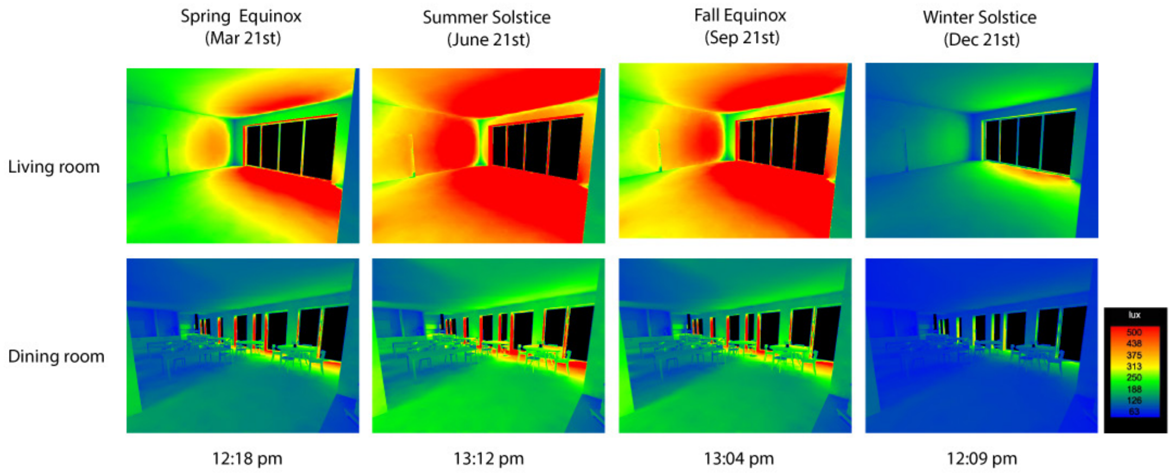


Figure 21: False-color daylight illuminance map during the spring equinox, summer solstice, fall equinox & winter solstice, for sunny weather conditions, at the time where the sun is at its highest position

As described in the previous section, due to the orientation of the communal areas, the dining room is illuminated directly by sunlight at sunrise and the living room during sunset. Therefore, the illuminance levels during these periods of time on a sunny day are definitely much higher (Appendix 4).

Dialux software is used to display the maximum illuminance levels when the space is illuminated from both electric and natural light. The illuminance calculations conducted in a horizontal plane at a height of 0.75m (table level). Figure 22 depicts the illuminance levels on a sunny March day at 9:00 am. Direct sunlight penetrates the dining room, therefore the illuminance levels are extremely high (reaching 15000lux) at the areas right in front of the windows and the illuminance in the rest of the space is at least 1000 lux. The illuminance levels in the dining room vary from 750-1000 lux, while in the hallways there is only one small part with access to daylight so the illuminance levels are mainly determined by electric light.

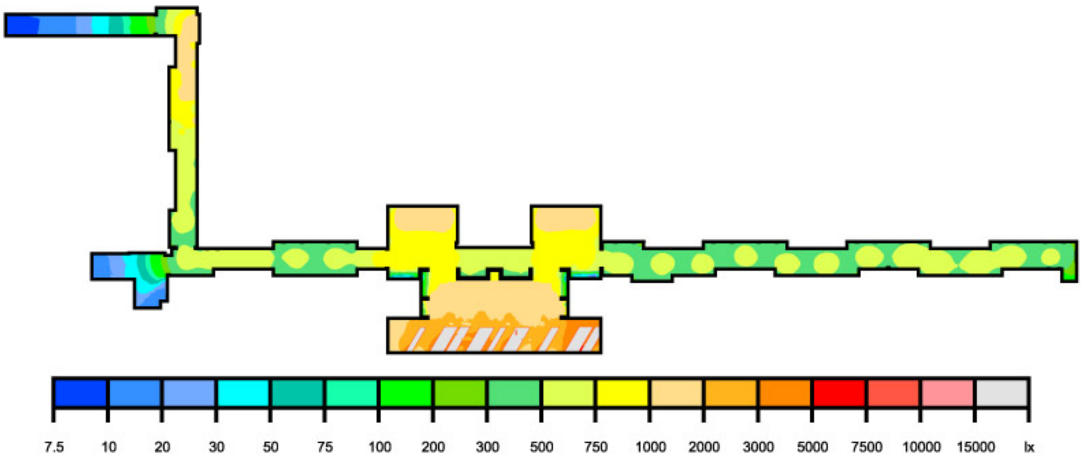


Figure 22: False-color illuminance map of both electric & natural light | March | Sunny | 9:00 am

6.Users

The users of an eldercare house can be categorized based on their different needs and expectations. There are three main categories, the residents - elderly people, the staff and the visitors. This report will focus only on the first two groups of users (residents and staff) since their needs are considered as the most important to determine the characteristics and qualities of the proposed lighting design.

The **residents** are people with varying physical and cognitive abilities. In specific, on the third floor, which is the focus area of this thesis, residents have no or low levels of dementia, meaning that they are quite self-sufficient.

The daily schedule that is followed is quite flexible and every resident is allowed to set their own specific schedule according to their personal routines. They are allowed for example to specify their preferable waking-up time. However, there is a loose time schedule which is as follows:

Waking-up time	Breakfast	Morning activities	Lunch	Relaxation time-Siesta	Afternoon activities	Dinner	Evening activities	Sleeping time
~7:30 am	~8:00 am	9:00 am - 12:00 pm	12:00 pm	13:00 -14:00 pm	14:00 -17:30 pm	17:30pm	18:00 - 22:00 pm	22:00pm

Table 2: Albertshøj's daily schedule

In the morning, residents use both the living room and the dining room for their morning activities. They perform individual activities such as reading newspapers/ books, handicrafts, etc. or group activities with other residents, such as card games. In addition, accompanied by the staff, residents can take part in food preparation or perform physical activities such as stretching or exercises adapted to their physical abilities. While the day passes (mainly after lunchtime), residents mostly use the living room. Residents' afternoon and evening routine includes socializing with each other, performing crafts, watching television, reading, and more.

The **staff** consists of skilled social and health assistants, nurses, and activity workers. They are responsible for ensuring a safe and enjoyable stay for residents. Their main duties in the communal areas include supervising residents throughout the day, providing assistance and care to residents, providing their medication, preparing food, and participating in residents' activities.

5

State of the art

1. Introduction

In this chapter, the LIGHTEL project is presented. Its anthropological aspect, in particular, constitutes an excellent approach, exploring how new circadian lighting, when applied in an eldercare home, has not only physical but also mental and psychological impacts on everyone involved. Valuable insights are provided about residents' practice of home and the challenges experienced by residents and staff collectively, when new lighting conditions occur in the space.

2. LIGHTEL

In 2017 a project called LIGHTEL took place in Albertshøj assisted living facility for elderly people with varying degrees of dementia. This is a project that was implemented with the collaboration of Alberslund's municipality, Aalborg university, Chromaviso, Gate 21 and Hvidovre hospital. A Circadian LED lighting system, provided by Chromaviso - a Danish company specialized in health-promoting lighting, was applied throughout the 5th floor of the nursing home (private rooms, hallways, common areas, and staff rooms). The aim of the project was to investigate the effects of the Circadian LED lighting on Albertshøj's residents. As part of this study, Aalborg university conducted an anthropological study, where qualitative methods were implemented in order to examine how the new lighting affects users' well-being and daily routines (Schledermann et al., 2020).

As it is described in the "Electric Lighting" part of the "Case study analysis" chapter (4.4), the lighting system that was implemented changes around the clock following the natural transition of daylight in brightness and tonality. The brightest and coolest light is emitted during midday and when the sun is set the light is transformed into a dimmed warm one excluding all the blue tones. During the nighttime, the circadian lighting of the private rooms is turned off and a quite subtle warm light is turned on in the bathroom to enhance safety. In the hallways the circadian lighting remains on, emitting the warm dim night lighting. The correlated color temperature (CCT) varies from 1800K to 6500K while the intensity is fully dimmable (0.1-100%) causing no flicker effect, with a maximum luminous flux of 6600 lumens.

Most of the gained evidence about the beneficial effects of circadian lighting comes from laboratory experiments that are mainly focused on the biological effects of the light on human health and most of the time do not take into account the contextual parameters that might affect the results. This study does not only focus on the effects of circadian lighting on users' well-being but highlights the importance of implementing qualitative methods and tools when investigating circadian lighting. Therefore the conclusions of this anthropological analysis provide very valuable insights regarding the challenges that appear during the actual implementation of such lighting systems.

First of all, one of the main challenges that appeared was residents' difficulty to adapt, mainly because the way the circadian light was set did not account for their daily routines and activities and they couldn't also control the light. As a result, the lighting system did interfere with the residents' habits without allowing them to carry out some of their activities and thus caused an overall negative mood and experience. This finding highlighted the fact that it is very important not to focus solely on the biological effects of light, but also to the satisfaction of one's emotional and social needs through the use of light. Particularly when talking about the application of circadian lighting to such spaces that constitute the elderly's home, it is absolutely essential to adjust the transitions and the changeability of the light with residents' needs and activities.

Only so, the residents will be able to feel relaxed and feel this place as their home.

Another challenge this study brought in light, is the fact that the staff felt uncertain about how to operate the control system of the lighting, resulting in increased stress and reduced job satisfaction. In addition, the staff stated that there is a correlation between residents' mood and the quality of their work environment, meaning that the aforementioned residents' poor experience of lighting resulted in making their work more difficult and tedious.

Eventually, two basic needs emerge:

1. The adjustment of the Circadian lighting according to residents' daily routines. In a way that will account simultaneously for users' well-being, comfort and experience of home.
2. The appropriate design of the control system to facilitate the needs of both staff and residents, taking into account that the elderly are not familiar with modern technology. In addition, staff must be trained in the use of the control system.

Furthermore, this study discloses some insights regarding residents' preferences and lighting culture. The researchers used a qualitative tool that allowed the residents to indicate the way they shape the atmosphere of their private areas with the use of their personal luminaires while they practice their daily routines. With the use of a map, residents showed the exact placement of their luminaires in their private space and they classified the intensity of each of them as being low, medium or high intensity. The aforementioned method reveals how the light is used as a tool for residents' practice of home (Schledermann et al., 2020).

- Residents' private areas are mainly illuminated by daylight during daytime and their personal luminaires during evening and nighttime.
- Their favorite seating spot is close to the window, experiencing sunlight/daylight and the view.
- The use of residents' personal luminaires is absolutely related to their routines and the experience of home.
- The majority of their luminaires emit quite dimmed and warm light and they illuminate residents' immediate surroundings creating a focused cozy spot.
- Residents use their personal luminaires in a way that shapes their preferable atmosphere, according to the time of the day and their routines.
- Most of the residents evaluate low-intensity lighting as a good lighting condition. Firstly, this can be related to Danish lighting culture that highly appreciates the dimmed warm light that creates the “Hygge” feeling. However, this preference indicates also the attitude of this generation regarding energy consumption, where energy saving is of high priority.

As it has been already highlighted by Boyce (2014), this study also indicates that even though high-intensity light levels (5000 lux) are proposed as very efficient for light therapy treatment, it is not feasible to be implemented in eldercare homes. This paradox underlines the importance to balance the use of the Circadian Lighting for its benefits in human health, with users' preferable light conditions in order to enhance their comfort and a home-like atmosphere (Schledermann et al., 2020).

6

Research Question

This thesis aims to find out the lighting attributes and qualities that can be used in the common area of an eldercare home in order to positively affect the overall mood and well-being of its residents, to enhance the feeling of being at home and stimulate their biological clock, while simultaneously provide an efficient and pleasant work environment for the staff by supporting their task performance and circadian entrainment.

Therefore the goal is to answer the following question:

How can a lighting design in the common area of an eldercare home improve the everyday living of residents and at the same time ensure an efficient work environment, while supporting both users' physical and mental state?

7

Success Criteria

The research question consists of 3 main objectives. Therefore, it is necessary to determine a set of success criteria for each of them, based on the findings of the prior theoretical work, so that the lighting design fulfills the research question.

- To improve the everyday living of residents, the lighting design should:
  - Enhance the feeling of being at home
  - Enhance the feeling of safety
  - Support visual needs for personal routines and activities

- To ensure an efficient work environment, the lighting design should:
  - Provide visual comfort on task performing
  - Allow for control and adjustment of the light

- To support both users' physical and mental state, the lighting design should:
  - Support both users' circadian rhythm
  - Ensure no glare or flicker issues
  - Provide a stimulating & pleasant visual experience

8

Design Concept

1. Introduction

The design concept begins to form with the proposal of a customized 24-hour lighting scheme that is based on the daily schedule of Albertshøj eldercare home. An exploration of moodboards is then presented to communicate the design qualities of the prior theoretical work. The conceptualisation continues with a lighting design proposal for each space separately (hallways, living room & kitchen/ dining room) and is completed with the "window to nature" - a lighting element that aims to stimulate users' senses by creating a natural view through light. Finally, the chapter concludes with the proposed control systems and some additional design components.

2. 24-hour lighting scheme

Dynamic lighting

Taking into consideration the findings of the research regarding the ways light affects humans' circadian rhythm, humans' inherent inclination to the ever-changing character of daylight and the necessity of satisfying users' biological needs, the use of dynamic lighting appears like a prerequisite.

Furthermore, the insights obtained from the LIGHTEL project (chapter 5.2) and specifically the anthropological part of the study, lead to consider the routines and activities of the users as a key factor in shaping the dynamism and the transitions of the lighting scheme. The findings of the aforementioned research, that are in line with Vacher's definition of "home" as an overall experience of living in a space where specific activities and social relations have been established (Vacher, 2010), demonstrate the importance of supporting users' everyday needs, in order to adapt and embrace this new lighting and eventually manage to become familiar with their new context and develop a sense of home.

Therefore, the proposed lighting scheme will not follow solely the principles of circadian lighting, that is the light transitions according to the time of the day and the recommendations regarding the light exposures for light therapy. But it will balance the good practices for the entrainment of users' circadian rhythm and the natural variations of daylight, with users' visual needs according to their activities and routines. In this way, the lighting system will be able to enhance users' overall experience, spatial appreciation, and provide clues regarding the time of the day while supporting the entrainment of their circadian rhythm.

Lighting Standards

The European Standards of Light, DS/EN-12464-1, specify the technical characteristics of light for indoor workplaces. Taking into consideration the fact that eldercare homes have also a professional function for the caregivers, it seems logical to follow these specifications.

Table 3 demonstrates the current European standards of Light, which are also followed by Denmark and can be applied to the common area of eldercare homes, regarding the minimum illuminance (E), the maximum discomfort glare (UGR), the minimum uniformity (U) and the minimum color rendering (Ra) (DS/EN-12464-1:2011, 2012).

DS/EN-12464-1	Living room	Dining room	Reading &Work places	Kitchen	Hallways Day	Hallways Night
E (lux)	200-300	200	500	500	100	50
UGR	22	22	19	22	22	22
U	0.4	0.4	0.7	0.6	0.4	0.4
Ra (CRI)	80	80	80	80	80	80

Table 3: European standards of Light, DS/EN-12464-1:2011

However, these standards are made for healthy people that have a fully functional vision. Figueiro has proposed that in order to overcome elderly's decreased visual performance, it is needed to "Increase ambient light levels [...] by at least 50% over those comfortable for younger people [...] Light levels on the task should be at least 1000 lx" (Figueiro, 2002, p.4). In addition, De Lepeleire et al. have also suggested that in order to ensure a good visual performance for the elderly, the lighting levels recommended by European Standards should be increased by about 55% (De Lepeleire et al., 2007).

Table 4 demonstrates the recommended minimum horizontal illuminances according to DS/EN-12464-1 and the modified version of it according to Figueiro's & De Lepeleire's suggestions. By implementing the illuminance levels of the modified version on the different areas and surfaces will ensure a good visual performance for both staff and residents.

	Illuminance levels as per DS/EN-12464-1	Modified illuminance levels for elderly people
Living room	200 lux-300 lux	300 lux-450 lux
Dining room	200 lux	300 lux
Reading & Hobbies & Work place	500 lux	1000 lux
Kitchen	500 lux	1000 lux
Hallways Day I Night	100 lux | ≥ 50 lux	150 lux | ≥ 75 lux

Table 4: Minimum horizontal lux levels as per DS/EN-12464-1 & modified lux levels according to Figueiro's & De Lepeleire's suggestions

24-hour lighting scheme proposal

As a result the following 24-hour lighting scheme is proposed (Figure 23). It follows the natural transitions of daylight color temperatures and supports the principle of using high-level short-wavelength light during the first morning hours and warm dim light during the evening and nighttime to regulate both users' circadian rhythms. Additionally, it satisfies the modified illuminance standards and incorporates slow illuminance transitions to account for elderly's decreased visual performance and reduced accommodation ability. Finally, it supports residents' daily routines, balancing users' preferences based on their light culture (Danes' lighting preference for low-intensity warm light) with the regulations applying in the specific areas.

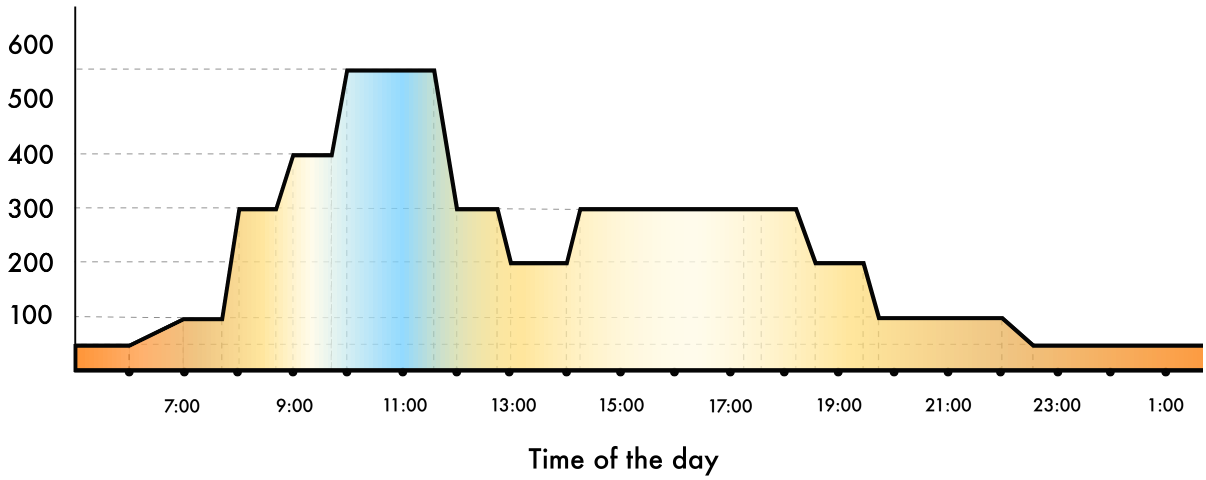


Figure 23: 24-hour lighting scheme

- 6:00-7:00: Wake-up transition light where the light gradually becomes cooler (1800K to 2500K) and more intense (50 lux to 100 lux), in order to reach the "Wake-up" lighting conditions.

- 7:00-7:45: Wake-up light with a color temperature of 2500K and illuminance of 100 lux.

- 8:00-8:45: Breakfast light with a color temperature of 3000K and illuminance of 300 lux.

- 9:00-9:45: Morning activities transition light with a color temperature of 4000K and illuminance of 400 lux.

- 10:00-11:30: Morning activities light. High circadian stimulation light with a color temperature of 6000K and illuminance ≥ of 550 lux (Vertical illuminance ≥ of 400 lux).

- 12:00-12:45: Lunch light with a color temperature of 3000K and illuminance of 300 lux.
- 13:00-14:00: Relaxation time - Siesta light with a color temperature of 3000K and illuminance of 200 lux.
- 14:15-17:15: Afternoon activities light with a color temperature of 4000K and illuminance of 300 lux.
- 17:30-18:15: Dinner light with a color temperature of 3000K and illuminance of 300 lux.
- 18:30-19:30: Evening activities light with a color temperature of 2700K and illuminance of 200 lux.
- 19:45-22:00: Late evening activities light with a color temperature of 2700K and illuminance of 100 lux.
- 22:30-6:00: Night light with a color temperature of 1800K and illuminance of 50 lux.

The Circadian Stimulus calculator is used to ensure that the proposed attributes of light support users' circadian rhythms. Since it is not known what are the exact light sources that will be used, for the calculation of the Circadian stimulus metrics the predefined light sources of the calculator are used (Appendix 5). It is therefore concluded that the Circadian Stimulus metric for the morning hours (after breakfast) is higher than 0.3, reaching almost 0.4 during 10:00 - 11:30 am, fact that according to Rea and Figueiro results to the regulation of users' circadian system and therefore to their overall good mood and sleep quality (Rea and Figueiro, 2016). In addition, it is concluded that the evening and nighttime lighting conditions do not allow any circadian distraction, since after 18:30 the Circadian Stimulus metric falls to 0.18, until 19:45 reaches almost 0.1, and during nighttime the value is lower than 0.1.

3. Lighting Design Proposal

As already described, common areas include hallways, living rooms, and kitchen/ dining areas. Each of these spaces has different functions and features. Therefore, the lighting design proposal should focus on the needs of each space separately.

3.1 Hallways

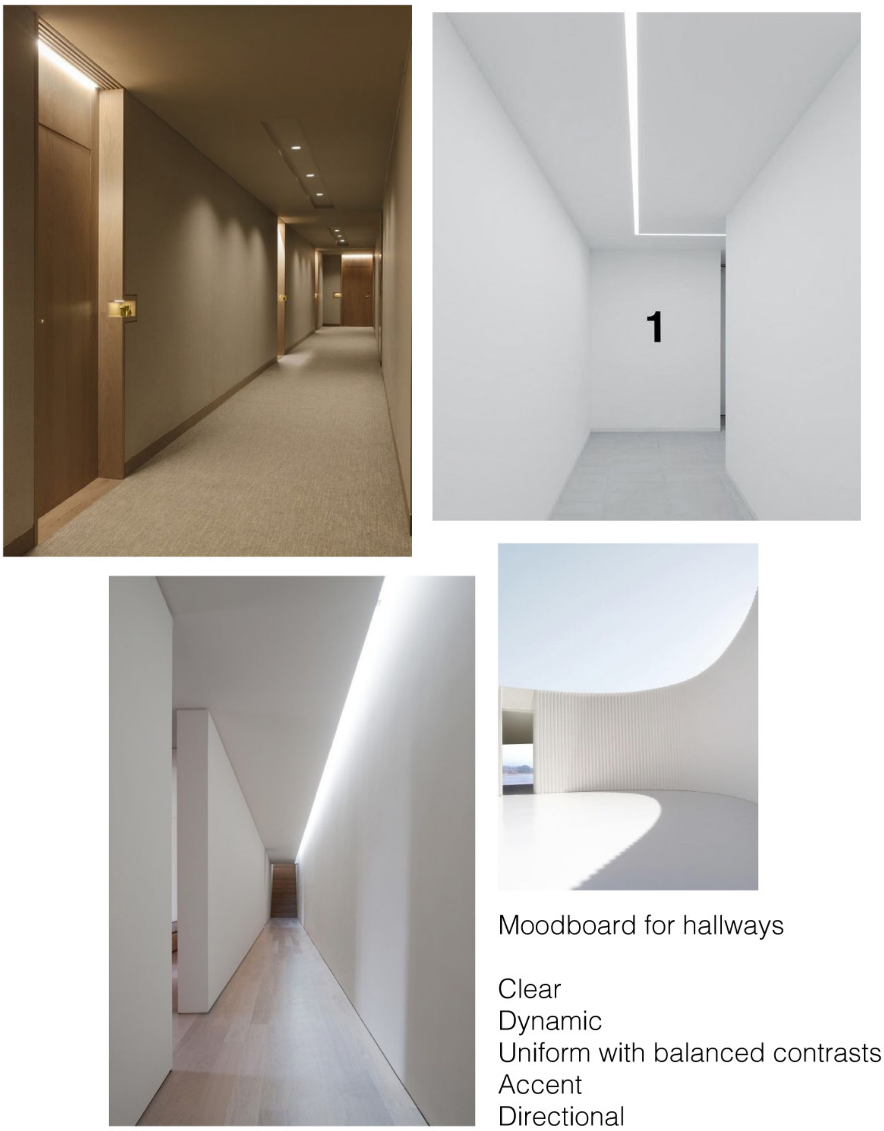


Figure 24: Moodboard for hallways

Hallways are transitory spaces that connect the private with the public areas, allowing access from residents' private rooms to the communal spaces and vice versa.

The lighting design proposal for the hallways should:

1. Ensure a good visual performance through sufficient ambient illumination and well-balanced contrasts.
2. Enhance wayfinding through lighting elements that provide orientation cues.
3. Support users' circadian rhythm.

The ambient lighting of the hallways will follow the lighting scheme proposed earlier. The color temperature and the illuminance levels will be the same throughout all the common areas resulting in a coherent lighting design and at the same time ensuring that the elderly will not face any visual performance issues due to their decreased dark adaptation.

In the **first proposal**, the general lighting is provided through recessed ceiling circular fixtures that emit diffuse illumination and is supplemented with additional lighting elements that support users' wayfinding. A subtle line of light is placed on the wall at the floor level in between the entrances of the private rooms to indicate their location and enhance users' orientation (Figure 25).

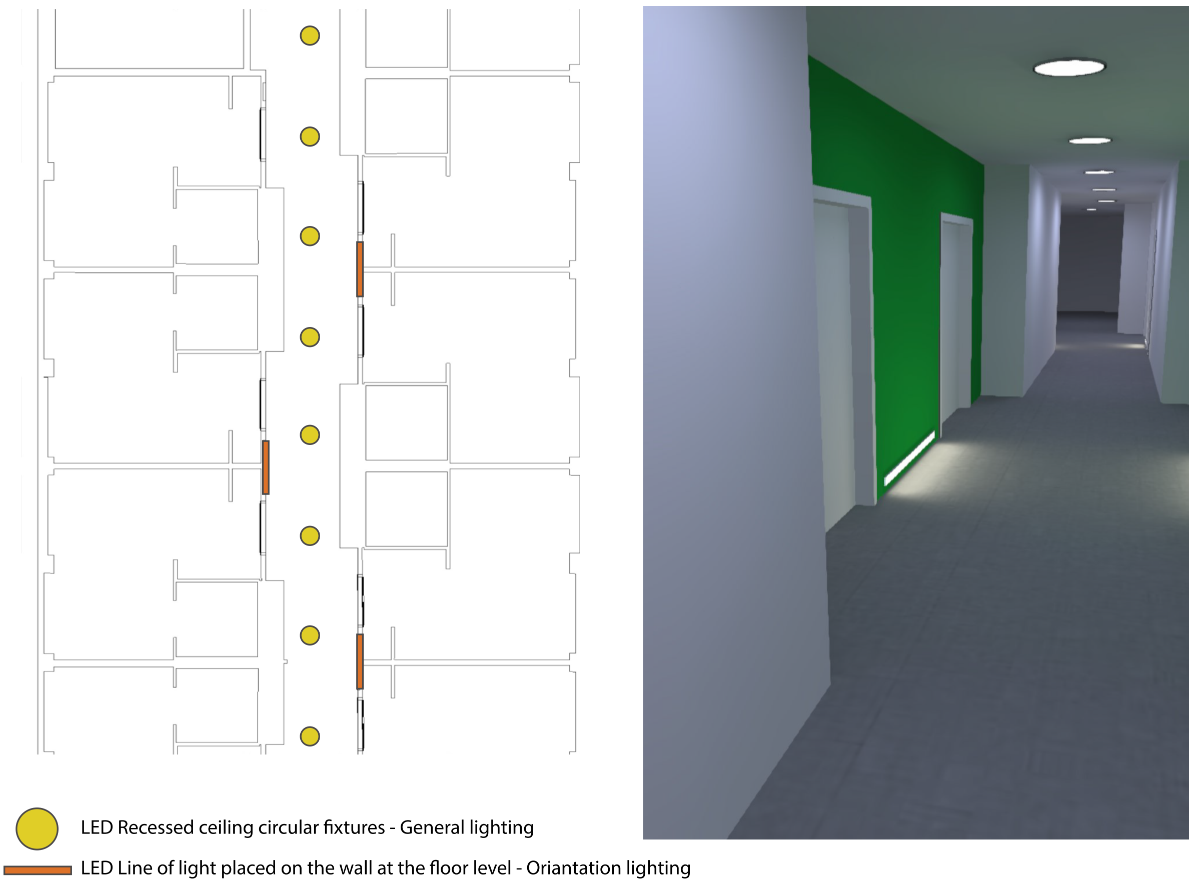
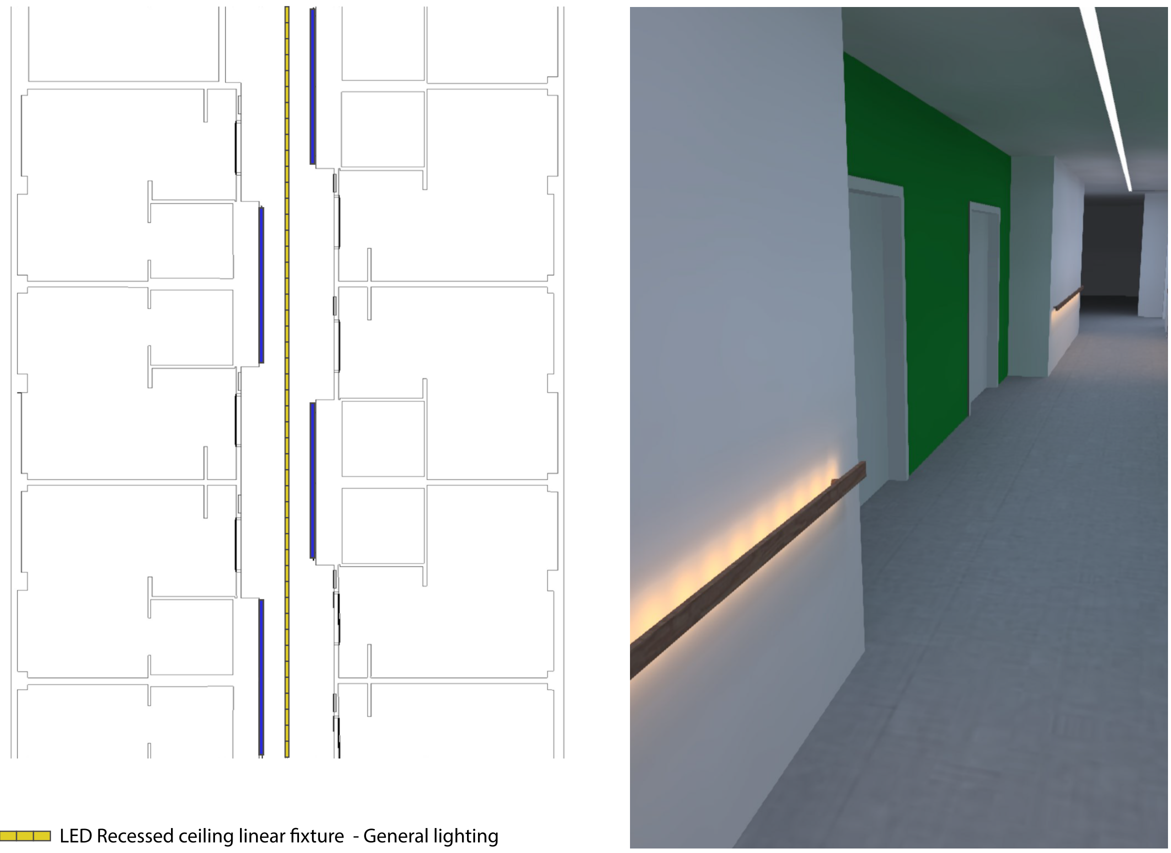


Figure 25: Lighting design for hallways - 1st proposal

The **second proposal** uses a recessed ceiling linear fixture to provide diffuse light for the general illumination. An integrated lighting element is proposed to be placed on the handrails. The hallways have a characteristic structure that consists of some extruded parts in between the walls adjacent to the entrances of the private rooms. This proposal suggests the placement of handrails on each extruded wall in the hallway. During the evening and nighttime that the ambient light levels are relatively low, the implementation of this lighting element will indicate the location of the handrails, will point out the architectural forms, while also marking the location of the doors through its absence. That being said, this lighting proposal aims to enhance residents' feeling of safety and sense of orientation.

The basic idea of this proposal is to use a line of light as a guide that leads users to their rooms or public spaces. Therefore, for the sake of optical homogeneity, the linear design of the fixtures for general lighting was chosen in order to be consistent with the linearity of the additional lighting element (Figure 26).



LED Recessed ceiling linear fixture - General lighting

LED integrated lighting element placed on the supporting bars - Oriantation lighting

Figure 26: Lighting design for hallways - 2nd proposal

The **final lighting design proposal for the hallways** can be considered an improved combination of the previous two proposals. The ambient illumination is provided through RGBW LED recessed ceiling directional downlights (covered with an opal surface) with a maximum luminous flux of 1700 lumens and a varying color temperature from 1800 K to 6000 K. The light sources should be 100% dimmable, causing no flicker effect and they should also provide a good colour rendering (CRI>90). The light fixtures are placed in the center of the ceiling, therefore the light is distributed mainly in the center of the corridor providing a lower illumination on its edges. During the evening and nighttime, the general illumination is supplemented with the use of the additional aforementioned lighting elements. Both the integrated lighting element of the handrails and the lighting element next to door entrances illuminate the edges of the corridor balancing the overall outcome while maintaining a lower illuminance level in the areas next to the entrances (Figure 27 & Appendix 12 & 13). The illuminance levels in the private areas are darker than the common areas, therefore the darker spots in front of the entrances facilitate a smooth transition.

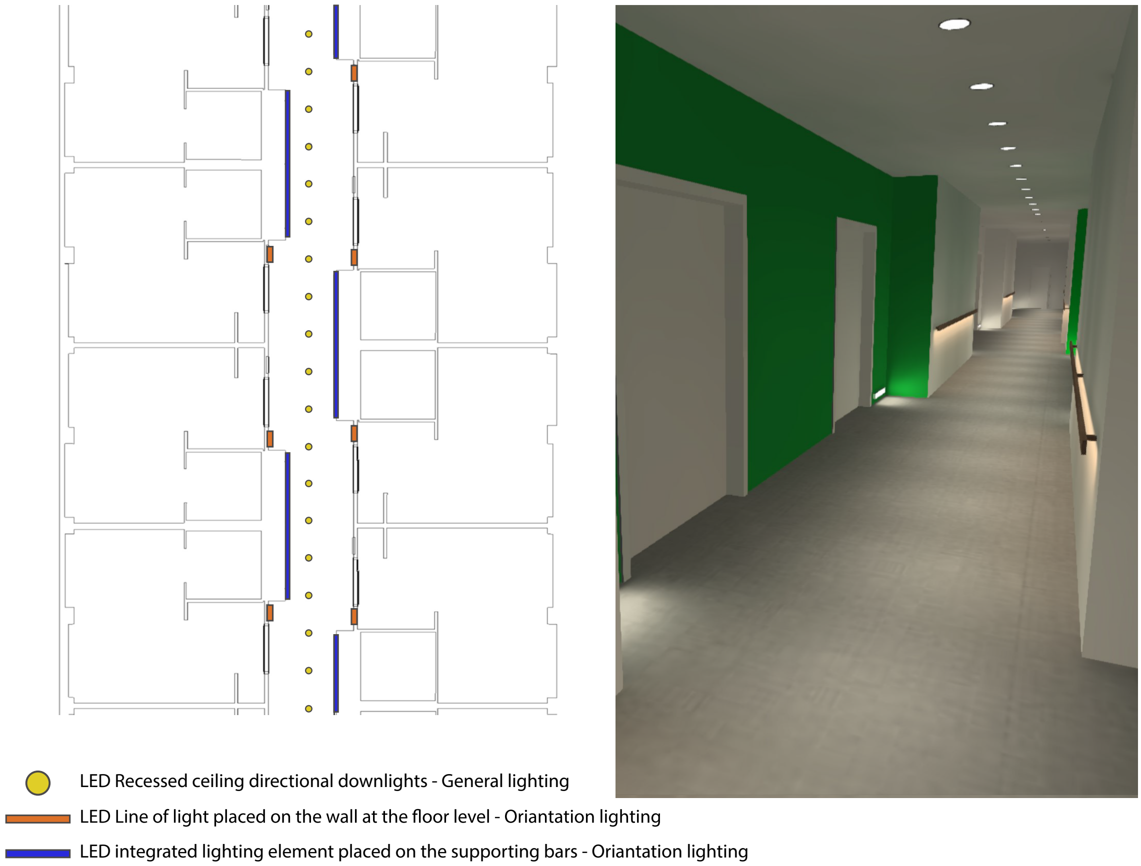


Figure 27: Lighting design for hallways - Final proposal

The integrated lighting element of the handrails presented in the second proposal uses an LED strip that emits a luminous flux of 510 lumens (340 lm per meter) and is placed on the backside of the bar facing the wall. In this way, the light is distributed on the wall providing vertical illumination up and down of the handrail (Figure 28).

An analysis of the lighting distribution according to the different placements of the LED strip was made via Dialux software. Finally, it is decided to place the LED strip on the bottom of the handrail in order to illuminate the lower part of the wall (under the handrail) and the floor (Figure 29). By illuminating the area beneath the handrail, the contrast is becoming bigger facilitating the residents to identify it.

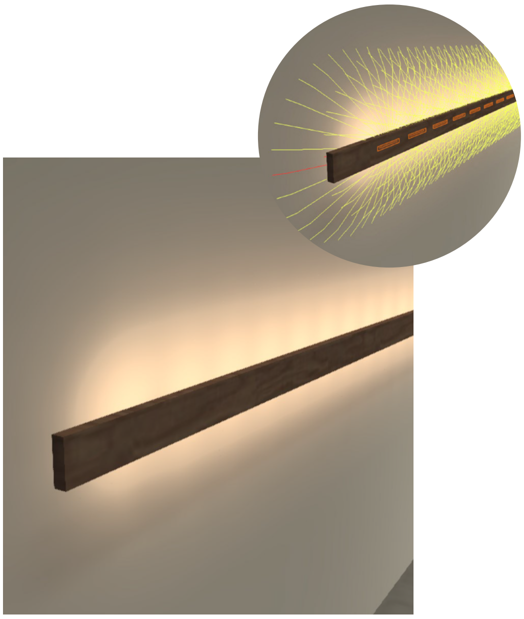


Figure 28: Handrail integrated lighting - Option 1: LED strip facing the wall

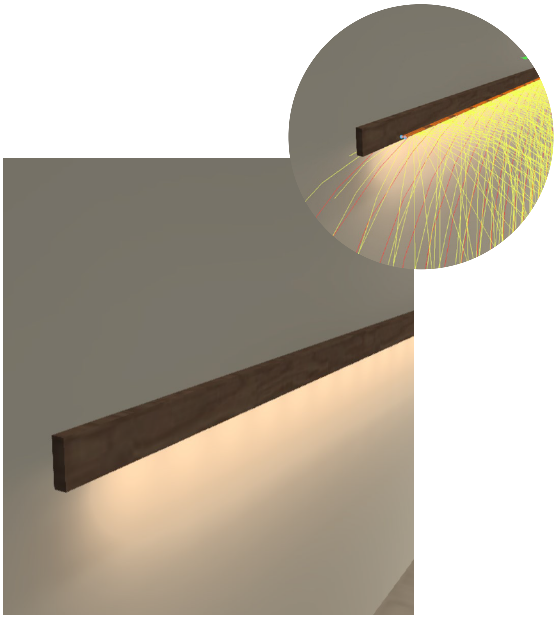


Figure 29: Handrail integrated lighting - Option 2: LED strip facing the floor

Analyzing further the lighting element, used to indicate the entrances, that is presented in the first proposal, some changes regarding its placement are proposed. Having a closer look at hallways' interior design, it is recognized that usually the space between the entrances of the private rooms is decorated, using some furniture. It is therefore decided that the lighting elements will be located on the other side of the door. As mentioned earlier, an LED linear fixture that provides a luminous flux of 550 lumens, will be placed on the wall at the floor level to indicate the location of residents' private rooms supporting their orientation.

Both the additional lighting elements are placed at a low height, emit a warm illumination of 2700 K and are turned on during the evening and nighttime. While the day passes the intensity levels are dimmed, the color temperature becomes warmer and the height of the light moves downwards creating a cozy atmosphere that at the same time highlights the essential parts of the space ensuring a safe move (Figure 30). That being said, the lighting helps the residents to feel more secure, enhancing their autonomy, thereby facilitating staff tasks. Finally, the attributes of the light ensure no distraction of the circadian rhythm of both users.

An analysis of the lighting distribution according to the different placements of the LED strip was made via Dialux software. Finally, it is decided to place the LED strip on the bottom of the handrail in order to illuminate the lower part of the wall (under the handrail) and the floor (Figure 29). By illuminating the area beneath the handrail, the contrast is becoming bigger facilitating the residents to identify it.

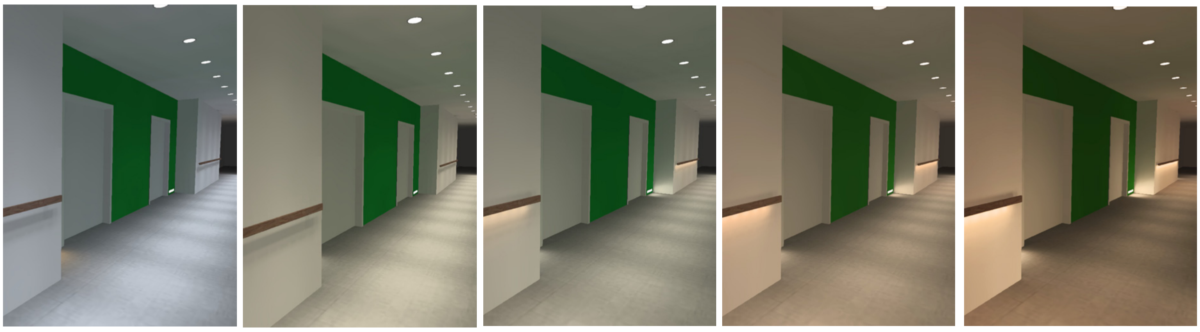


Figure 30: Lighting transitions in the hallways during the day

3.2 Living rooms

Moodboard
for living room

Dynamic
Stimulating
Functional
Focusing
Activating & Relaxing

Figure 31: Moodboard for living rooms

The lighting design proposal for the living rooms should:

1. Ensure a good visual performance for both users through sufficient ambient illumination
2. Support residents activities through additional functional lighting
3. Create a home-like atmosphere, respecting residents' light culture (low level dim warm light)
4. Provide control to residents, enhancing their autonomy
5. Support users' circadian rhythm
6. Stimulate users' senses

Figure 32: Lighting design proposal for living rooms

The general lighting follows the lighting scheme mentioned earlier, supporting users' biological rhythms and following their daily schedule. Recessed ceiling circular LED fixtures that are covered with an opal covering to account for no glare issues are used for the general lighting. The proposed light sources are RGBW LEDs, with a maximum luminous flux of 3300 lumens and a varying color temperature from 1800 K to 6000 K. They should be 100% dimmable, causing no flicker effect and they should provide a good color rendering (CRI>90). It is proposed that the diameter of the selected luminaires should be considerably smaller than the size of the existing ones, avoiding the institutional feeling in the space (Figure 32).

Three floor-lamps are placed between the armchairs, following the existing layout of the furniture in the space (Figure 34). They are used as functional lighting intended to complement the general lighting during the afternoon and evening hours, creating a warm atmosphere and also providing a sufficient amount of light for residents' activities. Each floor lamp has a standard switch, that residents can operate independently. In this way they are allowed to shape their preferred atmosphere, enhancing their sense of control and autonomy.

As can be seen in the space analysis, the floor lamp currently in use is the model "PH 80" of Louis Poulsen company (Figure 13 & Figure 33). This luminaire emits a warm light (2700 K) mainly downwards, but also allows the distribution of a small percentage of light upwards (Appendix 14 (h)) which illuminates the top red reflector of the luminaire and results in an even warmer glow.

The distribution of light provides a soft, indirect and glare-free illumination creating a warm pool of light around the luminaire that illuminates residents' immediate surroundings when they are seated, while also enhancing the overall ambient illumination. In addition, this particular luminaire was designed in 1925-1926 and is considered as classic, while its choice in the space proves the users' preference for it. Thereby, it seems reasonable to conclude that the use of the same luminaire will enhance users' feeling of being home while supporting their evening and nighttime routines. Unlike the existing lighting conditions, it is decided to place a floor lamp in between every set of armchairs so that all users can experience the atmosphere it creates.

Figure 33:
Louis Poulsen luminaire "PH 80"

Considering residents' decreased visual performance and their need to perform their daily routines (during afternoon & evening), it is necessary to provide them additional lighting. Therefore, wall-mounted spotlights are proposed to be placed at four different places in the living room (Figure 34). They are intended to be used as functional lighting, supporting users' individual activities such as reading, knitting, etc. Users are able to use the luminaire when they need it, simply by turning it on through a typical switch. The spotlights provide a luminous flux of 250 lumens and a warm color temperature of 2700 K. They will be placed at a height lower than the average eye level of a seated person (<740 mm above seat level), in order to avoid any possible glare issue due to direct view of the light source.

Finally, low-intensity (luminous flux of 380 lumens) warm (3000 K) spotlights with a relatively narrow beam, are proposed to be used to illuminate artworks in order to highlight them during the dark hours (Figure 32 & Figure 34).

Figure 34 illustrates the location of all the proposed light sources in the living room.

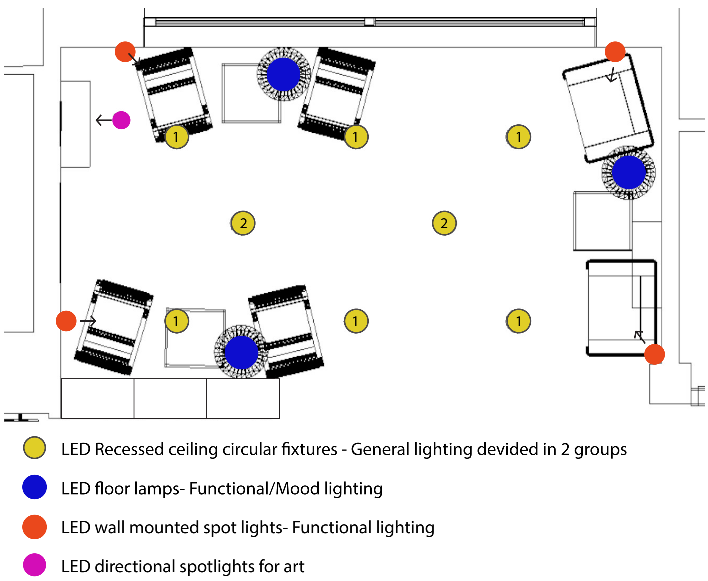


Figure 34: Lighting design proposal for living rooms

The fixtures of the general lighting are divided into two groups. Group one consists of six luminaires and group two of two luminaires (Figure 34). From the morning until late noon both groups of the general lighting fixtures will be turned on and while the day will pass and the illumination levels will gradually fade, group one will be turned off and group two will emit dim warm light that will illuminate mainly the central area (circulation area) of the living rooms (Figure 35). According to the existing interior design, the furniture is placed on the edges of the space to allow for the safe movement of the residents with mobility issues preventing any possible falls. In the edges of the living room where the furniture are located, the illumination of the floor lamps will prevail, allowing for dim and warm low-level lighting around the users, creating a relaxing "hygge" atmosphere, while in the cases that the users want to perform activities that require higher amounts of light they will be able to use the wall-mounted luminaires.

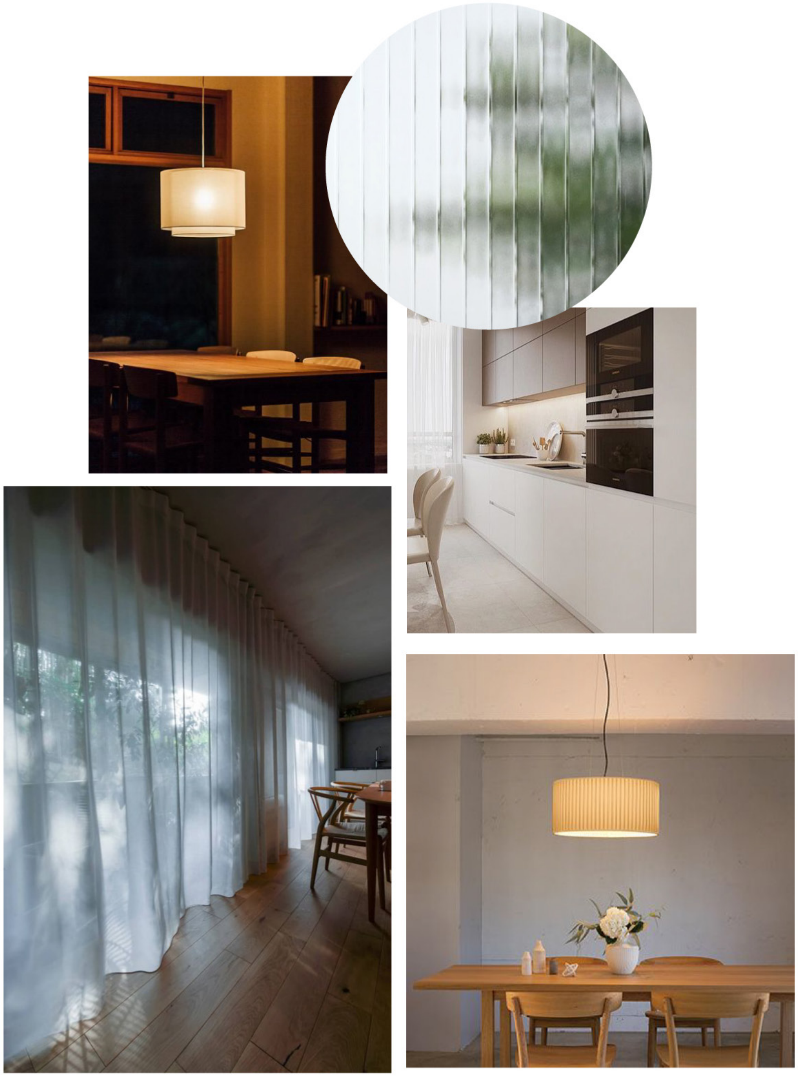
Figure 35: Lighting design proposal for living rooms - Evening scenario

Figure 36 demonstrates the intensity and color temperature variations of the proposed electrical lighting throughout the day.

Figure 36: Lighting transitions in the living rooms during the day

The combination of the dim general lighting with low-level functional lighting during the evening/nighttime, results in a sufficient visual environment for staff, who need to easily monitor the condition of the living room, while allowing residents to orchestrate the atmosphere, as they would do in their homes. The location and the distribution of light ensure that there will be no glare issues, while at the same time all light sources follow the rule of low intensity and warm illumination so as to avoid any possibility of circadian distraction for both users.

3.3 Kitchen/Dining room



Moodboard
for kitchen/dining area

Dynamic
Stimulating
Functional
Focusing
Activating & Relaxing

Figure 37: Moodboard for kitchen/dining room

The lighting design proposal for the kitchen/dining room should:

1. Ensure a good visual performance for both users through sufficient ambient illumination
2. Support staffs’ tasks - illuminate efficiently kitchen task areas
3. Create focal points emphasizing the dining tables
4. Support residents activities
5. Support users’ circadian rhythm
6. Stimulate users’ senses

Figure 38: Lighting design proposal for kitchen/dining room

For the general lighting, recessed ceiling circular LED fixtures are used that are covered with an opal covering (same with the ones used in the living rooms - RGBW LEDs, with a maximum luminous flux of 3300 lumens, varying color temperature from 1800 K to 6000 K, 100% dimmable, flicker-free and CRI>90). The general illumination follows the same lighting scheme as the rest of the common areas accounting for users' biological well-being and supporting their visual needs for their daily activities in this space.

On top of each dining table, a pendant fixture is placed (Figure 38). The proposed fixtures emit a luminous flux of 2100 lumens, their color temperature varies from 3000 K to 6000 K and they are covered with an opal surface. Their main purpose is to highlight the dining tables creating a relaxing atmosphere during the meals, and also to supplement the ambient illumination of the space in the morning hours that the needed illuminance is relatively high. Specifically during the morning hours after breakfast (10:00 am - 11:30 am), the illuminance levels on the table surface will reach ~1000 lux, providing a vertical illuminance higher than 400 lux on eye level for a seated person (Appendix 7 & 8) and thus ensuring a high circadian stimulation lighting for the users (Figueiro, 2008). The operation of the pendants will be activated automatically at breakfast time and will remain active until lunch. After lunch, they will be turned off and they will turn on for the last time during dinner time.

The fixtures of the general lighting are divided into 4 groups (Figure 39). As mentioned, the whole area can be divided into two identical spaces that might not follow the exact same schedule (since residents are given the freedom to specify it for themselves). Therefore it is necessary for the lighting of each space to be controlled separately. Additionally, in each space, there are also two groups of luminaires, one group for the dining room and one for the kitchen.

The kitchen is considered a task area since the staff has to perform some tasks related to meals' preparation, thus the lighting should be controlled accordingly for these times of the day, while during the rest of the day the light levels of the kitchen can be dimmed down. That being said, in the kitchen the "Auto mode" will be on having as a maximum intensity the 60% of the overall illuminance that the light sources can provide, emitting a maximum illumination of about 400 lux. However, during meal preparation time, the staff will be able to select the "Work mode" where 100% of the light intensity is emitted resulting in an illuminance of about 1000 lux on the task areas (Appendix 11). The color temperature variations follow the ones specified in the lighting scheme, without any differentiation between the modes. In the dining room, in the cases where the schedule is shifted or the residents prefer to have their meal at a different time than the regular one, the general lighting can also be tweaked from the "Auto mode" to the "Meal mode". The "Meal mode" adjusts the general lighting in a way that the illuminance level of the recessed ceiling fixtures falls to 60% of their maximum intensity (providing illumination of about 250 lux in the dining area) (Appendix 9) and the pendants' illumination prevail highlighting the dining tables with an illuminance of about 700 lux (Appendix 10).

Directional warm spotlights with a relatively narrow beam (same as those used in living rooms) are proposed to highlight the artworks during evening and nighttime. Lastly, in the kitchen area, a linear LED fixture with a luminous flux of 240 lumens and a color temperature of 3000 K is placed beneath the cupboards as a functional light, to enhance the illuminance levels of the task area when necessary (Figure 39).

Figure 39 illustrates the location of all the proposed light sources in the space and the 4 groups of the general lighting.

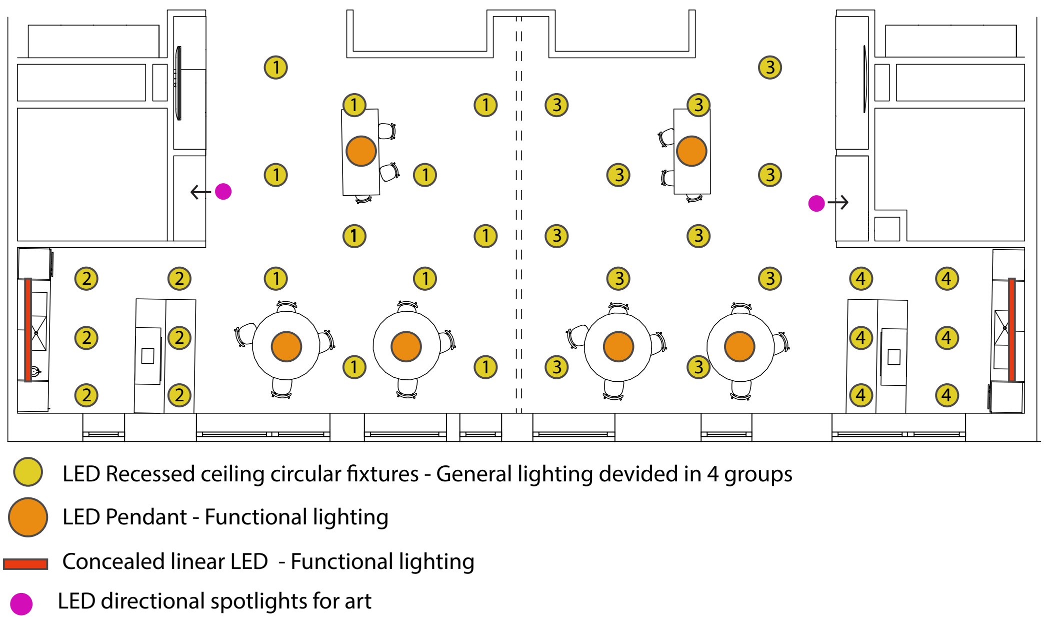


Figure 39: Lighting design proposal for kitchen/dining room

The following figure illustrates the overall lighting effect in the kitchen/dining room, during the day (Figure 40).

Figure 40: Kitchen/dining room during the day

3.4 Lighting element that stimulates users' senses - "Play of brilliants"

In order to achieve a holistic lighting design proposal for the common areas, it is necessary to develop an additional layer of light (third layer of light), that according to Kelly is the one that stimulates users' senses, also known as the "play of brilliants".

The lighting design proposal for the third layer of light is grounded on the findings of the research regarding the effect of nature on humans' well-being. That is, daylight and other real or artificial representations of natural elements have been proven to have a very beneficial effect on humans' physio-psychological state, especially for people who spend the majority of their day indoors and are deprived of a physical connection with nature.

The idea is to create artificial "windows" to complement daylight during dark days in the living room and the dining areas. The goal is that this lighting element will add a "natural sense" in the space throughout the whole day, enhancing users' connection with nature.

Following the findings of the research regarding "the restorative effect of nature" and the effectiveness of integrating the so-called "biophilic patterns" in the built environment, the fact that the artificial "windows" will simulate the view of a natural element, becomes evident. Ulrich's theory, supporting that natural views improve people's mood and psychology, reduce stress and create an overall more pleasant atmosphere (Ulrich, 1997), coupled with Clay's findings on enhanced work satisfaction and productivity (Clay, 2001), suggest that a lighting element that embodies nature, leads to a more relaxing and joyful experience for both residents and staff.

In order to determine what would be the most appropriate natural element in this layer of light, emphasis is given on Kellert's statement for the importance of connecting users with the geography and ecology of the place in order to feel connected to their environment (Kellert, 2008). Therefore, it is decided that the natural elements depicted should come from the natural environment of the area.

The surrounding space of the eldercare home is mainly urban with some small green areas. The windows in the kitchen/dining area look on a parking area, while the ones in the living rooms overlook a moderately trafficked road and a residential area. In a further distance, there is Hundeskov Park (Figure 41), which offers a view of a distant green area.

Figure 41: Map illustrating the location of Hundeskov Park & Albertshøj eldercare home

As a “window to nature”, the third layer of light will bring the natural elements of the surrounding environment closer, namely the green view created by the trees. The light will illustrate a gentle movement of the foliage of a tree illuminated by daylight as it follows the natural light transitions throughout the day. Additionally, the colors of the leaves will change following the natural seasonal transitions throughout the year (Figure 42).

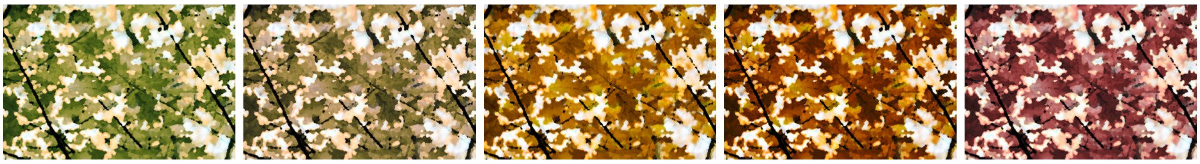


Figure 42: Color transition of the leaves during the year

The decision of depicting the daylit moving foliage through artificial light becomes even stronger considering Browning, Ryan & Clancy’s findings regarding “Biophilic patterns” and their contribution to humans’ well-being (Browning et al., 2014). The moving foliage effect offers a view of biomorphic forms and patterns providing non-rhythmic sensory stimuli and combined with the transitions in brightness throughout the day and color throughout the seasons, creates a direct link to the ever-changing character of daylight providing time orientation and enhancing users’ connection with nature.

Implementation

To achieve the effect of the “window to nature”, a video is filmed showing the sunny foliage of a tree in Hundeskov park moving slightly in the wind (Figure 43 & Appendix 15). Ideally, at least 2-3 24-hour videos per month should be filmed, in order to smoothly display daily and seasonal transitions.

Figure 43: Frames of the video showing the sunny foliage of a tree

Individually controllable LED strips will be placed on the back of a wooden structure. The design of the wooden structure consists of horizontal wooden pieces placed in a vertical arrangement maintaining a constant distance between them, in order to resemble Venetian blinds and to strengthen the idea of a window look (Figure 44).

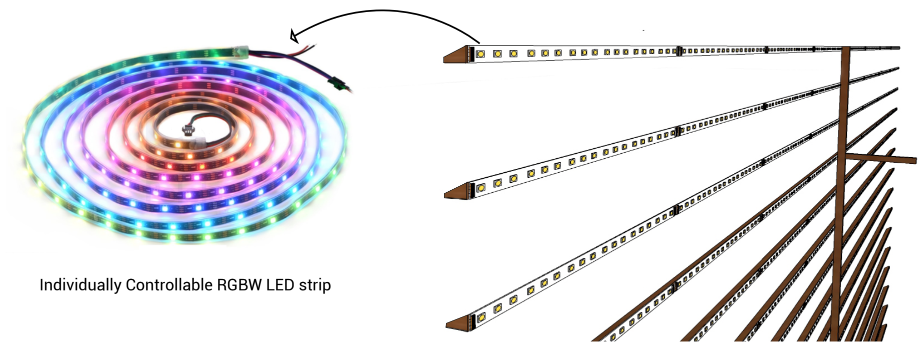


Figure 44: Construction of “Window to nature”

The video will be projected through individually controllable LEDs to the wall behind the wooden structure. The light will bounce off the wall composing the images/frames of the video (Figure 45).

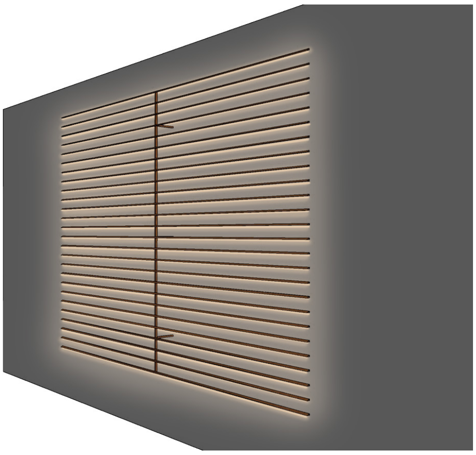


Figure 45: Construction of “Window to nature”

Unfortunately, the period we are going through due to the COVID-19 pandemic, does not allow real tests to be done in order to determine all the technical details needed for the project. However, other projects are used as a reference/guidance in order to identify possible ways that could lead to the desired result.

Jim Campbell's "Low resolution works" are a reference. Those projects use the dynamics of LED technology (intensity and color variations) to illustrate videos. He creates LED grids, where each LED is assigned to a pixel of the video. Specifically, the projects "Exploded Flat 2" (Figure 46) and "Taxi Ride To Sarah's Studio" (Figure 46) are created using LEDs facing the wall. The LEDs reflect off the wall casting a circle of light, and these circles of light then mix, creating a blurry image. Since the "window to nature", like Campbell's work, assigns LED to pixels in a video, it is concluded that the final outcome will be rather blurred. The degree of the image analysis depends directly on the distance of the light source from the wall and the distances of the light sources themselves. However, as Jim Campbell's projects prove, the human brain is able to comprehend an image even when there are parts missing. In this case, the overall outcome will not be a sharp representation of the foliage shape, but the color and brightness variations combined with the movement will compose an abstract yet recognizable visual result.

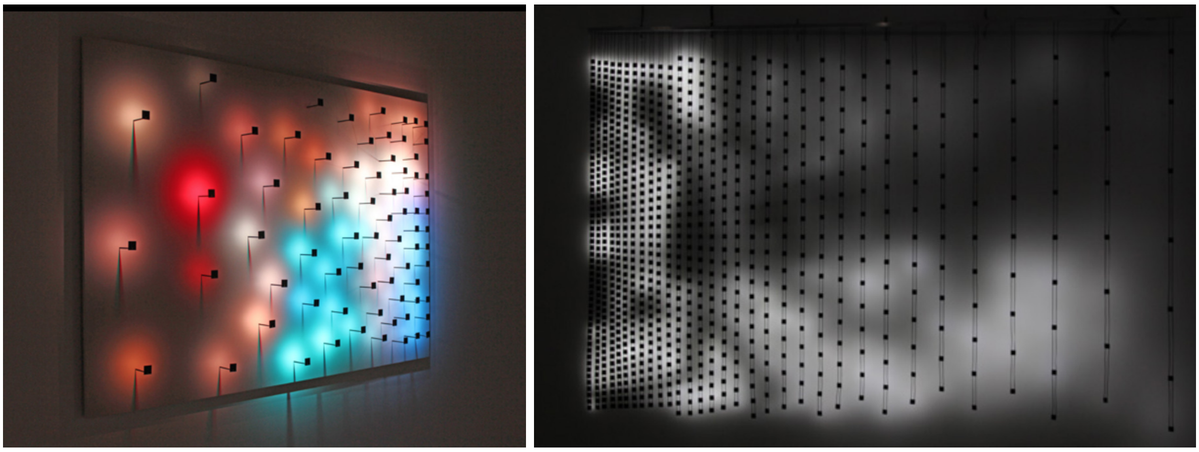


Figure 46: "Exploded Flat 2" & "Taxi Ride To Sarah's Studio", Jim Campbell's projects

In order to determine how dense the LEDs must be to make the movement readable and therefore the image recognizable, some tests were performed using Adobe After Effects. The mosaic filter was used to divide the video into pixels. The amount of pixels determines the distance between the LEDs. Four tests were performed, one having a pixel every 2 cm (125 x 75 pixels), one every 3 cm (83 x 50 pixels), one every 4 cm (63 x 37 pixels) and the final having a pixel every 5 cm (50 x 30 pixels) (Figure 47 & Appendix 16).

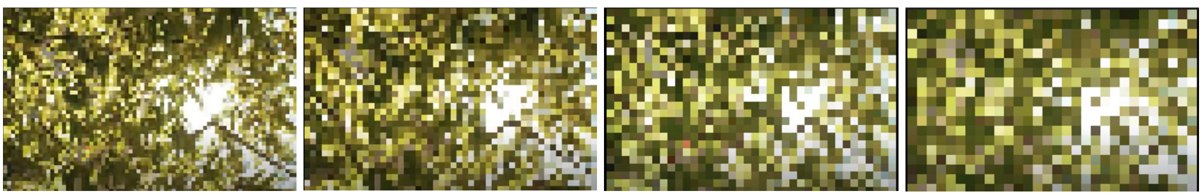


Figure 48: Frames of the blurred videos (test 1, 2, 3 & 4 respectively)

After dividing the video into pixels, a blur filter was applied to give a better sense of what the effect will look like when the light is mixed from the LEDs on the wall (Figure 48 & Appendix 16). Considering the fact that the fewer the LEDs are, the farther they need to be placed from the wall in order for the projected light to mix properly, the tests with fewer pixels were blurred more to give a more realistic view of the expected visual result.

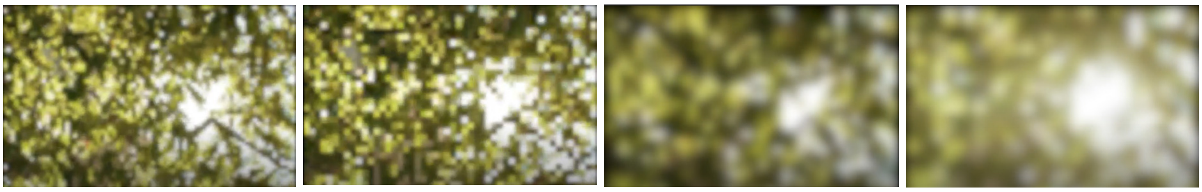


Figure 48: Frames of the blurred videos (test 1, 2, 3 & 4 respectively)

Another very critical factor for the implementation is that the distance of the LEDs should be the same horizontally and vertically, that also affects the wooden construction. That is, the 2 cm pixel / LED distance allows the gap of 2 cm between the wood slats, the 3 cm pixel / LED distance allows the gap of 3 cm, etc. The experiments showed that all the three first resolutions are likely to produce the desired visual result, however, the decision must be made taking into account the limitations of the wooden construction and the way it affects the overall result.

The overall size of the construction is set to be 2.5m wide and 1.5m high. Considering that the narrowest LED strip on the market is 0.6 cm wide, it has been decided that the maximum height of the wooden slats will be 0.8 cm - having a small recess at the height of 0.2 cm for the LED strip to be placed, while their front side will be 0.2 cm high (Figure 49 & Figure 50). In this way, the geometry of the construction will be closer to the form of the Venetian blinds, while the view of a more subtle construction will also strengthen the lighting effect.

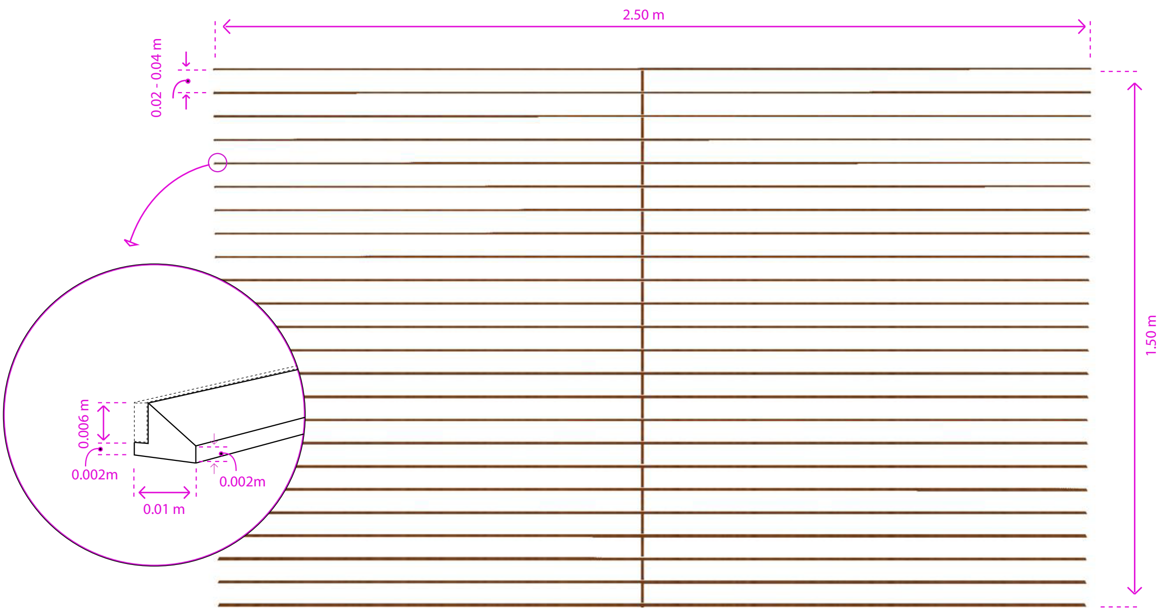


Figure 49: Construction of “Window to nature”

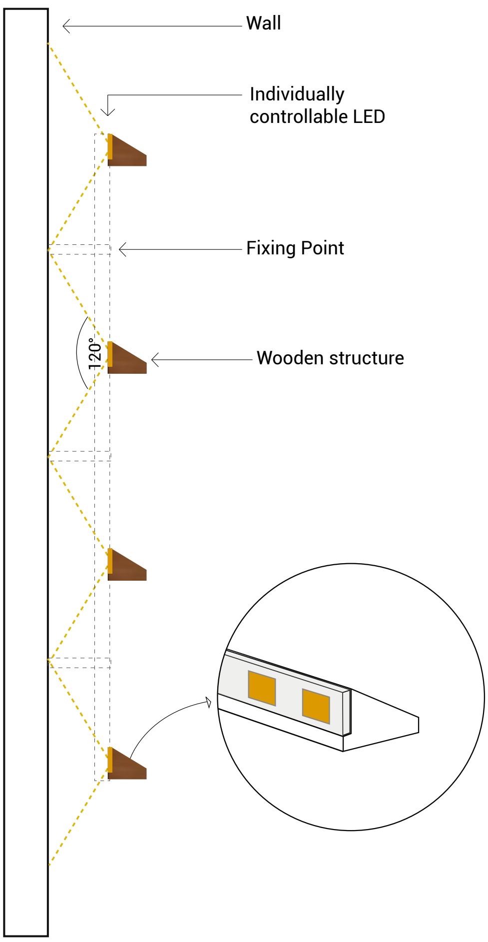


Figure 50: Construction of "Window to nature"

In order for the effect to be visible, the "window to nature" is necessary to be placed in a relatively darker place. Based on the architectural layout of the space and the way the light is distributed (both daylight and electric light), the locations where the "window to nature" can be placed are identified (Figure 51 & Figure 52).

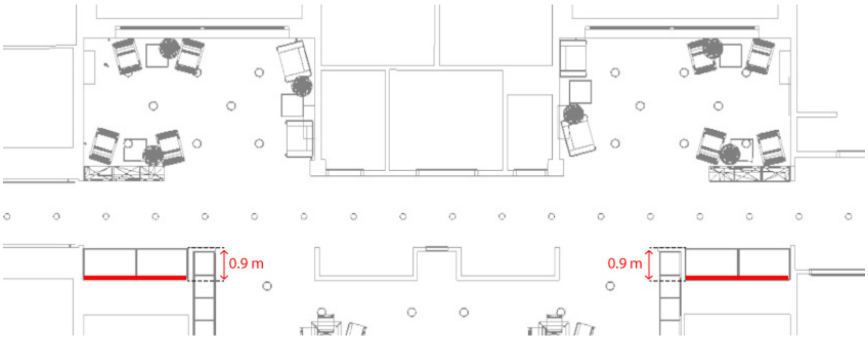


Figure 51: Location of "Window to nature" in the space

In the extension of the living rooms, there are two recesses of 90 cm deep, that prevent light from entering, resulting in a relatively dark illumination of those particular locations (Appendix 6, 9 & 12).

These spots are considered ideal for the ”window to nature” since they are darker and also their location is at the “entrance” of the common areas, thus users can experience the lighting effect during their stay in the living rooms and when move to and from their private spaces or other areas of the eldercare home.

Figure 52: Location of “Window to nature” in the space

Lastly, another very critical parameter that affects the final visual effect is the distance of the LEDs from the wall. Real tests and observations must be made to determine the appropriate distances, taking also into account the position of the viewer.

The following images illustrate the overall lighting effect in the living room, during the day.

3.5 Control systems

Control systems/Displays should be placed in all the different spaces of the communal area to ensure that they will be easily accessible from the staff regardless of their position. Specifically, It is recommended to have one control system in each living room, one in each kitchen area, two in the dining area, and five in the hallways (about every 15 meters). Remote/wireless access to the lighting system must also be possible.

In all different spaces of the common area, the “Auto mode” will be activated automatically. The “Auto mode” is the one that follows the 24-hour lighting scheme. Besides, in all spaces, there will be the option of the “Emergency mode” that activates all the light sources in the space at their highest brightness with a color temperature of 4000K. In the kitchen area, there will be a mode called “Work mode”, that increases the light intensity when the staff has to perform tasks in the kitchen. Finally, an additional mode will be available in the dining area, called “Meal mode” that activates the lighting conditions for meal time in cases where the schedule has been shifted or the residents want to have their meal at a different time than the regular one (Table 5).

Space / Modes	Auto mode	Meal mode	Work mode	Emergency mode
Hallways	*			*
Living room	*			*
Kitchen	*		*	*
Dining room	*	*		*

Table 5: Available light modes in the different spaces of the common area

The lighting system should be connected to responsive light controllers to account for energy-saving and safety issues. Presence detectors should be placed around the common areas to automatically dim the general lighting to 20% or less when a space is not occupied or on the contrary to turn on the light when a space is occupied during the nighttime. Additionally, the general lighting should be automatically dimmed or increased in response to daylight conditions via daylight sensors. In this way, the ambient lighting will be balanced according to daylight, resulting in energy efficiency and a more dynamic indoor experience.

Finally, the use of a DMX lighting controller is necessary in order to ensure smooth transitions for an optimized experience of both “window to nature” and the 24-hour lighting scheme.

4. Additional design components

Self-illuminating screens

It is a fact that the blue-light emitted from the self-illuminating screens (as the television or the computer screens), has a detrimental effect on humans circadian rhythm (causing melatonin's suppression) during evening and nighttime. Therefore, it is of high importance that all the self-illuminating screens be covered with screen filters that block the short-wavelength light, in order to ensure that they will not disrupt users' circadian rhythm.

Reflectances of materials & surfaces

Due to the restrictions imposed during the COVID-19 pandemic, no quantitative analysis was performed in the focus area, so there are no data regarding the reflectances of the existing materials and surfaces or information on whether they meet the lighting standards.

The reflectance of surfaces and materials used in a space plays a significant role in the overall brightness, spatial appraisal, and users' comfort. Especially in this context, where light levels are relatively high (mainly during daytime), the use of highly reflective materials can lead to unpleasant situations. As DS/EN12464-1:2011 recommends the reflectance of the ceiling should range from 0,6-0,9, the walls from 0,3-0,8, the working planes from 0,2-0,6 and the floor should range from 0,1-0,5 (DS/EN 12464-1:2011, 2012). Finally, as stated in the Danish Standard DS700, it is necessary to take into account that the contrast in the reflectances of the salient parts in the space (eg. the contrast between the door and the wall) should be at least 0.4, so that they are easily perceived by the residents.

9

Evaluation

The goal of this thesis was to answer the following research question:

“How can a lighting design in the common areas of an eldercare home improve the everyday living of residents and at the same time ensure an efficient work environment, while supporting both users’ physical and mental state?”

To fulfill the research question, various criteria were created, on the basis of which the design proposal was developed.

Since the communal area consists of three separate parts (hallways, living room, kitchen/dining room) with distinct functions and needs, the design proposal was developed accordingly for each one of the spaces accounting always for both residents’ and staffs’ needs. Additionally, a 24-hour lighting scheme was created that is the basis of the design concept and it is implemented in all of the common areas, resulting in a coherent lighting design. The proposed 24-hour lighting scheme is customized according to Albertshøj’s daily schedule, ensuring a good visual environment for both users throughout the day while at the same time supporting their biological rhythms.

All in all, it can be confidently assumed that the overall design concept is able to:

(1) Improve the everyday living of residents since it:

- Enhances the feeling of safety.

The feeling of safety is enhanced due to the lighting conditions throughout the whole communal area that ensure a good visual environment (with smooth light transitions, adequate light levels and balanced contrasts), but also due to the orientational lighting elements that highlight the handrails and the entrances of residents' private rooms in the hallways.

- Enhances the feeling of being at home.

The sense of being at home is interrelated with residents' feeling of relaxation and their ability to control the lighting conditions according to their needs (Percival, 2002). It is therefore assumed that the lighting design proposal in the communal areas can reinforce residents' feeling of being home mainly due to the flexibility of the lighting conditions in the living room. Especially after dinner time, when the illuminance levels of the general lighting are dimmed, users can orchestrate the living room's atmosphere according to their mood and preference. The combination of the ambient and the functional lighting results in a rather dim and warm illumination, creating a relaxing and "Hygge" atmosphere.

- Supports visual needs for personal routines and activities.

The 24-hour lighting scheme supports residents' daily schedule accounting for their decreased visual performance and providing adequate light levels for their activities during the day. Additionally, the use of the functional lighting in the living room ensures proper lighting conditions for residents' personal routines even during evening and nighttime. All the light sources are recommended to have CRI>90 for a good color rendering.

(2) Ensure an efficient work environment since it:

- Provides visual comfort on task performing.

The 24-hour lighting scheme supports staff's visual needs, providing adequate light levels that meet the lighting standards. Additional functional lights are also available for specific task areas/surfaces (eg. kitchen). Finally, it is recommended, that all light sources provide good color rendering (CRI>90), without creating flicker or glare issues.

- Allows for control of the light.

The staff is able to control the lighting conditions either by tweaking the modes of the general lighting or by using the functional lighting when they need it. The accessibility of the control systems (due to the location of the control displays) and the flexibility of the lighting scenarios (through the different modes & the additional use of the functional lighting) leads to a more pleasant and safe work environment where staff can respond instantly to the changing needs.

(3) Support both users' physical and mental state since it:

- Supports both users' circadian rhythm.

The Circadian Stimulus metric was calculated for the proposed lighting attributes and used as a guide to ensure that the intensity and color temperature variations of the 24h lighting scheme support users' circadian rhythm. It is therefore concluded that it does so, since during the morning the lighting conditions ensure high circadian stimulation, while during evening and nighttime no or minimal circadian disruption occurs.

- Ensures no glare & flicker issues.

It is recommended all light sources to be covered with an opal surface or placed lower than the eye height of a person sitting. In this way, it is ensured that none of the light sources will be able to cause glare issues. Finally, it has been stated that all of the light fixtures should be flicker-free.

- Provides a stimulating & pleasant visual experience.

The "window to nature" works as the play of brilliants that stimulates users' senses, introducing a natural view into the space. Providing the view of a moving foliage that changes throughout the day and the seasons, it enhances users' connection with nature that according to Ulrich contributes to mood elevation and stress reduction (Ulrich, 1997). Therefore, "window to nature" is an additional lighting element that creates a pleasant and relaxing atmosphere, supporting all users' physical and mental state.

10

Discussion

“Window to Nature”

The implementation of the “Window to nature” is based on a theoretical correlation, with Jim Campbell’s projects, created using similar technology and techniques, and on a number of tests that try to visualize the final result, utilizing the resolution (pixels/cm) of the displayed video. However, in order to be sure of the desired visual effect, additional real tests are necessary to be performed. Tests via mockups are expected to be able to examine in detail all the technical characteristics in order to determine the optimal LED array density, the array’s distance from the wall taking into account the position of the viewer/user, and finally the exact dimensions of the construction itself.

The testing part should also include exploration regarding the exact material that should be used for the construction. Experiments using different kinds of materials (eg. materials that create a high contrast with the white walls or not, with matt or more glossy coating, etc.) will examine the way the lighting effect interacts with the construction and will identify the material that leads to the best experience of light.

In order to present the daily and seasonal transitions of the foliage as naturally and smoothly as possible, ideally a series of real videos should be filmed for a period of one year. However, this solution is very time consuming, and on the other hand, there is great progress in video editing programs and programs that create digital content that simulates nature. It is therefore useful to conduct further research on the digital solutions that can be provided to create the video content.

Finally, it is a fact that the brighter the surrounding environment is, the weaker the lighting effect will appear. Daylight analysis showed that on a sunny day, during sunset, the sunlight can reach the wall where the “window to nature” is placed. Hence, from an energy-saving point of view, it is important to identify the highest illuminance level that allows the effect to be visible, and then use daylight sensors in order to turn the “window to nature” off when the illuminance threshold is exceeded.

Circadian Stimulus metric

The CS metric was calculated using the vertical illuminance approximately at the eye level of a seated person and not the exact ocular illuminance (as it is defined by the creators of the calculation system). Therefore, CS calculations should be considered as an estimation and not an accurate value.

As it is referred in the literature review chapter (3.10), CS metric is considered as a means of assessing how light affects the circadian rhythm, however, there are some critical parameters that are not taken into account (eg. history of exposure, timing, duration of exposure, etc.). In addition, given that the scientific community is still uncertain regarding the way various parameters affect the circadian rhythm, the complexity of the circadian system is proven. Thus, it is reasonable to say that although CS is a way of estimating circadian stimulation, much more research is needed on a metric that will be able to accurately demonstrate the effect of light on people’s circadian rhythms.

Night-shift workers

The night light scenario proposes low intensity warm light, in this way light cannot suppress melatonin production, supporting both users’ circadian rhythm. Although these light conditions are biologically very beneficial also for night-shift workers, they might not be enough for task performing or there might be the need of some additional lighting elements for boosting their alertness. This thesis does not include any specific lighting solutions related to the needs of night shift workers, since there was insufficient information regarding their schedule and duties in the communal areas. However, it is very important to consider the needs of this specific target group and adjust the lighting conditions accordingly.

Placement of light sources for general lighting

For the general lighting of the space, it has been proposed to use light sources with specific attributes (amount of lumens, RGBW, covered with opal surfaces, flicker-free, CRI> 90, specific light curves), without specifying specific lighting fixtures. The placement of the light sources has been determined, based on their characteristics and the existing furniture layout of the space, in order to provide the desired results, in terms of light levels, uniformity, and atmosphere.

However, the ceiling of the common areas of the Albertshøj eldercare home is a 60 x 60cm ceiling grid, which due to lack of the necessary plans and data was not taken into account. Therefore, it is necessary to consider the proposed placement of the light sources in accordance with the limitations created by this type of ceiling in order to be confirmed or reviewed accordingly.

Residents autonomy in controlling lighting

As it is mentioned earlier, residents have a certain amount of control in shaping the atmosphere of the living room according to their preference. Functional light fixtures (floor lamps and wall-mounted spotlights) were suggested to be used in particular places of the living room, accounting for easy access. Those fixtures can be turned on simply by using a regular switch. A critical parameter worth considering is the design of the switch. It is necessary for its size, shape, and placement to ensure that residents will be able to recognize and handle it easily.

Furthermore, this amount of control is recommended to be given to self-sufficient residents, with any or very low levels of dementia. However, this cannot be applied to places with highly demented residents. In these cases, it is best to consider more automated solutions to control such luminaires, in order to facilitate staff tasks.

Tackling glare issues caused by daylight

Both the living room and dining room have big windows that allow a great amount of daylight to penetrate the space. However, given the elderly's sensitivity to glare, and the low solar altitude in Denmark, it is reasonable to assume that especially during summertime, the elderly may often experience glare issues. One way to overcome this problem is the use of curtains, nonetheless, while reducing the glare, the long-distance exterior view is also limited. Instead, further investigation would be useful to consider the use of sun protection films for the windows, for selecting the right type according to the needs of the space (in terms of transmittance, etc). This way, daylight will be transmitted avoiding potential glare issues, while users will have access to the exterior view.

11

Conclusion

An eldercare home is primarily a home for its residents, namely elderly people, but also a workplace environment for the caretaking personnel. Lighting design can be an effective way of facilitating and supporting both residents' and staff's everyday life. This thesis' aim was to identify the necessary parameters that can provide a pleasant and safe environment for residents to live in, and for caretakers to work at. Emphasis is given on how lighting design can support residents' visual, biological and psychological needs during their practice of home, while at the same time support all personnel's biological, mental and professional demands.

Thorough research on all different aspects related to the context of an eldercare home including its users, reinforced with the knowledge gained from the state of the art LIGHTEL project, led to a deep understanding on the fundamental elements that should be taken into account when designing for such a context. Having as a case study the common area on the third floor of Albertshøj eldercare home, an in depth analysis of the space was made to identify the use of the space, the daylight intake, the existing electric lighting conditions, and users' characteristics, routines and needs.

The findings of the literature review, state of the art and case study analysis led to the formulation of the research question:

"How can a lighting design in the common area of an eldercare home improve the everyday living of residents and at the same time ensure an efficient work environment, while supporting both users' physical and mental state?"

and finally on the identification of the Success criteria needed to ensure the fulfillment of the research question.

The design concept is being developed in two branches. Firstly, a 24-hour dynamic lighting scheme is incorporated, that is based mainly on Albertshøj daily schedule, and the CCT variations of daylight throughout the day. Other factors that are met to complete the lighting scheme, are also the modified lighting standards, to account for elderly's decreased visual performance, and the principles for lighting that entrains users' circadian rhythm. On the second branch, the design concept continues with a lighting design proposal, one for each of the spaces of the common area (hallways, living room, kitchen/ dining room). The goal of every individual proposal is to meet the residents' visual demands, to support their routines, and to enhance safety as well as the general sense of control and autonomy. It is equally essential for the staffs' visual needs, necessary for task performance, and the demand for them to have control rights, to be met. Two ways to achieve that are flexible lighting modes, accounting for different activities, and additional functional lighting when necessary. The design proposal is completed by incorporating a lighting element that aims to stimulate users' senses by introducing a natural element into the space. The "window to nature" creates an abstract interpretation of a moving foliage's natural view over time, aiming to enhance users' connection with nature and thus create a relaxing and pleasant environment for both residents and staff.

Despite the specific solutions proposed, based on the architectural and furniture layout of the focus area, the design guidelines that were created and followed for each space can be applied to any other nursing home, always focusing on the specific needs of its users. Respectively, the 24-hour lighting program can also be modified according to the schedule of each eldercare home, following the same principles and control capabilities. Finally, the idea of introducing a natural element through light indoors, as "window to nature" does, can also be implemented in similar contexts where users have no or minimal contact with nature. All in all, following the principles and the approach used for the proposed design concept, leads to lighting conditions that can enhance residents' well-being and the valuable feeling of being at home, while providing an efficient, safe, and pleasant workplace for the caretaking personnel of all eldercare homes.

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Figures & Tables

All the figures that are not included have been made by the author.

Figure 1: Paimio Sanatorium, Alvar Aalto, 1993. Retrieved from https://www.landscapefirst.it/learning-from/aino-e-alvar-aalto-viaggio-alla-scoperta-di-paesaggi-e-architetture-tra-finlandia-e-italia/

Figure 3: The experience of dynamic and diffuse light. “Visionaire, New York, NY. Pelli Clarke Pelli Architects” (Browning et al., 2014 p.36)

Figure 4: Non-rhythmic sensory stimuli. “Kinetic membrane of the Brisbane Domestic Terminal Airport Carpark by Ned Kahn” (Browning et al., 2014 p.30)

Figure 5: Biomorphic forms & patterns. “Facade of Manuel Gea González Hospital, Mexico” (Browning et al., 2014 p.38)

Figure 6: Illustration of the retinohypothalamic tract (Boyce, 2014 p.94)

Figure 7: “Spectral biological action curve Bl (based on melatonin suppression), bold line, and the visual eye sensitivity curve Vl, thin line” (van Bommel, 2004 p.257)

Figure 8: “Double plot (2 x24 h) of typical daily rhythms, between their relative minimum and maximum values, of body temperature, melatonin, and cortisol in humans for a natural 24-h light/dark cycle” (van Bommel, 2004 p.261)

Figure 9: Albertshøj eldercare home. Retrieved from Google Maps https://www.google.dk/maps

Figure 12: Albertshøj’s dining area. Retrieved from LIGHTEL project, Aalborg university

Figure 13: Albertshøj’s living room. Retrieved from LIGHTEL project, Aalborg university

Figure 17: Albertshøj’s hallways. Retrieved from LIGHTEL project, Aalborg university

Figure 24: Moodboard for hallways, by Poulaki Varvara-Nepheli. Images retrieved from Pinterest, references are listed left to right, top to bottom: (1)https://gr.pinterest.com/pin/471892867205996937/,(2)https://gr.pinterest.com/pin/571535008945751028/,(3)https://gr.pinterest.com/pin/524106475366284200/,(4)https://gr.pinterest.com/pin/655766395713890070/

Figure 31: Moodboard for living rooms, by Poulaki Varvara-Nepheli. Images retrieved from Pinterest, references are listed left to right, top to bottom: (1)https://gr.pinterest.com/pin/654288652098764428/,(2)https://gr.pinterest.com/pin/143552306852097204/,(3)https://gr.pinterest.com/pin/518125132131165043/,(4)https://gr.pinterest.com/pin/383509724499257622/,(5)https://gr.pinterest.com/pin/94153448447304126/

Figure 33: Louis Poulsen luminaire "PH 80". Retrieved from: https://www.louispoulsen.com/en/catalog/private/floor/ph-80?v=90397-5744610816-01&t=about

Figure 37: Moodboard for kitchen/dining room, by Poulaki Varvara-Nepheli. Images retrieved from Pinterest, references are listed left to right, top to bottom: (1)https://www.pinterest.jp/pin/845058317568976615/,(2)https://gr.pinterest.com/pin/185492078383615621/,(3)https://www.pinterest.co.uk/pin/683280574702339644/,(4)https://gr.pinterest.com/pin/383791199498027099/,(5) https://www.pinterest.jp/pin/629800329117335395/

Figure 41: Map illustrating the location of Hundeskov Park & Albertshøj eldercare home, by Poulaki Varvara-Nepheli. Image retrieved from Google Maps https://www.google.dk/maps

Figure 46: "Exploded Flat 2" & "Taxi Ride To Sarah's Studio", Jim Campbell's projects. Retrieved from Jim Campbell's website:
https://www.jimcampbell.tv/portfolio/low_resolution_works/exploded_

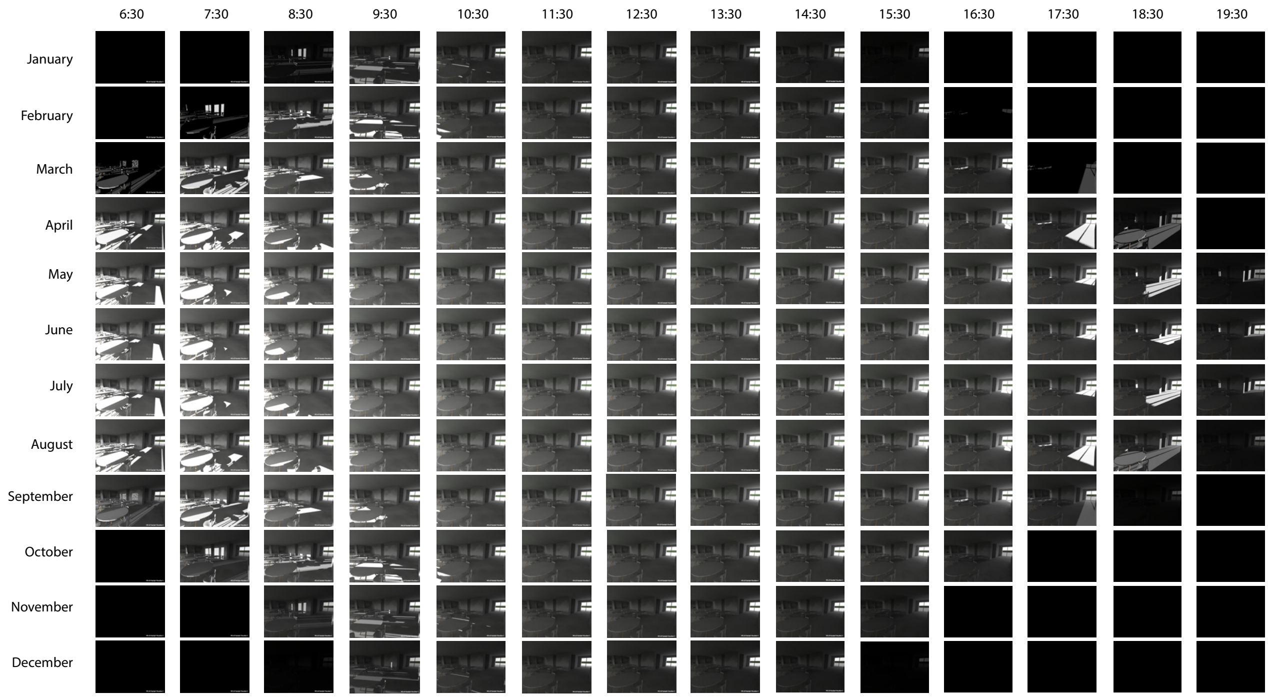
Table 3: European standards of Light DS/EN-12464-1:2011(DS/EN-12464-1:2011, 2012)

Appendix 3:The average daily sunshine hours in Copenhagen. Retrieved from: https://www.holiday-weather.com/copenhagen/averages/

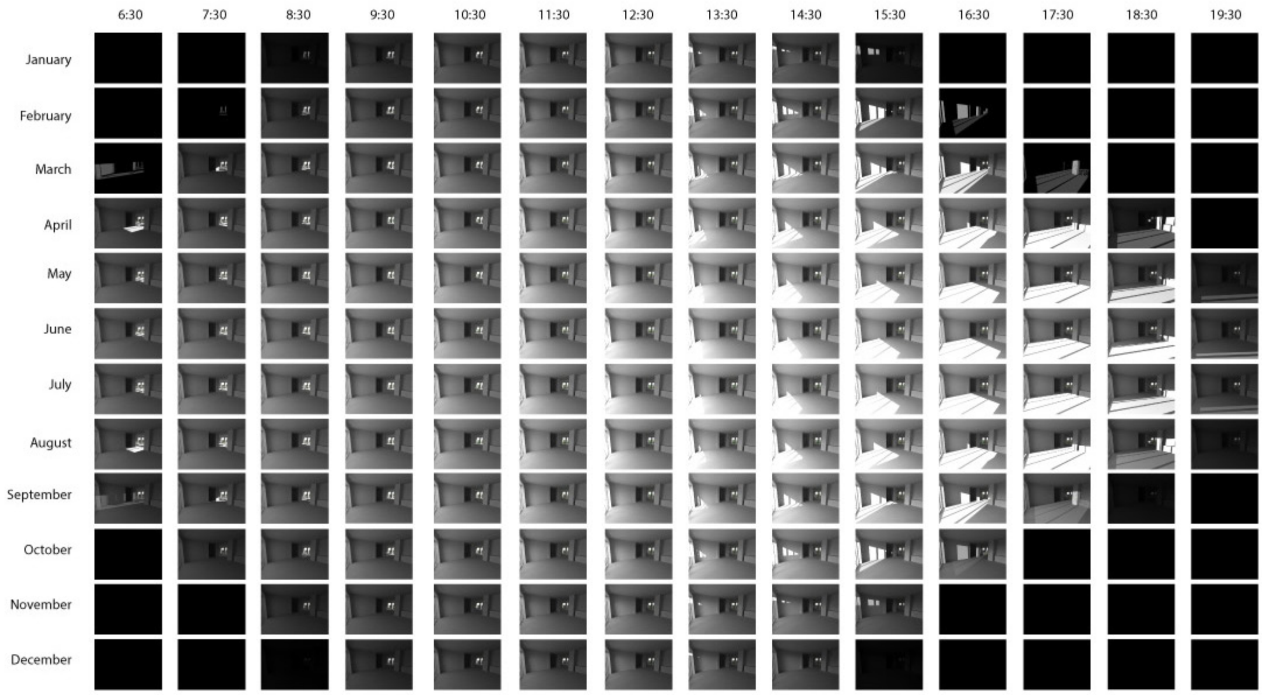
Appendix 5: Calculation of the Circadian Stimulus metric. Retrieved from: https://www.lrc.rpi.edu/cscalculator/

13. Appendix

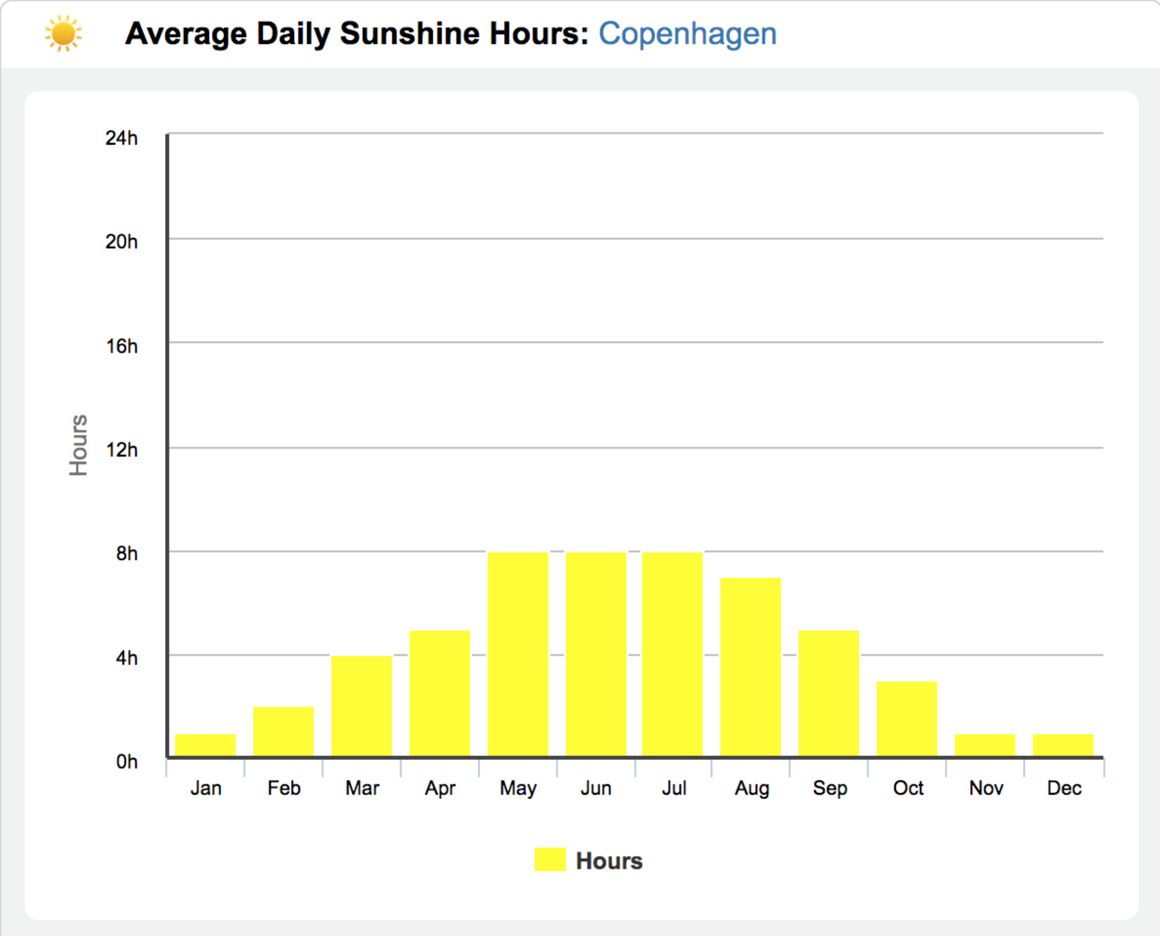
Appendix 1: Annual analysis of Sunlight effect_Dining room | Sunny | 6:30 am - 7:30 pm



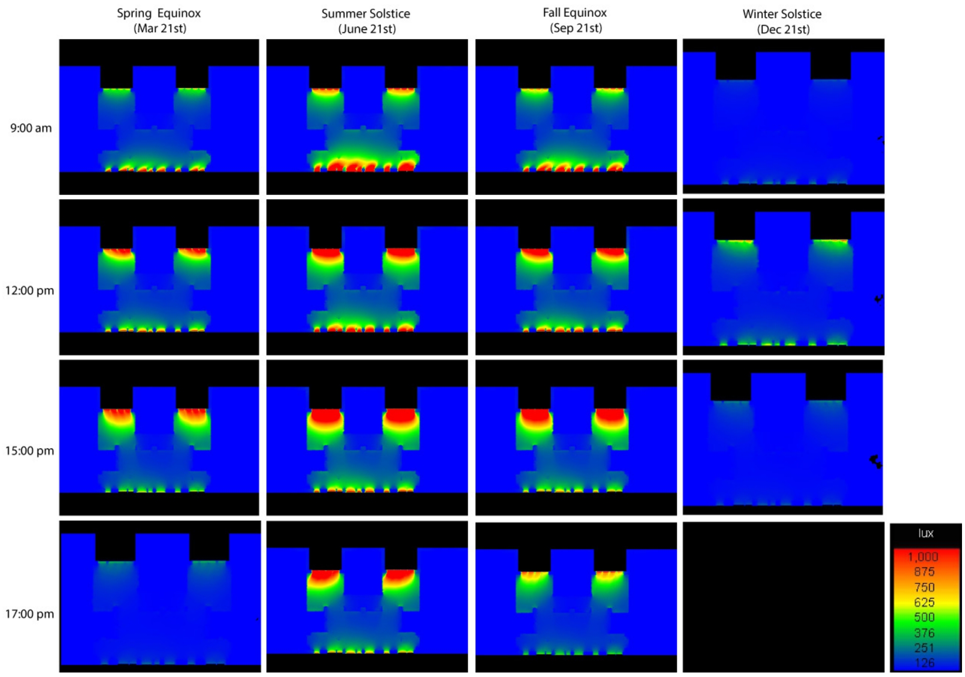
Appendix 2: Annual analysis of Sunlight effect_Living room | Sunny | 6:30 am - 7:30 pm



Appendix 3: The average daily sunshine hours in Copenhagen

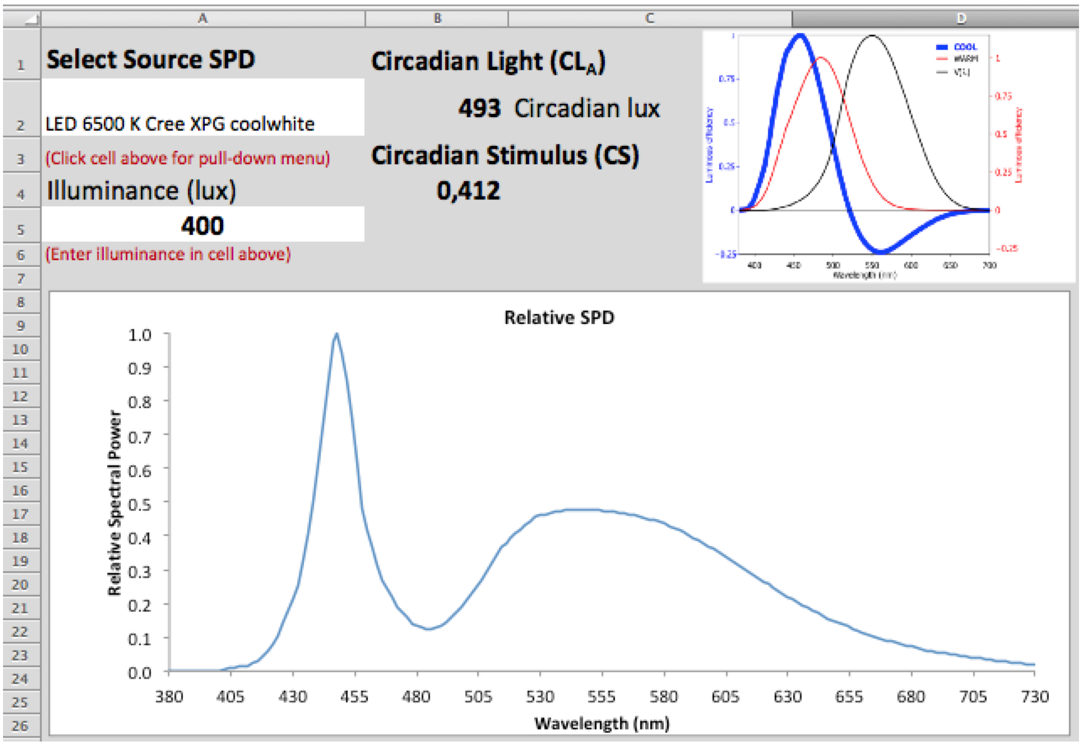


Appendix 4: False-color daylight illuminance map during the spring equinox, summer solstice, fall equinox & winter solstice, for sunny weather conditions, in four different times of the day (common area top view)

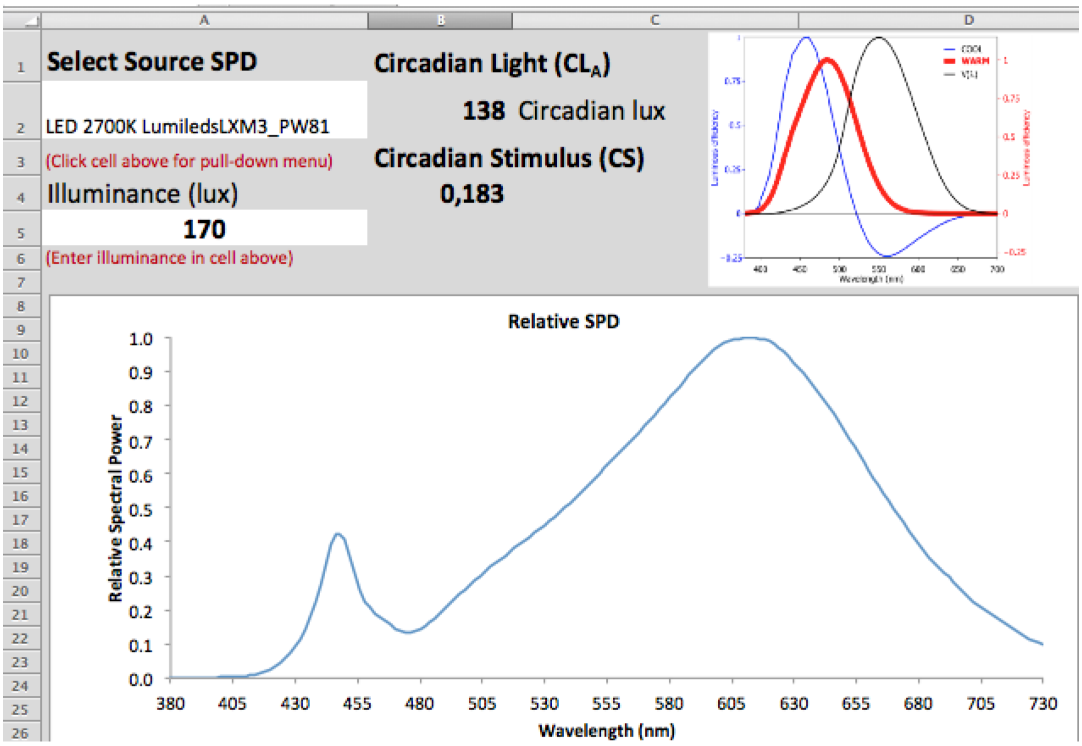


Appendix 5: Calculation of the Circadian Stimulus metric

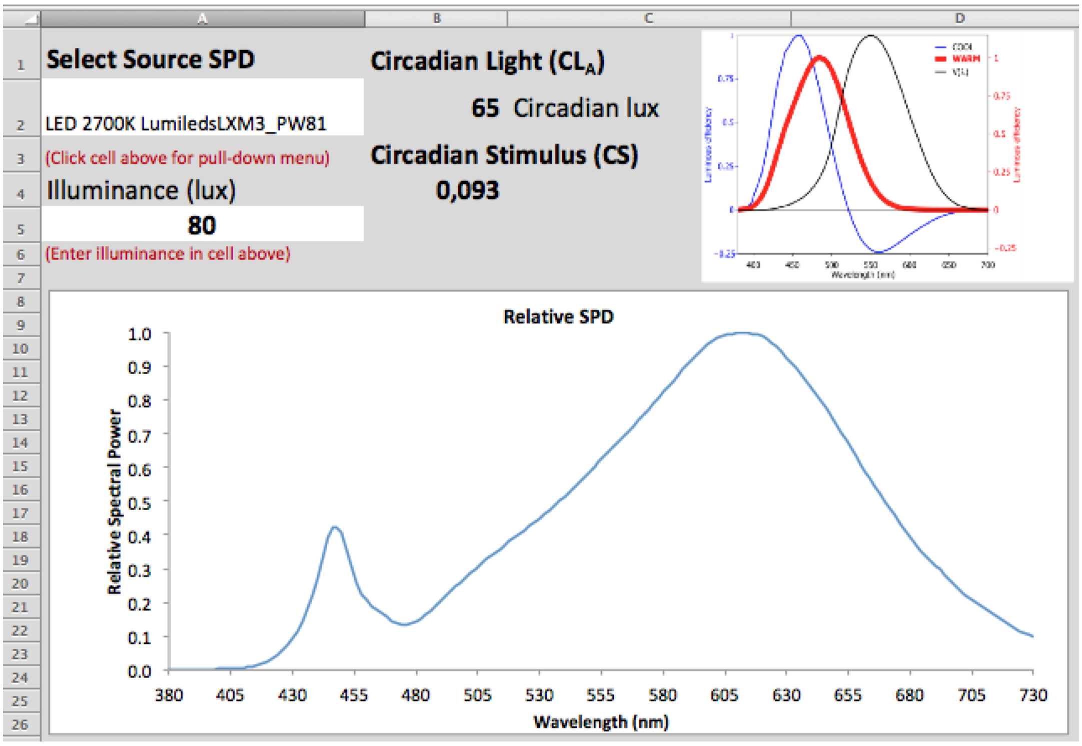
(A) Calculation of the Circadian stimulus metric during morning activities time (10:00 am - 11:30 am)



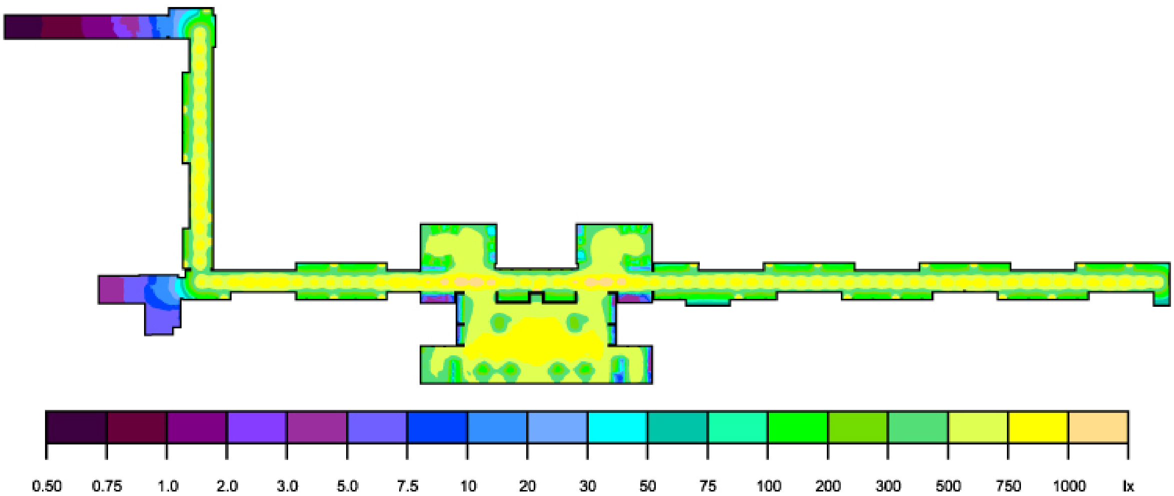
(B) Calculation of the Circadian stimulus metric during evening hours (18:30 pm - 19:30 pm)



(C) Calculation of the Circadian stimulus metric during late evening hours (19:45 pm - 22:00 pm)

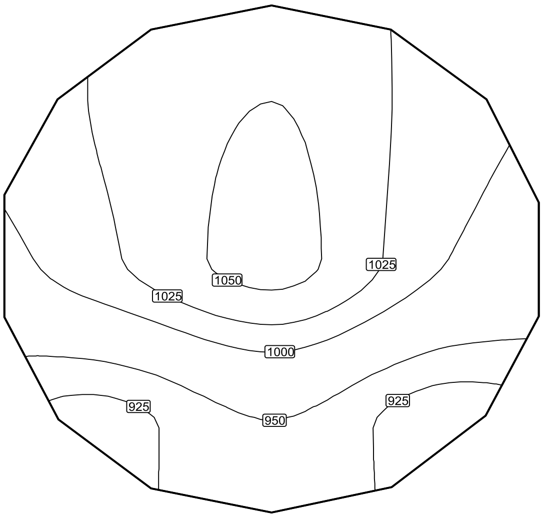


Appendix 6: False-color illuminance map during morning activities time (10:00 am - 11:30 am)

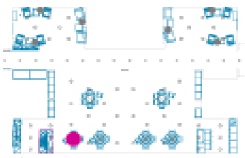


Appendix 7: Illuminance levels on the dining tables during morning activities time (10:00 am - 11:30 am)

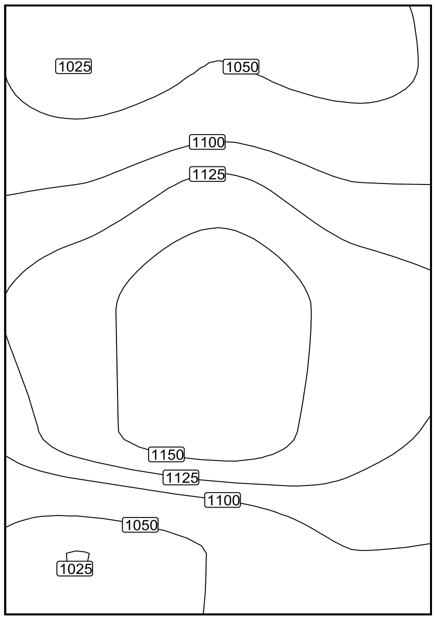
Isolines [lx]
Dining table



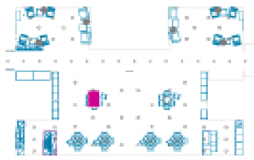
Scale: 1 : 10



Isolines [lx]
Dining table

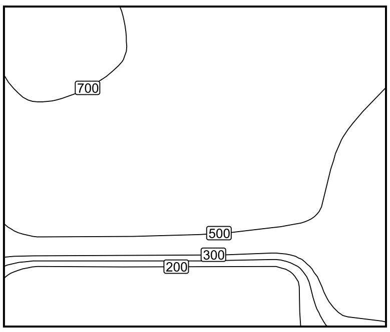


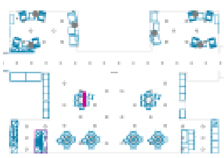
Scale: 1 : 10



Appendix 8: Vertical Illuminance levels at the eye level height of a seated person during morning activities time (10:00 am - 11:30 am) in dining room & living room (respectively)

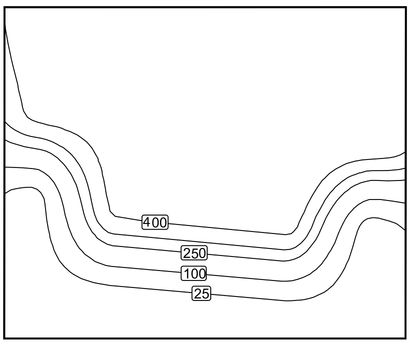
Isolines [lx] Vertical Illuminance Dining room

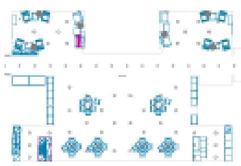




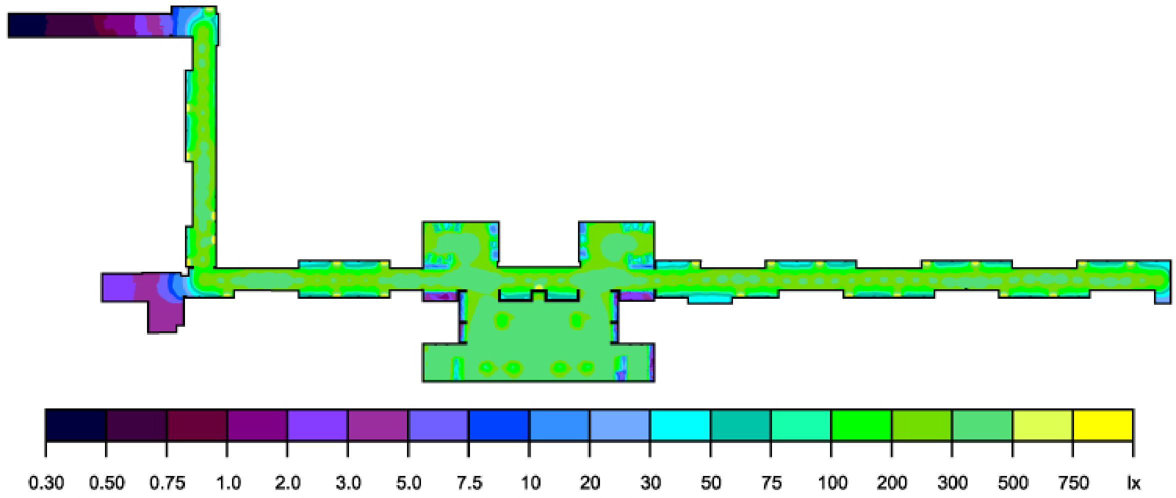
Scale: 1 : 10

Isolines [lx] Vertical Illuminance Living room





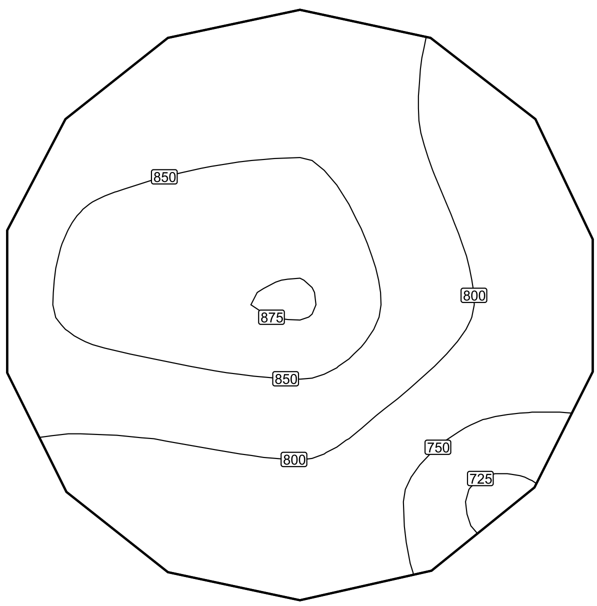
Appendix 9: False-color illuminance map during meal time (breakfast, lunch & dinner)



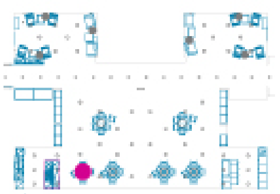
Appendix 10: Illuminance levels on the dining tables during meal time (Breakfast & Lunch & Dinner)

Isolines [lx]

Dining table

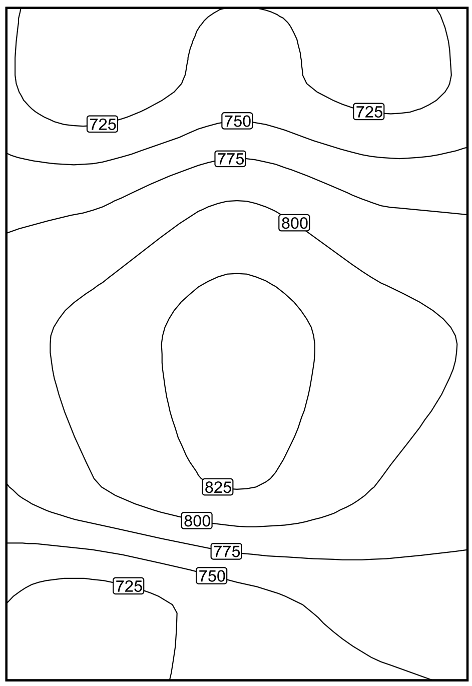


Scale: 1 : 10

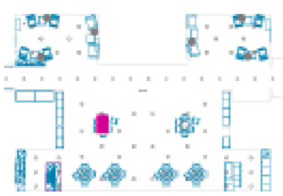


Isolines [lx]

Dining table

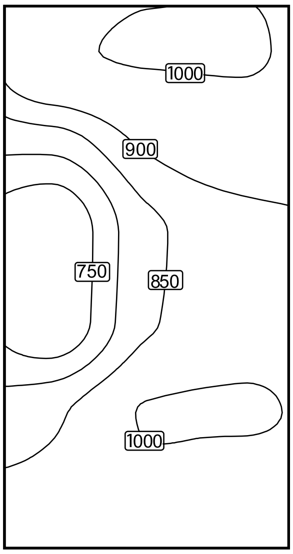


Scale: 1 : 10



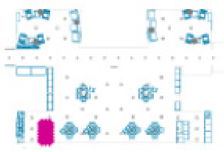
Appendix 11: Illuminance levels on the task area when the “work mode” is on in the kitchen

Isolines [lx]

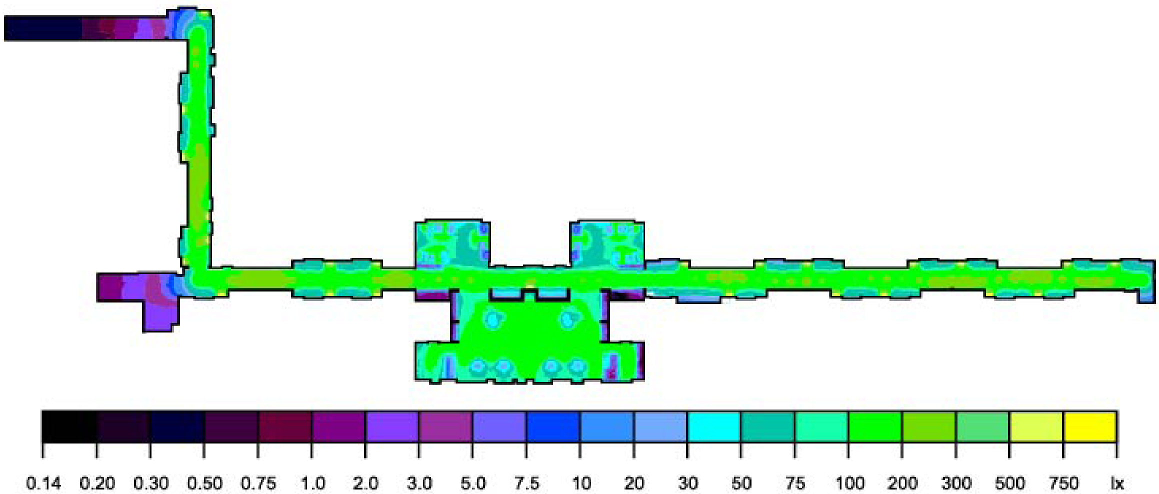


Scale: 1 : 25

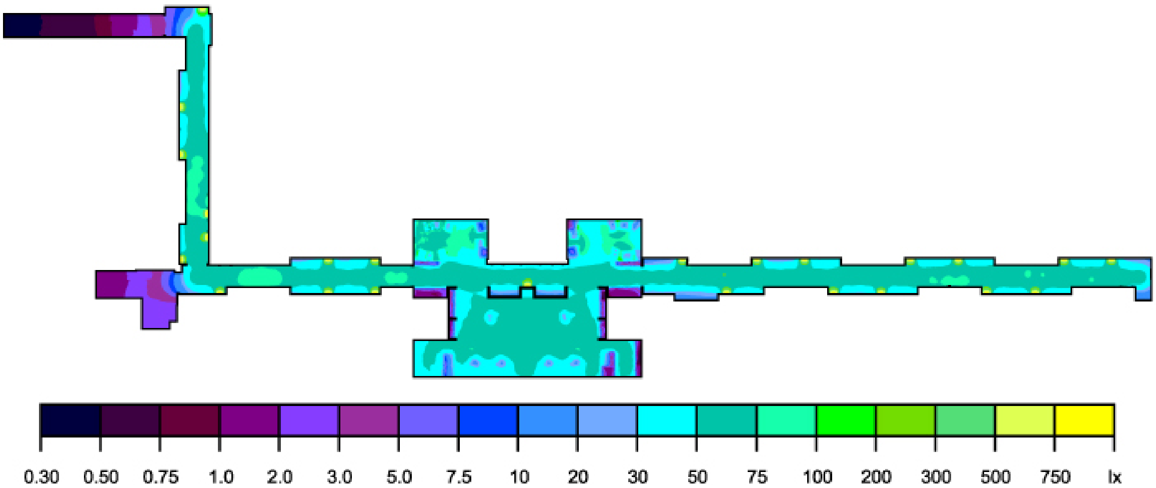
Scale: 1 : 25



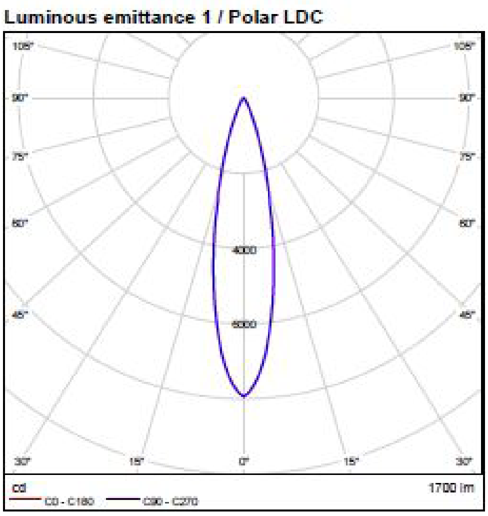
Appendix 12: False-color illuminance map during evening (20:00 pm - 21:30 pm)



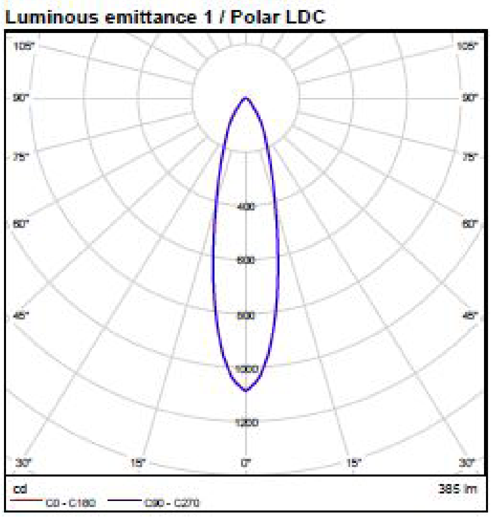
Appendix 13: False-color illuminance map during nighttime (10:00 pm - 06:30 am)



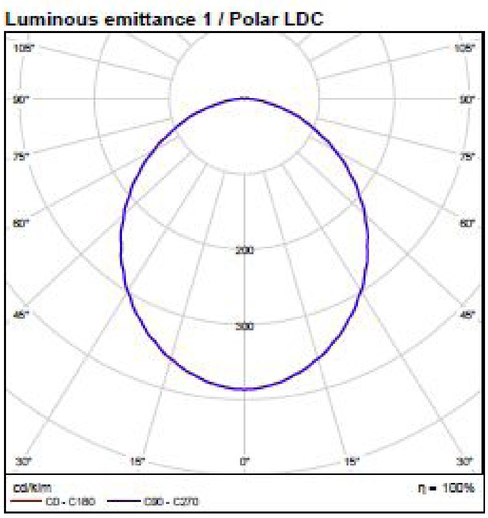
Appendix 14: Proposed Light distribution curves



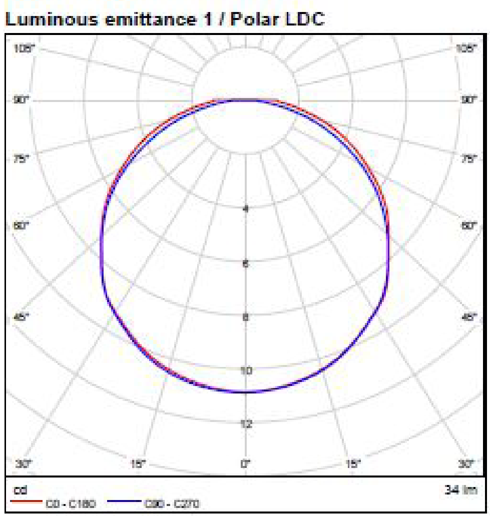
(A) Recessed ceiling directional downlights for hallways



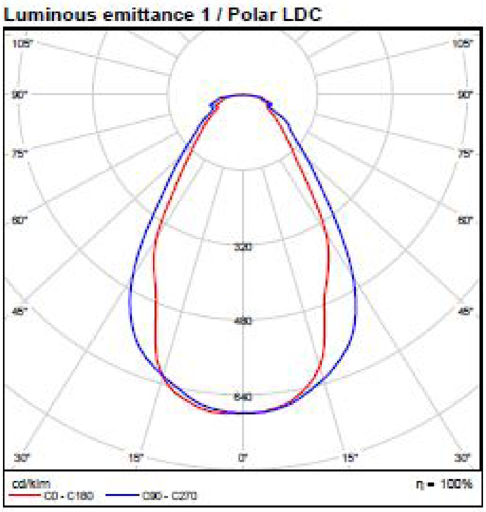
(B) Spotlights for art



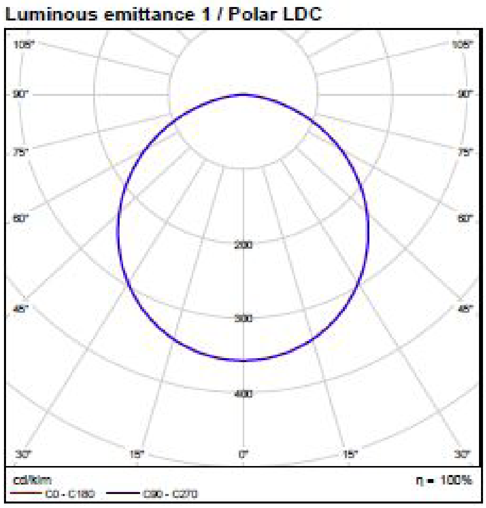
(C) Recessed ceiling fixture for living room and kitchen/dining room



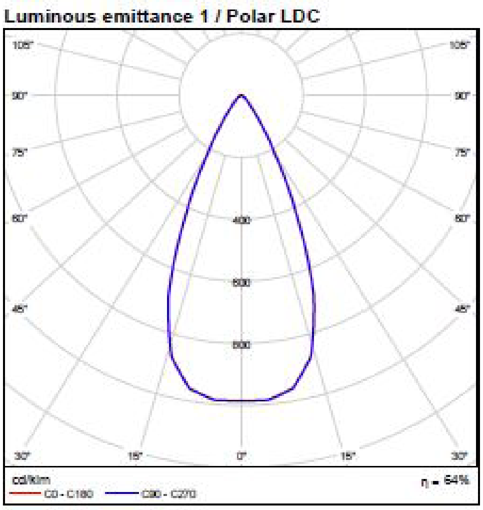
(D) LED strips for kitchen functional light, integrated element on the handrails in hallways & “window to nature”



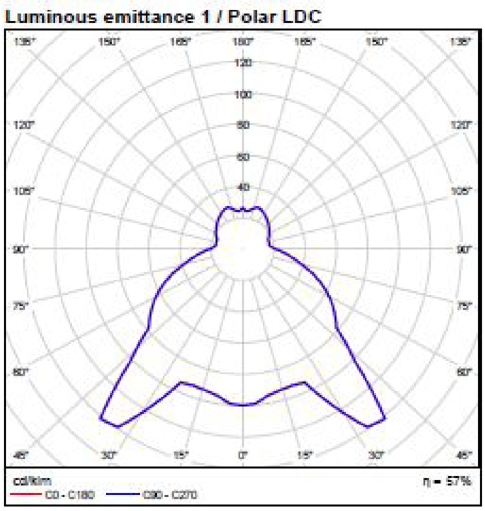
(E) Orientational linear fixture placed next to the entrances of the private rooms



(F) Pendants - Dining room



(G) Wall-mounted spotlights - functional lighting living room



(H) Louis poulsen “PH 80” floor lamp

Appendix 15: Video showing the sunny foliage of a tree moving slightly in the wind, https://vimeo.com/421031709 (password: Poulaki Nepheli)

Appendix 16: Videos testing the visual effect of the “Window to nature” based on the density of LED arrays, https://vimeo.com/422427726 (password: Poulaki Nepheli)