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Visual and Non-Visual Lighting Design Principles for Nightwork Environment

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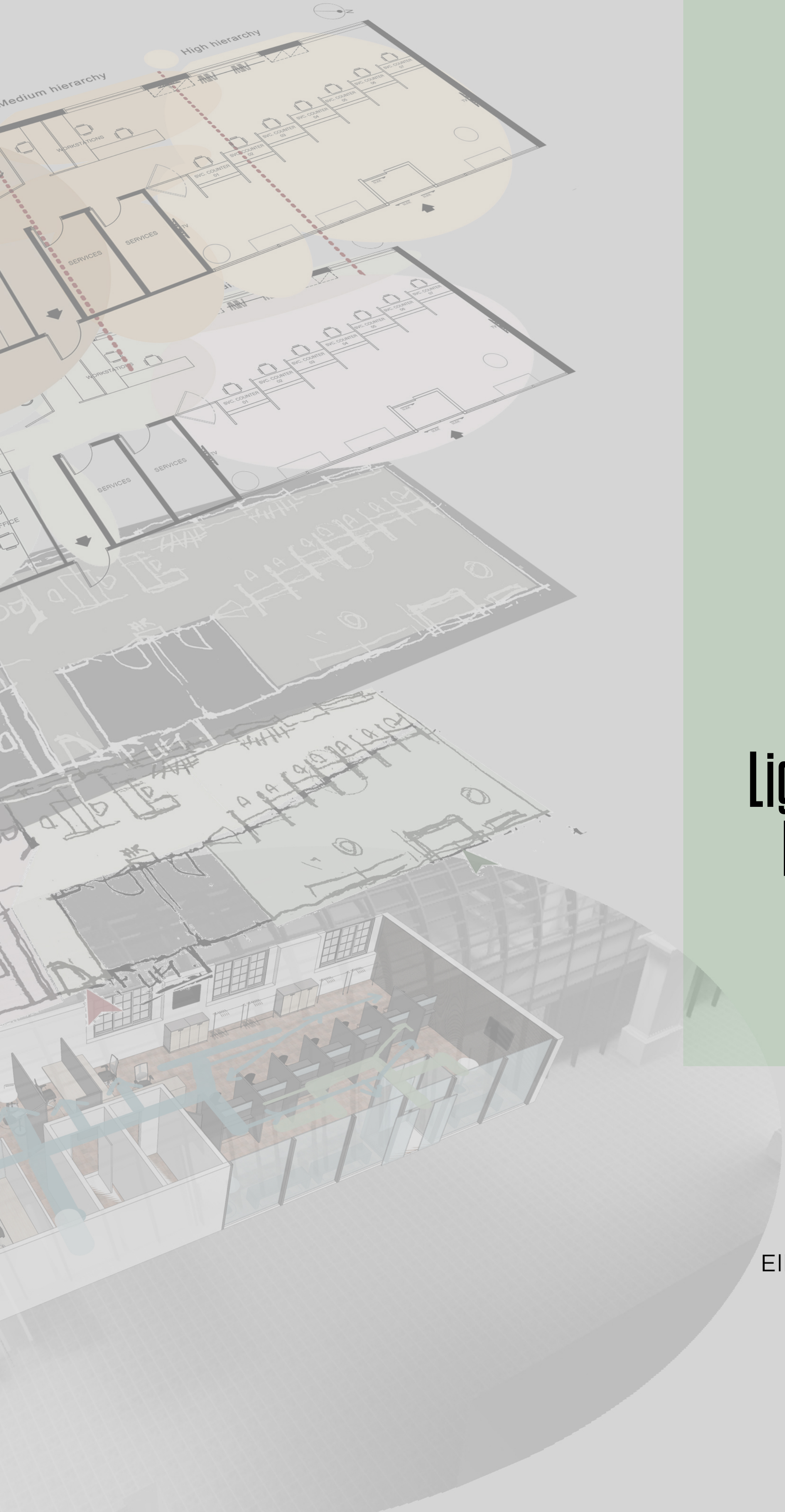
Abstract:
As humans evolve further into the modern world, more and more industries are operating at a 24-hour capacity, which automatically resonates in the increasing amount of work force required for the night shifts. At this point, circadian disruption is inevitable and this warrants for a better solution to minimise its effects in nightworkers, of which are destructive to human health (as stated by the World Health Organisation). The research aims to produce a lighting strategy that can be used by lighting designers using a case study and implemented into other nightwork environment. The result was a schematic design in lighting principles for the visual and non-visual system that works by categorising areas into the accompanied spatial functionality classification. The lighting principles for nightwork environment produced are categorised into 3 main lighting schemes – Low, Medium and High Functioning, which details varies under 4 different light elements, which are – corneal illuminance, horizontal illuminance, CCT/Spectral Distribution and Spatial Distribution. This schematic principle could not be concluded with data from field testings and experiments, thus, may render it refutable without further works, but the evidence is supported by a case study analysis and theoretical framework.



Visual & Non-visual Lighting Design Principles for Nightwork Environment

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Report Summary

As the world rapidly evolved into a 24-hour globalisation, a lot of industries are directly affected by the development with increasing demands for nightshift work force. The diurnal human physiological system however has not evolved to fit the nocturnal activity, causing nightworkers issues with adapting to the change in their circadian rhythm. Effects of nightshift are carcinogenic to the human body, according to the WHO, with health implications like obesity, heart diseases, increased cancer risk, and insomnia among other social problems.

Exposure to lighting at night has been discovered to be a major factor in this issues. For a long time, the method was to maximise light intake under bright direct fixtures to prevent sleepiness during nightshift (which has been the main concern in declining work performance) but it disregards user interaction, spatial hierarchy, visual comfort and post-shift sleep quality.

This study aimed to provide lighting designers with a strategy that could be applied in nightwork environment, combining the visual and non-visual theoretical framework from previous studies on the same topic as evidence. A case study was used in the research as a pragmatic approach to conduct spatial and lighting analyses. The end findings are concluded in a schematic design diagram containing 3 different schemes for 3 different spatial functionalities - Low, Medium and High Functioning. Each scheme describes the visual and non-visual lighting principles under 4 elements - Corneal illuminance, Surface Illuminance, CCT/SPD, and Distribution.

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Contents

1 INTRODUCTION

Circadian Rhythm is the 24 hour sleep-wake cycle that revolves around the movement of the Earth to the Sun, also normally related to the layman's term of 'biological clock' (Haus & Smolensky, 2006). The human anatomy has adapted to and relied on this rhythm for a healthy mind and body. That being said, when the rhythm is disrupted, for example; staying up late at night or waking up late in the day, it causes a disturbance in the normal secretion of the bodily function (Vetter, 2020). The effects of this event are destructive to human health, as stated by the World Health Organisation (Stevens, et al., 2011). But as humans evolve further into the modern world, more and more industries are operating at a 24-hour capacity, which automatically resonates in the increasing amount of work force required for the night shifts. At this point, circadian disruption is inevitable and this warrants for a better solution to minimise its effects on nightworkers – to find a more 'humane' working condition for nightshifts, without sacrificing the alertness level required to carry out work tasks properly.

Lighting has been a very important factor in the circadian rhythm as the brain naturally relies on the emergence of light during sunrise and its receding during sunset to adjust the biological clock in regulating the dark/sleep hormone, melatonin (Lewy, Sack, & Singer, 1985). The eyes have a way of knowing what certain type of light will do to our brain and body. For example, when the eyes detect blueness and intensity in the morning sun, it triggers secretion of 'stress' hormone (cortisol) that helps us feel energized to start the day. And vice versa with the redness and dimming light in sunset, which triggers 'sleep' hormone (melatonin) to help us wind down (Mirick & Davis, 2008). The technological advancement of electric lighting today can mimic these behaviors the way daylight does by tricking the brain, thus providing a chance to find the balance between a healthy rhythm and a good work performance.

1.1 Research Background

1.1.1 Declaration of Previous (first) Report

This research was conducted on the preliminary basis and knowledge of a previous report written by the same author, during an internship semester in the same university programme. These two reports are directly connected to each other, thus, as a follow-up study revolving the same topic, works excerpted from the first report are cited in the texts in this second report.

The first report discussed an overall understanding of what circadian lighting is and how it can be integrated in the architecture of a work environment. The were no deliberate or detailed focus on any particular lighting variables from the topic, with minimal categorisation between the interior and exterior factors. The hypotheses were based on a generic structure of what the researcher experienced in the industry and inspired by during her internship period. Despite having a broader outlook and an undetermined research protocol, the knowledge gathered from the first report was directly used and analysed in the process to form a new research criteria that helped to establish a clear perimeter in this second report.

1.1.2 Chronology of Circadian Lighting

Discussions about how every organism has a 'timekeeper' in their physiological functions have been around for centuries before the term circadian rhythm was actually defined. From the Latin word *'circa'* (meaning 'approximately') and *'dies'* (meaning 'day'), the term was brought upon by Franz Halberg in 1959, when he mentioned;

> *"... it may serve to imply that certain physiologic periods are close to 24 hours, if not exactly that length. Herein, "circadian" might be applied to all "24-hour" rhythms, whether or not their periods, individually or on the average, are different from 24 hours, longer or shorter, by a few minutes or hours."*
>
> \- (Halberg, 1959)

Multiple scientific studies were conducted throughout the years since the definition of the term, to find out in further details, what are the factors and how they are affecting the circadian rhythm. It was found that one of the major circadian factors for human is the light-dark exposure and its strong relationship to our sleep-wake pattern (Wright, et al., 2013).

Lighting as a basic human need has continued to develop its meaning as human evolves into more complex beings. During the cavemen age where daylight and fire were the only source of light, the absence of sunlight as the day ends and the emerging dim shade of moonlight became a signal of rest and sleep. This was when the movement of daylight was assumed to be the only governance of our internal clock. The establishment of windows in the Roman era started when human built roofs over their heads and created indoor dwellings (Paarhammer, 2017). When humans began staying indoor during the day with windows acting as the primary connection to daylight, that was the start of our species's detachment from the natural day and night cycle. As dwellings became more complicated and sheltered, a major part of the human life was spent in the shadow of these indoor areas, shaded away from daylight (Allison, 2020).

The invention of electric brings forward a great leap in the meaning of light as basic human need. It allows for buildings to be made bigger, thus increasing indoor areas that were deep enough, daylight were unable to reach them directly through means of openings (Allison, 2020). Electrical light was the reason for this condition to exist, although it did not last long until humans started experiencing the negative effect on our mind and body, most probably from the lack of daylight exposure. In retrospective following this condition, standards or guidelines today, for example the EN-12464, made huge efforts to comprise the importance of daylight exposure, but new discoveries about daylight and its effects on our non-visual functions continue to surprise the lighting industry.

It was once a typical and ancient understanding that the human eyes receive light in order to see and that human sees colours and details better in bright light conditions compared to dark surroundings, also known as the photopic vs. scotopic visions. The rods and cones photoreceptor (light-sensitive) cells response to visible cues in light, such as brightness, causing changes in our visual perception of space and motion. That was until a group of researchers discovered a new set of cells in the eyes, other than the rods and cones, that also detects the elements of light to produce non-visual reactions (Schlangen & Price, 2021). These cells, namely ipRGC, are still religiously studied in the lighting industry and they continuously bringing in newer conclusions to this date.

When it was proven and concluded that electrical lighting could inhibit circadian effects through our non-visual pathway the same way daylight can, it spiked technological progress in finding ways of 'healthier' electrical lighting. It was uncertain when the term 'circadian lighting' came about in these recent years, but it was believed to be inspired by the pursuit of using non-visual factors in electrical light for the betterment of human health from the disruption of circadian rhythm, also as a generation that has fully adapted to being indoor (Velux, 2018). Today, several terms like Human Centric Lighting (HCL) and Integrative Circadian Lighting, has even branched out as a result of Circadian Lighting dialogues and are in the centre of many 'humane' lighting technology discussions.

1.1.3 Circadian Lighting for Night-workers

From the rise of fast-speed internet to the advancement in transportation technology, the generation today are at the peak of globalisation in human history, and it can only keep rising. Distance that used to take days of traveling decades ago, now only takes several hours. The result of that is increased normality in jetlag, which is a big impact on the circadian disruption seen in long distance travels (Srinivasan, et al., 2010). To accommodate to these overnight travellers, industries created this big pool of work force running the transportation industry behind curtain on a graveyard shift. In the manufacturing industry, productions and customer service operate at 24/7 capacity to facilitate the competitiveness between companies, creating a high demand for night workers required to drive this operation. People who work in stock markets commonly sit in front of the computer day and night, in the effort to observe the market that is happening at a different time zone, on the other side of the world (Perez, Traversini, Fioriti, & Taddei, 2019).

As a diurnal species, humans depend greatly on the oscillation of day and night and for their environmental condition to be synchronised to this pattern (Figueiro, Sahin, Wood, & Plitnick, 2016). The health implications that surrounds the topic of night work is endless, some of which involves stress, heart diseases, obesity and insomnia are to name a few (Puttonen, Harma, & Hublin, 2010). Some work-related implications are drowsiness, high mistake count and decreased performance (Smith & Eastman, Shift work health, performance and safety problems, traditional countermeasures, and innovative management strategies to reduce circadian misalignment, 2012).

1.2 Research Objectives

The end findings in this research aims to provide a schematic design of lighting principles, used as a basic guideline for designing a nightwork environment. The principles should cater to the different spatial needs of user alertness, work performance, physical interaction and post-shift sleep quality.

1.2.1 The “Other” Nightwork Industries

The increased in demand for night workers has never been higher than what human has seen in this current generation. Less than a few decades ago, night work used to be almost exclusively within the healthcare, transportation and public services (Garbarino, Traversa, Spigno, & Bonsignore, 2011). The type of activities that are carried out by these essential industries in their night shifts are different than other industries, which may consist of a limited amount of detailed-oriented tasks, computer tasks, reading, writing and other office-related activities. In the globalised world today, not only that night shifts have expanded well into other industries, but the common office tasks that are normally carried out during day shifts, like reading and typing on the computer for 6 hours a day, have seen great extension to night shifts as well (Kecklund, Di Milia, Axelsson, Lowden, & Åkerstedt, 2012).

In the past years, the majority of circadian lighting researches have been conducted within the healthcare industry. Therefore, a lot of improvements in the lighting technology of these healthcare facilities were introduced and modified to cater to the circadian and functional needs of a healthcare night worker. It goes without saying that the healthcare service is probably the most essential type of night shift works, but in a hindsight, other industries which are also related to the public services and safety are being overlooked, and they might be equally important in ensuring a functioning society. During the time of publication of this report, not much information has been found about circadian lighting for those night-work industries that indirectly contribute to serving the public, such as road and transportation maintenance and repair, treatment plants or gas station operators. It is important to understand that these essential services are working on a non-natural human day-night oscillation with the same set of critical tasks and performance level on par with that of day-workers.

1.2.2 Balancing Alertness and Circadian Disruption

There are endless amount of articles published on the internet of proven facts on the health implication of circadian disruption and how serious the risks are in long term cases. In this modern society, night-work is spread out to almost all industries and disruption in circadian rhythm for these night workers is inevitable despite all the efforts. Therefore, the purpose of this research is not to find ways of eliminating circadian disruption completely, but it is to minimise the impact without sacrificing work performance by using the elements of light. It is important to understand that a good work performance would require certain level of alertness, which would mean to suppress the feeling of sleepiness to a certain degree.

Typically, the idea about reducing sleepiness in order to achieve adequate alertness translates to suppressing melatonin level in the body, although this theory has been tested in other scientific studies to prove that it can work otherwise. In one of those studies, participants were subjected to a series of GO/NO-GO alertness tests at different hours of the night while under the exposure of light conditions that theoretically will not suppress melatonin level, and this was compared with dim light conditions that is ideal for a natural melatonin cycle (ref). The result was an obvious increased in alertness level in the bright light condition compared to the dim, without any changes to the natural melatonin cycle. It was not mentioned what set of activities the participants were engaged in, outside of the alertness test. Therefore it is unclear at which stage of alertness is considered adequate to carry out work related tasks in a particular night shift.

1.2.3 Circadian Lighting Guideline

The topic of circadian lighting has been one of the most popular advancement that was made between lighting developers in recent years, which stems from different perspectives and sub-industries within lighting itself, in order to produce a result that covers the various aspects of circadian lighting. While lighting designers have been heavily involved in the aesthetic and functions of light, lighting engineers and programmers are constantly developing the light technology in ways that align with findings of circadian scientists, for example, an automatic tunable-white system that calculates the movement of the sun in order to help with healthy circadian entrainment by mimicking the right amount of wavelength to the natural cycle of human's physiologyical function (Nie, Wang, Dang, & Dong, 2019).

One of the very few standards in circadian lighting produced by the International WELL Building Institute (IWBI) introduced a new unit that measures the biological effects of light in the non-visual pathway. The unit, namely "Equivalent Melanopic Lux" (EML), is calculated based on a metric that responds to the ipRGCs in the eyes instead of the rods and cones cells (which is the traditional way of measuring the normal lux value). The way EML was verified, is measured the same way with corneal illuminance, – a vertical point at a height similar to a human occupant, depending on the various types of space and activities. The activity types are divided into four main spatial categories; offices, residentials, office's resting areas and institutions. The standard is constantly amended to new findings within the circadian topic (WELL, 2016). Although it is currently only focusing on the use of architects and interior designers, and is limited to a general working condition which presumably is the conventional day-working condition.

1.3 Research Criteria

1.3.1 Problem Statement

This research is conducted under the problems found in the industry that is relevant to the topic of the research interest. As the research objectives aim to produce a schematic design of different lighting principles for guideline purposes, the problem statement listed below is derived from the general issues found in the nocturnal industries that revolve around the topic of lighting in both the visual quality and the non-visual system of these shift workers;

- Reduced work performance during the nightshift compared to dayshift, as their productivity lowers and judgment is impaired from sleepiness issues.
- Poor sleep quality after their night shift due to excessive melatonin suppression.
- High safety and security risk, especially in the public sector where majority of the nightwork industry operates, caused by low alertness level.
- Serious health implications and risk surrounding the nightshift workers from circadian disruption when not properly entrained.

Concluded from the above problem statements, the initial research question for this research is stated as follows:

"Imagine if architectural lighting can improve work performance while maintaining sleep quality in nightwork environment?"

1.3.2 Inter-disciplinary Model for Lighting Design

There is a lot to study in order to produce a standard that is well verified by all aspects of circadian lighting. Due to its scientific background needs, lighting designers alone should not be considered as equal experts in the topic, thus, validating the need for an inter-disciplinary research. Given the various limitation during this report, the end findings of its published work may not be sufficient to produce a guideline or standards in the circadian lighting for night workers, but it aims to offer a strategy or recommendation in the principle of its application that could help take this unprecedented topic one step further.

This research was conducted on the basis and protocol from the inter-disciplinary research model of Lighting Design (Hansen & Mullins, 2014). The research model is described in figure below. The main idea of this model is to intercept knowledge from three main disciplines of lighting design, with the aim of forming a conclusion that has been considered and reviewed by these aspects. The rationality in this step is the sensitivity of circadian knowledge that interacts actively between its scientific background, physical functionality and human well-being.

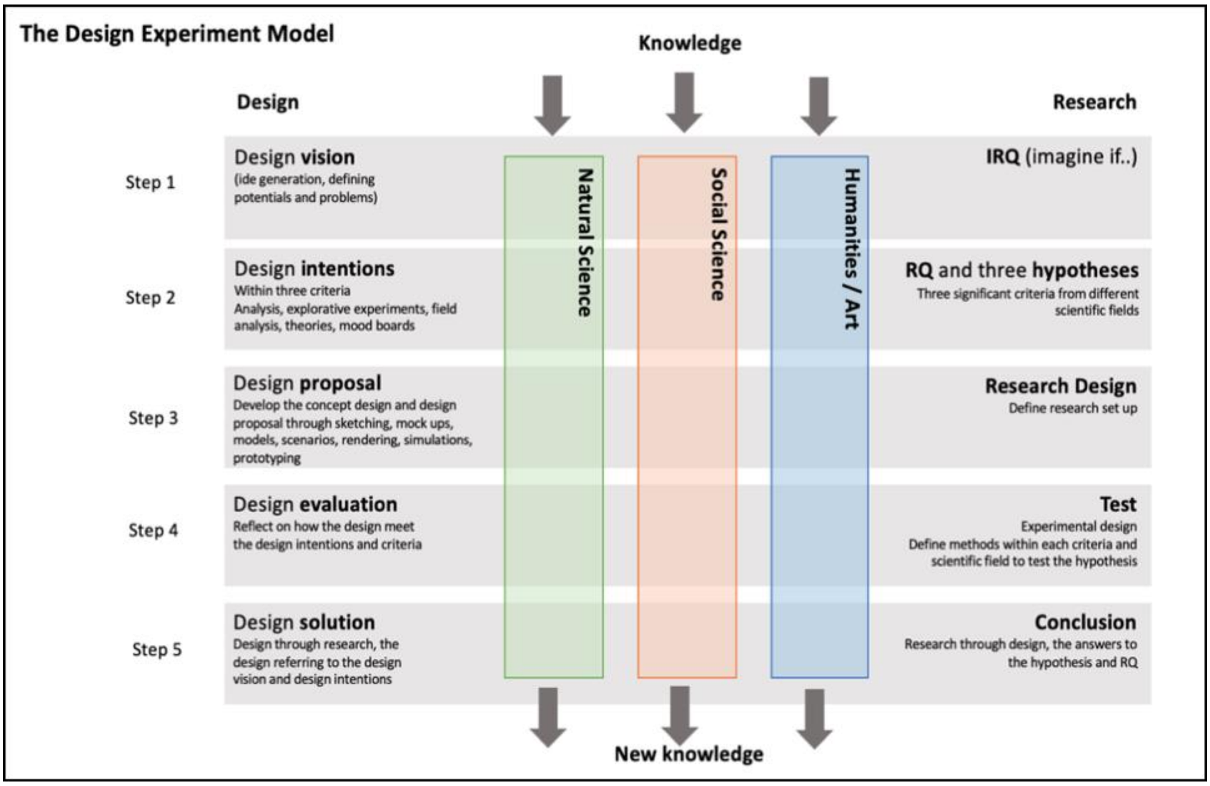


Figure 1.1: The transdisciplinary design experiment model of the Lighting Design curriculum. The three fields of knowledge in the vertical columns integrate at each step of the research (Hansen & Mullins, 2014).

1.4 Hypotheses and Research Question

Natural Science:

High and direct corneal illuminance can elicit adequate alertness level to increase work performance and visual acuity.

Social Science:

Controlled exposure of warm and cold light under dim conditions during the shift can regulate sleepiness to aid post-shift sleep quality.

Humanities:

A clearly defined light hierarchy in a nightwork environment can boost efficiency of spatial functions and user interaction.

***Research Question**:*

"How can light distribution, CCT and hierarchy be utilised to regulate user alertness and aid spatial functionality in nightwork environment?"

1.5 Field-Based Case Study

1.5.1 Case Introduction

Figure 1.2 The main entrance to Copenhagen's Central Station located Northwest of the building, taken on 24th March 2021 at 2013 hours. (Source: self-owned)

The case selected in this research is the Police Station in Copenhagen's Central Station (Hovedbanegård), Denmark, located in the main hall of the building, and the police employee that is working on the nightshift at the station.

Acting as the main station in Copenhagen, it is also the biggest railway station in Denmark (Preisler, 2011). The building is currently owned and operated by *Danske Statsbaner* (translated: Danish State Railways), the biggest train operator in Scandinavia region. The station was first established in 1847 and initially designed by Heinrich Wenck, although the current physiques of the building was from 1911 (Bonnevie, 2014). Multiple upgrades, refurbishments and overhauls were carried out between 1980 to 2008 to the construction of the building, although the initial lighting design of the main hall by Gunver Hansen, a Danish lighting architect, remains to be from the year 1992 with only one upgrade work to switch the incandescent bulbs into LED in the year 2000 (Hansen G., 1992).

The police station in the main hall, acting as the only branch for the Central Station, is located on the first floor at the Southwest end of the building. The Southwest entrance of the railway station is situated right below the police station and connects directly into Reventlowsgade and Istedgade of Vesterbro, while main entrance of the building (pictured in Figure 1.1) faces Northwest and connects directly into Vesterbrogade through Banegårdspladsen. Referring to Figure 1.2 below of the site plan, the indoor space of the main hall comprised of 7215 square meter area (excluding the area covering tracks and platforms on Ground Level and general DSB offices which are not within the main hall) and the police station takes up 163 square meter of that area. Currently the operating hours of the police station at this branch is from 0800 hours to 2100 hours on weekdays, and 0800 hours to 1700 hours on weekends, although there have been future plans to extend the hours to 12 midnight. This statement is elaborated more in Chapter 1.5.2 and Chapter 4 Case Analysis.

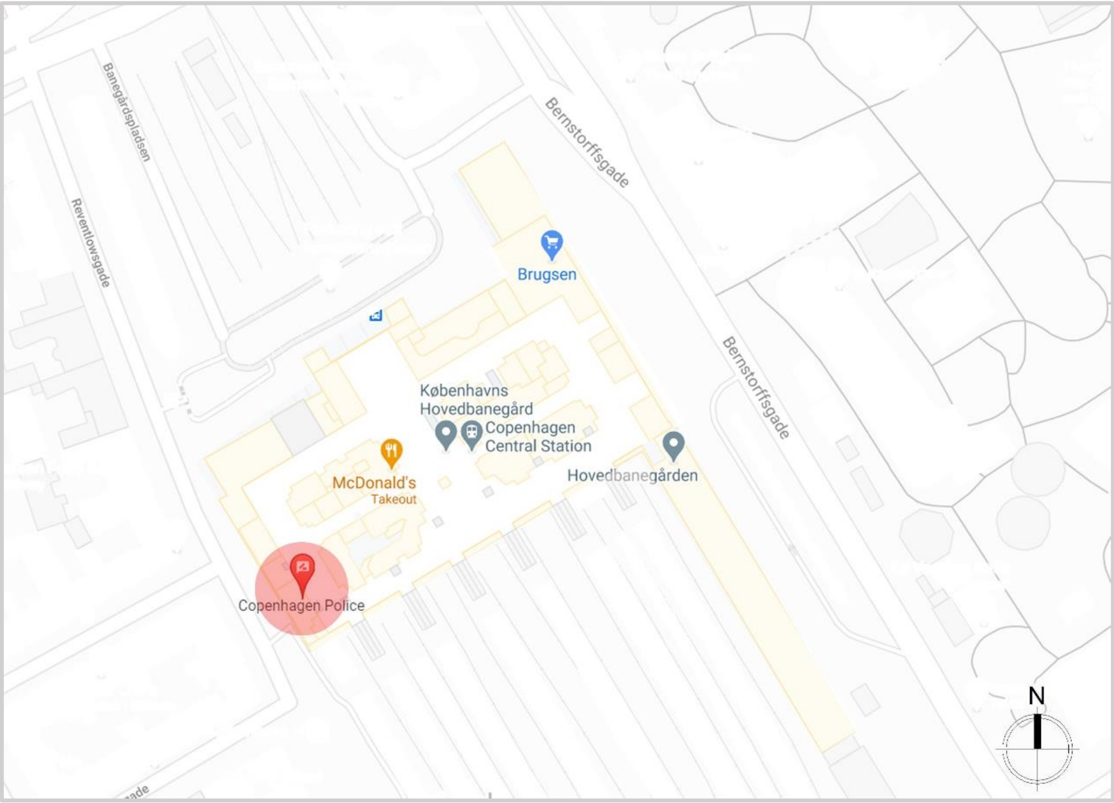


Figure 1.3 Location of the Police Station in relation to the whole building marked in red. The building is marked in yellow. Map faces North. (Source: Googlemaps)

1.5.2 Motivation

During the period of the first report, the author had the opportunity to be working on an upgrading project for the lighting in Copenhagen's Central Station (Hovedbanegård) between MOE Engineering and DSB as the project's clientele, while serving under an internship position with Gottlieb Paludan Architects. The author received help in establishing connection and network to the representative from the police station by Gottlieb Paludan Architects, due to her previous involvement in the project itself.

The mobilisation of the project was first established from a complaint made by the officers working at the police station located inside the building, on the Southwest end of the building. The complaint was primarily about the eye-strains that the employee in the station were experiencing from catching the reflection on their glass facade during their night shift, which is dissected in further details in Chapter 4; Case Analysis. The project main discussion revolves around upgrading the high-ceiling light fixtures in the main hall of the central station to increase the overall ambient illuminance in the hall, which aims to balance out the brightness from inside the police station. This action targets to eliminate the reflection that is currently causing glare and eye strains to the officers and employee in the police station, which happens only on their nightshift due to the lack of daylight.

Since the time of the publication of this second report, the project was still in approval stage and installation of the new fixture has not been carried out. Although, from the experience of being actively involved in the project at the time of the author's internship, it was an intriguing thought to investigate if the increase in overall ambient illuminance, as was requested, would completely solve their eye-strain and visual discomfort issues from working on the night shift. The motivation for this idea is that; while the balance in general ambient of the two spaces is important, the intricate practice and science behind the nightwork lighting condition could be more effectful, given how often it is overlooked.

Figure 1.4 The facade of the Police Station, on the right side of the photo, located on the interior of the railway building. Photo taken on 24th March 2021 at 2030 hours. (Source: self-owned)

Figure 1.5: View of the fieldsite's facade from another angle. (source: self-own)

It was made known in an interview, which is further elaborated in Chapter 4, of the future plans and suggestions from the police to extend their current opening hour until 12 midnight, although it is not known when will this plan be implemented yet. Currently, their nightshift ends at 2130 hours. It is thought provoking to consider how big of an effect it will make to the current working condition, despite it being only an additional of three hours to the current shift. Also, it should be investigated and evaluated of how the preparation and upgrade needs to take place to the lighting condition for this nightworking time extension to function.

As the second busiest railway station in Denmark following Nørreport Station (Preisler, 2011) on the count of passenger throughput, the fact appeals that presumably, as a very busy transit point in the country, the building would be a hotspot for all kinds of criminal activities. It is well-speculated that the police working to service the safety and security of the high human traffic that is using this building, they would need to extend the police station operating hours to a much later period than 12 midnight and eventually, the demand might arise where it would be required to operate 24 hours as the building continues to expand its transportation services.

1.5.3 Site Access

Despite having a limited access to the site, it was an opportunity that could not be missed – to be granted close access to the back-of-house and operations behind one of the highest security body of authority of the nation and at one of the most known location in the country.

Access to site was granted and controlled by the Work Environment Representative for the police station. An in-depth explanation of the interview with the personnel is presented in Chapter 4. With the help of the engineers and architects from MOE Engineering and Gottlieb Paludan Architects, who were involved in the upgrading work of the main hall, the author had successfully established a connection to the aforementioned personnel from the police station. With the connection, site visits, photos, observations, interviews and taking measurements, were made possible as part of the methodology used in the analysis of this case study.

The site visit was made on 24th March 2021, from 1930 hours to 2030 hours, guided by mentioned personnel, upon approval of upper management. The limitations that the author had encountered during the case visit is elaborated further in Chapter 2.4.

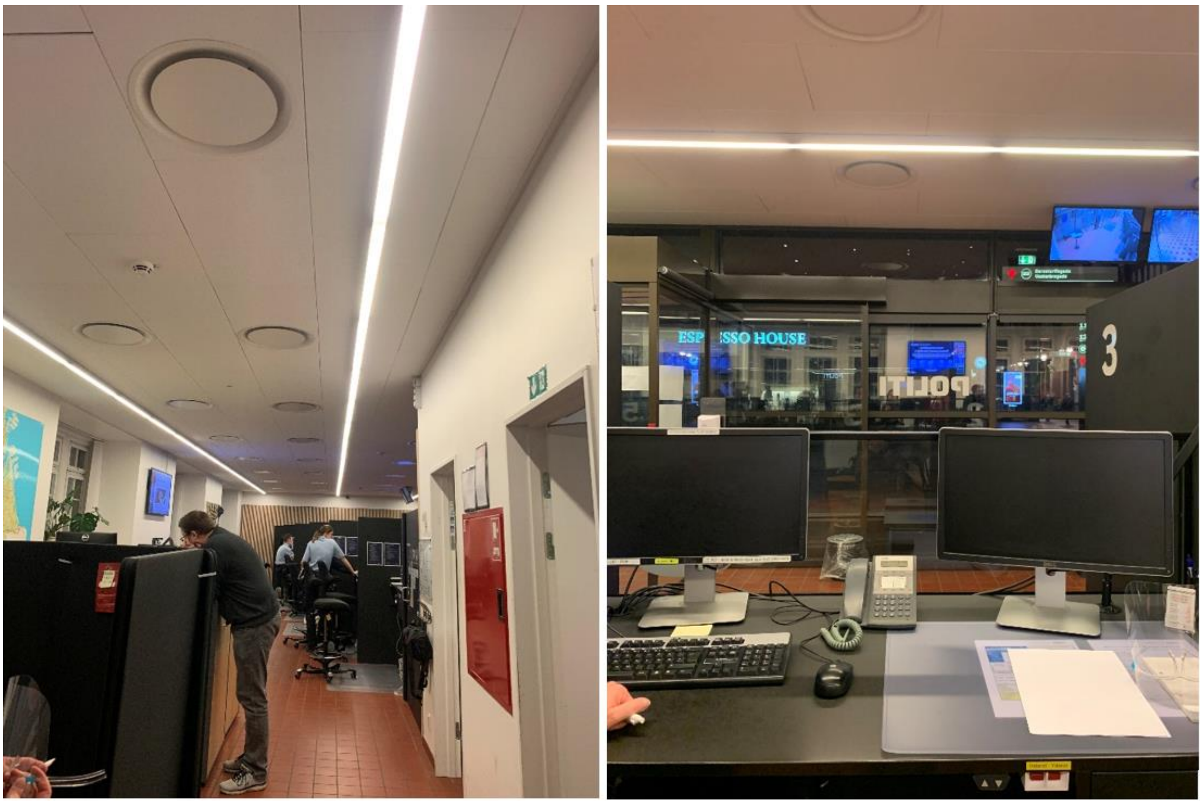


Figure 1.6: Several interior photographs taken from inside the police station upon granted with access. (Source: self-own)

2 THEORETICAL FRAMEWORK

2.1 Circadian Rhythm in Lighting

The text below is excerpted from the researcher's Literature Review from her first report as declared in Chapter 1. (Azrudin, 2020):

> *"Circadian rhythm is the 24-hour (approx.) light-dark pattern that human has developed has a diurnal species, concerning the production of enzymes & hormones in the physiological system of the body* (Figueiro, Bierman, Plitnick, & Rea, 2009)*. The biological mechanisms work when the brain receives information from external stimuli that gets processed in the amygdala, and the superchiasmatic nuclei (SCN) in the hypothalamus is then responsible to secrete chemicals to the body that would be perceived as an "appropriate" response to the mentioned stimuli* (Hattar, Liao, Takao, Berson, & Yau, 2002)*.*
>
> *Even though the hypothalamus is well-known as a stress and arousal response mechanism, new studies have shown that light intake in the eyes is also affecting this pathway through non-visual cells in the eyes* (Provencio, Jiang, De Grip, Hayes, & Rollag , 1998)*. The cycle works from the morning daylight to the darkness of nigh. The morning sunlight exposure has the right properties in its light to boost energy by suppressing melatonin and peaking level of cortisol. This secretion progressively regulates until night-time and thus, the rhythm is reset when we sleep. Numerous studies have followed up to this finding since, to investigate better of what "kind" of lighting affects it in which way. Some factors with lighting that has been popular as variables among these studies and were proven to be detected by the pathway, are:*
>
> - *wavelength (spectral power distribution)*
> - *duration*
> - *timing of the day*
> - *intensity (brightness)*
> - *task and activity*
> - *spatial distribution*
> - *light history of subject*
> - *age of subjects*
>
> (Foster, 2020)
>
> *A lot has been discovered and proven about the effects of lighting on the visual functions in our eyes that is controlled by the photoreceptor cells of rods and cones in the retina. It is well concluded that the rods are sensitive in scotopic vision while cones are used in photopic vision* (Gronfier, 2014)*. The same can be said to the understanding of our non-visual pathways that are controlled by the ipRGC cells, which existence was discovered by Provencio in his research in 1998, but later known to affect major cognitive performances* (Berson, Dunn, & Takao, 2002)*. These ganglion cells, located in the retina, send signals to the brain that perform the following bodily system;*
>
> - *circadian rhythm regulation,*
> - *pupil reflex*
> - *motor activity*
> - *sleep*

- *alertness*
- *metabolic processes*

(Gronfier, 2014)

A research has even taken a statement to indicate that through all this different sets of cognitive modulations, ultimately light can affect mood and behaviour (Vandewalle, Maquet, & Dijk, 2009). *Through these non-visual pathways, melatonin is secreted in phases, psychomotor performance and alertness level changes and mood is regulated as the study has shown. It was also known that people who have been blind since birth have the same light-reactive physiological function on their circadian rhythm despite not having any understanding of visual perception* (Czeisler, 1995)*"*

2.2 Circadian Disruption in Nightworkers

The text below is excerpted from the researcher's Literature Review from her first report as declared in Chapter 1. (Azrudin, 2020):

"The circadian rhythm is not entirely fixated on the day and night cycle or the Earth's oscillation. Circadian adaptation or circadian alignment is a method to shift the phasing of the rhythm relative to the work shift hours. Permanent night shift is suggested for healthy circadian rhythm for nightshift workers. For much better effects, a controlled lighting scheme of 24 hours must be closely monitored. For example, in a study by Figueiro suggested the use of colour tinted goggles on their commute home in the morning hours to block out short wavelength in the morning sunlight and avoid further melatonin suppression (Figueiro M., 2013). *It should also be considered to block out daylight in their bedrooms to maintain the consistency of their light history. At this hour, the main focus should be for the body to prepare itself for sleep. Other than the early mornings, exposure to light should also be controlled in the evening and early part of the night as this is when natural melatonin rhythm begins its production. By doing so, it enables the body to delay circadian phase, and progressively if done consistently over a period of time, will shift the circadian phase to align properly to their night shift. As this reduces circadian disruption significantly, therefore it may also increase worker's performance during their night shift* (Smith & Eastman, Shift work: Health, performance and safetyproblems, traditional countermeasures, and innovative management strategies to reduce circadian misalignment., 2012).

Rotating night shift is not recommended due to the confusing effects it has on the body. Although it has been debated that out of social values and concerns of the social life of these workers outside of the work life, rotating shift is still widely used by the night-time industries to enable them to have a work-life balance."

2.3 Non-visual Properties

2.3.1 Wavelength and CCT

The text below is excerpted from the researcher's Literature Review from her first report as declared in Chapter 1. (Azrudin, 2020):

"*In order to contribute to the lighting system design for night workers and provide a solution that is considerably healthy on the circadian rhythm, it is important for lighting* *designers to understand the 24-hour flow of the rhythm itself and the internal bodily changes that occur with the sleep-wake cycle. Melatonin is a dark hormone that is directly responsible to make us sleepy at night. With the right amount of daylight exposure during the day and in the right pattern, melatonin reaches its peak at around midnight and decreases as the morning arrives. At this point, cortisol, a stress hormone, will then take over when it reaches its peak at around 7am in the morning* (Thapan, Arendt, & Skene, 2001)*. The circadian rhythm is maximally sensitive to spectral exposure of around 460nm, a short-wavelength light that we perceive as blue-ish to suppress nocturnal melatonin production. This is slightly different to what the visual pathway is most sensitive to, that is around 555nm, somewhere between yellowish green* (Brainard, et al., 2001)*."*

Several studies had been conducted to investigate the effectivity of wavelengths and CCT values in melatonin suppression. One of the studies examined this relationship by conducting an experiment under dim light conditions but in varying short-wavelength range. It was found that melatonin production is greatly suppressed under short-wavelength exposure of 460-490nm, with the highest sensitivity to 479nm and therefore, they concluded that this spectral range could elicit a bigger response to the non-visual system in comparison with the long-wavelength range, under these dim conditions (Bailes & Lucas, 2013).

Another more recent study looked at CCT value and performance level under 3 consecutive simulated nightshifts, with constant intensity of 200 lux at eye level (Sunde, et al., 2020). The blue-enriched light (7000K) was found to increase performance level compared to the 2500K white light, however detected the same deterioration rate over time with both conditions at the end of each shift. The study made an important conclusion whereby, despite the increase in cognitive performance with 7000K, subjective alertness was not relatively higher compared to the 2500K.

2.3.2 Intensity and Corneal Illuminance

The text below is excerpted from the researcher's Literature Review from her first report as declared in Chapter 1. (Azrudin, 2020):

"Many researches have presented experiments that conclusively indicating the same statement; light of any wavelength will elicit alertness during the night. This statement is important as alertness is mostly used an indication of the feeling opposite to sleepiness. According to Plitnick, lighting in both long and short wavelength lead to similar effects in melatonin reduction to reduce feeling of sleepiness, which translated into evidence of alertness (Plitnick, Figueiro, Wood, & Rea, 2010)*. The paper then suggested from its result, it is important to understand that "red" or warm light in any brightness level, does not aid our sleep time, contrary to most assumptions. Warm light is just "less harsh" to the melatonin suppression compared to "blue" or cold light (short wavelength). The temporary effects of calmness and other momentary moods that we obtain from a warm candlelight in a dark room (dimmed light condition) is not significant enough to affect a subject's history of fatigue experience acquired from a series of late study nights and other sleep-restricting activities. In this case, it is then depending on how we define a certain level of alertness that is measured as adequate in performing work-related tasks.*

Following this study, another research was done to study the effects of different illuminance level on the cornea in comparison to the work planes. Badia and colleagues did an experiment to study brightness and alertness level at night-time by inducing 5000 lux to 10000 lux of white light (Badia, Myers, Boecker, Culpepper, & Harsh, 1991)*. Another study by Cajochen and colleagues investigated different level of brightness relative to* *brain activities. The study found that 3190 lux of long-wavelength (red) light distributed at the eye generate an increase in the cognitive function, and a much lower lux of short-wavelength (blue) can achieve the same level of brain activities* (Cajochen, Zeitzer, Czeisler, & Dijk, 2000).

An important factor in these studies that were not recorded is the level of melatonin during these different brightness exposures. Figueiro explained in a study in 2009 that exposure of only 40 lux at the cornea is considered high in eliciting alertness and that of below 10 lux is considered low through recorded levels of melatonin. The study investigated that both blue and red light had induced the same effect at these mentioned brightness levels, although only during the blue light exposure that melatonin level is "significantly suppressed" relative to a condition of darkened surrounding."

In one of the more recent study of intensity and alertness that was conducted via a simulated laboratory nightwork environment, it was concluded that an ambient of 900 lux improved alertness and performance, compared to 90 lux at the same CCT (Sunde, et al., 2020). A study in 2017 tried to vary CCT values from 2166K to 4667K while keeping 150 lux of corneal illumination and found that this variance of different short-wavelength did not affect alertness and performance, therefore concluded that in CCT values with insignificant variance, intensity plays a bigger role in eliciting alertness and increasing performance in nightworkers (Canazei, Pohl, Bliem, & Weiss, 2017).

2.3.3 Alertness vs. Sleepiness

The text below is excerpted from the researcher's Literature Review from her first report as declared in Chapter 1. (Azrudin, 2020):

"Studies have shown that melatonin suppression results in increased alertness level in night shift workers, but newer researches are questioning if changing the natural bodily secretion of this dark hormone is necessary at all in achieving the same alertness level. Figueiro had experimented with implications of melatonin suppression in shift workers and discovered that some alertness level could be achieved without exposure to short-wavelength light (Figueiro, Sahin, Wood, & Plitnick, 2016)*. This was done so by measuring bodily biological data in dimmed light condition compared to long-wavelength condition. Although in the end, she concluded that the results still showed insufficient work performance level that could be increased if alertness level was higher from blue light exposure. She also concluded that her data was insufficient as it does not consider caffeine intake that might disturb this function.*

Whether it is light intensity or wavelength, it is valuable to the lighting industry to know what properties in lighting triggers the right response from the brain that affects alertness level at night to maintain a good work performance for the night workers although the night-time result of this knowledge might not be translatable to the daytime condition. It is only sensible to look at the re-definition of a series of important keywords within this topic; - "alertness", "sleepiness" and "arousal", and how to measure them, quoted in table below:

Keyword	Definition
Alertness	*"A construct associated with high levels of environmental awareness"* (Figueiro, Bierman, Plitnick, & Rea, 2009) *"Achieving and maintaining a state of high sensitivity to incoming stimuli"* (Posner, 2008)
Sleepiness	*"Indication of an adverse state, opposite of alertness"* (Lok, Woelders, Gordjin, Hut, & Beersma, 2018) *"Perceived experience of the propensity to fall asleep"* (Moller, Devins, Shen, & Shapiro, 2006)
Arousal	*"Non-specific activation related to changes in sleep and wakefulness"* (Oken, Salinskya, & Elsas, 2006)

2.3.4 Light History & Time in DLMO Entrainment

Another important factor in circadian lighting for nightworkers is light history and time of subjects. As mentioned by Foster in the Integrative Light Summit conference proceeding, time of light exposure and history of light exposure are key factors in DLMO entrainment of nightworker's circadian adaptation (Foster, 2020). History of light exposure is the amount and type of light that the subject has been exposed to in the past 24 hours, that is known to affect subject's sleep quality and nocturnal behaviour, which ultimately can change time of melatonin secretion.

Suprachiasmatic nuclei (SCN) located in the hypothalamus acts as a pacemaker for the body in generating the 24-hour (approx.) signal. It is also known as the location of the 'biological clock' which regulates melatonin production (Saper, Scammell, & Lu, 2005), (Vandewalle, Maquet, & Dijk, 2009). The DLMO (Dim Light Melatonin Onset) is an assessment tool created as a marker for this circadian pacemaker in night-time situation, which reflects its nocturnal secretion (Pandi-Perumal, Srinivasan, Maestroni, & Cardinali, 2006). It is a representation of a person's circadian description where it marks the start of melatonin production in the body and is normally described via the Phase-response curve (PCR), recorded 12 hour before DLMO. Schlangen and Price explained in a study that the sleep-wake cycle closely follows the 24 hour melatonin regulation, where we habitually fall asleep 2 hours after DLMO, and the habitual waking-up typically occurs about 10 hour after DLMO. When exposed to light at the same time for an extended amount of nights consecutively, it can affect DLMO and delay the habitual sleep time. Given the right light, at the right time, and for the right number of nights, circadian adaptation can occur in nightworkers, ultimately increasing their daytime sleep quality. (Schlangen & Price, 2021).

This is why a variety of studies conducted can be seen to strictly control type of light intake outside of simulated condition, by using filtered goggles on subjects and black-out blinds in subject's homes to reduce circadian misalignments. DLMO is normally measure via saliva sampling, EEG and heart-rate monitor devices. In the study of nightshift workers, DLMO samples are normally taken before and after nightshifts for a consecutive period of nights. The readings before the start of shift would be recorded as baseline DLMO, and the readings after the shift is recorded as final DLMO, to illustrate the circadian adaptation that has occurred (Crowley, Lee, Tseng , Fogg, & Eastmen, 2003).

3 METHODOLOGY

3.1 User Interview

A user interview with a representative from the employee working at Copenhagen Police, Local Police Unit (Københavns Politi, Lokalpolitienheden) in Copenhagen Central Station (Hovedbanegård) was conducted to obtain a united opinion towards the overall lighting experience and preference in the fieldsite. The interview questions were initially designed to be used as a survey for multiple employees and officers working in the station. Due to the certain limitation in conducting surveys, the representative answers are used as the collective voice for all the employee and officers working at the station. To minimise close contact during the Corona pandemic that this research was conducted in, the lighting preference questions were prepared on an online platform – Google Forms, and answered via a link sent to the interviewee email. The questions can be viewed in the Appendix section (refer to Appendix 1).

This lighting preference interview use a combination of Likert Scale, multiple-choice answers and open-end questions. The multiple-choice answers were intended for demographic purposes if there was a pool of response. The scale is used for questions that involve preferences with aspects that are subjective to the interviewee, and the open-end questions were used as a tool for further elaboration as this may help to investigate and bring forward topics that weren't examined in the form.

The interview was also used to obtain information on the direction of the police station in working towards their aim and future plans for the station's operation. The information gained from this section of the interview is used as part of the motivation for this research itself. The final design solution is intended to be used in the direction of achieving the police station's future goals.

3.2 Field Observation

3.2.1 Empirical Ethnographic Observation

The ethnographic approach in this case study was designed to understand the nature of interaction between the users/occupants, their spatial behaviour, and their response to existing architectural lighting. The observation was conducted by the researcher as an observer and for a limited period of around 60 minutes on the evening of 24th March 2021 from 1930 hours to 2030 hours. The time limitation was due to the high security concerns in the nature of the police working environment, where the observer was required to be guided and in the presence of a personnel at all times.

In the conduct of an empirical based data collection, it was deducted from the theories and hypotheses that the observation should include several methods combined and analysed to best prove its validity under these special Corona limitation and circumstances, which prohibits a testing to be carried out. Align with the objective of this research, the final solution was an induction from these empirical data to form a theory of lighting principles for the night workers.

From the ethnographic approach, the observer deduction uses the Fly-On-The-Wall method to collect data of user circulation, user-to-user behaviour, and user-to-light interaction. This is used to counter check the limited interview data and absence of surveys. Another observation method used is the Social Mapping and People Count, to provide better analysis of user movement, foot traffic and their interaction to the surrounding. These observational methods have helped to form more concrete empirical evidence for the study.

3.2.2 On-site Measurement

During the case observational visit conducted on 24th March 2021, several on-site readings were carried out to provide evidence of the site existing condition and as a conclusive data to build-up a more concrete problem statements and its background. The readings conducted were;

- the illuminance measurements for selected surfaces, corneal illumination and facial recognition within the police station using a luxmeter,
- the illuminance measurements for selected surfaces, corneal illumination, and facial recognition outside the police station (the central station main hall) using a luxmeter,
- the spectral distribution and CCT from the existing architectural lighting at selected surfaces within the police station using a spectrometer,
- the reflectivity calculation of selected photometric properties for materials within the police station by using the reflectivity formula,
- the transmittance calculation of selected translucent surfaces by using the transmissivity formula, and
- the built-up spatial dimension of the whole fieldsite taken manually using a conventional measuring tape.

Special tools were used in the collection of above data. All the illuminance readings were taken using a Voltcraft MS-200 LED luxmeter as shown in Figure 3.1 below. The spectral distribution readings were obtained using the Asensetek Lighting Passport and connected via Bluetooth to transmit measurement data into an Apple iPhone X smartphone through an application developed by Asensetek called ‘SGM+’. They were later extracted from the smartphone to be downloaded into a computer via e-mail. These devices were visualised in Figure 3.2 and Figure 3.3 respectively. The reflectivity and transmittance formulas were used to obtain the photometric properties of selected major surfaces, and this information is used in the texture mapping during the 3D modelling process to provide an accurate lighting calculation for the final simulation. The transmittance reading was taken 0.5 meter from the glass facade inside the station and 0.5 meter from the same glass surface outside the station (in the building main hall). The reflectivity reading was taken at 0.3 meter above the selected surface in the station. These formulas are described as:

$$\%\,T = \frac{I_{in}}{I_{out}} \times 100\,\%$$

Equation 1: Transmittance formula used to calculate the glass facade photometric properties during the case visit.

$$r = \frac{E_r}{E_f}$$

Equation 2: Reflectance formula used to calculate the selected matte surfaces to define their photometric properties during the case visit.

Figure 3.1: Voltcraft MS-200 LED lux meter device that was used by the researcher to take readings of illuminance during field visit. (Source: votlcraft.ch)

Figure 3.2: On the left is the Asensetek Lighting Passport device used by the researcher to take readings of spectral distribution during the field visit. (Source: asensetek.com), which data was transmitted to the Apple iPhone X smartphone (Soure: apple.com).

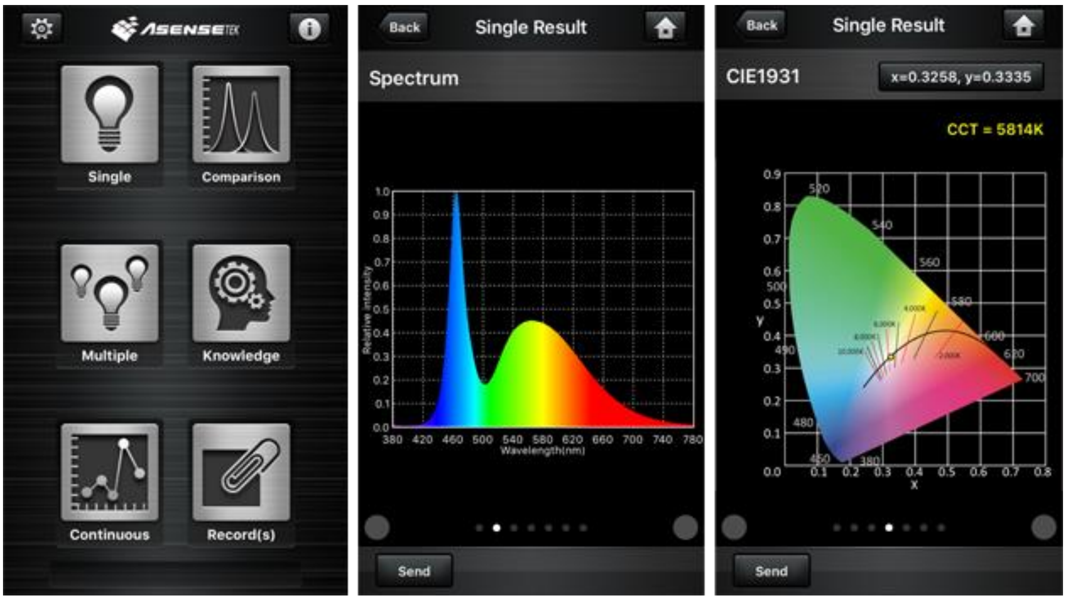


Figure 3.3: Screenshot examples of the interface of the 'SGM+' mobile application for iOS 10, developed by Asensetek. Screenshot was taken from an Apple iPhone 10 smartphone. (Source: self-own)

3.3 Conceptual Design

3.3.1 Moodboards

In the conceptual stage of the design solution development, several series of moodboards were created to describe the atmospheric objectives in visual form, from a collective of image collage. These images were mainly gathered from the Internet. The purpose of moodboards during this design process is to provide a sense of how the final solution would feel like through real and existing images in the effort of initial exploration of the design. These images were also arranged carefully in its collage appearance to construed one combined theme, rather than delivering it individually, which would result in poor visual representation of one theme language.

3.3.2 Digital Simulation

The design solution is presented through digital simulation of the newly proposed architectural lighting for the case work, using the DIALux EVO (ver. 8.2) software, a widely used and reliable software for lighting engineers and lighting architects. The researcher uses the Calculation Surface and False Color function in the software to show numerical evidence of the lighting design proposed. The normal rendering was obtained from the Ray-tracing rendering function to visualise the overall outlook of the design. The spatial textures photometric properties of the simulation were manually input by the researcher, by using the data gathered during the field visit, in order to simulate an accurate photometric calculation.

Prior to implementing lighting properties into the Dialux EVO software, the geometrical modelling of the Central Station's main hall which comprises of 7215 square meter area was first developed in Google Sketchup Pro 2019. The detailed modelling works of the interior of the case study, such as the furniture and texture mapping, were developed in the same software and imported to combine under one DIALux file.

3.4 Limitations

3.4.1 Case Work Limitation

A questionnaire was designed and intended to be used via an online platform for the employees and officers working in the station to minimise face-to-face contact during the corona time. Although after several weeks that the questionnaire was published on the online platform, it has failed to obtain sufficient pool of responses for it to be used as quantitative evidence in an empirical deduction. This incident has thus rendered the one response acquired from the platform unusable for a numerical approach to analyse as statistical data. This has resulted in non-concrete information gathered to be used in a way that this research was initially meant as a mixed quantitative + qualitative study.

There was also a security concerns in regards to the chosen case work, as it is a place of public authority. The researcher was allowed an hour time within the fieldsite during the visit to conduct the empirical and ethnographical observation, and the data from the observation presented in this report is based on the one-hour visit. More hours may be more favourable to increase credibility of the data gathered.

It should also be noted that the current field observation conducted in this case work is with the employees on a shift-hour from 2.30pm to 9.30pm. This shift may be considered as an extended dayshift by some parties instead of nightshift, as initially intended by the researcher. Although it was later mentioned in the Motivation section in Chapter 1 that the case work has future plans of extending their hours until 12 midnight.

3.4.2 Covid-19 Limitation

Another Case Study, the DSB train maintenance depot, was intended to be used as the primary case study in this research due to its well-established nightshift schedule and the long experience in night work that the organisation has. The request was well received initially but was later rejected due to corona restrictions imposed by the organisation itself.

The police station had to also rejected the request for a second field visit by the researcher. The second visit was intended for execution of the on-field experiment and testings, which outcome was planned to be analysed and used in the development of the design solution. According to an email sent by the representative, the rejection was caused by the outbreak of the coronavirus in the fieldsite when several of their officers were tested positive for the virus.

There were difficulties with engaging in one-on-one questionnaire. A questionnaire that requires physical presence was constructed align with the aim of this research, and to investigate user-based preference and problems (see Appendix 1). It was intended to be carried out on the nightshift workers during the first observation visit but nobody could participate due to tight corona restriction from the police department, therefore an interview with a representative was conducted to replace the questionnaire. The data from the interview is still used to provide similar information as the questionnaire result was intended to, but without the numerical and statistical translation.

3.4.3 Time Limitation

Most of the time limitation were ultimately caused by the CoVid-19 pandemic, where it resulted in a longer time to obtain answers on accessibility for case visits. There were a lot of uncertainties in both sides of the table that causes several delays in decision-making, when most of the people liaised in the making of this research were working from home. It should also be remarked that the research has developed into a very intriguing topic which has not received a solid outcome from previous studies. The topic is considered new and is constantly developing, therefore there was difficulties with the given time for this master research to conduct a better theoretical framework. This master research was conducted by one researcher in the given period of approx. 4 months, carried out fully under the CoVid-19 national lockdown.

3.4.4 Exclusion of Other Non-visual Considerations

It can be concluded from existing knowledge that the major factor in circadian disruption is lighting exposure, although there are several other factors in consideration when studying about circadian effects. In this research, the following factors are not taken into account when designing for its final solution due to time and resources limitations for being a research on Master's level.

- **Light History** : Time and duration of light exposure in subjects
- **Circadian Entrainment :** Phase-response curve (PRC) of Dim-Light Melatonin Onset (DLMO)
- **Seasonal Effect** : Physiological effect of Seasonal Affective Disorder (SAD)
- **Physical Movement** : Bodily motion of strenuous activities during the shift
- **Dietary Effect** : Nutritional value in meals and caffeine intake during the shift

4 CASE ANALYSIS

4.1 Observation Findings

As discussed in Chapter 2 Methodology, an ethnographic study through means of observation and self-subject was carried out in the limited period of one hour. The limitation regarding this visit was explained further in the Limitation chapter. The observation was carried out on in the evening of 24th March 2021, from 1930 hours to 2030 hours, thus all data and information produced from the analysis is in relevance to the night working environment within the fieldsite boundary of the police station unless mentioned otherwise.

4.1.1 Lighting and Spatial Understanding

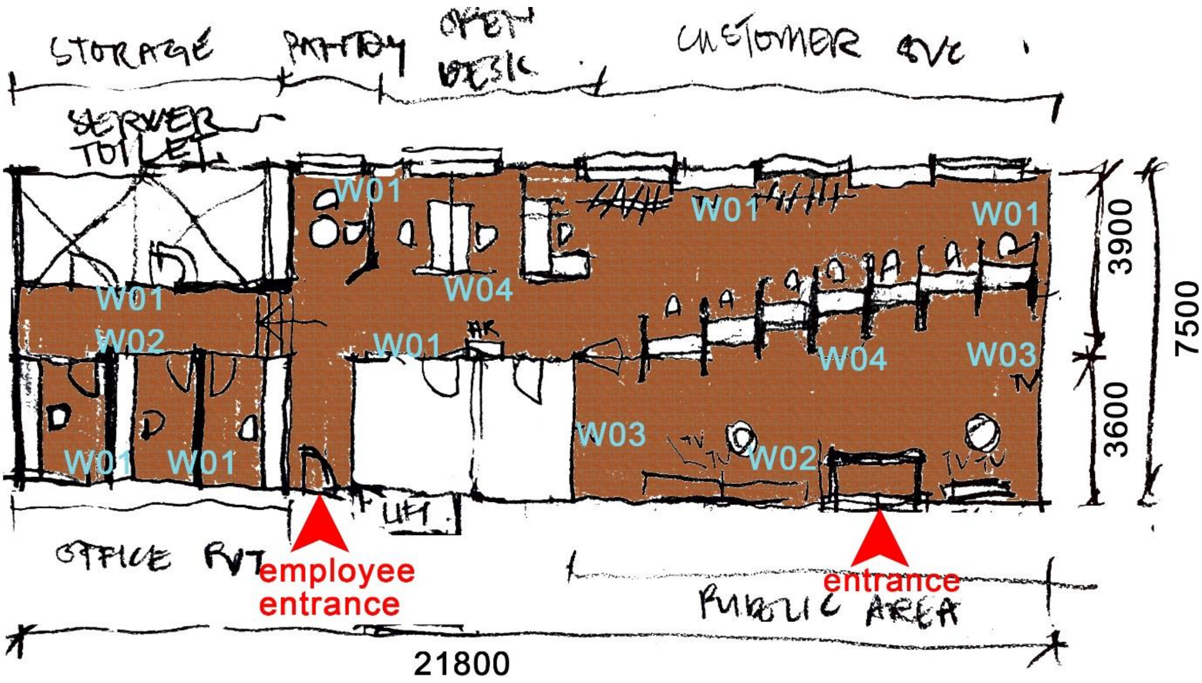
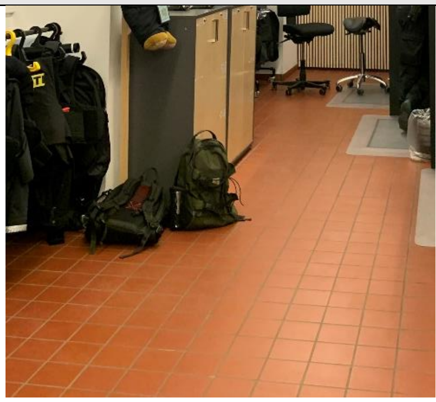
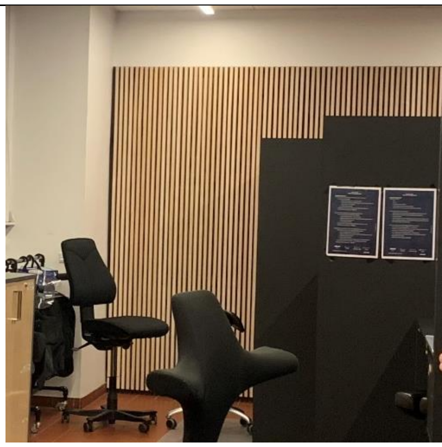


Figure 4.1 The layout plan of the police station developed using AutoCAD, with general dimensions. Labelled are key materials in the space.

Referring to Figure 4.1 above, the interior of the Police Station is very straight forward. It has 7 counters to serve the public for report taking which is manned each by the civilian employee. The counters sit in front of an open area which acts as a waiting space for the civilians, equipped with 3 benches and 2 round standing tables. The office area has 3 private office rooms and 3 working desks in the open area. An approximately 9-meter square pantry area positions between the open desk area and the private offices. Further into the back of house locates a storage room and a toilet for employee usage. The key materials in the space and its relevant characteristics were identified and recorded in the table below. Multiple vertical materials on the walls were identified and recorded in the code form of W-(XX) and labelled in the layout.

Location	Code	Description	Photometric Properties	Photos
Floor	-	150 x 150mm Terracotta tiles with matte finish	Reflectance = 0.13	
Wall	W01	White emulsion paint with matte finish	Reflectance = 0.72	
	W02	Glass wall	Transmittance = 50%	
	W03	Timber texture in vertical fins/lamellas	Reflectance = 0.15	

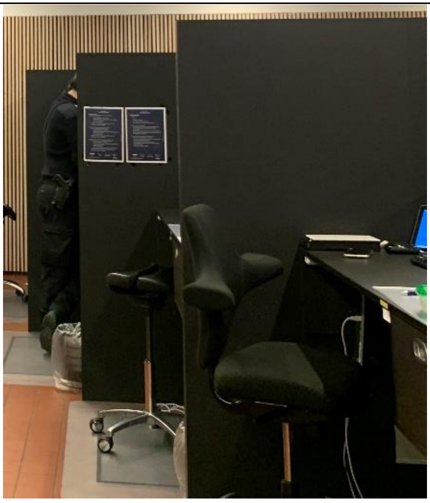
	W04	Black laminated partition in matte finish	Reflectance = 0.04	
Ceiling	-	White emulsion paint	Reflectance = 0.73	

Table 4.1 List of key materials in the space, with coding number to be cross referenced to the layout plan in Figure 4.1.

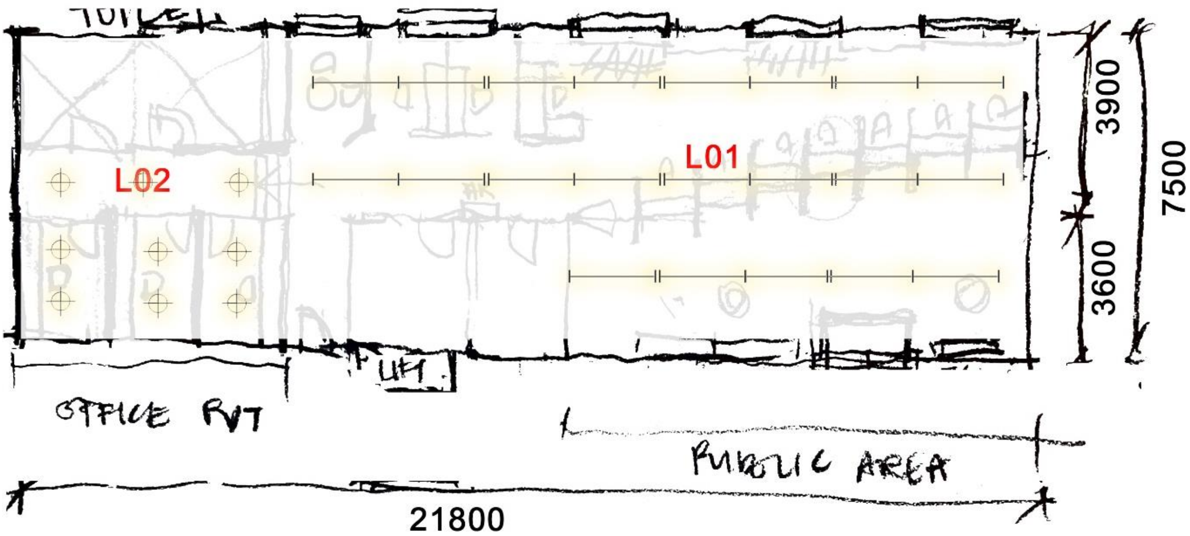


Figure 4.2 The ceiling plan showing locations of lighting fixtures in the police station, with coding to categorise the different types.

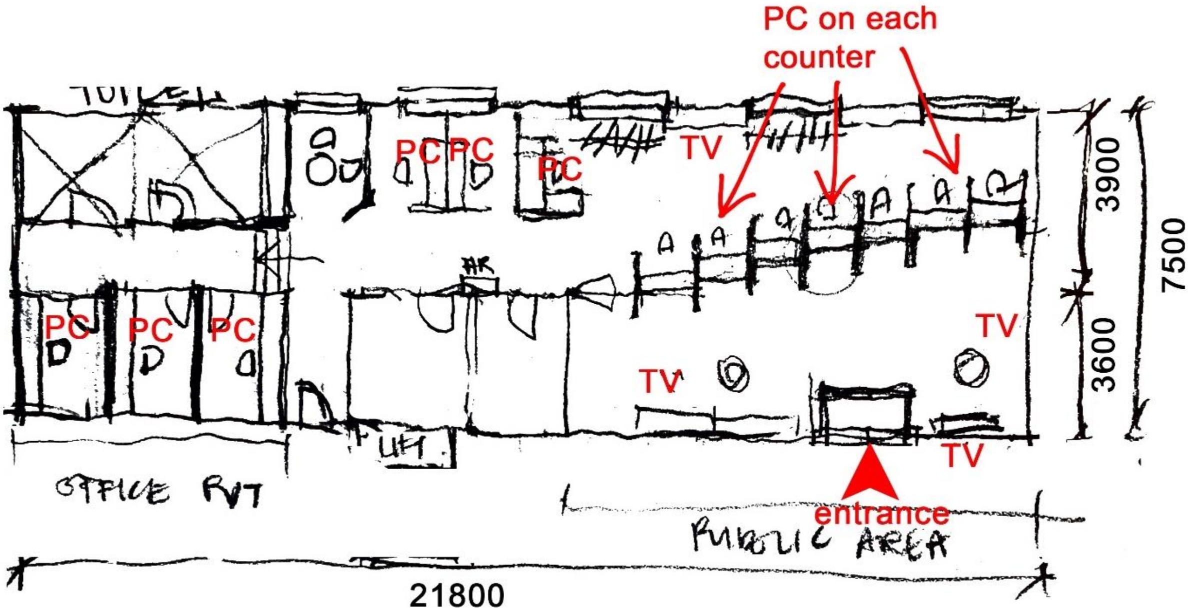


Figure 4.3 Locations of all LED displays such as PCs (computers) on desks, TVs on walls and hanging from ceiling that can also be considered as a light source in the space.

Referring to Figure 4.2 and Figure 4.3, the light sources were identified and recorded in Table 4.2. The two light sources are separated into two: light coming from lighting fixtures and light coming from LED displays. The latter is considered to be an informal light source due to its main purpose of displaying information, while still directly impacting the non-visual pathway and visual acuity of the occupants as it still projects a form of light but with different wavelength than that of the primary sources. The LED displays are labelled with 'PC' to locate the computers placed on desks and the counters, and 'TV' to show positions of televisions fixed on walls in varying heights. All the LED displays were switched on throughout the observation period and were meant to be switched during opening hours. The readings of these sources are further dissected in another subtopic within this chapter.

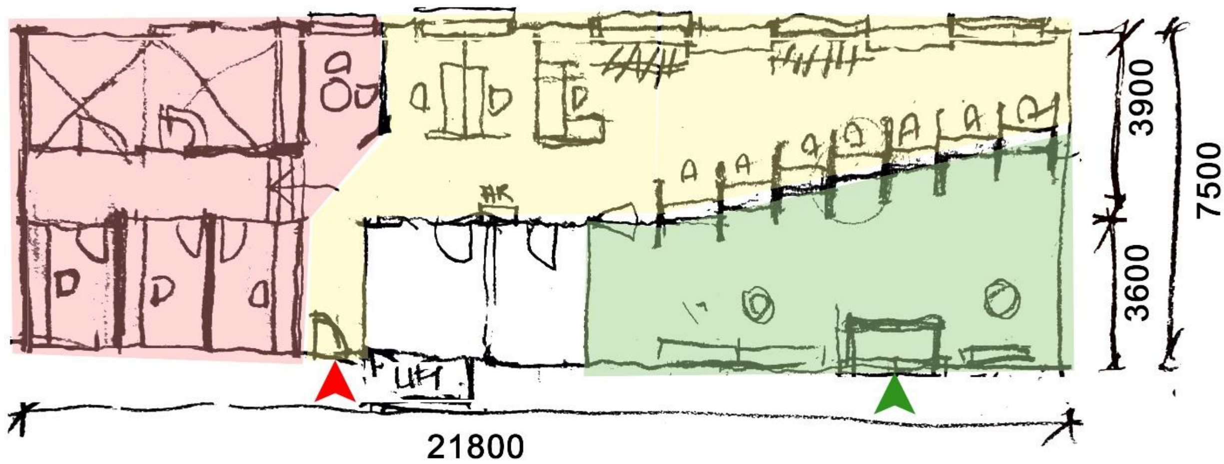
Item	Description	Photos
L01	Fluorescent fixtures with centralised dimmer system in 3000K CCT	

L02	Downlight LED fixture with individual on/off switch in 3000K CCT	

Table 4.2 The description of each type of lighting fixtures used in the police station's interior. The item coding is to be cross referenced to the lighting plan displayed in Figure 4.2. (Source: self-own)

4.1.2 User Interactions and Zonings

As the ethnographic approach in this observation, the data is analysed and processed in different forms of zoning to understand user behaviour in the space, their interaction with the lighting, foot traffic and movements, and user flow with the different privacy levels throughout the space.



Green: Public	Yellow: Semi-private	Red: Private

Figure 4.4 Privacy zoning of the police station. The different colours indicate the 3 levels of privacy: public, semi public and private. The different colored arrows indicate the different type of entrance; private and public entrances.

As a public civilian, it requires you to proceed through the main entrance where you will need to pass through two layers of glass doors. The first layer has a motion sensor and slides open when a person stands in front of it, while the second layer is controlled by an officer in charge from the inside. This acts as a security barrier between the public space and the police station in the unfortunate case of unwanted trespassing. The area highlighted in green (referring to Figure 4.4) is the only area where public/civilian is allowed to be in. The are highlighted in yellow is considered as semi private due to the low partitions of the counter that divides the public and the employee-only areas, making the semi private area visible to public. The yellow areas are also an open space which makes it visibly transparent through out with very minimal vertical surfaces which are half partitions. The areas in red are private offices that are normally used by higher ranking officers during day shifts, although it was mostly unoccupied during the night shift.

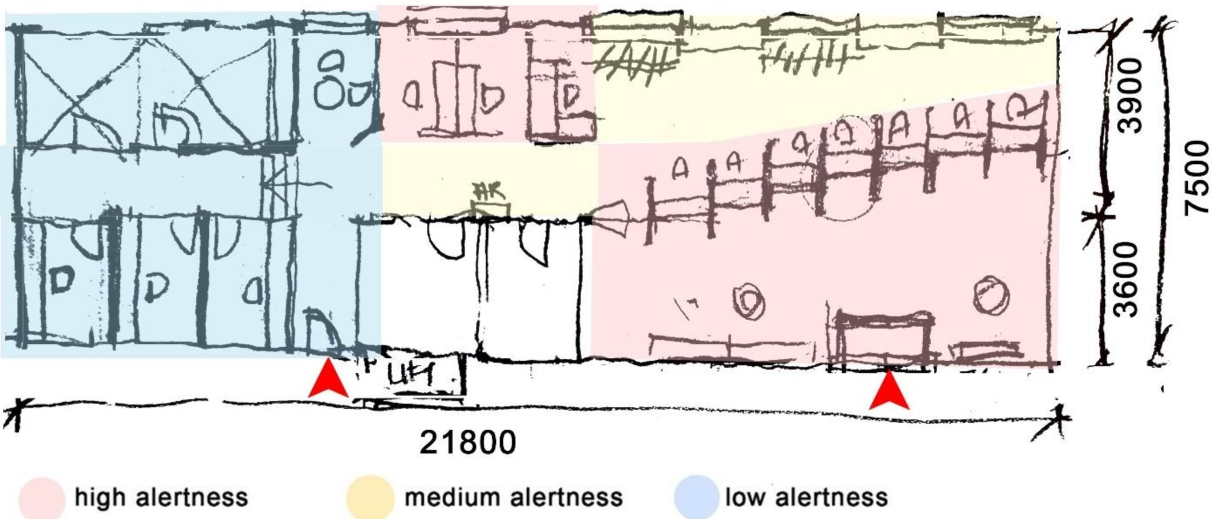


Figure 4.5 The alertness zoning shows the different alertness levels required in different areas of relevance with the function of each space. The zones are colour coded from high to low alertness level.

As the function and usage of each area is clearly established, the alertness level required in each of these spaces can be defined as Figure 4.5. The areas highlighted in red is considered and observed to require a high level of alertness. Within the public area, is important that the officer who are responsible for accepting civilians into the fieldsite is on very high alertness level. He/she has the responsibility to visually judge and decide whether a civilian that is requesting to enter the second door into the fieldsite is a possible threat, as the civilian stands to wait for entry at the first layer of the glass door. At this stage, visual acuity should be on the highest efficiency to recognise faces and other details on a person that is standing on the other side of the glass wall. The thought process from this visual judgment, is their cause for safety for others inside the fieldsite. The other areas marked in red are considered of high alert too due to the nature of the work tasks that are being carried out here. Employee occupying these areas were seen reading and typing on a computer majority of the time. The counters where report-taking and writing take place, is also very crucial to high alertness level. Civilians that are having their report taken, are often in distress and under stress. Therefore, the process of information exchange, while interacting with stressed civilians, are concentrated here and must be done with good alertness.

The areas marked in orange were seen to be used for transiting from one area to another and therefore categorised as medium alertness. They are a transition space from one alertness level to another where employee are required to still possess adequate alertness to proceed with ease and safety in their transition, and to still be aware of what is happening in the fieldsite. The blue indicates areas that require a lower level of alertness compared to the rest of the areas, as they are mainly for resting and recharging. The areas included in the blue are the pantry, employee toilet and storage room.

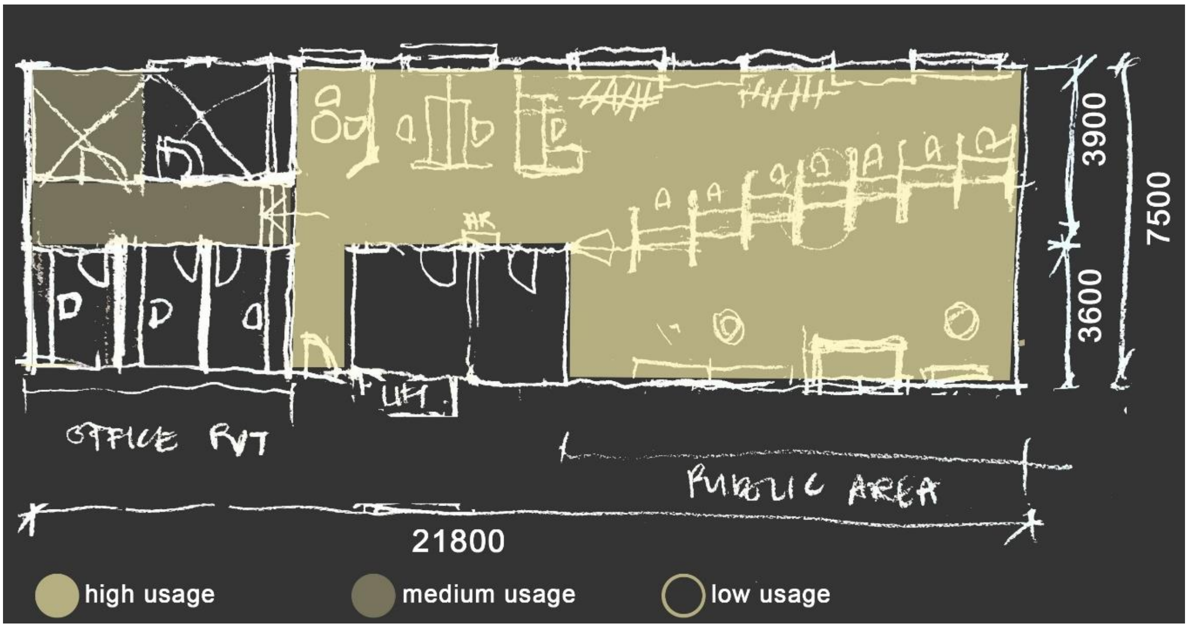


Figure 4.6 The usage of lighting within the police station is divided into 3 levels; high, medium, and low. Data analysed from time of observation conducted.

During the observed nightshift, there was no daylight seen coming through the windows, although this statement might be of exception during summer nights. On the day of the observation, the sun set at 1831 hours and no daylight was observed from the fieldsite windows at 1930 hours onwards. Figure 4.6 depicts the level of lighting usage during the observation period. The areas marked with high usage are where the electrical lights stayed switched on. It is also where the dimmer system is installed, although it stayed to be on maximum flux during the observation. Medium usage is defined as areas at which users turned the lighting on during occupancy and switch it off when it is unoccupied or as when they leave the room. Low usage areas are marked for when the room's lighting was never in use throughout the observation period, regardless of occupancy status. This may happen when a room is divided with glass walls that permit light transmittance, that is sufficient for medium alertness usage.

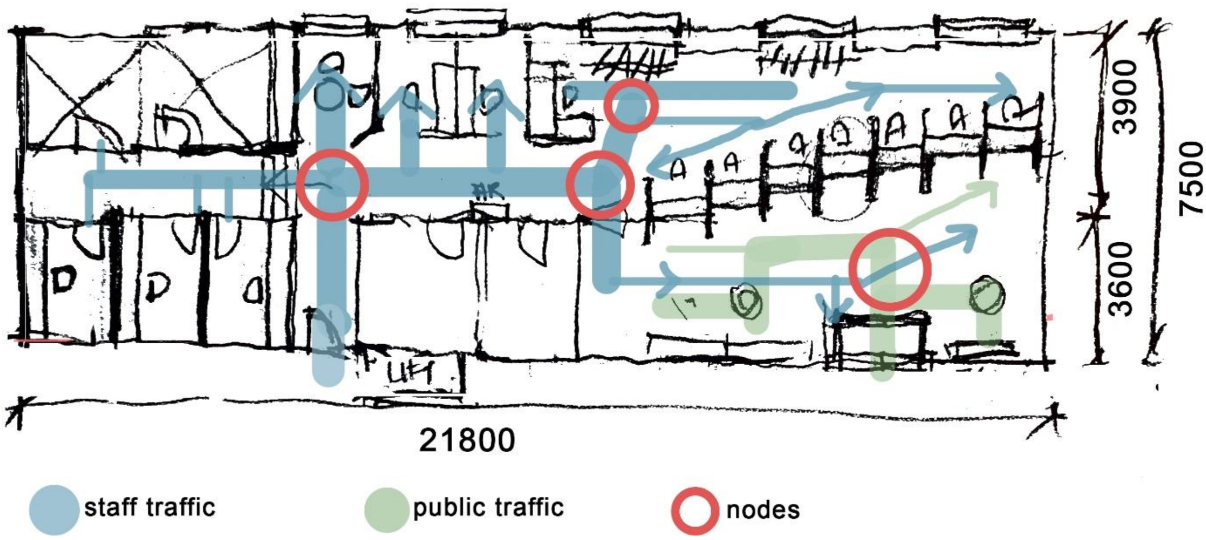


Figure 4.7 The foot traffic of the occupants shows how the users interact and move within the space. The different user type is divided into employee and public in different colors. The thickness of the lines define the weight of the traffic in a given path.

Figure 4.7 displays the movement of user within the space. The information is obtained from the ethnographic fly-on-the-wall method of counting foot traffic in the observation period. The thick line represents heavy traffic while the thinner lines indicate the lighter movement. The different colours separate the employee traffic from the public traffic and the arrows indicate the direction most taken on each pathway line. There is a clear pattern of movement on the heaviest traffic where the walkway is used as the main path for employee to commute from one end of the fieldsite to the other. By using Kevin Lynch method of identifying city elements (Lynch, 1960) the nodes identified in this web of movement is marked in the red circles. These points were observed to be the common locations for employee interaction. From this diagram, it can be seen that the employee refrained from using the main entrance to commute in and out of the fieldsite, instead they used the secondary entrance on the left of the facade to divide the privacy usage out of security reasons. Figure 4.8 below describes the social movement of the employee and public by counting the numbers of users occupying a particular spot in a period of 10 minutes. It is also apparent from this diagram that the main point of interaction and communication between employees gathered count near the workstations along the main walkway.

In relevance to Figure 4.5, Figure 4.6, and Figure 4.7, there is an obvious pattern that shows a form of spatial hierarchy within the police station. The open working area and the public area can be concluded as the most concentrated area both in regards of spatial function and usage. The pyramid diagram in Figure 4.9 is an illustrated conclusion of the usage alertness level in the different spatial hierarchy. The conclusion was produced through the various factors and data that were analysed in this chapter. The highest step in the pyramid represents the most important alertness usage relative to each area, with '01' being the most important spatial function to '03' as the least.

Figure 4.8: The social mapping count diagram produced by drawing a dot to represent an occupant that has gathered in a spot for a period of 10 minutes.

Figure 4.9: The concluded diagram that shows the spatial hierarchy in the space, with considerations of spatial and lighting usage, functionality, user movement and interaction to their alertness level observed. (Source: self-own)

4.2 Interview Findings

The interview was conducted with a representative employee from the place of the case study. The were two parts to this interview in the way that it was conducted. The first part is the lighting preference questions which method was explained in detail in Chapter 3 Methodology. The findings from the questions can be described in summary in the table below;

Research Area	Focus of Investigation	Findings
Demographic	Profiling	The interviewee is a female employee in the age group of 50-60 years old, responsible for report-taking at the service counters.
	Shift hour	Her shift covers from 2.30 pm to 9.30pm for a period of 7 hours. This shift fulfils between 7-13 working days in a month.
Alertness Level	Nonvisual effects of the current lighting exposure	The interviewee felt more tired/sleepy upon exposure to the current lighting than before she arrived at work, but the feeling fluctuates throughout her shift
	User understanding	With a 4/5 rating, she believes that a brighter light can increase her alertness and consequently may increase her nightshift work performance.
Sleep quality	User experience	With a 1/5 rating, she never has problem falling asleep after her shift and stated that her sleep quality is above average.
User Preference	Visual effects of the current lighting	In general, the lighting is visually unpleasant and of unsatisfactory level to the interviewee, this is mainly due to poor visual acuity and facial recognition at the service counters and the fieldsite's exterior view.
	Visual effects of lighting in general	The interviewee claims that very warm light elicit calming effects for her. She prefers to work in a slightly less warm lighting than what she would prefer in her house.

Table 4.3: The summary findings to the questionnaire prepared for the interview with the employee representative which can be viewed in Appendix 1.

The second part of the interview are generic questions for the researcher to establish a good understanding of the police station's background, working culture and preference in the fieldsite. During this part, it was made known that the police station has future plans of extending the nightshfit hours to 12 midnight from the current 9.30pm. Several dissatisfactions of the current lighting condition were brought to the researcher's attention during the interview. The interviewee mentioned that the lighting in the public and entrance area of the fieldsite is the most problematic. She experienced very poor facial recognition when sitting at the service counter, viewing towards the entrance and glass facade, where other employees and officers have claimed to experience difficulties in determining basic features and even the genders of civilians that approaches the police station. The interviewee explained that aside from the very low light levels outside of the fieldsite, another major problem for her is the reflection casting on the inside of the glass facade. She expressed concerns of occasional headaches from the reflection. Thus, the employees would sometimes lower the dimmer value as an effort to avoid the headaches. The dimmer is also often used on a lower value by the employees to best suit their preference. It was assumed by the interviewee that on average, the employees here think the full dimming value is too bright.

4.3 On-site Readings

A list of field readings that were conducted by the researcher were explained in Chapter 3, Methodology, as well as the equipment used to obtain the measurement data. The data was gathered and analysed in this subchapter, under three main categories which are – the spectral distribution of the existing lighting at selected locations inside the fieldsite, the brightness levels (illuminance) on these mentioned locations, and the brightness level (illuminance) of the immediate area outside of the case study boundary (located within the main hall of the building). These locations are indicated in the layout below:

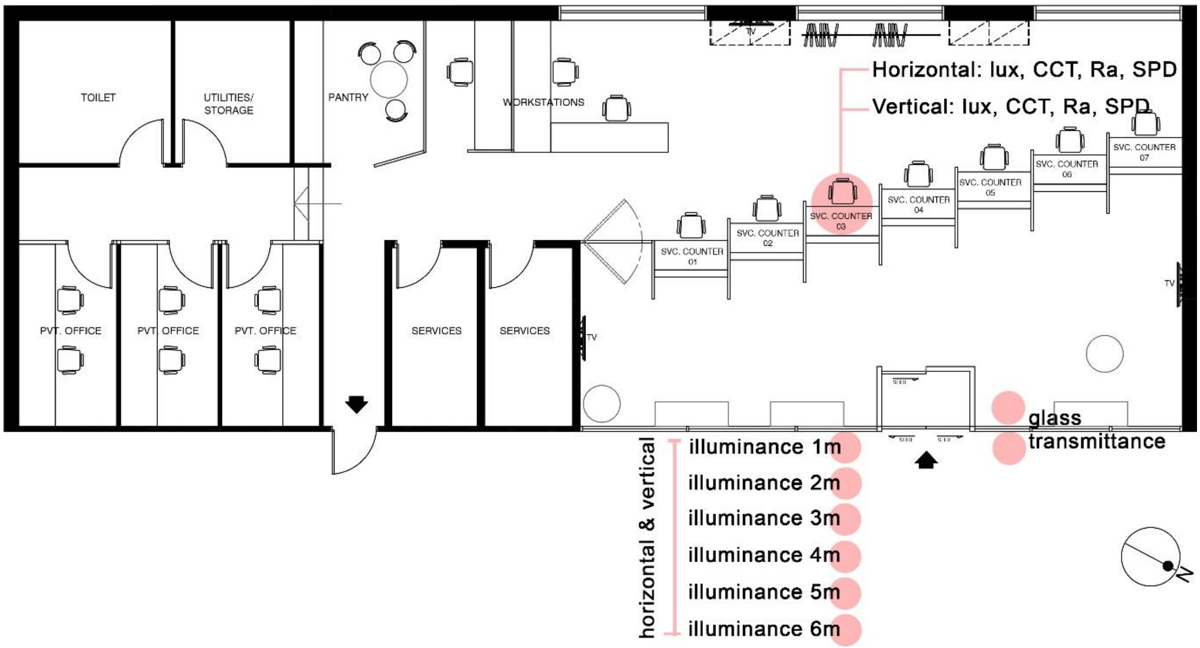


Figure 4.10: A layout of the fieldsite showing the locations of the readings taken in different ways. The types of readings taken are explained briefly.The drawing was developed in Autodesk AutoCAD.

The spectral distribution and illuminance readings that took place inside the fieldsite were each conducted in two separate ways. The first method was carried out to investigate the spectral properties and intensity of light that hits perpendicularly to a point on the work surface. Thus, the readings were taken with each device placed horizontal on the surface and facing upwards. This is to mainly understand the level of visual acuity in the relevant surrounding of the space.

The second reading was conducted to investigate the properties and brightness of the light entering and is being reflected on corneal level for the employee working with report taking at the service counters. This was done so understand the connection between occupant's behaviour and alertness to the lighting condition in the space. The readings were carried out by holding up the device vertically at 600mm height from the work surface, which was 1500mm from floor level, and facing outwards towards the public area. This position was decided to be the closest position to imitate the employee's eye level while sitting down and working on report taking tasks for the public.

The area in which these readings were taken operates under a manual dimming system (refer to Table 4.2, Item L01). The dimmer was on full flux power at the moment that these readings were recorded.

4.3.1 Spectral Distribution

For these readings, the data was gathered and automatically developed from the mobile application of the spectrometer used in the reading (refer to Chapter 3). The readings are presented in graphs as Figure 4.11 and Figure 4.12 for both horizontal and vertical position respectively. Other relevant data that were also automatically measured and generated from the same device are explained in Table 4.4 and Table 4.5, in accordance with the position of the reading taken. These data are the lighting's colour temperature (CCT), colour rendering index (CRI), and the peak relative wavelength.

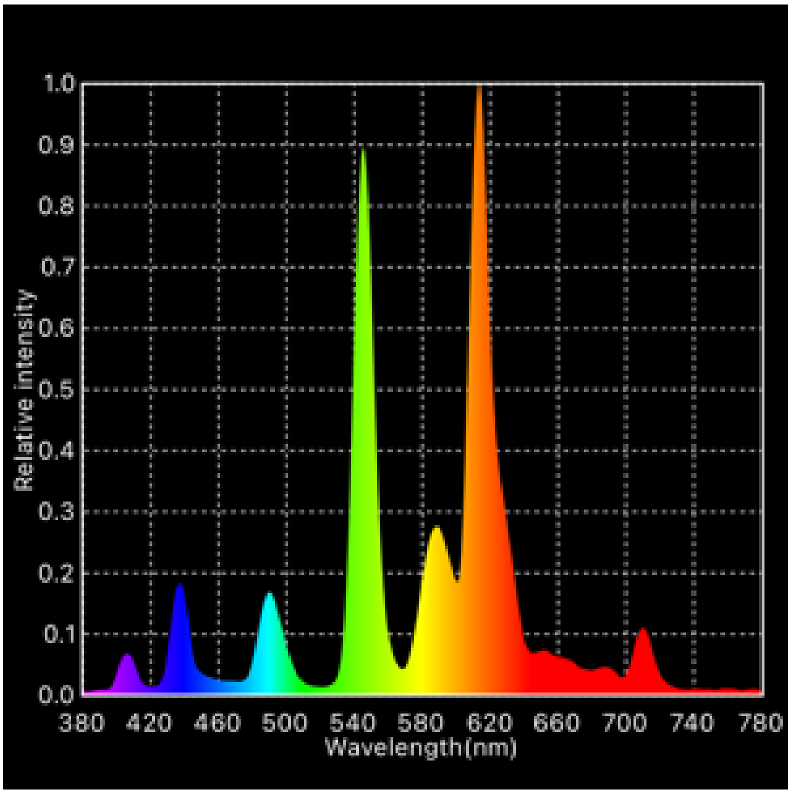


Figure 4.11: The spectral distribution of the existing lighting taken horizontally at the height of 1100mm from floor level, on the working surface of the Service Counter.

Light Properties	**Horizontal Readings**
Correlated colour temperature (CCT) / Kelvin	2807K
Colour Rendering Index (CRI)	Ra 85
Peak wavelength	614nm

Table 4.4: Relevant information produced by the spectrometer at the horizontal level of work surface under one reading with the spectral distribution graph.

Both of the readings were conducted under the linear fluorescent fixtures. Visually, both showed similar patterns in the spectral distribution, with non-visible difference. The only difference that was detected in the spectral properties of the two positions is the CCT value, which differs by 18 Kelvin more in the vertical plane than the horizontal plane. This small difference is not visible to the human eye, but the assumption is that the difference came from the two computers that sets out about 450mm in horizontal distance from the employee's eye. The computer screens face the employee's eye in a vertical manner.

This assumption could not be proven as there were no evidence in the difference that reflects in the peak wavelength relative value between the two positions. The absence of higher blue wavelength value restricts the assumption that the computer screens are displaying short wavelength lights that is significant enough to affect the alertness level or disrupt circadian disruption by suppressing melatonin in these nightshift workers. No further investigation was conducted to examine this aspect of non-visual impact of lights from this method.

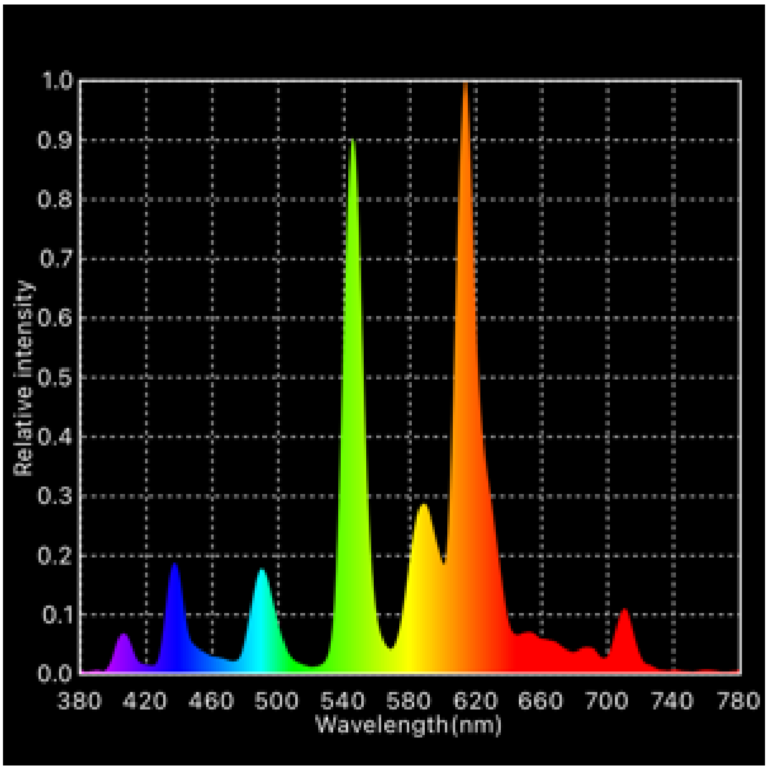


Figure 4.12: The spectral distribution reading of the existing lighting taken vertically at the height of 1500mm from floor level, close to eye position of the employee working at the service counter.

Light Properties	**Vertical Readings**
Correlated colour temperature (CCT) / Kelvin	2825K
Colour Rendering Index (CRI)	Ra 85
Peak wavelength	614nm

Table 4.5: Relevant information produced by the spectrometer at the vertical eye-level of work surface under one reading with the spectral distribution graph.

4.3.2 Illuminance

The illuminance level in this research was measured by using a luxmeter at three different parts of the fieldsite which were described in Figure 4.10. At the two points where spectral distribution was measured, illuminance readings were also taken in the same way, horizontal and vertical planes, respectively, under the linear fluorescent fixtures. In the horizontal plane aligned with the spectral measurement in Figure 4.11 and Table 4.4, the illuminance reading was 374 lux. It is apparent that this value does not comply with the standard EN 12464-1, but there have not been any complaints from the employee and officers working in the fieldsite about having insufficient illuminance level on work surfaces. The vertical reading was recorded at 181 lux at eye level. This value may be considered desirable as it is proportionately suitable for the illuminance value to its horizontal plane, which should be around half the value of the latter. There were also no complaints by the employees in regards to this value. The readings are summarised in Table 4.6.

Surface	Readings
Horizontal Plane	374lx
Vertical Plane	181lx

Table 4.6: Illuminance readings recorded on the two measurement methods, the horizontal and vertical planes, in similar ways with the spectral readings.

4.3.3 Exterior Illuminance

In the interview findings in previous sub-chapter, it was mentioned that the reflection problem on the glass facade is affecting the visual acuity of the employees and officers. Upon inspection of the problem, it was found that the problem may be coming from the irregular values in the illuminance ratio between inside the glass and outside. This caused a strong reflection casting on the inside surface of the glass, affecting the visibility of the occupants in the fieldsite.

The measurement of the exterior illuminance was conducted as an investigation in order to prove the assumption mentioned above. The readings were recorded in Table 4.7. The investigation found that the low values suggests that there is insufficient illuminance level in the main hall of the central station. The values do not comply to the standard EN 12464-1 as a place of public transportation, which was stated as 100 lux on average at floor level. As the record suggests, only the first 1-meter distance from the glass facade of the police station is of 100 lux, which is contributed by the light trespass from the interior of the fieldsite. With a 50% transmittance on the mentioned glass facade, it should be noted that this results in a higher possibility of uncomfortable reflection.

Distance from glass facade (meter)	Horizontal Illuminance (lux)
1	100
2	37
3	27
4	23
5	13
6	16

Table 4.7: The illuminance readings taken horizontally on floor level on the immediate exterior of the fieldsite, with the interval of 1 meter distance.

It was mentioned during the interview session with the representative employee that another main concern is the poor facial recognition on the outside of the glass facade, when viewing from the inside. Thus, a measurement was conducted to record the level of facial recognition in the area. This was done by measuring the illuminance level on a vertical plane at the height 1800mm from floor level, on the outside of the fieldsite. The luxmeter was put up in the direction of the police station in the same distance interval as the horizontal plane. The readings were recorded in the table below;

Distance from glass facade (meter)	Vertical Illuminance (lux)
1	65
2	36
3	26
4	23
5	17
6	13

Table 4.8: The illuminance readings taken vertically at 1800mm height from floor level, on the immediate exterior of the fieldsite with the interval of 1 meter distance.

5 DESIGN CONCEPT

5.1 Preliminary Zoning

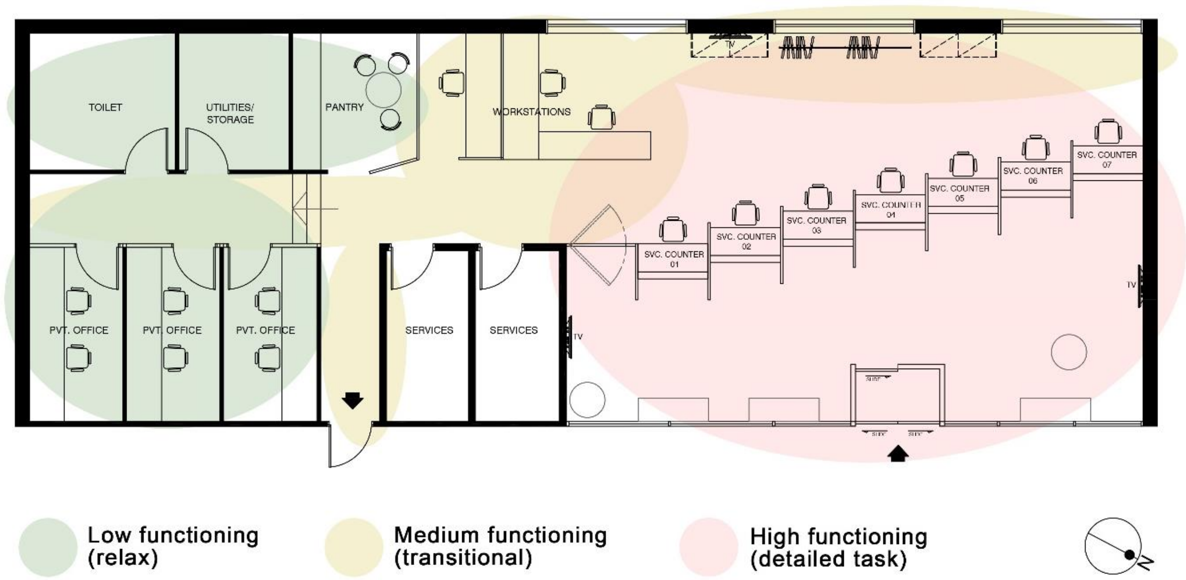


Figure 5.1: Zoning of the different alertness levels required in different areas of the full fieldsite. The colours represent the various levels as described in legend given. The N-symbol shows North direction in correspondence to the layout. The plan was developed by Autodesk AutoCAD and edited in Adobe Photoshop.

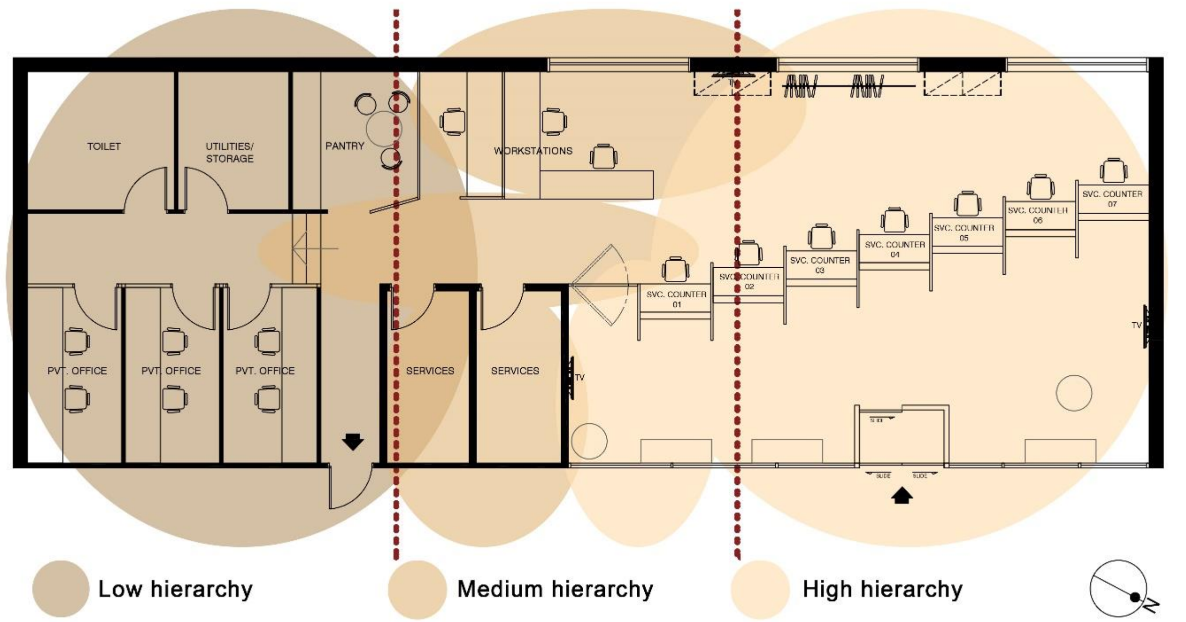


Figure 5.2: A bubble diagram describing the different hierarchical factors within the fieldsite with an apparent flow going from Low into Medium and into High. The different saturation shadings represent different hierarchical power. The layout was developed with Autodesk AutoCAD and edited in Adobe Photoshop.

Referring to Figure 5.1, the zoning diagram is an infographic that was based on the result of observation analysis in Chapter 4. The AutoCAD plan was developed from the initial sketch with the correct spatial dimension that was measured on site during the case visit. It was visible from the analysis that different areas are meant for different function, and therefore have different levels of alertness required for each task.

The word ‘functioning’ in the diagram describes how important the occupants should correspond to their designated tasks in order for the whole fieldsite to function well for its purpose. For example, ‘high functioning’ would mean that it is very important for the employee operating in that area to carry out their designated duties with high performance as this would greatly contribute to the overall operation of the fieldsite. And vice versa, a ‘low functioning’ area means that tasks carried out in this space is not required to be of high performance for the whole station to deliver its function. The zoning also considered the safety and security of each area, due to the nature of the police working environment. This is reflected in the area marked red, majorly covering the Service Counters (which are the public serving counters for report taking), the Waiting Area and the immediate area behind the Service Counters where there is plenty of displayed information visible for the public.

Low-functioning areas marked in green, have been identified to include the Pantry Area, the Utilities/Storage Room, Toilet, and the Private Offices. Occupants in these areas were observed to be more relaxed when using the space. They are covered from the public visibility and accessibility, therefore are more secured for occupants to not be in high alert concerning their safety. It is an appropriate remark to be made concerning the Private Office being considered as Low-Functioning. This is because the Private Offices are meant for chief officers who only works on day shifts. During the nightshift, these areas were observed to be used as an impromptu break space for taking private calls, checking personal updates on mobile devices, and having private conversation with other employee, thus it is concluded as such to suit its actual usage during the nightshift.

The areas labelled in yellow as ‘Medium Functioning’ play a connecting role from the High to the Low Functioning. They are open intermediate spaces in spatial properties with 1500mm high dividers. The office desks in this zone are not fixed to a particular employee and have a high communal interaction between employee due to its transitional location. It is positioned along the main and heaviest employee circulation of the fieldsite, as seen in Figure 4.7 (Foot Traffic). Occupants moving through this zone should be able to notice the changing transverse of different alertness and importance required from one level to another.

As the understanding of this conceptual zoning grows deeper, it is apparent that this transverse pattern exists and should be construed as such when designing for a lighting scheme that fits this functional pattern. A bubble diagram to illustrate this understanding is developed into Figure 5.2. The diagram is an interpretation development from the previous zoning, to better visualise the occurrence of this pattern. The wave is described in a hierarchical form and goes from Low to High Hierarchy, and is coded in different saturation shades, from darkest to brightest. Low Hierarchy categorises the areas that has low count in foot traffic, social mapping, and light usage as analysed in Chapter 4, and vice versa with the High Hierarchy and its functions. The dotted lines were used to further highlight this transitional pattern.

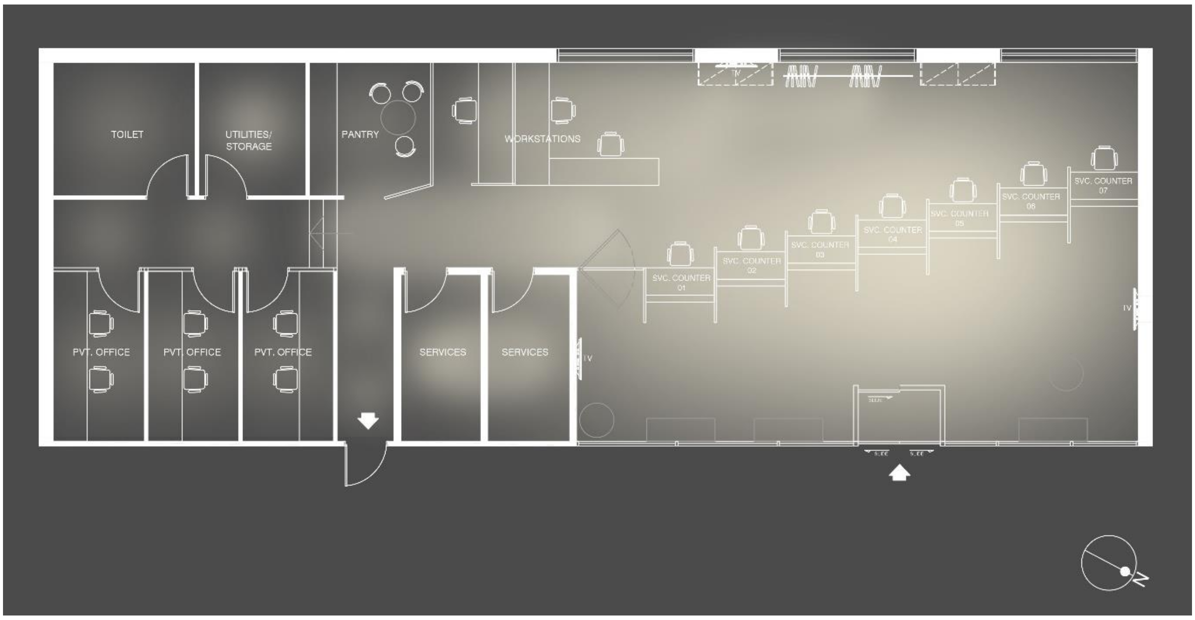


Figure 5.3: A dark schematic diagram showing the proposed conceptual language of the lighting. The illustration reflects the hierarchical flow and is visible from the intensity of the 'light glow' observed here. The layout is developed in Autodesk AutoCAD and edited in Adobe Photoshop.

From the hierarchical flow established in Figure 5.2, a dark schematic diagram is used on the same drawing to illustrate the initial language of lighting that is later used for the design development in the lighting principles proposal for this case study, shown in Figure 5.3. The diagram uses a basic form of light intensity to show concentration of importance in areas relevant to the hierarchical flow. Where the lighting seemed more concentrated in comparison to the rest of the areas, indicates a space that are higher in hierarchy and functional usage. The diagram does not intend to reflect the colour temperature (CCT) or surface illuminance with the varying concentration.

As seen in Figure 5.3, the areas displaying low concentration in this conceptual lighting language, take majority in the left most section of the floor plan. These are areas where occupants were observed to be relaxing and attending to personal affairs, under visibly low level of alertness required to conduct these non-hazardous and individualistic tasks in closed spaces. Occupants in this space should still have good visual but limited to only their immediate surroundings, as it is considered to be of low risk. Those areas are Toilets, Utilities/Storage Room, Pantry, and the empty Private Offices.

As the circulation flows towards the middle of the floor plan, occupants were remarked as being alert, while they carry out their official tasks, such as reading, discussing between employee, working, and typing on the computer, at the same time maintaining a relaxed and benign behaviour towards each other. Occupants should feel promoted to establish communications and social interactions among employee, compared to the low concentration areas due to the room's architectural properties of an open space. These two concentration levels are similar in a way that they are contained within authorised personnel only areas, which are the open workstations, walkways, and bulletin boards on walls.

On the right side of the diagram are the Public and Semi-Public remarked areas, as referred to in Figure 4.4. These areas are shown to be visibly brighter and highly concentrated because it symbolises the highest importance in terms of both functionality and hierarchical. This is because, employee and officers that work in the area are expected to be on high alert due to public exposure and consequently, it demands to be treated as a high-risk area. Employee working behind the service counters for report-taking should be able to focus on detailed computer tasks and face-to-face communication throughout working hours, while the police officers in charge of guarding the main door to permit public entry should have high visual acuity to detect any suspicious details and behaviour on people, such as facial recognition, from a long distance. These officers are considered to be the first line of immediate defence for the fieldsite. They require fast and accurate cognitive process to maintain throughout operational hours in order to conduct good judgment, thus the lighting scheme for this area should support these activities properly.

5.2 Initial Design Schemes

The analysis and conceptual zoning have resulted in 3 main design schemes for the case study. These 3 schemes are categorised as;

- Low Functionality,
- Medium Functionality, and
- High Functionality

This division is made based on their usage, functions, and acquired alertness level. The different requirement for each scheme is explained and visualised in this sub-chapter to explore is practical capabilities and the possibilities of its application into the field. A conceptual outlook of the 3 schemes is put side by side to see how it reflects the usage flow discovered previously. These schemes worked as a basis for the final design of the police station in the design solution.

5.2.1 Scheme 1: Low-Functionality

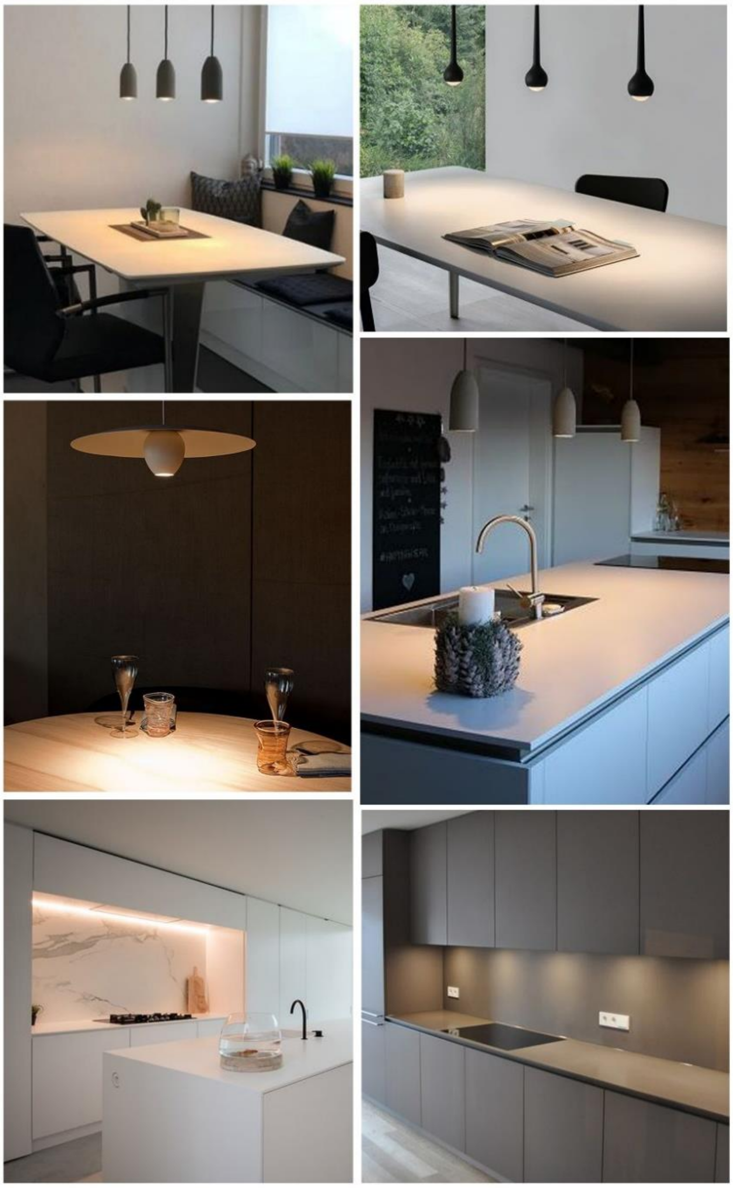


Figure 5.4: Collection of inspirational images to describe the atmospheric feeling in regards to lighting for the areas that falls under the Low-Functioning category. (Source from top left to right: buchenbusch.de, architonic.com, diariodesign.com, buchenbusch.de, ooburo.be, martimm.com)

A collection of inspirational images were placed into a moodboard collage as seen in Figure 5.4, for a visual description of how the Low-Functionality scheme would appear in the final design solution. In this moodboard, the atmospheric properties is aimed to provide a calming environment suitable for relaxing purposes, while supplying minimal but sufficient illuminance to conduct personal and benign tasks such as leisure reading and eating/drinking. The lighting can be described as having a narrow beam, centered and focused on task surfaces, without unnecessary amount of light spilling in its surrounding. The final two images at the bottom provide an idea of how the kitchen cabinet lighting can be used to serve its main function for food preparation while still creating calming effects for the users and surrounding occupants. This is done so by eliminating general ambient ceiling light to create this bubble of low but concentrated lighting in the contrast of its immediate environment.

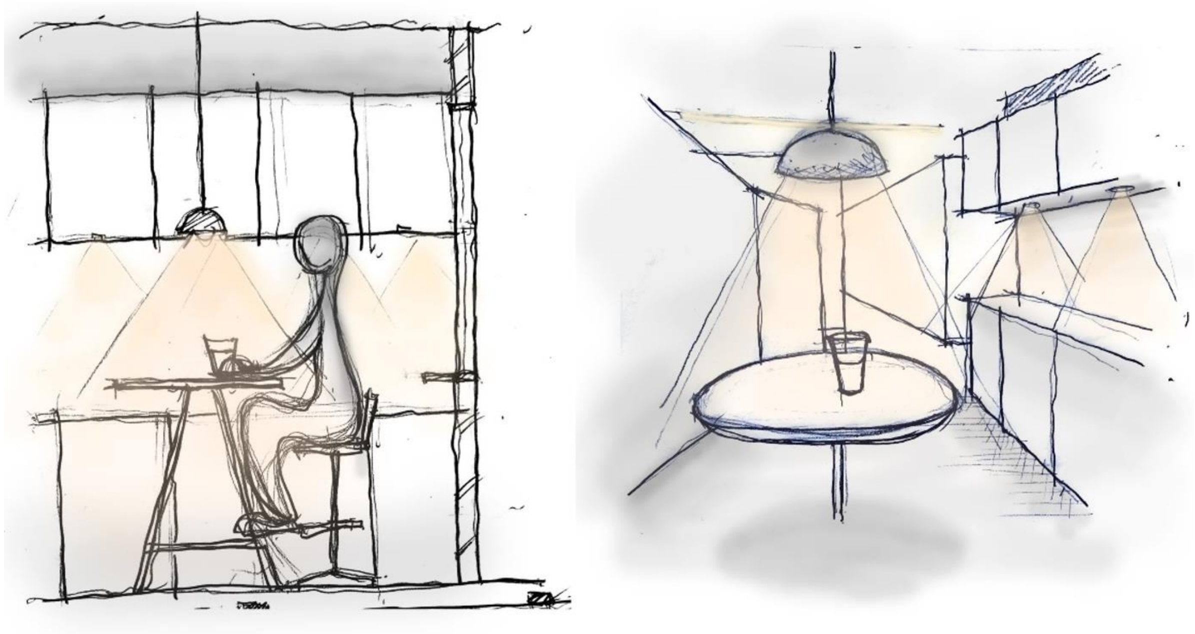


Figure 5.5: On the left is a sectional sketch depicting a human figure incorporated into the Low-Functioning scheme that can be applied in the Pantry area. On the right is the perspective view from the most common seating position taken within the area. The sketch is hand-drawn and lighting effects were added in Adobe Photoshop.

A collection of inspirational images were placed into a moodboard collage as seen in Figure 5.4, for a visual description of how the Low-Functionality scheme would appear in the final design solution. In this moodboard, the atmospheric properties is aimed to provide a calming environment suitable for relaxing purposes, while supplying minimal but sufficient illuminance to conduct personal and benign tasks such as leisure reading and eating/drinking. The lighting can be described as having a narrow beam, centered and focused on task surfaces, without unnecessary amount of light spilling in its surrounding. The final two images at the bottom provide an idea of how the kitchen cabinet lighting can be used to serve its main function for food preparation while still creating calming effects for the users and surrounding occupants. This is done so by eliminating general ambient ceiling light to create this bubble of low but concentrated lighting in the contrast of its immediate environment.

Referring to Figure 5.5, the sketches were drawn to describe the pantry area in the fieldsite as a following step in its application into the case study, from the moodboard. The Pantry area in this case study is used as a base point to represent the function and acquired alertness of the Low-Functionality scheme, due to its very straight-forward usage description. This representation could be applied to other areas categorised under the same scheme. The sectional sketch shows a narrow beam and low CCT light in a top-down distribution onto the table, where the cone distinctly avoids direct corneal illumination of the human figure, as much as possible. The technique of using pendants and other low positioned fixtures ,without the generic ambient light at ceiling, is used to bring down the height of lighting source closer to the eye level. This is to further minimise unnecessary corneal illumination. Corneal illumination in this space should mainly be yielded by the indirect light reflected off surrounding surfaces and of values that is low enough to not suppress melatonin secretion.

In the background, the built-in kitchen lighting has similar properties of narrow cone in low CCT values. The warm CCT can be seen as an added quality, align with the purpose of sustaining melatonin production naturally to reduce circadian disruption in these nightworkers. By eliminating unnecessary corneal illumination, occupants can use this space as a winding down area especially towards the end of their night shift, when they have to commute home and fall asleep after the shift.

5.2.2 Scheme 2: Medium-Functionality

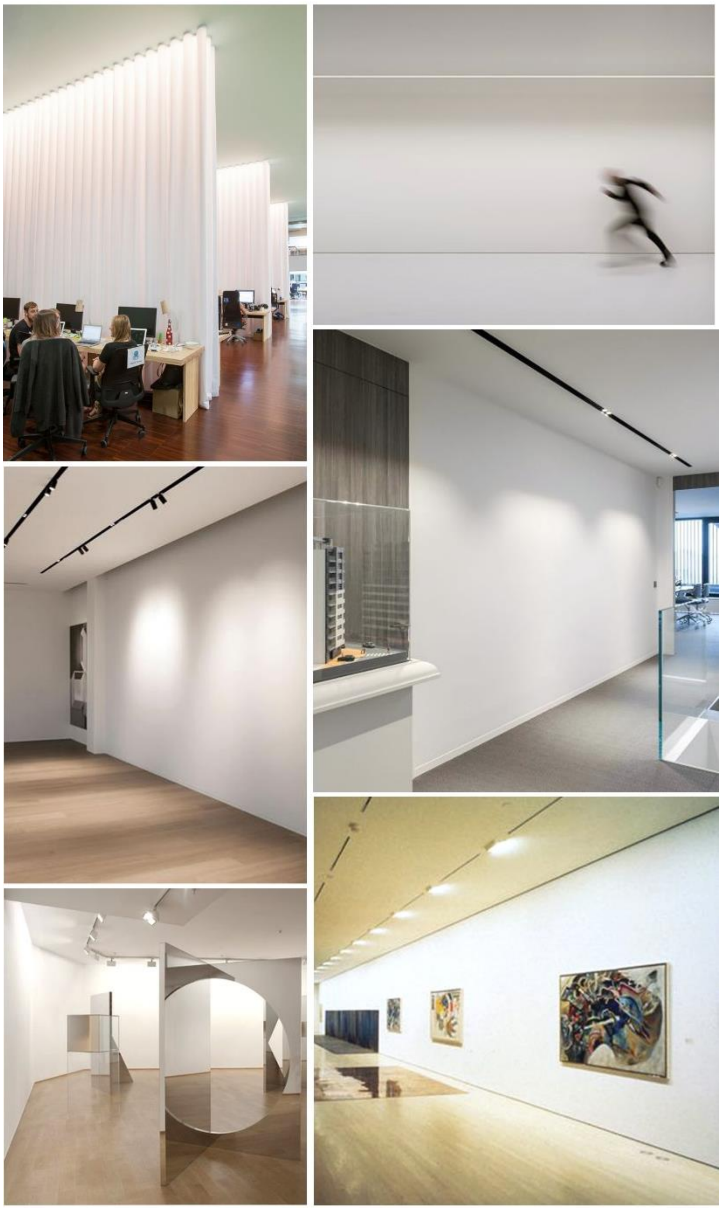


Figure 5.6: Collection of inspirational images to describe the atmospheric feeling in regards to lighting for the areas that falls under the Medium-Functioning category. (Source: Pinterest.com)

Figure 5.6 shows a moodboard collection for the Medium-Functionality scheme. The moodboard conveys a combined feeling and atmosphere dedicated for the areas marked as medium functioning and hierarchy in the preliminary zoning. The images as a whole concentrate on vertical illumination to light up an open space and the feeling of mobility. It qualifies the usage and characteristics of the areas that fall under this category for being an open space with relatively well visual acuity for working and as a passage of connection from one alertness level to another. This can be seen from the analysis of high foot traffic count in Chapter 4 (Figure 4.7). From the social mapping analysis in Figure 4.8 of previous chapter, most of the occupants in these areas on average do not occupy the space for more than 10 minutes, with the exception of working at the workstations. Thus the lighting should be on a medium generic ambient, without any purpose of highlighting a particular spot, but with adequate illuminance to conduct short discussions and general computer work.

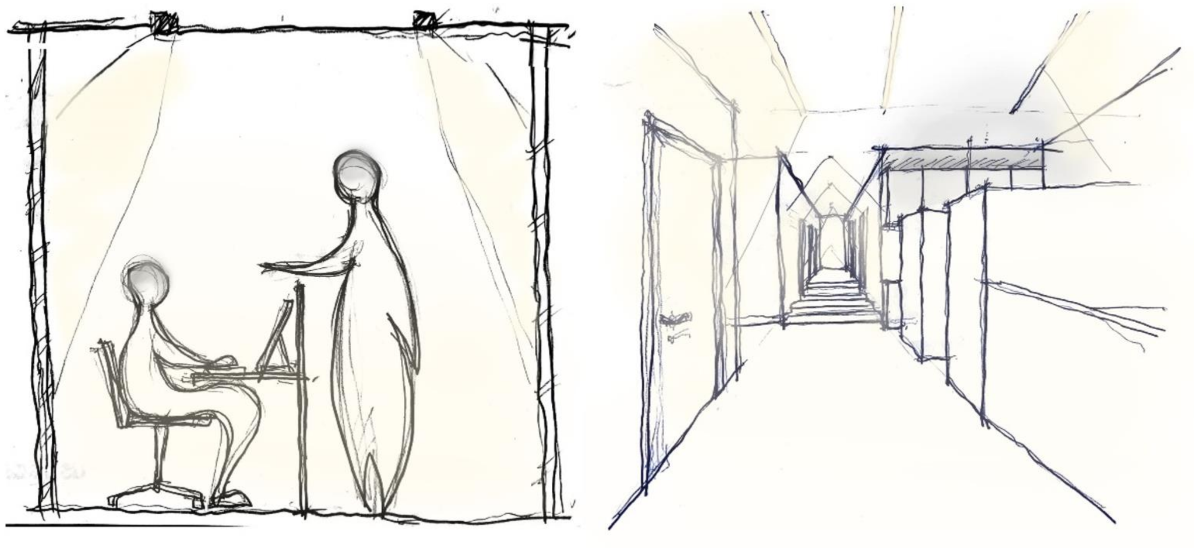


Figure 5.7: On the left is a sectional sketch depicting a human figure incorporated into the Medium-Functioning scheme that can be applied in the Open Area. On the right is the perspective view from the most common standing position along the walkway. The sketch is hand-drawn, and lighting effects were added in Adobe Photoshop.

In further details to line out the lighting principles used for this scheme, the sectional sketch on the left of Figure 5.7 above visuals the communication that happens between two human figures. One of the figures is sitting down working on a computer, while the other is standing up on the other side of the desk, in the walkway, conversing with each other. The placement of these figures is based on real-life, common instances that was observed to take place during the case visit between two employees. This interaction is noted to be the guideline of how the lighting should serve the purpose of easy but moderately important human interaction between employees, excluded from the public area but still visually permissible from the public's view.

Following the identity seen in its moodboard, the sectional sketch for this scheme shows two lighting fixtures with Wall-Washing optical distribution that are delivering sufficient ambient levels through vertical illumination. The reason for this lighting technique is to keep out direct corneal illumination. In the previous scheme (Scheme 1, Low Functionality), the same indirect illumination technique was used for similar purpose but with lower flux and CCT levels, therefore this ensures a continuation of flow as the person goes through transition from one alertness level to another. A user moving through these areas should be made aware of the different alertness level required but still maintaining visual comfort to make the transition feels naturally occurring.

The perspective sketch on the right of Figure 5.7 shows a user point of view from the most common transition point in the area. The position was derived as most common from the movement traffic diagram in previous chapter (Figure 4.7). From the sketch, the wall-washers illumination can be seen coming from two linear ceiling fixtures. These fixtures are visualised as such due to the current existing architectural lighting in the area. This is to indicate that the practicality in applying the proposed scheme considers its implementation from the current lighting condition. The proposed wall-washing technique makes full use of the long rectangular layout of the fieldsite, with narrow wall to wall width in the medium functioning areas. This maximises the efficiency of the wall-washing to stretch the reflected illuminance level sufficiently towards the middle-most point between the two major white walls in the area. The open space characteristic of the area also contributes to the efficiency of wall-washing, as it makes it easier to distribute good uniformity and to function as generic ambience.

5.2.3 Scheme 3: High-Functionality

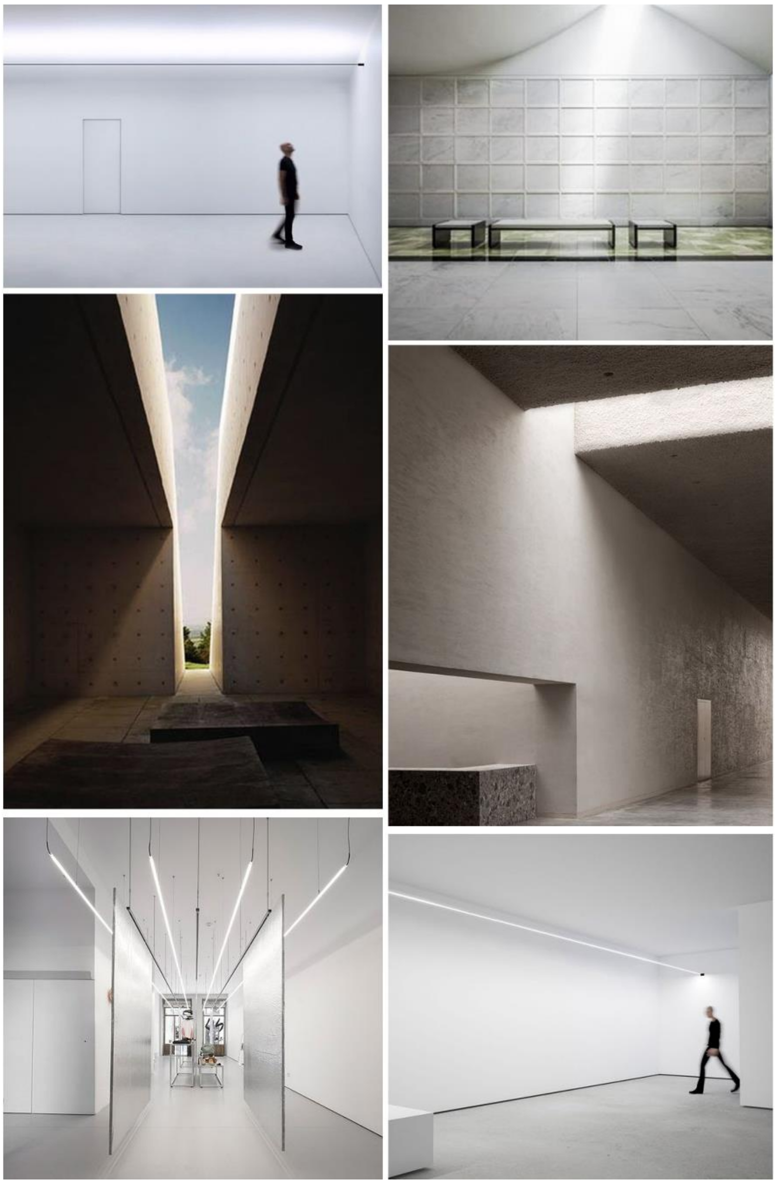


Figure 5.8: Collection of inspirational images to describe the atmospheric feeling in regards to lighting for the areas that falls under the High-Functioning category. (Source: Pinterest.com)

The moodboard in Figure 5.8 shows a series of inspirational images chosen to represent the feeling and atmosphere in the High-Functionality areas. The way the lighting effects in this moodboard conveys a unified theme of elevated illumination compared to the previous two schemes (Low and Medium Functionality) and it describes the high alertness level required in the areas marked as such. The effect shows a colder and more concentrated distribution to further intensify the importance of acquired alertness in these areas. The light cones that can be seen in some of the images, have a focused beam pointing downwards in a top-down distribution within a surrounding with lower illuminance. This creates a soft contrast that forms an elongated bubble of intense centralisation from linear light sources. The linear outlook goes well to provide concentration in the long rectangular layout of the fieldsite, especially in the public and high functionality area. The lighting principle used in these areas should be of direct illumination and increased corneal illumination compared to the two previous schemes, in order to effectively build up to the required alertness level.

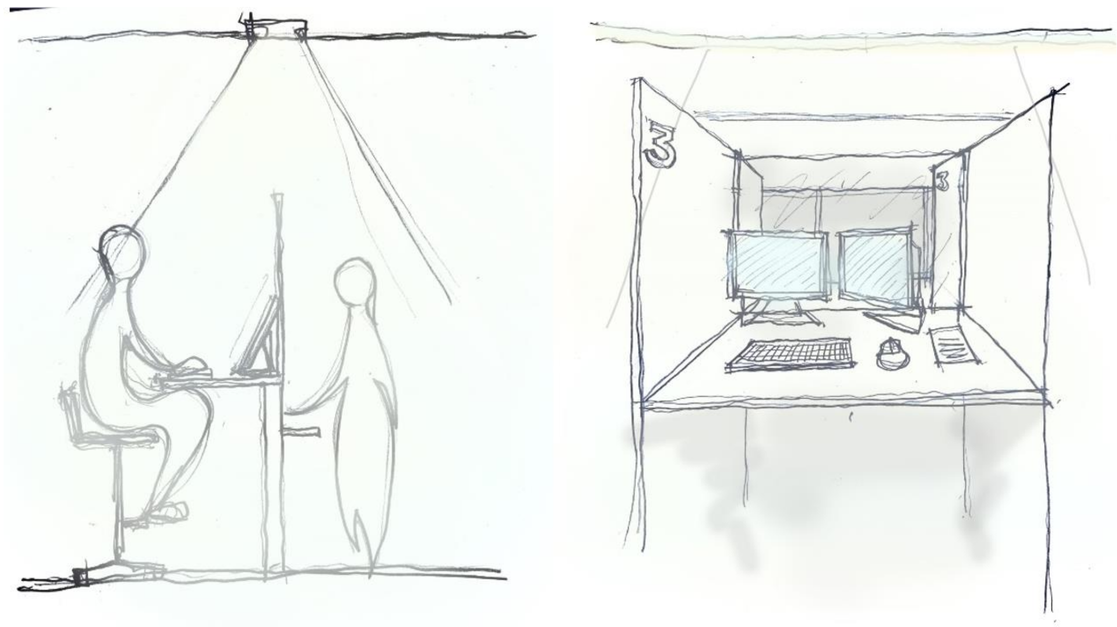


Figure 5.9: On the left is a sectional sketch depicting a human figure incorporated into the High-Functioning scheme that can be applied at the Service Counters. On the right is the perspective view from the most common working position at the desks of the employee. The sketch is hand-drawn, and lighting effects were added in Adobe Photoshop.

Figure 5.9 shows the sketches for this High-Functionality scheme. The objective is to provide high visual acuity and builds high alertness level for users in this area through means of high and direct corneal illumination for occupants to be able to distinguish the difference functionalities between the other areas. The colour temperature of the lighting in the sketches is shown to be colder than the previous schemes, to accentuate the need for an increase in the lighting blue wavelength.

The sectional sketch on the left of Figure 5.9 shows two human figures communicating to describe the situation during report taking activity that takes place in the public area of the fieldsite. The sitting figure on the left represents the situation of the employee responsible for report taking, while the standing figure on the right represents the civilian that requires for their report to be made. In between those figures is the service counter that acts as barrier from the civilian area to the employee area, with a glass divider that prevents direct contact between the two parties for security purposes. The light fixture in the sectional sketch located in the ceiling has a top-down distribution and can be seen to have a wide distribution cone. This wide-flood optics enable the cornea to reflect direct illumination from the fixture and from both standing points. The lighting for this area should be designed to highlight the density in its concentration for the employee to gain acquired alertness level when conducting report-taking tasks, as it is a detail-oriented work. Due to the high security reason when dealing with civilians, it is also important to make the civilians present in the area feels like every detail of their behaviour and appearance in being observed.

From the position of the employee responsible for report taking, the view is described in the perspective sketch on the right of Figure 5.9. It is significant to the corneal illumination of real-life situation in this view that each counter has two computers which screens are always switched on. This should be identified as contribution to blue wavelength in the spectral distribution of light reflected at the employee's eye. Another important remark in this view is the glass wall that conquers the station's facade. The glass wall has a low transmittance value and therefore should not have direct light reflecting on the surface to avoid casting reflections and diminish visual acuity to the view outside. This is highly critical to the officer responsible of granting civilian's access into the fieldsite, as they act as security barrier and therefore require high facial recognition through the glass facade.

6 DESIGN SOLUTION

The proposed final solution for the case study is presented in the form of simulations that was developed through DiaLUX EVO. The documentation from this simulation does not focus on the lighting products used in the modelling, but rather the quality of lighting that was produced to align with the theoretical framework of this research. The calculations and false colour renderings can be used as evidence in achieving the appropriate lighting for both the visual and non-visual systems in nightworkers, with all considerations from the case analysis.

6.1 Simulations and Calculations

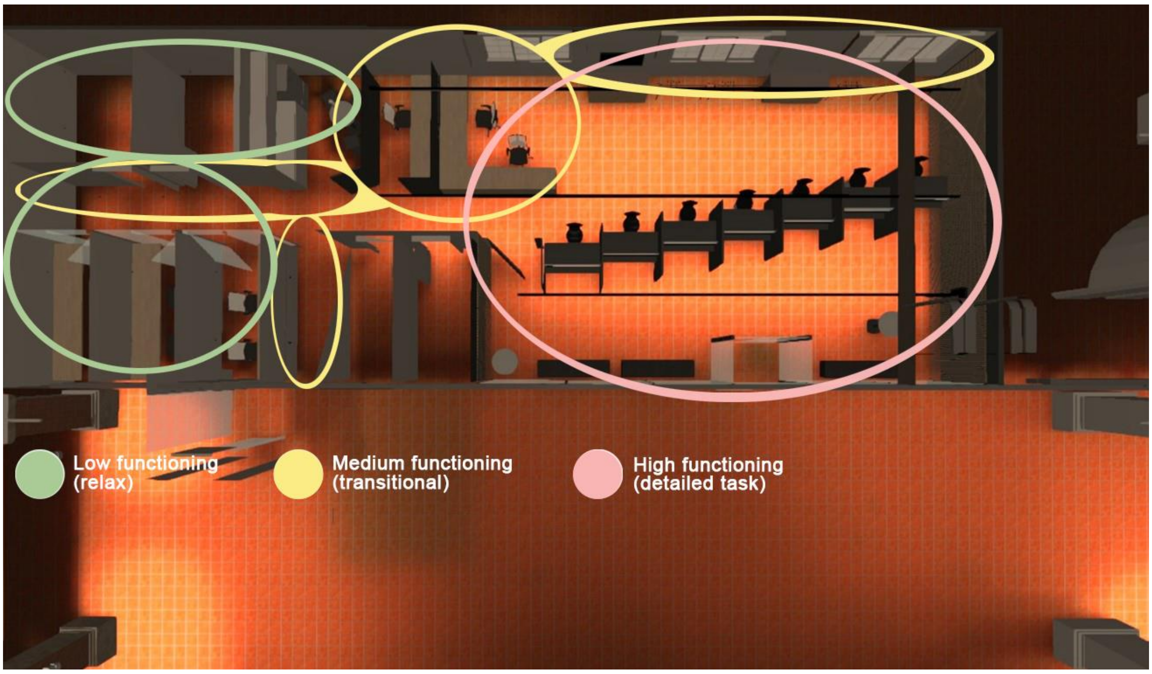


Figure 6.1: The top view of the simulation modelling showing an overall outlook and atmosphere of the fieldsite with the immediate surrounding of the fieldsite in relevance to its location inside the Central Station.

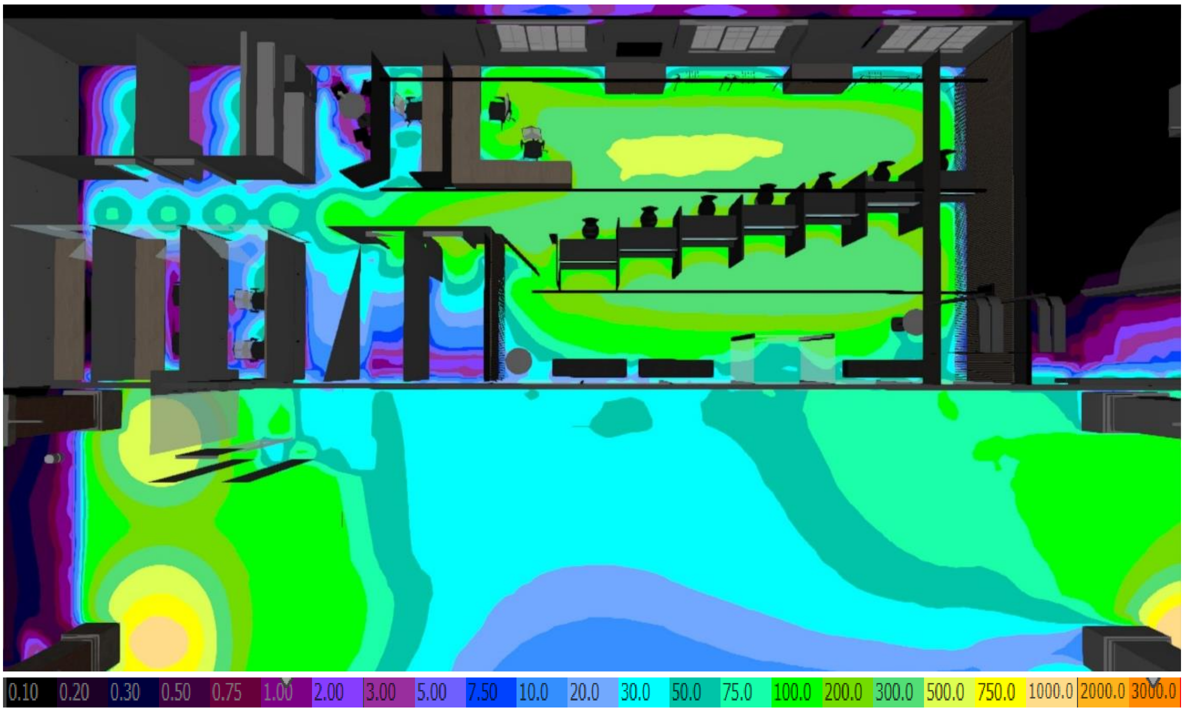


Figure 6.2: The top view of the simulation modelling showing the general surface illuminance in false colour rendering.

The 3D layout views from Figure 6.1 and Figure 6.1 show a different viewing mode from the same angle. The atmospheric condition and overall visual feel of the design is displayed in Figure 6.1 and the false colour in Figure 6.2 describes its general surface illuminance. The scale below the false colour is an indication of the lux levels of the whole building modelling (including the Central Station main hall) that ranges from 1 lux to 3000 lux, but within the fieldsite, it is visible that the lux level ranges only from 1 lux to 750 lux. All other false colour renderings presented in this chapter refer to the same scale. The coloured bubbles in Figure 6.1 indicate the important parts in the fieldsite that represent each lighting scheme proposed in the design solution. The colours here are maintained from the functionality zoning (refer Figure 5.1) in Chapter 5 as a connection between the two diagrams.

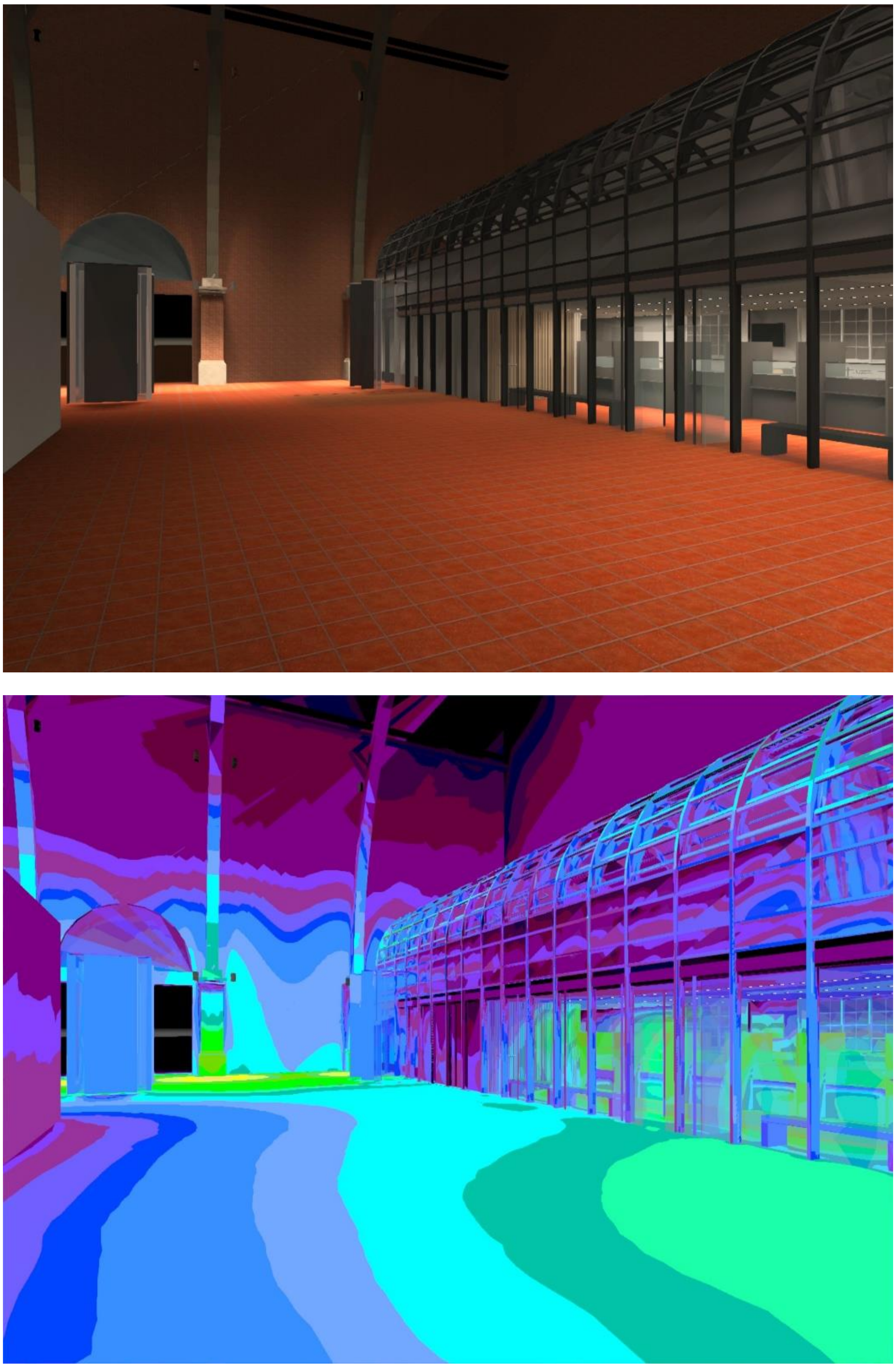


Figure 6.3: The glass facade of the police station, viewed from inside the main hall of the Central Station. The main hall is also modelled to be as close as possible to the real condition on site.

The materials have been modelled to similar photometric values – reflectance and transmittance, of the real condition on site, as the data described in Chapter 4. The application of the lighting products introduced in this simulation followed the same physical pattern with those on site, in order to not differ much from the intended architectural properties already existed on site, thus making the design more easily acceptable. The lighting on the outside of the fieldsite was modelled to be as close as possible to the existing lux values. This is to allow more accurate simulation of the light trespass into the fieldsite, although there is no light being modelled in the exterior space of the building, where the three windows are bordering to. This is because the lux levels on the pavement located outside of the windows are too low and is considered an irrelevant factor that would cause an effect significant enough in the interior of the fieldsite. Figure 6.3 shows the glass facade view of the police station on the right of the image. The rendering is viewed from inside the main hall of the central station building. The light levels and materials properties in the main hall is also modelled to be as close as possible to the existing site condition, so as to provide a more accurate visualisation of the view.

Following the design schemes developed in the conceptual stage, the idea of applying lighting schemes in relevance to the usage and acquired alertness of a space, were maintained and brought forward into this design solution. The schemes were used as a guideline to produce a design that fits the need of a space in regards to alertness and nightworking conditions. Calculation objects are placed in areas that represents each scheme and different parameters are produced in relevance to the usage and functionality of each location. The measuring grid is set at a distance of 300mm on both the X-axis and Y-axis for all calculations, appropriate to the small size of the planes. The exact values in CCT, wavelength or intensity in this design solution should not reflect as a general rule for applying these principles in another working environment. The values proposed here are the combined result of the case analysis findings and the theoretical framework. This is to ensure that any proposed solution in the end would also consider the spatial characteristics and the work culture in each casework to better suit its need.

6.1.1 Scheme 1: Low-Functioning

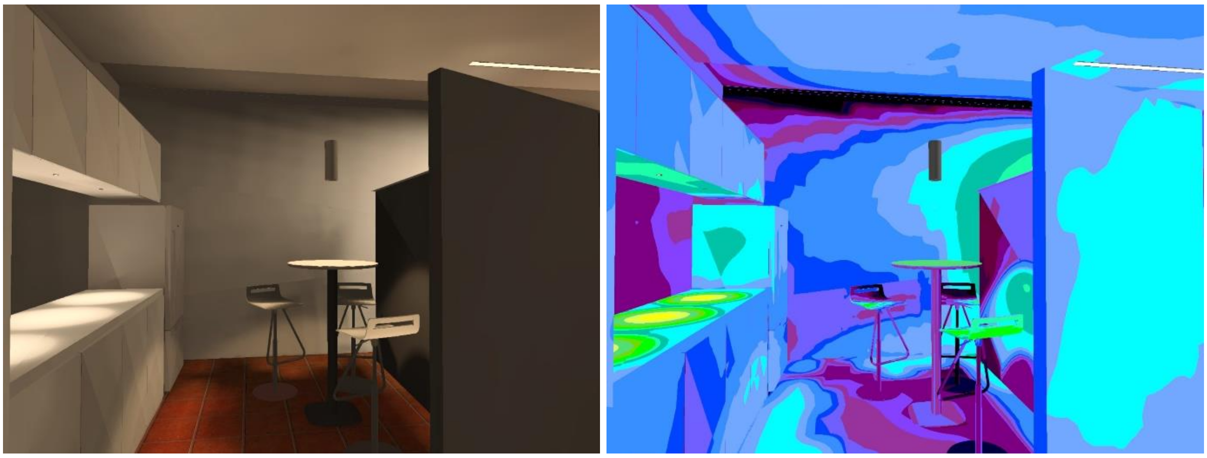


Figure 6.4: A view towards the Pantry in the fieldsite. Figure on the right is the same view in false colour.

As mentioned previously in this report, each scheme has an area in the fieldsite that represents its usage. The pantry described in Figure 6.4, represents the Low-Functioning scheme and is located in the green bubble of the plan view (refer Figure 6.1). Two types of lighting are used in this area – the pendant light hanging above the table and the downlight installed on the bottom surface of the top kitchen cabinet. The pendant light functions the ambient lighting in the area and has a medium flood distribution to avoid direct illuminance reflecting at the cornea when sitting at the table. There is no general fixture on the ceiling to ensure low ambient illuminance. The kitchen cabinet lighting is provided by 3 narrow spots downlight. The small angle enables minimal light spills into the whole room while still maintaining adequate illuminance concentrated only on the kitchen surface for food preparation task of min. 200 lux, in compliance with EN 12464-1. Overall outlook of the Low-Functioning scheme should provide a calm feeling and thus, the lighting here has a warm 2700K CCT.

Figure 6.5 illustrates the view of a user that is seating at the table inside the Pantry for his/her perspective. Seen in the view is a narrow walkway that leads to the employee exit, which is also proposed to be under the same scheme. The walkway uses downlight with wall-washing distribution to minimise direct corneal illumination. This is to create a calming atmosphere as the employee walks out of the fieldsite as they finish their nightshfit. It is also to provide a smooth transition space for the employee in helping them adapt to the low light level from the central station's main hall.

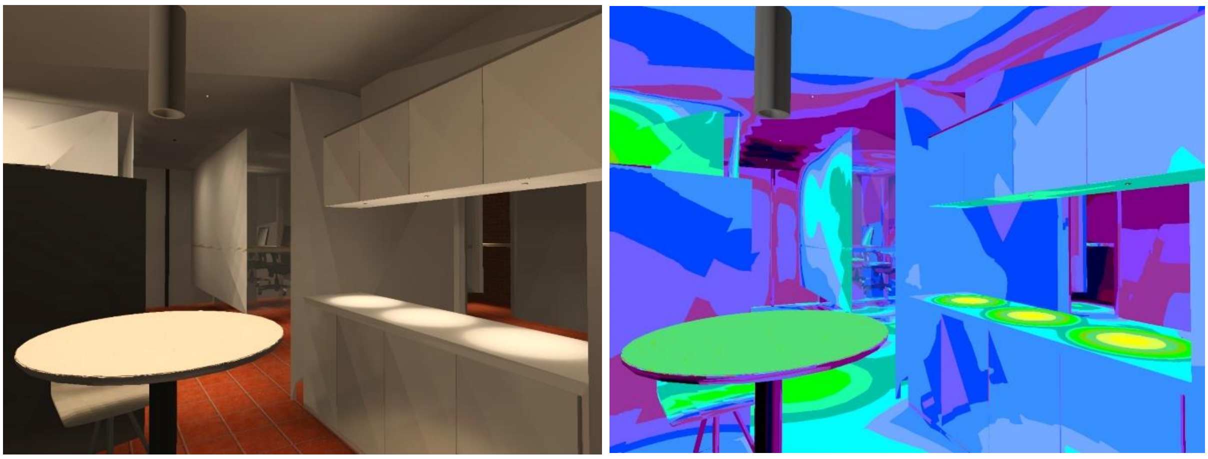


Figure 6.5: A view from the perspective of a user seating at the table in the Pantry. The figure on the right is the same view in false colour.

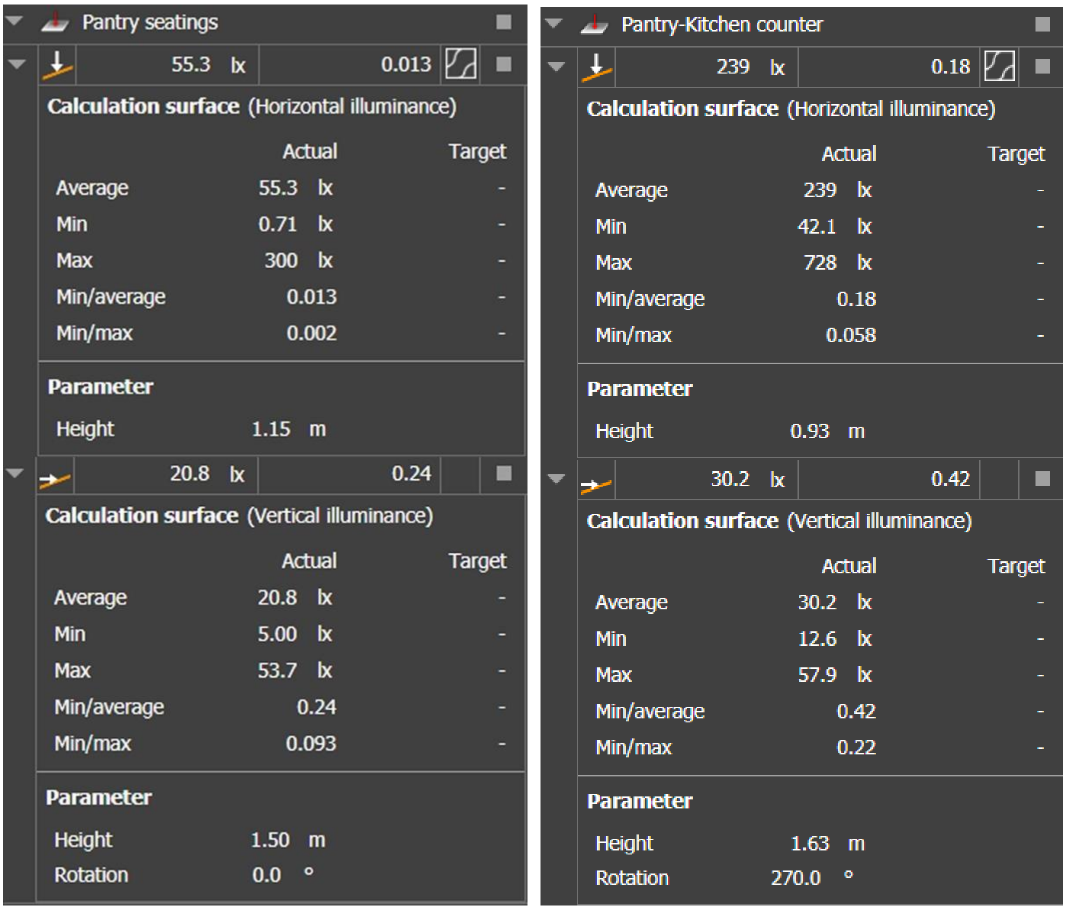


Figure 6.6: The list of calculation values from a pre-determined calculation planes for the Pantry Area. The left value is for sitting at the table and the right is for standing at the kitchen counter.

The calculation results in Figure 6.6 were documented from two calculation planes that were inserted in the modelling. The first plane is placed for sitting at the table while the second plane is placed for standing at the kitchen counter. The parameters taken in both results are the average horizontal illuminance and vertical illuminances in several directions. The vertical illumination values appear in various heights to depict the corneal illumination at appropriate eye level, to fit each activity. These values are kept below 50 lux as to reduce the alerting effect of the non-visual system. The warmer CCT of 2700K instead of 3500K as in the rest of the fieldsite, may also aid in relaxing the nervous system. The combination of the two principles could help the employee to fall asleep better after their shift and thus, reduce circadian disruption for nightworkers.

6.1.2 Scheme 2: Medium-Functioning

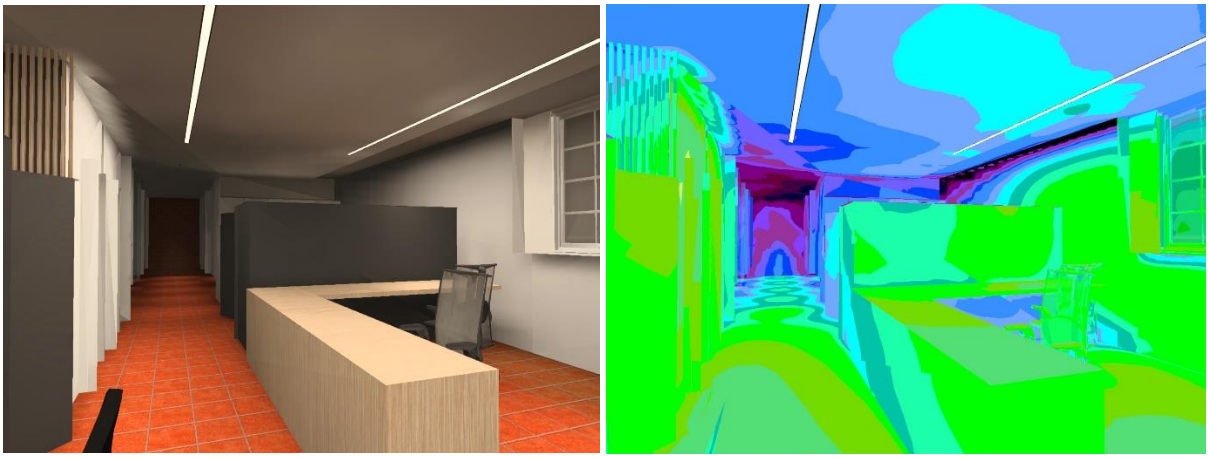


Figure 6.7: An overall view of the Medium Functioning in the fieldsite. Figure on the right is the same view in false colour.

From the conceptual outline of the Medium Functioning scheme, the areas categorised under this scheme are the main walkways and open workstation area. These areas are shown in Figure 6.7 and is indicated within the yellow bubble in Figure 6.1. For this case study, only one type of light fixture is used in these areas, which is the linear ceiling recessed fixture. The decision was made to reuse the existing physical intention currently on site, and not introduce new physical elements that does not provide any additional benefits. These linear fixtures physically extend to the end of the service counter areas, but different lighting properties are implemented in the fixtures to produce different effects suitable for the two different functionality groups. This is because the service counter area is categorised under the High Functionality Scheme. This solution gives a uniform visual of the overall design but still able to provide the right lighting principles required.

The proposed linear for this section of the fieldsite has a wall-washing distribution that uses the white wall along the walkways to project vertical illumination. The windowless part of the opposite wall is also used in the same way to distribute light on the desks. This is another approach to reduce direct corneal illumination. The CCT used in this scheme is 3500K to introduce shorter wavelength in spectral distribution. The indirect corneal illumination and the higher CCT may each suggest different purposes in the non-visual system, but the combination could make it suitable for transition areas and a relaxed working atmosphere, away from public access. The existing linear design uses fluorescent bulbs, therefore the solution suggests the switch to LED which should result in a higher CRI value.

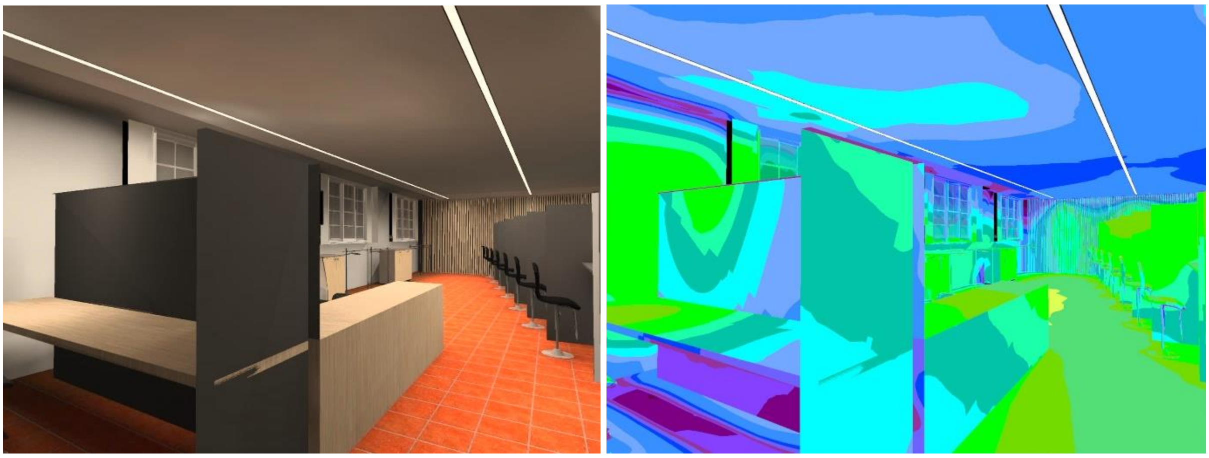


Figure 6.8: A view from the perspective of a user transiting through the open workstations along the main walkway. The figure on the right is the same view in false colour.

Walkway & Workstation

200 lx | 0.00

Calculation surface (Horizontal illuminance)

	Actual	Target
Average	200 lx	-
Min	0.00 lx	-
Max	454 lx	-
Min/average	0.00	-
Min/max	0.00	-

Parameter	
Height	0.80 m

84.8 lx | 0.18

Calculation surface (Vertical illuminance)

	Actual	Target
Average	84.8 lx	-
Min	15.6 lx	-
Max	205 lx	-
Min/average	0.18	-
Min/max	0.076	-

Parameter	
Height	1.80 m
Rotation	270.0 °

85.5 lx | 0.16

Calculation surface (Vertical illuminance)

	Actual	Target
Average	85.5 lx	-
Min	13.6 lx	-
Max	176 lx	-
Min/average	0.16	-
Min/max	0.077	-

Parameter	
Height	1.20 m
Rotation	0.0 °

186 lx | 0.55

Calculation surface (Vertical illuminance)

	Actual	Target
Average	186 lx	-
Min	103 lx	-
Max	270 lx	-
Min/average	0.55	-
Min/max	0.38	-

Parameter	
Height	1.80 m
Rotation	90.0 °

Figure 6.9: The list of calculation values from a pre-determined calculation plane in the Medium Functioning area. The left table is a continuation from the various parameters taken for this result.

Referring to Figure 6.9 above, the luminous flux and uniformity for this scheme has higher values compared to the Low-Functionality scheme to support the alertness level required and the employee interactions that occur in this space. The average horizontal illuminance is of 200 lux and may seem low for a typical day-working environment, but from user preference data in the case analysis, the nightshift users in this case study favours a lower light level than that of the normal standard.

The vertical illuminance is recorded in 3 different viewing rotations. At 0 degree, it is the direction for working at the desk. At 90 degree, the direction faces the service counters and at 270 degree, it heads towards the Pantry. This approach was taken to reflect the many types of interaction and high foot traffic count in the area. The values are kept below 100 lux for the Medium-Functioning Scheme, except for the 90-degree rotation facing the service counters. The increased corneal illumination can work as an indication to alert the occupant that they are crossing into the High Functioning area and will be visible to the public eye, which requires a different behaviour and alertness.

6.1.3 Scheme 3: High-Functioning

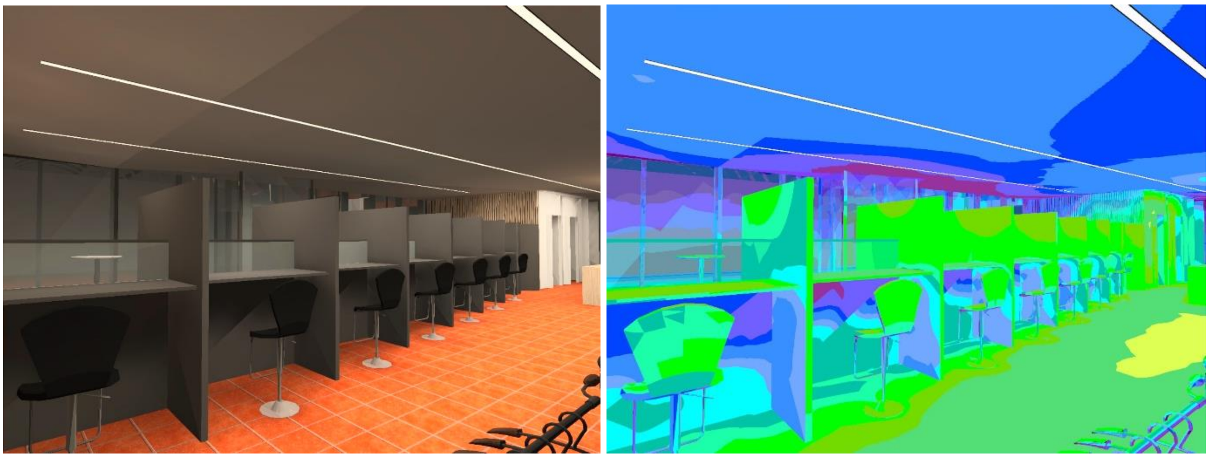


Figure 6.10: An overall view of the High Functioning of the service counters area in the fieldsite. Figure on the right is the same view in false colour.

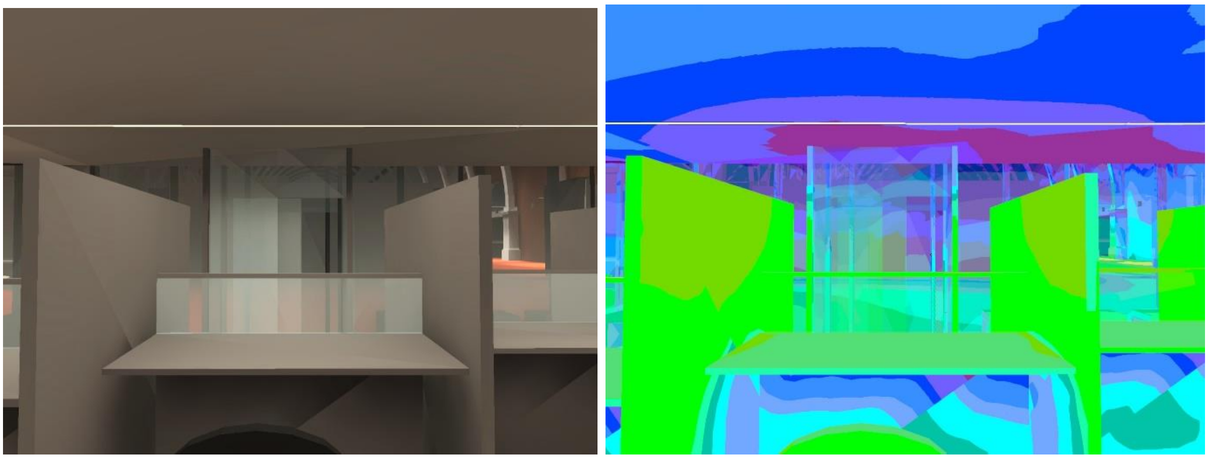
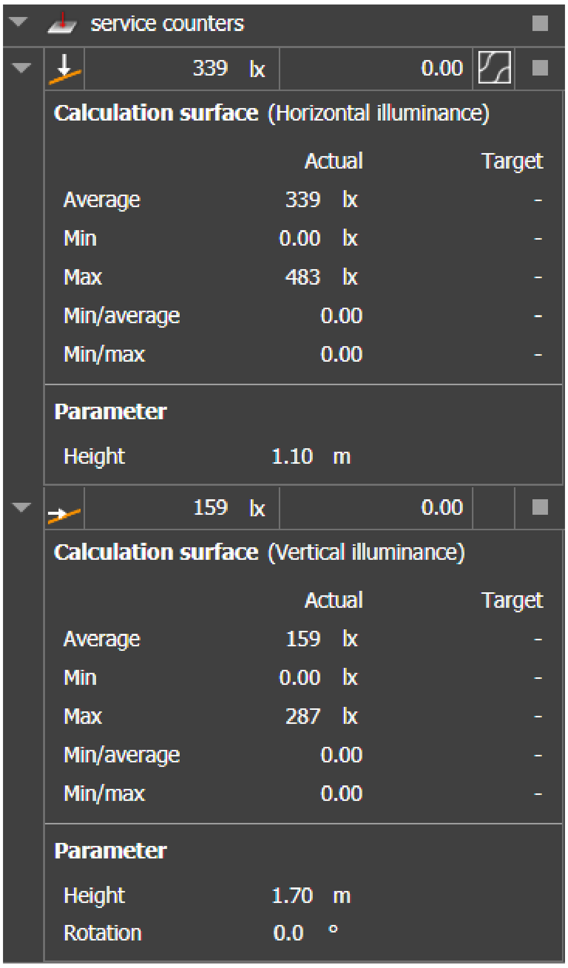


Figure 6.11: A view from the perspective of an employee sitting at the service counter for report-taking. The figure on the right is the same view in false colour.

The areas classified as High Functioning area by using the conceptual outline are the service counters and the public waiting area which includes the main public entrance. The service counters area includes the immediate space behind the service counters because this space is exposed to the public field of view. The scheme does not consider the visual and non-visual comfort of the public visiting the fieldsite, but rather the employees placed to work in the area because this research focuses on lighting in the working environment. Thus, the calculation planes are placed to investigate result for the employee at service counters responsible for report-taking, and the officer guarding the main entrance responsible for granting public access. Views for these two types of employee can be seen on Figure 6.11 and Figure 6.13 respectively.

Figure 6.10 shows the overall view of all the 7 service counters taken from the described immediate space behind them. Similar to the previous scheme (Medium Functioning) proposed for this case study, lighting in this area is only contributed by the linear fixtures. Following the current form of the existing fixture design, this open area has 3 lines of the linear fixtures, instead of 2 as per the Medium Functioning area, due to the bigger wall to wall width. Mentioned in previous scheme design, the linear fixtures has the same form but the lighting produced is designed differently to cater to the different tasks, usage, interactions and alertness level required. It was also important to remark the reflection issues complained by the employees in the interview, thus the presence of glass elements in the space is also addressed in this design.

The middle linear fixture has a wide flood distribution in higher flux value to exert direct corneal illumination to the employees sitting at service counters. The other two linear fixtures on each side have a wall-washing distribution towards the middle of the space and away from the existing windows and glass facades. The reverse functioning wall-washers are key to reducing the amount of light reflected on these glass elements thus, projecting less reflection, and also to form a concentrated pool of light that accumulates at the centre of the room, where the service counters are. This can visually brings the occupants attention to the service counters, aligned with the spatial hierarchy of the fieldsite. The atmosphere of this scheme aims to demand a more serious behaviour and a high alertness level from both the public and employees, for being a high-risk and highly detail-oriented task area. The CCT is set to be the same with the previous scheme which is 3500K, as to avoid visual discomfort of varying range in CCT in one field of view.


service counters

339 lx | 0.00

Calculation surface (Horizontal illuminance)

	Actual	Target
Average	339 lx	-
Min	0.00 lx	-
Max	483 lx	-
Min/average	0.00	-
Min/max	0.00	-

Parameter

Height	1.10 m

159 lx | 0.00

Calculation surface (Vertical illuminance)

	Actual	Target
Average	159 lx	-
Min	0.00 lx	-
Max	287 lx	-
Min/average	0.00	-
Min/max	0.00	-

Parameter

Height	1.70 m
Rotation	0.0 °

Figure 6.12: The list of calculation values from a calculation plane at the Service Counter, under two parameters.

The calculation result is for the Service Counter is shown in Figure 6.12 above. The two parameters, horizontal and vertical illuminance, taken in this calculation should demonstrate the effectivity of the designed scheme. The average horizontal illuminance in the result has seen an increment from the previous Medium Functioning scheme, but is still kept quite low due to user preference. This is to reflect back to the case analysis in which the recorded horizontal illuminance at the desk on-site is only 374 lux at 100% dimming value and the interview claim of the dimmer being turned down slightly. The value challenges the compliance of EN 12464-1 for having minimum 500 lux for work task, as the standard was not made to cater to newer research findings of nightshift worker. The viewing contrast from the low light levels in the immediate area outside of the glass facade to such a high ambient illuminance value could also cause visual discomfort and lowers visual acuity.

In this scheme, the corneal illuminance aims to reach above 150 lux and the average vertical illuminance in the calculation records 159 lux, which also comes to almost half of the horizontal illuminance and this ratio is generally considered desirable. This is to elicit high alertness level required to carry out the tasks with good performance.

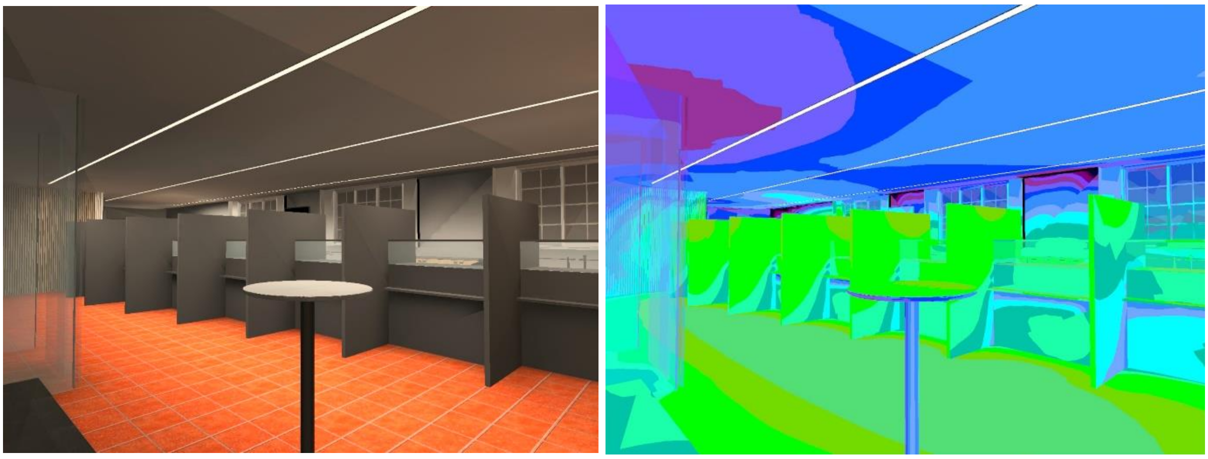
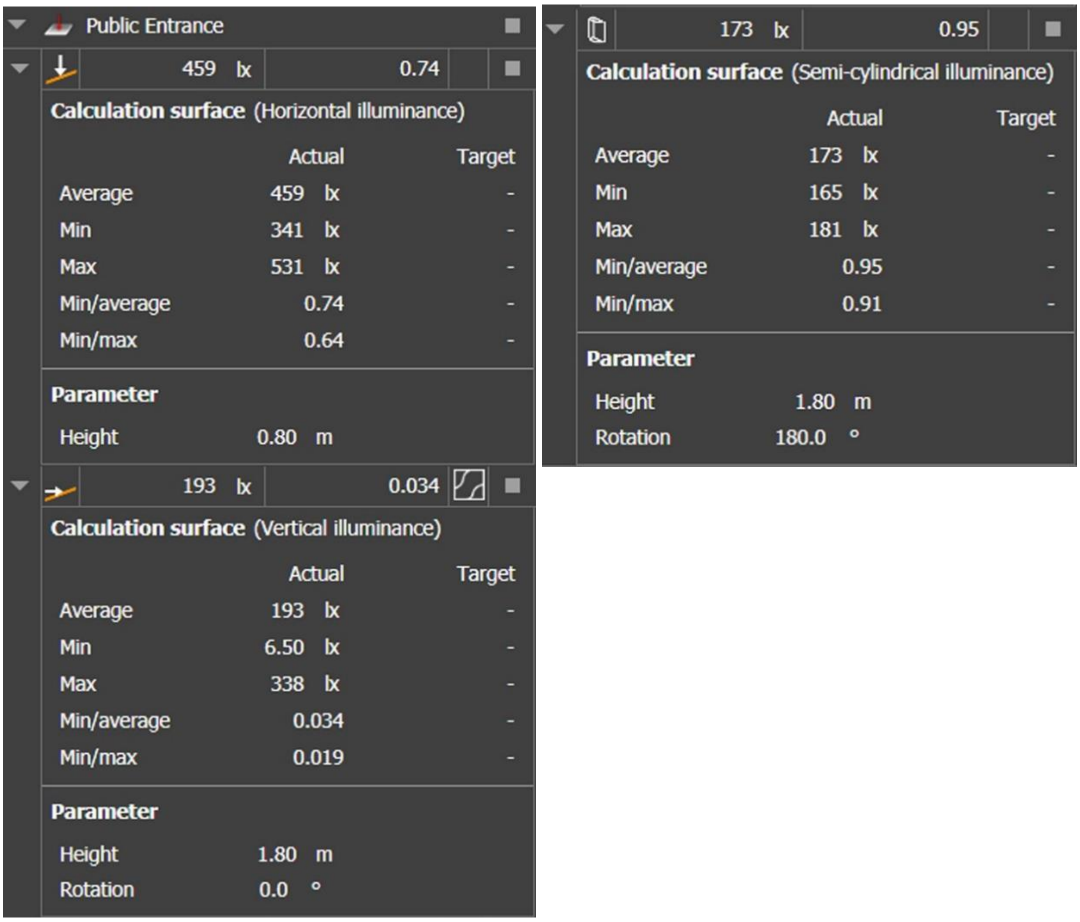


Figure 6.13: An overall view of the High Functioning at the Public Entrance. Figure on the right is the same view in false colour.



Public Entrance

459 lx | 0.74

Calculation surface (Horizontal illuminance)

	Actual	Target
Average	459 lx	-
Min	341 lx	-
Max	531 lx	-
Min/average	0.74	-
Min/max	0.64	-

Parameter

Height	0.80 m

193 lx | 0.034

Calculation surface (Vertical illuminance)

	Actual	Target
Average	193 lx	-
Min	6.50 lx	-
Max	338 lx	-
Min/average	0.034	-
Min/max	0.019	-

Parameter

Height	1.80 m
Rotation	0.0 °

173 lx | 0.95

Calculation surface (Semi-cylindrical illuminance)

	Actual	Target
Average	173 lx	-
Min	165 lx	-
Max	181 lx	-
Min/average	0.95	-
Min/max	0.91	-

Parameter

Height	1.80 m
Rotation	180.0 °

Figure 6.14: The list of calculation values from a calculation plane at the Public Entrance floor, with 3 parameters.

Figure 6.13 and Figure 6.14 shows the view and calculation value around the public entrance area. The lighting for this part of the fieldsite is mainly supplied by the additional third line of the linear fixture. As mentioned before, the fixture uses the opposite function of its wall-washing distribution to redirect the light away from the vertical surface and reduce reflection projecting on the glass facade, creating a highly concentrated light bubble that offsets from the walls.

The calculation plane is placed right in front of the main entrance, to represent the position of the officer in charge of granting public access, who was observed to be standing in between the entrance door and the service counters. The two common parameters were taken in this calculation and also an additional parameter which is a semi-cylindrical illuminance to represent the quality of facial recognition. The third parameter in rotation of a civilian entering the fieldsite through the main entrance. Due to the reverse functioning wall-washers, the horizontal illuminance has a high value of 459 lux, suitable for the most important location of this scheme. The vertical illuminance is also recorded at a high value of 193 lux, which is the highest in this case study. This is to aid in eliciting high alertness appropriate to the security level involved in this location. The semi-cylindrical illuminance has an average of 173 lux to provide good facial recognition for the officers to be able to see details on people's faces. It is vital for the officer to recognise emotions on faces for the security of the fieldsite.

7 EVALUATION

7.1 Lighting Design Principles in Nightworkers

Table 6.1 below shows a summary result of the lighting principles proposed as the major findings in this research. These principles were designed through evaluations of the theoretical framework established in Chapter 2 and the case analysis conducted in Chapter 4.

Scheme	Spatial Functionality	Proposed Lighting Principles
Low Functioning	• Low alertness requirement or non. • Low-risk areas • Low movement / motion areas • High privacy areas • Non-work-related task areas. Fx, eating, casual reading, waiting. • Areas that is acceptable for users to attend to personal matters. Fx, taking a personal call, checking mobile updates. • Areas that act as a retreat/escape from the working environment. • Examples: pantry/canteen, toilet, changing room, waiting area for guests, games room.	Corneal illuminance: < 50 lux Horizontal illuminance: < 100 lux CCT / SPD: low CCT with peak in long-wavelength Distribution: Narrow and indirect
Medium Functioning	• Low to Medium alertness requirement • Medium risk areas • Medium movement / motion • Semi-private areas • Low or non-detail-oriented work areas. • Intermediate spaces that act as a connection between low and high functioning. • Examples: phone booth, breakout spaces, gym, walkways.	Corneal illuminance: 50-100 lux Horizontal illuminance: 100-200 lux CCT / SPD: medium CCT with peak in long-wavelength Distribution: Medium flood and indirect.
High Functioning	• High alertness requirement • High risk areas in safety and security • High movement / motion area • Medium to low privacy areas • High accuracy work task requirement • Areas with high retained attention requirement • Examples: office workstations, meeting rooms, production lines, repairment areas, loading bays.	Corneal illuminance: > 150 lux Horizontal illuminance: > 300 lux CCT / SPD: high CCT with peak in short-wavelength Distribution: Wide-flood and direct

Table 7.1: The lighting principle suggested for nightshift environment, categorised in 3 different schemes.

The way the research has been carried out reflects the appropriate method that these principles should be used, as the details of the principles are subjected to the spatial characteristics, understanding of local usage and the working culture norm in the area of application. Three schemes are established to reflect the ease of usability to categorise areas into different functional levels, which are – Low, Medium and High. The spatial functionality describes the characteristics of the space and how they are used by occupants. This involves user-to-space and user-to-user interactions, and also what is demanded by a space for it to function well, fx., alertness level. Some of these characteristics are defined by activities and task that commonly occur in a space.

The proposed lighting principles column describes the lighting suggestions in these designated areas upon spatial categorisation. The principles are elaborated in 4 different light elements, which are – corneal illuminance, horizontal illuminance, CCT / Spectral Distributions and Spatial Distribution. These items were derived from the theoretical framework conducted earlier in the research and inspired by Kevin Houser's underlined Integrative Lighting elements (Houser, Boyce, Zeitzer, & Herf, 2020), although excluding 'Time of Exposure' factor due to the limitation mentioned in this research.

7.2 Success Criteria

7.2.1 RQ and Hypothesis

Natural Science	High and direct corneal illuminance can elicit adequate alertness level to increase work performance and visual acuity.
Social Science	Controlled exposure of warm and cold light under dim conditions during the shift can regulate sleepiness to aid post-shift sleep quality.
Humanities	A clearly defined light hierarchy in a nightwork environment can boost efficiency of spatial functions and user interaction.
Research Question	How can light distribution, CCT and hierarchy be utilised to regulate user alertness and aid spatial functionality in nightwork environment?

Table 7.2: A recap of the hypotheses and research question described in Chapter 1.

From Chapter 1, the hypotheses model used for this study followed the Koskinen Design Research through Practice method of using 3 different practice application, which are – natural science, social science and humanities, to represent the lab, field, and showroom respectively (Koskinen, Zimmerman, Binder, Redstrom, & Wensveen, 2011). Due to the limitation in conducting experiments and testing stated in Chapter 3, these hypotheses and research question success criteria is evaluated from the design solution presented in Chapter 6, backed up by theoretical framework and case analysis done in Chapter 2 and Chapter 4.

In the natural science hypothesis, the relationship between alertness level and light intensity at corneal illuminance was investigated to improve performance and visual acuity. High intensity should result in higher alertness level, and this was measured by varying ranges of corneal illumination (lux) in the schemes. The social science hypothesis studied the importance of spectral distribution under lower light levels in inducing sleepiness. This was evaluated by implementing warmer CCT for areas under Scheme 1, which has the lowest intensity and alertness requirement, compared to Scheme 2 and 3. This combination was proposed based on a study that shows how spectral distribution makes significant difference in sleepiness only at low light levels (below 200 lux) (Cajochen, et al., 2019). Similar values have been found in a much older study from the year 2000, where its result showed melatonin suppression occurring only at intensity greater than 200 lux and minimal suppression occurring between 80-160 lux, with no suppression at below 40 lux in a nightwork environment (Zeitzer, Dijk, Kronauer, Brown, & Czeisler, 2000). In the same study, it was concluded that 9000 lux has significant alertness response but 100 lux (approx.) at eye-level can achieve half of that alertness response, despite being 100-times less in intensity value. This is evidence that very bright light can be unnecessary to induce acquired alertness.

Conclusively, it indicates that the corneal illumination and CCT values underlined for each scheme should elicit enough alertness level required, without impacting their post-shift sleep quality, as these values are shown to avoid excessive melatonin suppression. Low corneal illumination of below 50 lux in Scheme 1 can inhibit any suppression that may occur in areas of Scheme 2 or 3, ultimately reducing alertness and bringing calmness to occupants. This dim light condition in Scheme 1 is paired with the low CCT relative to Scheme 2 and 3, to further induce sleepiness effects which is necessary for the spatial usage of Scheme 1. In the design solution of the case study, corneal illumination for Scheme 3 is higher relative to the Scheme 1 and 2 to obtain acquired alertness, but because the nightshift is currently planned for only until 12 midnight as required by the fieldsite, it does not exceed 200 lux as to minimise interference in post-shift sleep quality. Higher illuminance level more than 250 lux may be required for other case study that has a longer extended nightshift. It could also be suggested in the future implementations of the current case study when preparing for further extension in their shift hours, as the central station develops increased night-time usage by commuters.

In order for these schemes to function well, it is important to obtain thorough understanding of the spatial function as this is a major part in establishing areas for different schemes. The details in the scheme's light elements themselves are the direct result of good spatial understanding process. As stated in the humanities hypothesis, a detailed analysis of the spatial hierarchy in the case study was conducted in this case study and the result is a clear categorisation of each area and flow of usability from one area to another. It can be said that without the spatial understanding process, the schemes' principles cannot be used effectively. This ultimately may result in wrongful lighting application that diminishes the overall performance of the place in nightwork conditions.

7.2.2 Inter-disciplinary Research

From what was mentioned in Chapter 1, this research was conducted under the inter-disciplinary model introduced to the MSc. Lighting Design program in Aalborg University (Hansen & Mullins, 2014). It is apparent that this research has crossed between different disciplinaries in the lighting knowledge to produce accurate findings. The author had combined her illustrative skills developed from her experience of being an interior architect, with the knowledge obtained from this program and the literature review conducted during this research. The design development process in this research uses an architectural approach under a mixed media method, fx., moodboards, building modelling, and figurative sketches, to explain its atmospheric and ambient identity using a combination of different technical software and media platform. Further than that, multiple literatures from scientific papers were studied and reviewed. These papers mainly revolved in the field of psychological and physiological effects of light and sleep pattern, due to the nature of the focused topic in the research. Scientific papers from other fields also include the occupational safety industry and the built-environment health, to understand the issues that lie within the nightwork environment.

7.3 Future Field Testings

Due to the limitation explained in Chapter 3, testings and experiments were not conducted in this research. The experiment was planned thoroughly and comprehensively to align with the hypotheses and research question of this research, and therefore would have been able to produce a more accurate findings for this research that could be proven with the test results as evidence. From these circumstances, the planned experiment is proposed as a future work that can be done after the duration of this research. This post-study experiment is defined by 3 major steps. The first step is the procedure of the set-up, the second is establishing a suitable testing protocols, and the third is to analyse the result.

7.3.1 Set-up Procedure

This procedure was planned to be conducted as a field testing, under real night working situation and stimulus, although simulated night-work condition in laboratory can also be considered. The reason for this preference is because lab experiment lacks the "confound" or inadequately-controlled variables that can result in manipulation of a person's typical working environment. In this case, confound variables can be accounted as an advantage in developing a more natural result. Most of previous studies regarding this topic were conducted in lab settings. Lab settings normally has very precise control of variables including nutritional intake, movement and subject's lighting environment (Brainard, et al., 2001), (Thapan, Arendt, & Skene, 2001), (Lockley, et al., 2006). Sunde et al. expressed concerns over this matter by saying that "more naturalistic studies are warranted" and that most studies try to limit external factors as much as possible with the use of goggles, spheres and light boxes, which are not typically available and practical in normal night working conditions (Sunde, et al., 2020).

The field set-up should involve 8 participants, exposed to 4 different lighting conditions, for a period of 5 consecutive work nights to actually see any pattern in circadian adaptation and also to mimic the typical night shift weekly rotation as the weekend arrives. During the weekend where the rotation is reset, it is typical to assume that the workers will be sleeping at night instead of working as they do in the 5 working nights. The set-up uses individually controlled table lamp in different CCT and intensity parameters placed on the subject's tables as independent variables. The ceiling light of the fieldsite is maintained at its existing values and constant CCT and intensity among all 4 conditions. Exposure from the table lamp acts as a tool of intervention in individual lighting to increase performance at night with minimal circadian disruption, while the generic ceiling lamp is a constant factor that provides general ambience for all. This reflects well with the real night working environment that has less possibility of total control in subject participation outside of the fieldsite. These parameters are described under the lighting conditions as follows and illustrated in Figure 7.1;

1 – Condition WD (Warm 2400K, Dim 90lx)

2 – Condition WB (Warm 2400K, Bright 300lx)

3 – Condition CD (Cold 6000K, Dim 90lx)

4 – Condition CB (Cold 6000K, Bright 300lx)

These conditions use the two different CCT values to represent the independent variable of spectral distribution in seeing changes of alertness level and performance. There is possibility of remote management for these variables via smart tunable white bulbs, widely available today. Based on the theoretical framework, corneal illuminance of 90 lux is used to see alerting effects in low intensity, and 300 lux is used to represent high intensity. The combination of these two parameters produces 4 different conditions, in investigating different outcomes of the dependent variables, which are – alertness and performance level.

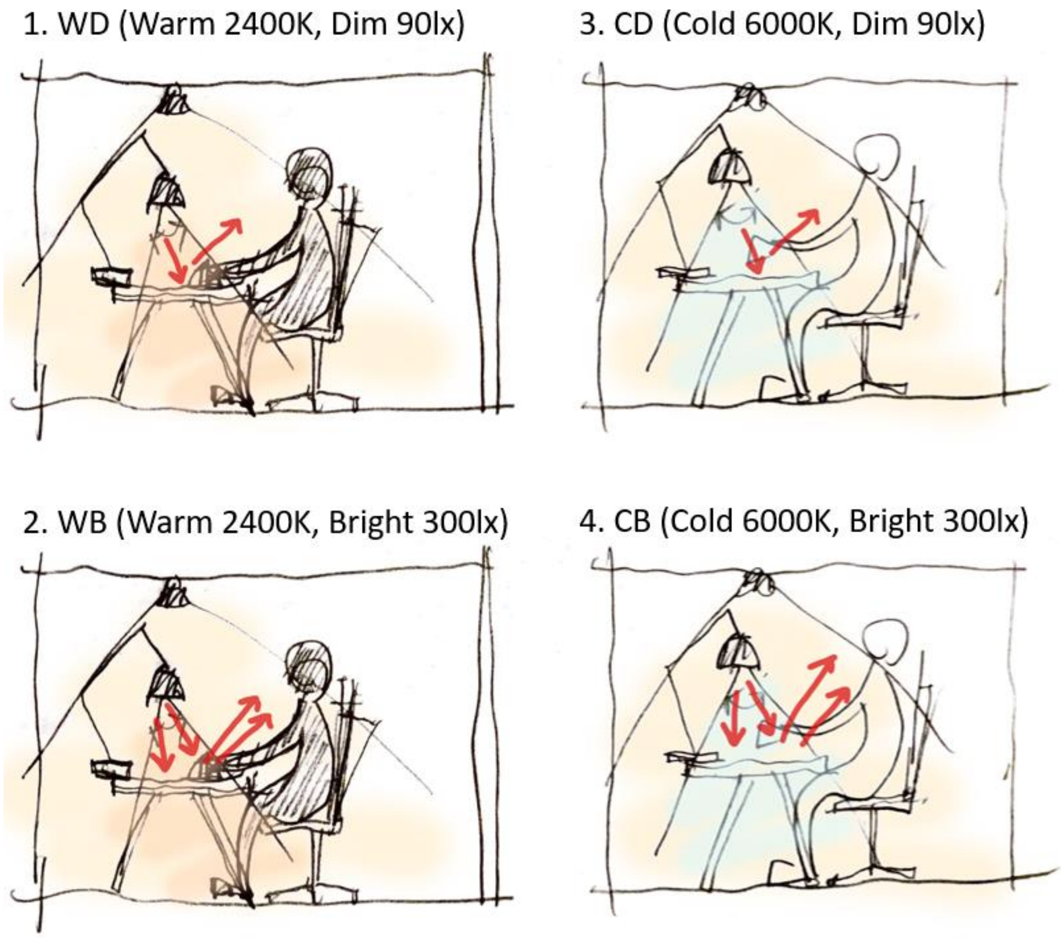


Figure 7.1: A brief illustration describing the set-up parameters. (Source: self-own)

7.3.2 Testing Protocols

To measure the outcome from the 4 lighting conditions, protocols for several test methods were designed to collect data from the dependent variables. The table below described the design of the test protocols.

Area of Investigation	Aim of Investigation	Test Protocols	Methods of testing
Demographic	To setup subject's profile and exclude confound factors relevant to non-visual system such as jetlags, color blindness, very old age, or related diseases.	Online Questionnaire	To be conducted one time throughout the experiment, prior to the other test protocols, via online platforms for ease of access.
Preference	To include subject's preference and experience as a determining factor for visual comfort and acuity.		
Alertness Level	To test subject's vigilance from their response time and number of mistakes made.	Psychomotor Vigilance Test (PVT)	To be conducted twice on each night shift; firstly at the start of the shift, secondly at the end of the shift, for all 5 consecutive nightshifts, with possibility of remote supervision via online platforms, available as application on mobile devices.
Work Performance	To evaluate performance level by testing subject's cognitive functioning.	Digit Symbol Substitution Test (DSST)	
Sleepiness Level	To examine induced sleepiness in subjects via self-report scale.	Karonlinska Sleepiness Scale (KSS)	

Table 7.3: The testing protocols and methods of conduct that could be implemented in the post-study experiment.

7.3.3 Result Analysis

Results from the tests designed in Table 7.3 is proposed to be analysed using the ANOVA method. This is because the presence of multiple independent variables that produces direct manipulation in the investigation outcome. By combining the test protocols and methods of testing mentioned in Table 7.3, the statistic is expected to also illustrate both the visual and non-visual effect of lighting exposure and possibly the circadian adaptation that may take place at the end of the 5 consecutive nights.

The different tests used in the protocol can produce a more concise understanding of the 3 main outcome factors in the research question of this study, which are – Alertness, Sleepiness and Work Performance. The proposed method for these 3 factors, when conducted at the start and end of each shift, may reveal statistics of DLMO entrainment and deterioration rate of these factors throughout the shift, although this majorly depends on how the data is analysed from the ANOVA method.

7.4 Perspectivation

The principles developed as a product of this study in Table 7.1, can be used as a starting point or pilot study in creating a lighting strategy for the nightwork environment, although more work needs to be done in order to reach that level, especially with the details in application evidence. This work is warranted today more than ever due to the rapid development of the night industry in the 24-hour globalisation of the world.

The different schemes are designed to be easily transferable and applied into other typical nightwork places, that also involves interchanging public and private usability or just private workplaces. The spatial functionality can be developed in further details to include a comprehensive list of nightwork places and their characteristics for easy categorisation (for example, gas station, treatment plants, transportation depot, public stations, factories), although limited to exclude the medical industry and services (hospitals, nursing homes, and laboratories) as they require special guidelines that were not considered in this study.

The conceptual development of the case study is highly recommended to be carried out when producing the schemes for other workplaces to ensure the right scheme application. The way the case analysis was conducted for the police station, could also be progressed into different sub-categories such as types of user and range of shift periods. This is to reflect user interaction with themselves, with other users and with their physical space, for example, an office worker would interact differently with his surrounding, compared to a janitor in the same building. In a bigger context, workers that deals with the public as a main part of their job requirement would require higher alertness compared to workers of quality control and mechanical inspection that occurs majorly as private interactions. The latter may require less alertness but higher cognitive functioning, and this result in different evaluation values of work performance.

7.5 Conclusion

In conclusion, more work needs to be done further than the findings of this study for the lighting principles to be implemented as a general guideline in nightwork environment, although the schemes produced can be used as a starting point or a design model to help lighting designers mobilise their design works in the right direction. The use of experiment proposed in this study is highly recommended to be conducted as preliminary data prior to construction of the schemes. The outcome of this study was construed without data from the experiment, thus, could not be proven in application, although knowledge from previous studies was used in replacement of evidence. This is why it could not be concluded for a certain that these schemes would actually produce intended result, as it has not been tested in this study.

From the experience of the author when conducting literature review for this study, it was found that a lot of the previous papers were inconsistent with their outcomes and it was difficult to find a clear pattern of knowledge that could be cross verified among other related studies. This reveals the immense need for more research to be conducted in this topic of nightshift workers, despite the century-old existence of nightwork conditions. The accessibility of information differs greatly with similar knowledge and area of study to the daywork condition, where guidelines and standards were seen to be readily available and approved by different lighting associations (WELL, 2016). Admittedly, it is a more complex application as human is not evolved to operate as nocturnal creatures, which means that this 24-hour globalisation phenomenon could imply the restructuring of human's millennial-old physiological evolution.

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Appendix

Appendix 1:

Lighting for Night-workers

The world today is running at a 24hour capacity, partly due to the traveling technology and ease of worldwide communication with different time zones, which has created a high demand for nightshifts. Night works used to be limited to the health and public emergency sectors but now, airports, gas stations, factories are all operating around the clock. This caused the public sectors to also widen their nightshift territory in order to cover these other industries.

Until the 1800s, the primary source of light were only the sun and fire. Times were simpler when everyone worked during the day & slept at night. Thanks to the invention of electrical light, working at night was made easier. But in 2010, World Health Organisaton (WHO) formally implied that nightshift is highly unhealthy due to the disruption of our circadian rhythm (a.k.a biological clock), and it was later found that the lighting (under which these night workers are exposed to) has a big role in the disruption. There is also a big difference of work performance compared to the dayshift, due to the depleting alertness level & visual quality during nightshifts.

The aim of this research is to investigate what are the lighting elements at play in a nightwork environment that requires high alertness level, and how it can be improved to better work performance while still minimising effects of unhealthy circadian disruption.

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1. State your gender.

Mark only one oval.

- ◯ Male
- ◯ Female
- ◯ Not specified

2. State your age group.

Mark only one oval.

- ◯ 18-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50 & above

3. On average, how many night shifts do you have in a month?

Mark only one oval.

- ◯ Less than 6 days
- ◯ 7-13 days
- ◯ 14-21 days
- ◯ More than 21 days

4. 4. How long is one night shift?

Mark only one oval.

- Less than 4h
- 5-8h
- 9-12h
- More than 12h

5. 5. State the time of your night shift. (Fx, 10pm to 4am)

____

6. 6. In general, how does the lighting in your workplace makes you feel during your nightshift?

Mark only one oval.

- More energized/alert than before I arrive
- More tired/sleepy than before I arrive

7. 7. Do you feel a difference in your alertness level throughout the nightshift?

Mark only one oval.

- Yes, my alertness level INcreases as time passes
- Yes, my alertness level DEcreases as time passes
- No, my alertness level maitains the same as time passes
- Depends, my alertness level goes up and down

8. 8. In your opinion, can a brighter light make you more alert during your nightshift?

Mark only one oval.

	1	2	3	4	5	
Not at all	○	○	○	○	○	Yes, much more

9. 9. In your opinion, does high alertness = better work performance during your nightshift?

Mark only one oval.

	1	2	3	4	5	
Not at all	○	○	○	○	○	Yes, very much

10. 10. On a scale of 1 to 5, how often do you have trouble falling sleep after returning home from your nightshift?

Mark only one oval.

	1	2	3	4	5	
Never	⬭	⬭	⬭	⬭	⬭	Always

11. 11. On a scale of 1 to 5, how would you rate your average sleep quality after a nightshift?

Mark only one oval.

	1	2	3	4	5	
Very poor	⬭	⬭	⬭	⬭	⬭	Very good

12. 12. On a scale of 1 to 5 , how satisfied are you with the current lighting at your workplace now?

Mark only one oval.

	1	2	3	4	5	
Not at all	⬭	⬭	⬭	⬭	⬭	Very satisfied

13. 13. Based on your answer from the previous question, why?

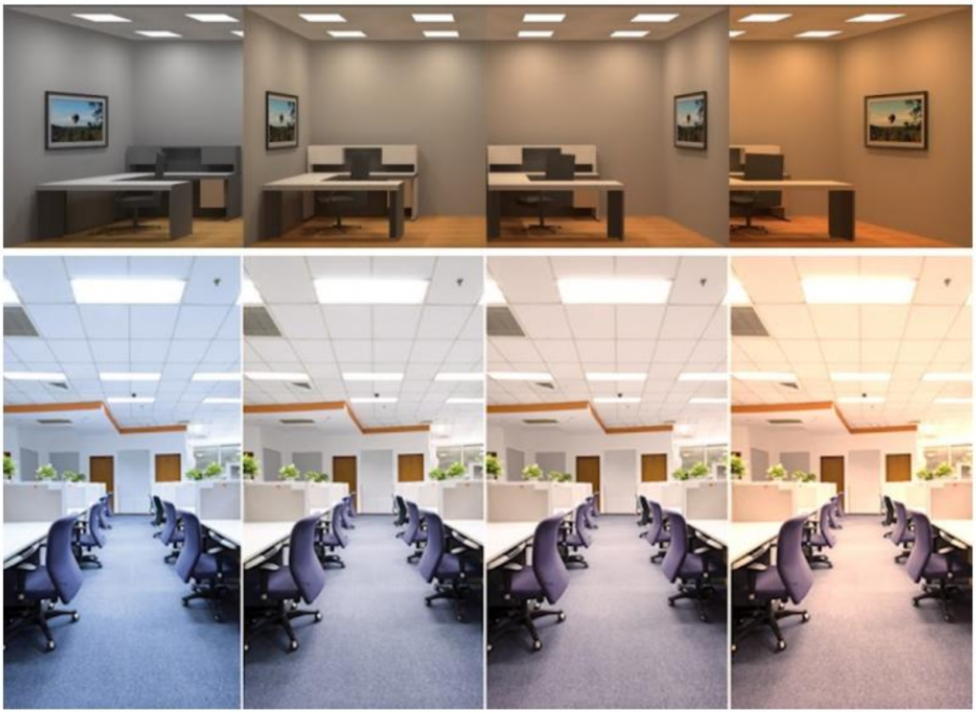
Visuals for Question 14.

14. 14. What lighting colour do you prefer when relaxing at home?

Mark only one oval.

	1	2	3	4	5	
Very cold / blue-ish light	◯	◯	◯	◯	◯	Very warm / red-dish light

Visuals for Question 15.



15. 15. What lighting colour do you prefer when working on your night shift?

Mark only one oval.

	1	2	3	4	5	
Very cold / blue-ish light	◯	◯	◯	◯	◯	Very warm / red-dish light

16. 16. Lastly, how do you think your workplace lighting can be improved to help you in any way?

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