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Title: Designing Atmospheres: A Natural and Lively Luminous Environment Through Dynamic Lighting

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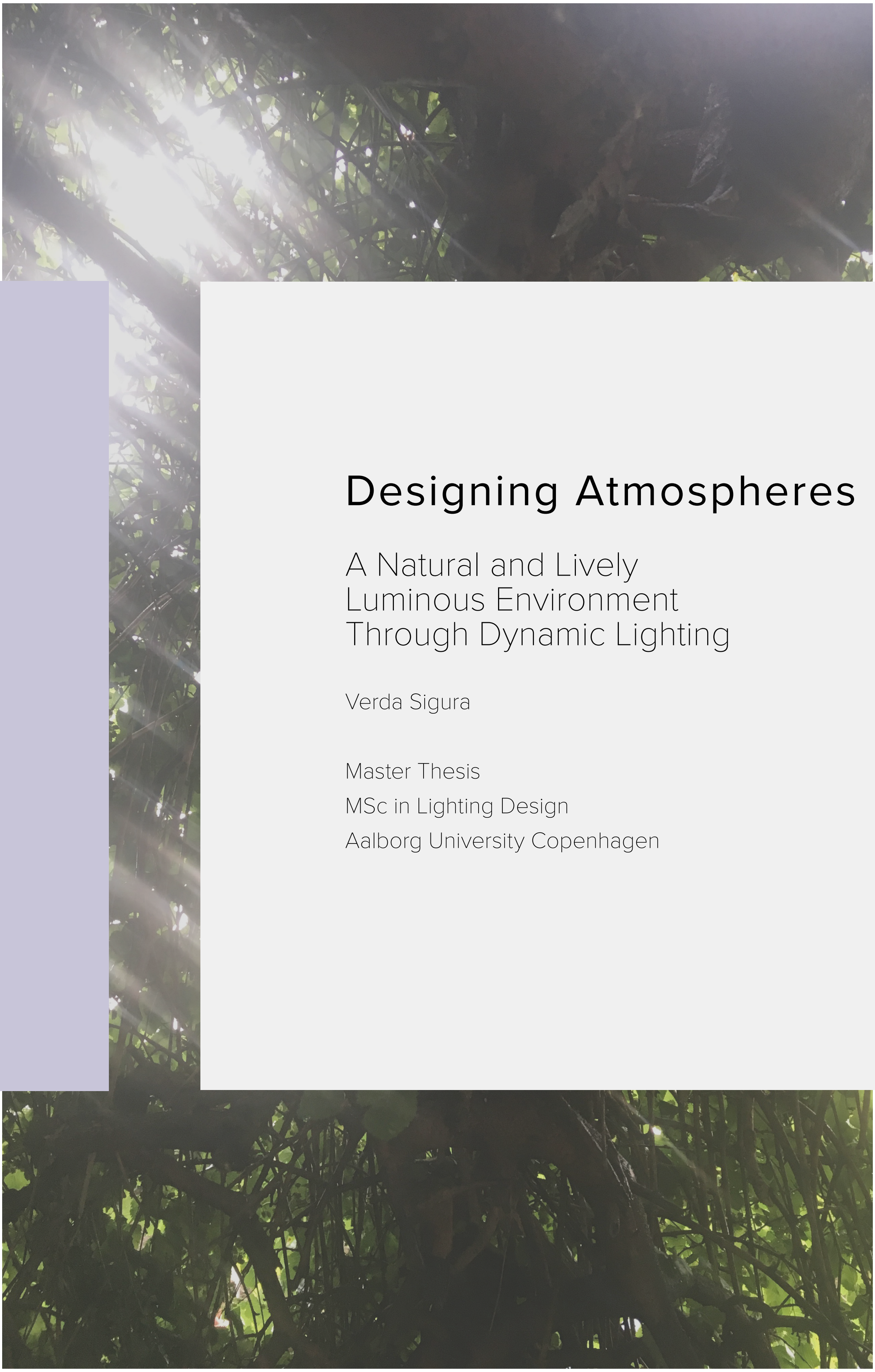
Abstract:
Throughout history, the main goal of office lighting has been to increase efficiency through bright lighting having an even distribution. Yet, recent research indicates that this kind of lighting leads to an unstimulating, boring, and dull luminous environment that supports neither task focus, nor a pleasant atmosphere. The primary goal of this thesis is to design an indoor lighting that creates a lively and natural atmosphere- similar to the feeling of lighting associated with sunlight filtering through the trees under a blue sky. One of the meeting rooms of the company "Freja Ejendomme" is used as a case study. For the specific case, the design also aims to enhance the function of the meeting room as a formal space where negotiations are held and shows the identity of the company to the business partners while supporting employees' sense of belonging to the company culture. A mixed-method approach that combines qualitative and quantitative methods is used for the design process: User survey on Perceived Atmosphere and Visual Appearance; semi-structured interviews with a user and building administration; researcher's personal observations of atmosphere, visual appearance of light and architectural elements in the space; input from Double Dynamic Lighting Research; testing through simulations for daylight and electric light and finally Richard Kelly's three elements of lighting- Focal glow, Ambient luminescence, and Play of brilliants, as a design tool. The result is a lighting design that creates a lighting hierarchy in line with the architectural elements of the space and complements daylight through electric lighting in a dynamic way while taking sky-type and daylight inflow into consideration. Future work would be required; first, to fine-tune the design through site testing; second, to make sure the intended atmospheric qualities and function are accomplished by receiving user feedback through photorealistic renderings and in the case of realization of the design concept, conducting a post occupancy user survey.



Designing Atmospheres

A Natural and Lively Luminous Environment Through Dynamic Lighting

Verda Sigura

Master Thesis

MSc in Lighting Design

Aalborg University Copenhagen

This report is a documentation of the master thesis executed by

Verda Sigura in Spring-Summer 2021.

Programme: MSc in Lighting Design

Supervisors: Henrik Clausen & Ellen Kathrine Hansen

Hand in-date: August 16, 2021

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Throughout history, the main goal of office lighting has been to increase efficiency through bright lighting having an even distribution. Yet, recent research indicates that this kind of lighting leads to an unstimulating, boring, and dull luminous environment that supports neither task focus, nor a pleasant atmosphere.

The primary goal of this thesis is to design an indoor lighting that creates a lively and natural atmosphere- similar to the feeling of lighting associated with sunlight filtering through the trees under a blue sky. One of the meeting rooms of the company “Freja Ejendomme” is used as a case study. For the specific case, the design also aims to enhance the function of the meeting room as a formal space where negotiations are held and shows the identity of the company to the business partners while supporting employees’ sense of belonging to the company culture.

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Initiation

Introduction

Atmosphere can be defined in many ways, yet I believe the simplest definition is the one expressed by architect Peter Zumthor: “I enter a building, see a room, and in the fraction of a second- have this feeling about it.” (Zumthor, 2006)

Transferring the phenomenological perspective to architecture, Finnish architect Juhani Pallasmaa provides us (lighting designers) with a very valuable framework. Pallasmaa (2014) describes atmosphere as a phenomenon that precedes other perception and exists beyond the Aristotelian five senses. He refers to the concept of Genuis loci- spirit of place, as a similar term to atmosphere as they both encompass unique identity and characteristics of a space. This notion makes me think of the challenge of giving a character to an office space. Offices are typically considered as formal and neutral spaces, serving one main function: an effective working environment. Throughout mid-20th century, the aim of office managers was to ensure high visibility to facilitate workers’ task performance through bright lighting (fluorescent lighting with even distribution), in the context of a transparent and efficient atmosphere in the workplace (Petty Maile, 2008, as cited in Edensor, 2015). Still, in our century, the dominant cultural approaches cherish productivity above all else, a lot of workplace lighting research focuses on factors like attention span, focus and other various criteria of productivity. On the other hand, nowadays, due to the pandemic, we are seeing blurring lines between our homes and offices. Some companies are already looking for ways to transform their office spaces via new learnings of this era. I would like to illustrate this trend with a few examples. Research and design lab Space10 renewed their office space to adapt to the “new normal” by creating an office space that is tailored around its users’ needs, providing more flexibility, fluidity, and variety (“Reimagining the Office for ‘The New Normal’ | SPACE10,” 2021). The company managed these changes via reshaping materiality, colours, spatial re-organization and of course light: all the necessary tools to create a desired atmosphere in the workplace. Similarly, design consultancy firm IS IT A BIRD created a homely atmosphere in their Copenhagen office. Their CEO Rasmus Thomsen explains it in a way to inspire others:

> “This approach is neither easy nor cheap, but it creates an atmosphere that is pleasant to spend time in, which in turn makes employees lower their guards and be more present at the benefit of both themselves and the company. I would even go so far as to argue that a truly inspiring, warm and human workspace plays a significant role in attracting and retaining the highest calibre of employees… () My experience from many visits to (especially large) companies is that most offices look very similar, and most of all they signal cold efficiency, without much personality.”
>
> (Thomsen, 2020)

Although the culture of each company is unique and hence calls for a unique identity catered to its needs, these examples demonstrates that the ideology of designing workplaces based on productivity alone is no longer valid. For corporate offices such as Freja, considering the degree of formality that the company culture requires, it might not be plausible to create a totally home-like atmosphere. Yet, it would still be highly valuable to create a natural luminous environment to inspire and comfort the users of the space. More specifically, dynamic lighting could be the key answer to human need for variation, to ensure pleasant atmospheres and well-being.

Pallasmaa (2014) argues that atmospheric qualities stem from a degree of irregularities and vagueness and that a static design, perfect form, and formal cohesion work against the creation of atmosphere. In his writings, this notion also connects to the idea that dynamic spaces and atmosphere create each other, which, intuitively supports the use of dynamic lighting to create atmospheres. Moreover, for the context of this thesis, I start asking the questions; what does the atmosphere of the office space communicate? Which acts does it invite its occupants to? How do we create an atmosphere where people enjoy spending time and working? What are the lighting qualities of an inviting and pleasant workplace?

Hypothesis

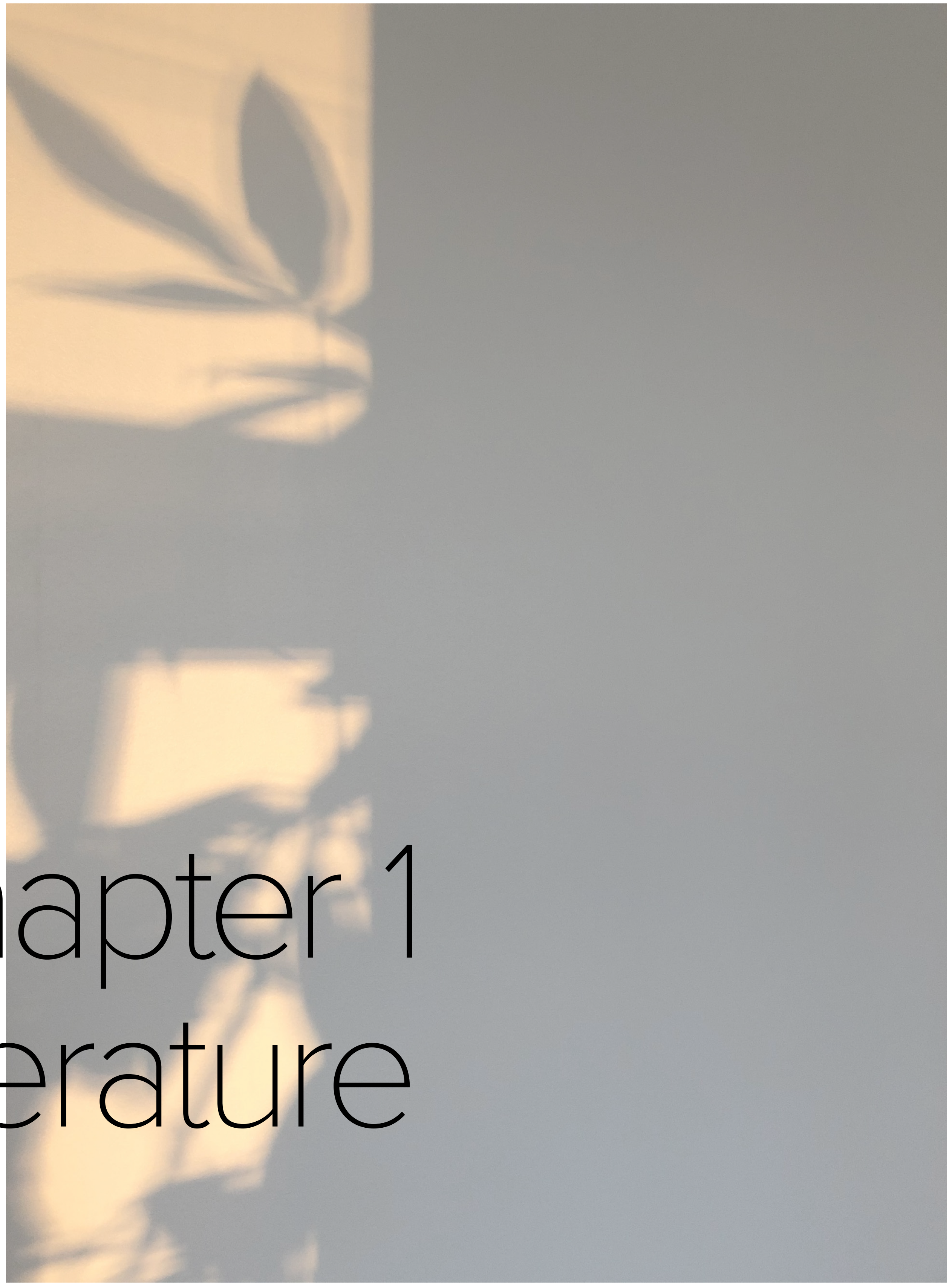
The hypothesis of the thesis in relation to the questions I stated above is as follows:

By using perceived atmosphere as a metric for a dynamic lighting design of an indoor environment, with electric lighting complementing daylight, we can achieve a natural, lively, and pleasant atmosphere in the space.

Method

A mixed-method approach that combines qualitative and quantitative methods has been used for this project. First, a user survey provided input at the research stage. The “Perceived Atmosphere Questionnaire” developed by (Vogels, 2008) has been used as a basis to understand the affective evaluation of the space by the users. To achieve a more comprehensive picture, the complete survey has been designed to start with an open-ended question providing qualitative data on participants’ general evaluation of the lighting in the space, followed by modified “Perceived Atmosphere Questionnaire” and “Visual Appearance Questionnaire” (with identifying terms that fit the evaluation of an office space). From the 38 atmosphere terms (Vogels, 2008) mentioned, 12 were used for this study: cosy, motivating, personal, intimate, formal, stimulating, relaxed, lively, detached, boring, clinical, tense. The visual appearance terms have been selected among the ones previously used in Double Dynamic Lighting Research (Hansen et al., 2021) The following 9 terms have been used to understand visual appearance of lighting: comfortable, sufficient, task-focused, natural, contrasting, dim, bright, glary, disturbing. the participants rated each adjective’s applicability on a 7-point Likert scale: 1- Not applicable at all; 7- Very applicable. Due to Covid-19 restrictions, it was difficult to reach all the employees, hence 6 out of 25 employees of Freja Ejendomme completed the survey. The qualitative side of the user research has been supported by two semi-structured interviews, one with a user of the space (in person interview), the other with Business Area Manager of the company

(Klövern Danmark) that is responsible of the administration of Codanhus building (phone interview). Second, I have documented my own observations of atmosphere, visual appearance of light and architectural elements in the space. Third, I have investigated the results of Double Dynamic Lighting Research (Hansen et al., 2020, 2021; Hansen & Mathiasen, 2020) and transferred those that fit the current project. Fourth, DIALux Simulations have been conducted both to understand the amount of daylight intake and the movement of daylight throughout various seasons and to test my own design ideas in connection to lighting standards. Finally, the three elements of lighting (Kelly, 1952)- Focal glow, Ambient luminescence, and Play of brilliants, have been used as a design tool.



Chapter 1 Literature

Concept of Atmosphere

Atmosphere of a space, by nature, is generated and reproduced on a constant basis, by a combination of factors, such as the weather, sounds, the time of the day, people, architectural forms, incidents, representations, sensations and interactions, and light and dark (Edensor, 2015) Furthermore, Pallasmaa (2014) argues that in order to create atmospheres we need aspects of embodied, haptic and enveloping nature, such as materials, colour, rhythm and illumination. All contributing to the peripheral perception of the atmosphere, rather than a focus on details. He explains how light and its interaction with architecture prevails among all these factors in an interview as such:

> "Light is the most subtle of the means of architecture; it can express joy and happiness, as well as melancholy and sorrow. We do not "see" light directly, and architecture must somehow "materialize" light by means of reflecting surfaces, in order to bring light to our attention. James Turrell speaks of "tactile light" and "the thingness of light"."
>
> (Pallasmaa, 2018, as cited in Amundsen, 2018)

Böhme (2013) investigates the idea of making atmospheres with objective reality and states that an atmosphere communicates a feeling to the subjects (us/participants/users) through its character. He explains further by saying that a formal atmosphere makes one's mood serious and a cold atmosphere causes shivering. He stresses the fact that atmospheres are involved whenever we talk about "design". More precisely, whenever there is an intention to stage and manipulate certain feelings. Light is emphasized as closely connected to atmosphere having the characteristic of an "in-between existence", of a "fluid" between components of the space.

As all of these academics/professionals working with atmospheric design point out, atmosphere being understood more at an intuitive level (a polyphonic grasp of ambiance) rather than an intellectual level, makes it really difficult to work with it at a practical level design projects.

My research on atmospheric qualities of light started in Fall 2020, during my internship that I have worked with light installations and atmospheric qualities of a space created by them. I have used the construct of "Perceived Atmosphere" in an effort to overcome aforementioned challenge and merge quantitative and qualitative accounts of atmosphere. In the scope of thesis, I am following on the footsteps of Richard Kelly, a pioneer of architectural lighting design who solidifies the connection between atmosphere and lighting with his works and words:

> "Successful lighting makes moods. A burst of warm light above and about you spreads a feeling of welcome. Soft diffuse light extending over large areas

is soothing. Warm areas of light blending into one another are comforting. Concentration of the most strongly lighted areas near the floor is cosy; while concentration near the ceiling is formal. Lighted areas at eye level give a sense of security, defining the room and its contents. In other words, good lighting adds to good living"

(Kelly, 1949, as cited in (Nuemann et al., 2010)

Perceived Atmosphere

In the assessment of how we perceive the atmosphere, it is crucial to point out that the evaluations of certain design, colours, and illuminations, by people coming from different cultural backgrounds, would vary (Edensor, 2015). In turn, as Böhme (2013) points out: "Independently of the culture-relative character of atmospheres, their quasi-objective status is preserved. It manifests itself in the fact that atmospheres can be experienced as surprising, and, on occasions, in contrast to one's own mood. An example is when, in a cheerful mood, I enter a community in mourning: its atmosphere can transform my mood to the point of tears."

On the other hand, how people are affected by the atmosphere of the space depends not only on environment but also on their cognition and prior experiences. On any given day, mental state and thoughts of the individual can alter how s/he experiences the environment (Vogels, 2008) as cited in Sigura, 2020). Hence, there is a dynamic bidirectional relation between atmosphere (collective) and mood (individualistic).

If we wish to understand the atmosphere of a space from as objective as possible perspective, we should approach questionnaires measuring the affect, such as Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988), as cited in Sigura, 2020) with caution as those can lead to biased and controversial results, a subjective evaluation. As a more stable concept, (Vogels, 2008 as cited in Sigura, 2020) proposes the use of the measure "perceived atmosphere" as it implies "an affective evaluation of the environment". A modified version of the measurement tool proposed by her, has been used in the scope of this research in an effort to quantify "perceived atmosphere" which has mostly been studied as an intuitive and abstract notion, especially in the context of phenomenology. Pallasmaa (2014) points out that we use language to communicate about atmosphere. I believe that this argument justifies further the use of self-report questionnaire through adjectives as descriptors of atmosphere.

As stated earlier in the method section, in order to achieve a more comprehensive picture of the perceived atmosphere and related factors, the complete survey has been designed to start with an open-ended question providing qualitative data on participants general evaluation of the lighting in the space, followed by modified "Perceived Atmosphere Questionnaire" and "Visual Appearance Questionnaire".

The model below that I formulated, aims to illustrate these intricate connections between concepts revolving around atmosphere studies. Atmosphere of the space and cognition have both an impact on our mood (subjective), the combination of these two create the "actual effect of atmosphere". On the other hand, when we are using our cognitive abilities to conduct an affective evaluation of the atmosphere, we reach the notion of "perceived atmosphere" which is the "expected effect of atmosphere". Expected effect of atmosphere is a more objective notion compared to the actual effect of atmosphere. Yet, it is impossible to claim full objectivity upon human judgement. Hence, following on the path of aforementioned researchers, I have classified, perceived atmosphere and cognition as "quasi-objective". Lastly, culture and prior experience are classified as subjective inputs that have impact on our cognition.

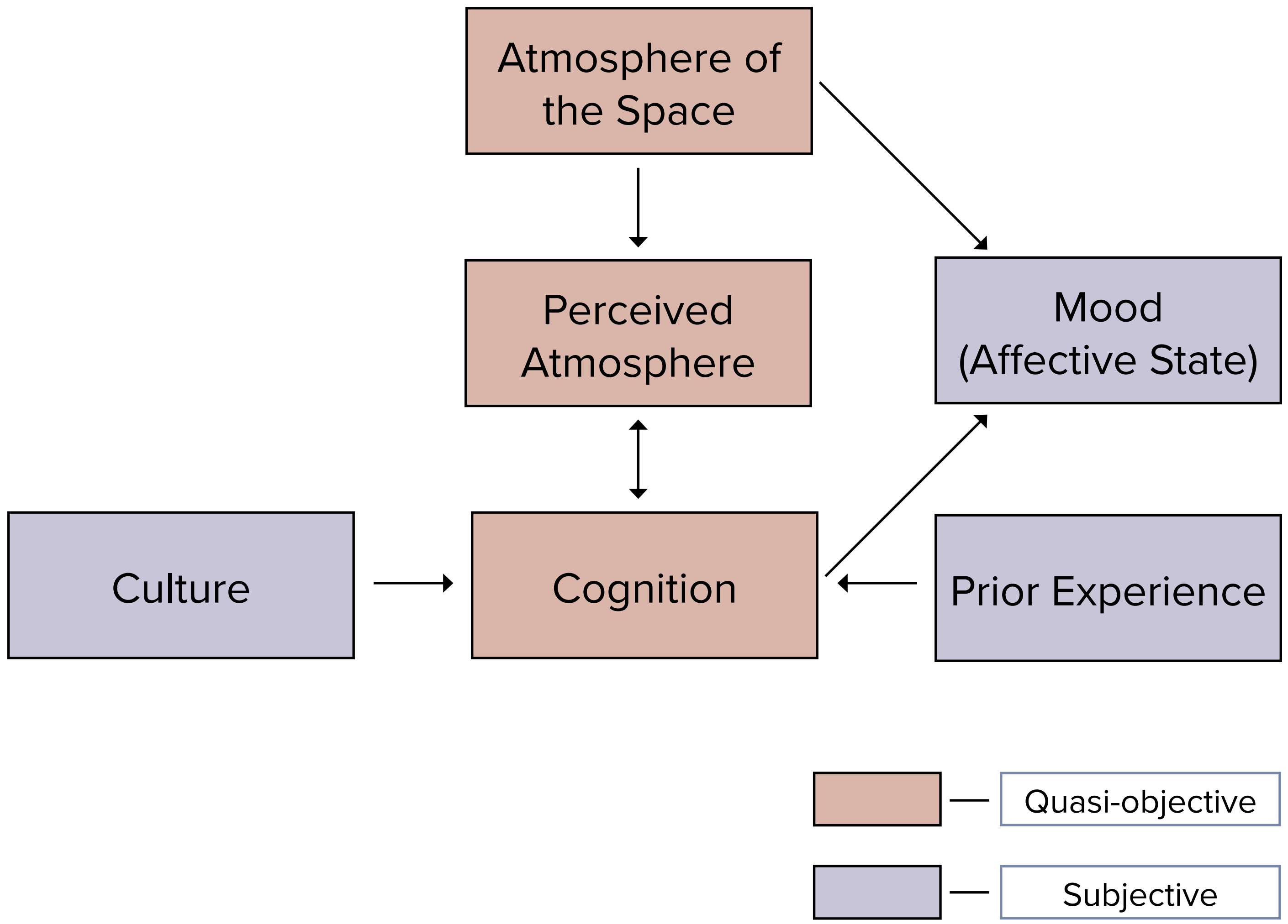


Fig. 1. Illustration of the model for understanding dynamics of atmosphere.

Visual Appearance

In the context of Double Dynamic Lighting research, visual appearance encompasses lighting concepts such as flow of light, illumination hierarchy, light zones, and light modelling of objects (Hansen et al., 2020)

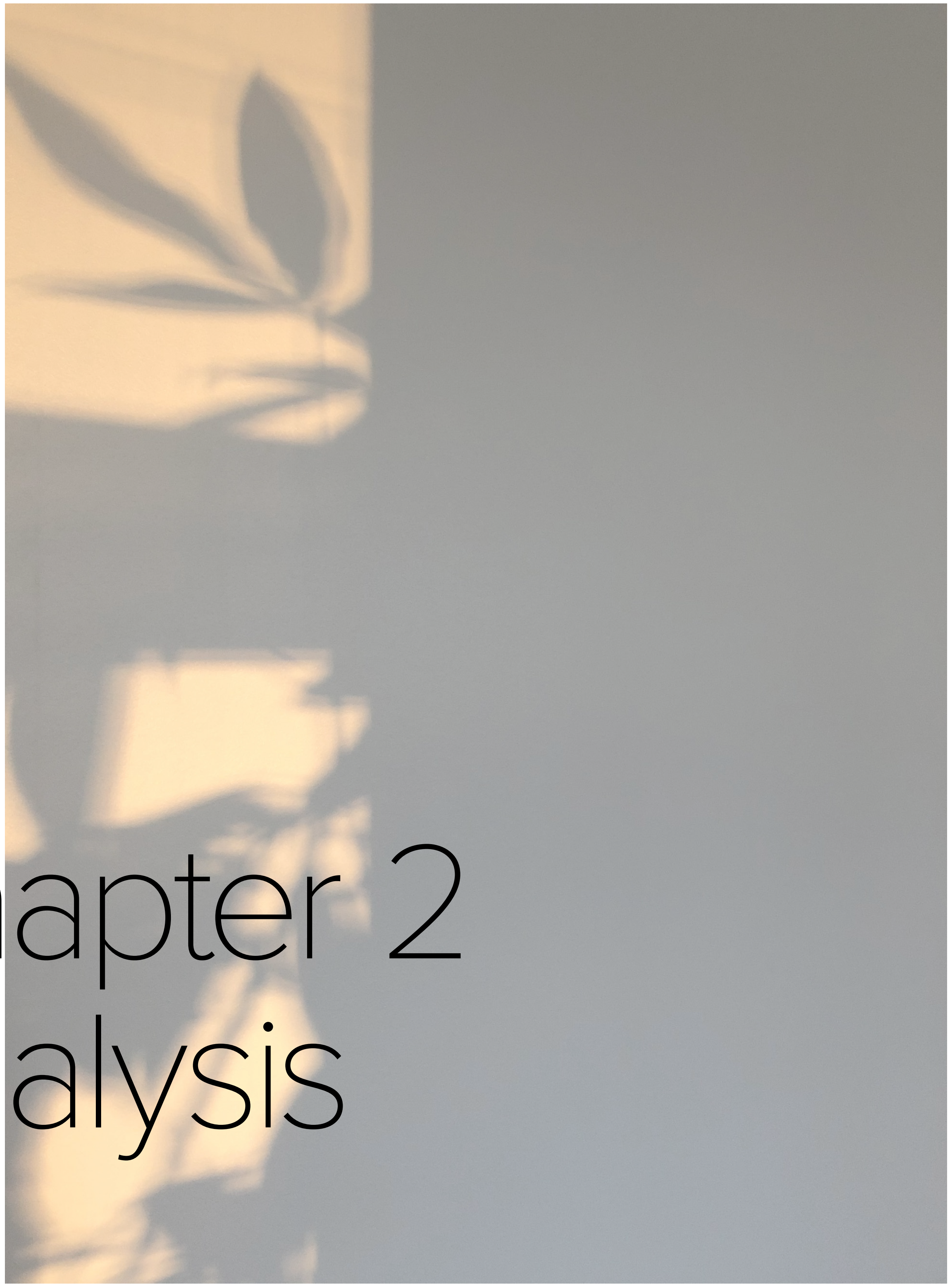
In a practical sense, it emphasizes the role of light for the perception of object characteristics such as lightness, colourfulness, texture, and gloss while it connects to shadow pattern- brightness and chromaticity values determine appearance of objects rather than object's own qualities. For the overall perception of a space, it corresponds to lighting variables such as, general amount of light (Bright/Dim), distribution, direction, intensity of light (glare/sparkle), contrast (High/low) and perception of illumination colour (colour appearance) and coloured materials (colour rendering) (Cuttle, 2015) Getting into the mind of users in terms of how they evaluate the visual appearance of the space with the current lighting reveals the points that need improvement and guides the design process.

Nordic Light & Sky Types

From the 15 CIE General Sky types, CIE3 (Overcast, moderately graded with azimuthal uniformity) and CIE13 (CIE Standard Clear Sky, polluted atmosphere) sky types (Tregenza & Wilson, 2011) have been chosen for the purpose of this project, as these were also formerly used for experiments investigating double dynamic lighting (Hansen et al., 2020; Hansen & Mathiasen, 2020)

There are two important qualities of CIE standard skies. First, only the relative luminance distribution is provided. Second, they represent homogeneous skies. CIE Standard Overcast sky is characterized by a steady luminance, grey colour and overcast condition (many cloud layers, no visibility of the sun) possibly with rain. The CIE Standard Clear Sky is described as a blue and cloudless sky condition (Tregenza & Wilson, 2011)

The quality of the daylight of a particular geography has a great impact on sensory and affective experience of the space (Edensor, 2015) Hence, it is noteworthy to take into account the characteristics of Scandinavian light while designing the complementary electric lighting. The sun in Denmark has a low altitude and the Nordic light is cool and weak in intensity (Mathiasen, 2010 in Dahl, 2010). These characteristics of the Nordic light necessitate a lighting design that both creates a continuity between the exterior and interior by matching the skylight but also balances out the coolness with addition of warmer shades.



Chapter 2 Analysis

Presentation of the Space

The space is the biggest meeting room of the office of Freja Ejendomme- A real estate company owned by the Danish State. The office is located on the 15th floor of a 19-storey building called Codanhus - the tallest commercial office building in Frederiksberg. Codanhus was built in 1961 and it is located on the corner between Gammel Kongevej and Vodroffsvej in Frederiksberg (*Codanhus (Frederiksberg) - Wikipedia, the Free Encyclopedia, n.d.*)

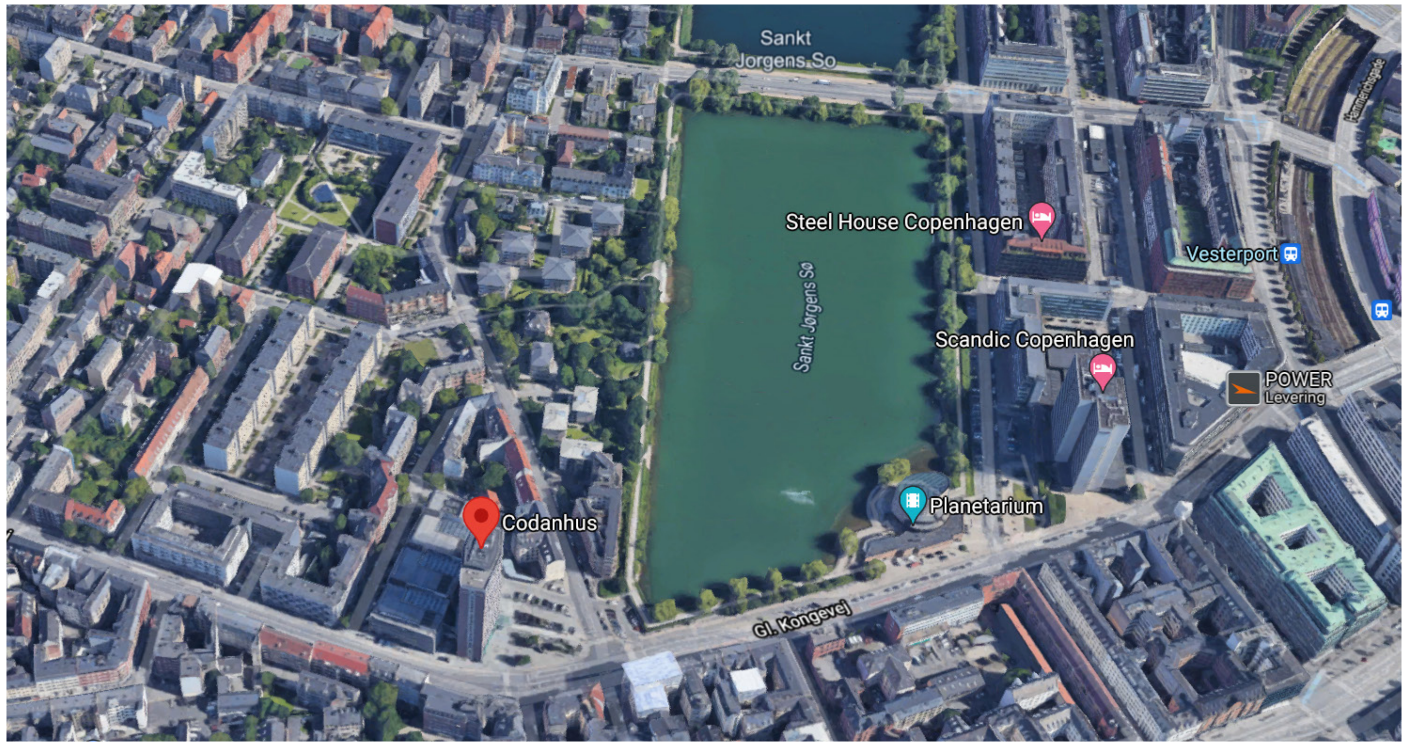


Fig. 2. Location of Codanhus Building

Fig. 3. Photographs of Codanhus Building

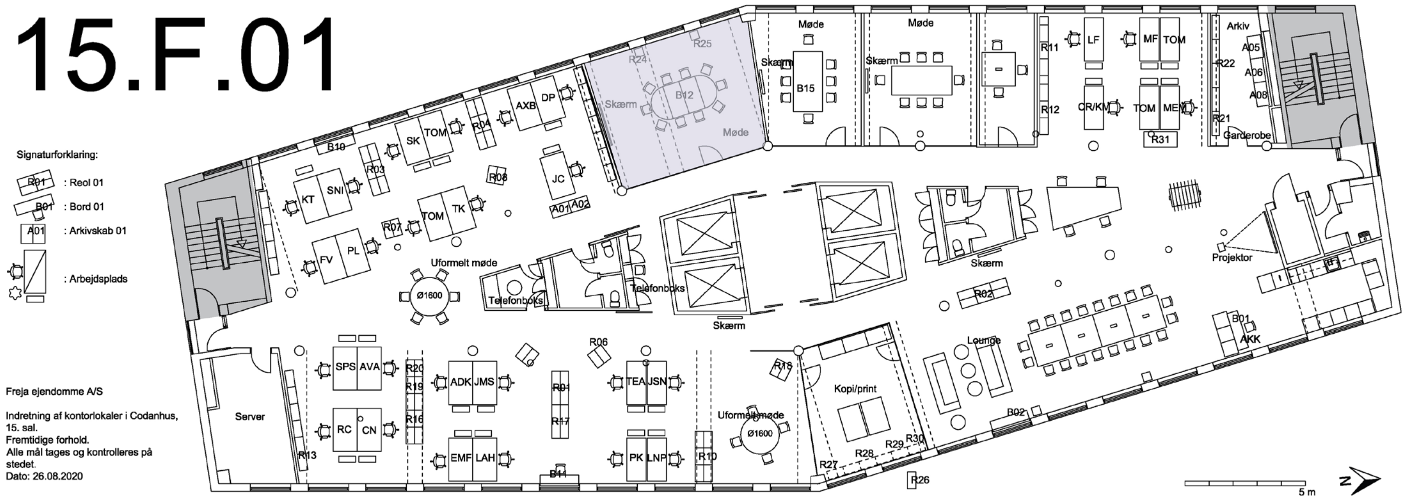


Fig. 4. Original floor plan of Freja Ejendomme Office- Meeting Room 1 (Highlighted)

The building has been designed in a way that all the spaces have equal total access to sunlight (when present), with its east (sunlight in the first half of the day) and west (sunlight in the second half of the day) facades. The meeting room subject to this thesis gets daylight through three windows on the façade facing west and it is separated by a glass wall (with a dark grey curtain) from the corridors of the office space. There are venetian blinds on the windows, but the users mentioned that they don't use the blinds as the meeting room faces west, hence doesn't receive direct sunlight to the level that would require blocking of light. There is a fascinating city view from the windows. The room is lit by six recessed luminaires on ceiling panels. The fluorescent light sources have a colour temperature of 2700 K (warm white), a Colour Rendering Index of 82, 1800 lumen output and are dimmable (*MASTER PL-T 26W/827/4P 1CT/5X10CC MASTER PL-T 4P - Philips, n.d.*) The electric light is triggered/dimmed automatically by a light sensor for evaluating daylight intake and presence/absence of users. The users don't have access to manual control of lighting.

Fig. 5. City view from Freja Ejendomme- Meeting Room 1 -04.05.2021

Fig. 6.1 Current lighting Freja Ejendomme- Meeting Room 1 -04.05.2021

Fig. 6.2 Current lighting Freja Ejendomme- Meeting Room 1 -04.05.2021

Fig. 6.3 Current lighting Freja Ejendomme- Meeting Room 1 -04.05.2021

An analysis of the space in terms of architectural and light characteristics has been conducted on May 4, 2021, between 10.00-16.00.

Dimensions of the Space

The measurements have been made during the visit to the space and as the actual size of the table and placement of the door were different from the original floor plan, alterations have been made to match the actual setting. The green wall which was not in the original plan has also been added to this version of the floor plan.

Light Measurements

In order to analyse the lighting situation of the space, two consecutive measurements have been conducted: first, only daylight; second, only current electric lighting. Unless stated otherwise, all the measurements have been made on the indicated surface horizontally. For all the lux measurements, Testo 540 luxmeter has been used.

The measurements revealed that daylight alone does not provide enough light in the room, especially on the task area (horizontally) and for lighting of faces (vertically) of users sitting on the side of the table their back and side facing windows. The light levels provided with electric lighting alone is mostly inadequate both for task lighting (horizontally) and lighting of faces (vertically). The light distribution is uneven as well. In Copenhagen, these are especially problematic for winter months that it gets dark around 15.30, which is a time slot in working hours.

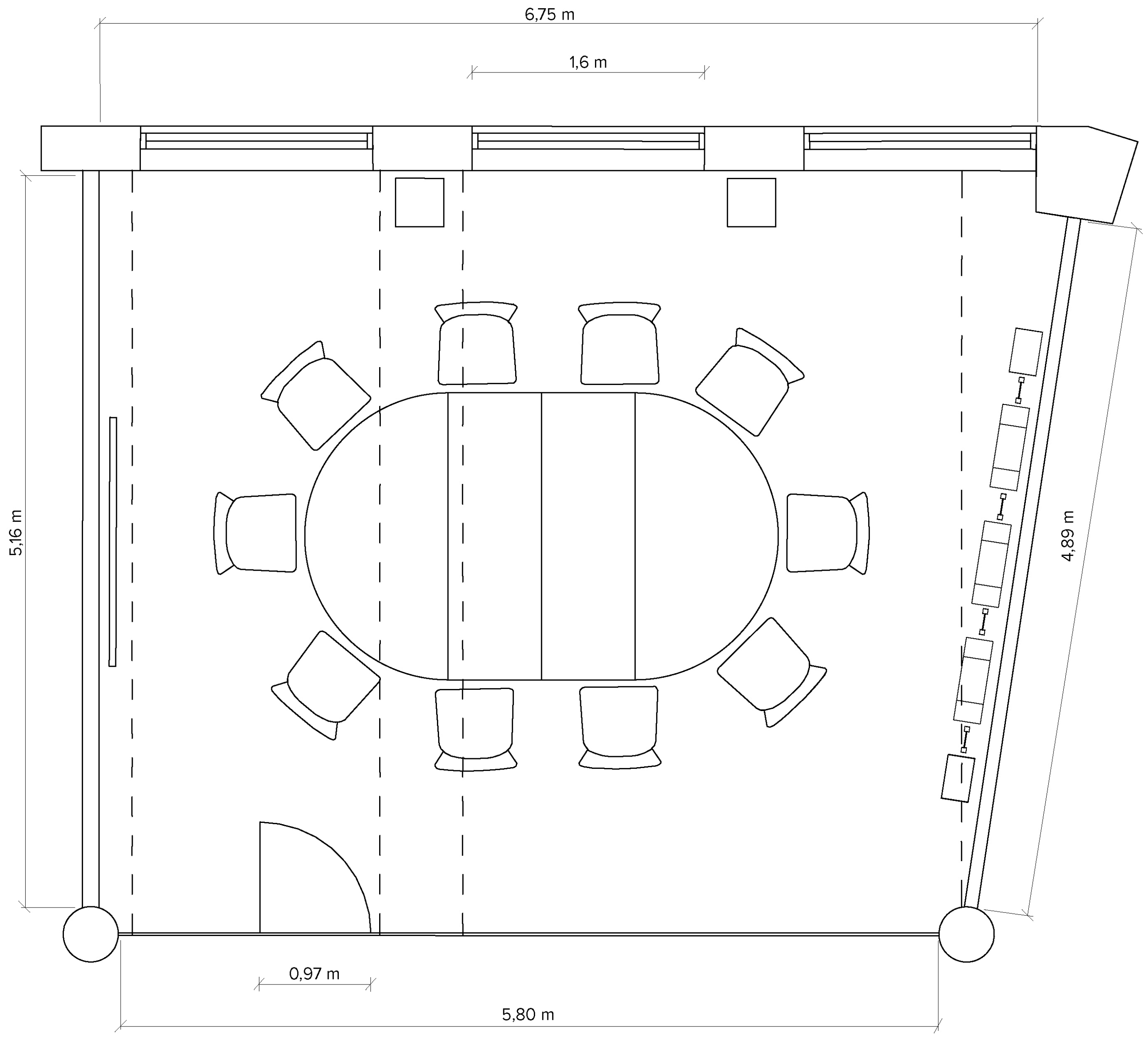


Fig. 7. Modified floor plan of Meeting Room 1 with dimensions

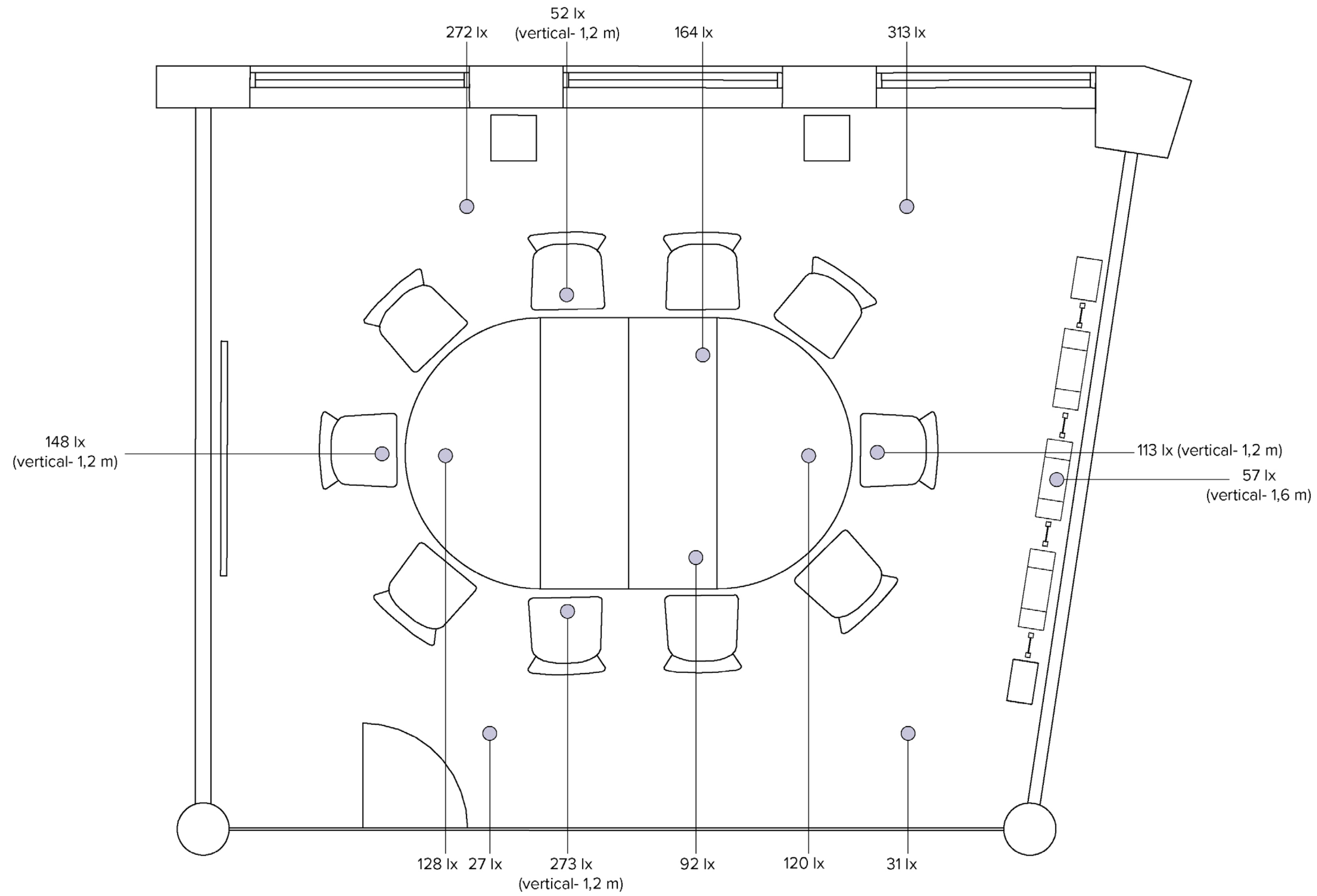


Fig. 8. Only Daylight- Lux Measurements of Meeting Room 1 -14:25-04.05.2021

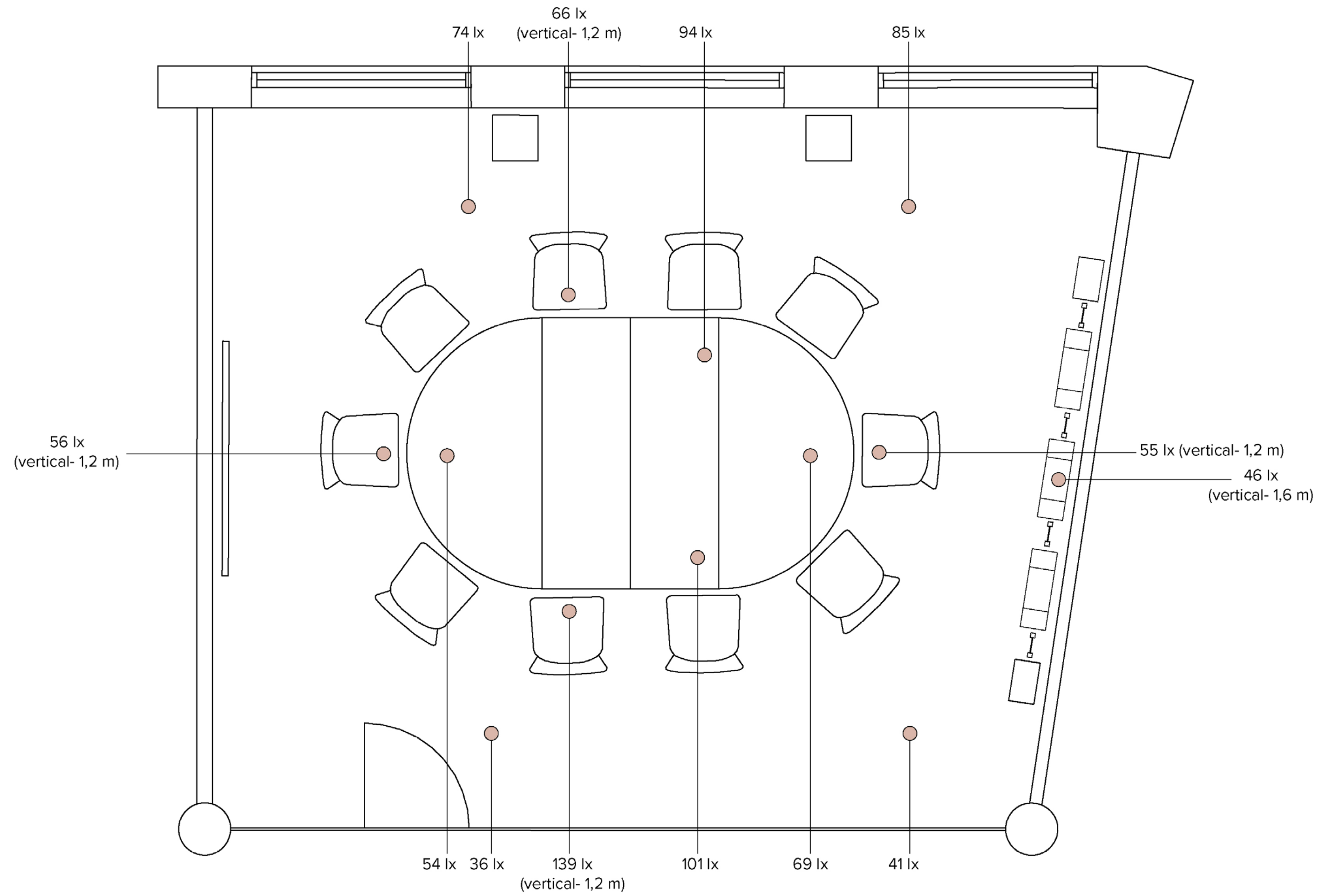


Fig. 9. Only Electric Light- Lux Measurements of Meeting Room 1 - 15:25-04.05.2021

Materials

Light is only visible through its interaction with the materials in the space, therefore it is crucial to understand how much light materials reflect/absorb in order to comprehend the needs for lighting.

For diffuse materials, reflectance (ρ) was estimated using a Testo 540 Luxmeter. Illuminance has been measured 15 cm distance from the material's surface, first toward the surface (reflected light) and after away from it (surface incoming light) as done in previous DDL studies (Hansen et al., 2020) For non-diffuse materials, such as glossy and specular, this method cannot be used and due to the lack of access to measuring device such as a gloss meter, a visual method has been used to classify the reflectance type of these materials. From different angles, photos of the materials have been made and the presence of a directional distribution of light has been assessed.

The reflectance of ceiling paint (0,90), most of the wall areas (0,80 and 0,69 for the beige and white walls respectively) are high values that increase the light levels in the space by reflecting most of the incoming light. On the other hand, the reflectance of dark grey painted wall (0,32) and mixed grey carpet (0,08) are low values that decrease the light levels by absorbing most of the incoming light. The glossy beige laminate table, glossy white windowsill paint and specular light grey ceiling panels are also high in reflectance whereas, the glossy dark grey fabric of the curtains has a low reflectance. The dark red/brown colour of chairs and medium brown colour of wood plant pots contribute to creating warmer reflections of light in an area mostly designed with muted/cold colours.

Windows

The façade works as a light filter, which controls incident light and determines the outward view by means of the apertures. Façade's aperture contributes to the creation of variations in light and shadow, so that the eye perceives details and colours, making it possible to recognize form and objects (Mathiasen,2010 in Dahl, 2010). Therefore, it is crucial to analyse the windows and daylight intake through them.

In order to understand the properties of daylight input into the room, transmission of the window glass has been investigated. To understand the transmission and coating of the glass, illuminance, the spectral power distribution, and CRI of the daylight has been measured first pointing spectrometer directly to daylight with windows open, second touching the spectrometer to the glass with windows closed. The spectral distribution and CRI of these two measurements have been compared to investigate which wavelengths of light pass and which are blocked through the glass. The measurements have been conducted with the spectrometer: AsenseTek Lighting Passport (ALP-01).

My interview with the building administration had provided me information that there have been some concerns about too much heat in the building and they have tried to reduce it with windows film. The windows are double-glazed, and a neutral colour of glass has been used. Per characteristic of glass, a slight greenish tint is visible when looked from certain angles, especially towards the edges. Comparing the lux values (windows open vs windows closed), the transmission of the visible

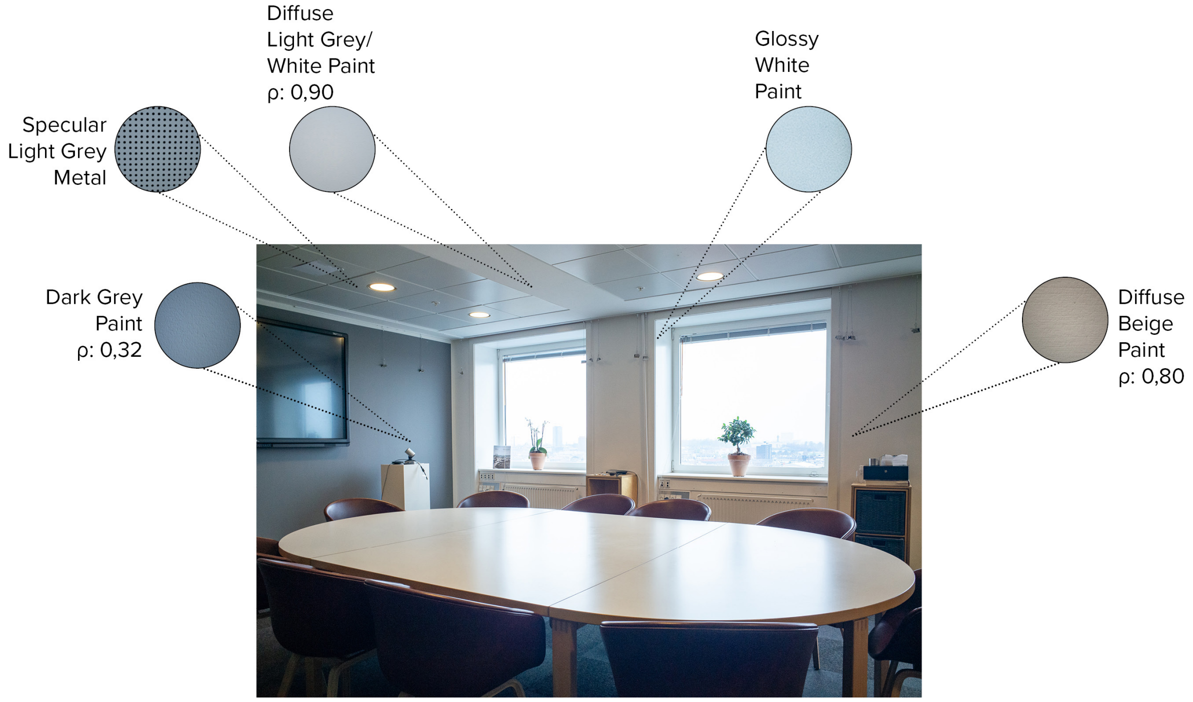


Fig. 10.1. Reflectance of Various Materials

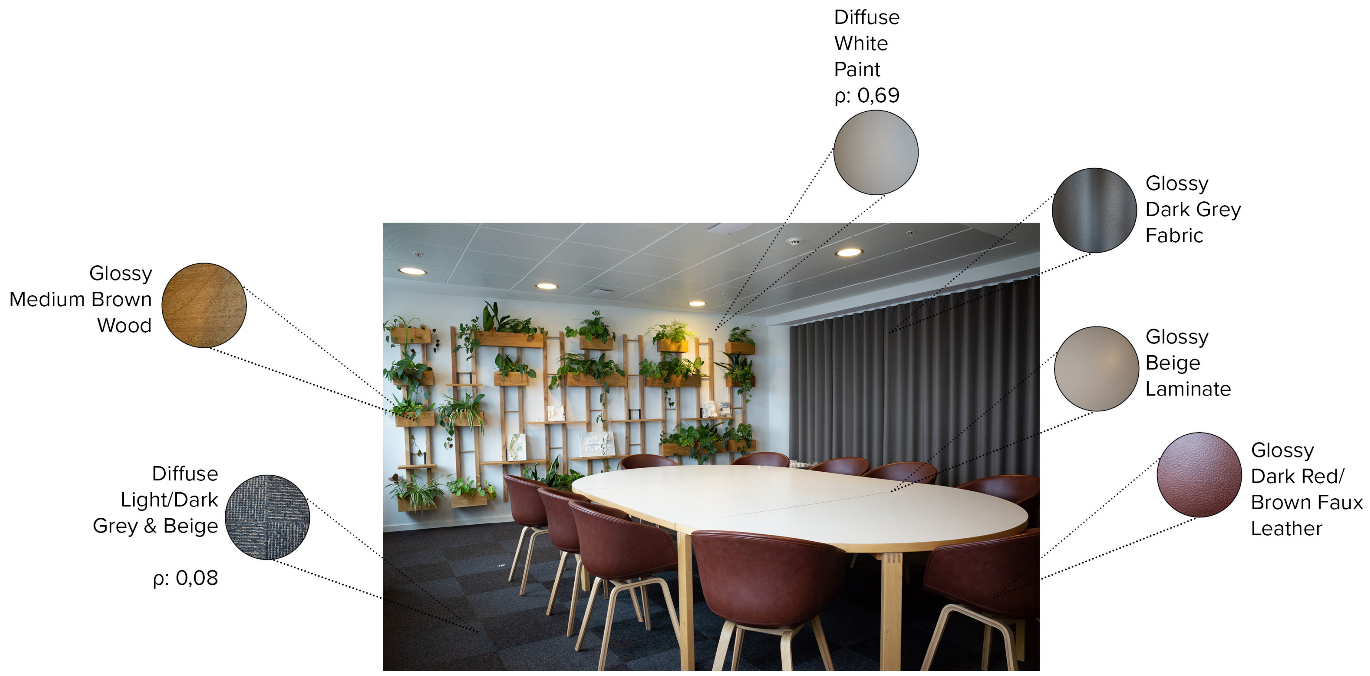


Fig. 10.2. Reflectance of Various Materials

light has been calculated as the following ratio: 4314/1968 = 0,46. The comparison of Spectral Power Distributions (windows open vs windows closed) shows that the glass absorbs light at some of the shorter (violet-blue) and some of the longer (yellow-red) wavelengths and lets the mid length (blue-green) wavelengths pass.

Fig. 11. Windows at the Meeting Room 1

Blue Line- Direct Daylight (Windows Open)

Orange Line- Daylight through Glass (Windows Closed)

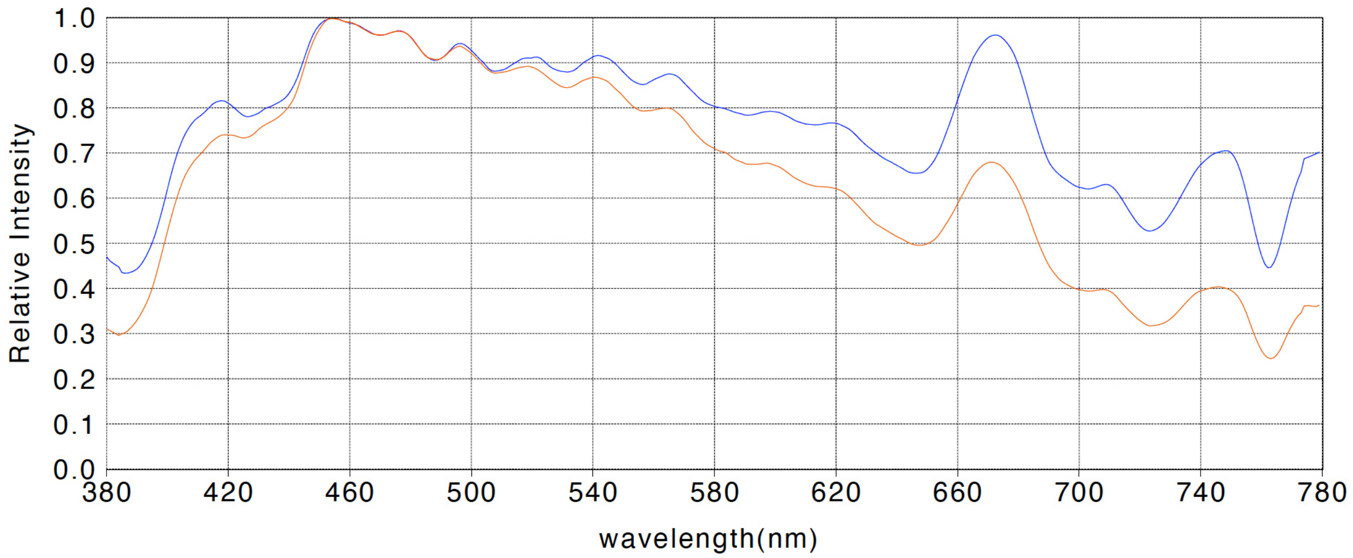


Fig. 12. Comparison of SPD for Direct Daylight and Daylight through Glass

	CRI (Ra)	CRI (Re)	CCT	Illuminance
Direct Daylight (Windows Open)	100	99	6288 K	4314 lx
Daylight through Glass (Windows Closed)	95	93	7242 K	1968 lx

Table. 1. Comparison of Daylight Qualities- Direct and through Glass

In terms of overall CCT, daylight through glass is colder with 7242 K, compared to 6288 K for direct daylight, which is also evident seeing higher wavelength of yellow and red being filtered out. In terms of CRI, we notice a decrease when we compare direct daylight (CRI:100) with daylight through the glass (CRI:95). According to Extended CRI, the biggest difference is for the rendering of R9 (Strong Red) out of 15 test colour samples defined: with a CRI of 98 for direct daylight and a CRI of 75 for daylight through the glass. For all the other colours, CRI of daylight through glass is over 90.

Sun Path Diagrams

The 3D sun path diagrams have been made for the following three dates: ***December 21, 2021- Winter Solstice***, the shortest day with sunrise at 08:37, sunset at 15:38 (Total daylight hours: 07:01); ***March 20, 2021- Vernal Equinox***, day and night are of equal length with sunrise at 06:12, sunset at 18:23 (Total daylight hours: 12:11); ***May 4, 2021***- The day that I have physically been to the space to do the light measurements and observations with sunrise at 04:20, sunset at 19:53 (Total daylight hours: 15:33)

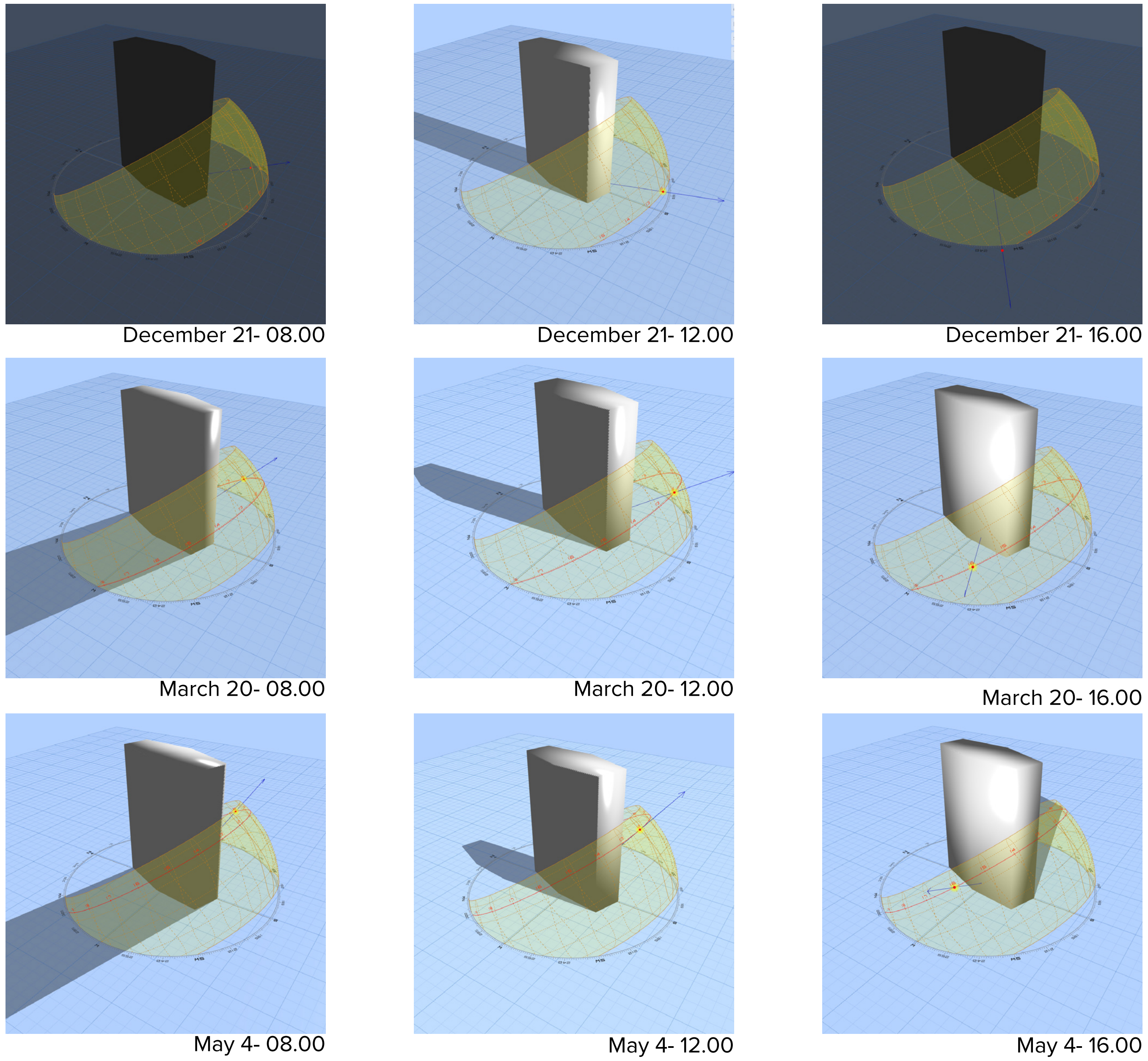
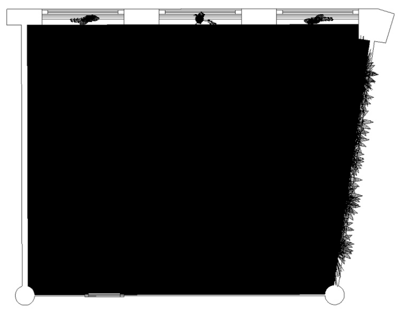


Fig. 13. 3D Sunpath Diagrams for Codanhus building west facade

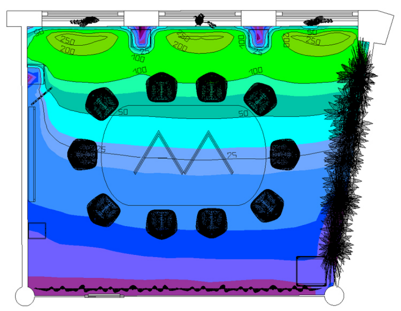
These diagrams illustrate the earlier mentioned point that the Meeting Room 1 with a west façade only gets sunlight (when present) in the afternoon hours. It also demonstrates the stark differences in sun elevation and total daylight hours throughout the seasons as a characteristic of Scandinavia.

Daylight Calculations

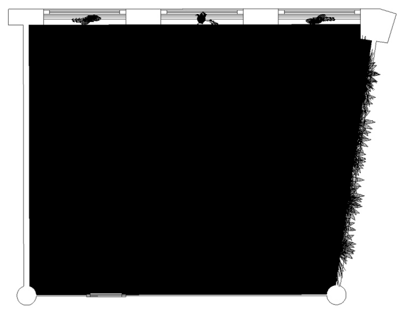
Each window has a glass area of 143 cm by 136 cm and total glass area of all three windows equals to 18% of the floor area. However, as stated in BR18, there is a need to adjust the glass area for any reduced light transmittance (Agency, 2018) As mentioned earlier the visible light transmittance has been calculated as 0,46, which leads to a readjusted glass area/floor area ratio of 8,3%, which is less than minimum 10% required to document sufficient access to daylight by BR18 (Agency, 2018). The daylight factor has also been calculated through DIALux Software and has been found to be 0,767 %. Tregenza & Wilson (2011) argue that when average daylight factor from side windows in an office setting is around 1%, the room has a gloomy appearance and there is a harsh contrast with the view outside. In turn, complementary electric lighting during daylight hours can help to balance daylight variations. Furthermore, as the space is facing west, even when it gets sunlight in the afternoon, the light modelling values are not sufficient.



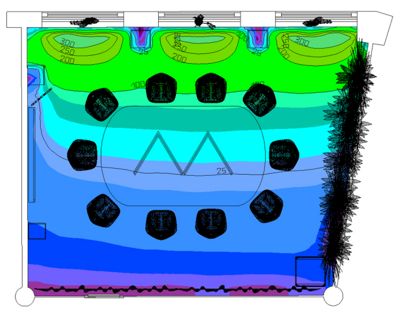
December 21- Morning (Overcast Sky)
Unmet light requirements:
No daylight



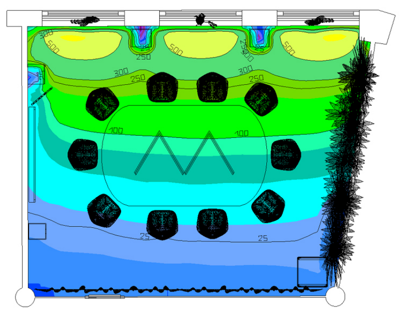
December 21- Afternoon(Overcast Sky)
Unmet light requirements:
No requirement is met.



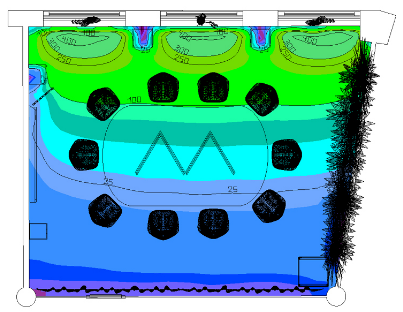
December 21- Afternoon(Overcast Sky)
Unmet light requirements:
No daylight



March 20- Morning (Overcast Sky)
Unmet light requirements:
No requirement is met

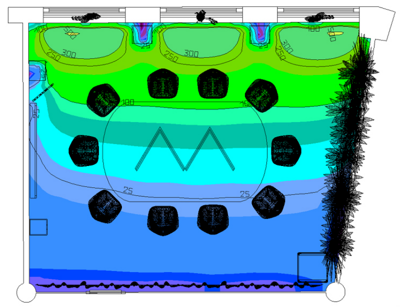


March 20- Noon (Overcast Sky)
Unmet light requirements:
Gray wall, area of activity: standing presenter, windows wall, visual task area and immediate surroundings

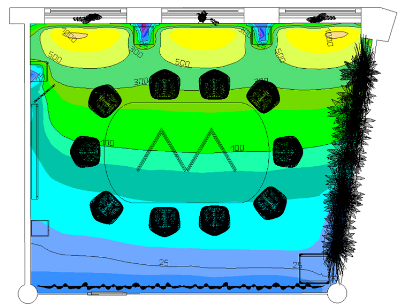


March 20- Afternoon (Overcast Sky)
Unmet light requirements:
All room main surfaces except green wall, area of activity: standing presenter, visual task area and immediate surroundings

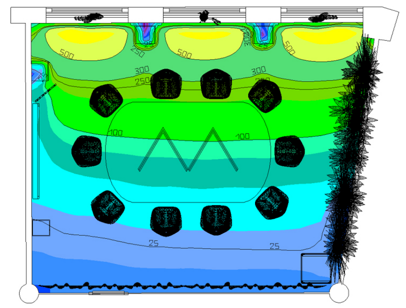
Fig. 14.1 Illumination simulations for daylight intake for the Meeting Room 1 at 0,8 m height



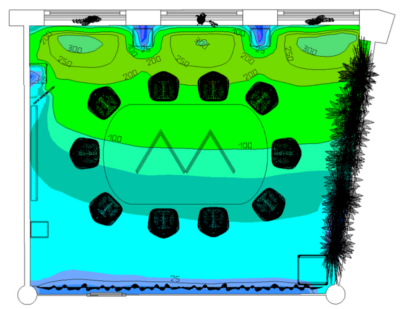
May 4- Morning (Overcast Sky)
Unmet light requirements:
Grey wall, area of activity: standing presenter, windows wall, ceiling, visual task area and immediate surroundings



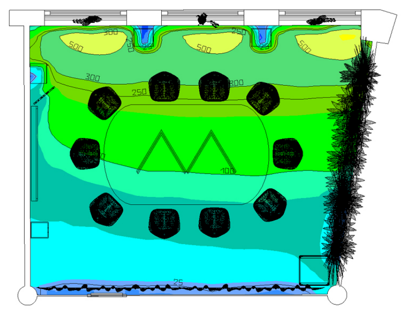
May 4- Noon (Overcast Sky)
Unmet light requirements:
Grey wall, area of activity: standing presenter, windows wall, visual task area and immediate surroundings



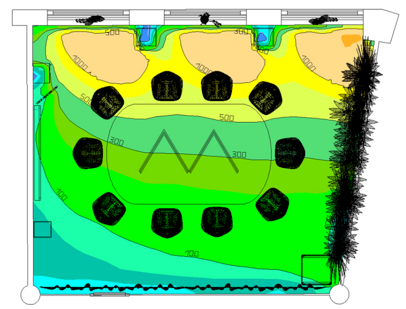
May 4- Afternoon (Overcast Sky)
Unmet light requirements:
Grey wall, area of activity: standing presenter, windows wall, visual task area and immediate surroundings



May 4- Morning (Clear Sky)
Unmet light requirements:
Grey wall, area of activity: standing presenter, windows wall, ceiling, visual task area and immediate surroundings



May 4- Noon (Clear Sky)
Unmet light requirements:
Grey wall, area of activity: standing presenter, windows wall, visual task area and immediate surroundings



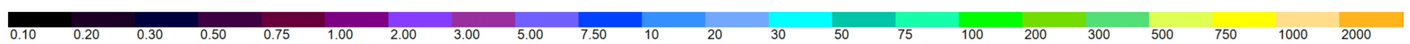
May 4- Afternoon (Clear Sky)
Unmet light requirements:
Grey wall, area of activity: standing presenter, visual task area and immediate surroundings

Fig. 14.2 Illumination simulations for daylight intake for the Meeting Room 1 at 0,8 m height

Daylight simulations run in DIALux Software for the following dates and times through seasons have demonstrated that there is a need for electric light in all cases.

An overview of where the light requirements are not met with daylight alone in different light scenes is above and left. The reasons behind the choices of these dates are the same as explained in the section above. All the simulations have been run for 2020 (December) and 2021 (March & May). For May 4, both overcast and clear sky situations have been run in simulations but for March 20 and December 21, only the overcast sky scenarios have been run as the probability for overcast sky is 70% and 80% respectively for those dates in Copenhagen (*Average Weather on March 20 in Copenhagen, Denmark - Weather Spark, n.d.*) (*Average Weather on December 21 in Copenhagen, Denmark - Weather Spark, n.d.*)

Scale for False Color Images (lx values)



Daylight Observations

The dynamic nature of the daylight in the space has been observed and documented through time-lapse photography. Even in one hour duration, the daylight intake demonstrates a great variation, which supports the need to adjust the electric lighting to dynamic changes of daylight.

Time-lapse Specifications

Date: 04.05.2021

Time 14:24- 14.27

Duration: ~ 1 hour

Location: Freja Ejendomme- Meeting Room 1

Weather Condition: Mostly cloudy

Intervals for each photo: 30 seconds

Camera setup: Ricoh GR + Tripod

Fig. 15. Selected frames of the time-lapse with time stamps

User Survey Results

The survey results for “Visual Appearance” and “Perceived Atmosphere” are illustrated in the charts below. The number corresponding to each term is the average score it received on a 7-point Likert scale: 1- Not applicable at all; 7- Very applicable.

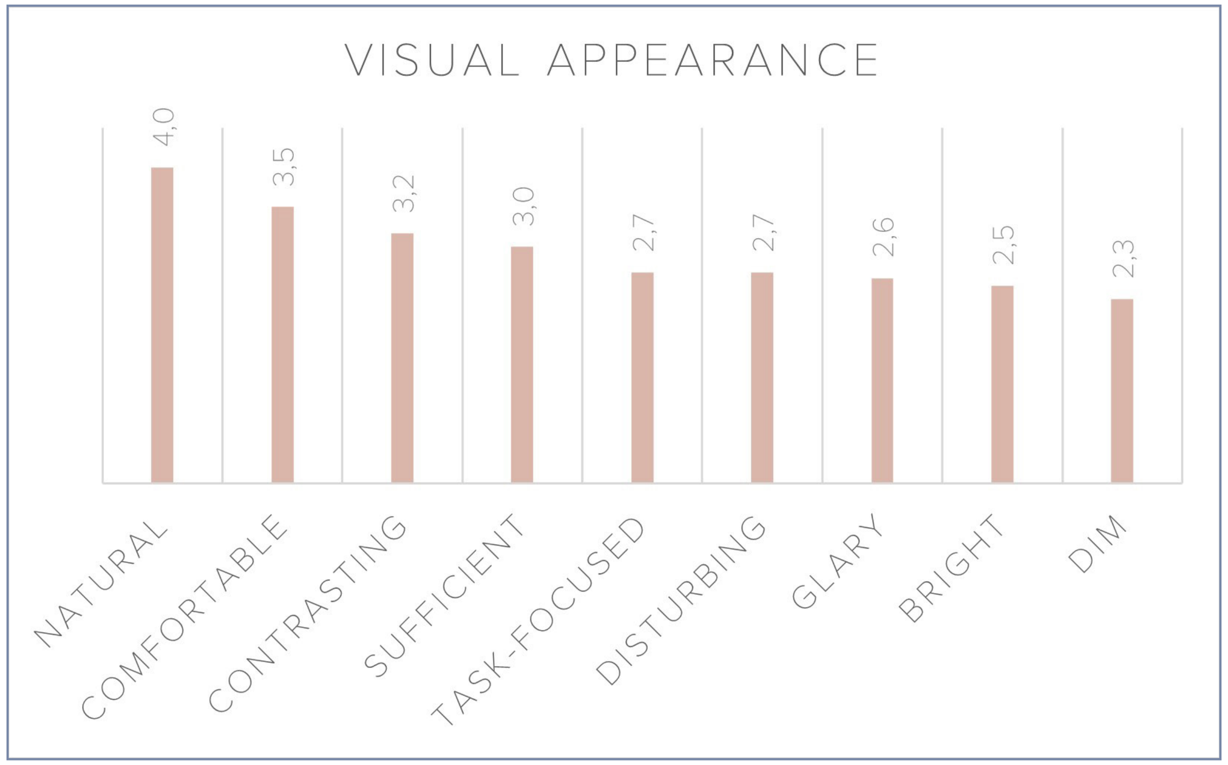


Fig. 16. Average scores for Visual Appearance metric

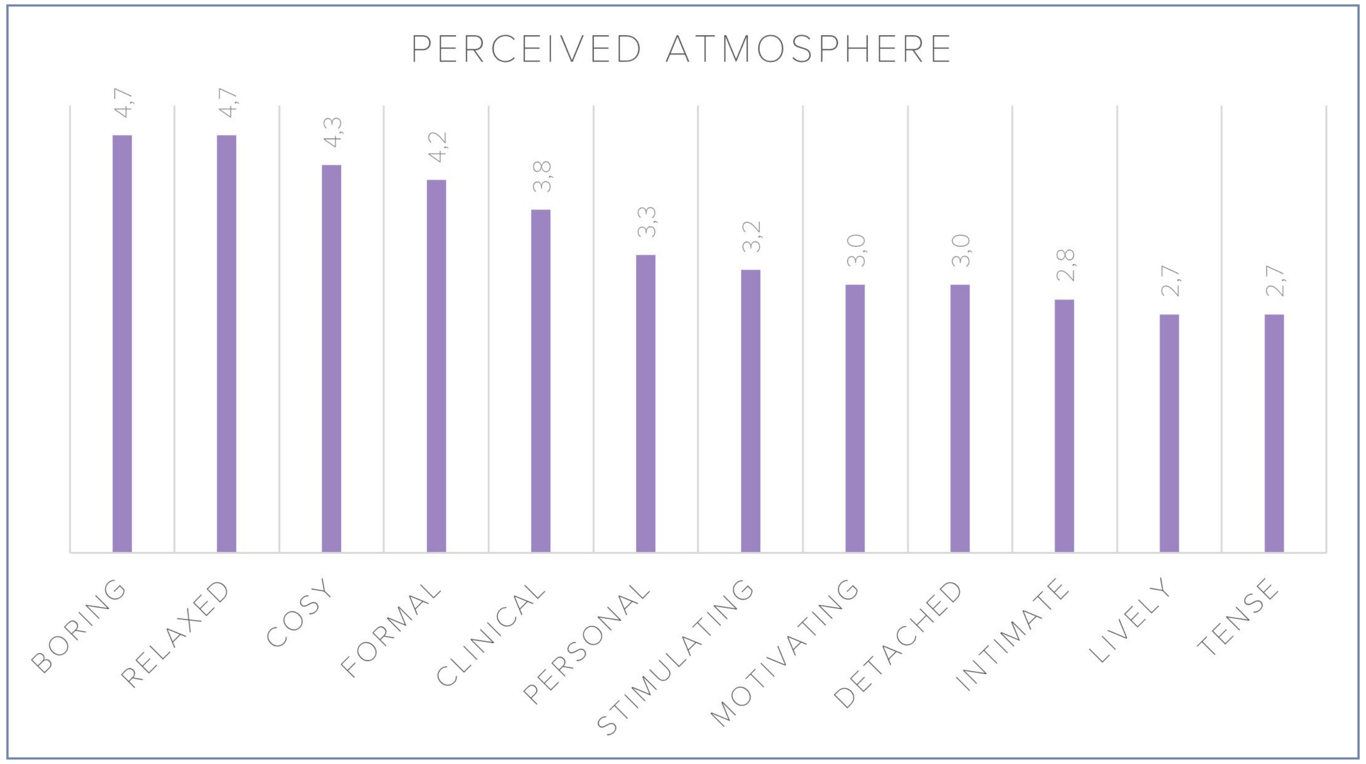


Fig. 17. Average scores for Perceived Atmosphere metric

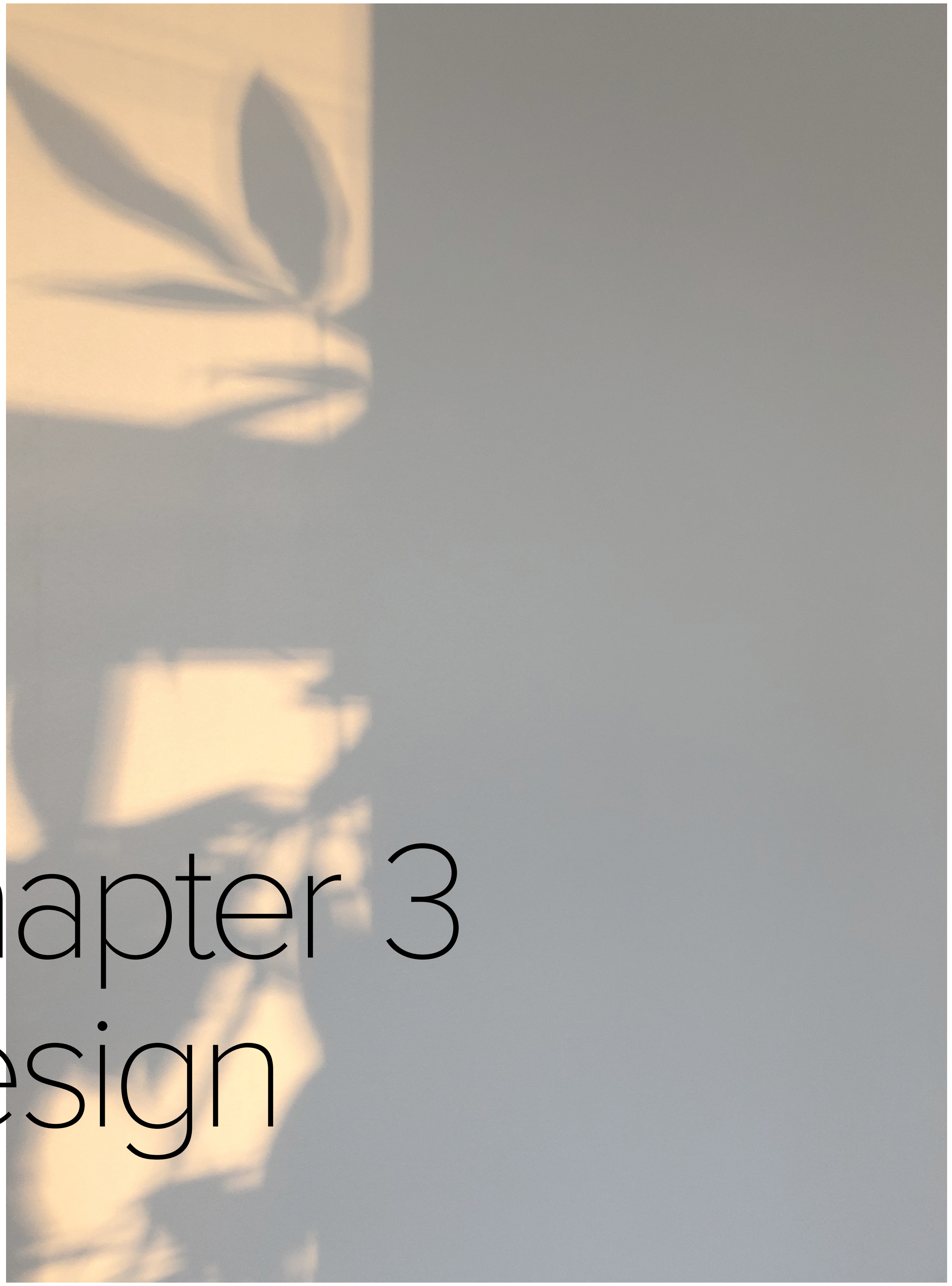
Overall, the space is evaluated as not having sufficient light and lacking a task focused lighting. Users scored the space high on “relaxed” but answers to the open-ended question reveal that it is not actually a positive aspect, as it implies a lack on users’ levels of focus and alertness as expressed by Participant 6 as, “maybe too relaxed”. This argument is supported by the fact that the lighting in the space has been scored high on “boring” and low on “stimulating, lively and motivating”. Accordingly, Participant 5 expressed the overall experience of lighting in the space is as, “Not good for working. Often very dark. A bit cold” and Participant 3 as “A bit dull/sleepy, especially during winter”.

Interviews

As mentioned earlier in the method section, I have conducted two semi-structured interviews, one with a user of the space (in person interview), the other with Business Area Manager of the company (Klövern Danmark) that is responsible of the administration of Codanhus building (phone interview).

The user of the space that I interviewed has been working at Freja Ejendomme for 8 years. He mentions that the current lighting is perceived as “lazy, dull, sleepy” and they would like “more light”. They have experimented by replacing the light bulbs in ceiling panels in three meeting rooms by keeping the lumen output constant but changing the colour temperature to see if this would give the impression of “more light” but the general perception is that it hasn’t been a success. He states the lack of manual control of lighting by users (No on/off switch or dimming possibility) as an issue and says that once they wanted to have a Christmas party in the room, they could not turn off the light. They had to cover all the fixtures to make the room “Hygge”.

Business Area Manager from Klövern Danmark who is responsible from Codanhus Building, shares his experiences with tenants of Codanhus. He thinks that when they refurbish a new building, new tenants are more interested in discussing the interior decoration, rather than the lighting. He states that to adhere to BR18 standards, they install a sensor that tracks both daylight (and dims automatically if needed) and presence (and turns the light on/off automatically). Only in the meeting rooms, there is a switch to turn the light on or off and users mostly use it to turn it off or dim it a little bit, which emphasizes the need for renovation at Freja as their meeting rooms don’t have this control. He also shares his personal opinions on how the lighting should be and argues that it is important that the fixtures look good, and it is not enough that they provide “good lighting”. Lastly, he mentions that there have been some concerns about too much heat in the building and they installed window films to decrease the heat but those didn’t serve the intended purpose.



Chapter 3 Design

Design Vision

Following the literature study on atmosphere, visual appearance, Nordic light, and CIE sky types, I have completed the analysis of the space using input from various sources: user survey results, user interviews, my own observations on atmosphere and architectural characteristics of the space, daylight, and electric light measurements. As a result, I have formulated the design vision with a focus on “Connectiveness” and “Natural Feeling” in terms of atmosphere. My aim is to transform the current lighting in the space (described as unstimulating, boring, demotivating, and dull by users) to a task focused, motivating and lively lighting that complements architectural elements in the space. At the same time, I strive to enhance the function of the meeting room in two layers: First, representing the company identity to the business partners while negotiations are held during meetings. Second, supporting employees’ sense of belonging to the company culture.

Design Criteria

Delving into outcomes of most recent double dynamic lighting research, the following criteria have been adapted for this project: 1. Neutral ambient lighting of less than 5000 K for overcast sky and cooler ambient lighting of more than 5000K for clear sky 2. Combination of direct warm light with diffuse cool or neutral light to achieve a natural feeling (Hansen et al., 2020, 2021; Hansen & Mathiasen, 2020) It has been found that having some direct lighting, compared to all the light provided by diffuse lighting, increases socializing in the space (Hansen et al., 2020), which in turn makes it a viable design solution to meet the functional needs of a meeting room: human interaction. As in nature everything is balanced, a balance between diffuse and direct lighting is desired for the design: too little direct light causes to a loss of details whereas too much causes harsh shadows (Hansen & Mathiasen, 2020)

In order to adhere with standards accepted in Denmark, the lighting in meeting rooms should provide an illuminance maintenance value of 200 lux for visual task area(*Lys og belysning - Belysning ved arbejdspladser - Del 1: Indendørs arbejdspladser = Light and lighting - Lighting of work places -Part 1: Indoor work places., 2015*) , Unified Glare Rating should not exceed 19, uniformity should not fall below 0,60 and the CRI (Ra) should be minimum 80 and the lighting should be adjustable. In addition, illuminance maintenance value should be higher than 50 lux on the walls and 30 lux on the ceiling, both having a uniformity of at least 0,10 (*Lys Og Belysning - Belysning Ved Arbejdspladser - Del 1: Indendørs Arbejdspladser = Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places., 2011*)

Although, the Danish Annex to European Standard EN 12464–1 deems 200 lux acceptable for visual task area in meeting rooms, to provide a better visual environment, the values in EU Standard are taken as design criteria: minimum 500 lx level on the task area and 300 lx in the immediate surroundings (*Lys Og Belysning - Belysning Ved Arbejdspladser - Del 1: Indendørs Arbejdspladser = Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places., 2011*) Standards don’t specify rules on illuminance for peripheral surroundings yet, according to my investigations, it is suggested to have at least a third of the illuminance of immediate surroundings, for peripheral surrounding, which in this case is 100 lux (*Principles for the Working Area - Fagerhult (International), n.d.*) For the purpose of this project, the definitions of all three areas are as follows: task area- 70 cm inward from the edges of the table, all around; the immediate surroundings- 50 cm outward from the edges of the table; peripheral surroundings- starts at a distance of 0.5 meters from the room's walls.

In addition, as the space is a meeting room, there is a need to calculate mean cylindrical illuminance at 1,2 m above floor level- for people seated around the meeting table to enable good visibility of faces. In order to ensure good light modelling, the ratio of the cylindrical illuminance to horizontal illuminance at any point (at 1,2 m is a good height) is advised to be between 0,30 and 0,60 (*Lys Og Belysning - Belysning Ved Arbejdspladser - Del 1: Indendørs Arbejdspladser = Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places., 2011*)

Overview of Design Concept

The overall lighting concept guided by the design vision and criteria stated above addresses the design challenges of the space using Kelly's (1952) three elements of lighting- Focal glow, Ambient luminescence, and Play of brilliants, as a design tool. Kelly (1952) describes Focal glow as highlights from one direction that create hard shadows and grabs attention; Ambient luminescence as diffuse lighting creating graded washes without shadows and a calm feeling; Play of brilliants as sharp details that create excitement and interest. He suggests that a successful combination of these three kinds of light create an aesthetic lighting design and pleasant atmosphere.

The dynamic aspect of the design is achieved through matching the colour temperature of diffuse component of electric lighting to the sky condition. As the sensor technology for programming dynamic lighting reacting to sky condition automatically is not yet commercially available, following procedure is suggested:

One person in the company is in charge of controlling the lighting, there is an application on a tablet located in the meeting room. Programming of the lighting is done via DALI lighting control system. The user encounters the interface below on the tablet, look out from the window to see the sky type and make his/her choice accordingly. Diffuse lighting is programmed to be 5500 K for clear sky and 4000 K for overcast sky condition. Diffuse lighting is programmed to be 3000 K for both scenarios. For no daylight situation, the same scenario as overcast sky automatically applies, without need for choice by users.

The room is divided into 3 light zones: Light zone A- Meeting table, Light zone B- Green wall, Light zone C- Gray wall. A dimmer slider controlling all three light zones and subcomponents (direct and ambient lighting) of light zone B separately in the room is part of the user interface on the tablet to meet the occasional needs for manual user control supporting different functions of the space. For instance, during a presentation using the screen, users can turn off Light zones B and C to decrease general light levels and provide focus on the screen while keeping Light zone A brighter to meet the requirements of reading and writing. For special occasions like Christmas or birthday celebrations, they can dim most of the diffuse lighting in the room, partly dim Light zone A but keep all the direct

Design Challenge	*Design Intention*	*Design Solution*
The lighting in the space is described as not task focused by users.	How to support primary function (task) of the space: holding meetings?	Create ***Focal glow*** via a direct and warm light forming a pool of light around the meeting table.
As the meeting room is located on 15th floor of a high-rise building, it doesn't get any light reflected from the ground to the ceiling inside the space. The light comes from above but floor at the space doesn't reflect it due to dark grey/black carpets that absorb the light.	How to make a feeling of sky light in the space? How to create a lighting that will accentuate/complement the contrast between the grey carpet and white ceiling?	Create ***Ambient luminescence*** by lighting up the ceiling complementing the sky type in terms of CCT.
The wall that the screen is mounted on is painted grey which absorbs the light and as the space is facing west, this wall gets the least daylight.	How to light the grey wall so that the tone of grey is perceived beautifully, instead of trying to go against the grey (dark colour) by trying to make it bright?	Create ***Ambient luminescence*** by amplifying the (blue) undertones of grey.
The lighting in the space is described as unstimulating, boring, demotivating and dull by users.	How to make a lighting design that excites the optic nerves and creates interest but doesn't harm the plant growth?	Create visual interest and increase alertness of users by ***Play of brilliants***, lighting up the plant wall in a natural way so that it comes to life as a decoration element/piece of art, amplifying the green colour with warm light reminiscent of sun rays.

Table. 2. Summary of overall design concept

lighting component of Light zone B.

On daily use (except occasions exemplified above), a light level sensor automatically dims the light according to daylight intake and ensures light levels described in the criteria are met. The sensor also functions as a presence sensor and turn the lights automatically on upon detection of users. The product E- sense Customized (*E-Sense Customised: Customised Lighting Control via DALI - Fagerhult (International), n.d.*) is suggested as the sensor to be used.

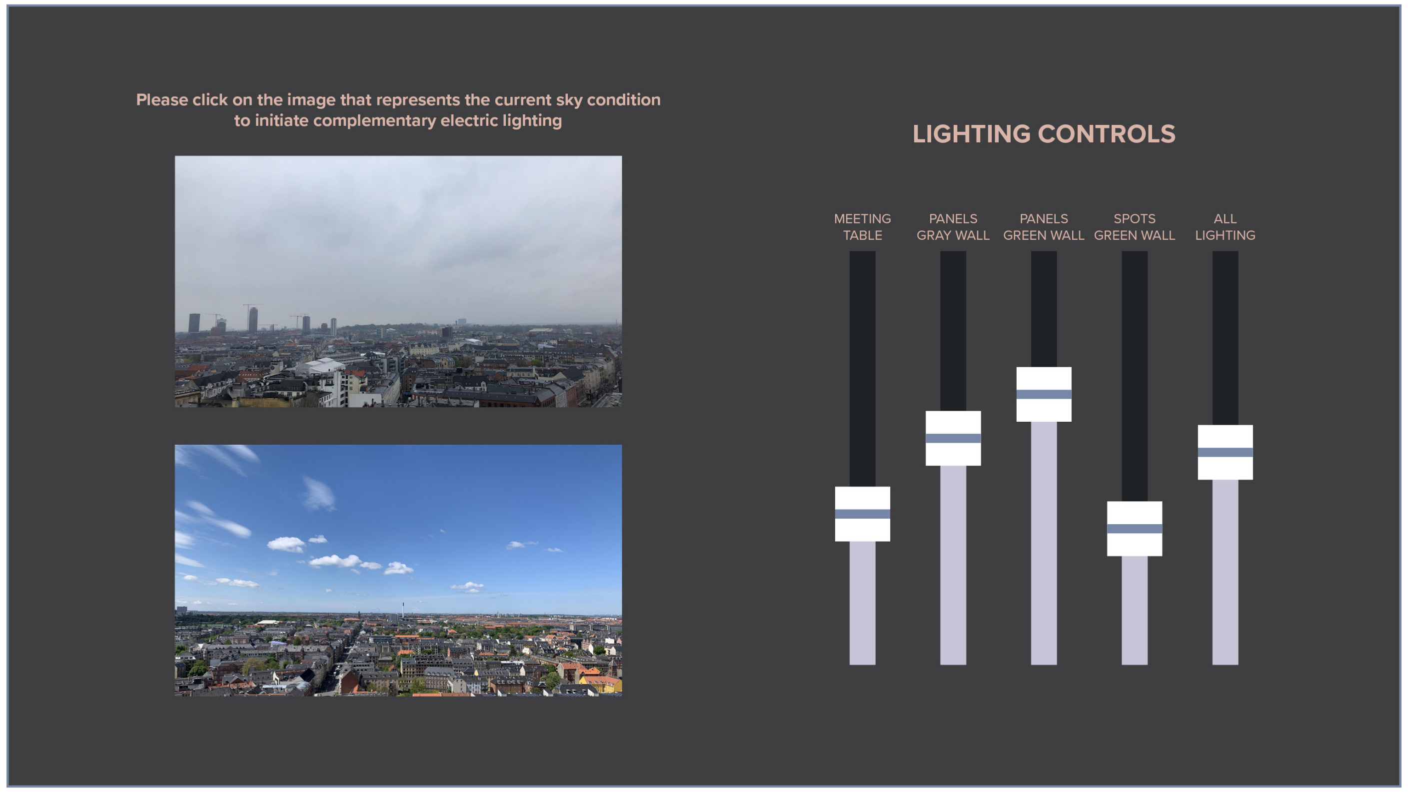


Fig. 18. Sample user interface for lighting program & control

Development of Design Concept

Light Zone A- Meeting Table

For this light zone, the aim is to create a light pool (focal glow) around the table, enabling people to focus on the meeting and making faces look good: Direct lighting that will not create harsh shadows but will create some light modelling without causing glare, which is very important as people also use laptops in meetings. Another important point is to achieve harmony with other direct lights in the room in terms of CCT.

The aim of creating a focal glow around the meeting table connects to the inspiration of various manifestations of focal glow that has been part of human evolution through ages in nature: sunset, campfire, moon.

Fig. 19. Inspiration for focal glow
Images 1 & 4: Amager-Copenhagen/Denmark
Image 2: Cesme-Izmir/Turkey
Image 3: Reffen-Copenhagen/Denmark

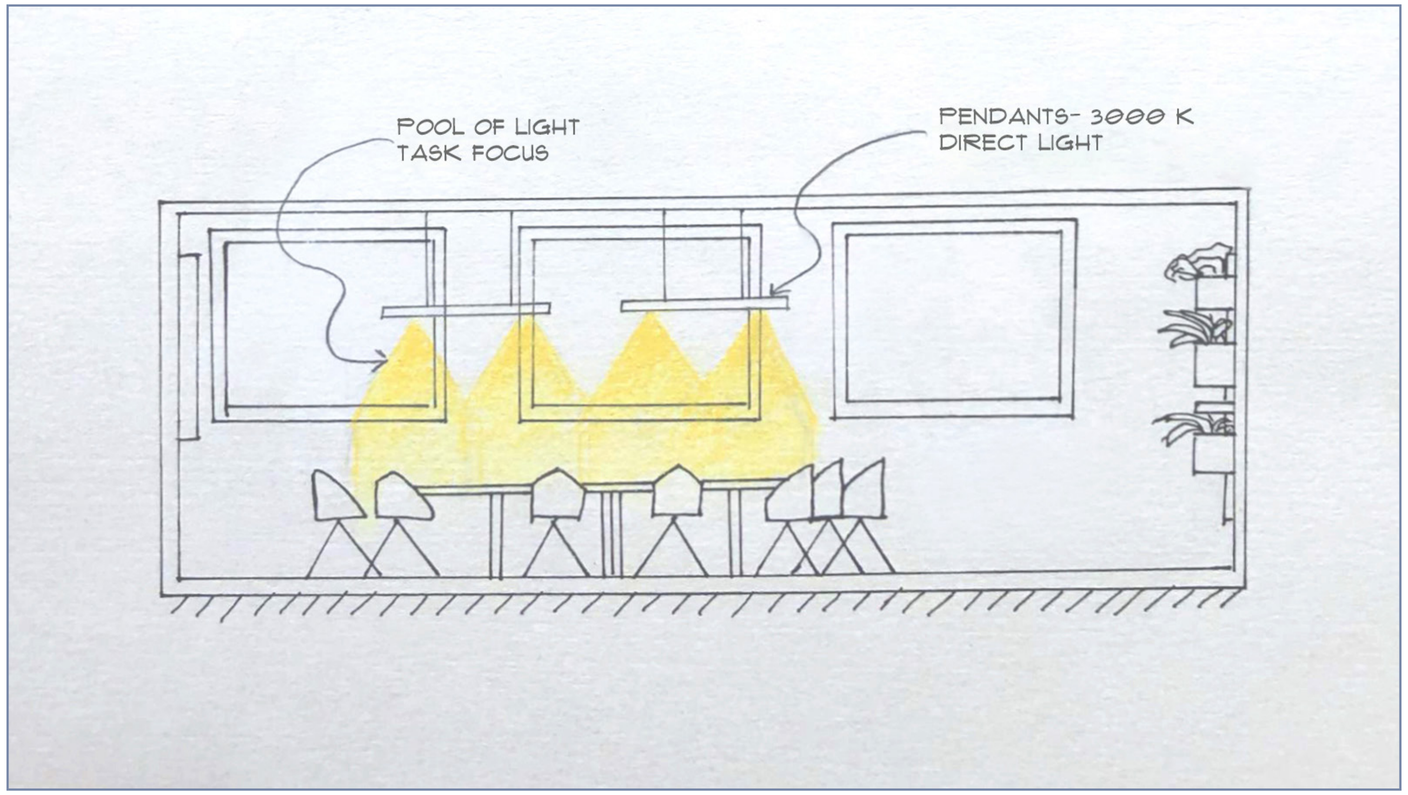


Fig. 20. Sketch for Light Zone A

Design Solution: Light Zone A- Meeting Table

A pendant is found to be the appropriate type of fixture to create task-focus for the meeting table. The product, Jilly Linear (*Indoor - Pendant Luminaires - Jilly Linear | ERCO, n.d.*) has been selected as its light distribution and lumen output achieve required light levels through the big meeting table with a minimum number of light fixtures while minimizing glare. 2 pendants have been used to provide sufficient visual task and immediate environment lighting. The colour temperature for this direct lighting has been set to 3000 K complying with the criteria set by Double Dynamic Lighting research.

Pendant- Meeting Table (Light Zone A)

Beam angle (optics): 85 °- Extra wide flood
Luminous Flux: 780 * 2 = 1560 lm (custom)
CCT: 3000 K (warm white)
CRI: 92
No daylight: Not dimmed
Overcast Sky (March 20 noon): Dimmed to 92%
Clear Sky (December 21 morning): Dimmed to 88%

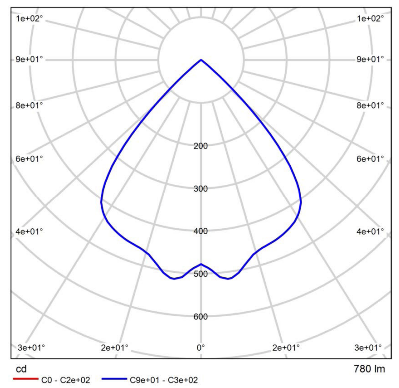


Fig. 21. Fixture characteristics- Pendants

Light Zone B- Green Wall

For this light zone, the aim is to create a play of brilliants through lighting without causing glare and to light up the green wall so that the shadows of boxes are avoided but shadows of the plants cast in a soft and beautiful manner, which would be possible through the support of ambient lighting that will match the sky condition as suggested by DDL research. As the green wall has living plants, it is also important to make the lighting suitable both for humans and plants. Communication with the company, TagTomat (*Grønne Fællesskaber, Urban G ardening Og Urban Farming - TagTomat, n.d.*) who built the green wall at the meeting room, along the care guide (TagTomat, 2020) they provided for Freja, revealed that current daylight intake is sufficient for the plants as the plant types used can survive in low light conditions. In this case, the electric lighting is not needed to be planned specifically for plant growth but in a way to not harm the plants. As plants use light both at red-orange (chlorophyll production) and blue wavelengths (photosynthesis) of the spectrum, full-spectrum (good CRI) light sources that generate white light are good to use (*Lighting Requirements of Green Wall Plants | Energylight, n.d.*) Also, as plants grow toward the light with the effect of their photo receptors (Hohm et al., 2013), it would harm them to use uplighting and having the direction of light from the ground upwards isn't an option.

For the ambient lighting, the aim is to bring the sky in and light the ceiling in a creative way by emphasizing architectural features of the space, which connects to the inspiration of various uses of natural/artificial skylights complementary to architectural characteristics of spaces.

Fig. 22. Inspiration for ambient luminescence
Image 1: Operaen-Copenhagen/Denmark
Image 2: Glyptoteket-Copenhagen/Denmark
Image 3: Lincoln Memorial-Washington DC/USA

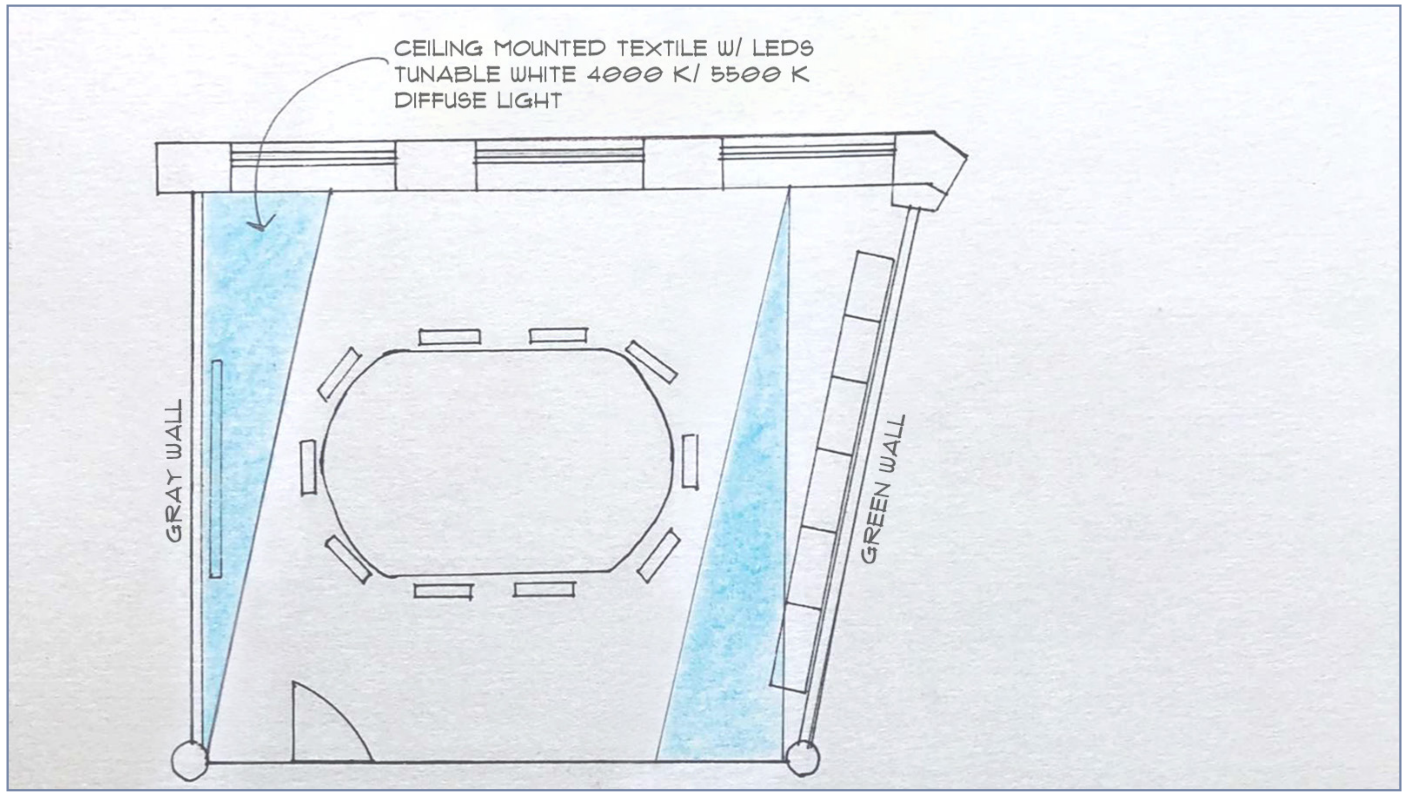


Fig. 23.1. Sketch for Light Zone B- Diffuse Component (Same for Light Zone C)

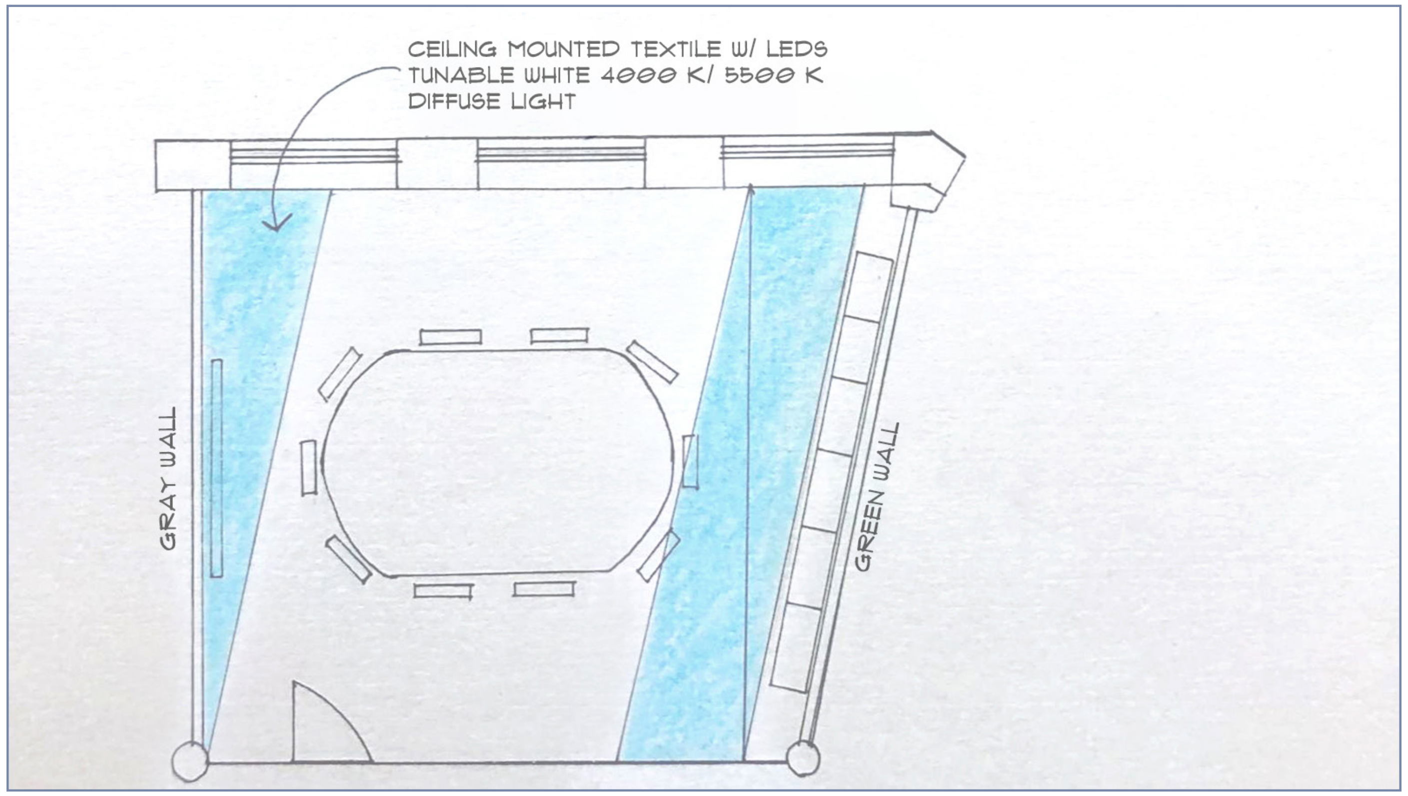


Fig. 23.2. Sketch for Light Zone B- Diffuse Component (Same for Light Zone C)

For the accent lighting, the aim is to create a play of brilliants that has a natural look and feeling which connects to the inspiration of the concept of Komorebi- (n.) Japanese Script- 木漏れ日 which describes “Sunlight filtering through trees” (木漏れ日 - Wiktionary, n.d.)

Fig. 24. Inspiration for play of brilliants
Images 1 & 2: Selcuk-Izmir/Turkey
Image 3: Møns Klint-Borre/Denmark
Image 4: Freja Ejendomme Meeting Room 1 Frederiksberg/Denmark

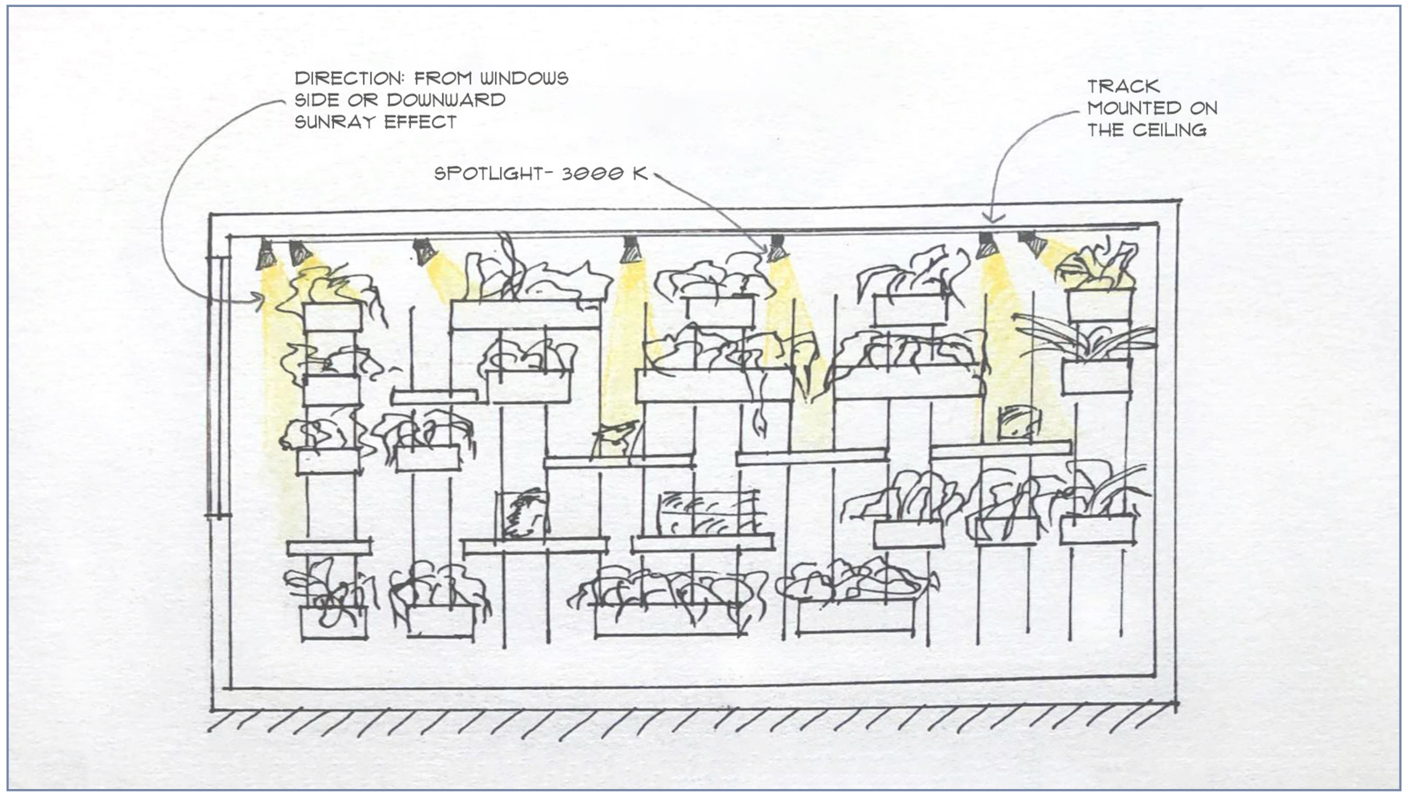


Fig. 25.1. Sketch for Light Zone B- Direct Component

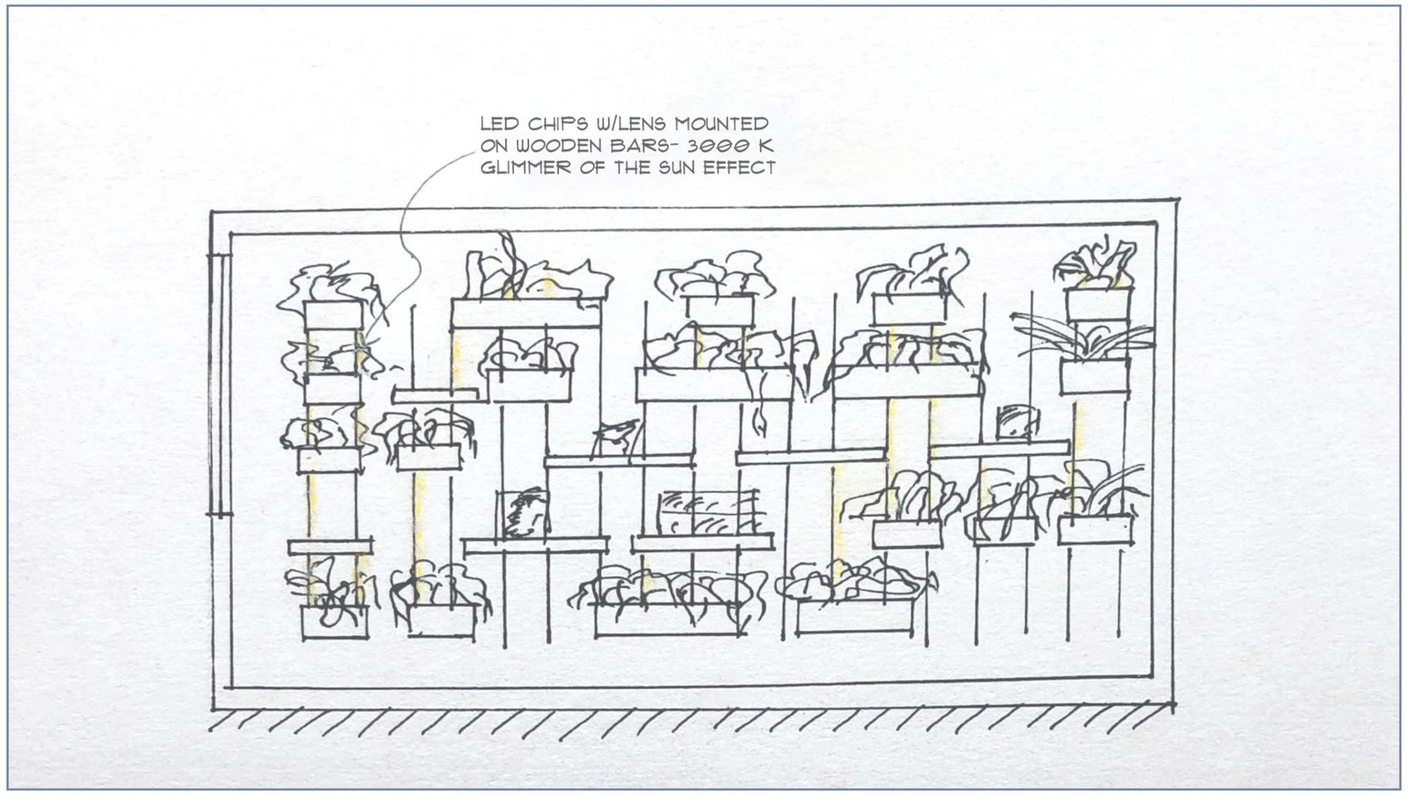


Fig. 25.2. Sketch for Light Zone B- Direct Component

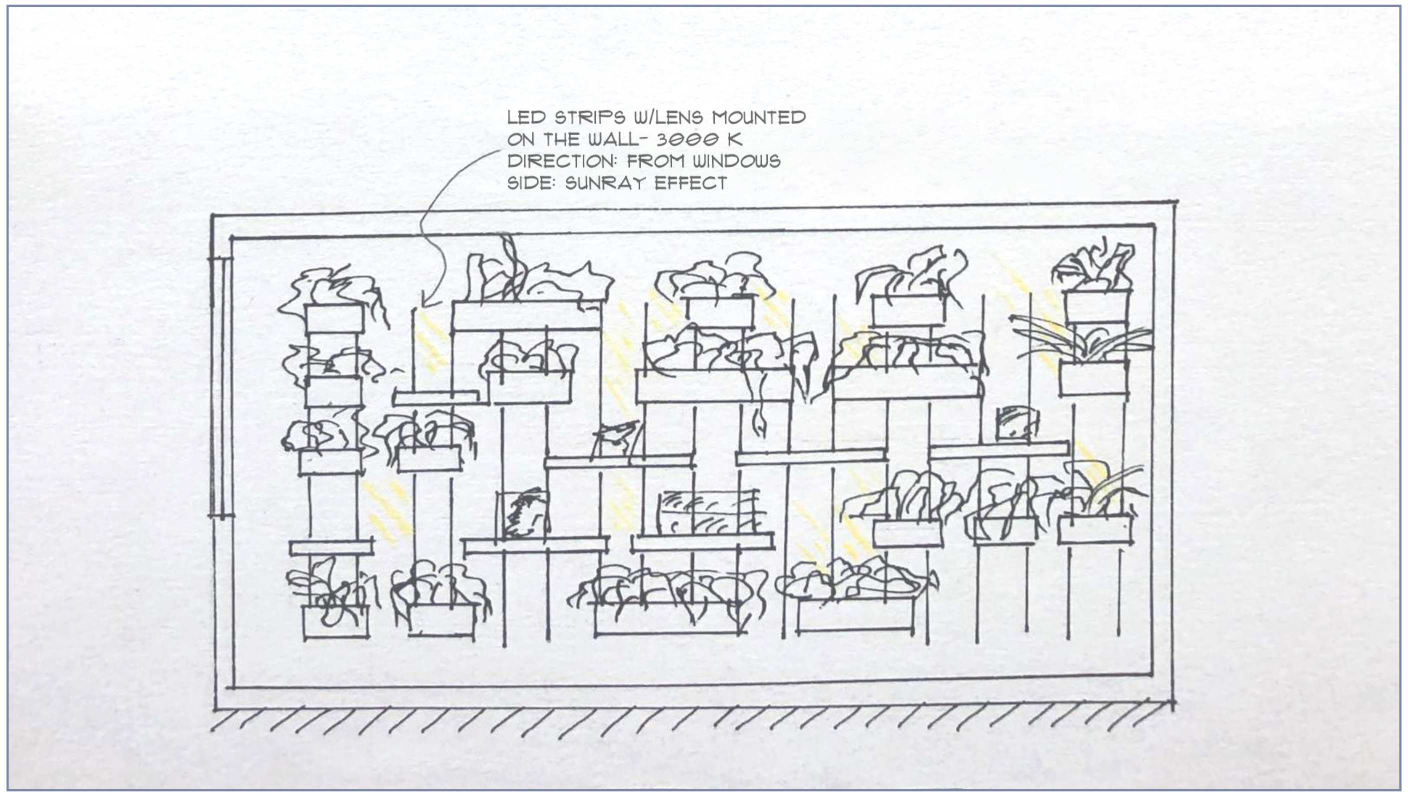


Fig. 25.3. Sketch for Light Zone B- Direct Component

For the interplay of direct and diffuse lighting, the aim is to create soft shadows of plant which connects to the inspiration of the shadows of plants created by natural daylight and sunlight of late afternoon hours.

Fig. 26. Inspiration for shadow play Amager-Copenhagen/Denmark

Design Solution: Light Zone B- Green Wall

As (Mende, 2010) puts it: “Shadow executed skilfully has a 3-D quality but has a melancholy air if light and shadow contrast is too stark”. Following on this, this light zone involves a combination of direct and diffuse lighting. The direct lighting component provides shadows and light modelling, whereas the diffuse component softens those shadows.

For direct lighting that creates play of brilliants effect, spotlights have been used. A degree of irregularities and vagueness has been suggested to create a natural atmospheric effect (Pallasmaa, 2014) Hence, the spotlights have been positioned in an irregular manner and with a variety of direction/tilt angle, some from the direction of windows- diagonal and some downwards. The track structure allows for the re-positioning of spotlights as plants grow and upon addition of new objects to be highlighted on the shelves. The product, Diamo (*DIAMO - Ceiling Lights from Zumtobel Lighting | Architonic, n.d.*) has been selected as it provides a good CRI, the necessary flexibility for tilting and has a good glare rating. CCT of these fixtures is in line with the lighting criteria from DDL Research- 3000 K.

For the diffuse component, an illuminated ceiling solution that consists of LEDs covered with textile diffusor has been used. The triangular zones created through the presence/division/absence of ambient lighting on the ceiling are in line with the geometry of the space that already contains an (almost) triangular corner on the side of the green wall. Hence, this design makes for a creative ambient light which helps define the space while making room for the installation of a ceiling mounted track with spotlights (as mentioned for direct component). The product, Cieluma (*CIELUMA - Zumtobel, n.d.*) has been used as it provides the necessary flexibility for creating custom made geometric shapes, has a high CRI, and also can contribute to the acoustics of the room, which is important for a meeting room. CCT of these fixtures follow the dynamic changes stated by the lighting criteria from DDL, with 4000 K for overcast sky and 5500 K for clear sky conditions.

Spotlight- Green Wall (Light Zone B)

Beam angle (optics): 27 °- Flood
Luminous Flux: 1400 lm
CCT: 3000 K (warm white)
CRI: 90
No daylight: Not dimmed
Overcast Sky (March 20 noon): Not dimmed
Clear Sky (December 21 morning): Not dimmed

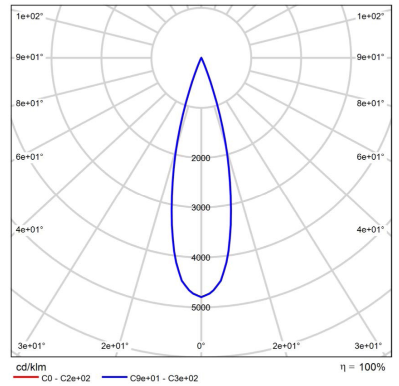


Fig. 27. Fixture characteristics- Direct Component- Spotlights

Illuminated Ceiling (Light Zone B)

Beam angle (optics): Textile- Lambertian
Luminous Flux: 2800 lm
CCT: Tunable white (custom)
CRI: 90
No daylight: Not dimmed
Overcast Sky (March 20 noon): Dimmed to 75%
Clear Sky (December 21 morning): Dimmed to 65%

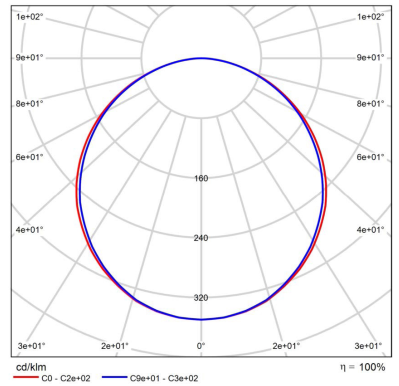


Fig. 28. Fixture characteristics- Diffuse Component- Ceiling- Light Zone B

Light Zone C- Gray Wall:

The concept for this light zone is a continuation of the approach of bringing the sky in and lighting the ceiling in a creative way by emphasizing architectural features of the space, explained for the Light Zone B. Additional aims are lighting up the grey wall so that the tone of grey colour is perceived beautifully and embracing the fact that grey absorbing light and making the wall appear darker instead of trying to go against it.

The aim is to bring the sky in while emphasizing blue undertones of grey connects to the inspiration of the sea looking shades of blue/grey under various sky types.

Fig. 29. Inspiration for ambient luminescence (Grey wall)
Image 1: Amager-Copenhagen/Denmark
Image 2: Yenikoy-Istanbul/Turkey

Sketch for Light Zone C (See above Fig. 23.1 & 23.2)

Design solution Light Zone C- Gray Wall

CCT of lighting fixtures on the ceiling by the grey wall area follow the dynamic changes stated by the lighting criteria from DDL, with 4000 K for overcast sky and 5500 K for clear sky conditions. Diffuse lighting with neutral to cool CCT both matches the dynamics of daylight changes and serves well to highlight the undertone of the blue-based grey wall paint. Although the same lighting fixture has been used both for the ceiling of Light Zone B And C, to embrace the darker feel of the grey wall, the lumen output of the panel fixtures for this zone has been kept around %30 less than the ones over the green wall (Light Zone B). As mentioned earlier for Light Zone B, the triangular zones complementing architectural characteristics of the space are also created in this light zone.

Illuminated Ceiling (Light Zone C)

Beam angle (optics): Textile- Lambertian
Luminous Flux: 1850 lm
CCT: Tunable white (custom)
CRI: 90
No daylight: Not dimmed
Overcast Sky (March 20 noon): Dimmed to 70%
Clear Sky (December 21 morning): Dimmed to 55%

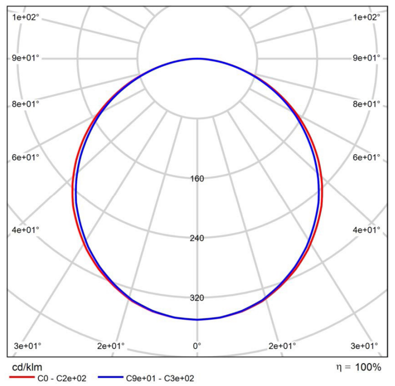


Fig. 30. Fixture characteristics- Ceiling- Light Zone C

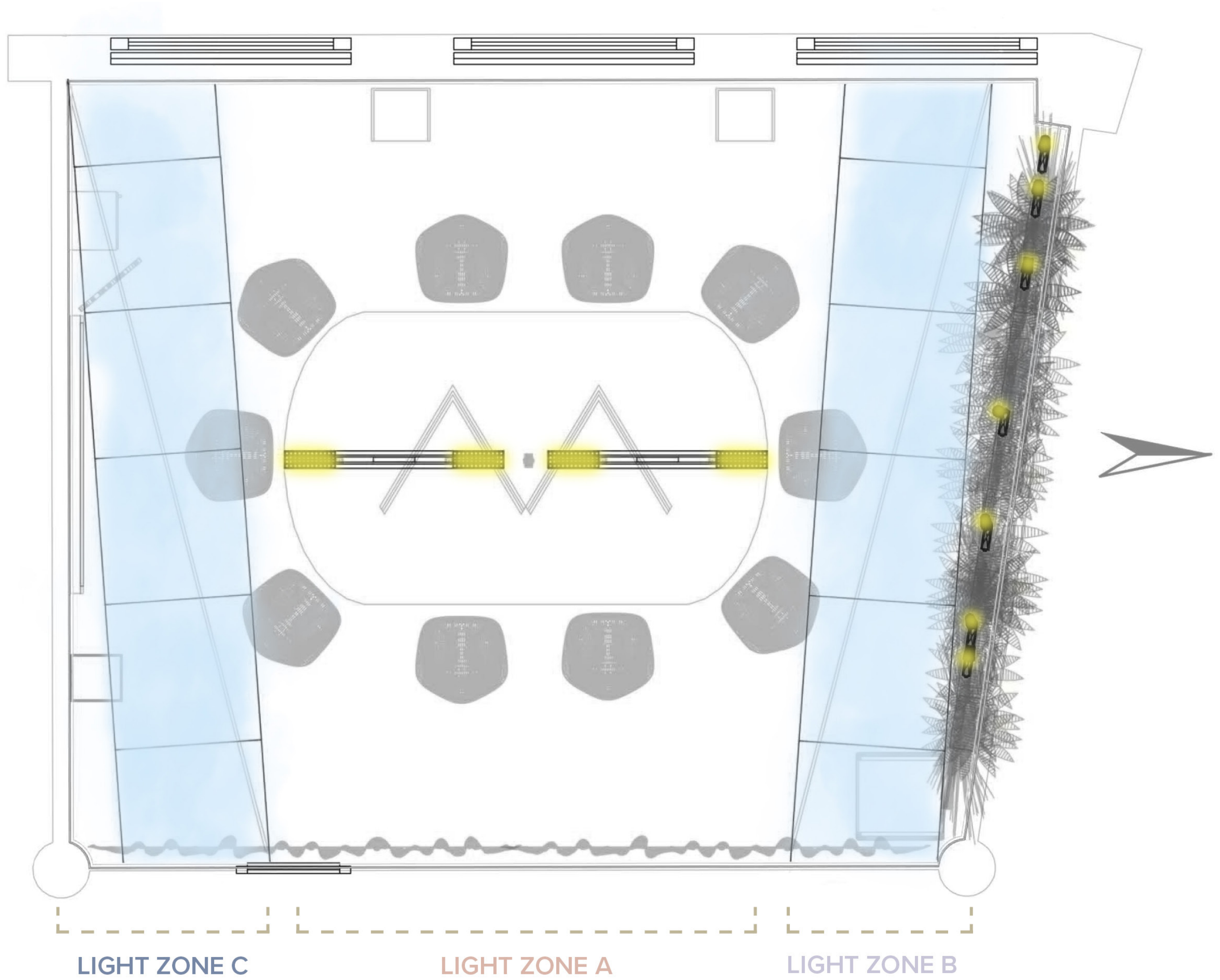


Fig. 31. Final lighting plan indicating location of light sources according to light zones

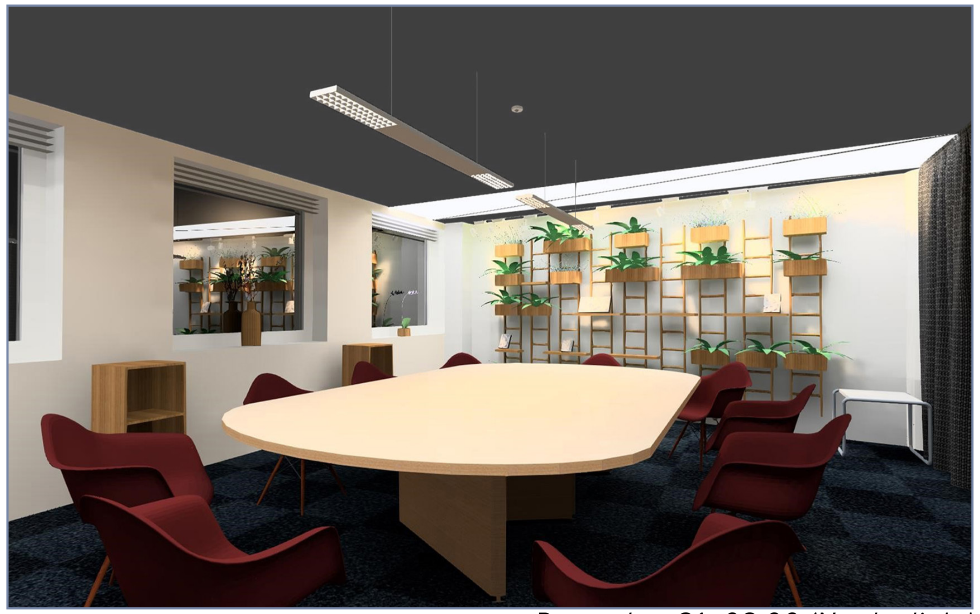
Fig. 32.1 Visual representation of the Final Lighting Solution for Meeting Room 1
March 20-12:00 (Overcast sky)

Fig. 32.2 Visual representation of the Final Lighting Solution for Meeting Room 1
March 20-12:00 (Overcast sky)

Fig. 32.3 Visual representation of the Final Lighting Solution for Meeting Room 1
March 20-12:00 (Overcast sky)

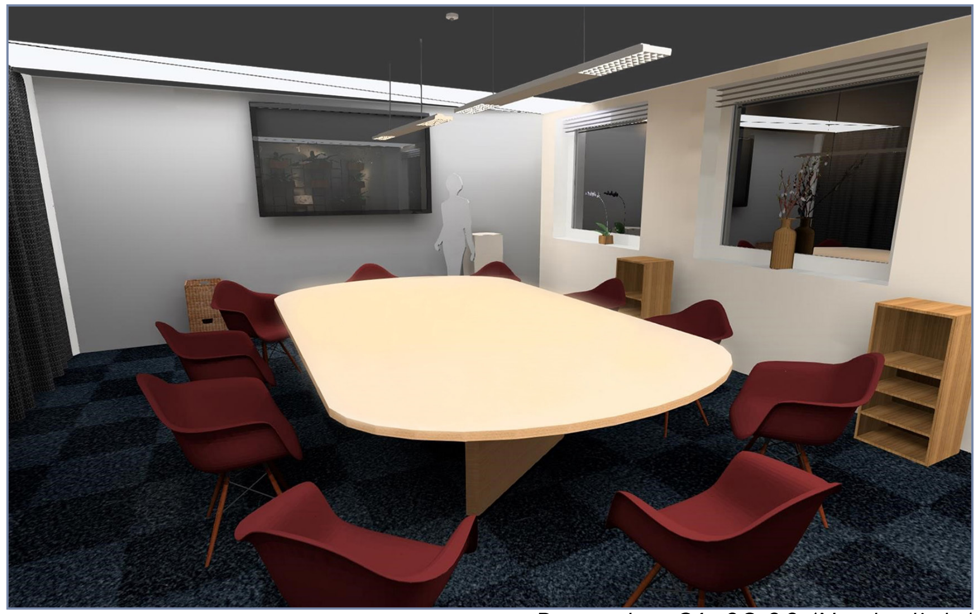

May 4- 12:00 (Clear sky)


March 20- 12:00 (Overcast sky)

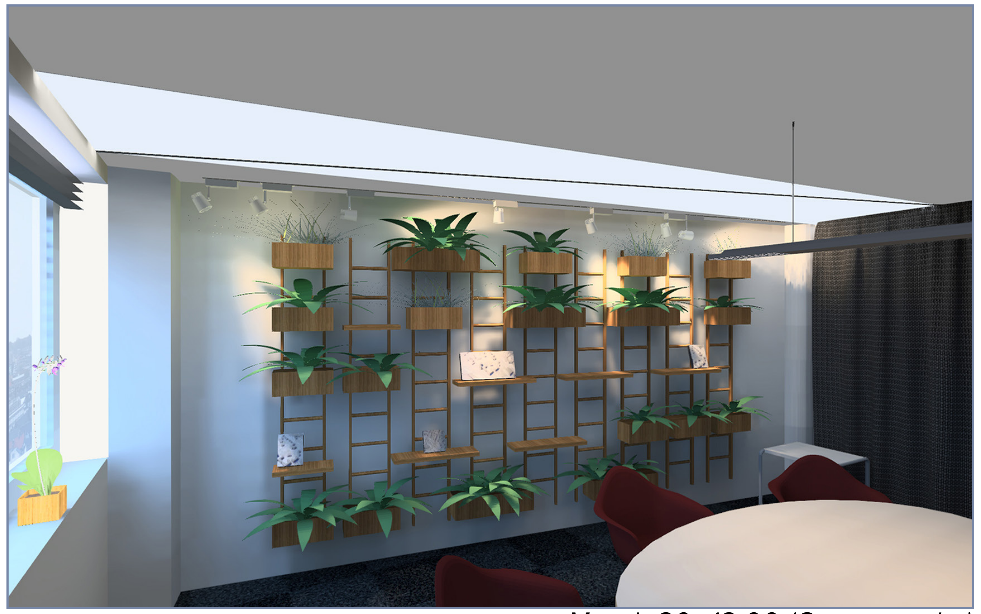

December 21- 08:00 (No daylight)


May 4- 12:00 (Clear sky)


March 20- 12:00 (Overcast sky)


December 21- 08:00 (No daylight)


May 4- 12:00 (Clear sky)


March 20- 12:00 (Overcast sky)


December 21- 08:00 (No daylight)

Fig. 33. Visual representation of the Final Lighting Solution for Meeting Room 1- Various sky conditions

Testing of Design Concept

The design solution has been tested in DIALux for various light scenarios. 3 main lighting scenarios have been chosen for further investigation:

1- December 21- 08:00 (No daylight)

2- March 20- 12:00 (Overcast sky)

3- May 4- 12:00 (Clear sky)

The following table demonstrates how the lighting design performs according to the criteria set in the earlier chapters. Glare rating are only indicated for no daylight scenario as glare rating by the UGR method applies only to artificial lighting (*Lys Og Belysning - Belysning Ved Arbejdspladser - Del 1: Indendørs Arbejdspladser = Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places., 2011*) The height for calculating the UGR for standing presenter has been set to 1,6 m and for seated people at the meeting table to 1,2 m.

The values that don't match the target are highlighted in pink. For light modelling at the areas of activity (meeting table), the range is explained to be as a "rough guide" in the standard (*Lys Og Belysning - Belysning Ved Arbejdspladser - Del 1: Indendørs Arbejdspladser = Light and Lighting - Lighting of Work Places - Part 1: Indoor Work Places., 2011*) For no daylight and overcast sky scenarios, the values are quite close to the target values (though outside the range) and for clear sky condition it is a higher value which is considered to be due to more diffuse light levels through increased daylight intake. As site testing has not been possible in the scope of thesis, it has been a challenge to fine tune the design. For further work, light modelling qualities can be fine-tuned through site testing. For UGR levels, only one value (Meeting-seated 3) is higher, but it is very close to max value with only one point difference. To illustrate light distribution on the workplane height, false colour images according to illuminance values have also been created for each light scenario. Overall, I believe it is safe to argue that the lighting design meets most criteria successfully.

	Symbol/Area	December 21 Morning (No daylight)	March 20 Noon (Overcast Sky)	May 4 Noon (Clear Sky)	Target
Room main surfaces	$\bar{E}_{\text{Ceiling}}$	115 lx	122 lx	126 lx	≥ 30.0 lx
	$g_{1\ \text{Ceiling}}$	0.43	0.38	0.39	≥ 0.10
	$\bar{E}_{\text{Walls}}$	115 lx	131 lx	122 lx	≥ 50.0 lx
	$g_{1\ \text{Walls}}$	0.38	0.41	0.40	≥ 0.10
Visual task areas	$\bar{E}_{\text{Task Area}}$	501 lx	501 lx	505 lx	≥ 500 lx
	$g_{1\ \text{Task Area}}$	0.80	0.79	0.77	≥ 0.60
	$\bar{E}_{\text{Surrounding Area}}$	410 lx	429 lx	426 lx	≥ 300 lx
	$g_{1\ \text{Surrounding Area}}$	0.48	0.46	0.48	≥ 0.40
	$\bar{E}_{\text{Background Area}}$	307 lx	347 lx	301 lx	≥ 100 lx
	$g_{1\ \text{Background Area}}$	0.43	0.31	0.32	≥ 0.10
Areas of activity	M	0.29	0.66	0.88	[0.30 - 0.60]
	$\bar{E}_{\text{Horizontal}}$	488 lx	452 lx	431 lx	≥ 50.0 lx
	$\bar{E}_{\text{Vertical}}$	210 lx	201 lx	246 lx	≥ 50.0 lx
Glare (UGR)	$\text{UGR}_{\text{Standing Presenter}}$	17.6 (max)	N/A	N/A	≤19.0
	$\text{UGR}_{\text{Meeting (Seated) 1}}$	16.8 (max)	N/A	N/A	≤19.0
	$\text{UGR}_{\text{Meeting (Seated) 2}}$	18.5 (max)	N/A	N/A	≤19.0
	$\text{UGR}_{\text{Meeting (Seated) 3}}$	19.1 (max)	N/A	N/A	≤19.0
	$\text{UGR}_{\text{Meeting (Seated) 4}}$	17.5 (max)	N/A	N/A	≤19.0

Table. 3. Lighting calculations according to criteria for various settings

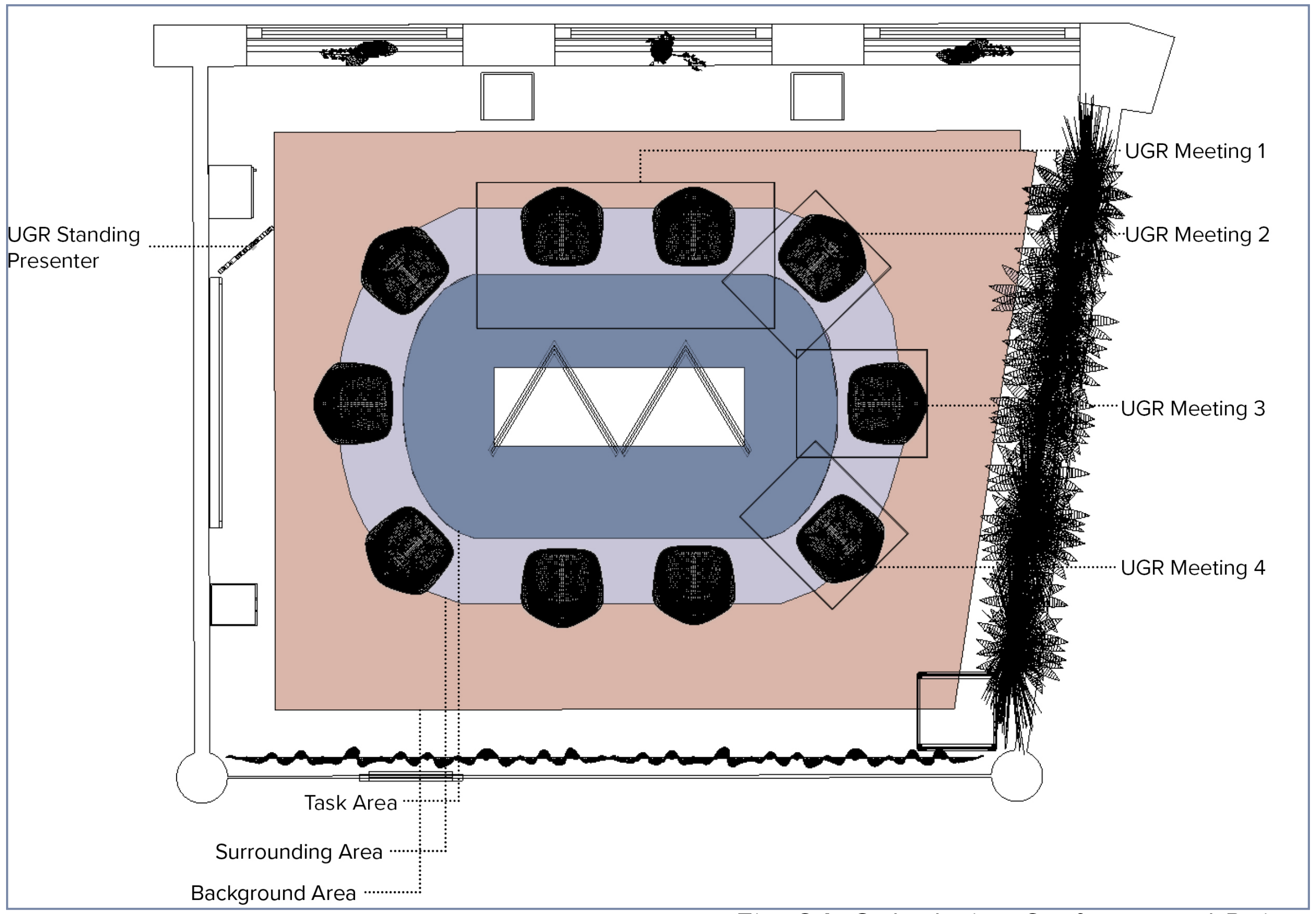


Fig. 34. Calculation Surfaces and Points

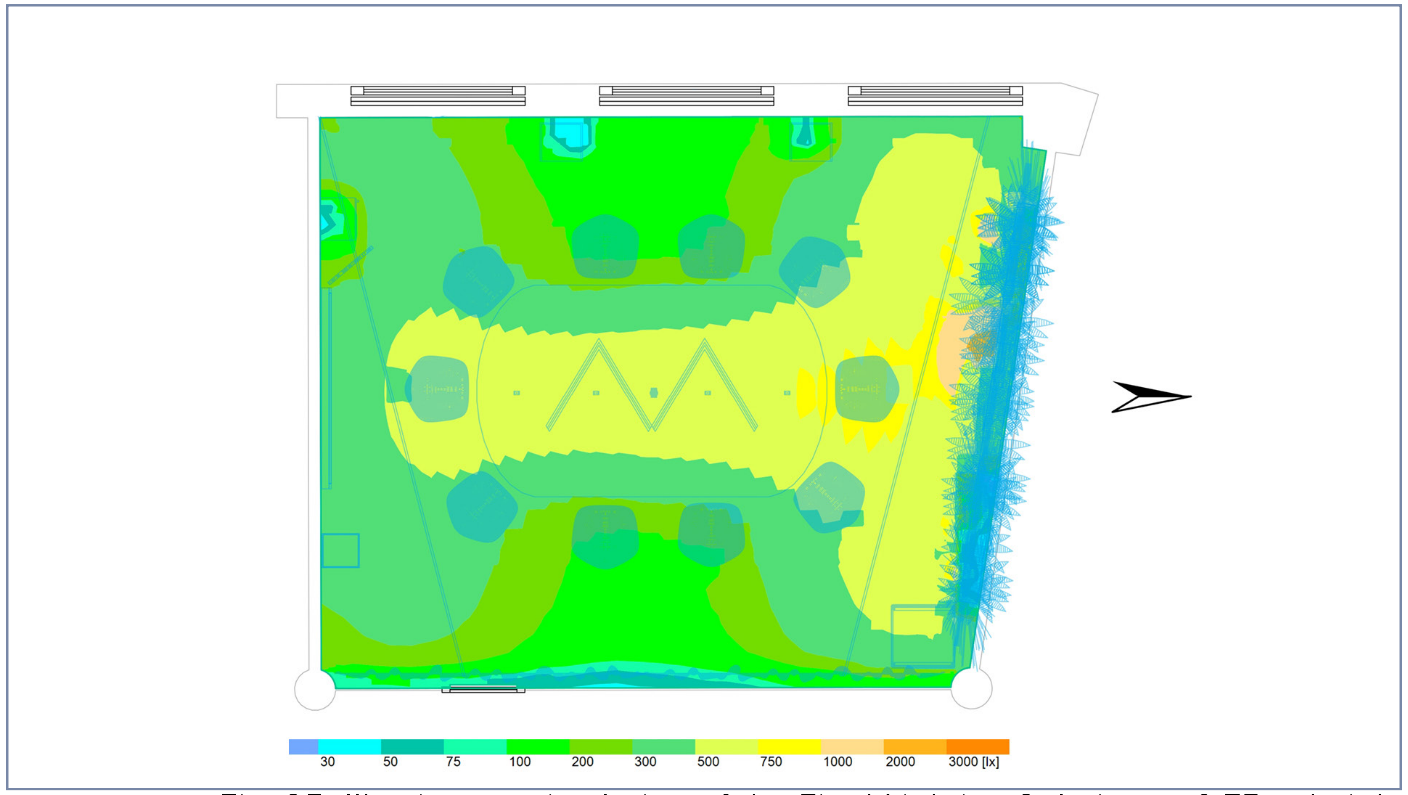


Fig. 35. Illuminance simulation of the Final Lighting Solution at 0,75 m height December 21- 08:00 (No daylight)

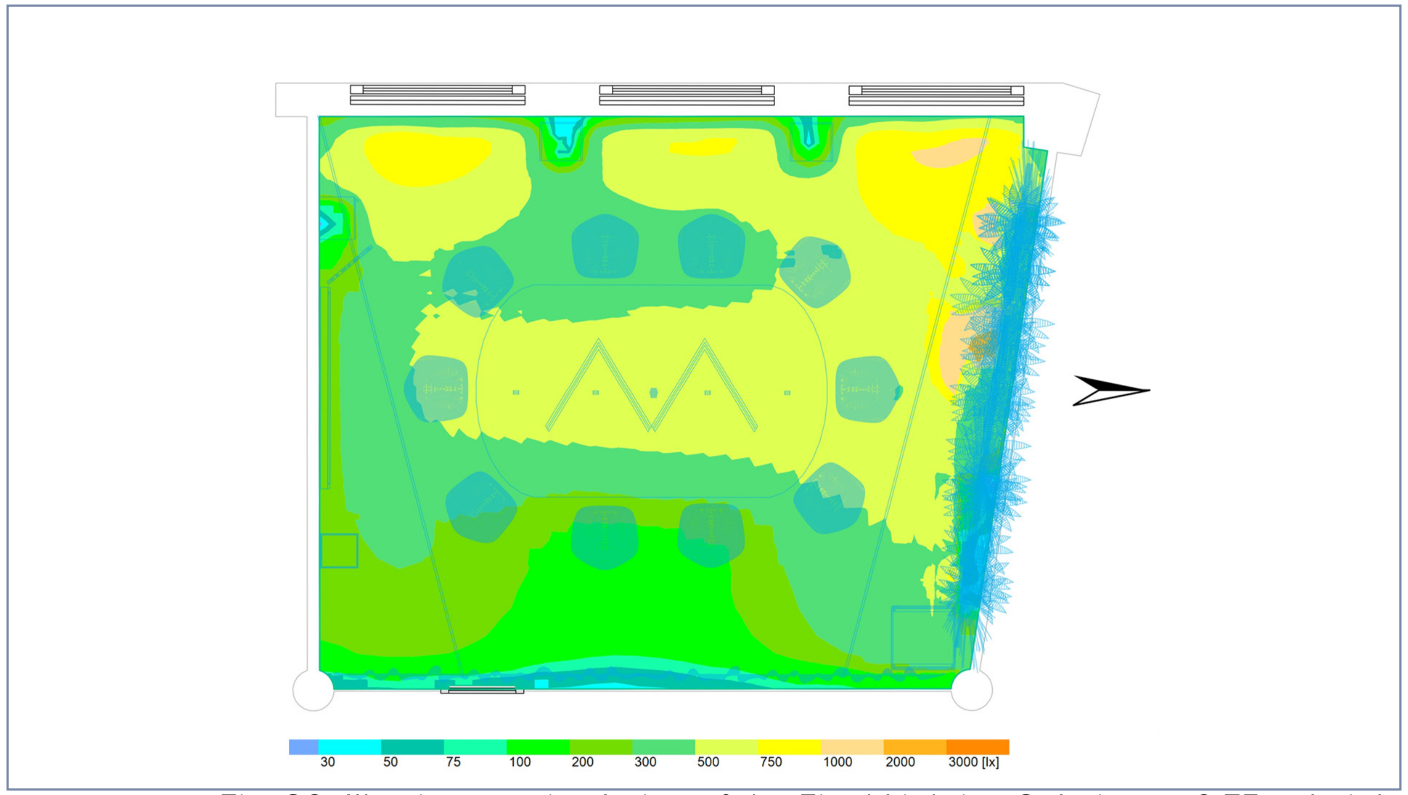


Fig. 36. Illuminance simulation of the Final Lighting Solution at 0,75 m height March 20- 12:00 (Overcast sky)

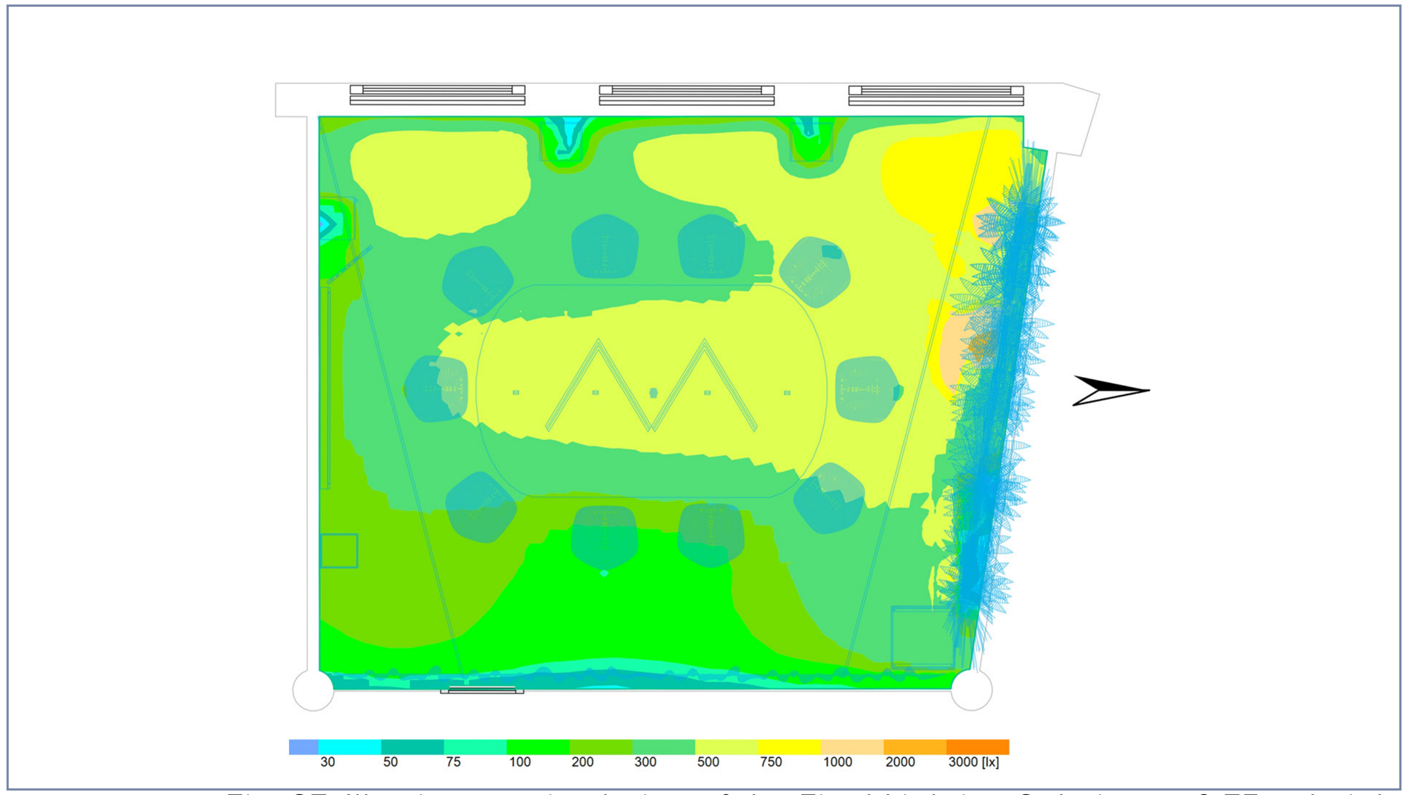


Fig. 37. Illuminance simulation of the Final Lighting Solution at 0,75 m height May 4- 12:00 (Clear sky)

Round-off

Discussion

This thesis followed a design process guided by a combination of qualitative and quantitative methods to address a complex and intangible issue as atmosphere and at the same time to support the function and unique character of the space. The main methods that have been used included: User survey on Perceived Atmosphere and Visual Appearance; semi-structured interviews with a user and building administration; my own personal observations of atmosphere, visual appearance of light and architectural elements in the space; input from the results of Double Dynamic Lighting Research (becoming part of design criteria); testing through simulations for daylight and electric light (to adhere and go beyond Danish and European Office Lighting Standards) and finally Richard Kelly's three elements of lighting- Focal glow, Ambient luminescence, and Play of brilliants, as a design tool. When the users said they wish for "more light" in the space, the usual approach would be just to make existing lighting brighter (i.e., double the lux levels) but previous Double Dynamic Lighting Research already proves that this approach would not actually solve the problem but would just add more flat light. Yet, from the perspective of a lighting designer, the aim has been to transform the space described as unstimulating, boring, demotivating, and dull by users to a stimulating, lively, motivating and task focused natural luminous environment by using the methods summarized above.

This study has certain limitations. First, due to Covid-19 restrictions, the access to the space has been limited to a duration of one day visit which made it impossible to do mock-ups and site testing. Therefore, there is a definite need for site testing to fine-tune the design, in case of realization. Second, due to difficulties reaching all employees, It was only possible to receive feedback for the user survey for 6 out of 25 employees. Nevertheless, considering each survey result pointed out to some "need to be improved" points, have been supports with interviews and complemented my own observations of the space, I believe that I managed to obtain a clear picture of the user perspective. Third, to make sure the intended atmospheric qualities and functions are accomplished, future work should include receiving user feedback through photorealistic renderings and in the case of realization of the design concept, conducting a post occupancy user survey. Fourth, a specific light scenario for daylight transition hours (in the morning and afternoon) hasn't been included in the scope of this thesis as this is a quite large area of research/design on its own and the season that the study has been conducted, the sunrise and sunset hours have been beyond work schedule hours.

Conclusion

This thesis started with an investigation of complex interplay among factors affecting the perception of atmosphere and pointed out to the effect of cultural and individual differences in perception. I argue that, despite cultural and individual differences, design solutions inspired by our common evolutionary traits that define our connection to nature, lead to a more universal perception of atmosphere. This approach has guided me through the entire process.

The hypothesis of this thesis claimed that by using perceived atmosphere as a metric for a dynamic lighting design of an indoor environment, with electric lighting complementing daylight, we can achieve a natural, lively, and pleasant atmosphere in the space. While making the desired atmosphere described in the hypothesis, the lighting design solution for this case study should also succeed in creating a lighting hierarchy in line with the architectural elements of the space and complementing daylight through electric lighting in a dynamic way, taking sky-type and seasonal changes in daylight inflow into consideration. It is reasonable to conclude that the hypothesis stated above holds true for this case as; first, the design solution has been achieved through a mixed-method approach providing support for the design with anthropological research methods (surveys and interviews), well-established architectural lighting principles and adaptation of criteria resulting from extensive testing through long periods of time and in various office settings in the context of previous Double Dynamic Research Projects and other relevant literature; second, the design solution has been simulated in 3D with real climate and location data across different seasons and times of the day and been tested both visually through renderings and for standards through light calculations.

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Figures & Tables

Appendix

User Survey

How would you describe overall experience of lighting in Meeting Room 1 at your office?

Please rate the applicability of each term by circling the corresponding number to evaluate the lighting in Meeting Room 1 at your office.

Comfortable

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Sufficient

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Task-focused

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Natural

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Contrasting

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Dim

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Bright

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Glary

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Disturbing

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Please rate the applicability of each term by circling the corresponding number to describe the atmosphere in Meeting Room 1 at your office.

Cosy

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Motivating

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Personal

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Intimate

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Formal

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Stimulating

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Relaxed

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Lively

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Detached

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Boring

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Clinical

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Tense

1 2 3 4 5 6 7

Not applicable at all — Very applicable

Verda Sigura

Master Thesis

MSc in Lighting Design

Aalborg University Copenhagen