Degree Project in Architectural Lighting Design
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Light as a biophilic medium
Workspaces with no view to nature

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LIGHT AS A BIOPHILIC MEDIUM
WORKSPACES WITH NO VIEW TO NATURE

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*The illustrations are created by the author, unless otherwise indicated
ABSTRACT

A substantial part of our lives is spent in offices where lighting is affecting our well-being and health, even if we are not aware of that. Offices are most commonly illuminated by high intensity ceiling lights or suspended linear luminaries which emit uniform light over our heads and cause glare. In this thesis, I question this practice from perspectives of visual ergonomics and well-being and suggest a biophilic approach to lighting. Biophilic design strategies can guide us in a direction of creating comfortable visual environment and improving our well-being along with boosting work performance and creativity. This thesis explores ways to incorporate biophilic lighting design into workspaces that lack views to nature on a case study of an open office in Stockholm, Sweden. Results of this study support the existing knowledge that downlights cause glare and should not be used above desks where people sit for prolonged period of time. I propose conceptual design solutions for indirect ambient lighting and indirect task lighting which are glare free and tuneable in terms of light intensity and correlated colour temperature. Other suggested biophilic lighting solutions include dappled light and water reflection effects, as well as interactive dynamic digital lighting depicting water movements.

KEY WORDS:
lighting design, office lighting, daylight, visual ergonomics, well-being
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To my dear parents, thank you for supporting me in all my beginnings. To my dear husband Robin, thank you for your loving support throughout this journey and for always believing in me. To my dear daughters Alicia and Chloe, thank you for your love and encouraging me to play and explore.
1.1 Questioning current office lighting practice

Offices and other workspaces, including universities and schools, are spaces where people sit for prolonged periods of time every working day, and therefore it is important that these environments are supporting their health and well-being. One crucial element in these work environments is lighting, as it influences the way we perceive the atmosphere in a space and it can completely transform the space from cozy to tense (de Kort 2019). Moreover, apart from the perception, light affects our psychological functioning in various ways simultaneously. Psychological functioning includes “outcomes such as alertness, mood, cognitive performance, social behaviour, and mental health and well-being” (Ibid., p.86). In work spaces, light has been shown to have an effect on satisfaction as well, e.g., with the entire workspace, and influence motivation and mood which in turn have an impact on productivity and work performance (Ibid.).

There are many factors related to light that are important to consider in order to ensure healthier lighting conditions in a workspace, such as access to daylight and view, lighting typologies, position of luminaires, illuminance levels, luminance ratio, colour rendering and colour temperature, glare, reflexes, flicker, contrast, position of the computer screen in relation to the daylight and the artificial light sources etc. (Hemphälä 2022).

When we imagine ourselves a modern office, we would probably think of a large open space with high intensity ceiling lights or suspended linear luminaires which emit uniform light over our heads. Previously, when people worked mostly on horizontal surfaces, e.g., read books and printed documents, wrote on paper etc., it was important that their desks were sufficiently illuminated to ensure good visibility. Yet, I wonder, why the light needs to come from above at such a distance that in order to achieve a certain required level of illuminance on the desk, the intensity of light needs to be rather high? This bright light coming towards one’s head might feel uncomfortable and cause glare, which in turn can trigger headaches, migraines and photophobia (Hayne & Martin 2019). Currently, most of the office workers work on computers and a computer screen, where they are looking most of the time, is a vertical surface and a light
source on its own, which means that we do not need high illuminance levels on our desks. This calls for challenging the current practice of illuminating office spaces and for finding an alternative solution that would be visually comfortable and glare free.

According to Hillevi Hemphälä, visual ergonomics expert/researcher, downlights, commonly used in offices, should be avoided in a space where people are sitting for prolonged period of time and LED panels should be avoided everywhere, as these luminaires cause glare and their luminance ratio to ceiling is too high, which cause discomfort and eye strain (Ibid., de Kort 2019). Eye strain in turn is related to musculoskeletal symptoms in the neck and shoulders (Zetterberg et al 2019), which can be so painful that it leads to sick leave, and in any case these symptoms obviously affect both work performance and well-being (Hemphälä 2022).

Apart from the common practice of overhead high intensity lighting in offices, it is the uniformity of light that we should reconsider as well. While it is important to ensure that working area is more or less evenly illuminated (Hemphälä 2022), areas surrounding the desk do not need to be uniformly lit. According to Pallasmaa 2012, uniform bright light disables the imagination and erases the sense of space itself as well as weakens our experience of being. Similarly, Volf 2010 argues that light is not visible without the darkness and uniform illumination is blinding us. Furthermore, lighting designer Colin Ball (2022) advocates for the use of darkness and lower illuminance levels as well and states that “people tend to work better in a pool of light surrounded by darkness”.

Moreover, now in post-Covid times, people have returned to the offices after working from home for about two years, where they did not have the same high intensity uniform lighting as in the office. Perhaps, people start to shape their understanding on what light qualities and quantities they prefer, if they were able to choose that individually. Therefore, considering individual preferences of people and the fact that they can vary a lot, tuneable lighting which can be controlled at the desk is recommended in workspaces (Appleman 2022).

1.2 Biophilic lighting design for offices

From my point of view, all the aforementioned elements of lighting design cohere with the concept of biophilic design, and even more - biophilic design can potentially add more elements into lighting which can further improve well-being of users in workspaces. Incorporating elements of nature into workspaces can
improve well-being for the users, bring mental restoration and reduce stress, as well as enhance cognitive performance, apart from boosting productivity (Mahmoud El-Bannany et al 2022).

The term biophilia (from ancient Greek ‘bio’-life and ‘philia’-love) was introduced independently by German psychologist Erich Fromm in 1964 and American biologist Edward O. Wilson in 1984 (Barbiero & Berto 2021). Defined by Fromm, biophilia is “the passionate love of life and of all that is alive” (Fromm 1973, p. 406), it manifests in the “wish to further growth” (Fromm 1973, p. 406) and implies “love for humanity and nature” (Fromm 1994, p. 101). Defined by Wilson, biophilia is “our innate tendency to focus upon life and life-like forms and, in some instances, to affiliate with them emotionally” (Wilson 2002, p. 134). Both Fromm and Wilson acknowledge that biophilia has a biological basis and it is fundamental for “developing harmonious relationships between humanity and the biosphere” (Barbiero & Berto 2021).

If we apply this term in the context of lighting, I think that biophilic lighting is first of all daylight, as it is vital for all living organisms; and it is darkness and shadows, as these provide conditions for sleep as well as shelter for some species; it is all the variations of daylight throughout the day and different seasons which support circadian and other rhythms and cycles in living organisms; it is dynamic and fluid in terms of colour temperature, intensity and degree of diffusion. When it comes to artificial lighting, biophilic lighting would mean it is soft, direct and indirect, impermanent, flexible, tuned to the specific needs of users, dynamic and varied in terms of intensity, colour temperature and diffusion, non-uniform and three-dimensional. Luminaires as well can be a symbolic representation of life, in terms of shape, texture and patterns resembling those that can be found in nature. Through biophilic lighting, people are connected to nature and to each other.

1.3 Aim and research question

In this thesis, I aim to explore different strategies for incorporating biophilic design into lighting in office spaces, in order to create healthier lighting conditions and improve users’ well-being, while saving energy and resources. I question and argue against the common lighting practice of overhead and horizontal lighting with high illuminance and glare, as well as propose to tailor the lighting design to actual needs of users while surrounding them with biophilic patterns. I investigate these strategies on a specific office space - the office of KTH Library service. This space is an indoor space within another indoor space, which means this space has
limited access to daylight in some areas and lacks views to nature.

Thus, specifically, this thesis project intends to answer the following research question:

**How can biophilic design strategies be incorporated into lighting design for an office with varied access to daylight and lack of views to nature?**

With my master’s thesis, I aim to contribute to a new practice of illuminating workspaces, which focuses on sustaining well-being of the users, in line with the Sustainable Development Goal G3 Good health and well-being (UN 2015). Furthermore, maximizing the use of daylight and minimizing the use of artificial lighting would allow saving energy and resources, contributing to the achievement of the goal G12 Responsible consumption and production (Ibid.). At the same time, using fewer luminaires and less energy would help to prevent emissions of CO₂ and other greenhouse gases into the atmosphere, which facilitates achievement of the goal G13 Climate action (Ibid.). Additionally, all the used luminaires should be able to be re-lamped and repaired in order to reduce electronic waste which might end up in landfills of developing countries, damaging the environment and health of already marginalized communities (Goal 3 Good health and well-being, Ibid.).

2 METHODS

There are two main blocks of methods that I use in this thesis: literature review and case study, which first run in parallel and then connect to each other (fig. 1). The literature review is mostly focused on lighting in workspaces, including the latest Swedish standards SS-EN 12464-1:2021 and requirements for WELL certification; on impacts of artificial lighting on well-being of users; visual ergonomics considerations and biophilic design. The case study - KTH Library service office located on the second floor of KTH Library - is an example of an office that lacks views to nature, where I explore different possibilities of “bringing nature” in a more abstract, representational way with means of light.

The methods used in this case study include both qualitative and quantitative methods of data collection. The qualitative methods are: personal observations, analysis of the space according to the strategies and patterns of biophilic design (suggested by Kellert 2018, Browning et al 2020 and El-Bannany et al 2022) and development of proposal for incorporating biophilic design into lighting in the space. The quantitative methods are: survey of the users, measurements of illuminance, luminance contrast ratios, colour
temperature, spectrum of light, glare, flicker and lightness of materials in the interior.

Figure 1 - Chart showing the thesis process stages and their interconnections
At the final stage, the proposed solutions for the lighting design in the selected office space are supported by literature showing benefits of such solutions in terms of well-being of users and savings of energy and resources. Lastly, I outline suggestions for future research on the topic of biophilic lighting and lighting in workspaces (fig.1).

2.1 Literature review

I selected literature from course material received during the Master’s courses in the Architectural Lighting Design Programme and individually, by searching the keywords of my thesis in books and online via Google Scholar. Furthermore, in the selected literature I found examples of biophilic design and modern organic style, which I then reviewed on Google and Pinterest.

Within the selected literature I focused on two books by Kellert 2018 and Browning et al 2020, as well as on the article by El-Bannany et al 2022. I found the most extensive list of 15 patterns of biophilic design in the book by Browning et al 2020, which I then complemented by two more principles from Kellert 2018. After that, I chose those biophilic patterns and principles which are directly or indirectly related to lighting. Then, I searched for applications of those selected patterns in the article by El-Bannany et al 2022 which presents examples of biophilic patterns for design of workspaces in general.

2.2 Case study

The office “Biblioteksservice och lärandestöd. Mediaförsörjning” is located on the third floor of the KTH library and it is an open landscape office with two parts divided in the middle by restrooms and other service rooms (fig. 2).

Figure 2 - Left: plan of the third floor of KTH Library. Source: A&P Arkitektkontor AB 2016. Right: the selected office. Source: author, software: Rhino
2.2.1 Qualitative methods

Observations
I visited the selected office on the 12th (11:00-12:00) and the 19th of April (13:00-14:30). During my visits, I took the measurements, talked to the users, took photos and wrote down notes. I looked at this space through the lens of biophilic design, described in the introduction and experientially assessed the existing lighting conditions at that moment of time.

Analysis of the space
Later I analysed the workspace from the biophilic design perspective, based on Kellert 2018, Browning et al 2020 and El-Bannany et al 2022.

Proposal
Many factors define my proposal for re-designing lighting in the selected office: the knowledge received during the Master’s Programme in Architectural Lighting Design, background research for this thesis, including visual ergonomics, standards SS-EN 12464-1:2021, requirements for WELL certification, strategies and patterns of biophilic design (based on Kellert 2018, Browning et al 2020 and El-Bannany et al 2022), inspirational examples of biophilic design and the users’ needs and preferences identified in the survey. The process of the proposal starts with hand sketches and then realized on a virtual model in Rhino and Twinmotion software.

2.2.2 Quantitative methods

Survey

Participants
Total of 16 users of the space have replied to the questionnaire in April - May 2023.

The survey was carried out by giving a QR code to an electronic questionnaire to the office users. It contained ten multiple choice questions, each allowing alternative answers, where respondents could add their own reply or a comment. The questions investigated the uses of the space, type of tasks that the users perform there, daylight conditions and access to view outside, how these are influencing them and their task performance, how the artificial lighting in the space is being controlled, how the users would prefer to control it, how the artificial lighting makes them feel and how they would like it to be changed or improved.

The QR code leading to the questionnaire is included in the Appendix B.
Measurements

Measurements for the existing lighting conditions in the selected office were taken during two study visits, on the 12th and 19th of April 2023. The aim for measuring the lighting conditions was to assess them in relation to the requirements by Swedish standards SS-EN 12464-1:2021 on lighting in workspaces and WELL certification, as well as in relation to recommendations from visual ergonomics perspective and the responses of the questionnaire. Results of this comparison serve as a starting point for the proposal for re-design of the lighting in the space.

The following measurements were taken of the existing lighting conditions that include both daylight and artificial lighting (downlights were on and all the table lamps were off):

1.) luminance levels measured by luminance meter Konica Minolta on the 19th of April 2023 at 13:30 with clear sky conditions for desks and surrounding surfaces: desk shields, keyboards, walls, windows and window shades and frames, ceiling, floors and carpets

2.) illuminance levels on desks measured by illuminance meter Hagner Detector EC1-X on the 12th of April 11:00-12:00 with clear sky conditions and cylindrical illuminance at workspaces measured by the same tool on the 19th of April 13:00-14:00 with clear sky conditions as well.

3.) flicker at different dimming levels of the downlights was measured in two meeting rooms and of the table lamps by spectrometer GL Spectis 1.0 touch on the 19th April 13:00-14:00

4.) lightness level of materials (level of reflectivity) was measured by NCS Lightness meter on the 19th of April 13:00-14:00 with clear sky conditions

Views and lighting control were observed and documented by photos.

Additional information, such as floor plan was received from the users of the office, which includes the distances and sizes of the selected space. The height of the ceiling was measured by a laser distance meter.
3 RESULTS

In this chapter I present combined results of my literature review and case study. I start with the summary of my literature review, which is then used for the analysis of the space according to the patterns of biophilic design. After that, I briefly present the results of the survey of users. I will then continue describing the space, but from the point of view of my personal observations. Next, I present my interpretation of all the measurements I have done in that office space. Lastly, I present my proposal for redesigning the space in terms of lighting.

3.1 Results of the literature review

I summarize strategies and patterns of “biophilic experiences in the built environment” (Browning et al 2020, p. 2) related to lighting directly or indirectly in table 1.
Table 1 - Patterns of biophilic design, based on Kellert 2018, Browning et al 2020 and El-Bannany et al 2022

<table>
<thead>
<tr>
<th>Biophilic design strategy / pattern</th>
<th>Examples</th>
<th>Sketch of an example (by author)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bringing daylight into interior spaces</td>
<td>❖ skylights, atria, clerestories, glass walls ❖ reflective materials and colours ❖ mirrors (tracking the sun path and reflecting it into the interior)</td>
<td>Daylight House, Japan</td>
</tr>
<tr>
<td>2. Manipulating qualities of light and darkness</td>
<td>❖ varying intensities of light ❖ the diffusion of light ❖ the presence of light wells and shadows</td>
<td>Maggie’s Centre, UK</td>
</tr>
</tbody>
</table>
3. Bringing visual connection with nature in the space by the patterns representing nature

- indoor plants: bushes and trees, potted or hanged plants, green walls etc.
- maximizing the access to outdoor natural views through full height windows
- outdoor gardens and roof terraces

4. Bringing non-visual connection with nature

- natural materials in the interior: wood, stone, marble etc.

5. Presence of water

- water fountains, aquariums, water walls or images depicting water

6. Adding more dynamism and diffusing daylight

- switchable opaque glass walls
- wall installations and façade skins for dynamic daylight patterns and enhanced shadows in the interior space
7. Using nature analogues that mimic nature

- biomorphic patterns and forms: fluid and organic forms of design elements, wall partitions and furniture
- colour palettes inspired from nature: earthy shades, blue and green tones
- complexity and order of geometrical patterns of natural forms: fractal patterns, complex configurations and symmetries similar to those found in nature, e.g., in building skins, partitions, modular floorings and carpet textures

8. Providing refuge – a private space to allow the users observe the surrounding environment from a withdrawn protected place

- recharge rooms
- private nooks
- telephone pods
- swing seats

9. Adding mystery pattern through partially obscured views to stimulate exploration

- curved walls
- see-through partitions
Thus, I have nine patterns of biophilic design that I focus on in this master thesis. Though, not all the elements mentioned above are directly related to lighting, they are interacting with and affecting the light distribution in the interior and therefore important to consider.

3.2 Analysis of the space according to the patterns of biophilic design

In table 2, I present the results of my analysis of the space through the perspective of biophilic design (based on Kellert 2018, Browning et al 2020 and El-Bannany et al 2022). This summary shows to what extent the selected office corresponds to the patterns of biophilic design today and what strategies could be added in order to incorporate biophilic lighting design in that space.
Table 2 - Analysis of the office space through the perspective of biophilic design based on Kellert 2018, Browning et al 2020 and El-Bannany et al 2022

<table>
<thead>
<tr>
<th>Biophilic design strategy / pattern</th>
<th>Examples</th>
<th>Present in the space or missing (Yes/No)</th>
</tr>
</thead>
</table>
| 1. Bringing daylight into interior spaces | ❖ skylights, atria, clerestories, glass walls  
❖ reflective materials and colours  
❖ mirrors (tracking the sun path and reflecting it into the interior) | Yes  
No  
No |
| 2. Manipulating qualities of light and darkness | ❖ varying intensities of light  
❖ the diffusion of light  
❖ the presence of light wells and shadows | Yes (daylight), No (artificial lighting)  
Yes, but inefficiently (movable window shades)  
No |
| 3. Bringing visual connection with nature in the space by the patterns representing nature | ❖ indoor plants: bushes and trees, potted or hanged plants, green walls etc.  
❖ maximizing the access to outdoor natural views through full height windows  
❖ outdoor gardens and roof terraces | Yes  
No (lack of outdoor natural views)  
Yes (roof terrace accessible from one floor up) |
<p>| 4. Bringing non-visual connection with nature | natural materials in the interior: wood, stone, marble etc. | Partly yes – wooden desks |
| 5. Presence of water | water fountains, aquariums, water walls or images depicting water | No |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
| 6. Adding more dynamism and diffusing daylight | ✓ switchable opaque glass walls  
✓ wall installations and façade skins for dynamic daylight patterns and enhanced shadows in the interior space | No  
No |
| 7. Using nature analogues that mimic nature | ✓ biomorphic patterns and forms: fluid and organic forms of design elements, wall partitions and furniture  
✓ colour palettes inspired from nature: earthy shades, blue and green tones  
✓ complexity and order of geometrical patterns of natural forms: fractal patterns, complex configurations and symmetries similar to those found in nature, e.g., in building skins, partitions, modular floorings and carpet textures | No  
Yes, partly (green wall)  
No |
| 8. Providing refuge – a private space to allow the users observe the surrounding environment from a withdrawn protected place | ✓ recharge rooms  
✓ private nooks  
✓ telephone pods  
✓ swing seats | No  
No  
Yes, but not well-designed (no visual and no acoustic protection)  
No |
| 9. Adding mystery pattern through partially obscured views to stimulate exploration | ✓ curved walls  
✓ see-through partitions | Yes  
No |
3.3 Survey

Extensive results of the survey are available in Appendix B. In this section, the results are presented rather briefly.

Half of the respondents say sun glare is prohibiting their task performance.

Only six out of 16 users say they feel comfortable with the existing artificial lighting. On the contrary, four users complain about negative effects of artificial lighting on their health (headache, eye strain, irritation from downlights). Seven respondents would like to have different type of lighting in the office. Ten respondents out of 16 would like to have tuneable lighting that can be regulated at each desk. Moreover, about half of the respondents (nine out of 16) would like to be able to dim the lights down in the office.

To summarize the results of the survey, I present the issues and needs identified in table 3.

Table 3 - Issues and needs regarding lighting conditions in the office, identified through the survey of the users

<table>
<thead>
<tr>
<th></th>
<th>Daylight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Partly, not enough daylight</td>
</tr>
<tr>
<td>2</td>
<td>Partly, too much daylight, direct sunlight, sun glare</td>
</tr>
<tr>
<td></td>
<td><strong>View</strong></td>
</tr>
<tr>
<td>3</td>
<td>Lack of view to nature, sky, ground and people outside</td>
</tr>
<tr>
<td></td>
<td><strong>Artificial lighting</strong></td>
</tr>
<tr>
<td>4</td>
<td>Glare leading to headaches, eye strain, irritation, feeling angry</td>
</tr>
<tr>
<td>5</td>
<td>The need to change to a different type of lighting</td>
</tr>
<tr>
<td>6</td>
<td>Lighting in the meeting rooms and the lunch room is too cold</td>
</tr>
<tr>
<td></td>
<td><strong>Lighting control</strong></td>
</tr>
<tr>
<td>7</td>
<td>The need for tuneable lighting regulated at each desk</td>
</tr>
<tr>
<td>8</td>
<td>The need to dimming the lights down in the office manually</td>
</tr>
<tr>
<td>9</td>
<td>The need for different scenes with different intensities of light changing automatically throughout the day. The need for automatic lighting control system that would turn on the lights when it is getting dark outside</td>
</tr>
</tbody>
</table>
3.4 Observations

The space is located within a larger indoor space of the library and only one side of the office is facing the street and has view to outside. The view to the larger indoor library space and the reading balcony (fig. 3) is perhaps pleasing for some people, and yet it is missing important elements such as ground and nature; sky is visible but only partly (fig. 4).

Figure 3 – View to the library indoor space

Figure 4 – Little slice of the sky visible from the window facing the library indoor space
The library view side offers view on people studying in the library (fig. 3); however, the office users might feel exposed as they are visible from the reading balcony. The other side of the office has the view to outside, however, that view is limited to the view of the nearby building (fig. 5 and 6), the sky is visible only partly as well (fig. 7).

Figure 5 – View to the street and the nearby building

Figure 6 – View from the window facing the street
Visual ergonomics perspective recommends access to a view with any point of focus at a distance to rest one’s eyes (Hemphälä 2022). Both sides of the office offer that. However, according to three layered views approach adopted by the British Standard Institute BS 8206-2:2008 and suggested by Heschong 2021, best views should contain a view of all the three layers: the sky, the ground and a layer in between these (vertical elements such as buildings, trees, landmarks). Thus, both sides of the office lack a view to the ground, which usually includes nature and people. Yet, a view of people is provided by the library view windows - of students, studying on or passing by the reading balcony just in front. Moreover, from biophilic design perspective, both sides of the office lack a view to “an element of nature, living systems and natural processes” (Browning et al 2020, p. 4).

The two sides of the office differ a lot in terms of access to daylight; it was obvious during the first visit that the street view side is well daylit, while the library view side is much darker and does not get as much daylight. Access to daylight on that side is inhibited by the larger library space that envelopes that part of the office. The ceiling of that large indoor library space is solid, and daylight comes in only through the large clerestories (fig. 8).
During my visits, I observed that the street view side receives direct sunlight, and even though, there are adjustable shades, some desks have bright sun patches (fig. 9). These sun patches have extremely high illuminance levels (highest measured 16760 lux).

When I visited the space the first time, I also directly noticed harsh contrasts of materials in the space. For instance, dark grey carpet on the white floor and near white walls, dark green cubicles and light wooden desks and white shelves (fig. 10). According to Hillevi Hemphälä (2022), too harsh contrasts and colours should be avoided in order to ensure a good visual environment. Moreover, from the perspective of biophilic design, colours and gradients found in nature are usually soft, and whenever harsh contrasts are present, e.g., on animals or plants, they always work as a warning signal for danger of being venomous or poisonous. Therefore, I assume harsh contrasts make us alert and stressed.
Figure 10 - Harsh contrasts between the materials in the interior of the office

Artificial lighting in the space is produced by LED downlights and LED table lamps (fig. 11). I noticed directly that the downlights are too bright and they are placed within the visual field (fig. 12) and causing glare. According to the users, the downlights are always on during the working hours.
As mentioned in the introduction, Hillevi Hemphälä, argues against downlights being placed in rooms when people are sitting, as they cause glare. In this particular office, the glare from downlights was so disturbing, that many of the users requested to cover the downlights above their desks (fig. 13).
The downlights are covered by a plastic sheet and it does reduce their brightness to some degree (measured luminance of an uncovered downlight – 350100 cd/m², of a covered one – 78030 cd/m²). However, as one of the users pointed out, covered downlights create more glare from distance, i.e., for other users. Originally, these downlights are recessed and caused glare only at a certain angle, now the downlights that are covered create even stronger glare from any angle of the view (fig. 14).
Moreover, even with these downlights covered some users have to use a hood or a cap to protect themselves from the glare. One of the users mentioned that the light from the downlights was too harsh, it gave them a headache and made them feel angry, that is why they asked to cover them. Still, a hood or a cap is needed to cover themselves from the glare, and the users describe this as having a great relief similar to when stepping into a shade on a bright sunny day.

3.5 Results of the measurements

All the collected data that was used for this study can be found in Appendix A.

As I noticed harsh contrasts in the interior and too bright light sources (the downlights), I have measured luminance contrast ratio for surfaces within and adjacent to work area, as well as background and other surfaces in the visual field (e.g., the ceiling). Table 1 of the Appendix A shows the measured values and how they relate to the requirements of WELL certification, Swedish Standards SS-EN 12464-1:2021, as well as visual ergonomics recommendations from Hemphälä et al 2021. None of the measured values complied with any of these requirements or recommendations. This serves as a support to my previously described issue of too harsh contrasts in the interior colours and materials. Moreover, the choice of colours can be questioned as well, for example, the black carpet (only 15% reflectivity) and the dark green shield of the desks’ cubicles (only 10% reflectivity) (table 3 Appendix A). Lighter materials with higher reflectivity would reflect more light and require less brightness of artificial lighting to achieve needed illuminance levels.

The luminance contrast ratio between the downlights and the ceiling is extremely high, for both uncovered and
covered downlights. This is a strong argument against using these types of luminaries in any workspace, as they can lead to a number of health issues for people who are more sensitive to visual stimuli - estimated as 20-40% of the population (Hemphälä 2022). These health issues include eye strain in the forms of photophobia and eye fatigue, headaches and migraines, as well as pain in the neck, shoulders, arms and upper back (Ibid.).

Illuminance levels of combined daylight and artificial lighting during my study visits varied a lot between the two sides of the office (table 2 Appendix A). The darker side facing the library indoor space fails to reach 500 lux minimum for all the desks where I took the measurements, however, the table lamps were switched off. The required illuminance level is most probably reached at those desks with switched on table lamps. Even though, the street view side comply with the 500 lux requirement, the values there are high and extremely high, which does not comply with the visual ergonomics recommendations by Hemphälä et al 2021. Studies show that too high illuminance levels lead to visual discomfort which in turn causes eye strain that further leads to musculoskeletal symptoms in the neck and shoulders (Hemphälä et al 2021; Zetterberg et al 2019).

The library view side that does not get any direct sunlight, qualified for the required illuminance uniformity ratio, while the street view side did not - the value was extremely low, meaning that illuminance levels vary a lot at different points of that area. Here again, as studies reveal, too much variation in illuminance is leading to visual discomfort and further negatively impacts human health (Ibid.).

Cylindrical illuminance for the library view side is not compliant with the required 150 lux for some desks, however, it would most probably would comply if the table lamps were switched on.

The fact that during my two study visits, even on the darker side of the office none of the users had their table lamp switched on during the hours of early afternoon, points out that it is sufficient with illuminance levels lower than the ones required by the Swedish standards (SS-EN 12464-1:2021).

As I mentioned earlier in the Introduction, I wonder why light fixtures in offices are commonly placed so high up - on the ceilings or suspended from the ceiling within the visual field of users? In this specific office, the downlights, that people have complained are too bright, fail to bring enough illuminance to the desks of users and to provide sufficient cylindrical illuminance at their workspaces, even with the presence of daylight.
According to WELL certification requirements, luminance of a luminaire should not exceed 6000 cd/m² within the visual field of users, and the downlights’ luminance measured for an uncovered downlight is 350100 cd/m² (78030 cd/m² for a covered one). This means that obviously glary downlights exceed the allowed number by 58 times (13 times for a covered downlight).

Information about these downlights was unavailable, as these are not the original luminaires that were placed in the ceiling during the construction of the library (1999-2002), according to the responsible architectural studio. These fixtures were installed much later and their lumen output and Unified Glare Rating (UGR) are unknown. Nonetheless, there is clear evidence that the existing downlights cause discomfort glare.

Flicker, a temporal light artefact caused by Temporal Light Modulation, was detected in meeting rooms when dimming down the downlights to the lowest levels and from the table lamps in the whole office (fig. 16 and Appendix A).

Frequencies of flicker detected were under 90 Hz (Critical Flicker Frequency) (Linden 2022), which means that flicker at these frequencies are not perceivable. Even if it is not perceivable, it is still being registered by the brain, and it affects reading speed, reading apprehension and visual performance (Hemphälä 2022; Linden 2022). It can lead to migraines and headaches, photophobia (Wilkins et al 2010), hypersensitivity to electricity (Wibom et al 1995), epileptical seizures (Fisher et al 2005) (as summarized on fig. 15). Moreover, other potential responses to flicker are stress and annoyance (Linden 2022).

Negative effects of Temporal Light Modulation are shown on fig. 15.
Figure 15 - Negative health effects of flicker and other temporal light artefacts. Based on Linden 2022

Summary of the results

Table 4 compiles all the results described in this chapter and defines the main strategies of the proposal for redesigning lighting in the selected office.
Table 4 - Compilation of the results

<table>
<thead>
<tr>
<th>Issues / needs identified by the qualitative methods</th>
<th>Issues / needs identified by the quantitative methods</th>
<th>Strategies (based on Kellert 2018, Browning et al. 2020, El-Bannany et al. 2022 and Hemphälä et al. 2021 and developed further by the author)</th>
</tr>
</thead>
</table>
| 1. Lack of natural views                           |                                                    | 1.) Bringing visual connection with nature in the space by the patterns representing nature:  
- dappled light  
- water reflections  
- miniature trees and potted plants |
|                                                    |                                                    | 2.) Bringing non-visual connection with nature:  
- natural materials in the interior |
|                                                    |                                                    | 3.) Using nature analogues that mimic nature  
- biomorphic patterns and forms  
- colour palettes inspired from nature  
- complexity and order of geometrical patterns of natural forms |
|                                                    |                                                    | 4.) Adding mystery pattern through partially obscured views to stimulate exploration:  
- shadow play  
- see-through partitions |
| 2. Daylight: inadequately filtered direct sunlight, too high illuminance levels and too low illuminance uniformity ratio (street view side) |                                                    | Manipulating qualities of light and darkness  
- the diffusion of daylight |
|                                                    |                                                    | - façade skins for dynamic daylight patterns and enhanced shadows in the interior space |
| 3. Limited access to daylight (library view side)  |                                                    | Bringing more daylight in  
- reflective materials and colours  
- mirrors (tracking the sun path from the other side of the office and reflecting it into this side) |
|   | Harsh contrasts between materials in the interior  
|   | Too high luminance contrast ratio and the use of dark materials (e.g., floor carpet, cubicle shield, window frame)  
|   | Changing to materials with higher reflectivity and soft natural colours, soft gradients between materials (no harsh contrasts)  
|   | Extreme glare from downlights  
|   | The need to change to a different type of lighting in the office  
|   | Changing to another type of lighting, glare-free, with the light source placed outside of the visual field  
|   | Flicker when dimming the downlights to the lowest brightness in the meeting rooms; when dimming down table lamps in the office  
|   | Changing to a dimming technique with Constant Current Reduction (flicker free) in the meeting rooms; changing the light sources of the table lamps to other LED with no flicker  
|   | Lighting in the meeting rooms and the lunch room is too cold  
|   | Changing to another type of lighting, warmer light (lower CCT)  
|   | The need for tuneable lighting regulated at each desk  
|   | The lighting solution for task lighting should be tuneable at each desk  
|   | The need to dimming the lights down in the office manually  
|   | The need for different scenes with different intensities of light changing automatically throughout the day  
|   | The need for automatic lighting control system that would turn on the lights when it is getting dark outside  
|   | 1.) Ambient lighting in the whole space should be dimmable (manual and automatic control).  
|   | 2.) Scenarios with different light intensities and CCT changing automatically (can also be manually adjusted) throughout the day.  
|   | 3.) Daylight sensor and smooth light transitions from lower to brighter during twilight hours to dark hours transition.  

3.6 Proposal

In this chapter I present, visualise and describe my proposal for lighting design in the selected office (fig. 16-20). I suggest a number of interventions of the interior and lighting design scheme for the office space, which includes conceptual design solutions for ambient and task lighting (table 5 and fig. 17-19). Both solutions produce indirect light, i.e., are glare free, and are tuneable in terms of light intensity and CCT. The task lighting is designed in a way that no light is coming towards the computer screen (fig. 19). Floor lamps with light directed upwards are suggested for the meeting rooms in the office, two in each meeting room on either side of the table (fig. 20). In that way, there is no glare and the light reflected by the ceiling bounces from the surface of the table, softly illuminating faces without creating harsh shadows.
Table 5 - Proposed interventions and solutions for the selected office

<table>
<thead>
<tr>
<th>Strategy (see table 4)</th>
<th>Intervention / solution</th>
<th>Placement in the office</th>
</tr>
</thead>
</table>
| 1.) Bringing visual connection with nature in the space by the patterns representing nature | - dappled light: light from four spotlights on a track is filtered by three curved panels with stretched textured fabric and paper (fig. 18, 19)  
  - dynamic water reflections created by ripple glass wall mounted luminaries (fig. 18, 19)  
  - miniature trees and potted plants                                                   | Common area between the two sides. The track with spotlights is installed on the ceiling and the dappled light is created on the floor  
  Around the curved wall                                                                 |
| 2.) Bringing non-visual connection with nature                                        | - stones at the base of the trees’ pots                                                 | Near windows                                                                     |
| 3.) Using nature analogues that mimic nature                                          | - organic shape of the ceiling coves (slightly wavy) (fig. 17, 19)  
  - shields for cubicle lighting - smoothly curved (fig. 19, 20)  
  - textured glass walls                                                               | The whole office  
  Meeting rooms                                                                         |
| 4.) Adding mystery pattern through partially obscured views to stimulate exploration | - shadow play: dappled light installation  
  - see-through glass walls with texture  
  - curved wall with water reflections effect  
  - interactive dynamic digital lighting showing abstract water movements (behavioural) | The common area between the two sides  
  The meeting rooms                                                                    |
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5.) Manipulating qualities of light and darkness</td>
<td>- the diffusion of daylight by semi-transparent curtains with gradient from pale yellow to peach, slightly textured</td>
<td>The street view side</td>
</tr>
</tbody>
</table>
| 6.) Bringing more daylight in | - reflective materials and colours  
- a mirror tracking the sun path from the other side of the office and reflecting it into this side | Whole office  
The wall parallel to the entrance from the reading balcony (placement shown on fig. 17) |
| 7.) Changing to materials with higher reflectivity and soft natural colours, soft gradients between materials (no harsh contrasts), using colour palettes inspired from nature | - all walls in light beige  
- taking away the dark carpet, white floors as they are  
- cubicles in light beige (similar soft material as the existing one)  
- ceiling in ivory white  
- walls to the meeting rooms - textured glass  
- curtains: semi-transparent with gradient from pale yellow to peach, slightly textured | Whole office  
Only on the street view side |
| 8.) Changing to another type of lighting, glare free, with the light source placed outside of the visual field | - cove lighting for soft indirect ambient illumination of the space (LED strips)  
- lighting integrated in the cubicles and hidden behind metal shields for task lighting (LED strips with diffusers)  
- floor lamps with hidden light sources directed upwards – only indirect light reflected from the ceiling and bounced from the tables (light source - LED) | Ceiling and along the wall in the middle of the office  
All the desks  
The meeting rooms |
| 9.) Changing to a dimming technique with Constant Current Reduction (flicker-free) | - all the lights will be dimmable with Constant Current Reduction technique to avoid flicker completely | Whole office, including the meeting rooms |
| 10.) Changing to another type of lighting, warmer light (lower CCT) | - cove lighting and floor lamps with indirect light with CCT range 2700-3500 K | Meeting rooms and the lunch room |
| 11.) The lighting solution for task lighting should be tuneable at each desk | - personalised dimming control and adjusting the CCT (2700-3500K) at each desk | Whole office |
| 12.) Ambient lighting in the whole space should be dimmable (manual and automatic control) | - automatic and manual lighting control for dimming the cove lighting (ceiling and along the wall) | Two controls: one on each side of the office |
| Scenarios with different light intensities and (CCT) changing automatically (can also be manually adjusted) throughout the day. Daylight sensor and smooth light transitions from lower to brighter during twilight hours to dark hours transition. | - this automatic lighting control includes different scenarios of lighting intensity and CCT which change according to daylight conditions outside (daylight sensor): day, twilight, evening, special events, cleaning | Two different control systems and daylight sensors for each side of the office |
L1 - cove lighting
L2 - indirect lighting integrated in cubicles
L3 - floor lamps with upward lighting
L4 - dappled effect lighting
L5 - water reflection effect lighting
L6 - interactive dynamic digital lighting

Figure 16 - Suggested lighting solutions for the selected office, top view. Software: Rhino, Photoshop
Figure 17 - Suggested lighting solutions for the selected office, sections. Software: Rhino, Photoshop
Figure 18 - Suggested lighting solutions for the selected office, perspectives. Software: Rhino, Photoshop
Figure 19 – Suggested lighting solution for task lighting at different height of desks, perspectives. Software: Twinmotion, Photoshop
Figure 20 - Suggested lighting solution for the meeting rooms in the selected office, perspectives. Software: Twinmotion, Photoshop

Description and specification of the suggested solutions are available in Appendix C.
The selected office has two sides that differ a lot in terms of received amount of daylight, it is therefore important, to facilitate the maximum use of daylight for both sides through solutions tailored to the conditions of each side. Six out 16 users of the selected office would like to have more daylight reaching their desks. In this particular office, it would be very difficult to increase the amount of daylight coming in due to the atrium (the larger indoor library space). However, the atrium itself could be improved by a glazed roof with diffusors – then more daylight would enter the office from that side. Here, a good balance between the amount of daylight and thermal comfort for the atrium should be achieved.

Daylight provides great benefits for physical and emotional well-being for office workers, yet, the sun glare should be tackled in a right way (Woo et al 2021). Dimming the artificial lighting down according to the daylight conditions outside is important both for visual comfort but also for saving energy. Use of artificial lighting when daylight conditions outside are sufficient should be discontinued, instead lighting control with daylight sensor and dimming should be implemented. This would allow saving energy and prevent CO₂ emissions, contributing to achieving the goals 12 and 13 (UN 2015).

Results of this thesis supports previously stated argument that the use of downlights for any workspaces should be discontinued, as these luminaries cause glare and the mentioned negative health impacts (Hemphälä 2022). Moreover, as this specific study showed, the downlights fail to reach the required by standards illuminance level (500 lux) on one side of the office, even with the presence of daylight. This means downlights can be insufficient as the only source of illumination above workspaces.

I suggest the current practice of illuminating workspaces should be reconsidered in favour of indirect lighting, i.e., avoiding placing light sources within users’ visual field in order to prevent glare, eye strain and pain in shoulders and back (Hemphälä 2022) (G3 by UN 2015). I encourage testing and further developing the lighting solutions for ambient and task lighting which I conceptually designed in this thesis. These solutions produce indirect lighting and by hiding the light sources, we protect the users from glare and all its negative consequences on their well-being and health.
Moreover, the installed light sources should be able to be re-lamped and repaired, to avoid trashing the luminaires and contributing to e-waste, but also to avoid situations when other types of light sources are installed without proper consideration. This is the case in the selected office, as the architects who designed the space are unaware what light sources replaced the original ones for the downlights after some years of use. I wonder, who took the decision of choosing the light sources for these downlights, that turned out to be so disturbing for the users? How can we as lighting designers assure that light sources specified by us, would be installed in the future?

Another important issue detected in the selected office and affecting well-being of the office workers is flicker. This phenomenon is often invisible for the users, yet, it impacts their visual and work performance (Hemphälä 2022; Linden 2022). It can cause migraines, headaches and photophobia (Wilkins et al 2010) and other health related issues; is also known to be associated with increased stress and annoyance (Linden 2022). Therefore, it is critically important to use dimming techniques with Constant Current Reduction to avoid flicker completely (Ibid.). Thus, electrical engineers or other specialists who are in charge of making decisions and installing lighting control systems, should be well informed. Furthermore, flicker should be checked by work environment authorities to contribute to G3 by UN 2015.

I also suggest creating dappled light effect in the common area of the office to bring connection to nature in an abstract way, as it is associated with trees and sunlight (Chamilothori et al 2022). Moreover, adding water reflection lighting effect can be beneficial for an office environment, as presence of water (of water images) are one of the strategies of biophilic design (Browning et al 2020 and El-Bannany et al 2022). Reflective water also has its own special aesthetic value (Nasar and Li 2004). Biophilic design brings the mental (improved cognitive functioning etc.) and the psychological benefits (for concentration etc.) as well as positive physiological responses (reduced stress hormones etc.) - resulting in improved well-being, creativity and productivity (Guzowski 2019) - G3 by UN 2015. Furthermore, an interactive dynamic digital lighting showing water movements can work as a behavioural nudge for drinking water and going outside for a break (Rosenius 2023) - G3 by UN 2015.

In terms of interior design interventions, textured glass walls of the meeting rooms (instead of regular walls), allow light, both daylight and artificial light, to penetrate the walls and bring and borrow the light in both
directions (to and from the meeting rooms), while preserving the privacy - as they are not transparent. This contributes to the goals G12 and 13 (UN 2015), as fewer light fixtures and less energy would be needed in order to illuminate the meeting rooms. Moreover, textured glass creates beautiful effect of “inner glow” and contributes to “mystery”, one of the biophilic strategies suggested by Browning et al 2020 and El-Bannany et al 2022.

Another intervention is adding miniature trees near windows in order to create connection to nature and the outside world. I advise to move the existing potted plants closer to the windows as well. The plants need to stand near windows to receive daylight, and they also need darkness (the cycle of light and darkness) (Zielinska-Dabkowska et al 2019). I argue against artificial light for plants in workspaces where access to daylight is available, as daylight has a better quality of light, it supports plants’ day-night cycle. Besides that, it is dynamic and therefore together with a plant creates beautiful interplay of light and shadow that is changing during the day. Importantly, it allows saving on energy and resources for the artificial lighting specifically installed for plants (G12 and 13 by UN 2015). Moreover, light fixtures illuminating plants can cause glare (G3, Ibid.).

To summarize, during this thesis work, I explored numerous possibilities for incorporating biophilic design into workspaces through light. These include daylight control and lighting solutions, but also interventions in the interior design, as colours and materials in the space interact with light and influence perceived brightness in the space (Muro 2022; Enger 2022). Lighter colours and materials in the interior reflect much more light than dark materials, therefore less light is needed to achieve desired perceived brightness. This means saving both energy and resources used by and for unnecessary light fixtures - G12 and 13 by UN 2015.

The explored and suggested biophilic lighting design strategies can be applied for other workplaces, especially the ones that lack view to nature. Moreover, other indoor environments such as educational spaces, i.e., schools and universities, as well as health-care facilities could adopt these strategies in order to improve visual environment, bring in the missing connection to nature and thus benefits for well-being and health of users (G3, Ibid.). This in turn, can further foster and support social interactions.

Limitations

This thesis is focused on lighting and it is a site-specific project in Stockholm, Sweden during spring (April-May).
Due to the time limit of this study, it would not be possible to account for evaluating benefits of the proposed design strategies and solutions for well-being of the users. Instead, similar studies with shown effects for well-being were used to support the proposed solutions.

Moreover, the following factors influencing well-being of users in a workspace were excluded: indoor temperature and air quality, levels of noise and presence of hazardous materials in the indoor space, as they are not directly or indirectly related to lighting.

Furthermore, existing lighting conditions were assessed and measurements were done during daytime with combined daylight and artificial lighting. It was not possible to observe the space and take measurements during dark hours with the artificial lighting on only this time of year, as the sun sets between 21:00 and 22:00. Therefore, the existing lighting conditions could not be assessed according to the standards SS-EN 12464-1:2021 on lighting in workspaces and WELL certification requirements, which assess daylight conditions and artificial lighting conditions separately.

6 CONCLUSION

In this master thesis, I explore and suggest a compilation of biophilic lighting solutions and interventions of the interior for the selected office that has varied access to daylight and lacks views to nature. Research question of this work was:

*How can biophilic design strategies be incorporated into lighting design for an office with varied access to daylight and lack of views to nature?*

As I show in my thesis, this can be done by using the framework of 15 patterns of biophilic design suggested by Browning et al 2020 and applying it to lighting (reduced by nine patterns). It is important to conduct social research by survey about users’ needs and activities (tasks) and assess the existing lighting conditions in a space in order to tailor the lighting design to the specific context and needs.
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Figure 20 - Suggested lighting solution for the meeting rooms in the selected office, perspectives.
   Software: Twinmotion, Photoshop
APPENDIX A

Results of the measurements in the selected office

Table 1 - Luminance contrast ratios (important note: measurements were done with combined conditions of daylight and artificial lighting)

<table>
<thead>
<tr>
<th>Luminance contrast between</th>
<th>Measured values (measured by luminance meter Konica Minolta on the 19th April 2023 at 13:30, clear sky conditions)</th>
<th>Comparison to WELL certification requirement: not more than 10</th>
<th>Comparison to Standards Standards SS-EN 12464-1:2021 requirements: less than 10:1 (workspace to background)</th>
<th>Visual ergonomics recommendations from Hemphälä et al 2021: less than 1:5 (for both work area and visual field)</th>
</tr>
</thead>
<tbody>
<tr>
<td>desk to shield (wood to dark green)</td>
<td>1:29, 1:18</td>
<td>all the measured values do not comply</td>
<td>all the measured values do not comply</td>
<td>all the measured values do not comply</td>
</tr>
<tr>
<td>shield to wall (dark green to white)</td>
<td>1:34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>curtains to window frame (translucent yellow to black)</td>
<td>1:36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>downlights to ceiling</td>
<td>1:10782</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>downlights covered to ceiling</td>
<td>1:2406</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>desk to keyboard (wood to black)</td>
<td>1:17, 1:19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>curtains to shield (on a sunny day)</td>
<td>1:549</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point of measurement</td>
<td>Measured values (measured by illuminance meter Hagner Detector EC1-X)</td>
<td>Comparison to WELL certification requirement illuminance uniformity ratio 0.4 or more for any horizontal task plane</td>
<td>Comparison to Standards Standards SS-EN 12464-1:2021 requirements desk – 500 lux (only by artificial lighting); illuminance uniformity ratio 0.6 or more; cylindrical illuminance minimum 150 Lux</td>
<td>Visual ergonomics recommendations from Hempälä et al 2021 not too low or too high illuminance levels; more or less even illumination over the work area</td>
</tr>
<tr>
<td>----------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Illuminance levels measured combined daylight and artificial lighting (downlights on, all table lamps were switched off)</td>
<td>Library view side Desks near window Second desk Street view side Desks near window Second desks</td>
<td>496, 294, 358 206 1307, 1332, 974, 1704, 1461, 13790, 1112, 16760, 3080, 720, 12670, 1770 716, 544</td>
<td>do not comply (probably would comply with the table lamps on) comply (with daylight)</td>
<td>do not comply - high and extremely high values</td>
</tr>
<tr>
<td>12th April 11:00-12:00 Clear sky</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3 - Lightness of materials measured by NCS Lightness meter

<table>
<thead>
<tr>
<th>Material</th>
<th>Lightness values</th>
</tr>
</thead>
<tbody>
<tr>
<td>White wall</td>
<td>0.95</td>
</tr>
<tr>
<td>Light beige wall with texture (on the curved wall as well)</td>
<td>0.90</td>
</tr>
<tr>
<td>Green wall</td>
<td>0.55</td>
</tr>
<tr>
<td>Black carpet</td>
<td>0.15</td>
</tr>
<tr>
<td>White floor</td>
<td>0.55</td>
</tr>
<tr>
<td>Dark green shield</td>
<td>0.10</td>
</tr>
<tr>
<td>Wooden desk</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Flicker diagram for dimmed downlights in the meeting rooms

Flicker diagram for dimmed table lamps
APPENDIX B

Survey

Questionnaire questions are available online at

Results

The tasks performed in this office are work on computer, meetings - both face-to-face and digital, writing by hand and reading printed documents or books.

Regarding daylight and view, users’ opinions differ: roughly half of the respondents (nine out of 16) feel that they get enough daylight at their workspace and like the view to the library indoor space. In contrast, six respondents would want more daylight at their workspace. Five of them respondents say that they often feel sleepy or tired at their desk, as they do not get direct sunlight and or very little daylight. Five users also stated that they miss a good view, specifically seeing nature, sky, ground and people outside, four respondents feel disconnected with the world around them.

If we look on how the users perceive the daylight is regulated in the office, the majority (11 out of 16) is happy or satisfied, while three respondents say the daylight (sunlight) is too bright sometimes. Half of the respondents say sun glare is prohibiting their task performance.

Only six out of 16 say they feel comfortable with the existing artificial lighting. On the contrary, four users complain about negative effects of artificial lighting on health (headache, eye strain, irritation from downlights). Interestingly, five respondents answer that they do not know how the artificial lighting is affecting them. Seven respondents would like to have different type of lighting. One of them mention that the light in the meeting rooms and the lunch room is too cold, it feels uninviting and boring, and a warmer light would be more cheerful.

Preferences in terms of lighting control are the following: 10 respondents out of 16 would like to have tuneable lighting that can be regulated at each desk. Moreover, about half of the respondents (nine out of 16) would like to be able to dim the lights down in the office.
I miss a good view (seeing nature, sky, ground, people etc.)

I like the view to the library spaces it does not matter to me

Other - "I have a nice view from my window"

Do you feel that you get enough daylight at your workspace?

N OF RESPONDENTS

How do you feel about the view?

N OF RESPONDENTS
I often feel sleepy and tired at my desk, as I do not get any direct sunlight and/or very little daylight.

I feel disconnected with the world around me.

I miss following daylight changes throughout the day and seasons as well as seeing what weather is like outside.

I am satisfied with the amount of daylight I get.

I am happy with the daylight conditions at my workspace.

I get too much daylight - it is too bright for me.

This does not matter to me / I have never thought about it.

Other - "...I'm sure there are improvements to be made. Not certain exactly what"

Other - "When it is sunny, and at certain times of the year, the light is much too bright to work comfortably at my desk."

How do you think the daylight conditions at your workspace influence you and the way you feel?
Do you get so much direct sunlight at your desk, that it makes you squint and disturbs you when you are working on a computer?

- Yes, often: 0
- Yes, but very seldom: 7
- No: 8
- I do not know / I do not pay attention to this: 0
- Other - "Yes often, but we do have curtains that help": 1

Would you like to have more daylight at your workspace?

- Yes: 6
- No: 9
- It does not matter to me: 1
- Other: 0
How is the artificial lighting in the whole office being controlled?

- Automatically: 0
- Manually: 10
- Both: 4
- I do not know: 3
- Other: 0

How did you wish the artificial lighting was regulated at your office?

- I would prefer being able to dim the lights down: 9
- I would like an automatic control system that would turn on the lights when it is getting dark outside: 4
- I would like different scenes, e.g., morning, afternoon, evening with different intensities of light, which would be changed automatically: 5
- This does not matter to me: 2
- Other - "Good as it is.": 1
How do you think the artificial lighting at your workspace is affecting the way you feel?

- It gives me a headache: 1
- Tension/pain in my eyes: 2
- I feel comfortable: 6
- I feel stressed: 0
- I feel awake: 1
- I feel productive: 1
- It does not affect me: 2
- I do not know: 5
- Other - "Irritation from spotlights": 1

N of Respondents
It would be nice to be able to change the light myself at my desk, but I am even more interested in what kind of light we are using. In the dining room and the meeting room, the light is very cold and grey, so it feels uninviting and boring. A warmer more yellow light would cheer me up here! But this is not an issue at my desk. And one is able to change the light (dimming and brightening) in the meeting rooms. This is something that I appreciate, even though the light is a bit too grey in my opinion.

Additional responses acquired while talking to the users in the selected office, regarding the covered downlights:

“The light from the downlights was too harsh, it gave me a headache, made me feel angry. I am using a hood and my colleague - a cap, to get some relief. It is like to step into a shade on a bright sunny day. But now we have another problem with the downlights that are covered [glare from distance].”
APPENDIX C

Description and specification of the proposed lighting solutions for the selected office

<table>
<thead>
<tr>
<th>Lighting solution</th>
<th>Picture</th>
<th>Placement and amount</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L1 – Cove lighting</strong></td>
<td><img src="image1.png" alt="Diagram" /></td>
<td>Cove (ceiling) - see fig. 18</td>
</tr>
<tr>
<td>Flexible LED strips</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuneable White 2700-3500K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flicker free LED</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimmable with Constant Current Reduction technique</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| <strong>L2 – Task lighting</strong>    | <img src="image2.png" alt="Diagram" /> | All the individual desks in the office     |
| integrated in cubicles   |         |                                            |
| (indirect light - reflected and bounced within the cubicle) | |                                            |
| LED strips with a diffusor placed behind the shields | |                                            |
| Tuneable White 2700-3500K (individual control) | |                                            |
| Flicker free LED          |         |                                            |
| Dimmable with Constant Current Reduction technique (individual control) | |                                            |
| Cubicle - soft light fabric with high reflectivity 85% (same as the wooden desks) | |                                            |
| Shields hiding the LED strips – the same material as the cubicle | |                                            |</p>
<table>
<thead>
<tr>
<th>L3 - Floor lamps with upward lighting</th>
<th>Two lamps in each meeting room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light source LED - completely outside of the visual field</td>
<td></td>
</tr>
<tr>
<td>Tuneable White 2700-3500K</td>
<td></td>
</tr>
<tr>
<td>Flicker free LED</td>
<td></td>
</tr>
<tr>
<td>Dimmable with Constant Current Reduction technique</td>
<td></td>
</tr>
<tr>
<td>or approved as equivalent</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>L4 - Dappled light</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Parscan intrack spotlight with intrack adapter, size M, white, version 1 - Spherolit-lins narrow spot (one LED chip) by ERCO</td>
<td></td>
</tr>
<tr>
<td>LED module: 4,2 W, 357 lm, 2700 K</td>
<td></td>
</tr>
<tr>
<td>Multidim</td>
<td></td>
</tr>
<tr>
<td>DALI controlled</td>
<td></td>
</tr>
<tr>
<td>2) ERCO track, white</td>
<td></td>
</tr>
<tr>
<td>3) DALI connection to the tracks</td>
<td></td>
</tr>
<tr>
<td>4) ends of the track</td>
<td></td>
</tr>
<tr>
<td>or approved as equivalent</td>
<td></td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5) textured fabric from Fabric Forest or similar - Fishnet 3122 and Rib 3121 in colour amber</td>
<td></td>
</tr>
<tr>
<td>6) honeycomb packing paper</td>
<td></td>
</tr>
<tr>
<td>Two types of fabric and the honeycomb paper are layered and overlapped, the paper is in between the two fabric layers</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>4 spotlights</th>
</tr>
</thead>
<tbody>
<tr>
<td>length 4 m</td>
<td>2</td>
</tr>
<tr>
<td>exact amount of material calculated after testing on site</td>
<td>2</td>
</tr>
<tr>
<td>L5 - Water reflection effect lighting</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Water Effect Light system 150 with ripple effect by Radiant</td>
<td>The curved wall, number of luminaires to be determined after testing</td>
</tr>
<tr>
<td>Wall mounted</td>
<td></td>
</tr>
<tr>
<td>Dynamic, DMX controlled</td>
<td></td>
</tr>
<tr>
<td>A series of LEDs under a rippled glass panel</td>
<td></td>
</tr>
<tr>
<td>Up to 1500 lumens</td>
<td></td>
</tr>
<tr>
<td>3500K</td>
<td></td>
</tr>
<tr>
<td>Optics: stippled (subtle rounded pattern texture) with white finish</td>
<td></td>
</tr>
<tr>
<td>Satin white body finish</td>
<td></td>
</tr>
<tr>
<td>or approved as equivalent</td>
<td></td>
</tr>
</tbody>
</table>

![Image of a light fixture](image_url)