Sustainable lighting in offices

"How to save energy in offices with a new lighting design?"

An energy efficient Lighting design approach in offices

Project Study: ÅF Office

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Abstract:

Sustainable efficient lighting has become as one of the most important issues in the office environment. In Sweden, energy demand for lighting corresponds to 20% of the total electricity used in office buildings (1), while, It has been estimated that lighting accounts for about 20% of the total power generation of the world (2).

This thesis investigates how to make lighting in offices more sustainable and focuses on energy efficiency, to save energy through creating guidelines related to light source technologies, lighting control systems and the user preferences. Then those guidelines are applied to an existing office through suggesting a new lighting design. The existing office in this case is the ÅF company 10th office floor located in Stockholm, Sweden.

This investigation methodology consists of two main parts literature review and Project (Case) study. In the first part, methods used are a combination of literature review related to saving energy through sustainability in lighting and how light source technology, lighting control systems and the effect of user behavior could help to create more energy efficient lighting systems. In the second part, the methods are qualitative such as surveys, quantitative methods and personal observations.

In the results, the new suggested lighting design saves energy up to 31.96% more than the current lighting situation.

Key words:

1. Introduction

UN sustainable development goals 2030:

The United Nations created the World Commission on Environment and Development, which defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs".

The UN is always involved in the global sustainable programs and cooperates with many countries to achieve that, the most recent Agenda titled "Transforming our world: the 2030 Agenda for Sustainable Development".

In the agenda, there are 17 Sustainable Development Goals (SDGs) that have been set by the UN as an urgent call for action by all countries - developed and developing - that should be met by 2030. Between these goals are the Goal 7 Affordable and Clean Energy and Goal 11 Sustainable Cities and Communities and lighting are between the main factors that affect these goals (3).

![THE SUSTAINABLE DEVELOPMENT GOALS](https://sustainabledevelopment.un.org/?menu=1300)

Fig 1

Fig 1-2-3


Fig 2

Fig 3
The relationship between lighting systems and energy consumption is significant, as a shared research between both the US and Chinese governments shows. Lighting energy use in large office buildings is as high as 20% to 40% of the building total energy consumption in both China and the U.S.

Figure 4 and Figure 5 show that energy use profiles of typical large office buildings in both countries. Figure 4 is compiled from sub-metering the electricity of dozens of large office buildings in Beijing, China. Figure 5 was based on 130 large office buildings in California Commercial End-Use Survey (CEUS 2006) (4).

According to the UN reports, energy is the main contributor to climate change, it produces around 60% of greenhouse gases (5). UN facts shows that more efficient energy standards could reduce building and industry electricity consumption by 14% (5), thus comes the importance of using more energy efficient lighting systems that could be done through using a suitable light source technology, lighting control systems and understand the effect of user behavior on energy consumption.

![Figure 4: Electricity end-use profile of typical large office buildings in Beijing, China](image)

![Figure 5: Electricity end-use profile of typical large office buildings in California, U.S.](image)

These factors would be studied in this thesis to create guidelines that will be used in a suggested new lighting design for 10th office floor at ÅF Building. ÅF is an Engineering and design company within the fields of energy, industry and infrastructure since 1895) and a world leading office in lighting design, located in Solna, Stockholm.
1.2 Challenges and Needs:

After a meeting with ÅF representative, I summarized the sums of challenges and needs to address about the current lighting design as the following:

**Challenges to address:**

1. Consume too much energy in relation to W/m².
2. Limited user abilities (Weak controlled, non adjustable and non dimmable).
3. Aesthetically unattractive as the visual interest of the space is dull, boring, have no variety as it is uniform cold light.
4. They believe that the existed not favorable lighting design could negatively affect their employees, both psychologically and physically.

**The needs:**

- A new lighting design suggestion for the whole 10 floor building (ÅF Solna), that would:
  - Save more energy than the current one, and be more efficient in energy consumption, (Energy saving aspects).
  - Give the users (occupants) more control over light, to be able to choose where they need less or more light.
  - A better light control system than the current one.
  - Create (Aesthetically) a new lighting atmosphere, different from only cold uniform ceiling lights, like adding dynamic lights, or different color temperature.
  - The ÅF HQ building are relatively far from Stockholm city center, that is way the company have to spend on advertising and recruitments more than if it was near the center, so if lighting could help to promote for the company more it would be nice (Promotional aspects).
  - (Health aspect) to make the new lighting design helps in motivate their employees more (psychologically) and maybe even keep them healthier physically (lowering the sick leave amount).
  - Use the company new lighting concept called (Liquid light).
  - They would like to have investments returns calculation for the new suggestion.
2. Project Motivation and Limitations:

The motivation inspired from the need to try to implement the knowledge learned from the Master program and reflect it on a real life project, and try to approach sustainability aspects like energy consumption. I believe it is important to increase the awareness about using more efficient Energy lighting designs and understand how the users of the space could affect that, without forgetting the To use light where it is needed by studying vertical and horizontal surfaces and to use light efficiently regarding energy consumption and the function for the lit surface.

Limitation:

It is interesting to tackle all the needs and have a wider understanding to the situation but because of the limited time I have I chose to focus on a part of the offices 10th floor, through studying the current situation and create a better lighting design in 3 main aspects as following:

1- Energy efficient lighting that save more energy than the current one.

2- Understand the relation between Energy saving and users behavior in term of what type of light control would be more energy efficient (Automatic or Manual).

3- In the (RFI) it will mention what type of lighting control system and light sensors should be used and why, taken from the literature based research but it will not be a part of the energy calculation or the new suggested light design.

4- Trying a different approach than the regular office lighting in addition to dynamic lighting systems.

5- Suggest a lighting design.

6- Daylight effects would be mentioned in the Literature review as to understand the role of it, and the importance of the daylight sensors as it will be part of the (RFI) for future consecration but it will not be taken in consecration in the light calculation or the new suggested design.
3. Methodology

Used methods and justification:

The methodology used in this research consists of two main parts as follows:

1- Literature review:

Review former research and related materials that help to discover and understand the possibilities and the elements related to the researched subject, in a border scale like (Sustainable lighting, efficient lighting techniques…) then decide and choses a way of approach and elements to be focused on, then review researches related to them. Link the former collected research, with the Swedish lighting standards (Ljus & Rum 2013) based on European one EN12464-1, that will help to decide the working frame.

The former information in addition to the info from the Surveys will help to define project design guidelines.

2- Project Study (ÅF 10th floor part):

This will be done through Quantitative methods through calculating Current energy consumption and light sittings, Qualitative method through a surveys and a personal observation method through analyzing the current situation, that will add to the project design guidelines that helps at the end to suggest a new lighting design.

Both of the former parts will help in creating Recommendations for improvements (RFI) - Shown in the methodology structure - as it will serve a starting point for the suggested new lighting design.

Note:

Not all the Points that will be mentioned in the (RFI) would be take in consideration during the energy calculation or the suggested new lighting design, It will be there based as a literature based results that help to understand the situation in border perspective for any future considerations. It will be interesting to take all of them in consideration but because of the thesis time limit it is not possible.
3.1 Methodology structure and Main question forming:

In the below figure it shows the steps to how the question of the thesis get formed just to under in bigger scale how one thing lead to another, all steps related to the forming of the main question have been explained in details in P.6-7-8 in the thesis.

"How to save energy in offices with a new lighting design?"
4. Literature Review

4.1 Sustainable Lighting:

It is important to put always in mind how we can be more sustainable, by choosing the right lighting design approach and the right application to it. Thanks to the new lighting products and technologies, sustainability and energy efficiency is within reach. With the correct knowledge, these solutions can be put to good use in offices, commercial and industrial facilities, saving time and money, while benefiting the environment. Understanding the basics of energy efficiency and investigating unconventional concepts will help increase the productivity, comfort and well-being of the users of the space and empower companies to become more sustainable.

Why are more and more companies in Sweden switching to energy-efficient lighting?

The reasons include a reduction in energy bills and greenhouse gas emissions, and state laws that are beginning to mandate energy-efficient systems in new buildings in addition, the advancements in new lighting technologies are improving working environments, enhancing productivity. (6).

4.2 Factors & techniques that influence Energy Efficient in Lighting systems:

Under this main title is the summarize for the Chosen Energy saving methods and techniques. (To read all the literature collected about the other methods and techniques they are mentioned in details in the Appendix.)
In order to save energy, lighting systems should consume energy efficiently as possible, so it is important to understand what is Energy Efficient Lighting.

When the energy usage of a product is reduced without affecting its output or final response or user comfort levels is referred as energy efficiency. An energy efficient product consumes less energy to perform the same function when compared to the same product with more energy consumption. The energy efficiency in the lighting sector gives the required illumination level of the lighting scheme for the application it has been designed for, while consuming the least amount of energy. Simply, energy efficient lighting can save the electricity while maintaining good quality and quantity of the light (2).

There have been major improvements and innovations in lighting technologies which can offer a great potential for energy savings in many lighting applications such as household lighting, street lighting, hospitality and retail spotlights, office and industrial lighting, etc (2).

The following are the Chosen factors and techniques used in energy efficient lighting which are commonly practiced as energy-saving opportunities: (2)

1- New light source technologies give many option to Re-lamping with Energy-Efficient Lights sources have a main impact on energy saving potential in addition to choose lighting with more options than to turn ON/OFF, as the developments in light source technologies make that possible, for example Dynamic lighting with it (Tunable and Dimmable) abbelites open the door for many possibilities and benefits in addition to energy saving potential (2).

2- Improving the Lighting Controls system. Whether it is the system that is already in use or create new one, but in both cases Lighting Controls systems should be suitable to the lighting scenario, (In this case Energy efficiency). One way to improve a lighting controls system is by using a the right compensation of sensors and luminaires (2).

There is more factors and techniques could be used depending on the lighting case scenario, See the Appendix.
- **Light source technologies :**

Using the right lighting concept have a direct effects on any office or company on many levels, it affects energy consumptions levels related to the used light technology combined with control systems prevent any undue pressure on Infrastructure, and it affects the employees both (psychologically and physically), in addition to the Aesthetic, promotional aspects (7).

- **Energy saving light source Types & Comparison**

Energy efficient lamps can deliver the same amount of lighting with greater energy saving at low cost, when compared with conventional lamps. Traditional incandescent lamps consume a lot of energy to produce light in which 90 percent of consumed energy is given off as heat and also they consume more energy, typically 3-5 times more than the actual amount to produce light (2).

However, because of their lower energy efficiency and shorter lamp life, incandescent lamps should be used carefully for lighting of specific features.(8)
There are different types of CFL lamps available in today’s market. Some of these are spiral lamps, triple tube lamps, standard lamps, globe lamps, flood lamps and candelabra lamps. In case of replacing incandescent lamps, CFLs are chosen to match lumens that indicate the amount of light being generated as shown in figure below.(2)

Table 1: Comparison chart for incandescent, CFL and LED bulbs .(2)
These are available in a variety of light temperature such as warm white and soft white, cool white and bright white, etc. depending on the type of application. The table below illustrates a range of light temperatures of CFLs for specific application (2).

<table>
<thead>
<tr>
<th>Type</th>
<th>Purpose</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm white and soft white</td>
<td>Standard replacement of incandescent bulb</td>
<td>2700-3000K</td>
</tr>
<tr>
<td>Cool white and bright white</td>
<td>Good for kitchen and work spaces</td>
<td>3500-4100K</td>
</tr>
<tr>
<td>Natural or Daylight</td>
<td>Reading</td>
<td>5000-6500K</td>
</tr>
</tbody>
</table>

Table 2: Range of light temperatures of CFLs for specific application (2)

From the former information, the one shown in figure 3, Chosen to use LED or CFL will be the best lighting source technology in terms of power consumption, (RFI).

- Dynamic lighting (Tunable, dimmable) and its benefits:

A study with the “title Comparison of user satisfaction with four different lighting concepts” aims at comparing user satisfaction for different lighting concepts in an office environment. The lighting concepts being compared are a conventional static lighting concept from ceiling mounted luminaires against three different types of dynamic task lighting concepts, the first providing occupant controlled task illuminance, the second concept providing occupant controlled CCT and the third providing automatically controlled CCT. Another aim is to identify which of the four lighting concepts is rated as most preferred by the test subjects. Adjustable CCT of the task light was the most preferred lighting concept followed by adjustable task illuminance. Automatically controlled task CCT and conventional lighting were the least preferred (15).
Color-tunable or ‘Tuneable lights ’ control allows users to create preset ‘scenes’ for diverse scenarios. For example, a classroom wall switch might be set up, with different light level and CCT settings suited for those activities. An interior patient room at a hospital might have a ‘morning’, ‘lunchtime’, and ‘bedtime’ scenes to mimic natural daylight. Color-tunable control provides more flexibility than warm dimming and in addition to mimicking daylight for circadian rhythm or assisting with behavior control, can also provide different ambience and enhanced environmental control for a variety of situations. This type of control is well-suited for healthcare, educational, office, and multifamily spaces (10)

- Tunable lighting:

Tunable white lighting technology is defined as the ability to control a light source’s color temperature output. It is also referred to as variable white, dim to white, hybrid white, or custom temperature lighting from other manufacturers. This is done by manufacturing the lightbulb or lighting strip with different color temperature LEDs. Using a remote control or external control system, you are able to select the desired color of white anywhere between the available range specified by the manufacturer. (9)

Classify ‘white’ light? What is CCT?

The color of white light can be quantified by referring to its color temperature. temperature called, CCT (Correlated Color Temperature) refers to the color temperature of light, measured in degrees Kelvin (K). The temperature rating directly correlated to what the white light will look like to us humans. The daylight color temperature are best suitable for offices, workshops, bathrooms or other areas where high detail visibility is important. (like 5700k color temperature light) (10), As Daylight are 5500-6500K (11).
What is the best color temperature for office?

Neutral to cool color temperatures (3000-4000K) are generally appropriate in office space (12).

- Dimmable lighting

Dimmers are devices connected to a light fixture and used to lower the brightness of light. By changing the voltage waveform applied to the lamp, it is possible to lower the intensity of the light output. (13)

What are the Benefits of Dynamic lighting ?(Tunable and Dimmable)

Having the option to control the lighting can be beneficial in several ways (9) :
- Health Benefits - Your Circadian Rhythm and lighting
- Increased productivity
- Sustainability
- Design Focus

The ability to have full control over the CCT of your light source was previously inconceivable. A scientific study shows the benefits of using dynamic lighting technique in indoor architecture lead to the following final considerations:
- The application of a dynamic lighting system surely offers some benefits to an environment: well-being, comfort, relaxation. The benefits are especially evident in environments like offices and they can be assessed economically only as a decrease of absenteeism in the workplace .
- The dynamic lighting system can lead to minimum but not significant energy savings compared to standard lighting system.
- As things stand now, the cost of the equipment of a dynamic lighting system is not economical compared with the standard system, however:
- The dynamic lighting system opens new possibilities for artistic lighting of the exhibition spaces and gives them a feeling of open space (14) (RFI).
4.9. Improving Lighting control systems

Lighting control system is an intelligent network based lighting control solution that incorporates communication between various system inputs and outputs related to lighting control with the use of one or more central computing devices. Lighting control systems are widely used on both indoor and outdoor lighting of commercial, industrial, and residential spaces. Lighting control systems serve to provide the right amount of light where and when it is needed. (15)

Lighting control systems are employed to maximize the energy savings from the lighting system, satisfy building codes, or comply with green building and energy conservation programs. Lighting control systems are often referred to under the term Smart Lighting.

The term lighting controls is typically used to indicate stand-alone control of the lighting within a space. This may include occupancy sensors, time clocks, and photocells that are linked to control fixed groups of lights independently. Adjustment occurs manually at each devices location. The efficiency of and market for residential lighting controls has been characterized by the Consortium for Energy Efficiency. (16)

The term lighting control system refers to an intelligent networked system of devices related to lighting control. These devices may include relays, occupancy sensors, photocells, light control switches or touchscreens, and signals from other building systems (such as fire alarm or HVAC). Adjustment of the system occurs both at device locations and at central computer locations via software programs or other interface devices. (17)

- Types of Automated control systems

Lighting control systems typically provide the ability to automatically adjust a lighting device's output based on: (17)

* Chronological time (time of day)
* Solar time (sunrise/sunset)
* Occupancy using occupancy sensors
* Daylight availability using photocells
* Alarm conditions
* Program logic (combination of events)
One way to understand the relationship between the Control system and energy saving in lighting systems is through Occupancy-based lighting control.

In an article published by Christel de Bakker *, Tom van de Voort and Alexander Rosemann with the title The Energy Saving Potential of Occupancy-Based Lighting Control Strategies in Open-Plan Offices: The Influence of Occupancy Patterns it stated that,

"Occupancy-based lighting control strategies have been proven to be effective in diminishing offices’ energy consumption. These strategies have typically worked by controlling lighting at the room level but, recently, lighting systems have begun to be equipped with sensors on a more fine-grained level, enabling lighting control at the desk level.

The study examined the influence of occupancy pattern variance within an office space on the relative energy savings of control strategies with different control zone sizes. "In all cases, lighting control at the desk level showed a significantly higher energy savings potential than strategies with lower control zone granularity, suggesting that it is useful to implement occupancy-based lighting at the desk level in all office cases.” (RFI)

"In addition to new lighting sources, automatic lighting control strategies are being applied to provide lighting based on the real-time needs of offices. The main variables determining these needs are (1) the availability of daylight, and (2) the presence of occupants in an office space. These factors can be determined with light and occupancy sensors, respectively. Occupancy sensors have been applied for many years in offices and have been proven to produce energy savings of between 20% and 60% [5–7]. However, to achieve maximal energy savings, occupancy sensors should be combined with daylight controls [8,9] “ (RFI)

In North America, two studies have evaluated lighting control at the desk level on energy savings potential [20,21], finding that the relative savings were 42% and 40% compared to baseline cases, where, respectively, lighting was used according to the daily work schedule and where lighting was switched on and off manually [20,21]. (18).
Figure 8. Relationship between lighting energy use and occupancy spread for the three different control strategies (individual control = green, subgroup control = blue, room control = red).(19)
"In order to meet all the recommended guidelines the lighting has an impact on to define where the workplace is and its size. The visual performance and a visual comfort were the lighting have to be formed so that the eye can fast perceive the surroundings and obstacles adaptively and easily without having any disturbance. The brightness and light intensity has to vary for the different work assignments and workers. It's also important to know where and in which position in the working area the placement of the lights should be, how the actual space is and what kind of interior design is applied to the space. The light angles/directions should be adjustable according to the task, since a working area can differ from the diverse heights which effect the light distribution; this make it hard to meet the regulations of the lighting equability, glairiness and intensity. For example, the location of a display and work areas" "heights can vary. These kind of dynamic changes must also be taken into consideration to avoid any disturbing sources as glare, light intensity, uniformity etc." (19)

A good flow chart in the planning process while designing the lighting conditions in an office environment, according to guidelines in Ljus & Rum, is to:

1- **Specify:** The visual-comfort (conditions) and make sure to follow up the guidelines regarding risk zones and safety etc.
2- **Analyze:** The legal requirements regarding quality, specifications, physical demands, economy, energy etc."
3- **Plan:** The natural and artificial lighting, sun screening (glairiness), choice of lighting system & luminaires, control & maintenance systems, calculations etc."
4- **Document:** If The lighting system follow up the guidelines, efficiency, economy etc."
5- **Verify:** Document and measure the light-system etc.

(19)
Daylight and windows:

The varied daylight gives both character and energy efficient lighting to the lit space. The daylight provides a divided quality of the colors and the uniformity to the space which provide a positive feeling/experience for the employees. The horizontal daylight that shines through the windows gives a constantly changed natural contrast. The main task of the windows is for an employee to be able to lookout, but the design and the location is also of great importance for the opportunity to exploit the daylight. The lighting planner should try to keep in mind to place the window in the darkest area of the room. According to the Swedish working environmental regulations should the working-staff which are intended to be staying in more than temporary times within a working area have an access to a satisfactory daylight and opportunity for an outlook (window). When planning the lighting in workplace it is of importance to find out the weather conditions, sun path, how the surroundings are and were the windows are facing. Daylight control of lighting is one of the best ways to save energy and reduce environmental impact. Windows planned and placed in right angles reduces the stress and benefits the well-being. (19).
5. Project study (Analyzing Current Situation)

Current situation of ÅF’s lighting system:

- The following Data summarized after interviewing Björn Berggren at ÅF infrastructure Division /Electrical Engineering:

The current lighting system in the ÅF HQ building has two different light control systems:

**DUC**: The main electronic lighting control system.
DUC (Data under central) unit, it is an electronic control system for real estate automation.

- On working days: It is turned on consistently from 6AM to 8PM
- On weekends: manual switch
- After 6PM: manual switches for different parts of the floor than turn on a group of lights in the needed part.
- Some Light fixtures that serve as guide lights are lit 24/24.

**DALI**: 2 DALI control systems, one in the Entrance 4th floor and the second one located in the 9th floor.

The DALI control system is more flexible than the DUC control system as it allow easier programing and more control options than the DUC. The building lighting system is designed in 1995 for an commercial offices spaces use without any specified inner walls to allow freedom of space use The standard back then stated that in an office building the power consumption should be around 30W/m2 but today standards from the SVENSK STANDARD SS 437 01 02, dated from 2014-09-16 States that it should be around 20W/m2.

Lighting should consume 5-10 W per square meter in modern buildings, as it was around 10-15W per square meter in older building (build from 10-12 years ago) the reason of the differences is due the developments in lighting technologies, as ÅF building in Solna have been build from almost 12 years ago.
Figure -- 10th floor different Areas controlled by manual light switches after 6pm

Figure -- 10th floor Location of manual light switches and the 24/24 Guide lights
This power consumption values are for all the electrical devices in the building like ( computers , printers , coolers and lighting ...etc. ) **There is no specific standards about what percentage should a lighting system consume from the total energy but as , an experienced base data it is 5 -10 Wm2 in modern build systems , and around 10-15W per square meter 10 -12 years old systems .**

- **Process and Analyzing :**

1- Analyzing current situation :

**The ÅF headquarter building in Solna consist of 10 floors ,**

3 underground and the entrance is at the 4th floor . The offices area is located in the 10th floor , and it is divide into many areas , the following is the Summering of the floor 10 :

Total Area = 2052 m2 , Total working places : 112 ( working places/station ) as followings :

- 100 unit as an open floor .
- 12 unit as a specified room .
- Meeting room for 22 pers 1 room
- Meeting room for 8 pers 1 room
- Meeting room for 6 pers 2 rooms
- Meeting room for 3-4 pers 7 rooms

All the rooms are shown in fig11 next page .
Pentry 2 areas
in addition to many, Time break (Fika areas) and spontaneous meeting areas.
copying and printing rooms 3 rooms
Big storge 1 room
Small storge 1 room

Coat/hangers rooms 2 rooms
WC 7 rooms
Special need WC 2 rooms
cleaning rooms 2 rooms
Fig11. Current situation Floor 10:

- Open floor working places
- Time break (Fika areas) and spontaneous meeting areas
- Office rooms
- Movement and circulation
- Printing, storage other service rooms
- WC & Pantry
5.1 Studied Project Area:

Project Area
237.5 m²

Figure -- Layout of 10th floor at ÅF HQ, Lightings office in Stockholm
5.2 Current ceiling lighting situation:

3D representation for Project study area, shows floor lamps.
## 5.3 Quantitative Approach:

### Current Energy Consumption Calculation:

In this studying scenario it is considered that all ceiling lights, pendant lights and floor lamps are ON, and desk task lights OFF.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Pic</th>
<th>Name</th>
<th>Type</th>
<th>color temp</th>
<th>Power</th>
<th>Amount</th>
<th>Total energy con in Watts</th>
<th>light source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image" alt="Louis Poulsen type 16200-LC Shutters" /></td>
<td>Louis Poulsen type 16200-LC Shutters</td>
<td>Pendant</td>
<td>2700K</td>
<td>1 * 70 W</td>
<td>3</td>
<td>210</td>
<td>Diffused</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Louis Poulsen Arque" /></td>
<td>Louis Poulsen Arque</td>
<td>Pendant</td>
<td>2700K</td>
<td>1 * 60 W</td>
<td>1</td>
<td>60</td>
<td>Diffused</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Rapido luminaire from Ecolux" /></td>
<td>Rapido luminaire from Ecolux</td>
<td>Recessed</td>
<td>2700K</td>
<td>2 * 14 W</td>
<td>1</td>
<td>28</td>
<td>T5(Fluorescent)</td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Rapido luminaire from Ecolux" /></td>
<td>Rapido luminaire from Ecolux</td>
<td>Recessed</td>
<td>2700K</td>
<td>2 * 28 W</td>
<td>31</td>
<td>1736</td>
<td>T5(Fluorescent)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total (Ceiling)</th>
<th>2034</th>
</tr>
</thead>
</table>

| ![LINETIK-S LED8000-830 SC WH SR2 IL](image) | LINETIK-S LED8000-830 SC WH SR2 IL | Floor lamp | 3000 Kelvin | 69 W | 15       | 1035                      | LED |

| Total (floor lamps) | 1035 |

| desk task lights | Not considered in the calculation too many different models and types, in some desks there is two desk lamps. |

| Total (Disk lights) | |

Total lighting energy consumption (without disk lights) = 3069 Watt

Per m2 energy consumption (without disk lights) = 3069/237.5 = 12.92W/m²

Per Person* energy consumption (without disk lights) = 3069/27 = 113.66W/person

* The amount of users in the studied are 27 as there is 38 desks with 12 of them considered Flexible not owned by a particular person (could be all empty/full), Shown in the next page figure 25.
Interestingly in the current situation not all the ceiling lights are ON in the office, reason way is because the company did a study report and on it the decided to turn them off and bring the floor lamps. So i took measurements in the areas where the ceiling lights are ON, as shown in the figure, (floor lamp and desk light where OFF).
Using a spectrophotometer shown in the figure below I took measurements of illuminance, color temperature, CRI (Color Rendering Index) to see how does it corresponds with the recommended standards, at night 11:30 PM. So natural light have minimum effect, location of measurements shown in the fig below.

Model CL-500A
Quantitative measurements:

<table>
<thead>
<tr>
<th>Point Nu.</th>
<th>Illuminance level (Lux)</th>
<th>CRI (Ra)</th>
<th>color temp.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>503.10</td>
<td>83</td>
<td>3340</td>
<td>Desk on the drawing LA-1</td>
</tr>
<tr>
<td>X2</td>
<td>367.31</td>
<td>82</td>
<td>3330</td>
<td>LA-2</td>
</tr>
<tr>
<td>X2</td>
<td>503.22</td>
<td>84</td>
<td>3350</td>
<td>LA-3</td>
</tr>
<tr>
<td>X3</td>
<td>393.22</td>
<td>83</td>
<td>3340</td>
<td>LA-4 (The disk is up most of the time)</td>
</tr>
<tr>
<td>X4</td>
<td>512.9</td>
<td>84</td>
<td>3340</td>
<td>LA-5</td>
</tr>
<tr>
<td>X5</td>
<td>497.81</td>
<td>83</td>
<td>3350</td>
<td>LA-6</td>
</tr>
<tr>
<td>X6</td>
<td>506.41</td>
<td>82</td>
<td>3333</td>
<td>LA-6 with LED floor lamp top ON</td>
</tr>
<tr>
<td>X7</td>
<td>638.11</td>
<td>82</td>
<td>3350</td>
<td>LA-6 with LED floor lamp down ON</td>
</tr>
<tr>
<td>X8</td>
<td>481.9</td>
<td>83</td>
<td>3340</td>
<td>LA-7</td>
</tr>
<tr>
<td>X9</td>
<td>502.22</td>
<td>82</td>
<td>3350</td>
<td>LA-8</td>
</tr>
<tr>
<td>X10</td>
<td>477.90</td>
<td>82</td>
<td>3323</td>
<td></td>
</tr>
<tr>
<td>X11</td>
<td>480.65</td>
<td>82</td>
<td>3350</td>
<td></td>
</tr>
<tr>
<td>X12</td>
<td>503</td>
<td>84</td>
<td>3340</td>
<td></td>
</tr>
<tr>
<td>X13</td>
<td>493.23</td>
<td>83</td>
<td>3320</td>
<td></td>
</tr>
<tr>
<td>X14</td>
<td>501.78</td>
<td>82</td>
<td>3310</td>
<td></td>
</tr>
<tr>
<td>X15</td>
<td>553.23</td>
<td>84</td>
<td>3320</td>
<td></td>
</tr>
<tr>
<td>X16</td>
<td>401.5</td>
<td>83</td>
<td>3350</td>
<td></td>
</tr>
<tr>
<td>X17</td>
<td>579.3</td>
<td>83</td>
<td>3310</td>
<td></td>
</tr>
<tr>
<td>X18</td>
<td>473.81</td>
<td>83</td>
<td>3340</td>
<td>in the middle between LA-5 &amp; LA-3</td>
</tr>
<tr>
<td>Point Nu.</td>
<td>Illuminance level (Lux)</td>
<td>CRI (Ra)</td>
<td>color temp.</td>
<td>Notes</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------</td>
<td>----------</td>
<td>-------------</td>
<td>-------</td>
</tr>
<tr>
<td>X19</td>
<td>838.61</td>
<td>83</td>
<td>3340</td>
<td></td>
</tr>
<tr>
<td>X20</td>
<td>383.41</td>
<td>83</td>
<td>3350</td>
<td></td>
</tr>
<tr>
<td>X21</td>
<td>403.25</td>
<td>83</td>
<td>3320</td>
<td></td>
</tr>
<tr>
<td>X22</td>
<td>395.31</td>
<td>83</td>
<td>3340</td>
<td></td>
</tr>
<tr>
<td>X23</td>
<td>395.75</td>
<td>84</td>
<td>3325</td>
<td></td>
</tr>
<tr>
<td>X24</td>
<td>218.31</td>
<td>83</td>
<td>3340</td>
<td></td>
</tr>
</tbody>
</table>

An former ÅF report shoe in the fig below, with a Dialux model of the studied area that Lux levels are 500Lux on average for all the studied area, the reason way is that lights system designed from the company that build the office as they considered the whole studied area as a Direct working space because they don't know how the furniture will be organized in the space, as (Ljus & Rum (2013) P. 94) standards indent lux level for Direct working space to be 500Lux.

Before starting to install the lighting installation we built up the space in the program DialuxEVO to simulate the new light situations as well as measured the light level of the existing light situation with a lux meter. In the following table you can see the light level, the color temperature and the color rendering index for the lighting situation at floor 5 and 10 before and during the new lighting installation.

<table>
<thead>
<tr>
<th>Position A (first row from the window)</th>
<th>Floor 5</th>
<th>Floor 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light level in lux</td>
<td>469</td>
<td>472</td>
</tr>
<tr>
<td>Color temperature in Kelvin</td>
<td>3181</td>
<td>3345</td>
</tr>
<tr>
<td>Color rendering index (CRI)</td>
<td>87</td>
<td>88</td>
</tr>
</tbody>
</table>

This is way it is important to do a personal observation to understand the types of activities that is happening in the studied area so every activity zone should get the suitable standards lux level, as that would lower the energy consumption.
5.4 Personal Observation:

Activities in the space:

Figure 25 shows a small area in the studded office that contains different activates areas colored in different zones, it is important to put in mind the recommended standards (Ljus & Rum (2013) P. 94) for every activity area should have a Lux level correspond with the type of the activity, these recommendation are:

1- 500 Lux for the Direct working space, (Shape defined by the planner) I choose the size and shape of an A3 on the desks and full of on the Fika table, shown in Purple zone.
2- 300 Lux for Immediate environment, Shown in Yellow, light Green and light blue zone.
3- 100 Lux for External environment, Shown in red zone.

![Figure 25](image)

- Direct working space 500 Lux.
- Working zone, (Immediate environment) 300Lux.
- Bookshelf / brief reading zone (Immediate environment) 300Lux.
- Passing zone, (External environment) 100 Lux.
- Break zone (External environment) 100 Lux.
According to the former activity and lux levels Zone, Figure 26 Show the whole studied area, with type of activity and Lux level as the following:

Figure 26

- **Working zone**, (Immediate environment) 300Lux.
- **Passing zone**, (External environment) 100 Lux.
- **Bookshelf / brief reading zone** (Immediate environment) 300Lux.
- **Break zone** (External environment) 300 Lux.

In order to have an understanding about what surfaces, elements or areas that are interested to focus on or not, a personal observation about the lit surfaces and points of interest should be done.
5.5 Lit surfaces and points of interest:

In the following figure are some pictures taken at the studied place with the standing points are shown with numbers and direction arrow. This pictures will help to show the Interior architectural elements, surfaces and volumes and how the user of the space observe it, then use lights to enhance those elements that would help in enhancing the whole atmosphere. The points of interest are shown in blue circles.

As shown in picture 1-2,8,11 one of the first things that appear through the entrance is the columns, so by lighting up points of interest like that this would create a different visual experience than the current one and be more interesting to the occupants than the current situation.
Picture 3-4 - 9 show the wall of the corridor and meeting room as they are a big surfaces that are not shown enough that could be used to create a dynamic lights effects that change the regular Uniform ceiling lights.

Picture 5-6 show bookshelves that appear dark in it depth, and when some one try to have a book the lights from the background could create casted shadow that darken the shelves even more, an integrated frame lights would help in solving the problem.
5.6 Types of Vertical and horizontal surfaces:

- Working zone horizontal
- Working zone vertical
- Passing zone horizontal
- Passing zone vertical
- Reading zone horizontal
- Reading zone vertical
- Break zone horizontal
- Break zone vertical

- From the former sketch it show the user casted shadow on the bookshelves that prevent lights to lit the depth of the shelves, and integrated light with the farm is a suggested solution, the details of it will be shown in the results pages.

- The vertical surfaces like the Columns is a noticeable Architectural elements, that could provide a visual references and a point of interest.
6. Survey and Questionnaire (Qualitative)

7 Visual – Perceptual factors of light:

7 answered the survey, the 7 factors are graded with scale 1 to 5 and the it is done in May-2019, from 10:00pm till 12:00pm results are shown below:

<table>
<thead>
<tr>
<th>Employee No.</th>
<th>Level of light</th>
<th>Light distribution</th>
<th>Shadows</th>
<th>Reflections</th>
<th>Color of light</th>
<th>Appearance of surface color</th>
<th>Glare</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

1.1 Level of light (Evaluation)

2.1 Light distribution (Evaluation)

3.1 Shadows (Evaluation)

4.1 Reflections (Evaluation)

5.1 Color of light (Evaluation)

6.1 Appearance of surface color (Evaluation)
User Opinion/ Preferences, Questionnaire:

The aim of this Questionnaire is to get an idea about the users' preferences that would help in refining the choices of lights insulations. It is done in May-2019, from 10:00pm till 12:00pm. Results shown below:

Would you like to see different color temperatures in the office area?

What are the weather conditions?

Would you like to have more control over your desk light? (Dimmable, tunable lights)

In which age range are you?

Would you like to have dynamic lights in the office floor?

How would you like to control your desk lights?
From the 7 Visual – Perceptual factors of light table shows :

The level of light is acceptable and lean towards bright, and this means there is no need to rise the light levels. The light distribution is considered by the employees to be leaning towards uniformity, with vague (almost not so noticeable) shadows, as this is suitable for office environments. The level of reflections and Glare is in the acceptable levels. The color of light leans towards cold, with natural appearance of surface color as this is suitable for office environments.

From the Questionnaire it shows:

Most of the employee would like to see a different color temperature than the current used one and would like to have dynamic lights as the new suggested design show on the wall near the entrance and on the meeting room wall. (RFI)

More than 85% want more control over their desk lights that is way the in the new suggested design desk lights are Dimmable and tunable and have the flexibility to be controlled by mobile App or manual switches. (RFI)
7. Results

7.1 Recommendations for improvements (RFI) :

- The following (RFI) points are collected from the information gained from Literature Review, to be used to create the new suggested lighting design

From the literature based Review :

- As a light source technology it is recommended to use LED or CFL, as they are the best in terms of power consumption efficiency.

- It is advisable to use a Dynamic lighting (Tunable, dimmable) the reasons and benefits are explained in Page 15 to 17.

- It is advisable to use an implement occupancy-based lighting at the desk level in addition to daylight sensors, the reasons and benefits are explained in Page 18 to 20.

- According to Swedish light standards Ljus & Rum 2013, Lux level should be:
  - 500 Lux in Direct working space.
  - 300 Lux in Immediate environmental space.
  - 100 Lux in External environmental space.

Information shown in Page 21 to 23. Other Values for Corridors in Appendix.

From the Questionnaire :

- It is advisable to use different color temperature and dynamic lights, see Page 42.

- Giving the employees more control over their desk lights are required, see Page 42.

From Personal Observations :

- Use and integrated light with the farm of the bookshelves, helps to lit the shelves depth minimizing the casted shadow effects.

- Illumination to vertical surfaces like the Columns as it is a noticeable Architectural elements, would provide a visual references and a point of interest.
7.2 Vision and Mood board

Create a new visual experience, different than the current one by using light levels and color temperature corresponds with the type of activities in every zone, and create point of interests by emphasise on some architectural elements in the space to give a visual references, in an Energy efficient scenario.

![Fig 14 Integration light with the frame to lit the depth of the shelves](image1)

Fig 14 Integration light with the frame to lit the depth of the shelves

![Fig 15 The user have the ability to control task lights through mobile App or physical light switch located on the desk.](image2)

Fig 15 The user have the ability to control task lights through mobile App or physical light switch located on the desk.

![Fig 16 Tunable dynamic lights](image3)

Fig 16 Tunable dynamic lights

![Fig 17 Linear Modular ceiling allows easy to adjust lights positions to correspond with changes of the furniture.](image4)

Fig 17 Linear Modular ceiling allows easy to adjust lights positions to correspond with changes of the furniture.

![Fig 18 A point of interest for the employees to near the pantry help to change their focus and inspire them as it would look different everyday.](image5)

Fig 18 A point of interest for the employees to near the pantry help to change their focus and inspire them as it would look different everyday.
As there is different types of activities, different light temperature are used to give different visual effects (based on RFI information list) and mood board, the following design approach have been done:

- Circle 1, is a small place to sit and talk even for a quick (Fika) a warm color light to create a relaxing atmosphere differs than the cold lights that are used for the working space.

- Circle 2 The area in circle 2 a cold color temperature between (3500-5500K) and the fixtures are positioned in modular repetitive way to provide a uniform lighting.

- Circle 3 Is a dynamic lighting system linked to a daylight sensor that change color temperature and light intensity in relation with daylight. This lighting system also give the occupants the ability to change it color temperature manually through a pre programed switches near the entrance.

- Number 4 Creating a point of interest for the employee using a modular, touch sensitive wall light hexagonal magnetic tiles. Those tiles could be rearranged or change it color temperature. The aim from using it is to help employees to change their focus relax and inspire them as it would look different everyday.
A new ceiling design that allows more flexible light repositioning, as light units could be reordered to fit future changes in the type of activities in the space and furniture repositioning.

Details for the linear fixture is been fixed in the liner covered slots. The ceiling is a modular 600x600mm ceiling tiles between 100mm liner covered slots.
Frame Integrated LED lights for bookshelves, allows the user to see more details for along the depth of the shelves and avoid casted shadows.

A closer image to show the poisoning of the linear LED light and its effect.

A sketch to show the user casted shadow on the bookshelves that prevent lights to lit the depth of the shelves.
The columns are one of the first noticed elements in the space, as shown in picture 1 in Page 37. Lighting the surface of the columns by emphasizing on verticality gave the column a graceful appearance.

A Closer image to show the warm light at the break zone (Fika) in comparison with the cold color temperature surrounding.
Closer image that shows all light fixtures are ON. The dynamic lights at the background, vertically emphasized columns, desk lights and bookshelves.

The view from the warm light break zone.
- List of All used lighting fixtures in the design with all its properties:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Luminaire (Luminous Intensity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>ERP - 31260000 Lady Task light 1xLED 10W neutral white</td>
</tr>
<tr>
<td></td>
<td>Luminous intensity 1</td>
</tr>
<tr>
<td></td>
<td>Filling: 1xLED</td>
</tr>
<tr>
<td></td>
<td>Absolute photometry</td>
</tr>
<tr>
<td></td>
<td>Luminous luminous flux: 291 lm</td>
</tr>
<tr>
<td></td>
<td>Power: 13.6 W</td>
</tr>
<tr>
<td></td>
<td>Luminous efficacy: 22.4 m/W</td>
</tr>
<tr>
<td></td>
<td>Colorimetric data</td>
</tr>
<tr>
<td></td>
<td>1xLED 10W neutral white: CCT 4000 K, CRI 80</td>
</tr>
</tbody>
</table>

29 ERGO - 60020000 Quadra Downlight 1xLED 9W neutral white
Luminous intensity 1
Filling: 1xLED
Absolute photometry
Luminous luminous flux: 912 lm
Power: 13.6 W
Luminous efficacy: 78.5 m/W
Colorimetric data
1xLED 9W neutral white: CCT 4000 K, CRI 83

5 LERO GmbH - 30000000_e043 Site in-ground luminaire
Luminous intensity 1
Filling: 1xLED 24W neutral white
Absolute photometry
Luminous luminous flux: 1295 lm
Power: 21.6 W
Luminous efficacy: 59.1 m/W
Colorimetric data
1x CCT 4000 K, CRI 80

1 LERO GmbH - 80003000_e043 Starpoint Pendant downlight
Luminous intensity 1
Filling: 1xLED 5W warm white
Absolute photometry
Luminous luminous flux: 474 lm
Power: 11.2 W
Luminous efficacy: 42.1 m/W
Colorimetric data
1x CCT 3000 K, CRI 80

14 Fasshult Beyerling A3 - 232800000000_0040udec Delta Opt. 3K 1200 Elex
Luminous intensity 1
Filling: 1xLED
Absolute photometry
Luminous luminous flux: 2302 lm
Power: 15.0 W
Luminous efficacy: 153.4 m/W
Colorimetric data
1xLED; CCT 5691 K, CRI 84

5 iGuzzini illuminazione - EQ522_X361 LineaLux Min 47 - surface 25.7W
Luminous intensity 1
Filling: 1xLED, 1xLED, 1xLED, 1xLED
Light output ratio: 57.97%
Lamp luminous flux: 1591 lm
Luminous luminous flux: 916 lm
Power: 25.9 W
Luminous efficacy: 31.6 m/W
Colorimetric data
1x501 C, D: CCT 7735 K, CRI 95
1x501 C, Red: CCT, CRI 95
1x501 E, CCT 5691 K, CRI 84
The report below shows the amount of power consumption of the new lighting design (in blue) as it is 2088.2W for the studied area 237.5m2 that equal to 8.79 W/m2, compare it with the current level at 12.92W/m2 as a ratio that means the new lighting design saves 31.96%
A Group of 4 desks to be compared with the Standards recommendations (Swedish light standards for offices Ljus & Rum 2013) as it show a good similarity with 100 Lux External environment and 300 Lux for the Immediate environment.
The picture below shows Lux levels on different points in the studied area.

The strategy used when positioning light fixtures was to provide light just enough to achieve the Swedish light recommendation (Ljus & Rum 2013) with Lux levels that is suitable to the type of activate, to be energy efficient as possible.

Using the Erco LED Spot lights in a grid distribution to provide a uniform light for the (External environment) to achieve 100 Lux, required for Break zone (Fika) and brief reading/passing zones. Then use the linear ceiling lights to raise lux level to 300 to achieve the (Immediate environment) required in the working zone. Then add desk lights to achieve 500 Lux for the Direct working space.
8. Discussion:

In the results the new lighting design used an LED light sources that are more energy efficient than the current T5 fluorescent tube and with different range of color temperature from cold to warm corresponding to the type of activities in the lit area, as it is recommended in the Swedish standards Ljus & Rum 2013.

By using the right light in the right place at the right time, this helps to save energy while giving the needed light levels.

The light levels calculated in the Dialux for the design show a similarity to the recommended light levels missioned in Ljus & Rum 2013.

The use of dynamic lighting with daylight sensors create a new visual experience than the current one as it simulate the dynamic changes in daylight and raise or dim its lights to corresponds with recommended lux level, while giving the occupants the ability to tune the lights to their preferences if needed to enhance the user visual experience in an energy efficient scenario. The time and speed of light level and color temperature in dynamic light should slowly enough so it does not create focuses distractions.

For the desk lights the use of occupancy-based sensors helps to save more energy than the current ON/OFF switch manual control desk lamps as this is recommended by the research mentioned the literature review. In addition to the ability of the user to control the color temperature would lead them to more user satisfaction as the research show in the literature review.

The tunable and dimmable ability in the desk lights and the ability to control it both manually and through mobile App will give more satisfaction to the users as the questionnaire shows.

Using of the frame integrated LED light for the bookshelves serve better functional and visual experience comparing with current one as personal observation shows how the shadow of the user are casted on it as result of current light positioning.

The modular linear ceiling system give more flexibility than the current one, to adjust the position of the light fixtures in a way correspond with future furniture adjustments.
9. Conclusion:

This study investigated "How to save energy in offices with a new lighting design?" after comparing the current lighting energy consumption with the new suggested design it shows an energy consumption reduction by 31.96% in favor to the new design, and a visual experience that corresponds more to the users preferences. This insure more sustainable office environment that bring us closer to achieve the UN. global sustainable development goals for 2030 Agenda.
10. Future Outlook

For future research on the same studied area, the list of the (RFI) could be upgraded with more information linked to different factors related to saving energy in lighting systems. As more information added to it, that would give a better lighting solution.
11. REFERENCES:


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(3) https://sustainabledvelopment.un.org/?menu=1300


(6) https://sweden.se/nature/sweden-tackles-climate-change/

(7) licht.wissen 04 Office Lighting: Motivating and Efficient
www.all-about-light.org
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(8) https://www.wbdg.org/resources/energy-efficient-lighting

(9) https://buildingenergy.cx-associates.com/introduction-to-dynamic-lighting-systems


(11) https://www.batteriesplus.com/blog/lighting/seeing-things-in-a-different-light


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Figure 1: https://www.wbdg.org/resources/energy-efficient-lighting
Figure 2: https://www.electricaltechnology.org/2016/12/energy-efficient-lighting-techniques-to-implement-it.html
Figure 3: https://www.electricaltechnology.org/2016/12/energy-efficient-lighting-techniques-to-implement-it.html
Figure 3: Incandescent lamps https://www.lightbulbwholesaler.com/c-573-incandescent-light-bulbs.aspx
Figures 4, and 6 https://buildingenergy.cx-associates.com/introduction-to-dynamic-lighting-systems
Figures 5 https://www.availablelight.com/controls.php
Figure 7 https://it.dhgate.com/product/ac110-220v-silicon-controlled-led-dimmer/411552631.html
Figure 8 The Energy Saving Potential of Occupancy-Based Lighting Control Strategies in Open-Plan Offices: The Influence of Occupancy Patterns Christel de Bakker *, Tom van de Voort and Alexander Rosemann
Figure 9 The Energy Saving Potential of Occupancy-Based Lighting Control Strategies in Open-Plan Offices: The Influence of Occupancy Patterns Christel de Bakker *, Tom van de Voort and Alexander Rosemann
Figure 10 The Energy Saving Potential of Occupancy-Based Lighting Control Strategies in Open-Plan Offices: The Influence of Occupancy Patterns Christel de Bakker *, Tom van de Voort and Alexander Rosemann
Figure 11,12,13 https://sustainabledevelopment.un.org/?menu=1300
Figure 14 http://waploft.co/ideas/
Figure 16 http://as-ctc.com/creating-dynamic-living-spaces/
Figure 17 https://www.pinterest.se/pin/502010689690039174/?lp=true
Figure 18 http://www.bendehaanphotography.com/touch.html
13. Appendix:

The information in the Appendix are organized as following:

Appendix A - From Literature Review

Appendix B - Have copy of 7 Descriptors of light & User behavior (Preferences) Questionnaire and then a table with their answers as it have been made by Google Forms.

Appendix C - Full Interview with Björn Berggren at ÅF infrastructure Division, Electrical Engineering.
- What is the Need for Energy Efficient Lighting?

Lighting accounts for around 15% of the energy bill in most homes, and around 25% in commercial buildings. It is supplied by electrical power plants using fossil fuels, and is responsible for a significant percentage of carbon dioxide emissions, a leading cause of global climate change. (2)

Well-designed indoor lighting increases occupant mood, satisfaction, and productivity, since the typical person spends so much time inside (90%, in fact!), good lighting should not be overlooked. (3)

Energy efficient lighting is necessary also to lower greenhouse emissions because conventional lamps cause CO2 emissions. (1)

The following are MORE factors and techniques used in energy efficient lighting which are commonly practiced as energy-saving opportunities: (4)

- Replacing of Existing Fixtures and Ballasts (4)

- Using Smart Lighting Principles (5)

- Optimization of plant lighting (Lux optimization) (6)

- Optimum use of natural sunlight (6)
In the following are some examples about energy efficient lamps commonly used today.

**Fluorescent lamp (FLs):**
Like Compact Fluorescent Lamps (CFLs) Fluorescent Lamps are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer. To gain the most efficiency, use current and proven equipment technology and install fluorescent luminaires in places where they can be integrated with the architecture, available daylight, and switching or dimming controls. (8)

![Fluorescent lamps](image1)

*Figure 1: Energy efficient, fluorescent lamps*

**Light Emitting Diodes (LEDs):**
LED lamps use 75 percent less energy than traditional incandescent and 50 percent less energy than that of a CFL. They can last 8-25 times longer compared to incandescent and up to four times longer than a CFL. Unlike incandescent and CFLs, LED lamps produce no heat and hence they are cool enough to touch. But, these are more expensive; however, they are affordable over the long run. (9)

![LEDs lamps](image2)

*Figure 2: LEDs lamps*
Incandescent lamps:

Incandescent lamps are still used for accent and specialty lighting, where the warm color, controlled brightness, instant-on, and dimming capabilities of these sources is needed. Incandescent lamps can provide a "sparkle" that is not characteristic of more diffuse fluorescent sources. PAR and low-voltage lamps can provide good beam control, and if dimmed, can also provide a reasonable lamp life. 130V-rated incandescent lamps are also available which will last longer than their 120V counterparts when operated at 120V (with only slightly reduced light output for the same wattage rating).

Figure 3: Incandescent lamps
Dynamic lighting

In the mid-20th century, the lighting industry made major leaps forward with the evolution of dimming technology, which allowed users to control light levels. Today, modern lighting fixtures are equipped with digital controllers that provide many new capabilities that go far beyond basic dimming, including warm dimming, color-tunable, and color changing lighting options. (10)

Dynamic light can refer to a few different types of control options; the three major types are: warm dimming, color-tunable, and color changing control. (10)

**Warm dimming**: control builds upon basic dimming capability by adjusting light fixture color temperature (CCT) along with light level (see Figure 4 below). This type of control is intended to mimic incandescent fixtures or candlelight. As fixture light levels are lowered, CCT will decrease (light output is warmer; commonly as low as 1800K), and as fixture light levels are raised, CCT will increase (light output is cooler; commonly as high as 3000K). This type of control is well-suited for restaurants, hospitality, entertainment, and some residential spaces. (10)

**Color changing** control incorporates saturated colors to affect mood or appearance of a space (see Figure 5 below for an example). Another example might be accent lighting at a stadium gift shop that can be adjusted to represent a team’s colors. This type of control is well-suited for restaurants, entertainment, healthcare and office spaces.
The room and working space:

Previously in lighting planning the focus have entirely been on the horizontal levels. The new standard demands also a brightness in the surroundings of the areas, which the light is on walls and ceiling. It is also set new requirements for cylindrical illuminations in rooms with requirements on good visual communication, this is also so the human face should be naturally illuminated and to prevent powerful shadows from the light uniformity. It's important to avoid large light differences within offices, as the employers move through out of the whole areas; to prevent excessive luminance differences that are perceived to be disturbing and can give rise to glare (see figure 2). Normally the illuminance should not vary more than 5:1 between the average illumination level within the task area and the lowest illumination intensity within the surrounding environment, or medium illumination intensity in adjacent rooms, for example corridors (22).

The cylindrical illumination intensity can be measured and calculated by:

\[ Ev,z = \frac{(Ev1 + Ev2 + Ev3 + Ev4)}{4} \]
Lighting design process:

Some parameters that should be considered in general in the lighting designing process: Lighting concept—general lighting or localized lighting—definitions of the sizes and heights within the working area. Lighting requirements and distributions, also consider the lighting conditions on the ceilings and walls as well as the cylindrical values. Energy requirements. The location of the luminaires in relation to the workplaces. Factors that affect the lighting results reflectance factors, coloring, luminance uniformity, color temperature, room size, ceiling height, workplaces heights, are light els usually measured 0.5m from the respective outer wall Cleaning, maintenance, lifetime of luminaires, ambient temperatures which affects the choice of luminaire. Emergency and evacuation lighting Life cycle cost calculation (22).

Applications according to guidelines:
1- Office areas application according to guidelines

<table>
<thead>
<tr>
<th>Space</th>
<th>Guidelines (Lux: 1 lux=1 lumen/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceilings (Recommended values)</td>
<td>The appropriate relationship between work area and ceiling is 1:0.5-1.5 and refers to localized lighting systems of the ceiling top over the workplace. Recommended uniformity / by at least E 0.3</td>
</tr>
<tr>
<td>Ceilings (Minimum requirements)</td>
<td>According to standard 50 lux (30 lux minimum requirements) uniformity min / with at least E 0.1</td>
</tr>
<tr>
<td>Wall (Recommended values)</td>
<td>Recommended uniformity min / with at least E 0.3.</td>
</tr>
<tr>
<td>Wall (Minimum requirements)</td>
<td>According to standard 75 lux (50 lux minimum requirements) uniformity min / with at least E 0.1</td>
</tr>
<tr>
<td>Cylindrical illumination (Recommended values)</td>
<td>Cylindrical illumination 150 lux Recommended uniformity min / with at least E 0.3. Light considered 1,2 m from the floor for sitting assignments, 1,6 m for standing assignments</td>
</tr>
<tr>
<td>Cylindrical illumination (Minimum requirements)</td>
<td>According to standard 50 lux Recommended uniformity min / with at least E 0.3. Light considered 1,2 m from the floor for sitting assignments, 1,6 m for standing assignments</td>
</tr>
</tbody>
</table>

Formula 1. E is a value of uniformity in the light, which is stated as the ratio between the minimum light level and the average level in lux: \( E_{\text{min}} / E_{\text{avg}} \).

Some components on the walls as wall washer provide increased performance and visibility both visually-biologically and emotionally.
It's important to regard a good orientation, feeling of safety in movement and to light up the walls vertically. Floor levels should be 100 lux, Emin 0.4. Some variation through accent lighting on boards/orientation boards/signs, mark directional changes, meeting corridors, stairs, etc., is perceived as positive. For good visual comfort, visual guidance and visual communication within the space is it very important to avoid long distances between the luminaires. Rule of thumb is that the distance between the fixtures should not exceed 1.75 x the installation height(22).
1 Good office lighting

Good office lighting should be the right light at the right time at the right place.

1.1 Flexible working life

Today many office workers are able to work from home or any other location. We have connected devices which enables us to reach our emails or project folders anywhere we are. This might cause a lot of stress and a lot of responsibility is put on the individual to plan their own work. Working outside might also enable us to work more efficiently since we are less disturbed at home and we don’t need to spend as much time commuting which gives us more time to either work or spare-time. Since the time spend at the office is reduced with our flexible working life, energy can be saved with smart lighting controls.

1.2 A flexible office space

A major trend is activity-based offices. The idea behind activity-based offices is that you create different zones adapted for different types of working tasks and that the workplace supports the needs in this tasks (Prevent, 2018). This also concerns the requirements in the lighting in these zones. Depending on the tasks one might not need to have as much lighting as by the desks. By that it is also possible to save energy. It is important to invest in good lighting where it is needed.
Lighting control systems typically provide the ability to automatically adjust a lighting device's output based on:

- Chronological time (time of day)
- Solar time (sunrise/sunset)
- Occupancy using occupancy sensors
- Daylight availability using photocells
- Alarm conditions
- Program logic (combination of events)

- Daylight availability control system definition and importance

Electric lighting energy use can be adjusted by automatically dimming and/or switching electric lights in response to the level of available daylight. Reducing the amount of electric lighting used when daylight is available is known as daylight harvesting. Scientific Studies shows that Daylight control systems, which automatically adjust the artificial light levels depending on the daylight penetration, can result in substantial energy savings.

- Occupancy sensors definition and importance

An occupancy sensor is an indoor motion detecting devices used to detect the presence of a person to automatically control lights or temperature or ventilation systems. The sensors use infrared, ultrasonic, microwave, or other technology. The term encompasses devices as different as PIR sensors, hotel room keycard locks and smart meters. Occupancy sensors are typically used to save energy, provide automatic control, and comply with building codes.
Appendix B:
A copy of 7 Descriptors of light & User behavior (Preferences) Questionnaire.

7 Descriptors of light & User behavior
This is a Survey have 2 parts, the first to understand light properties from your perspective, the Second to understand what you would like to have and frequent using of lights in the office 10th floor at AF Solna, i am interested ONLY about the North west part of the 10th floor As shown in the pictures. This Survey will take less than 5 min to be completed thanks in advance and have a nice day.

* Required

1. This is the part of the 10th floor at AF Solna
this Survey is about!

2. 1- Level of light *
Mark only one oval.

Very dark


Very bright

3. 1.1 Level of light (Evaluation) *
Mark only one oval.

Good


Poor

https://docs.google.com/forms/d/1Gc861Lws-aC483_7qTI-AKqS0a7DVpFANbg7nINIdM/edit
4. 2: Light distribution
   * Mark only one oval.

A copy of the Questionnaire form:

<table>
<thead>
<tr>
<th>Uniform</th>
<th>Very dramatic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. 2.1 Light distribution (Evaluation) *
   * Mark only one oval.

<table>
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<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. 3: Shadows *
   * Mark only one oval.

<table>
<thead>
<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tbody>
<tr>
<td>very vague</td>
<td>very marked</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. 3.1 Shadows (Evaluation) *
   * Mark only one oval.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tbody>
<tr>
<td>Good</td>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

8. 4 : Reflections *
   * Mark only one oval.

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<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
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<td>None</td>
<td>Very marked</td>
<td></td>
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<td></td>
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</table>

9. 4.1 Reflections (Evaluation) *
   * Mark only one oval.

<table>
<thead>
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<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
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<td>Good</td>
<td>Poor</td>
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10. 5 : Color of light *
    * Mark only one oval.

<table>
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<th>5</th>
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<tbody>
<tr>
<td>cool/cold</td>
<td>warm</td>
<td></td>
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</tr>
</tbody>
</table>

https://docs.google.com/forms/d/1Go861Lws-aC493_7qTl-A/kqSO7b7V/FANbgi7nNloM/edit
11. 5.1 Color of light (Evaluation) *
Mark only one oval.

1 2 3 4 5

Good poor

12. 6: Appearance of surface color *
Mark only one oval.

1 2 3 4 5

Natural deteriorated

13. 6.1 Appearance of surface color (Evaluation) *
Mark only one oval.

1 2 3 4 5

Good Poor

14. 7 Glare *
Mark only one oval.

1 2 3 4 5

None Intolerable

15. 7.1 Glare (Evaluation ) *
Mark only one oval.

1 2 3 4 5

Good Poor

16. Would you like to have dynamic lights in the office floor ? *
Mark only one oval.

☐ Yes
☐ No
☐ Maybe

17. Would you like to have more control over your desk light ? ( Dimmable , tunable lights ) *
Mark only one oval.

☐ Yes
☐ No
☐ Maybe
18. How would you like to control your desk lights *
   Mark only one oval.
   ○ only manual switches
   ○ mobile App
   ○ Both
   ○ Other:

19. Would you like to see different color temperatures in the office area ? *
   Mark only one oval.
   ○ Yes
   ○ No
   ○ Maybe

20. how many hours on average do you turn on your desk light ? *
   Mark only one oval.
   
   1  2  3  4  5  6  7  8  9  10
   Hour ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Hours

21. In which age range are you ? *
   Mark only one oval.
   ○ 22-30
   ○ 31-40
   ○ 41-50
   ○ 50-75
   ○ Other:

22. What is today's date *
   Example: December 15, 2012

23. What are the weather condition ? *
   Mark only one oval.
   ○ Sunny
   ○ cloudy
   ○ Dark
   ○ Other:

24. Time of doing this Survey *

https://docs.google.com/forms/d/1Go851Lws-aC493_7qTl-AKqSOa7DJvFANbq7nINicdM/edit
Table with answers for the 7 Descriptors of light & User behavior (Preferences) Questionnaire.

This survey have been answered by 7 employees as points in the table show a chosen answer by an employee answered in May 2019 from am to pm the age range is between 22-40 and weather condition described as Cloudy.

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Table with answers for the 7 Descriptors of light & User behavior (Preferences) Questionnaire.

This survey have been answered by 7 employees as points in the table show a chosen answer by an employee.

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<td>Color of light</td>
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<td>Appearance of surface color</td>
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</table>
Table with answers for the 7 Descriptors of light & User behavior (Preferences) Questionnaire.

This survey have been answered by 7 employees as points in the table show a chosen answer by an employee.

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
<th>Maybe</th>
</tr>
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<tbody>
<tr>
<td>Would you like to have dynamic lights in the office floor?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Would you like to have more control over your desk light? (Dimmable, tunable lights)</td>
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<td></td>
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<tr>
<td>Would you like to see different color temperatures in the office area?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How would you like to control your desk lights</td>
<td>Only manual switches</td>
<td>Mobile App</td>
<td>both</td>
</tr>
<tr>
<td>how many hours on average do you turn on your desk light?</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
Appendix C:

Process and Analyzing :
- ( Energy aspects ) Analyzing current situation :

How does the current lighting system in the ÅF HQ building works ? ( Interview with Björn Berggren at ÅF infrastructure Division , Electrical Engineering )  

The lights turn on and off automatically according to time schedule programed in lighting control system the DUC ( Dataundercentral ) unit , it is an electronic control system for real estate automation . The lighting system turned on from 6 AM to 8 PM in working days but at the weekend it turned on and off only by an electric switch , switched by the user . The DUC unit is at the floor 3 Basement floor , ( floor 4 is the entrance ) at the Fläktrum ( Fan room ) number 3:002 OR 3:012 . This unit send a signal to the ( Cable distribution room ) at the 1st floor that is connected by cables to switchboards in every floor like the ( BC6-1) switchboard at the 10th floor , with a time sensor build in it . The switchboard light up a part of the floor , as every floor have many switchboards that are responsible about a part of the lighting system in the floor . After 6PM only the user have to go and switch on an electric switch in the floor to turn part of the floor lights , as it has a timer setted-for approximately 2 hours then it turn off again , but there is some lightings fixtures are always on 24/24 as it serve as a guide lights , shown in the plane with the letter ( F ) next to the light fixture name .

The building have 2 DALI control systems , one in the Entrance 4th floor and the second one located in the 9th floor .

The DALI control system is more flexible than the DUC control system as it allow easier programing and more control options than the DUC . The building lighting system is designed in 1995 for an commercial offices spaces use without any specified inner walls to allow freedom of space use The standard back then stated that in an office building the power consumption should be around 30W per square meter but today standard from the SVENSK STANDARD SS 437 01 02 , dated from 2014-09-16 States that is should be around 20W per square meter , the reason of the difference is regarding the development in light fixtures technologies and the sustainable consideration regarding lowering the power consumption .