Pilot evaluation of novel lighting solutions in indoor construction

- Opportunities for workers’ health and performance

Julia Ye Årfelt
Alessandro Conforti
Summary

A work environment with poor lighting conditions negatively affects many work aspects. However, there is limited evidence on the impact that new lighting technologies have specifically for indoor construction workers. The aim of this project was to investigate which aspects of new lighting technologies have an influence on indoor construction workers’ health and performance from the HTO-perspective. The research questions focused on how the introduction of new lighting technologies can impact worker health, productivity, and work quality. Also, how well the workers in a specific context experience the light sources used in the project to perform their work tasks. Two Swedish companies participated in the project. One of the companies manufactures work lighting and focuses on developing work lighting solutions that are ergonomic-friendly for the users and sustainable for the environment. The other company is a large construction company that can manage complex construction processes from start to finish.

Due to the current covid-19 situation and the restrictions and regulations regarding physical meetings, the number of workers that could participate was limited to three. The workers involved in the project used five new different lamps during a period of one week. To assess the work environment and evaluate the interventions, six methods were used. They were dialogue tours, observations, checklists, work diaries, focus groups, and technical simulations. The findings show that the current visual conditions of the work environment are inadequate. Therefore, the current situation could affect not only the health and well-being of the workers, but also quality and productivity. On the other hand, the results show that the use of new lighting technologies improved the visual ergonomics of the work environment. Nonetheless, in this case the use of both stationary lighting and individual headlamps was experienced as very important and beneficial in terms of subjective performance.

In this report, six distinct recommendations can be given to this and similar worksites. These can be implemented at this and other indoor construction sites utilizing the types of lighting used during this work. An important research question of this project was to find out how well the workers in a specific context experience the project lights when performing their work tasks. The use of both stationary lighting and individual headlamps was experienced as very important and beneficial in terms of performance. In conclusion, the findings of this project indicate that many aspects of the new lighting were found advantageous for the workers.
Sammanfattning


I denna rapport ges sex rekommendationer till denna och liknande inomhusarbetsplatser. Dessa kan implementeras med den typ av belysning som används under projektet. Projektet utforskar även hur arbetarna upplever att projekts lampor hjälper till att utföra deras arbetsuppgifter i ett specifikt sammanhang. Användningen av både stationär belysning och enskilda pannlampor upplevdes som mycket viktigt och fördelaktigt när det gäller prestanda. Sammanfattningsvis visar resultaten av detta projekt att många aspekter av den nya belysningen var ansedda som fördelaktiga för arbetarna.
# Table of contents

1. Introduction .................................................................................................................. 5  
   1.1 Description of companies ......................................................................................... 6  
   1.2 Problem .................................................................................................................... 6  
   1.3 Aim ............................................................................................................................ 7  
   1.4 Limitations ............................................................................................................... 7  

2. Background .................................................................................................................. 8  
   2.1 Theory ......................................................................................................................... 8  
      2.1.1 Visual ergonomics ............................................................................................... 8  
      2.1.2 Lighting .............................................................................................................. 9  
      2.1.3 Health & Well-being ......................................................................................... 10  
      2.1.4 Productivity & Quality .................................................................................... 11  
   2.2 HTO-Perspective ....................................................................................................... 12  
   2.3 Laws, regulations, and guidelines ........................................................................... 14  
   2.4 UN Sustainable Development Goals ....................................................................... 14  

3. Methods ....................................................................................................................... 16  
   3.1 Dialogue tour .......................................................................................................... 16  
   3.2 Observation ............................................................................................................. 16  
   3.3 Checklist .................................................................................................................. 17  
   3.4 Simulation ............................................................................................................... 18  
   3.5 Work Diary ............................................................................................................. 18  
   3.6 Focus group ............................................................................................................ 19  
      3.6.1 Ethical considerations ....................................................................................... 19  
      3.6.2 Interview ........................................................................................................ 19  

4. Results ......................................................................................................................... 20  
   4.1 Dialogue tour .......................................................................................................... 20  
   4.2 Observation ............................................................................................................. 20  
   4.3 Checklist .................................................................................................................. 22  
   4.4 Simulation ............................................................................................................... 23  
   4.5 Work diary ............................................................................................................. 25  
   4.6 Focus group .......................................................................................................... 27
5. Discussion ............................................................................................................................................. 30

5.1 HTO-perspective ................................................................................................................................. 30

5.2 Method discussion ............................................................................................................................... 31

5.2.1 Dialogue tour .................................................................................................................................... 31

5.2.2 Observation ....................................................................................................................................... 31

5.2.3 Checklist .......................................................................................................................................... 31

5.2.4 Work diary ....................................................................................................................................... 32

5.2.5 Focus group ..................................................................................................................................... 32

5.2.6 Simulation ....................................................................................................................................... 33

5.2.7 Limitations ..................................................................................................................................... 33

5.3 Results discussion ................................................................................................................................. 34

5.3.1 Health & Well-being ....................................................................................................................... 34

5.3.2 Productivity & Quality ................................................................................................................... 35

5.3.3 Subjective performance ............................................................................................................... 35

5.3.4 Reflections ..................................................................................................................................... 36

6. Conclusion ............................................................................................................................................ 37

7. Future work ........................................................................................................................................... 38

References ................................................................................................................................................ 39

Appendix 1. The project lightings ........................................................................................................... 44

Appendix 2. Dialogue tour ....................................................................................................................... 46

Appendix 3. Observations ......................................................................................................................... 47

Appendix 4. Checklist ............................................................................................................................... 49

Appendix 5. Work Diary ........................................................................................................................... 54

Appendix 6. Focus group .......................................................................................................................... 56

Appendix 7. Simulation .............................................................................................................................. 60

Appendix 8. Measurements during the simulation .................................................................................... 61
1. Introduction

Visual ergonomics is a vital factor of the work environment, especially in the construction industry. In fact, Aarås et al. (2001) argue that good lighting at work has a crucial importance in reducing musculoskeletal disorders (MSD) and a good visual environment is important for health and well-being. Moreover, there are statistics showing that individuals with eyestrain report musculoskeletal strain to a higher degree compared to those without eyestrain (Boyce, 2014; Hemphälä & Eklund, 2012). Many studies have shown that the illumination of a work environment should not be either too high or too low. Indeed, according to De Korte et al. (2015), a work environment with exaggerated illumination leads to nervousness and excitation in workers. Moreover, to work in a too high-illuminated work environment for long time results in workers experiencing tiredness and distraction, and, consequently, reduced work efficiency. On the other hand, a work environment with low illuminance will also result in reduced productivity (Grünberger et al., 1993; Kuller & Wetterberg, 1993).

Construction industry is the sector where most work-related accidents happen. Eurostat (2009) conducted a self-reported injury and illness survey in the 27 countries of the EU. The results of the survey showed that 7 million occupational injuries were reported in 2007 in the EU. Moreover, 8.6% of workers (20 million workers) in the EU encountered a work-related health problem in the past year. Additionally, one of the sectors where most work-related accidents were reported was the construction industry. Specially, the most serious work-related health problems are back problems (28%), neck-, shoulder-, arm- or hand problems (19%), and stress, depression, or anxiety (14%). Of the workers that had an accident, 73% reported lost workdays after the most recent accident, and, additionally, 22% of them reported time off for at least one month. Furthermore, due to a work-related accident, 7% of all the workers in the EU took sick leave for at least one month. In conclusion, between workers with work-related health problems, 22% encountered significant limitations in normal daily life activities (Eurostat, 2009).

Even though safety performance has recently improved in many industries, safety is still a concern in the construction industry (Nnaji et al., 2019). According to Hollnagel (2018), the use of emerging technologies has the potential to reduce the number of injuries and fatalities in the industry. Nonetheless, the implementation of technologies that can improve safety in the construction industry is still insufficient. Undoubtedly, implementing new technologies with safety purpose must be done in a proper way. Indeed, Straub (2009) indicates that, often, a new technology goes through three steps when becoming a standard practice in an organization: technology adoption, technology implementation and technology utilization. According to Takala et al. (2014), productivity, safety and health are connected to each other. By decreasing the number of incidents and accidents, will result in an increased productivity. Therefore, aware of this connection between productivity and safety, many high-income countries have reached a huge positive development in terms of safety at work. However, this development has become very difficult to continue and the number of fatal injuries is not decreasing as before. Therefore, both traditional and new risks need to be assessed, and new technologies, innovations and solutions are required.
1.1 Description of companies

Two Swedish companies were involved in the project.

**Company 1:** One of the companies produces work lighting and focuses on developing work lighting solutions that are ergonomic-friendly for the users and sustainable for the environment. The company believes that the poor lighting has negative effects on productivity and humans’ well-being. Also, they believe that lack of knowledge about ergonomic-friendly lighting negatively impacts the work environment. Therefore, the company tries to spread the knowledge about the importance of work lighting and aims for everyone to have the adequate light for the job, thus eliminating, for example, fall accidents in stairs, other injuries and back and neck strain caused by awkward working positions due to bad work lighting. They also want to eliminate tangled cables, bad batteries, and poor color reproduction. In conclusion, the goal and the vision of this company is: “no more bad light”. This company is involved in the project because it is interested to know how indoor construction workers perceive their lights and see what kind of needs the construction workers have in order to improve the workers’ work performance and safety. In this project, five different types of lights were provided by company 1 to facilitate an investigation into the effects of visual ergonomics on the workers performance and their health and well-being (Appendix 1).

**Company 2:** The other company involved in the project is a big construction company that can manage complex construction processes from start to finish. Indeed, this company builds schools, hospitals, bridges, houses, offices and more. Currently, the company has many working sites spread all over Sweden. This thesis project takes place in one of the company sites where they are currently renovating an old building. The company is involved in this thesis project because it is interested to know if and how they can improve the visual ergonomics aspects of their work environment.

1.2 Problem

In fact, a work environment with poor lighting negatively affects many aspects of the work. First, safety action ability is badly influenced. Second, the reaction time increases. Third, efficiency of work is negatively affected. Last, but not least, poor lighting increases fatigue and reduces operational reliability. There is, in fact, a link between increased fatigue, due to poor illuminance at work, and reduced productivity (Tanabe & Nishihara, 2004). The connection between high quality of visual ergonomics and work quality and safety is undeniable. Moreover, to work with good and adequate lighting guarantees that the working tasks are properly and successfully performed (SIS, 2011). In conclusion, as mentioned above, the utilization of emerging technologies for safety purposes in the construction industry is still limited (Nnaji et al., 2019). In particular, there is limited evidence on the impact that new lighting technologies have on just indoor construction workers’ safety, as well as on work quality and productivity. Therefore, the project is about to study how new lighting technologies have an influence on indoor construction workers’ safety and well-being, as well as on work quality and productivity.
1.3 Aim

The aim of the project is to investigate which aspects of the new lighting technologies have an influence on indoor construction workers’ health, well-being and performance from the HTO-perspective.

Research questions are:
- How can the introduction of new lighting technologies impact worker health, productivity, and work quality?
- How well do the workers in a specific context experience the project lights to perform their work tasks?

1.4 Limitations

The investigations of this project focus only on indoor construction worksites in Stockholm during wintertime. Due to the current covid-19 situation, there were some restrictions and regulations regarding physical meetings (World Health Organization [WHO], 2020). The number of workers that could participate was limited to three. Although there are other measurement approaches, this thesis investigated health, usability, productivity, and quality via worker perceptions.
2. Background

The project draws on important theories from the domains of visual ergonomics, lighting, health and well-being, productivity, quality and HTO-perspective.

2.1 Theory

2.1.1 Visual ergonomics

According to the International Ergonomics Association’s Technical Committee for Visual Ergonomics, visual ergonomics can be specified as (IEA, 2012):

“Visual ergonomics is the multidisciplinary science concerned with understanding human visual processes and the interactions between humans and other elements of a system. Visual ergonomics applies theories, knowledge and methods to the design and assessment of systems, optimising human well-being and overall system performance. Relevant topics include, among others: the visual environment, such as lighting; visually demanding work and other tasks; visual function and performance; visual comfort and safety; optical corrections and other assistive tools.”

Visual ergonomics can be divided into four main areas; eyesight, light, work object, and influence from the surrounding space. Furthermore, there is an important interaction between vision and body position (Nylén, 2017). The field of visual ergonomics forms an important part of ergonomics as vision provides a large portion of all sensory impressions reaching the brain. Vision is also important since it affects posture and movements of workers. Related to this are the sense of balance and the kinesthetic sense muscles and joints. These provide signals for head and body positions and movements (Nylén, 2017).

There are three aspects of visual ergonomics that need to be considered. The first one is the physical environment that relates to several aspects, such as how much daylight is available at the worksite and how much artificial lighting is added to this. The design of the actual workplace is also important. When the physical environment is degraded, there is an increased risk for reduced work performance. This can be due to discomfort, headaches, or eye strain for the worker. The second category is the visual ability of the worker and includes the person’s visual acuity and possible eye correction. Some work requires special visual aids that are provided by the employer. The third category is the work task itself which can mean how visible a specific object is or how demanding a certain visual work task is. There are both regulations and advice provided on this matter by the Swedish Work Environment Authority (SWEA) in their work “Physical Workload and Ergonomics” (AFS 2012:2).

Visual ergonomics come with a series of issues. It is therefore vital to collaborate with other relevant professionals in a multidisciplinary holistic manner. That way, a more complete picture of the visual ergonomics can be derived (Long & Helland, 2012). In order to improve the visual ergonomics environment at high level, it is crucial to understand both visual ergonomics at workplace level and individual level. This requires specialists within optometry, lighting design, and ergonomics all to work together.
2.1.2 Lighting

The terminology “general lighting” indicates whether the light from the source is direct or indirect. It also includes which direction the work light has against the working surface. Additionally, it provides information about the possibility to vary the light intensity, both on individual and group levels. The ability of the light source to recreate colors should be suitable for the work task according to §13 AFS 2009 (Arbetsmiljöverket 2009). The lighting condition is an important factor for the work environment. The reason is that it has an impact on productivity, health, and comfort. The effects are psychological, physiological, and physical (Bellia et al., 2011). In a work environment perspective, the light is used as a visual aid when performing work tasks. It is, however, also used as a modulator for cognitive performance, alertness, and ability to focus mentally. The latter are considered non-visual functions (Vandewalle et al. 2009).

Measurements of light are often performed by measuring illuminance and luminance. Luminance describes the measurement of the amount of light that is emitting, passing through or reflected from a surface. Moreover, luminance indicates how much luminous intensity can be perceived by the human eye. In other words, luminance indicates the brightness of light emitted or reflected off a surface and is measured in cd/m². On the contrary, illuminance indicates the light that falls on a certain surface and is measured in Lux (see Figure 1). Recommendations for illuminance can be found in the European standard SS-EN 12464-1: 2011 (SIS, 2011).

Figure 1. Illuminance versus luminance against a surface (Nylén, 2017)

Clearly, illuminance and its distribution on the task area and on the surrounding area have a great impact on how quickly, safely and comfortably a person perceives and carries out the visual task (SIS, 2011). Therefore, an appropriate level of illuminance is crucial for our ability to see objects with sharpness (Nylén, 2017) because when the lighting is not appropriate, the workers want to facilitate their vision and then take awkward body postures (Zetterberg et al., 2013). Moreover, too large differences between the lighting intensities in the room can cause visual stress and discomfort (Ljuskultur, 2013) and it is, therefore, important that the lighting is adapted to the individual and their needs. In addition, the need for illuminance changes with the age. In fact, due to the natural aging of the lens, a 60-year-old person needs about three times as much light as a 20-year-old person (Nylén, 2017).
2.1.3 Health & Well-being

There are many studies that have examined correlations between the lighting and health and well-being factors. One example is that reduced lighting can induce reduction in eye-sight or inflict pain in shoulders and neck of workers (Aarås et al. 2001). Lighting and visual ergonomic designs are important factors when considering eye strain prevention, headaches and fatigue, as well as for reducing the risk for musculoskeletal diseases (MSD’s) (Bohgard et al. 2009). When, on the other hand, the lighting conditions become improved, workers experience less headache and eye strain (Wilkins et al. 1989). General work performance increase and workers feel a higher level of job satisfaction (Newsham et al. 2009). There is also a direct correlation between lighting conditions and the mental state of workers (Veitch et al. 1998).

Glare is the most obvious problem when working with lighting aspects (Mainster & Turner, 2012); glare is undesired light picked up by the retina in the eye. In this case it is called disability glare and is stray light that causes a reduction in image contrast. When the illumination becomes too high, it can give rise to the person feeling annoyed which is often called discomfort glare. Glare affects different people in different ways and to different degrees (North, 1993). When lighting is poorly distributed in the work environment and parts of the ceiling or surroundings seem dark or create glare it can cause frustration or irritation for workers. This, however, does not necessarily affect their visual performance, only their visual comfort. Changing the lighting conditions, thus reducing glare, can improve their visual performance. How these improvements relate to task performance, however, has not been established. This is because visual performance affects workers' task performance differently depending on which task is performed. Good lighting is not required for all visual tasks. For example, a simple change in spectral distribution, for example, can for some tasks be sufficient to result in improvements (Juslén & Tenner, 2005).

Undoubtedly, inadequate lighting in a workplace leads to physiological and psychological strain such as anxiety, fatigue, lethargy, headaches, eyestrain, migraine, nausea, back pain, neck pain, shoulder pain, poor concentration or lack of mental alertness, and daytime sleepiness (Pauley, 2004). Some workers are in need of using eyeglasses while working. There are various kinds of eyeglasses available for workers. Many are used while working at a computer whereas others are used while performing work tasks without computers. This is important that the correct types of lenses with correct power are used for choosing spectacles (Horgen, 2003). Eye and bodily strain is caused by inadequacy in the visual environment. It is because the person tries to compensate for the poor visual environment by improving his or her vision (Boyce, 2006; Helland et al., 2008; Anshel, 2005).

Therefore, adequate use and color of indoor and outdoor lighting is meaningful not only to human’s health, but also to ecosystems. In fact, lighting fixtures must be designed to reduce, as much as possible, interferences with normal circadian rhythms in all the organisms, such as humans, plants, and animals (Pauley, 2004).
Pauley (2004) argues that the human circadian clock and its daily entrainment is important to have a healthy human life. A circadian rhythm is regulated by a biological clock rhythm that can be found in all living organisms and it is really important for good health. Specifically, light exposure has a big influence on the circadian rhythms, which has a big influence on individual performance at work (Juslén & Tenner, 2005). Van Bommel and Van den Beld (2016) showed that good lighting has not only visual positive effects but also biological positive effects. In fact, good lighting has a positive effect on health, wellbeing, alertness, and sleep quality as well.

Clearly, light pollution may disrupt the normal circadian rhythms as well. Therefore, attention should be put on artificial lighting and its use. Light pollution refers to a light that is not appropriate for a specific task, for instance a light that is too bright and uncomfortable to the human eye, or a light that causes unsafe glare to the workers, or a light that harms the biological integrity of ecosystems. According to Pauley (2004), adequate use and color of indoor and outdoor lighting is meaningful not only to human’s health, but also to ecosystems. In fact, lighting fixtures must be designed to reduce, as much as possible, interferences with normal circadian rhythms in all the organisms, such as humans, plants, and animals. Clearly, light pollution is not only a problem for health and safety, but also a sustainable problem for the environment, because it is a waste of energy. In conclusion, lighting must be favorable to the circadian clock.

2.1.4 Productivity & Quality

Lighting can have an impact on productivity. By improving lighting conditions for the workers, the overall output can be increased at the same time as the number of accidents and errors can be reduced. This can be related to Non-Image Forming (NIF). It is believed to consist of psycho-biological connections in the brains (van Bommel et al. 2002; Völker, 1999). Improved lighting conditions generally also increase production speeds. However, these improvements are not all related only to lighting levels. This is because factors such as spatial light distribution as well as the spectral distribution oftentimes are varied simultaneously with illuminance. Additionally, the frequency of change in these factors has in some studies been very large, sometimes as fast as once a day. This tends to minimize the measured effects of changes (Juslén & Tenner, 2005).

When the visual conditions in a work environment are inadequate workers tend to lose concentration, get more easily tired or take more sick leave (Lister et al. 1998). This can have large negative economic effects on the organization. Inversely, if the organization offers a safe and comfortable environment for its workers, it will improve productivity as well as produced quality (Akbari et al. 2013). Many organizations are driven by productivity requirements. According to Abrahamsson (2000), organizational profit is related to an organization’s employee work environment. It has been shown that an improved work environment is directly related to organizational profit. As an example, Swedish Steel AB was analyzed, and it was shown that improvements in the work environment (WE) led to clear profits for the company. From the profits made through WE improvements, 98% stemmed from basically two factors.
The first was quality improvements, and the second productivity. Only 2% could be attributed to cost savings from reduced sick leave. It is therefore important that calculations of profitability for a company are not merely restricted to direct costs when making WE improvement decisions (Abrahamsson, 2000).

According to Li et al. (2020), quality, productivity, and efficiency of an organization can be meaningfully improved by improving the lighting of the work environment. When the workers have better lighting conditions, they tend to make fewer errors and rejects (Katabaro et al., 2019). A poor quality of lighting in an indoor environment has negative impacts not only on human health, but also on their work performance. Moreover, a poor quality of lighting significantly affects the work efficiency and the workers’ well-being. In addition, the workers are also exposed to occupational diseases. Therefore, to provide a healthy work environment should be an indispensable right of the workers.

2.2 HTO-Perspective

HTO is a conceptual model especially useful for illustrating the interaction between three subsystems; human, technique, and organization (see Figure 2). HTO is a Swedish abbreviation that originated from the nuclear industry during the 1980s and focuses on safety and technical improvements. As technical improvements were made and accident frequency declined, focus was shifted toward the human factor. It was further noted that organizational factors such as leadership and organizational culture directly affected safety. HTO thus came to stand for the three component safety efforts, HTO (Rollenhagen, 1997; Eklund, 2003). The figure 2 shows the relationship between H (Human), T (Technique), O (Organization). Work activity is shown at the overlapping area of the three subsystems in the illustration of the conceptual model HTO (Karltun et al. 2017). The central part of the model, work activity, can be analyzed, described, and understood through the interaction between the subsystems. This interaction is a continual and dynamic process. It is noteworthy that the result as a whole exceeds the sum of the three components.

Figure 2. Illustration of the conceptual model HTO (Karltun et al. 2017)
By using the HTO perspective, a broad understanding can be developed for collaborating factors within a work activity system. This platform is a proper point of origin when developing and improving such a system. HTO-perspective can be used as the foundation when building models used on organizational systems, as seen in Figure 2. In this model, the individual’s work activity will remain at the center while interacting with the organization, the technology, and the environment. This way, the individual effort will benefit the organization. The organization also interacts with its surrounding context (Eklund, 2003). The “man” part of the system is an individual displaying physical, mental, cognitive, and social characteristics, all of which are taken into consideration during an analysis. All processes in an organization require involvement of man. The result of the activity is dependent on the well-being of the individual. This includes the interaction with work colleagues. The final results of the work activity further depend on the interaction between technical conditions and organizational functions (Karltun et al. 2017).

![Figure 3. Eklund's (2003) model, The extended HTO-framework](image)

The model focuses on how the work activity interacts with technology, the organization, and the environment. This type of interaction can either make it easier or more difficult to improve the organizational processes. By using the extended HTO-model, the improvement potential both at individual and organizational levels can be analyzed (see Figure 3). This includes safety, performance, and well-being. Because of the abstract nature of the model, the meaning of the variables’ organization, technology, and environment are not specified in detail. Rather, the variables are described in philosophical terms or as a way of life (Eklund, 2003). The organizational striving after change is a complex process requiring conscious effort of certain key variables. These variables affect the behavior both at the individual and at the organizational levels. Factors relating to man, organization, and technology are said to interact with one another. They are also in line with MTO as well as with a socio-technical system including ergonomics. The assumption is that the actual situation affects the behavior of the individual. This can be made more efficient by changing the behavioral aspects of the work activity system (Porras & Robertson, 1992).
2.3 Laws, regulations, and guidelines

Regulations from the Swedish Work Environment Authority, in particular the provision Workplace Design (AFS 2009:2), together with the guidelines from the standard SS-EN 12464-1:2011 Light and lighting – Lighting of workplaces – Part 1: Indoor workplaces, were considered in this project.

The lighting requirements of the individual workplace should be based on direction, intensity, and distribution of the lighting (AFS 2009:2). Special lighting needs as well as general lighting should be designed to suit the actual work tasks performed. Also, light sources should have appropriate color rendering and color temperature. The directives from the Swedish Work Environment Authority (AFS 2009:2) are clear to point at the fact that to provide a good quality lighting condition in a workplace does not mean to install a fitting quantity of lights. Indeed, many aspects must be contemplated to implement a suitable quality of lighting, such as illuminance uniformity, luminance distributions, light color, color rendering, color temperature characteristics, nature of light (natural or artificial), flicker, and glare control (Swedish Standard Institute [SIS], 2012).

Each specific work task requires its own level of lighting in order to reduce or eliminate health risks at work (Horgen, 2003). Standards such as the European Standard, “Light and Lighting – Lighting of Workplaces – Part 1: Indoor Workplaces (SS-EN 12464-1, 2011) give guidelines in how this should be done. This standard indicates lighting requirements for humans in indoor workplaces in terms of quantity and quality of illumination. Moreover, recommendations are given for good lighting practice. The standard shows and classifies the requirements for lighting in a work environment, which are generally applicable whether is provided by artificial lighting, daylight, or both. In addition, the standard specifies the requirements of minimum illuminance and luminance on the work task, surrounding area, background area, walls, and ceilings.

2.4 UN Sustainable Development Goals

The United Nations has developed 17 sustainable development goals with the main scope to promote prosperity while preserving the world (United Nations [UN], 2020). The United Nations Sustainable Development Goals were considered during the whole project process. Specifically, the United Nations Agenda 2030 intends to redirect humanity on a sustainable path and the core of this agenda are the 17 Development Goals which are universal, transformational and inclusive (see Figure 4).

The goals aim to secure a sustainable, peaceful, prosperous and equitable life on earth for everyone now and in the future (UN, 2020). Five of the goals are identified to correlate to the project and the interpretations are listed below.
Figure 4. 17 Sustainable Development Goals (SDGs), UN 2020

**Goal 3. Good health and well-being**

The UN sustainable goal nr.3 is to achieve good health and well-being by 2030. Indeed, according to the United Nations (2020) to ensure healthy lives and to promote well-being at any age is crucial for sustainable development. Clearly, this project is connected to the health and well-being of the workers by improving the work environment, and it is grounded on the UN sustainable goal nr.3.

**Goal 7. Affordable and clean energy**

The UN sustainable goal nr.7 is to ensure access to affordable, reliable, sustainable and modern energy by 2030. Moreover, the energy should be more sustainable, and the energy efficiency should improve. In summary, the UN sustainable goal nr.7 is connected to the project because the lights used in the project are equipped with new batteries that last a long time and save a lot of energy. Therefore, it contributes to the fulfillment of goal nr.7.

**Goal 8. Decent work and economic growth**

The UN sustainable goal nr.8 is to promote decent work and economic growth. Indeed, sustained and inclusive economic growth leads to progress, creates decent jobs for all and improves living standards in society. Specifically, goal nr. 8.8 is to “protect labour rights and promote safe and secure working environments for all workers”. As mentioned above, this project is related to the study of the work environment and, consequently, to the productivity of the workers. Therefore, this project is grounded on the UN sustainable goal nr.8 as well.

**Goal 9. Industry, innovation and infrastructure**

The UN sustainable goal nr.9 is to build resilient infrastructure, promote sustainable industrialization and foster innovation. Indeed, sustainable industrialization, innovation, and infrastructure promote dynamic and competitive economic aspects that generate employment and income. Moreover, according to the UN (2020), to introduce and promote new technologies and enabling the efficient use of resources have an important role in reaching this goal. Thus, taking in consideration that this project is, indirectly, promoting new technologies and innovation, then it is undeniable that the project is also connected to the UN sustainable goal nr.9.
3. Methods

This chapter describes various methods that are used for the project. According to Salvendy (2012), the involvement and participation of workers is important to assess a work environment and to develop an intervention process around the workers. Helander (2006) also argues that existing workplace situations can be well analyzed by using a participatory approach. Therefore, to involve the workers as much as possible, the following methods were chosen by the authors.

3.1 Dialogue tour

The dialogue tour was conducted on 2nd February 2021. The site manager, two workers and the authors took a dialogue tour of the building site together. During the tour, the site manager and workers showed and explained which were the workstations that they would use during the following week and where they intended to use the lamps. They also gave information of the building as well as planning of the project. During the dialogue tour, several pictures were taken, and they are shown in Appendix 2.

This method was chosen by the authors in order to get well acquainted with the work task as well as the work site. Indeed, according to Rolfö (2016), this is a method used to involve employees in a dialogue while walking in the worksite. However, in order to obtain a valid starting point, rigorous preparation work was required. The preparation consisted in sending a brief presentation of the selected themes to the company before the dialogue tour. So, the company manager could ask the participants to choose two or three locations at the work site they feel particularly important in relation to visual ergonomics issues.

As recommended by Rolfö (2016), the workers were first asked which areas were of greatest concern, then all participants moved from one location to the other while discussing visual ergonomics problems and possibilities for each chosen location. The worker who originally suggested a particular location provided a brief motivating explanation to why the location was important relative to visual ergonomics issues. After this, all involved personnel participated in a discussion about visual ergonomics problems and possibilities for each chosen location. Undoubtedly, this type of documentation was a vital starting point for the continued work. Moreover, a visit to the current work site was worth the time in order to initiate a dialogue.

3.2 Observation

During the second week of this thesis project, a number of observations were made. Specifically, physical bodily loads were studied while workers performed their daily activities. By being near to the workers, it was possible to get a clear view of how workers performed their various work tasks. The lights were mounted in various places at each of the three locations. The observation was conducted in three different places in order to see the effects of using different lightings in different work situations (Appendix 3).
The first observation was done in a workplace with many pipes of different sizes. The worker had to fix one of the many pipes. During the observation, the worker was using a headlamp while performing the work tasks. Also, the worker was using an auxiliary lamp attached to the metal as a complementary lamp (Figure 6 in Section 4.2). The second observation was a worse-case scenario. Indeed, the observation was done in a pipe assembly location of the basement. The working place was completely dark and there were no stationary lights. The reflective wall surfaces made it more difficult to see when using a headlamp. The first picture was taken when the worker used a lamp attached to the helmet. While observing, the worker was using both a headlamp and/or an auxiliary lamp (Figure 7 in Section 4.2). The third observation was also a worse-case scenario. In fact, the observation was done in a sub-level cavity of the basement when it was completely dark. The observation was conducted using firstly a headlamp only, and secondly by using a headlamp together with an auxiliary lamp (Figure 8 in Section 4.2).

According to Cohen, Lawrence, & Morrison (2007), field-based data collection implies that detailed information is gathered during real life situations. An example of this is performing observations. Data is thus collected firsthand, as opposed to related by third parties. Another advantage of observations compared to interviews is that several behaviors can be studied simultaneously. When observing workers, it is important that they are behaving as in normal working conditions. This will ensure that the data collected is as close to reality as possible. Several different locations give some idea of the variability in work environment factors.

3.3 Checklist

In this project, the checklist “Detailed checklist lighting / visual ergonomics, primarily for ergonomists / work environment engineers and other experts” from Prevent (2020) was used as a risk assessment (see Appendix 4). According to Prevent (2020) this checklist is applicable to either individual workers or organizations. Moreover, this checklist is recommended to be used by ergonomists, work environment engineers, and other work environment specialists. Therefore, it was considered by the authors as a good method to assess the existing visual conditions of the work environment.

Three of these checklists were used on the 10th of February 2021 at three different work locations where observations had been made (see Appendix 2). In the Prevent checklist (Prevent, 2020), there are eight categories to assess: workplace design, lighting, light measurements, daylight, assessment of lighting conditions, maintenance, assessment of vision requirements and working positions. Almost all the above-mentioned categories of the checklist were filled in on site by the authors except for the part “light measurements” because technical measurements were performed in a second moment during the simulation (Appendix 7). Consequently, the values of illuminance (lux) and luminance (cd/m²) were filled in the checklists after the simulation. According to Borsting et al. (2008) and Knave et al. (1985), it is advantageous to assess risk for the visual ergonomics environment when setting up a visual ergonomics system. Vision discomfort and related symptoms should be studied. As part of this effort, checklists can be found useful as there are many aspects that need to be considered.
3.4 Simulation

Due to the restrictions related to the pandemic of the coronavirus disease (COVID-19) and the advice for the public to reduce the risk of infection from the World Health Organization (WHO, 2020), it was not possible to perform measurements on the construction site. Therefore, light measurements were performed by doing a simulation in a second moment (Appendix 7). The simulation was performed at KTH Flemingsberg on the 23rd of February 2021. During the simulation, the authors tried to recreate the working conditions observed and photographed on the working site. Three workplaces were simulated. As recommended by SIS (2011), three working areas were considered when assessing the visual conditions of the work situation, namely the task area (central field of view), the immediate surroundings (nearby area), and the external environment (peripheral field of view), as shown on figure 5.

![Diagram of minimum dimensions of immediate surrounding and background area in relation to the task area (SIS, 2011)](image)

To assess both the current working light conditions (without lamps) and the light conditions with the use of the lamps, measurements of illuminance and luminance of three working areas (figure 5) were performed both without and with the use of the lamps (Appendix 7). Moreover, each measuring point was done by following the guidelines from the SIS (2011) as it shown in Appendix 7. The instrument used for measuring the light during the simulation, for calculating luminance (cd/m²) and illuminance (lux), was a Hagner Screen Master. Two instruments were loaned from KTH University (instruments nr. 31411 and nr. 31413) and they were used according to the instructions from Hagner Measures light (2020). No calibration documentation records could be found for the instrument.

3.5 Work Diary

Collection of data by using work diaries was planned as follows. Three workers used five lamps for one week. The three workers had different work duties within the construction site; 2 of them work as plumbers and one of them works as a sprinkler fitter. The workers were each given a diary in order to write reflections about the lamps. Instructions about the correct use of the lamps were given and lamps were tested on the work site. The five lamps were used and evaluated for a week and each worker tested each lamp for various work performances. Instructions on how to use the diaries were given and the workers were encouraged to write down all the reflections they had as soon as they had any. In this way, they would remember
which were their main points of view about the use of the lights and the effect that the lights had on their health, wellbeing, productivity, and quality of work. After a week, the authors and the workers had a meeting where the workers had the chance to discuss what they wrote in their diaries and express their opinions in words as well. The three work diaries were collected and summarized (Appendix 5).

Work diary is selected as one of the methods because Marrelli (2007) has shown them to be an intriguing data collection method. Indeed, in a work diary, workers document their own work experience. The content of a work diary varies depending on the data collection needed. Moreover, workers may be asked to write down all their work activities or only certain types of work. Marrelli (2007) has shown that this collecting data method has many advantages, including the fact that it is easy for most people to understand and complete. In addition, work diaries are an exceptional substitute for observations if in-person site visits are not possible, or if workers are not comfortable being observed. Undoubtedly, the data collected from work diaries is generally trusted as being written directly by the workers. In addition, work diaries are often appreciated by an organization because it is a not time-consuming method.

3.6 Focus group
3.6.1 Ethical considerations
At the beginning of the interview, the participants were informed about the ethical aspects of the report. All the participants were treated respectfully and equitable without trying to affect their opinions. The participants were also informed that the collected data would be kept confidentially. Moreover, they were informed that the collected data would be destroyed after a reasonable time. In addition, permission to register the interview was requested.

3.6.2 Interview
A focus group was conducted with three workers who have been using the various lamps for a week. The site manager was also present during the focus group but did not answer any question. During the interview, one author was leading the conversation and asking questions while another author was taking notes (Appendix 6). It took about an hour and data collection was done by recording the conversation with an audio device. By recording the conversation, the authors could focus on listening to the workers’ answers and be able to analyze the conversation in a second moment. Thereafter, the vocal registration was transcribed, and the contents of the conversation were identified and divided into meaning categories and subcategories. A focus group is an ethnographic interview format that includes more than two participants. Focus group was chosen as a method because, according to Kvale & Brinkmann (2014) this method has the purpose of elaborating participants’ perspectives associated with the research questions in a supportive environment. Moreover, as recommended by SIS (2011), the worker’s individual experience of the lighting conditions should be documented because it is important to find out if the worker thought that the lighting conditions were sufficient in order to perform work tasks satisfactorily.
4. Results

This chapter is presented in subsections. Every subsection shows the results of each method used during the project.

4.1 Dialogue tour

The results from the dialogue tour showed that the worksite had a complex layout which changes often since they rebuild an old building. The project manager mentioned that all the lights at the site combined would be several km long strip LED work lights as a general lighting and described the current lighting condition at the worksite as very good, even though there were no windows. However, both authors experienced the lighting conditions as very poor during the dialogue tour. Some work areas had no proper lighting at all and did not receive light from the general lighting. Indeed, workers were observed wearing headlamps and portable lamps as complementary lighting.

Because the worksite was an old building undergoing renovation throughout the year, many layouts of the workplaces had been altered. The manager mentioned during the tour that they were able to erect a wall, creating an additional room on a day’s notice. This means that there would be no general lighting reaching that new room. The room would be completely dark, and the workers would have to use headlamps and sometimes auxiliary standing lamps. Therefore, there was a need for better auxiliary lamps that are light, portable, and preferably cordless. The workers involved in the dialogue tour had experienced the current lighting conditions in different ways. Some perceived the lighting condition as adequate while others perceived it as quite dark. Based on current lighting conditions and conversation during the dialogue tour, the authors were left with the impression that workplace participants had poor knowledge of visual ergonomics.

4.2 Observation

The results from the observations (Appendix 3) showed some potential risks regarding workers' health and well-being due to poor general lighting. The daylight factor was poor because the observed workplaces were located in the middle of the building and underground.

The first observation was conducted at a work site with many small-diameter pipes of different sizes and colors (see Figure 6). The worker was supposed to repair one of the pipes and was using one of the headlamps that the authors had provided for evaluation. While performing the work tasks, the worker also used an auxiliary lamp attached to some metal (Appendix 3). During the observations, it was noted that workers had to bend their back and neck in order to better see the work objects. This was also done to avoid glare and shadows because of the incorrect light intensity. This workplace was located in the corner of the building to where the general lighting did not reach. Also, when the light hits the pipes, it creates shadows forcing the worker to bend the head and neck. The design of lighting and visual ergonomics are
important factors to consider for preventing eye strain, headache, and fatigue, as well as for minimizing the risk of musculoskeletal diseases (Bohgard et al., 2009).

Figure 6. The first workplace during the observation

The second observation was conducted in a pipe assembly location of the basement (Figure 7). It was a worse-case scenario since the working place was completely dark and there were no stationary lights, nor general lighting. The worker mentioned that they do not work at one workplace for a whole day and rotate the workplaces depending on the needs and planning of the work. Therefore, the second workplace is not their daily work area for a longer time. According to the worker, the reflective wall surfaces made it more difficult to see the work object when he was only using a headlamp (Appendix 3). During the observation, the worker used both a headlamp and/or an auxiliary lamp to see the effects on the work performances. The worker mentioned that the auxiliary lamp can be useful to have more lights in the background which makes the contrast of the headlamp and dark room less. During the observation, the worker squinted with his eyes while working as if he was having hard time looking into the work object. This may have resulted from the work area being too bright and it was too dark in the rest of the room, making his eyes more tired.

Figure 7. The second workplace during the observation
The third observation was in a subterranean cavity of the basement. This workplace was considered as a worse-case scenario (Figure 8) because the general lighting usually did not reach to the basement. When the observation was conducted, it was completely dark, and the worker was using a headlamp together with an auxiliary lamp on the floor. The worker mentioned that using the headlamp is essential to go downstairs to the basement.

![Figure 8. The third workplace during the observation](image)

He mentioned that the round auxiliary lamp on the floor was a bit inconvenient to bring it downstairs because it is too bright to look at. He also mentioned that the headlamp should be designed with a wide-spread beam instead of a spotlight beam. Because others can get blinded by the headlamp which could in turn have serious consequences. Regarding other fatigue that might be affected by the lighting, the worker mentioned that he sometimes gets tired with his eyes and he was wearing the lenses.

### 4.3 Checklist

The results from the checklist (Appendix 4) showed that the current lighting conditions were poor and that there was a need for improvement of the lighting situation. In fact, there was no daylight incident to the work environment and the direction of the artificial light was improper. Moreover, the light was too dim and could be regulated on an individual basis. In addition, the lighting intensity varied sharply between different parts of the work area also where work tasks were visually demanding. An important part of the checklist was to make technical measurements of the current situation. According to SIS (2011) in all enclosed places, the maintained illuminance on major surfaces shall have the following values:

- \( \bar{E}_m > 50 \text{ lx with } U_0 \geq 0.10 \) on the walls and
- \( \bar{E}_m > 30 \text{ lx with } U_0 \geq 0.10 \) on the ceiling.

(* \( \bar{E}_m = \text{maintained illuminance}; U_0 = \text{illuminance uniformity} \)*)
The illuminance values shown in Table 1 were too low. The results from the measurements of the current lighting situation (Appendix 8) show that there was not enough light to perform required work tasks. The illuminance and luminance values of the current situation are shown in Table 1. The luminance was too high at the first workplace where the pipe fitters were working. On the other hand, the values were too low at the second and third workplaces.

Table 1. Measurement of the current lighting situation

<table>
<thead>
<tr>
<th>Current status</th>
<th>Illuminance (lux)</th>
<th>Luminance (cd/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement areas</td>
<td>W</td>
<td>I</td>
</tr>
<tr>
<td>1st workplace</td>
<td>25,6</td>
<td>28,3</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>1,1</td>
<td>0,9</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Indeed, according to SIS (2011), the recommended reflectance range for major interior diffusely reflecting surfaces for walls are 0.5 to 0.8 cd/m2. In conclusion, the results of the checklist showed that the worksite had insufficient general lighting and no auxiliary lamps available for the workers. There was also a need for additional lighting in order to prevent the risks for deteriorated health and well-being for the workers.

4.4 Simulation

The light measurements during the simulation showed the values of illuminance and luminance at three different worksites (Appendix 7). The first simulation gave the results of the current situation without using any additional lamps. The second simulation gave the results of each single lamp used at the different worksites. The third simulation gave the results by using two lamps simultaneously.

The results of the first simulation showed that current lighting conditions were poor and that there was a need for improvements in the lighting situations (Table 1). According to the measurements, the illuminance values were too low which means that there is not enough light to perform required work tasks. Regarding the luminance values, the first workplace had too high value while the second and third workplaces had too low values. The results of the measurement show that the current worksite had insufficient general lighting and auxiliary lamps available. There is also a need for additional lighting in order to prevent the risks for deteriorated health and well-being for the workers.

The results of the second simulation showed that each lamp had a different effect on the work environment with different values of illuminance and luminance. As shown in Table 2 & 3, the results of the second simulation also showed that the variations in values between the working
areas were too big. For instance, some lamps have a major effect on the task area, but a low effect on the immediate surroundings or on the external environment. Some other lamps had low effect on the work area but high effect on the immediate surroundings or on the external environment.

Table 2. Measurement with the lamps (Illuminance)

<table>
<thead>
<tr>
<th>Measurement area</th>
<th>Own lamp (standard headlamp)</th>
<th>Lamp 1 (headlamp wide beam)</th>
<th>Lamp 2 (headlamp zoom-function)</th>
<th>Lamp 3 (portable work lamp)</th>
<th>Lamp 4 (square work lamp with a clip)</th>
<th>Lamp 5 (big and round work lamp)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>I</td>
<td>E</td>
<td>W</td>
<td>I</td>
<td>E</td>
</tr>
<tr>
<td>1st workplace</td>
<td>133</td>
<td>120</td>
<td>52</td>
<td>163</td>
<td>197</td>
<td>84</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>475</td>
<td>294</td>
<td>3</td>
<td>49</td>
<td>57</td>
<td>58</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>70</td>
<td>10</td>
<td>4</td>
<td>151</td>
<td>230</td>
<td>458</td>
</tr>
</tbody>
</table>

According to SIS (2001), large spatial variations in illuminance around the task area can lead to visual stress and discomfort. Therefore, the illuminance of the immediate surrounding area should be related to the illuminance of the task area. It should provide a well-balanced luminance distribution in the visual field. According to SIS (2011), the illuminance on the task area should be about 25-35% higher than the illuminance on immediate surrounding areas.

Table 3. Measurement with the lamps (Luminance)

<table>
<thead>
<tr>
<th>Measurement area</th>
<th>Own lamp (standard headlamp)</th>
<th>Lamp 1 (headlamp wide beam)</th>
<th>Lamp 2 (headlamp zoom-function)</th>
<th>Lamp 3 (portable work lamp)</th>
<th>Lamp 4 (square work lamp with a clip)</th>
<th>Lamp 5 (big and round work lamp)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>I</td>
<td>E</td>
<td>W</td>
<td>I</td>
<td>E</td>
</tr>
<tr>
<td>1st workplace</td>
<td>9.6</td>
<td>7.5</td>
<td>6</td>
<td>9.4</td>
<td>7.1</td>
<td>5.8</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>92</td>
<td>86</td>
<td>0.6</td>
<td>10</td>
<td>9.3</td>
<td>7.2</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>3.1</td>
<td>0.4</td>
<td>0.1</td>
<td>2.2</td>
<td>4.6</td>
<td>2</td>
</tr>
</tbody>
</table>

The third simulation gave the results of the illuminance and luminance values by using two lamps simultaneously. The results showed that the three workplaces had much better visual conditions compared to the current situations. However, there were still improvements needed, because even in this case, the illuminance of the immediate surrounding area was not related to the illuminance of the task area (Table 4 & 5).
Table 4. Illuminance values with combinations of two lamps

<table>
<thead>
<tr>
<th>Workplaces</th>
<th>Combinations</th>
<th>Measurement areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>1st workplace</td>
<td>Lamp 1 + Lamp 4</td>
<td>201</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>Lamp 2 + Lamp 3</td>
<td>843</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>own lamp + Lamp 5</td>
<td>354</td>
</tr>
</tbody>
</table>

Table 5. Luminance values with combinations of two lamps

<table>
<thead>
<tr>
<th>Workplaces</th>
<th>Combinations</th>
<th>Measurement areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>1st workplace</td>
<td>Lamp 1 + Lamp 4</td>
<td>20,6</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>Lamp 2 + Lamp 3</td>
<td>144</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>own lamp + Lamp 5</td>
<td>11,6</td>
</tr>
</tbody>
</table>

In conclusion, the results of the measurement during the simulation show that there is a need for improving the current lighting condition at the worksite. At the moment, there is insufficient general lighting and no auxiliary lamps for the workers. Even though all the illuminance values of the immediate surrounding area are lower than the illuminance on the task area, the lighting condition is still too poor and varies too much between the workplaces compared to the standard values.

4.5 Work diary

The results from the work diaries (Appendix 5) showed that there are many aspects of the lamps affecting workers’ performance and daily work-life. The project lamps that were evaluated are presented in Appendix 1. Most of the lamps were helpful for the workers to perform their work more efficiently. Also, the lamps could affect the workers’ health and well-being indirectly. The three work diaries were collected and summarized in Table 6.

One of the positive aspects of the lamps for its design is that the battery can be charged either by removing it from the lamp or by connecting a USB cable. This makes charging both easy and practical. It is not needed to keep additional battery charging devices on hand. The lamps can run for quite a long time between charges, resulting in time savings compared with the lamps used before. During the tests, the battery lasted the entire workday, and could therefore
be charged overnight when no work was performed. The headlamps are relatively light which was perceived as a very positive factor by the workers. They had been used to wearing hardhats with goggles, earmuffs, and heavy headlamps. This had led to workers experiencing neck pain. The lamps are cordless which makes them easy to move around without risk for stepping on the cord. They also help in improving work productivity.

Table 6. Collection of the work diaries

<table>
<thead>
<tr>
<th>Positive aspects</th>
<th>Design</th>
<th>Lighting</th>
<th>Battery</th>
<th>Usability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The headlamps are relatively light</td>
<td>The headlamp with the wider beam shines on a wider surface</td>
<td>The lamps can run for quite a long time between charges</td>
<td>Easy to set up the headlamp on the helmet</td>
</tr>
<tr>
<td></td>
<td>The lamps are cordless</td>
<td>Ability to adjust three lighting intensities</td>
<td>Chargeable separated battery</td>
<td>Placement of buttons on the lamps are reasonable for the users</td>
</tr>
<tr>
<td></td>
<td>Small and portable</td>
<td></td>
<td></td>
<td>No pre-learning required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Negative aspects</th>
<th>Design</th>
<th>Lighting</th>
<th>Battery</th>
<th>Usability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The smallest portable lamp 3 is not very useful since there is no way to place it in a stable way</td>
<td>The light intensity from the lamps is too strong</td>
<td>There is only one battery in the package</td>
<td>Connection with an App is a bit over-killed</td>
</tr>
<tr>
<td></td>
<td>Portable lamp 4 is too heavy for the size</td>
<td>Some lamps are too bright which creates glare</td>
<td>USB-charger is needed (limitation for outdoor workplaces)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lamp 4 &amp; 5 are inconvenient to carry around</td>
<td>Lighting is too white and cold</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The headlamp with the wider beam shines on a wider surface providing a wider view of the work area. This allows workers to see better, contributing to effectiveness and safety. The headlamps have three lighting intensities allowing workers to perform various assignments without changing lighting equipment each time. Moreover, this ability to adjust intensity contributes to saving working time. The workers mentioned that the lamps are easy to use which means there is no need for learning as a new user. The buttons are placed in a logical way. Also, the headlamps are easy to set up on the helmet. This is a positive aspect since they can save time for learning new technologies and making mistakes.

However, there were some aspects of the lamps that are perceived as negative. The workers wrote in their diaries that the following aspects should be improved for further developing the lamps. The light intensity from the lamps is too strong. Even though some of the lamps have three different intensity levels, even the lowest level was perceived as too powerful and too bright. This makes the workers feel discomfort when looking at the proximity of the light beam. This affects not only the health of the workers, but also their productivity in a negative way. This is because it takes more time for the workers to perform work tasks. According to the workers, the lighting is too cold and white. They mentioned that it would therefore be better if the lights had warmer color rendering and less intensity of brightness. This creates glare and it is, therefore, a negative aspect.

The compact sized portable lamp (lamp 3) is not very useful for the workers because there is no way to place the lamp in a stable manner while working. This is too small to put on the floor. It would be very helpful if the lamps had a magnet on the back, so you could attach them to e.g., metallic pipes and so on. The portable lamps (lamp 4 and 5 in Appendix 1) are perceived as too heavy and inconvenient to be called portable. This impacts productivity in a negative way since it increases the time to carry the lamp from one place to another. Also, it may cause musculoskeletal disorders and incidents when performing work tasks.

In conclusion, some aspects of the lamps should be changed in order to better suit this workplace. For instance, current lighting conditions need to be improved. This includes general lighting as well as auxiliary lighting for the workers. But the project lamps were not totally covered. The negative aspects that workers perceive were documented when completing the work diary as shown in Table 6. This information may be useful for manufacturing companies to consider when designing updates for new technology lighting, thus helping them to develop their products further. It is crucial to understand the end users’ needs and desires within specific scenarios when developing the lamps, especially work lamps. The detailed feedback from the work diaries can be found in Appendix 5.

4.6 Focus group

The results from the focus group (Appendix 6) showed the workers experience and perception using the lamps. All three workers had in general a very positive experience using the lamps. The worker who used headlamp 1 (Appendix 1) with a wide flood light thought the lamp was good because it could be adjusted for three different lighting intensities, providing for better
and wider sight. A second headlamp (lamp 2 in Appendix 1) was also deemed because it could be adjusted for range of lighting and it was easy to use. The workers mentioned that the headlamps are important for them since they provide for a better view of the work object.

According to the workers, the compact portable lamp (lamp 3 in Appendix 1) was not very useful when performing work tasks. The lamp cannot be clipped onto a pipe and has no magnet for attachment onto metal surfaces. Also, the lamp does not provide wide enough light spread so it was not as useful as the headlamps. The middle-sized square lamp with a clip (lamp 4 in Appendix 1) was perceived as good since it is easy to use and convenient to carry at the worksite. It was, however, too bright because it has only two light intensity levels. This can blind the worker for several seconds after accidentally directly looking into the light source. It can also disturb other workers. The current lowest level of brightness can be experienced as too strong. They all agreed it was too bright, but if it had yet another lower intensity level, the lamp would be more useful. The current lowest level of brightness can be experienced as too strong.

The workers mentioned that all the lamps are very good and sustainable because of their long battery life. This saves significant time for the workers. Indeed, the batteries lasted for the entire workday and could be charged overnight when not working. According to the workers the job became more efficient, and the work tasks could be completed in less time than before when using these lamps. For example, it takes less time to move cordless lamps than lamps with wires between work locations, thus saving time. Another worker said that he did not notice much difference, but that he thought that quality of work had improved, meaning that the job was performed in a better way. For example, it is advantageous that the lamps are easily attached to the hardhats without effort. Also, the lamps have detachable chargeable batteries, allowing the batteries to be charged without removing the lamp from the hardhat. This saves work time.

“By using these lamps, the work is performed in a more efficient way. I could work faster; it took less time to perform the same work task. “

During the focus group, workers were asked whether the quality of work results depended on lighting conditions. According to the two more-experienced workers, the lighting does not influence the quality of work since the work performance has to maintain the same high standard in order to fulfil the specifications. These two workers have worked in their field for over 20 years, either in Sweden or in other countries. They claimed that they can manage their work even in temporary poor lighting conditions. They all said that the current workplace has a relatively good work environment, yet they acknowledged that the lamps contributed to more efficient work performance and that time could be saved and therefore used for other work tasks. They also reported that the cordless lamps offered some obvious advantages compared to the traditional lamps regarding safety aspects. For instance, when using cordless lamps, some incidents can be avoided, and the risk for workers to trip on the cord is eliminated. This helps in avoiding serious work injuries.
Regarding health and well-being, one of the workers mentioned that he has experienced neck pain in the past due to the fact that the helmet is too heavy. He suggested therefore that the headlamps should be light to carry and easy to attach on the helmet. Another worker mentioned that his eyes get tired due to the work environment issues such as lighting and dusty. The poor lighting sometimes requires the workers to bend the body into awkward posture. Consequently, the workers feel pain in the shoulder, back or other parts of the body. One worker mentioned that if the lamp is placed in the right direction or intensity, then one can avoid bending the body, which contributes to a healthier and safer work environment. They all agreed that the lamps they tested for the project were relatively lightweight and assumed that this is because of no electric batteries on the devices. This is a positive aspect of the chargeable lighting for environmental reasons.

When the workers were asked about safety related to lighting, they agreed that the better lighting the safer workplace. They all agreed that the brightness of the lights could have consequences to their safety and health. Therefore, it would be better if the lamps have low-brightness options. In fact, according to the workers, the lamps were too strong, and it can be dangerous. When a worker has the headlamp on and other employees look directly into the headlamp, there is a risk of going blind suddenly. In general, their ideal work environment has better stationary lighting and not just good individual headlamps. One of the workers mentioned that the light conditions are often quite poor at construction work sites. Typically, it is too dark, and no one requires or requests to buy better lighting at work. There is a logistical challenge in that they rotate work areas and tasks which require different types of lights. The workers mentioned that, according to their personal working experience, poor lighting and dust are the two biggest and most common work environment problems in a construction industry.

“I can feel frustration and irritation when there is insufficient lighting compared to what the situation requires. I sometimes feel my eyes tired.”

One of the workers thought poor lighting could affect mental health since there is no window that he gets daylight, and he feels it is quite a big difference compared with the previous work situations. Another worker mentioned that he knows by experience that good lights are important in a work environment and that better lighting leads to better well-being. In addition, the workers feel frustration or irritation if there is no good lighting where they need to see properly while working. A worker mentioned that his eyes get tired sometimes and that he has bad vision and uses contact lenses lately. Finally, one of them reflected that the visual work environment is something new for him, but he believes now that it is important for the workers to have good lighting at work to promote health and safety.
5. Discussion

5.1 HTO-perspective

An analysis tool that was used during this project was the HTO-concept. It allows for performing a usability study when specifically looking at visual ergonomic aspects at indoor construction worksites. HTO helps to identify deficiencies in interaction between workers and the light sources used during work. One dominant aim of this study was thus to investigate possible improvements of lighting designs. Other environmental interaction aspects, like the visual conditions found at the worksite, were also considered. The study did not take into consideration aspects relating to organizational interaction. Organizational factors, such as leadership and organizational culture, directly affect safety (Karltn et al. 2017).

Since it is crucial to understand visual ergonomics both at workplace level and at individual level, the findings were interpreted using the HTO-perspective. Visual ergonomics come with a series of issues. It is therefore vital to combine the effort with other relevant professionals in a multidisciplinary holistic manner (Long & Helland, 2012). HTO contributes to some interesting results, even though it does not specifically provide clear explanations to current ergonomic problems. The advantage with this approach is that it suggests a holistic model that later can be developed further. HTO is considered a good analysis tool for developing sustainable work conditions and is therefore suitable for the type of worksite analyzed during this study.

A lighting manufacture company provided the lights used in this study. This study, therefore, helps the worksite to obtain better lighting conditions at the same time that it helps the lighting manufacturer to develop its products. At the construction site, the workers’ work performance, safety, and well-being were analyzed while these new visual aids were evaluated. Several interaction improvements were found during the HTO-analysis using the new lighting conditions. According to Porras & Robertson (1992), inadequate lighting situations affect the behavior of the individual. This was evident when the workers had the chance to use various lamps as auxiliary lighting. They experienced that the lamps were helpful and made their work more efficient. During the focus group, the workers mentioned that having a better lamp is beneficial for their work performance as well as working time.

Nylén (2017) reports that many workers are unaware of, or have limited knowledge of, lighting and how much lighting can be improved for their work tasks. Furthermore, the correlation between eye problems and lack of proper visual and lighting conditions are not always obvious. The workers believe that inadequate working lights can affect the behavioral aspects of work and mental health. This was especially so for those workers with prior experience at work sites with worse lighting conditions. They had experienced visual ergonomic work environment issues at their previous workplaces.
5.2 Method discussion

5.2.1 Dialogue tour
As recommended by Rolfö (2016), the workers chose themselves areas of greatest concern and then all participants moved from one location to the other while discussing visual ergonomics problems and possibilities for each chosen location. Moreover, the worker who originally suggested a particular location provided a brief motivating explanation to why the location was important relative to visual ergonomics issues. This step allowed an introduction between the authors and the workers and a discussion about visual ergonomics problems and possibilities for each chosen location could be done. Undoubtedly, this method was very fruitful as a start because it allowed to involve workers in a dialogue while walking in the worksite. Moreover, this method allowed the authors to familiarize with the work site and the work tasks. In addition, this type of documentation was a vital starting point for the continued work. On the other hand, there was a problem identified using the method. It was not easy to get the whole picture of the workplace, because the worksite maps keep changing dynamically according to the construction plan. Therefore, it was limited to workplaces that could be investigated during this project. It would have been interesting to compare other types of work areas with windows and daylight for the workers.

5.2.2 Observation
The first advantage of gathering field-based data was the fact that it was possible for the authors to get detailed information during real life situations. Indeed, as recommended by Cohen, Lawrence, & Morrison (2007), the workers were requested to behave as in normal working conditions. They were asked to behave as normal so their work environment could be compared before and after the implementation of the new work lamps. Another advantage of observations was that several behaviors could be studied simultaneously. Moreover, by being near to the workers, it was possible to get a clear view of how workers performed their various work tasks. In addition, pictures and videos were taken during the observation. This gave the authors the possibility to look at details in a second moment. However, there was a limitation on project visiting times to observe the workers. This was due to the varied work tasks as well as the covid-19 situation. Because of these limitations, the work diary method was performed as an auxiliary method.

5.2.3 Checklist
An advantage of using checklists to assess the work environment was that many aspects could be considered. Indeed, the checklist from Prevent (2020) is divided in eight categories: workplace design, lighting, light measurements, daylight, assessment of lighting conditions, maintenance, assessment of vision requirements and working positions. This gave the authors the opportunity to assess in detail all the composing aspects of the visual work environment on site. However, the checklist category “light measurements” was filled out in a simulated environment since it was not possible to perform technical measurements at the worksite. Although efforts were made to be consistent with the worksite conditions, simulation could
cause the values in the “light measurements” category to be different, compared to if the technical measurements had been performed at the worksite. In this project, it was not required to have exact values. However, having values from the worksite could be useful for a follow-up study in, for instance, evaluating work environment improvements.

5.2.4 Work diary

Marrelli (2007) has shown work diaries to be an excellent data collection method. Indeed, in a work diary, workers can document their own work status. Depending on the data collection needed, the content of a work diary can vary. Using a work diary has many advantages and was a suitable method for this project during the covid-19 pandemic. The work diary was an exceptionally practical substitute for observations whenever in-person site visits were not allowed. During the working day, the workers had a no-fixed schedule. This made it difficult to perform observations in each work area for extended time periods.

Undoubtedly, the data collected from work diaries was trustworthy since it was written by the people performing the work. In fact, the workers have deep and personal knowledge of their work and work environment, which is an advantage of this method. However, the method relies on some assumptions: that the workers will be candid in their responses and that they have enough time and interest to fill in the diary regularly. Moreover, workers' perception of the lighting may be more affected if more time could be spent for evaluation, rather than one week only. In addition, the three workers had different work duties within the construction site. Two of them work as plumbers and one as a sprinkler fitter. They used two different lamps for their work tasks, with varied work performance.

5.2.5 Focus group

Three workers were involved in the focus group. The site manager was also present during the focus group but did not answer any questions. This type of interview can have some limitations. For example, one participant can influence how other participants answer questions. It is easy to agree with others when being interviewed in a group. The presence of others can be particularly limiting when one is the project manager thus potentially influencing the workers’ answers.

Despite all the methods applied in this project, it was only the focus group that identified the issue of corrected vision among the workers. Indeed, it was realized, only during the focus group, that one worker wore glasses and another used contact lenses. Especially the worker using contact lenses had experienced eye dryness. This is important because to evaluate whether the worker experiences problems with high intensity lights is crucial. When it comes to eye strain, however, it is difficult to know from where it comes. The lighting could be a contributing factor (Ljuskultur 2013). An important consideration to make, however, is that only three participant workers were involved in the project. Moreover, they were all men. If the participants had been more numerous with a wider gender perspective, the results may have covered a wider range of working situations.
5.2.6 Simulation
Performing technical measurements is an important method as it provides a consistent indicator for calculating differences (Pruzan, 2016). In fact, technical measurements provide precise assessments of the grade of relationship between variables. The more precise the measurement instrument, the more meticulously the measurements are done, and the smaller the difference is between human perceptions of the physical world and the physical world itself. When performing the simulation, it was attempted to reproduce the identical working conditions observed at the work site. The results of the technical measurements during the simulation could be slightly different from the measurements that were done at the work site. If it would have been possible to perform measurements at the work site, the results could have been more realistic and more valid for the current work site.

5.2.7 Limitations
As mentioned above, the workers used the lamps for one week in different workstations. However, due to the restrictions related to the pandemic of the coronavirus disease (COVID-19) and the advice for the public to reduce the risk of infection from the World Health Organization (WHO, 2020), it was not possible for the authors to be on site for the whole week and consequently, it was not possible to perform observations and measurements of all the workstations used during this week. Therefore, observations on site were made only in 3 of the main workstations used during the week.

In addition, light measurements were performed by doing a simulation of the work environment, in a second moment. Even though the authors tried to recreate the working conditions observed and photographed on the working site as much as possible, it might be that the results of the light measurements would be different if done on site. Therefore, even though the simulation had its positive sides because measurements could be performed in a manageable time, it could still be a limitation of this study.

On average, the vertical eye position is lower for women than for men. This is the fact for sitting and for standing positions (Hanson et al. 2009). This could imply that women are exposed to different risks than men when it comes to lighting conditions. As an example, women may find themselves in a shadow caused by the position of the light fixture in combination with their eye position. Other factors that may influence are for instance women’s longer eyelashes and bangs (Arbetsmiljöverket 2016). In addition, reduced visual acuity is more common for women and it becomes more prevalent with age. This is due to biological as well as socio-economic reasons (Zetterberg 2016).
5.3 Results discussion

5.3.1 Health & Well-being

The findings in this report show that the current visual conditions of the work environment are inadequate. This is partly because there are no windows providing daylight, and partly because there are insufficient artificial lights. Therefore, the current situation could affect the health and wellbeing of the workers. In theory, electric lighting can provide as good visual performance as daylight if glare protection is available. In practice, however, there are some limitations in quality, such as in illuminance, colors, and variations during the day (Lowden, 2019). Lighting conditions and access to daylight is an important factor of a good work environment. Access to daylight is beneficial for the worker’s health and well-being (AFS 2009:2).

According to Aarás et al. (2001), reduced lighting can induce reduction in eyesight or inflict pain in the shoulders and neck of workers. The workers mentioned that during their careers, they had experienced pain in the neck and shoulders. It might be because the lighting was poor, or the helmet was too heavy. Indeed, the helmet is provided with personal protective equipment plus the headlight. Moreover, workers sometimes must work in an uncomfortable position and the heavy helmet is an overload for the neck and shoulders. Thus, the use of headlights that are relatively light, contributes to a better health and wellbeing of the workers. Moreover, if the light is pointed to a favorable direction and with proper intensity, bending the head or assuming an uncomfortable posture will not be necessary.

As Bohgard et al. (2009) mentioned, lighting and visual ergonomics are important factors when considering eye strain prevention, headaches, and fatigue. The workers also mentioned that they, sometimes, experienced tiredness in the eyes due to poor working light conditions and dust. Moreover, they feel frustration and irritation when there is insufficient lighting. However, if a light is too bright it is experienced as negative. Regarding other fatigue that might be affected by the lighting, the worker mentioned that he sometimes gets tired with his eyes and he was wearing the lenses. It could be from the overly brightened lamps from the auxiliary lamp or dust from the worksite. According to Lowden (2019), having LED lights are also proven to be a good way of saving energy and increasing the employees work performance and fatigue. The light has mental and physiological effects on our health and well-being.

In summary, the results show that the illuminance and luminance distribution are not adequate. According to SIS (2011), adequate illuminance values have a great impact on how fast, safely, and adequately a worker perceives and carries out a work task. Moreover, an adequate luminance distribution is very important, because in the visual field, it controls the adaptation level of the eyes. This affects task visibility as well as visual comfort. Both too high and too low luminance should be avoided. Too high luminance can give rise to glare. Moreover, too high luminance contrast can cause fatigue because of constant re-adaptation of the eyes. Too low luminance and too low luminance contrast, on the other hand, result in a dull and non-stimulating work environment.
5.3.2 Productivity & Quality

The results of the technical measurements during the simulation (Appendix 8) show that the current work situation has inadequate visual conditions to perform the working tasks efficiently. However, the results show that the use of additional headlamps, in addition to the existing stationary lamps, improved the visual ergonomics of the work environment. Therefore, the results of the technical measurements confirm what the workers wrote in their work diaries (Appendix 5) and mentioned during the focus group (Appendix 6), namely that the lamps provide better visual conditions and, consequently, improved productivity.

The results from the checklist (Appendix 4) and observation (Appendix 3) show that some working areas need to be improved for lighting conditions and this could affect productivity and quality negatively. However, regarding quality, the workers believe that bad lighting conditions in the work environment do not affect the quality of their jobs so much. Indeed, the workers mentioned that better visual conditions positively affect productivity and quality, but whether the visual conditions are good or not, the results of their work must conform to the standards of the company. The lighting needs to be designed for the workers task in hand as well as the general lighting or a combination of both. There are also recommendations on what light sources have the appropriate color rendering and color temperature. The lighting requirements of the individual workplace is based on the direction, intensity and distribution of the lighting (AFS 2009:2).

5.3.3 Subjective performance

As Newsham et al. (2009) mentioned in their study, improved lighting conditions increase workers’ performance and job satisfaction. Nonetheless, in this case the use of both stationary lighting and individual headlamps was experienced as very important and beneficial in terms of subjective performance. Indeed, the results from the focus group and the work diaries show that the workers experience the use of the project lamps as something very positive. It made a big difference compared to their earlier experience from previous workplaces, where lighting conditions were quite inferior. In fact, they feel that by using the lamps, work tasks can be performed easier and faster. Also, the new lamps could be switched between different spectral distributions, angles, and lighting intensity. This contributed to avoiding glare.

However, the worker mentioned that some lighting intensities are too bright, and some are too obscure for some work tasks. According to Horgen (2003), it is important that the correct type of lenses is used under given light intensity conditions. Lighting intensity is especially important for workers having poor eyesight. It is difficult to trace a root cause for how or when their vision deteriorated. Whether poor lighting conditions at work affected their vision is impossible to determine. Eye strain is caused by inadequacy in the visual environment. It is because the eyes try to compensate for the poor visual environment by forcing an improvement of the vision (Boyce, 2006; Helland et al., 2008; Anshel, 2005).
5.3.4 Reflections

Undoubtedly, using several methods such as dialogue tour, checklists, observations, simulations, work diary and focus group optimized the reliability of this report. However, there are many aspects to consider regarding visual ergonomics. The results of this project show that there were a number of correlations between the perception of the workers and managers on the one hand, and the observations and measurements on the other hand. This included general lighting and glare. One significant difference, however, was that the objective methods resulted in higher levels of risk than the workers had experienced.

The findings of this project indicate that there is a connection between good visual conditions and improvements in work performance, safety, and well-being. For instance, Li et al. (2020) argue that quality, productivity, and efficiency of an organization can be meaningfully improved by improving the lighting of the work environment. Furthermore, according to Blehm et al (2005), by improving the work environment and investing in user-centered lighting, anti-glare filters, and ergonomic placement of the general lighting, it can aid in improving the workers’ visual comfort, health, and well-being.
6. Conclusion

The aim of this project was to investigate how new lighting technologies influence indoor construction workers’ safety, health, and well-being, as well as on work quality and productivity, from the HTO-perspective. The results show that new lighting technologies do have an influence on indoor construction workers’ health and well-being, quality, and productivity.

The following aspects of the new lighting that were found advantageous for the workers are:

- The lamps are cordless which makes them easy to move around without risk for stepping on the cord. This also helps in improving work effectiveness.
- The headlamps have three lighting intensities allowing workers to perform various assignments. Moreover, this ability to adjust intensity contributes to saving working time.
- The headlamp with the wider beam shines on a wider surface providing a wider view of the work area. This allows workers to see better, contributing to efficiency and safety.
- The headlamps are relatively light which is perceived as a very positive factor. If workers had to wear hardhats with goggles, earmuffs, and headlamp, this would bring about negative consequences on workers’ physical health.
- The lamps have long battery life, and they can run for quite a long time between charges, resulting in time savings. During the tests, the battery lasted the entire workday, and could therefore be charged overnight when no work was performed.
- The battery can be charged either by removing it from the lamp or by connecting a USB cable. This makes charging both easy and practical. It is not needed to keep additional battery charging devices on hand.

These are the recommendations that can be given to similar worksites at this and other indoor construction sites to implement the type of lighting used during this work.

Another important research question of this project was to find out how well the workers in a specific context experience the project lights to perform their work tasks. The use of both stationary lighting and individual headlamps was experienced as very important and beneficial in terms of performance. Indeed, the workers experience the use of the project lamps as something very positive. It made a big difference compared to their earlier experience from previous workplaces, where lighting conditions were quite inferior. In fact, they feel that by using the lamps, work tasks can be performed easier and faster. Also, the new lamps could be switched between different spectral distributions, angles, and lighting intensity. This contributed to avoiding glare. However, the worker experienced some lighting intensities as too bright, and some as too obscure for some work tasks.
7. Future work

In this project, there were several methods used and three workers involved. More empirical studies are needed in order to gain a deeper understanding of the topic. For instance, the participants of the project were all men. Therefore, studies including a wider gender perspective would be suitable as follow-up investigations. Another aspect to consider in future work is to include a larger number of participants having different ages, and in particular involve older workers and those with visual impairments. Another recommendation for future studies is to let the workers use the new lamps for longer periods of time than one week. Because the study of usability is also important. In addition, this project focused on investigating the visual conditions of indoor work environments and on the correlation of workers’ health, well-being, and productivity to the new lamps. A recommendation for future studies would thus be to also focus on outdoor work environments. This would help to compare the lamps usability and its effects in different work environments.
References


39


Appendix 1. The project lightings

This appendix documents the details of the project lightings.

# Lamp 1: Rechargeable headlamp with wide beam pattern

Rechargeable headlamp with hybrid lamp, which means that it can be used with standard alkaline batteries as well, while charging the supplied rechargeable battery. This headlamp gives a wide beam pattern, providing a wide working light.

# Lamp 2: Rechargeable headlamp with zoom-function

Rechargeable headlamp with hybrid lamp which means that it can be used with standard alkaline batteries as well, while charging the supplied rechargeable battery. This headlamp is supplied with motion, distance and light sensors to promote flexibility while using it. However, the sensors can be disconnected if needed. Moreover, this headlamp has 3 different light settings plus a pulsating light and a zoom function that allows to focus the light on a smaller point.

# Lamp 3: Compact size portable light

This lamp is a compact size portable light. It is highly impact resistant and very easy to handle due to its compact size. Moreover, it has a rechargeable battery and variable dimmer function that is controlled from the back of the lamp. In addition, there is the possibility to select a high or low beam.
# Lamp 4: Middle-sized work lamp with a clip

Rechargeable work lamp with very bright light. This lamp is equipped with a clip at the base. This allows the worker to attach the lamp to different surfaces, such as table tops, pipes, platforms and machinery. In addition, this lamp is equipped with an app function for switching the light on and off, dimming the light, setting a timer and, if needed, connecting up to 100 devices in parallel to a smartphone. Moreover, this lamp is made of materials that make the lamp impact resistant.

# Lamp 5: Large-sized round work lamp

Rechargeable work lamp with a spherical light source. This lamp provides a light dispersion around the space intended to illuminate. This work lamp is a hybrid-lamp, namely it can be powered by the rechargeable battery and with the supplied 5 m long cable. For improving safety, the system of the lamp is furnished with an emergency light function that turns on when the power is switched off. In detail, it works by flashing 2-3 times before the lamp is turned on and then glows at 50 % of its capacity for about 1 hour. This lamp can also be controlled by an app, allowing the user to switch the light on and off, dim the light and set a timer. Moreover, if needed, the app can be used to connect up to 100 devices in parallel. In addition, this lamp is made of materials that make the lamp impact resistant.
Appendix 2. Dialogue tour

This appendix documents the details of the dialogue tour.

Date and time: 2021-02-02 at 12:00-12:30
Participants: Project manager, two workers and two authors

Picture 1. Discussion during the dialogue tour

Picture 2. Worksite 1 during the dialogue tour

Picture 3. Worksite 2 during the dialogue tour
Appendix 3. Observations

This appendix documents the details of the observations.

Date and time: 2021-02-10 at 12:00-13:00
Participants: Three workers who worked with different lamps

# First workplace

Picture 4. First workplace with lamp 4

# Second workplace

Picture 5. Second workplace with lamp 2
Picture 6. Second workplace with lamp 2&3
# Third workplace

Picture 7. Third workplace with lamp 1

Picture 8. Third workplace with lamp 1

Picture 9. Third workplace with lamp 1&5
Appendix 4. Checklist

This appendix documents the checklist used during the project.

Date: 2021-02-10
Places: Three various workplaces

Detaljerad checklista belysning/synergonomi, i första hand för ergonomer/arbetsmiljöingenjörer och andra specialister

Bilaga 3 till Prevents skrift Syn och belysning i arbetslivet (sidhänvisningar till höger gäller lästips i skriften.)

Bedömningen kan antingen gälla en verksamhet/lokal där flera arbetstagare arbetar eller förhållandena för en enskild person. Gör först bedömningen för verksamheten som helhet och vid behov därefter för enskilda arbetstagare.

Datum: ____________  Undersökare: ____________  

Företag/avdelning/lokal: __________________________ 

Vems arbetsplats (om bedömningen gäller en enskild arbetstagare): ____________

Arbetsplatsens utformning

I rutan till höger kan arbetsplatsen skissas sedd uppför.

Markera med symbolerna nedan:

a) Arbetsobjekt, t.ex. 
   - maskin
   - arbetsbord
   - dator

b) Arbetsstagarens normala position.

   c) Riktning dagsljusinfall.

   d) Placering armatur takbelysning.

   e) Placering armatur platsbelysning.

Beskrivning av rummet/lokalen (om relevant)

Längd: _____ m  Bredd: _____ m  Takhöjd: _____ m

Färgsättning (glansigt/matt, ljus/mörkt, skarp/neutralt):

Golvl: ____________  Väggar: ____________  

Tak: ____________  

49
Belysning

1. Vilken typ av ljuskällor finns i lokalen?
   - [ ] Lysrör
   - [ ] Kompaktlysstror
   - [ ] Energisparlampor
   - [ ] Glödlampor
   - [ ] LED
   - [ ] Kolväskelampor
   - [ ] Högtrycksnatrium
   - [ ] Vet ej

   Sidhänvisning 40-45

Om lysrör

2. Ange om möjligt lysrörens märkning, t.ex. 36 W 840

3. Har armaturen glimtändare?
   - [ ] Ja
   - [ ] Nej
   - [ ] Vet ej

4. Har något lysrör börjat blinka oregelbundet?
   - [ ] Ja
   - [ ] Nej
   - [ ] Vet ej

5. Har takarmaturen bländskyddshastare/lameller?
   - [ ] Bara uppljus
   - [ ] Bara nedljus
   - [ ] Både upp- och nedljus

6. Har takarmaturen
   - [ ] Ja
   - [ ] Nej
   - [ ] Vet ej

Kommentar:

Ljusmätningar (ange ungefärliga medelvärden)

Belysningsstyrkor

- Arbetsområde (centralt synfält): lx
- Omedelbar omgivning (näraliggande område): lx
- Yttre omgivning (perfekt synfält): lx

Mörkaste yta i arbetsområdet: lx

Jämnhet: / = 35,49

(jämnhet = mörkaste ytan / medel på arbetsområdet; t.ex. 180 lx / 600 lx = 0,3)

Luminanser

- Arbetsområde (centralt synfält): cd/m²
- Omedelbar omgivning (näraliggande område): cd/m²
- Yttre omgivning (perfekt synfält): cd/m²

Golv: cd/m² Väggar: cd/m² Tak: cd/m² 35,69,75

Dagsljus

- [ ] Ja för alla
- [ ] Delvis (för vissa)
- [ ] Nej (inte alls)

7. Finns tillfredsställande dagsljus?

8. Finns tillräckliga utblicksmöjligheter?

9. Finns möjlighet att låt skärna av besvärande solljus?
<table>
<thead>
<tr>
<th>Bedömning av belysningsförhållanden</th>
<th>Ja för alla</th>
<th>Delvis (för vissa)</th>
<th>Nej (inte alls)</th>
<th>Sidhänvisning</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Är ljusets riktning tillfredsställande?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>47-50</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Är kontrasterna tillfredsställande?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>59-60,75-76</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Är fördelningen mellan ljusa och mörka ytor (luminanskvoterna) OK?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>75-76</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Är någon del av belysningen bländande?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>70-78</td>
</tr>
<tr>
<td>Om Ja, var?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Om Ja, var?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Förekommer störande skuggor?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>47,70,103,105</td>
</tr>
<tr>
<td>Om Ja, var?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16. Är belysningen alltför svag?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>22,79-80</td>
</tr>
<tr>
<td>Om Ja, var?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Finns tillräckliga möjligheter att reglera belysningen individuellt?</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>46</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

51
<table>
<thead>
<tr>
<th>18. Uppfyller ljuskällornas färgåtergivning och de krav arbetet ställer?</th>
<th>Ja</th>
<th>Delvis (för vissa)</th>
<th>Nej (inte alls)</th>
<th>Sidhänvisning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kommentar:</td>
<td>🟢</td>
<td></td>
<td></td>
<td>36-37</td>
</tr>
<tr>
<td>19. Är färgpåtäckningen OK för personer med färuphänomen?</td>
<td></td>
<td></td>
<td></td>
<td>29-30</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Finns störande skuggbildning i gemensamma delar av lokalen?</td>
<td></td>
<td></td>
<td></td>
<td>85,103</td>
</tr>
<tr>
<td>Om ja, var?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Varierar belysningsstyrkan kraftig mellan olika delar av lokalen?</td>
<td></td>
<td></td>
<td></td>
<td>70-78</td>
</tr>
<tr>
<td>Om ja, var?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Underhåll

<p>| 22. Finns trasiga ljuskällor? | | | | 56-57,102-103 |
| Om Ja, var? | | | | |
| 23. Är armaturerna påtagligt smutsiga? | | | | 56-57 |
| Om Ja, var i lokalen? | | | | |
| 24. Förekommer flimmer eller brumljud från anläggningen? | | | | 39 |
| Kommentar: | | | | |</p>
<table>
<thead>
<tr>
<th>Bedömning av synkrav och arbetstillståndar</th>
<th>Ja för alla</th>
<th>Delvis (för vissa)</th>
<th>Nej (inte alls)</th>
<th>Sid- hänvisning</th>
</tr>
</thead>
<tbody>
<tr>
<td>25. Är arbetet synkravande?</td>
<td></td>
<td></td>
<td></td>
<td>70-73, 98, 100</td>
</tr>
<tr>
<td>Kommentar (t.ex. krävs någon åtgärd, för vem?):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26. Är arbetstillståndena rimliga?</td>
<td></td>
<td></td>
<td></td>
<td>87-93</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27. Bör arbetstagaren progressiva glasögon eller linser?</td>
<td></td>
<td></td>
<td></td>
<td>26-27</td>
</tr>
<tr>
<td>Kommentar (t.ex. medför det problem?):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28. Är behovet av synhjälpmedel till- godosett?</td>
<td></td>
<td></td>
<td></td>
<td>26-28, 94</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29. Är behovet av skyddsglasögon till- godosett?</td>
<td></td>
<td></td>
<td></td>
<td>98, 104</td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30. Vilket helhetsintryck ger den visuella miljön i lokalen?</td>
<td>Rört</td>
<td>Harmoniskt</td>
<td>68-79</td>
<td></td>
</tr>
<tr>
<td>Kommentar:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 5. Work Diary

This appendix documents the details of the work diary.

Period: 2021-02-03 to 2021-02-10
Participants: Three workers

Collection of three work diaries

Positive aspects:

- Every lamp is very helpful in general and useful in different way depending on the work situation and postures.

- Good to have the headlamp as an additional light for my work and I am very satisfied with the function that can change the range of the light.

- It is very positive that the lamps have no cords, so you can move the lights in a very easy way, without stepping on the cord and improving the effectiveness of the job.

- Regarding the headlamp with the round light shape, it is very good that you can adjust the light formation. I.e. that you can make the circle wider or narrower.

- The headlamp has three various lighting intensities which is very helpful for performing different work assignments.

- The headlamps are relatively light. Always better if the headlamp can be lighter because it could be very heavy wearing the helmet, headphone and headlamp on the helmet for the workers.

- The headlamp with the wider light design is great because it shines on a wider surface.

  The lamps have quite a long battery time which is great. You do not need to charge them that often.

- The battery can be charged directly into the USB-cable which is very good and practical.

- It is good to be able to take off the battery from the lamp for charging.

- It is easy to use without any instruction.

- The lightings are simple enough to learn how to use and easy to set up on helmet without pre-learning.

- Make sense with the placement of buttons on the lamps.
Negative aspects:

- It would be even better if the product includes two batteries for each lamp, so you can continue to use the lamp while the other battery is charging.

- Regarding two bigger lamps (round one and square one), the lighting intensity is too high. The lights are too bright and have only two intensity adjustments on the devices. You cannot even look at the lamp itself because you will be blind for a while. It is not possible to work with the lamp aimed at oneself.

- Regarding all the lamps, it would be better if the lights had warmer light color rendering instead.

- It would have been appreciated if the lamps had a magnet on the back, so you could attach them to e.g. metallic pipes etc.

- It feels like bluetooth is a bit unnecessary to have on such lights - overkilled for the construction workers who are busy and not be able to use the phone while working.

- It feels a bit overpriced for the lighting. There’s no big difference from the existing lamps in the market except for rechargeable.

- If there was an extra wall socket (vägguttag) on the lamps would also have been appreciated.

- The middle-sized light is not useful at all in the construction workplace. The light size is too small to put on the ground and also, it is not possible to attach anywhere (either on the wall or metal).

- The square light’s beam “screen” does not seem very strong - what happens if you drop the lamp on the ground because it has only one clip that can be attached.

- Regarding the square light, it feels not very safe to bring the lamp around due to the risk of screen damage. Also, it is a bit too heavy for being portable light.
Appendix 6. Focus group

This appendix documents the details of the focus group.

Date and time: 2021-02-10 at 12:00-13:00
Participants: Three workers who worked with the lamps for a week

Questions

Quality & Productivity

1. How have you experienced the lamps in general? Do you think that the lamps have influenced your daily work? ..... In what way?

2. Regarding quality, in what way have those lights affected the quality of your work tasks? Follow-up question: You mentioned last time that the new lamps worked well because they do not have a cord / cables. How did you experience them in real life? (eg battery life, different size and design, varying illuminance, etc.).

Is there anything that can be improved in the lights that can help your work assignments even more? (eg you mentioned that it would be better if the lamps had a magnet behind them to be able to place them on the tube, etc.).

4. Regarding productivity, have you experienced that the use of the lamps affected, for example, your working hours? (eg if you could save time or vice versa). How and in what way?

5. How did the use of the lamps affect the end result of the job itself? Tell us if it has given better or worse results? How?

Health, safety and well-being

1. Have you had pain anywhere (eg eyes, neck, head, shoulders) before using the lamps?

Follow-up question: Have you experienced that the use of the lamps can affect your health (neck, back, eyes) in the long term? How? Better or worse?

2. How do you think the use of the lamps can affect your safety (falling, falling, hitting) at work with and without the additional lamps. How?

3. How do you feel now with these complementary lights regarding well-being? How has it been affected? (eg you mentioned last time that you experience frustration / irritation if there is no good lighting at work).

4. Other views or reflections?
Answers

Quality & Productivity

Person 1: I am very positive about these lamps. I have experienced good feelings while using the lamps during the week. Especially the headlamp with a wide flood light. This one has the possibility to adjust three different lighting intensities which gives a better and wider sight.

Person 2: In general, all lamps are great, although I have some feedback on potential improvements. While using these lamps it is easier to work, i.e. it is easier to make measurements or make drawings on working surfaces. Using these lamps we have a better view of the environment, a better picture.

Person 3: I also liked the headlamp with wide rectangular light the most. It was easy to use for every different type of work assignment and helps to save time. But I like another headlamp that can be adjusted in three different ranges of lighting view.

Person 1: The compact portable lamp was not very useful for me. The lamp cannot be clipped onto a pipe and it does not have a magnet on its back side for attachment onto metal surfaces. It was difficult to find a suitable place to put it while working.

Person 2: The compact portable lamp does not provide wide enough light spread. It is not as useful as a headlamp.

Person 3: The middle-sized square lamp is easy to use and convenient to carry in the worksite. But it is too bright and has only two light intensity adjustments on the device. This can make you become blind for seconds after looking at the lamp directly which can disturb other workers.

Person 1: I like a lot of these lamps because they have a long battery life which makes us save a lot of time. Indeed, the battery lasted for the whole working day and we charged the battery only over the night, when we were not at work.

Person 2: An additional aspect that we like is that you can vary the brightness of the light. Even though the lower level can be experienced as too strong.

Person 1: Two batteries per lamp would be needed. In this way you can save time, because while one battery is charging you can use the other battery.

Person 3: A magnet behind the lamp would also be good, so the lamps can be placed easily by a steel tube or something like that.

Person 2: By using these lamps the work is performed in a more efficient way. I could work faster, it took less time to perform the same work task. For example, it takes less time to move
the lamps that do not have a cord between two different workplaces, and this makes us save time.

Person 1: I haven’t seen much difference in end-results, but I have seen differences in the quality of work. Indeed, I experienced that the job is performed in a better way. For example, it is great that the lamps do not have a cord, so they can be transported very easily and much faster than traditional lamps with cord.

Person 3: Well, basically we have seen the same results, but we have worked in an easier way.

Person 2: It does not affect quality in the end, but of course it can affect working time depending on the lighting conditions at work.

Health, safety and well-being

Person 2: During my careers, I have sometimes experienced pain in the neck due to the fact that the helmet is heavy. Therefore, I think that the lamps should be light to carry, especially the headlamps.

Person 3: The lamps are relatively light since there are no electric batteries on the device. It is rechargeable which is good for the environment.

Person 1: I feel sometimes my eyes are a bit tired, but I guess it is probably from the dust at the worksite. I agree regarding the hardhat. My shoulders sometimes hurt after wearing the hardhat, working in an uncomfortable position.

Person 3: Clearly, it feels safe with good lights. Obviously, when I see better I experience a safer work environment as well. Consequently, I experience better health as well.

Person 2: If the lighting is pointed in a favorable direction and with proper intensity, I think it would not be needed to bend the head or assume an uncomfortable posture. Therefore, it is important to have good lamps. Especially the headlamp is a good idea.

Person 1: The brightness of the lights could have consequences to our health. Therefore, it would be better if the lamps had less brightness, they are too strong! Indeed, e.g. when I have the headlamp on, the other employees that look at where the light is pointed at, get a risk to go blind.

Person 2: In general, our ideal work environment has better stationary lighting and not just good individual headlamps. Often the light conditions are poor at construction sites. In general it is too dark. It feels like poor lighting and dust are the two biggest and most common problems in a construction industry work environment.
Person 3: There is no window providing daylight, and I feel quite a difference compared with my previous work situation.

Person 1: I know by experience that good lights are really important in a work environment. Therefore, it is clear to us that better lighting leads to better well-being. A worker is affected psychologically as well.

Person 3: I can feel frustration and irritation when there is insufficient lighting compared to what the situation requires. I sometimes feel my eyes tired. In addition, I have bad eyesight and use contact lenses.

Person 2: Visual work environment is something new for me. I have never reflected over it before, but I can understand that it is important for workers to have good lighting. Because good lighting provides for improved health and safety.
Appendix 7. Simulation

This appendix documents the details of the simulation.

Date and time: 2021-02-23 at 12:00-15:00
Place: KTH Flemingsberg

Picture 10. First workplace simulation

Picture 11. Second workplace simulation

Picture 12. Third workplace simulation
Appendix 8. Measurements during the simulation

This appendix documents the results of the measurements done during the simulation.

Date and time: 2021-02-23 at 12:00-15:00
Place: KTH Flemingsberg

W = Work area (central field of view)
I = Immediate surroundings (nearby area)
E = External environment (peripheral field of view)

#1. Measurements of the current lighting status without the lamps

<table>
<thead>
<tr>
<th>Measurement areas</th>
<th>W</th>
<th>I</th>
<th>E</th>
<th>W</th>
<th>I</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st workplace</td>
<td>25.6</td>
<td>28.3</td>
<td>30.2</td>
<td>3.1</td>
<td>2.8</td>
<td>4.5</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>1.1</td>
<td>0.9</td>
<td>0.8</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

#2. Measurements with the lamps (Illuminance)

<table>
<thead>
<tr>
<th>Own lamp (standard headlamp)</th>
<th>Lamp 1 (headlamp wide beam)</th>
<th>Lamp 2 (headlamp zoom-funtion)</th>
<th>Lamp 3 (portable work lamp)</th>
<th>Lamp 4 (square work lamp with a clip)</th>
<th>Lamp 5 (big and round work lamp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement areas</td>
<td>W</td>
<td>I</td>
<td>E</td>
<td>W</td>
<td>I</td>
</tr>
<tr>
<td>1st workplace</td>
<td>133</td>
<td>120</td>
<td>52</td>
<td>475</td>
<td>294</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>92</td>
<td>86</td>
<td>0.6</td>
<td>10</td>
<td>93</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>3.1</td>
<td>0.4</td>
<td>0.1</td>
<td>2.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>

#3. Measurements with the lamps (Luminance)

<table>
<thead>
<tr>
<th>Own lamp (standard headlamp)</th>
<th>Lamp 1 (headlamp wide beam)</th>
<th>Lamp 2 (headlamp zoom-funtion)</th>
<th>Lamp 3 (portable work lamp)</th>
<th>Lamp 4 (square work lamp with a clip)</th>
<th>Lamp 5 (big and round work lamp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement areas</td>
<td>W</td>
<td>I</td>
<td>E</td>
<td>W</td>
<td>I</td>
</tr>
<tr>
<td>1st workplace</td>
<td>9.6</td>
<td>7.5</td>
<td>6</td>
<td>2.2</td>
<td>4.6</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>92</td>
<td>86</td>
<td>0.6</td>
<td>10</td>
<td>93</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>3.1</td>
<td>0.4</td>
<td>0.1</td>
<td>2.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>
#4. Measurements with the combinations of two lamps (Illuminance)

<table>
<thead>
<tr>
<th>Workplaces</th>
<th>Combinations</th>
<th>Measurement areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>1st workplace</td>
<td>Lamp 1 + Lamp 4</td>
<td>201</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>Lamp 2 + Lamp 3</td>
<td>843</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>own lamp + Lamp 5</td>
<td>354</td>
</tr>
</tbody>
</table>

#5. Measurements with the combinations of two lamps (Luminance)

<table>
<thead>
<tr>
<th>Workplaces</th>
<th>Combinations</th>
<th>Measurement areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>1st workplace</td>
<td>Lamp 1 + Lamp 4</td>
<td>20,6</td>
</tr>
<tr>
<td>2nd workplace</td>
<td>Lamp 2 + Lamp 3</td>
<td>144</td>
</tr>
<tr>
<td>3rd workplace</td>
<td>own lamp + Lamp 5</td>
<td>11,6</td>
</tr>
</tbody>
</table>