THESIS FOR THE DEGREE DOCTOR OF PHILOSOPHY

LIGHTING DESIGN IN COMPUTERISED OFFICES

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CHALMERS UNIVERSITY OF TECHNOLOGY

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ABSTRACT

This thesis is concerned with the design of the artificially lighted environment in computerised offices. The aim is to establish which kind of lighting solution is best suited to accommodate VDT-based tasks, and whether or not working in front of a VDT affects visual comfort and well-being.

The research question has been approached in four different studies. The studies were as follows: 1) A questionnaire study where lighting designers in Sweden evaluated different lighting criteria. This aimed to establish how different criteria are used in the office lighting design process. 2) An experimental study comparing the influence of different office light settings on perceptions. The study focused on the impact of light setting on room perception, the experience of the lit environment, perceived visual comfort and wellbeing. Additionally, the study looked into alertness as indicated by hormone samples, and into the influence of lighting on performance. 3) A comparison of the visual perceptions in an LED light setting to the perceptions experienced in a conventional light setting. 4) A review describing research related to office lighting, and including a discussion about methods and the applicability of research, as well as being a state-of-the-art in office lighting research connected to the scope of this thesis.

The findings are discussed using a framework based on contemporary Scandinavian office lighting design, and current lighting design practice. They show that there is a need for lighting education within the group of lighting practitioners, as well as for research that is accessible and applicable to lighting designs. The experimental studies could not verify that office lighting affects performance, even though it was shown that a varied light setting was perceived to enhance well-being more than a monotonous lighting solution. One important contribution in this thesis is the unfolding of the inadequacy of the methodology used in current lighting research. It is shown that quantitative measures alone do not possess the strength to explain the complex interactions between human perceptions, well-being, visual comfort and performance.

Keywords: office lighting, lighting design, lighting criteria, artificial lighting, visual environment, visual comfort, perceptions, performance, luminaire, design process, diode lighting, LED, light sensitivity, computer screen.

PREFACE / ACKNOWLEDGEMENT

Why do a PhD?

At some point I think all PhD students ask themselves this question.

Society is evolving by itself and commercialism provides the incentive. People struggle to adapt techniques and behaviour to new environmental challenges. At what point do old solutions to problematic issues cease to be acceptable, and where are we going to find new ones?

Lighting is integrated into our society, and short winter office hours or dark homes and city environments are not an option. The impact of lighting on people and ecology, as well as considerations around energy and building, need to be discussed. These questions are too complex to be left to politics. They should be well researched and carefully considered by researchers as well as by actors in the field before decisions are made. Society needs to keep the research front up to date and support it with the help of institutions, scholars and practitioners.

Synergy when sciences meet can trigger innovation. Can a society choose to refrain from research and still prosper? To truly benefit from research interaction, all fields of research need to build up from the base to reach and sustain a knowledge level where research interaction is possible. Lighting research in Sweden is being built from the base, and this thesis is my contribution to the field, to enable future lighting designers and researchers to reach further. It is made possible by generous support from the Bertil and Britt Svensson Foundation.

I would like to thank all the people who have supported me during my thesis work. In particular, I would like to thank my supervisor, Dr. Monica Billger at the Department of Architecture at Chalmers University of Technology, who accepted me as a PhD-student in my third year. She has guided and encouraged me to complete this thesis, as has Beata Stahre who was her co-advisor.

I also wish to thank my earlier supervisors, Dr. Maria Johansson at the Department of Environmental Psychology at Lund University, who helped me with my second study, and Dr. Kerstin Barup at the Department of Architecture at Lund University, who, in collaboration with Dr. Thorbjörn Laike at the Department of Environmental Psychology at Lund University, gave me a nice start with my studies and helped me with the first study.

I have received invaluable support from the Department of Lighting Science at Jönköping University, and I would like to give special thanks to Kharin Abrahamsson and Johan Röklander. I would also like to thank Monica Säter who has inspired and motivated me in my work.

Many thanks to Jennie Kermode for revising my English; any mistakes that remain are entirely mine.

Finally, I am very grateful for the support I have received from my family and friends. I wish to thank my parents, Gertrud and Klas, for always believing in and supporting me. Thanks to all my friends for being so encouraging, and last but not least, with all my love I wish to thank Staffan for putting up with me and helping me with all practical things. For your involvment, support and advice, and for always being there for me.

Thank You.

Annika Kronqvist

Göteborg September 2012

Publications

Paper A "Criteria influencing the choice of luminaires in office lighting" Proceedings 2nd CIE Expert Symposium on Appearance, Gent 2010

Paper B "Criteria influencing the choice of luminaires in office lighting" in press, Journal of Design Research.

Paper C "The Influence of Artificial Lighting on Performance and Well-being" Proceedings 2nd CIE Expert Symposium on Appearance, Gent 2010

Paper D "The Influence of the Lighting Environment on Performance and Well-being in Offices" Proceedings Colour and Light in Architecture, Venedig 2010

Paper E "The influence of light settings on room perception, comfort and well-being" accepted with revisions, Leukos

Paper F "The influence of light emitting diods on wellbeing and comfort in home offices" Proceedings 27th Session of the CIE, South Africa 2011

Paper G "Review of office lighting research from a Scandinavian perspective" in press, Journal of Interior Design.

Distribution of work

Paper A and B "Criteria influencing the choice of luminaires in office lighting". Kronqvist planned and executed, after an idea by Barup, an e-mail questionnaire. The questionnaire focused on the evaluation of different criteria in the design process, and the influence of age, gender, education and experience. Poster and paper written by Kronqvist.

Paper C, D, E	"The Influence of Artificial Lighting on Performance and Wellbeing", "The Influence of the Lighting Environment on Performance and Well-being in Offices" and "The influence of light settings on room perception, comfort and well-being" stem from a study that was planned under the supervision of Johansson. Kronqvist planned and wrote the papers. The study was executed by Kronqvist and Abrahamsson.
Paper F	"The influence of light emitting diodes on wellbeing and comfort in home offices". The experimental data was collected in a joint study planned in cooperation with Säter. The study was executed by Abrahamsson. Kronqvist analysed the results and wrote the paper.
Paper G	"Review of office lighting research from a Scandinavian perspective". The study was planned by Kronqvist. Abrahamsson assisted in the database search. Paper was written by Kronqvist.

Additional publications by the author

Jarskär Annika "Ljuset skapar rum o upplevelse" in "Inspirationsguiden Rum för Lärande" Målarmästarna och Lokalförsörjningsförvaltningen, Göteborg

"The Design of Visual Environment in Offices" Proceedings 20th IAPS Conference, Rome 2008

Report from 2nd CIE Expert Symposium on Appearance "When Appearance meets Lighting" 8-10 september 2010, Gent, Belgien, in Ljuskultur 2010

Abbreviations

CCT	Correlated colour temperature
CFL	Compact fluorescent lighting
CRI	Colour rendering index
CRT	Cathode ray monitor
EPA	Evaluation, Potency, and Activity are the intermittent scales used to evaluate words and phrases when using semantic differential scales.
FL	Fluorescent lighting
iPRGC	intrinsic photosensitive retinal ganglion cells
LED	Light emitting diodes
SAD	Seasonal affective disorder
VDU	Video display unit
VDT	Video display terminal

Table of contents

1 Introduction

This thesis is about office environments and one of the fundamentals of life: light. The thesis focuses on lighting design, its creation, the perception of it and its influence on our beings. We depend on light to provide us with visual stimuli and to stimulate the physiological and psychological processes that we have evolved as a result of the light and darkness generated by Earth´s rotation. In earlier times when people lived and worked outdoors, in harmony with the naturally lit environment, circadian rhythms and light related health were not an issue.

As our awareness of the impact of lighting on physiological and psychological processes in man grows, we have to reconsider the long term effects of working with a computer screen (VDT). In western society today, workplaces are increasingly based indoors, often in offices. In Sweden, more than 50% of the work force is based in offices (SCB 2009), performing tasks on VDTs. The VDT is the light source closest to the office staff but the influence of the light emanating from it is not always taken into account when planning the visual environment. The quality of the total lighting environment needs to be defined both to support the tasks associated with VDTs and to promote our health and performance.

The studies in this thesis were conducted in Sweden between 2006 and 2011, and involved study participants with backgrounds ranging from being part of the lighting design profession, to experiencing artificial lighting as office staff or students. They ranged from young and healthy to old and healthy, from late sleepers to early risers. The subjects who were engaged to participate in the studies, on a voluntary basis, are referred to as *participants* throughout this thesis. Professionals within the lighting design field with academic degrees in lighting design are defined by me as *lighting designers*. Other professionals working within the field of lighting design are called *practitioners* or *lighting practitioners*.

The research touches on different research fields but the viewpoint is consistently that of a lighting designer. The studies are based on my knowledge and the perspective that I have on the research field as a lighting designer, with my base in the practical field of interior architecture. This approach initially shaped the structure and development of this thesis. The thesis work has developed from a collection of studies where observations and measurements to capture the truth were performed, to an evaluative stance on current research and in particular the methods applied in my own research.

This thesis takes the position that lighting designs should support individual office staff and offer the best possible lighting conditions for each office environment. It reveals the inadequacy of quantitative measures to explain the complex interactions between human perception, well-being, visual comfort and performance, thereby making an important contribution to future research. Furthermore, the thesis demonstrates that a varied light setting is perceived as better enhancing well-being than a monotonous lighting solution. I further conclude that there is a need for lighting education among lighting practitioners, as well as for research that is accessible and applicable to lighting designs.

1.1 Outline of the thesis

The thesis is divided into three parts. The main text describes the successive development of the research, including summaries and discussion of the results in the seven appended papers. This form the base for this thesis. Also included are two appendices, the first including a compilation of the papers and the second noting the instruments used in the studies.

Chapter 1 introduces the topic of the thesis and identifies the problem area. The aims and research questions are stated. Additionally, the research approach and important concepts are presented.

Chapter 2 provides the theoretical framework for this lighting design research. The state of the art in office lighting research connected to the scope of this thesis is described, and an overview of related research is provided. A map illustrating the origin of this research in interior light planning research further serves to establish the niche for this thesis.

In *Chapter 3* the methods used in the different studies are described, as is the position taken in regard to validity and reliability.

Chapter 4 presents the results from the different studies in short.

Chapter 5 discusses and relates the results to the research questions. The findings from each study are reviewed and analysed.

Chapter 6 presents a reflection on applied methodology in relation to the individual studies. It considers how well the methods apply to the questions, and whether or not the results are valid.

Chapter 7 presents my final conlusions and outlines future research projects.

1.2 Identifying the problem area of work task lighting

As office tasks are transformed, earlier recommendations not to work in front of a VDT for more than 4 hours have been overrun in favour of full days in front of the VDT. Computerised tasks are becoming an all-day occupation, resulting in the VDT occupying the visual field for long periods and demanding a contrast relationship that differs from traditional paper work (Piccoli, Soci, Zambelli & Pisaniello, 2004). Studies have shown that illuminance preferences in the computerised office differ from preferences in traditional offices (Veitch & Newsham, 2000a; Escuyer & Fontoynont, 2001), and that the office lighting recommendations and standards (SS-EN 12464-1, ISO 9241-7, ISO 8995:2002(E) / CIE S 008/E-2001) (Fig. 1:1) need to be adjusted to suit VDT based tasks.

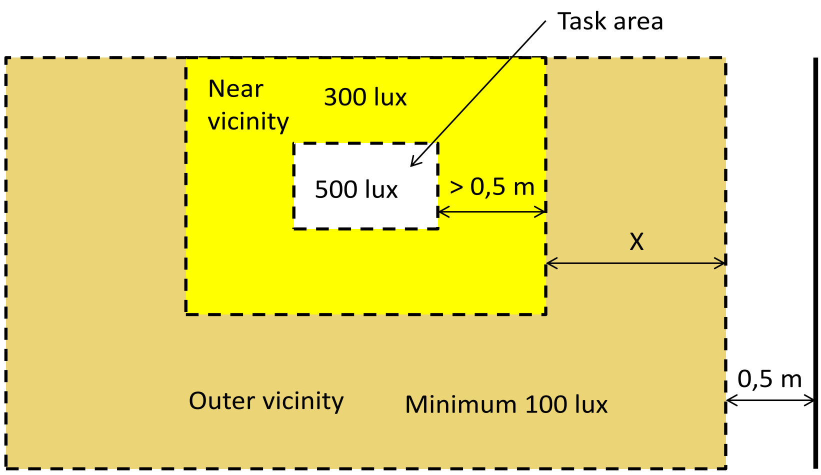


Figure 1:1; *Lighting recommendations for office tasks (SS EN 12464-1)*

Swedish law does not allow an office to be without sufficient daylight (AFS 2009:2), but in the northern hemisphere natural daylight in the winter is less abundant, and is therefore supplemented with artificial lighting. Depending on available natural daylight the need for artificial light to support human physiological and psychological processes varies (Harris & Dawson–Hughes, 1993; Begemann, van den Beld & Tenner, 1997; Partonen & Lönnqvist, 2000; Fleischer, Krueger & Schierz, 2001; Nicol, Wilson & Chiancarella, 2006; Rüger, Gordijn, Beersmaa, de Vries & Daan, 2006; Revell, Arendt, Fogg & Skene, 2006; Küller, Ballal, Laike, Mikellides &Tonello, 2006; Aan het Rot, Moskowitz & Young, 2008; Hoffman et al, 2008; Hubalek, Brink & Schierz, 2010). Lighting has an influence on visual acuity and there are implications that it influences well-being and health as well as performance, alertness, social interaction, safety and orientation. It also supports other visual needs indirectly, for instance by creating a stimulating environment (Loe, Mansfield & Rowlands 1994; Loe & Rowlands, 1996; Loe, Mansfield & Rowlands, 2000) (Fig. 1:2).

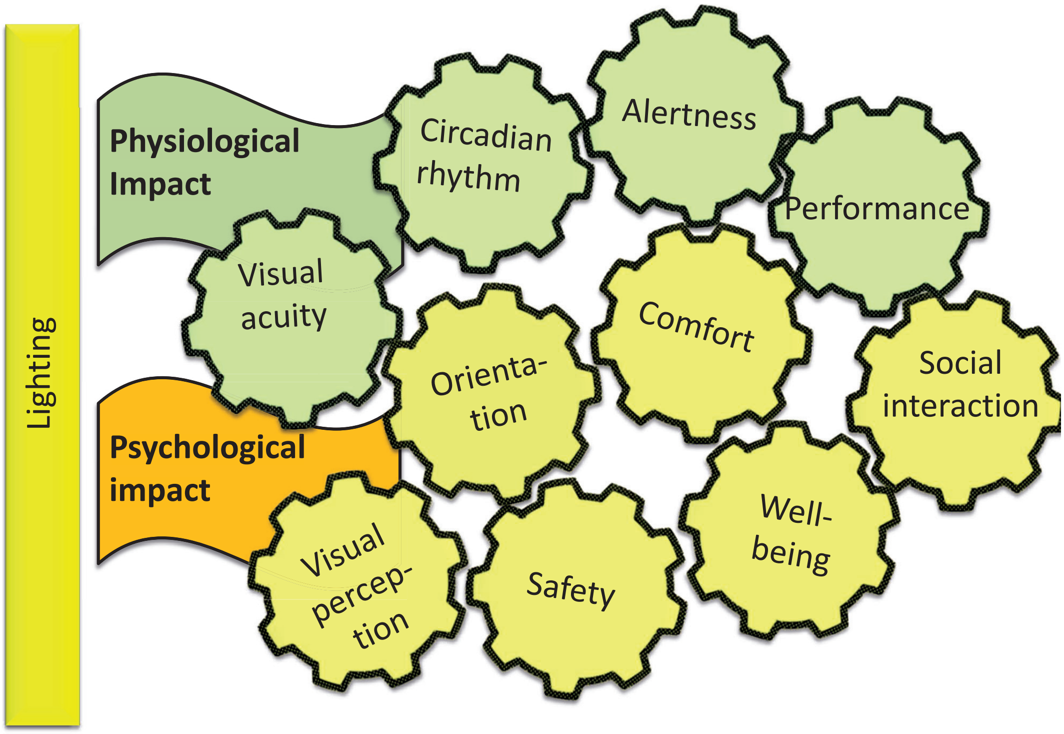


Figure 1:2; *Lighting impact. Light has an impact on physiological and psychological processes in man. A few of these processes are illustrated by the "cogwheels", and interact with one another, supporting or delimiting related reactions.*

Lighting is a three dimensional experience, where patterns of light and dark can be combined in a pleasing manner for a more visually interesting environment. It is a dynamically changing, perceptual experience, depending on the movements and positions taken by an observer. As a person moves, the angle of perception and subsequently the lighting experience changes.

Still, the light emanating from VDTs is not always taken into account when planning the visual environment, as can be seen in the in the figure illustrating lighting recommendations for offices (Fig. 1:1), where the VDT is absent.

When identifying the problem area, it was important to me that the physiological prerequisites for personal well-being influenced by lighting should be met within the work environment. The practice of preserving and translating the qualities of natural daylight into artificial lighting environments is ill-defined. Knowledge is needed to support designers and facilitate their choices.

The lighting designer decides on the illuminance, the distribution and proportion of direct – indirect light, the character of shadows and reflexes, the light colour, the colour rendition ability of the light source, how to handle glare and the colour and texture of reflecting materials etc., as a response to visual and indirectly visual demands in the design process. The use of these visual concepts is based on a mutual understanding of their meaning but is complicated by unspoken presuppositions. When is light bright? When is the lighting "good"? The concepts can be fully understood by all involved parties but interpretations are personal. A concept such as "lighting quality" varies with the position and the personal experience of an individual, and must be seen as an instrument rather than as a scientific truth. Several attempts to establish concepts for lighting quality have been made (Bean & Bells, 1992; Veitch & Newsham, 1996; Veitch & Newsham, 1997) but the concept has this far eluded the researchers.

1.2.1 Goals, aims and research questions

The main goal of this thesis is to incorporate the planning of aspects of light into the larger field of lighting research. Its conclusions, in view of the increasingly complicated processes shown to be influenced by light, should emphasise links with adjacent research in physiology as well as psychology, and promote future research opportunities. My specific intention is to describe which lighting quality is perceived to support VDT based tasks best, and to describe how the lighting design process can be strengthened, as part of the general goal.

In this thesis I ask which kind of lighting solution is best suited to accommodate VDT-based tasks, and whether or not working in front of a VDT affects visual comfort and well-being. The design process is studied with the objective of strengthening it, and it is presupposed that, if contradictory and inconclusive research can be balanced, the lighting design approach to office lighting is facilitated and reviewed with a focus on applicability. I further aim to describe how the lighting scenario influences spatial experiences, visual comfort and well-being.

The research questions in the thesis are:

- Which criteria are considered to be important in the lighting design process in Sweden today, and why?
    - It is known that several groups with different backgrounds are working in lighting design. I investigate whether or not academic education has an impact on the inferred values on different criteria in the lighting design process. I also want to determine whether or not the incorporation of research can be related to education and longer experience within the field. Furthermore, I see it as important to discuss how evaluations of lighting criteria relate to the outcome of the lighting designs.
- Does the lighting design process need to be strengthened, and if it does, how should it be done?
    - With this question I seek to discuss relevant issues and to spur on improvement in the design process, if weaknesses have been revealed by the first question.
- How should light settings be designed to create the most suitable lighting in an office environment with VDT based tasks?

- The impact of lighting on all aspects of life should be understood to include office lighting. To further support the findings of earlier research I use experimental studies to investigate how the light setting influences the perception of the task area, the visual comfort experienced and general well-being when working on a computer screen. I further seek to determine whether or not the relationship between spectral composition of lighting and alertness, described in earlier studies, can be replicated in an office environment.
- LEDs are increasingly popular and their application in office lighting is imminent. One financially advantageous option is to use retrofit LEDs in existing luminaires. I address the question of whether the inherent properties of retrofit LEDs are supportive of VDT based office tasks or not.

1.3 Research approach

The point of origin for this thesis is my view as a lighting designer and interior architect, with a personal impression of lighting designs utilised in Sweden as drawing on a wide field of methods and specialised knowledge. I ventured to test this view, to see if it could be substantiated. The research at the Department of Environmental Psychology at the Institution of Architecture, Lund University where I was accepted as a PhD candidate used quantitative methods, and this approach was adopted here.

My base for the studies is contemporary Scandinavian office lighting design, and current practice, as it is being taught in the lighting design education in Sweden. In Sweden, a method called "visual analysis" (Liljefors, 2006) is taught in the lighting design education and used in the construction of lighting designs. The method involves analysing lighting criteria using human vision. The criteria construct a holistic lighting environment where the totality adds up to more than the separate parts (for more details see 1.6 "visual analysis"). This method has been used in earlier studies describing the interaction of light and colour (Billger, 1999; Billger, Heldal, Stahre &

Renström, 2004; Stahre & Billger, 2004; Hårleman, 2007; Arnkil, Fridell Anter, Klarén, Matusiak, 2011).All the parameters described in the method by Liljefors are used in this thesis, except for surface colours, which I substitute with the colour rendering of the light.

The methodologies used for knowledge generation range from a questionnaire study, literature studies, exploring the internet and international networking to data collection in experimental settings.

The studies were as follows:

A study to establish how different criteria were used in the office lighting design process. Lighting designers in Sweden evaluated different lighting criteria (see Papers A and B) in a questionnaire.

An experimental study comparing the influence of different office light settings on perceptions. The study focused on the impact of light setting on room perception, the experience of the lit environment, perceived visual comfort and wellbeing. Additionally, the study looked into alertness as indicated by hormone samples, and into the influence of lighting on performance (see Papers C, D and E).

A comparison of an LED light setting with a conventional light setting. Surveys focused on visual comfort and the perception of task lighting were completed in different lighting environments (see Paper F).

A review of office lighting research. A database search retrieved articles describing research related to office lighting. The review was written from the perspective of a lighting designer and resulted in a discussion about methods and the applicability of research (see Paper G).

It was important to the studies to outline what kind of knowledge was sought and to understand the problem in order to be able to establish relevant facts. The questionnaire study was used to open up the research field and to inform the formulation of the research questions. The results from the study, in combination with the concepts described in the "visual analysis" method, were used for this work. The research questions were phrased and rephrased with consideration given to the controlled pursuit of knowledge.

The formulation of the research questions as well as the research process can be described as a circular movement, searching and evaluating, using an iterative process along a time axis (Figure 1:3).

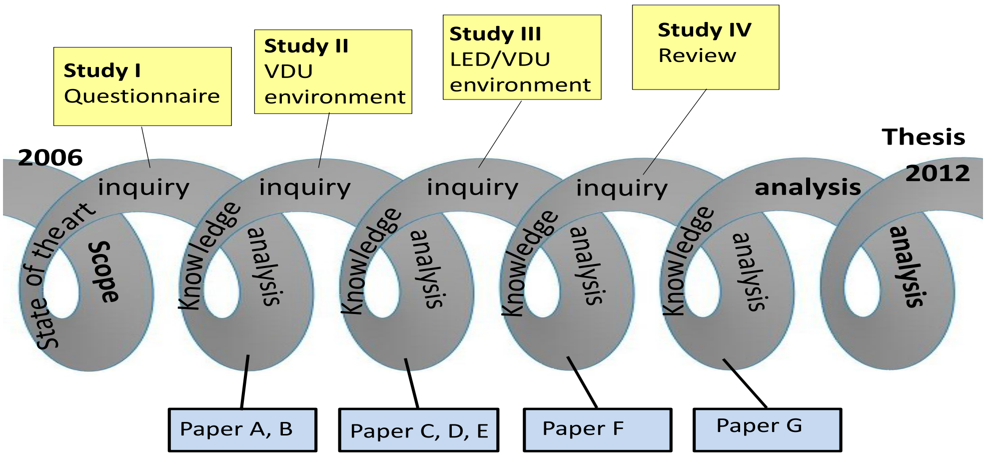


Figure 1:3; *The research process in this thesis.*

The explanations of observations in the experimental studies should be self-evident and make it possible to differentiate between knowledge and understanding. Emphasis was placed on the awareness that bad explanations can misdirect research if the pursuit of knowledge results in tunnel vision, and if considerations contradicting the hypotheses are overlooked, with only supporting evidence being considered. The understanding that if false knowledge was used to describe our observations, incorrect deductions would be made, made clear the importance of correctly evaluating the theoretical framework. Observations can lead to new concepts explaining regularities and exemptions, but the relevance of the new concepts can only be evaluated using existing, well-established facts. Established lighting practice and design hypotheses thus form the basis for my search for explanations of the observations made in the studies.

The take off point for my studies was not investigating how we perceive stimuli but, rather, asking when the perception occurs. Lighting design is open to questions of both descriptive (how) and explanatory (why) character. The explanatory questions often generate responses to visual observations e.g. that the lighting is “hard”, glare is incidental etc. The descriptive questions often generate more detailed responses to unobservable phenomena e.g. flicker and spectral composition of the lighting. It is recognised that even though participants in experiments might be able to point out which light setting they prefer, the reason why is not always clear.

Our visual perceptions are not only based on the impact of energy on the retina. The physiological processes are identical between individuals but the visual experiences are subjective (Fig. 1:4) and subject to personal interpretations.

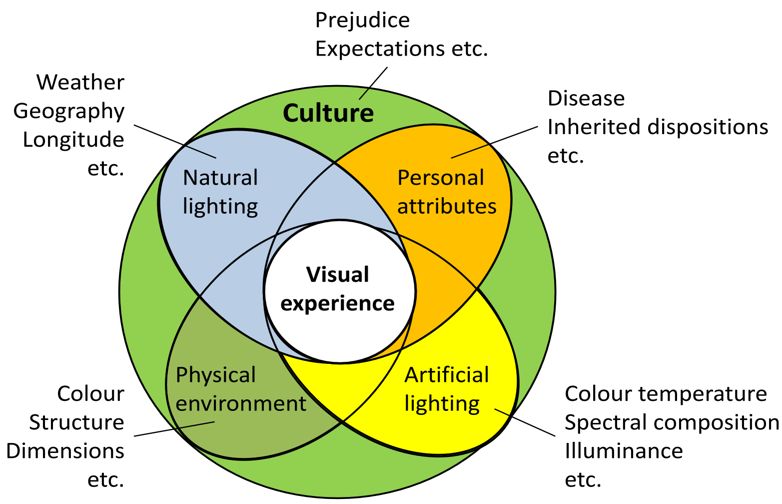


Figure 1:4; *Influences on the visual experience. If one parameter is changed, the visual experience will change.*

To convey observations, the viewer needs to understand applicable concepts and have the knowledge necessary to describe or agree to them. The observations are dependent on our physical status, while the concepts are based on education, prejudices and culture. The participants who were involved in my studies were presupposed to share the same concepts for lighting experiences, as they were all residents in the local area of Jönköping. The interplay between descriptive and explanatory questions, used to obtain complete answers from the participants, guided the thesis process. Even if there is a common understanding in the field of lighting design that there are many factors influencing office staff well-being, difficulties measuring these effects invites further investigations into the conception of methods.

The interior design in the experimental settings in earlier research has often been subdued and in some cases even non-existent in order to avoid influencing the results. In my view this creates a context that in itself might distort the results or, as a consequence of being too unobtrusive, suppress or fail to invite the hypothesised responses. I also consider models and studies excluding behavioural requirements and social interactions supported by interior design to be inapplicable to real life. Perceptions of lighting quality are dependent on context and related to designer and design criteria. Furthermore, the experience of light should not be separated from the colour experience. Together they construct our mental image of space (Figure 1:4). Boyce, Veitch, Newsham, Myer & Hunter (2003b) concluded that study participants see and appreciate differences in lighting conditions and that visual appraisal is influenced by appearance as a whole, including function, lighting and luminaires. Consequently the rooms in Study II (Paper C, D and E) and Study III (Paper F) simulated normal rooms and offices. The rooms were neutral in colour but not devoid of visual stimulation.

This thesis is influenced by positivist science[1] and the emphasis is on finding explanations and increasing understanding. A positivist approach to research applies quantitative techniques to find answers and causal factors to determine the influence of certain factors on the outcome. Such an approach considers all sciences to be linked and without isolates.

1.4 Limitations of the thesis

The thesis examines the planning of the VDT environment with a focus on the lived experience, including aspects of lighting quality, but the establishment of the concept is not an objective. Lighting quality as a concept is in this thesis regarded as a generic description, encompassing visual perceptions of

1 Positive theory attempts to establish predictable relationships between variables ie the effects of modifications on the physical environment. It is based on useful facts such as observations and uses a quantitative approach. It is "value-free" and hypotheses are tested against facts (Robson, 2002)

lighting[2] included in the different studies. The number of observations forming the basis for generalisations needs to be large and repeated under a number of different conditions. This thesis does not undertake such an extensive study. The repeated observations of a group in different situations did not reach this level, and thus the limitations of two of the studies were established.

The influence of different parameters on the visual experience of lighting are intrinsically connected. The design of windows, surfaces (material, texture, colour) and interiors, and the interaction of these criteria with natural and artificial lighting to create an environment that is supportive and stimulating to human health and well-being, is largely unexplained, but is not included in this thesis. Nor is the difficulty of describing visual concepts in a reliable way, distinguishing them from individual beliefs and perceptions, addressed. Lighting aspects influencing Seasonal Affective Disorders (SAD), ergonomic aspects (other than those affecting our visual system) and energy saving aspects are not included. I further decided to exclude view and daylight glare.

1.5 Important concepts in the thesis

In this section concepts that are used in the thesis are explained. The definitions are my own if no other source is referred to.

Brightness The perceived luminance (IESNA, 2008 p. 14). Brightness need not be related to illuminance, but is a visual perception.

CCT Correlated colour temperature is a comparison to the temperature of a Planckian radiator, measured in degrees Kelvin, whose colour most resemble that of the light source at the same brightness and under specified viewing conditions (Borbély, Sámson & Schanda, 2001).

CRI Colour rendering index ($R_{a)}$ is a measure of the ability of a light source to reproduce the colours of objects in comparison with an ideal (R_a100) or natural light source

2 The visual perceptions are included in the ”visual analysis” method described by Liljefors (2006).

(CIE). R_a is the short term for rendering average, and is a mathematically calculated average describing how well a number of test colours are rendered in the light emanating from a specified light source (Liljefors, 2006).

Field of vision The size of the space that the vision is capable of perceiving, with peripheral edges defined by the range where objects are visible without moving the head (IESNA, 2008) is called the field of vision.

Illuminance The amount of light that hits a square metre of an illuminated surface (Starby, 2006), measured in lux.

iPRGC The intrinsic photosensitive retinal ganglion cells, or melanopsin-containing ganglion cells, are a third class of retinal photoreceptors, excited by light even when all influences from classical photoreceptors (rods and cones) are blocked (Berson, Dunn & Takao, 2002; Berson, 2003).

Luminance The amount of reflected light that meets the retina (Starby, 2006), measured in cd (candela)/m^2.

Task area The area within the work space and field of vision where the visual task is performed (SS EN 1246-1).

Visual analysis Human vision is used in the analysis of lighting criteria. The criteria described by Liljefors (2006) construct a holistic lighting environment where the totality adds up to more than the separate parts. In the original method the following lighting criteria are included:

- Light level
- Light distribution
- Shadows
- Reflections
- Glare
- Colour of light
- Surface colours

Figure 1:5; *Brightness.*
Photo L. Vegehall

Light level. The light level is related to the total space as well as to a certain part of it, to the illuminance, to the reflective properties of surfaces and to the colour temperature of the light (Liljefors, 2006). Brightness need not be related to illuminance, e.g. a room can be perceived as being bright but have a task illumination that is unsatisfactory (Fig. 1:5).

Figure 1:6; *Light distribution.*
Photo Dept. of Lighting Science
JTH, Sweden

Light distribution. The light is distributed in the space and can be perceived to vary over a wide range, from a high variation with a single light source in the dark to a low variation with very even and monotonous distribution. Subtle changes in light distribution are perceptible (Liljefors, 2006) (Fig. 1:6).

Shadows. Visually, shadows are defined as differences in brightness and/or colour, but they are also defined by the type of division separating these. The division can be sharp, diffuse or gradient. Shadows can appear on the illuminated object or be cast on an illuminated surface by an obstructing object (Liljefors, 2006) (Fig. 1:7).

Figure 1:7; *Shadows.*
Photo A.Kronqvist

Reflections. Reflections can be seen on all but matte surfaces. They are dependent on the position of the light source and the angle of perception in relation to the reflecting surface, and are therefore perceived to differ depending on position. Reflections display a large variation in size, intensity and colour (Fig. 1:8). Characteristics of materials can be revealed by reflections (Liljefors, 2006).

Figure 1:8; *Reflections.*
Photo Dept. of Lighting Science
JTH, Sweden

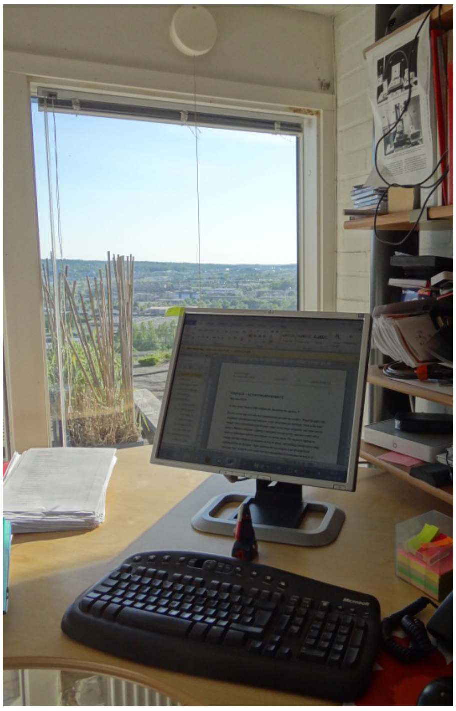


Figure 1:9; *Disability glare. Photo A. Kronqvist*

Glare. Glare occurs in all situations where the contrast within the field of vision is too high for the eye to adapt to. Glare is defined as either discomfort glare or disability glare. Disability glare occurs when the eye is adapted to brighter conditions than the task area e.g. a VDT in front of a window (Fig. 1:9). Disability glare need not be perceived as uncomfortable, but will in the long run be tiring. Discomfort glare occurs when the eye is adapted to a lower illuminance than a luminant object in the field of vision (Liljefors, 2006).

Figure 1:10; *Light colour. Photo Dept. of Lighting Science JTH, Sweden*

Light colour. Light is perceived as having a colour in itself, and it interacts with the surface colours in the space to create light colour. The most frequent distinction referred to is that between “warm” and “cold” light colours (Fig. 1:10). Light source colour can differ from light colour (Liljefors, 2006).

Figure 1:11; *Surface colour interaction. Photo M. Billger*

Surface colours. The colour rendering of light is dependent on the spectral properties of the light source but light reflecting surfaces have the ability to reflect light of different irradiances and thus influence perception. Light can also be reflected from one surface onto other surfaces, creating an interaction (Liljefors, 2006) (Fig. 1:11).

2 Theoretical framework and positioning of own research

The object of this chapter is to describe the state of the art in office lighting research (for more details see appended article "Review of office lighting research from a Scandinavian perspective", Paper G) connected to the scope of this thesis. Since light is intimately connected to perception and visual performance, both psychological and physiological aspects are relevant. The main fields that are referred to are psychological aspects such as mood, preferred illuminance and perceived glare; physiological aspects such as performance and alertness; and lighting design, as well as lighting technology such as light sources and controls.

The presence of a paradigm with the ability to support a scientific tradition is the dividing line between science and fiction. Theories however can only be preliminary as new discoveries might disclose flaws in them. By connecting different claims, theories are made more global, and a more complex understanding is gradually emerging. Albert Einstein (1879-1955) claimed that light is a particle phenomenon consisting of photons without mass. According to his theory, light has both wave and particle properties. His theory subsumed the theories developed by Niels Bohr (1885-1962), explaining light as bursts of electromagnetic energy, photons; and by Max Planck (1858-1947), depicting light as a stream of tiny energy particles, quanta.

Electromagnetic radiation has historically been regarded as a physical phenomenon, and as such one that has no influence on the individual or the well-being and performance of the individual when lighting conditions for the task environment are adequate. Thus theoretical constructs within lighting research have been concerned only with visual performance. The physical properties of electromagnetic radiation such as illuminance, irradiance and frequency can be measured using photometric instruments and their fulfilment of expectations can be tested in different experiments. The physical properties of light can however not be perceived by the human eye, as light cannot be perceived without an object reflecting it, thus proving that the old concept of light as visible radiation is untrue. There is still no theory to explain why humans function better and experience greater well-being in certain lighting conditions. The number of parameters that need to be included such as age, health, task, environmental factors, psychosocial factors etc. currently leave all theories lacking.

2.1 Physiological effects of light

Physiological reactions in man to electromagnetic radiation outside the range of 380 – 780 nm, where our visual system responds, have been studied over the last few decades, and it has been established that light has an influence on circadian rhythms in man. Contemporary research show a strong influence on circadian rhythms from short wavelengths and bright light (Brainard et al., 2001; Wright & Lack, 2001; Thapan, Arendt & Skene, 2001; Lockley, Brainard & Czeisler, 2003; Cajochen at al., 2005; Jung et al., 2010), but also show that humans are highly sensitive to ordinary interior lighting levels (Cajochen, Zeitzer, Czeisler & Dijk, 2000; Zeitzer, Dijk, Kronauer, Brown & Czeisler, 2000; Phipps-Nelson, Redman, Dijk & Shantha, 2003). The response is shown to be mediated through photosensitive ganglion cells (iPRGC) constituting a third receptor type in the retina (Berson, Dunn & Takao, 2002; Rollag, Berson & Provencio, 2003; Weng, Wong & Berson, 2009). Physiological measures such as core body temperature and heart rate are also found to be dependent on radiation wavelength (Figueiro, Bierman, Plitnick & Rea, 2009) as well as on the time of day when the bright light is administered (Rüger, Gordijn, Beersmaa, de Vries & Daan, 2006).

There are contradictions in studies claiming that the correlated colour temperature (CCT) of the lighting has an influence on perceived brightness. On the one hand there are findings that show smaller pupil size induced by a high CCT light source improved the depth of field, and maintained visual acuity at lower intensity illumination (Berman, Navvab, Martin, Sheedy & Tithof, 2006; Viénot, Durand & Mahler, 2009). Berman (2000) concluded that the sensation of brightness in an interior is dependent on both cone and rod receptor activity in the retina, and thus scotopically[3] enhanced illumination will be perceived as brighter. This was supported in other studies (Boyce, Akashi, Hunter & Bullough, 2003a; Fotios & Gado, 2005). On the other hand, there are contradictory findings (Laurentin, Berutto & Fontoynont, 2000; Begemann, van den Beld & Tenner, 1997; Houser, Fotios & Royer, 2009) showing that preferences for higher illuminance and higher CCT are correlated, and that the study participants (ibid, 2009) did not find the S/P ratio[4] or CCT to be predictors of brightness perception.

In addition to the above, high illuminance (but not light source spectral composition) was found to enhance visual performance (Veitch, Tiller, Pasini, Arsenault, Jaekel & Svec, 2002) but not task performance (Boyce et al., 2006a). Bright light was also found to reduce sleepiness at night (Boyce, Beckstead, Eklund, Strobel & Rea, 1997; Lowden, Åkerstedt & Wibom, 2004), an effect that was not detected by Wilhelm, Weckerle, Durst, Fahr and Röck (2010) during daytime work.

2.2 Psychological effects of light

Perceptual qualities of light and their interactions stimulate spatial experiences and sensations as well as affecting mood and performance. This dimension of light cannot be measured using standard light measurement techniques. Differences in lighting conditions are seen and appreciated by study participants (Boyce et al., 2003b) and visual appraisal is influenced by the appearance as a whole, including function, lighting and luminaires. The emotional impact of experiences is evaluated affectively, as the light setting will affect the emotional state. As a consequence, lighting could influence cognitive task performance and positively improve behaviour (Baron, Rea & Daniels, 1992). Psychological measures have been shown to relate to day length, with "worst" mood scores in the autumn and "best" scores in

3 Scotopic vision is the vision of the eye under low light conditions. It is produced mostly through rod cells. These are most sensitive to wavelengths of light around 460 nm.

4 The S/P ratio is the ratio between scotopic and photopic vision. Photopic vision is the vision of the eye under well-lit conditions. Photopic vision has good color perception, mediated by cone cells, and a high visual acuity. The highest sensitivity occurs at a wavelength of 555 nm.

spring or summer (Harris & Dawson-Hughes, 1993). High levels of bright light exposure (≥ 1000 lux) were found to induce lower levels of fretfulness and higher levels of agreeableness and more positive affect (Aan het Rot et al., 2008; Partonen et al., 2000; Fleischer et al., 2001). Other research did not find any major effects of lighting on mood, satisfaction or discomfort (Newsham, Arsenault, Veitch, Tosco & Duval, 2005).

Preferences for illumination are individual (Boyce et al 2006b; Veitch & Newsham, 2000b; Moore, Carter & Slater, 2003a; Moore, Carter & Slater, 2003b). Nicol et al. (2006) also found a strong difference in preferred indoor illuminance between countries. A majority of the participants in two other studies, chose illuminance levels below 500 lux (Veitch et al., 2000b; Boyce et al., 2006b), while Newsham, Aries, Mancini and Faye (2008) registered preferences for illuminance levels preferred by the participants differing by 25-50% over the day. Preferred illuminance was additionally shown to be influenced by the preferred CCT (Morita, Hirano & Tokura, 2003).

The CCT was shown to modify all subjective scales defining the character of the illumination (Viénot et al., 2009), as well as the visual appeal of the office (Manav, 2007). Other studies found that subjective perceptions were altered by CCT and light intensity (Fleischer et al., 2001; Veitch et al., 2002).

2.3 Lighting technology

Today technical systems enable us to control lighting set-ups and the energy consumption, and research based on energy savings needs, as well as on personal well-being, indicates that controls and dynamic lighting will gain importance in lighting systems (Boyce et al., 2006b; Moore et al., 2002b). It was found that participants displayed a preference for a manual override despite the advantages of automatic light dimming (Escuyer et al., 2001), and that the system configuration had a significant influence on the chosen illuminance (Moore, Carter & Slater, 2002a). Studies further showed that the frequency of usage of controls was low and the acceptance of the prevalent lighting condition tended to be high (Moore et al., 2003a; Boyce et al., 2003b; Boyce et al., 2006b). Control of workplace lighting did not influence performance, satisfaction, mood or health (Veitch & Newsham, 2000a; Newsham, Veitch, Arsenault & Duval, 2003; Boyce et al., 2003b; Newsham, Veitch, Arsenault & Duval, 2004a; Newsham, Veitch, Arsenault & Duval, 2004b; Newsham et al., 2005). However, Moore et al., (2002b) showed that users perceived control over the lighting to be very important.

New lighting technology raises the issue of interchangeability of light sources as well as physiological hazards. The most common light sources were evaluated by Okuno, Siato & Ojima (2002) for causing photochemical injury to the retina (photoretinitis), and were not found to pose any hazard during short exposure times. Evaluations of visual fatigue in a LED setting as compared to fluorescent lighting did not vary (Mochizuki, 2009), suggesting that there is no difference in influence between the two types of light sources.

2.4 Lighting design

The range of office types is widening. At one extreme is the “mega” office – the large city centre operation. At the other end of the range is the virtual office, that has no specific location and could just as well be in a café as in a private home. There are however practical reasons for using office buildings. The office is providing a stage where the company staff perform and meet visitors (Raymond & Cunliffe, 1997). Offices are also important for communicating the culture of the organisation (Nicolaou, 2006). Additionally, the nature of work is shifting from information processing to idea generation, where moving around within the premises is encouraged (Ross, 2006). Visible copresence may be the trigger for more face-to-face interaction (Rashid, Kampschroer, Wineman & Zimring, 2006). The ambient lighting is the lighting that provides us with the means of orientation, and supports and initiates social and biological processes. Flynn (1977) concluded in his studies that light offers opportunities for communication, in the sense that lighting patterns suggest and reinforce common ideas among people of the same cultural background. Thus lighting can be used to guide individual and group behaviour. The office layout can be supported by the lighting plan in different aspects of orientation, such as meeting points, general paths and task lighting of different illuminance for tasks of different dignity as well as difficulty. He (ibid) also noted that vertical lighting[5] seemed to create a more positive attitude to the surrounding space (Fig. 2:1) than horisontal lighting[6].

Earlier lighting research has concentrated on visual acuity as the most relevant measure of good lighting, and peripheral vision and vertical

Figure 2:1; *Lighting principles. Left, vertical lighting, right, horisontal lighting.*

illumination have been considered less important than horizontal illumination on the work task area. Nevertheless a light setting with more non-uniform light patterns was found to be more interesting and pleasing than an even light distribution (Loe, 1994). It has also been shown that room appraisal was affected by variations in lighting design (Manav, 2007).

It is in the interest of lighting designers to be able to predict lighting quality and how the different perceptual concepts interact. Attempts to describe how the different perceptual variables are interconnected and interact have not thus far been successful (Bean & Bells, 1992; Boyce, Veitch, Newsham, Myer & Hunter, 2003; Boyce et al., 2006a; Veitch, Newsham, Boyce & Jones, 2008). Lighting quality is context dependent and relates to the needs

5 Vertical lighting is said to be used when vertical surfaces, adjacent to the task area, are more illuminated than the horisontal task area.

6 Horisontal lighting is used when the horisontal surfaces are more illuminated than the vertical surfaces in a room.

of the occupants, economic demands and integration with architecture and environmental considerations, as well as global factors (Fig. 2:2).

It is recognised that the luminous environment is highly affected by light distribution and the colour rendering (CRI) of the light source. It was also

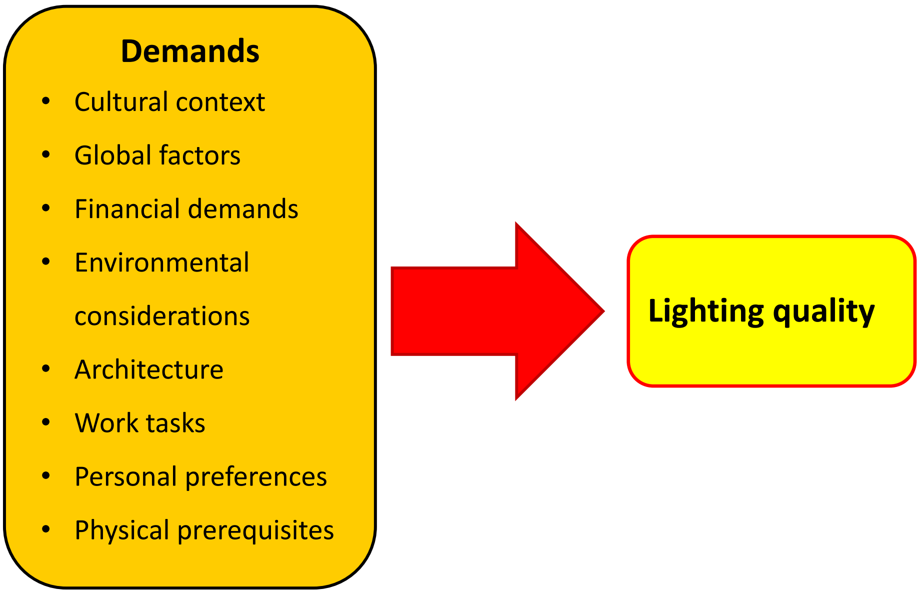


Figure 2:2; *Extraneous demands shape the desired lighting quality for a specific context.*

found, as early as in 1977, that CRI but not CCT was a good predictor of performance (Boyce & Simons, 1977).

There are indications that higher luminances in workplace luminaires can be tolerated when using the modern flat VDT, without influencing perceived display quality and performance (Wang & Chen, 2000). Veitch et al. (2000b) found that the preference for the luminance ratios, desk-to-partition and VDT-to-partition, was lower than recommended. This is in line with the observations made by Escuyer et al. (2001) that office workers with on-screen tasks preferred a low illuminance level. Preferences for light distribution however cannot be determined as results have been contradictory (Houser, Tiller, Bernecker & Mistrick, 2002; Pellegrino, 1999).

The quality of the lighting environment is determined by daylight and artificial lighting contributions together. Begemann et al. (1997) showed that their group of participants preferred to follow a daylight cycle with artificial light added to the daylight level on the desktop. Access to daylight and a window view is considered very important (Escuyer et al., 2001; Veitch et al., 2002b; Roche, Dewey & Littlefair, 2000; Newsham, Veitch & Charles, 2008), suggesting that the importance of daylight is underestimated and that daylight is still setting the standard.

A light setting designed with light emitting diodes (LED) presents itself as an attractive solution but is different from traditional light sources in terms of perceptual qualities, as well as having low illuminance. However, illuminance preferences are individual and the preferred contrast situation when working on screens is different from that for traditional paper-work. Nevertheless, the differences in the perception of light qualities when designing with LEDs are challenging the ideas suggested by previous research about which lighting criteria affect our psychological well-being.

2.5 Positioning of own research

To me, lighting design is a social science relating to man, and good quality lighting cannot be constructed as a glazing on predefined building demands; it must relate to the context as well as to visual perceptions. But lighting is also a natural science to the extent that it factors into physical and biological theories about man – psychological and physiological considerations are needed to explain social phenomena. The non-visual effects of lighting are not fully understood but understanding of the importance of spectral composition as well the effect of perceptual qualities in lighting on health related issues is growing. Research has been able to show that lighting has an influence on arousal and well-being (see 2.1-2.2). Radiation wavelength, light intensities and biological time of day play a major role in determining the size of the effect. Difficulties measuring biological impact suggests a need for new metrics and instruments, as well as for more stringent experimental settings and method development. If interior artificial lighting is not biologically inactive, as suggested in earlier research (Cajochen et al., 2000; Zeitzer et al., 2000; Phipps-Nelson et al., 2003), there is a balance to be reached between providing lighting capable of initiating physiological processes, and the induction of an arousal level adverse to high performance. Furthermore, technical advances offer the opportunity to mimic daylight and customise office lighting to individual needs, inviting further research.

It is suggested that standards are inadequate and photometric methods unable to grasp the complexity of our lit environment (Cuttle 2010), underlining the need for more research. This was investigated in Study II (Papers C, D and E) where a light setting based on standard recommendations was compared to light settings designed using visual concepts. In these settings, as well as in Study III (Paper F), the capacity of the lighting to stimulate spatial and emotional experiences was tested. Additionally, the ability of the participants to notice differences in the lighting conditions was investigated, as was the level of interest triggered by non-uniform lighting.

The VDT setting is different from traditional paper work. Coordinated knowledge of the design of visual working environments with VDTs is absent and recommendations for office lighting, based on horizontal illuminances needed to promote visual acuity, are not suitable for multi-tasking and the need for face-to-face communication in modern offices. In modern offices with VDT based tasks, a lower illuminance is preferred, and preferences for luminance ratios between VDT and near background are lower than recommended. I show in Study IV (Paper G) however that CRI, CCT, visual patterns and glare, etc. are not always considered in lighting research. Nor does research consider the impact of the visual experience of the lived environment on mood and feelings of satisfaction. I further suggest in Study IV, based on the individual variation in lighting preferences, that a quality concept including a range of lighting possibilities might be a first step to guide lighting designers in the design process. This range needs to be researched taking human health, visual comfort and energy savings into consideration.

Study IV (Paper G) displayed a preference for fluorescent or compact fluorescent light sources, in experimental settings, in the majority of the research. Other types of light sources that it is possible to use in a VDT setting need to be studied. Two of the settings in Study II and both the settings in Study III used other light sources, including halogen, incandescent and LED light sources. In my opinion, the experimental settings should be modelled for the working environment they simulate. Attempts to control for unwanted environmental variations result in unrealistic interior designs, censor colours and materials, and might in themselves influence the results, limiting the applicability of those results in real life. My settings were neutral in colour, using only white walls, NCS 1002-Y or NCS 0500-N, and wooden coloured floors. The furniture was likewise neutral, using off-white or black fabric and natural wood. Still, decorations in the form of white artificial flowers and translucent paper shades added visual stimulation to the settings. Colour is a parameter that has been neglected in lighting studies, and white or light grey are often assumed to provide a neutral experience but influence feelings and well-being. Consideration of these feelings in my studies resulted in the use of differently structured materials and shapes to provide stimulation. I acknowledge that lighting and colour construct our mental image of space, and should not be analysed separately, but in view of the influence of colour on the light colour experienced, I chose to conform to using neutral colours.

Up to now, this research has primarily been conducted with young participants, but the working population is aging, suggesting that not all results are applicable. An elderly population has different lighting needs, and problems with glare and detecting low contrast objects are accelerating with age. The participants in Study I, II and III included participants in the ages from 18-78.

In the field of interior lighting, environmental impact is not excluded but is allowed to interact with the lighting to construct an office environment that is supportive to human health, well-being and social interactions as well as to performance (Fig. 2:3).

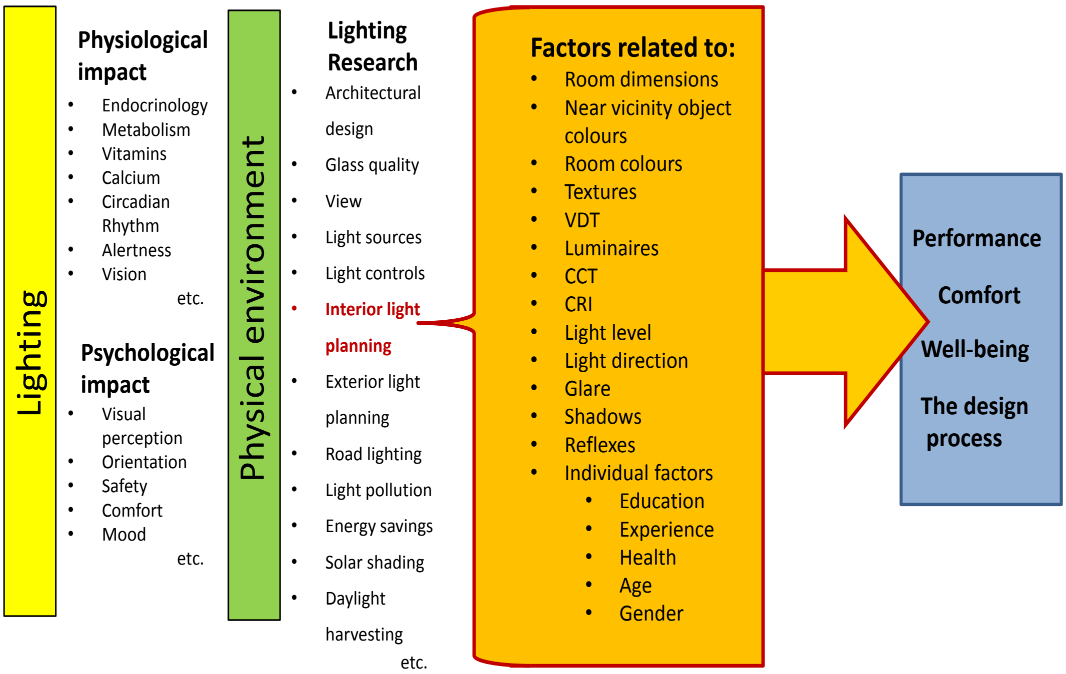


Figure 2:3; *Positioning of own research in relationship to the research field. The lighting research in the left column is unrelated to a context while the research in the next column is related to a specific context. The research in this thesis, to the far right, originates in the interior light planning research that is extracted into the right column.*

The questionnaire study included in this thesis seeks to establish current lighting practice. The experimental studies have a realistic setting, to allow psychological as well as physiological measures to be studied in an office environment. Careful consideration has been given to ensuring a normal interior design standard, and participant groups with a demographic constellation reflecting all groups in society add weight to the results. The intention is to further understanding of the interaction between man and lighting.

3 Methodology

The material for this thesis has been collected through four separate studies. The research consists of literature research, a questionnaire and experimental studies (Figure 3:1).

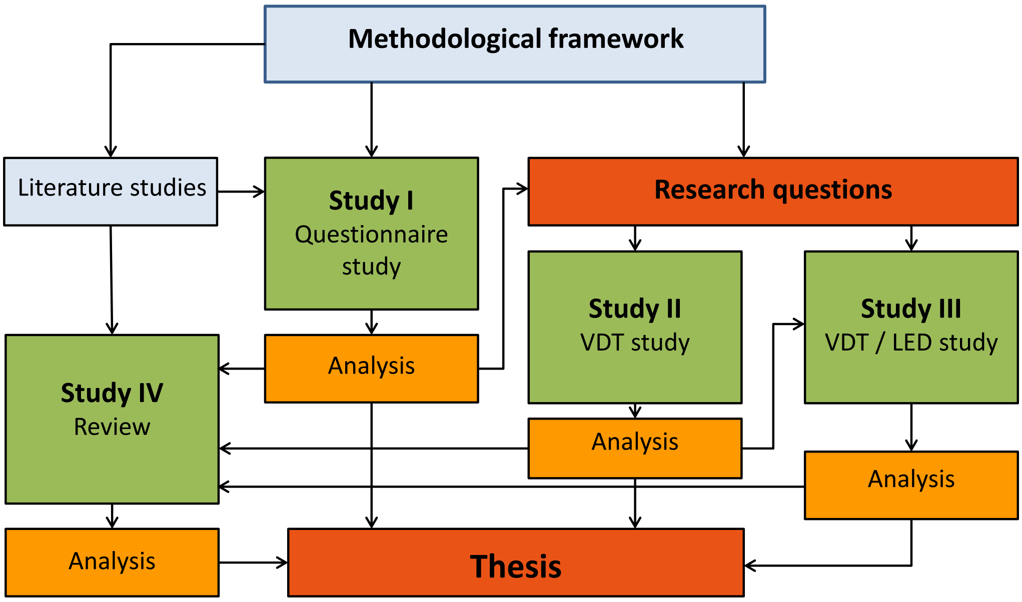


Figure 3:1; *Map describing the different phases included in the thesis work*

The angle of incidence on the subject of office lighting is from the field of architecture and lighting planning, and the first study was a questionnaire study (Papers A and B) that set our to map current practice, involving professionals within the field of lighting design in Sweden.
The questionnaire study was used to open the field of inquiry and to sharpen the focus of the thesis.

The second study (Papers C, D and E) was an experimental study seeking to establish the composition of electromagnetic radiation supporting hormonal balance and visual ergonomy, as well as comfort and well being, in constellations with VDT based tasks.

The third study (Paper F) was engaged in preferences for lighting quality in a home office, with particular emphasis on LED lighting. This study presented itself as an opportunity. A study of commercially available replacement LEDs for home use offered a setting with space available for a home office. The objective of this study was to investigate whether or not commercially available LEDs could replace traditional light sources and have a positive influence on well-being as well as supporting computer based tasks.

The fourth study was a review describing the present state of the art in office lighting research related to planning, perception, performance and psychology. The intention in the review study (Paper G) was to find relevant and valid research. The review was oriented towards office lighting and different aspects of lighting influencing human well-being and performance in an office environment.

A quantitative approach to the research questions was taken. With the questionnaire study based on the visual concepts described by Liljefors (2006) and leaning on current design praxis, research questions were emerging. The problem area was identified as the close task area of the office staff. In the ensuing experimental studies, Study II (Papers C, D and E), and Study III (Paper F), light settings using different designs with one feature in common, the VDT based task, were studied. Participant lighting controls were excluded and the artificial lighting had a set illuminance and irradiance. Illuminances within the range of "normal" office lighting as recommended in "Ljus och Rum" (the lighting guide in Sweden) were chosen for the studies. In Study II (Papers C, D and E), a room with only daylight was used as a comparison to the artificial light settings, with the intention of identifying lighting impact on melatonin and cortisol variations experienced by the participants.

The participant groups were tested on repeated occasions in different lighting environments and the links between cause and effect were investigated in each phase of the studies to establish the pattern of correlations between man and light. Global connections were sought to be able to systemise facts to possibly predict or expect certain results.

3.1 Instruments

The instruments include Likert type and Semantic differential scales as well as dichotomous questions involving aids such as glasses or lenses. Only previously validated instruments were used.

3.1.1 Likert-type or frequency scales

The Likert type scales used had a fixed choice response format and were designed to measure attitudes or opinions. The respondents marked their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. In this way the scales summed up the intensity of their feelings about a given item (Figure 3:2).

To what degree do you consider the environment to have the following characteristics:

LARGE

A little ___ ___ ___ ___ ___ ___ ___ A lot

Figure 3.2; *Example of seven level Likert type scale used in the studies.*

The scale assumes that the strength/intensity of experience is linear, i.e. on a continuum from a little to a lot, and it was assumed that attitudes are measurable. Respondents were offered a choice of five to seven pre-coded responses. Each of the five (or seven) reponses was given a numerical value which would be used to measure the attitude under investigation.

Likert type scales have the advantage of not generating a simple yes or no answer from the respondent but rather allowing for degrees of opinion. Quantitative data is obtained, which means that the data can be analysed with relative ease.

3.1.2 Semantic differential scales

Semantic differential scales can be used to describe the connotative meaning of abstract concepts. The respondent is asked to choose where his or her position lies, on a scale between two bipolar adjectives (for example: “Adequate-Inadequate”, “Good-Evil” or “Valuable-Worthless”). There are three intermittent attitudes that people use to evaluate words and phrases: Evaluation, Potency, and Activity. For example, the adjective pair “good-bad” defines the evaluation factor (E). The potency factor (P) is defined by the “strong-weak” adjective pair, and the adjective pair “active-passive” defines the activity factor (A). These three dimensions of affective meaning have been found to be cross-cultural universals. EPA measurements are appropriate when one is interested in affective responses. The EPA system is a generalised approach, applicable to any concept or stimulus, and thus it permits comparisons of affective reactions on widely disparate things. Usually, a middle position is used and labeled 0 “neutral,” positions 1 are labeled “slightly,” 2 positions “quite,” and if a 7 step scale is used, the 3 positions “extremely.” This type of scale measures the directionality of reaction (e.g., good versus bad) and also intensity. In the studies a straight numerical scale was used, invisibly labeling the positions from 1 to 4 (Figure 3:3), thus transforming the semantic scale into a Likert type scale. To avoid neutral answers, no middle position was used.

Very tired (1)	(quite tired)	(quite rested)	Very rested (4)
___	___	___	___

Figure 3:3; *Example of transformed semantic differential scale used in the studies.*

Scales defining the lighting were also used. The positions were invisibly labeled with numerical values from 1 to 7, transforming the scale into a Likert type scale (Figure 3:4).

Dark	___	___	___	___	___	Light
(1	2	3	4	5	6	7)

Figure 3:4; *Example of lighting evaluation scale.*

The instruments applied in the different studies varied (Table 3:1). General questions, and in Study II stress sensitivity evaluations, were used for collecting demographic data. Hormonal variations were identified using saliva sampling (for more details see Papers C and D), and performance was measured using a digitial performance test (Appendix 8).

Table 3:1; *Study instruments*

Instrument / Appendix	Measurements	Study I	Study II	Study III	Study IV
Appendix 1	General questions	X	X	X	
Appendix 2	Luminaire information criteria	X			
Appendix 2	Luminiare properties criteria	X			
Appendix 2	Ambient lighting criteria	X			
Appendix 2	Work task lighting criteria	X			
Appendix 2	Influence assessments	X			
Appendix 5	Stress sensitivity		X		
Appendix 6	Room evaluation		X		
Appendix 7	Well-being assessments		X		
Appendix 8	Performance		X		
Appendix 10	Ambient lighting assessments		X	X	
Appendix 11	Work task lighting assessments		X	X	
Appendix 12	Visual comfort asssessments		X	X	
	Cortisol levels		X		
	Melatonin levels		X		
	Extraneous factors		X	X	
Appendix 13	Debriefing interview		X		
	Illuminance preferences			X	
Appendix 14	Keywords				X

3.2 Methodology used in Study I

In order to gain information about current practice in lighting design in Sweden, a questionnaire was sent to different categories of planners such as lighting designers, architects, engineers and brand designers. Engineers are, in this study, either university or college educated, while brand designers do not necessarily have a lighting designer education and are employed by a retail agent or producer within the lighting field. The respondents were of different ages, sexes and educational backgrounds (Papers A and B), and were members of the Swedish Lighting Associations or the Swedish Architect Association. The questionnaire was carried out as a survey distributed by e-mail during the period from October 2007 to March 2008. The questionnaire (Appendix 2) was completed on the respondents´ computers and returned by e-mail.

The respondents were asked to grade different criteria in a fictitious design situation on a 4-point scale ranging from 1 (very little) to 4 (very much) or fill in tick-boxes with specific answers to given questions. The questionnaire included evaluations of different kinds of photometric measurements, as well as evaluations of different visual descriptors for qualities of light for ambient lighting and work task lighting, and evaluation of different aspects of the luminaire (Figure 3:5).

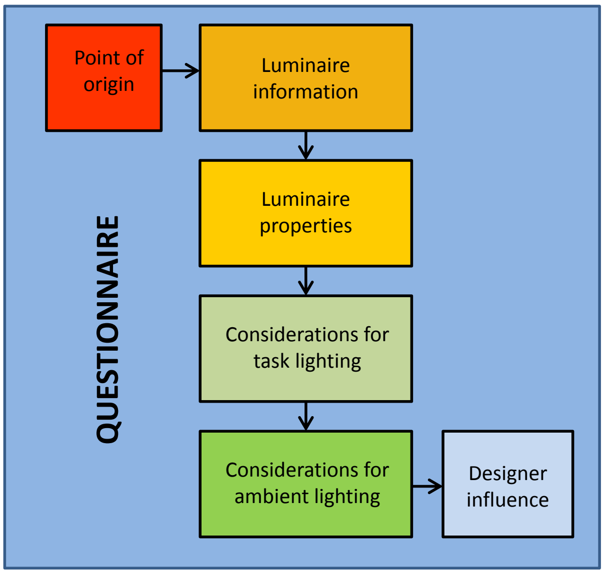


Figure 3:5; *The construction of the questionnaire, Study I, with the different areas of inquiry. The questionnaire set-up is illustrated with the arrows.*

The role of the lighting designer was also investigated, with respondents asked to describe their point of origin in the design process and to evaluate their perceived influence on the planning process. Criteria in the evaluation process whose significance might be uncertain to the respondents were explained in brief. The evaluated criteria were divided into technical and perceptual criteria depending on whether they were quantifiable (technical criteria) or needed to be evaluated visually (perceptual criteria).

The data was statistically analysed to provide information about the practitioners' preferred criteria when designing the lighting environment in offices. For a more detailed description see Papers A and B "Criteria influencing the choice of luminaires in an office environment".

3.3 Methodology used in study II

In this study (Papers C-E) three different settings, two with artificial lighting and one with only daylight, were investigated to find out which of the three had the most positive influence on well-being, alertness and performance in a person exposed to it while performing tasks on a VDT. The study was designed to find out if the relationship between spectral composition of lighting and alertness, described in earlier studies, could be replicated in an office environment. Furthermore, it was intended to assess the influence of perceived lighting quality on self-assessed well-being. An additional aim was to find out if more varied artificial lighting supported well-being and performance differently from a light setting with only fluorescent lighting.

A pre-study was carried out to ensure reliability of measurements and verifiable results in the main study. The result was interpreted as showing that the rooms were identical prior to the introduction of the light settings.

Fifty-one participants were recruited through advertising, e-mails and the local employment office, and participated in the study between March and June 2009.

Three rooms were used (for details see Papers C-E). Two of the rooms were set with only artificial lighting and no daylight, and one room with only daylight (Figure 3:6).

Room One ***Room Two*** ***Room Three***

Figure 3:6; *Experimental settings, Study II. Room One used fluorescent lighting, Room Two a mix of incandescent and fluorescent lighting with added diffused decorative light, and Room Three had only daylight. All three rooms were equipped with a flat LCD VDT on which all tasks were completed.*

The lighting in Room One followed the standard recommendations for office lighting (SS EN 12464-1). The lighting set-ups in the two artificial light settings were designed to appear normal but different from one another. The task light in Room Two illustrated the visual variety often experienced in an office, but had a fixed position. The illuminance in Room Three with only daylight varied over the day as natural light was diffused through paper screens. This room served as a reference and was compared with the two artificial light settings when analysing the hormone samples.

The study was carried out between March 16 and June 5 in 2009, on site at the University of Jönköping in Sweden. The participants spent from 9 am until 4.30 pm in each room at weekly intervals. The first experimental setting encountered could be either one of the three rooms. During the experiment each participant was asked to complete simulated office tasks on the VDT. All surveys and the performance tests were scored on the VDT. Sampling of saliva for cortisol and melatonin was conducted three times a day. For more detailed descriptions of the procedure see Appendix 3.

The five different surveys completed by the participants included

1. evaluations of spatial experience of the room using semantic scales (Appendix 6).
2. evaluations of well-being through Likert type scales (Appendix 7).
3. evaluations of the ambient lighting through Likert type scales (Appendix 10).
4. evaluations of the work task lighting through Likert type scales (Appendix 11).
5. Visual comfort was measured with a semantic scale and a Likert type scale relating lighting quality to personal preferences (Appendix 12).

A personality mapping survey (Appendix 5) was used to grade the stress sensitivity of the participants.

The above described surveys, together with the vigilance test and the variations of cortisol and melatonin shown in the analyses of the saliva samples, provided the data for the statistical analyses. For more detailed descriptions see Papers C, D and E.

3.4 Methodology used in study III

The third study (Paper F) sought to determine whether or not commercially available LEDs could replace traditional light sources and have a positive influence on well-being as well as supporting computer based tasks. The study used two identical rooms. The lighting was arranged with incandescent, fluorescent and LED lighting in Room One, and commercially available replacement LED lighting in Room Two (Figure 3:7).

Illuminances and luminances were measured. For more detailed descriptions of the settings see Paper F. Participants were recruited using

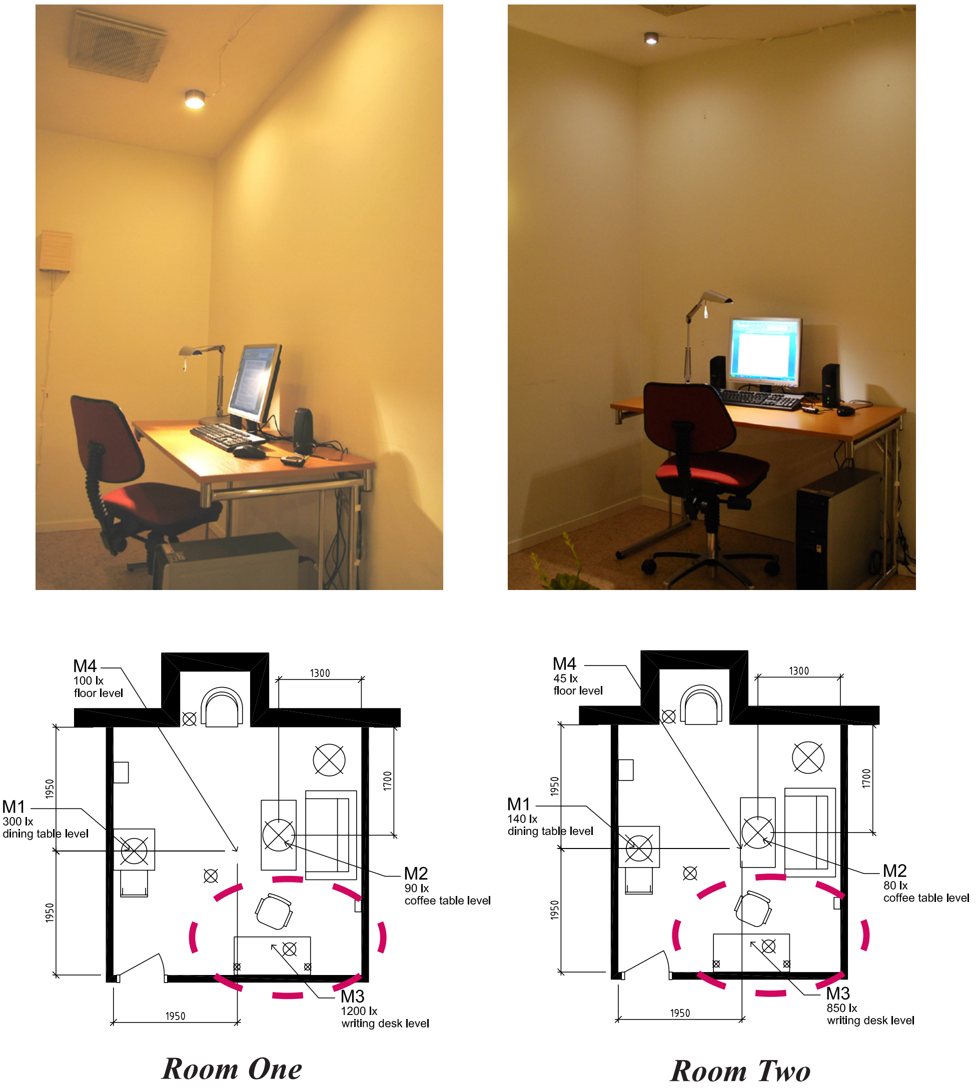


Figure 3:7; *Experimental settings, Study III. Room One was set up with various light sources, and Room Two with only LED light sources. Both rooms were equipped with a flat LCD VDT. Red circles mark the study area.*

student and staff e-mail at the University as well as by word of mouth. The study was completed between October and November, 2009. The participants spent 1/2 hour in each room, at weekly intervals, evaluating the two light settings. After undertaking an on-screen task, the participants completed surveys (Appendix 10-12) in which they evaluated their visual comfort, the visual experience of the room, the task area and the lighting experience.

The surveys were correlated to illuminance preferences performed prior to entering the first room, and provided the means for statistical analyses. For a more detailed description see Paper F "The influence of light emitting diodes on wellbeing and comfort in home offices".

3.5 Methodology used in study IV

The review is based on a database search using keywords (Appendix 14). The keywords were chosen based on an earlier database search using more global keywords. The articles retrieved in this first search were screened and the keywords listed in the most relevant articles were used in Study IV. The articles retreived in the Study IV database search were screened and three relevant categories for office lighting design were chosen (Figure 3:8).

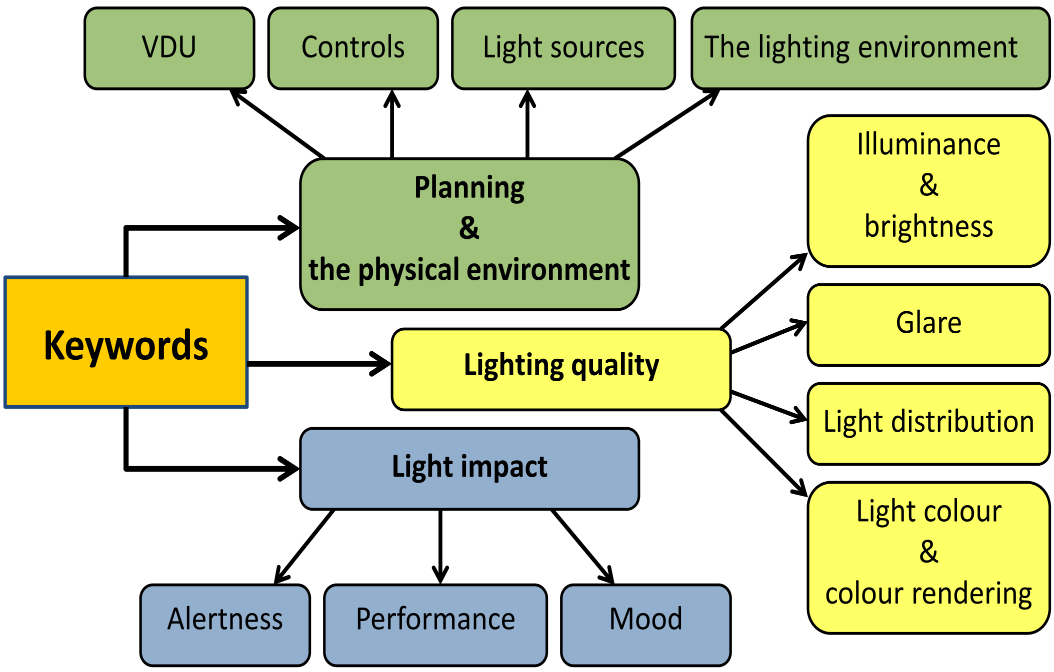


Figure 3:8; *Map of research included in the review article.*

The scope of the articles retrieved covers current research on how electromagnetic radiation supports personal well being, alertness, concentration and performance in office settings. The scope of research articles was limited to the indoor lit environment and specifically to the office environment with emphasis on planning and room experiences. I evaluated the scope to comprise the context base for present lighting recommendations for office lighting and lighting practice. The search targeted research describing field studies in office environments or experiments in laboratory settings applicable to office environments. Not only articles published in peer-reviewed journals and conference proceedings were included, but also scientific reports of interest published elsewhere. Research performed prior to 2000 was viewed with caution since the office layout, work tasks and tools have undergone significant changes in the last decade. Database searches were made in databases available at the University of Jönköping, Sweden, during the period from November 2010 to January 2011. Included were the databases of Medline, Oxford Journals, Sage, Science Direct, Scopus, Springer Link and Wiley online Library from the year 1980 onwards. See Paper G “Review of office lighting research” for further details.

3.6 Validity and reliability

Validity and reliability are essential in all research. Internal validity was addressed in the studies, using experimental settings that help rule out, or make implausible, irrelevant factors as explanations of the effects studied. The settings were neutral in colour and texture but normally furnished and not devoid of visual stimulation. The presentation order of the rooms was random. The same kind of food was served to all participants at all occasions. Procedures followed a strict protocol (Appendix 3) and instructions were recorded and repeated in a set order to ensure construct validity. The study that looked into hormone levels was initiated after the spring onset of annual hormonal rhythms to avoid winter “lows”. Data triangulation, drawing on several different data sources, was used to obtain data on the same perceptions. To ensure the reliability of the measurements, only instruments that had previously been validated were used in the studies. Data was analysed using a standard statistics calculation programme and the results were viewed conservatively to eliminate the risk of premature conclusions being drawn. External validity, with broad generality, was sought in the group constellations and in the relation of experimental settings to lighting recommendations. Despite this, extraneous variation could not be totally eliminated, as the studies involved human participants who visited the settings on a weekly basis; nor was it possible to control for participant bias when answering the surveys.

4 Results

In this chapter the findings from each study are summarised and presented.

4.1 Study I

In the first study (Study I) I looked into the importance of different criteria in the design process. The results are presented in detail in appended Papers A and B. The e-mail method resulted in 202 completely answered questionnaires. The answers indicated that the lighting practitioners involved in the design process are working individually or as a group, within the process, relying on their experience and loosely interacting with other categories of actors. Contemporary research on spectral composition, colour of light and performance was not considered in all situations and "new" criteria in the design process were not considered important, indicating that research is not well-known.

4.1.1 The impact of education, experience and influence on criteria evaluations

I postulated in Study I that education and experience would correlate with a difference in the evaluation of criteria and in perceived influence (see paper A and B). I found however that in general, experience and gender but not education influenced the evaluation of criteria. A statistically significant difference in the evaluation of different criteria by groups with different education was only found for the perceptual criteria for the luminaires, where designers with university degrees gave higher ratings for the perceptual, visually evaluated criteria.

Futhermore, it became clear to me that longer experience influenced the evaluation of criteria for work task lighting and ambient lighting, where criteria were given higher evaluations with more years of experience (see Papers A and B). I also found that perceived influence increased with more years in the profession, but surprisingly also with lower level of education.

Out of the three questions in the questionnaire where respondents were asked to grade their influence, two revealed a significant difference between groups: the positioning of luminaires and the number of luminaires, where an academic education resulted in a lower experienced influence.

4.1.2 The impact of age and gender on criteria evaluation

The consideration given to different criteria in the design process correlated to the age and gender of the lighting practitioners. Not only did age have an influence on evaluation, when rating criteria for the luminaire and personal influence, but younger practitioners with less education were more prone to consider luminaire qualities and to rate their own influence more highly (for more details see Papers A and B). There was a significant difference between age groups, with younger designers (age 22-44) evaluating perceptual qualities of the luminaire information more highly than the other groups. Perceptual criteria for both ambient and work task lighting were rated more highly by the oldest group of designers (age 57-78).

The analysis of the data indicated a difference associated with gender in the evaluation process. Women generally gave higher values to the criteria and evaluated the perceptual criteria more highly than the men (see Papers A and B). The difference also manifested itself in the evaluation of the luminaire, where women evaluated perceptual criteria concerning information about the luminaire more highly and men rated the perceptual criteria for the luminaire properties more highly (see Appendix 2).

4.1.3 Luminiare evaluations

When asked about the luminaire, the practitioners were most concerned with light distribution, light quality and the design of the luminaire. Properties requiring integration into the building were not considered as important, nor were the price and cost. Recycling of the discarded luminaire was given less consideration than any other criterion.

The information based on perceptual criteria was considered to be more important than the technical information about the luminaire. I found a correlation between perceived influence and a high level of importance ascribed to technical criteria in the choice of luminaires, as well as to features of the luminaire. I also found that the quality of the illumination from the luminaire was considered more important than the actual design of the luminaire.

4.1.4 Ambient lighting

The respondents answered that they gave most consideration to glare when designing ambient lighting. Colour of light was considered to be important and was second only to glare when evaluating criteria for ambient lighting. Technical criteria were given a higher mean value in the evaluations than perceptual criteria such as shadows, reflexes, direction of light and light quality (see Papers A and B).

4.1.5 Work task lighting

The respondents considered the most important criterion for work task lighting to be glare. The position of the luminaire in relationship to the work task area was also considered very important. The mean value of the evaluations for technical criteria for work task lighting was higher than the mean value for the perceptual criteria (see paper A and B).

4.2 Study II

In Study II (Papers C, D and E), I studied the influence of the light setting on perception, comfort, well-being and performance. The results are presented in detail in appended papers C, D and E. The light settings were designed with different light sources, to establish whether the different lighting had a different impact on the participants. The strongest result in my analysis however is the discovery that presentation order impacts on the lighting experience, both for ambient lighting and work task lighting, obstructing discovery of more modest reactions to the light stimulus.

4.2.1 Ambient lighting

The instruments revealed a difference between the settings that was statistically significant when presentation order was a covariate. This however only applied to variables denominating variations in illuminance, light distribution and colour temperature. Variables describing personal experience of the lighting such as comfortable/uncomfortable and hard/soft were not affected by presentation order. I could also see in the analyses that participants considered Room One to have the most neutral lighting with the least variation.

4.2.2 Work task lighting

There were no significant differences between the rooms in the evaluations of task area lighting. The quantitative variables were affected by the presentation order but variables describing personal experience of the lighting were not affected.

4.2.3 Comfort and well-being

I found that most participants felt the lower illuminance settings enhanced well-being and increased the ability to perform. There were no significant differences between experienced well-being related to age, gender or presentation order. Visual comfort was significantly different between the light settings, with more visual discomfort experienced in Room One (for more details see paper C, D and E). Presentation order did not affect comfort.

4.2.4 Performance

Performance scores registered using a computer based performance test (Appendix 8) indicated that a higher level of concentration was sustained in the room with only daylight, despite a lower illuminance. Neither the level of cortisol nor that of melatonin displayed a correlation with illuminance or performance. A tendency to differ between gender was found, with men performing better under fluorescent lighting and women better in the light setting with various light sources. Additionally, the room with only fluorescent lighting was assessed as providing the best support for an on-screen work task (see papers C, D and E).

4.3 Study III

The third study looked into the impact of different lighting on visual comfort and well-being. The results are presented in detail in appended Paper F.

4.3.1 Visual comfort

In this study I found that more than one third of the participants considered the colour of light to be cold, or too cold, in Room Two (LED) while only one fifth thought the same of the lighting in Room One (various light sources). Comfort was subsequently experienced to a slightly higher degree in Room One than in Room Two. Parameters for light quality were overall given higher ratings in Room One (see Paper F) with a variety of light sources. The strength of physical symptoms in the visual system indicated that the LED setting was less supportive for on screen work tasks.

4.3.2 Well-being

Parameters for light quality were overall given higher ratings in Room One with various light sources. There was no relationship between age or gender as to which light setting was preferred.

4.4 Study IV

The review study (Paper G) resulted in a state of the art article for office lighting, "Review of office lighting research from a Scandinavian perspective", including a discussion where the experimental setting, sample selection, quality lighting, implementation of controls and the importance of the design of light settings were discussed. In this article I also indicated knowledge gaps as suggestions for future research. The review resulted in the finding of knowledge relevant to the research questions in this thesis. It forms the basis for chapter 2 and is included in the discussion in chapter 5.

5 Discussion

The discussion includes the results according to the research questions they relate to. Results from the different studies are subsequently discussed in the same section if they relate to the same research question.
The research questions in this thesis are:

- Which criteria are considered to be important in the lighting design process in Sweden today, and why?
- Does the lighting design process need to be strengthened, and if it does, how should it be done?
- How should light settings be designed to create the most suitable lighting in an office environment with VDT based tasks?

5.1 Which criteria are considered to be important in the lighting design process in Sweden today, and why?

The first study sought to establish whether or not a lighting design education leads to a difference in lighting design practice. Lighting design education in Sweden teaches a visual analysis method (Liljefors, 2006) (see "Important concepts in this thesis") where perceptual criteria are evaluated. This method is used to supplement photometric measurements. I found it important to establish whether this means that a designer with a lighting education would infer that there was more value in perceptual criteria. Study I (Paper A and B), shows that lighting practitioners with an academic education evaluate both technical and perceptual criteria (for definitions see 1.6) more highly than lighting professionals with a shorter education. In Sweden light settings are often designed by architects. Despite this, architecture education in Sweden includes little or no lighting education. This implies that practitioners within the field of lighting with an academic education do not by default have a lighting design education. Consequently, as the research method defined academic level but did not separate lighting designers from other professionals with an equivalent degree, the proposed influence of education can only be partially substantiated. Academic education related to higher evaluations of perceptual criteria in some, but not all, situations, and the correlation was not statistically significant. The women in this study, however, generally had more academic education than the men, and even though the type of education was unknown, it could mean that the correlation that was found between gender and higher evaluation of the perceptual criteria was in reality correlated to education. Further studies are needed to clarify this correlation.

The correlation between perceived influence and the evaluation of technical, quantifiable, criteria, in the choice of luminaire as well as in the technical features of the luminaire, could be an effect of the technical criteria being easier to discuss, and to evaluate in the planning process, than perceptual criteria. The concern displayed in Study I (Papers A and B) for luminaire light distribution is understandable, as recommendations for office lighting (SS EN 12464-1) do not recommend light distribution and research has not been able to determine specific preferences (Houser, Tiller, Bernecker & Mistrick, 2002; Pellegrino 1999). Furthermore, Study I (Papers A and B) revealed a duality between evaluation of the design and evaluation of the function of the luminaire. When inquiries were made asking about the importance of different criteria in the luminaire information sheath, the photo was evaluated as most important, surpassing the other criteria. When asked to evaluate the properties of the luminaire, the light modelling properties of the luminaire were evaluated as more important than the design. This duality will affect lighting designs. It is also evident in other research where luminaire design and positioning is considered an important part of the interior design (Fridell-Anter, 2012). The impact of these aspects is dependent on different personal factors (Figure 5:1).

In research, ambient lighting is considered to be important for space orientation and spatial comprehension (Flynn, 1977; Loe et al., 1996). Furthermore, research has shown that office staff tend to evaluate the luminous environment as a whole (Moore et al. 2003b). The criteria most influential on these features, i.e. perceptual criteria such as shadows and

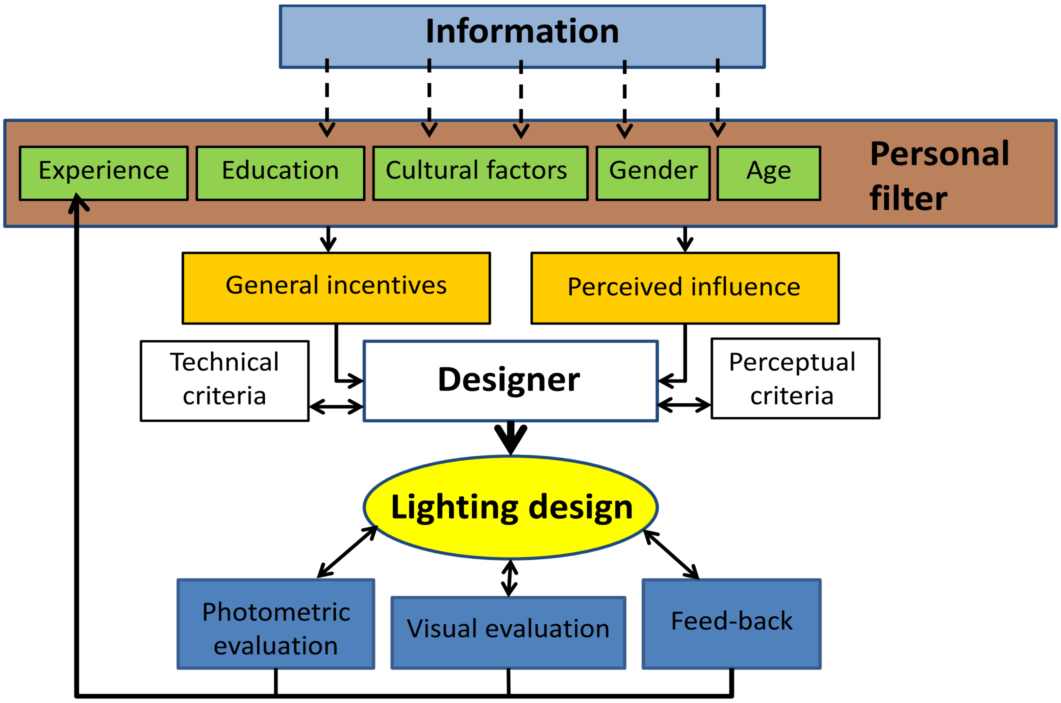


Figure 5:1;*Factors influencing the design process. The information that is used to acheive the best possible design in a specific context is processed in a personal filter where experience, education, cultural factors, gender and age are used to assess the importance of the information. The information is further influenced by general incentives from other actors in the process and from the lighting designer's own perceived influence. The designer sorts the information into technical and perceptual criteria that are interacting in the ensuing design phase. The resulting lighting design is evaluated and adjusted. The results from the design process are finally added to previous experiences.*

directions of light, were overall given lower ratings than the technical criteria in Study I. Longer experience however led to higher values being ascribed to these criteria. This could be an effect of perceptual criteria being more difficult to discuss in the planning process, and only with longer experience is the result considered to be worth the effort.

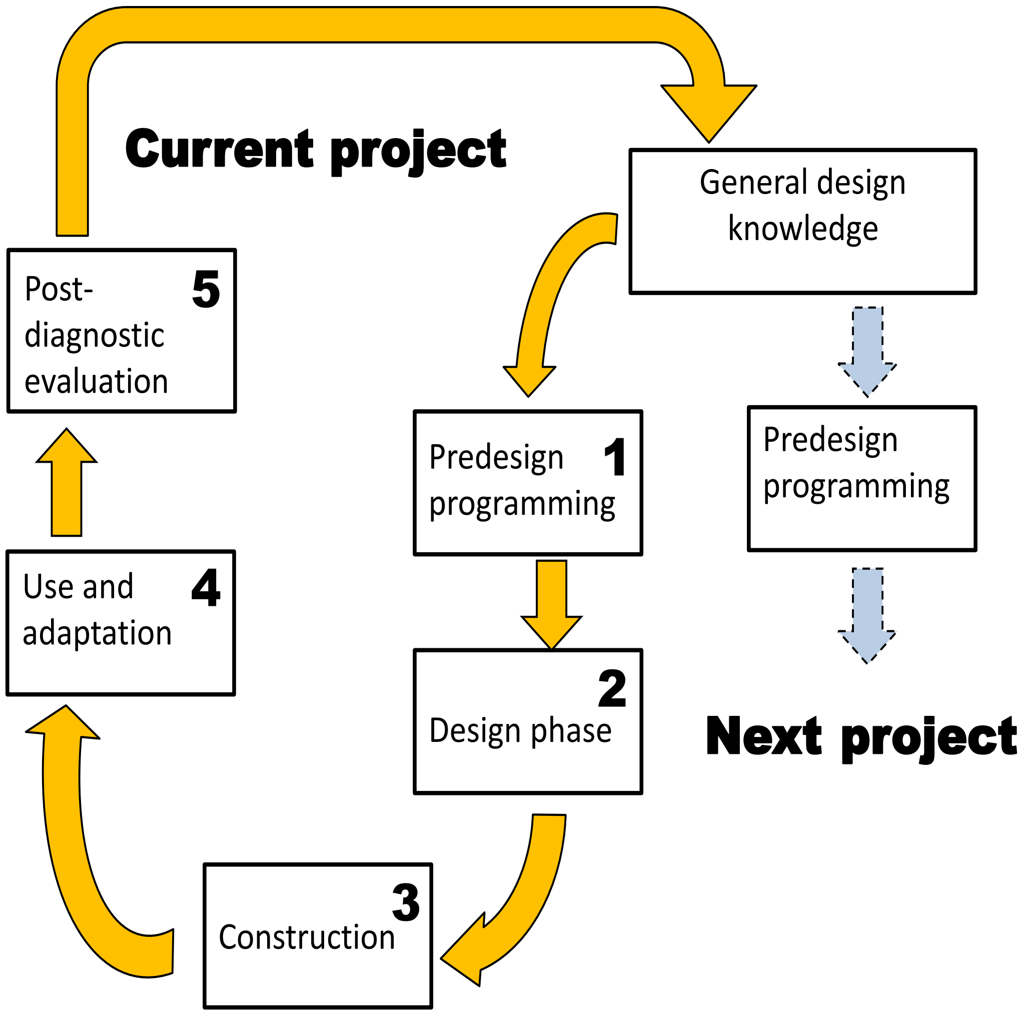
Earlier studies show that a higher CCT was preferred for impressions of comfort and spaciousness, while a lower CCT was perceived to be more related to impressions of relaxation (Manav, 2007). Fridell-Anter (2012) reports in her Swedish interview study that colour temperature is a more current topic now that LEDs have entered the field. The colour of light is, in her study, considered to be a creator of atmosphere. Study I (Papers A and

B), also found colour of light to be important, and it was second only to glare when evaluating criteria for ambient lighting. However, when designing the work task lighting, colour of light was one of the criteria least considered, indicating that the suggested connection between spectral composition, colour of light and performance (Newsham, Veitch, Arsenault & Duval; 2004b) is not generally known, or is related more to impact from ambient lighting. This also indicates that the impact of lighting on circadian rhythms found in contemporary research (Brainard et al., 2001; Wright et al., 2001; Thapan et al., 2001; Lockley et al., 2003; Jung et al., 2010) is not considered, unknown, or in conflict with the aim of designing a comfortable environment.

The modern layout commonly used in Swedish offices, with large open spaces with a number of work stations, imposes new challenges on the lighting designer as the number of luminaires makes it more difficult to control glare. Research has reported that the responses to glare from individual subjects are inconsistent (Osterhaus, 2005; Tuaycharoen & Tregenza, 2005; Tuaycharoen & Tregenza, 2007) and strongly influenced by other variables. Despite this, the most important criterion for work task lighting as well as for ambient lighting in Study I (Papers A and B) was considered to be glare.

Today growing concern about pollution and the environment is added to the criteria that need to be considered. Energy consumption and recycling will probably increase in importance as energy costs are increasing and recycling is becoming a part of our life. Despite this, less consideration was given to recycling than to any other information about the luminaire. A possible explanation can be found by scrutinising the demographic information about the participants. More than two thirds of the respondents were age 45 or older. Recycling is a late invention and the age distribution could be a factor contributing to the low evaluation of this criterion.

I consider it unfortunate that criteria requiring a need to cooperate with other actors in the building process, such as heat emission, spatial demands and mounting, are rated as less important in Study I. One possible reason for this may be the strong presence of the designer in the design phase of the design cycle (Figure 5:2), while the phases of construction and use and adaptation are left to the builders.



1.*Predesign programming* (Analysis). Design objectives, constraints and criteria are identified.

2.*The design phase* (Synthesis). Design decisions that satisfy criteria are made. Design alternatives are singled out considering the different technical and perceptual criteria, and the scope of choices gradually narrows until it lies within the concept of acceptable solutions.

3.*Construction.* Realising the project and modifying the plans under changing constraints.

4.*Use and adaptation* (Reality Testing). End users are moving in and adapting the environment.

5.*Postdiagnostic evaluation* (Review). Monitoring final products in terms of objectives and use – ideally to be transformed into future design criteria and to ascertain that solutions acceptable to lighting designers are also solutions that promote comfort, well-being and performance for the end users.

Figure 5:2; *the design process in five steps (adapted from Zeisel, 1975)*

It has also been pointed out that different actors in the building process use different terms and do not understand or respect cases made by people from other occupations within the process (Fridell-Anter, 2012). Moreover, post-occupancy evaluations, in my experience, rarely involve builders, providing a possible explanation as to why criteria influencing the construction are overlooked in the design process.

Overall, the results show that an information filtering effect is at hand and suggest that the outcome of the design process is dependent on the qualifications of the individual designer (Figure 5:1).

5.2 Does the lighting design process need to be strengthened, and if it does, how can this be done?

Study I suggests that lighting practitioners need to relate more to research. It is apparent that the design process is highly individual, and that application of research is not axiomatic. The practitioners rely on experience to solve design issues. If experience, as shown in Study I (Papers A and B), is the decisive factor when evaluating lighting criteria, then the profession is undermining itself as designers are moving backwards into the future. In general, the evaluations did not relate to contemporary research. This illiteracy is also shown by Fridell-Anter (2012). There seems to be an inherent divide between design and research in the minds of many practitioners, and it is true that the design process, being a "subjective" process, cannot be fully captured by rule-based propositions (Figure 5:3).

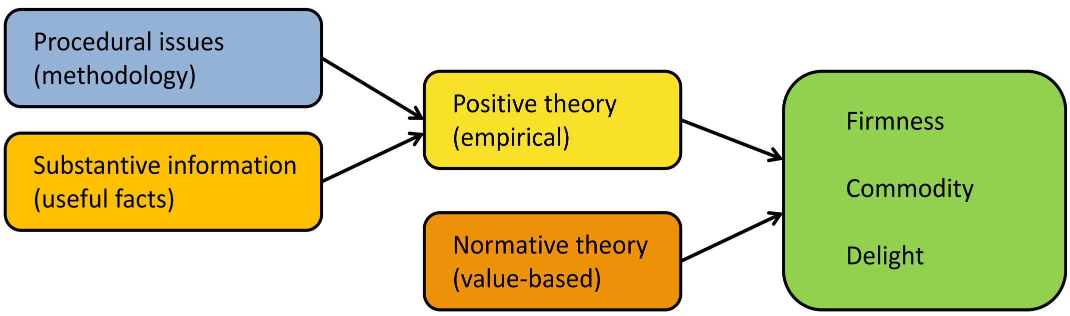


Figure 5:3; *The relationship between normative and substantive theories and design (adapted from Lang, 1988) The model integrates positive theory based on predictable relationships with normative theory based on design values, resulting in a lighting design that is able to provide commodity, firmness and delight.*

A more general application of lighting education to the profession could reduce unconscious bias, and provide designers with the knowledge that make them irreplaceable. Filtering effects depending on age, gender and cultural factors (Figure 5:1) when evaluating lighting criteria, would then be less influential. To further strengthen the process, several of the design considerations evaluated in Study I should be advanced from the design phase into the predesign programming phase where considerations can be given full attention, resulting in stringent guidelines for the specific project (Figure 5:2). When all phases of the lighting design process are validated and realised, feedback from the post occupancy evaluations will strengthen the interaction in all phases of the design process.

The theoretical model (Figure 5:3) for the outcome of the design process can be applied when both kinds of criteria, technical (quantifiable) and perceptual (visual), are rated as equally important, contributing to a well-balanced framework for lighting designs.

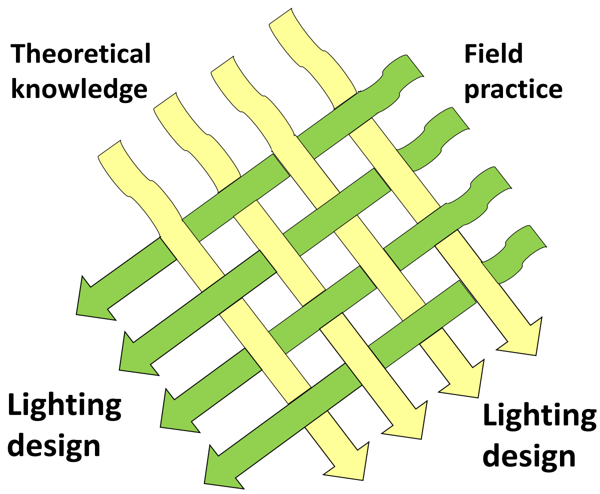


Figure 5:4; *Theoretical knowledge and field practice are combined to create different lighting designs. They cannot stand alone, but are dependent on one another in the creation of a design.*

In my opinion, a more explicit awareness of the process and how it can be modified by incorporating elements from research would considerably strengthen the role of the lighting designer. I suggest that, in order to strengthen the lighting design process, design work should be considered a learned skill and a more gradate attitude to criteria influencing the design process should be furthered, promoting academic education within the profession. To ensure that personal bias does not impair the process, and that a supportive lighting environment can be designed, an academic lighting education and a better knowledge of research should be encouraged (Figure 5:4).

Research can offer a template for understanding a pattern of creative and relevant solutions. Historically, scientific methods in our society devalue subjective experience and place a high value on propositional understanding (Groat & Wang, 2002), but the complex factors building a design process will not be limited to pure propositional (cause-and-effect) definitions, as they elicit other manifestations of working reason. Design in itself is a different activity from research, but research about the design process can help inform the actors in the process. This in turn would bring about more careful and considerate design regarding human requisites, task requirements and environmental issues.

5.3 How should light settings be designed to create the most suitable lighting in an office environment with VDT based tasks?

This question was adressed in Study II, Study III and study IV. In these studies I specifically looked at the influence of lighting on performance, visual comfort and well-being.

5.3.1 Performance

The studies reviewed in Study IV, Paper G, agree that the visual surroundings in offices need to provide light with illuminances and irradiances capable of initiating biological processes, without inducing an arousal level adverse to high performance. It is suggested that the recommended level of lighting in offices, 500 lux on the work surfaces, is in conflict with this need, if a person spends an entire day in an office (Rea, Figueiro & Bullough, 2002). The light settings in Study II (Papers C and D), were designed to be perceived as normal offices, and the target illuminance was set to 500 lux on the work task area. As a result there were no statistically significant differences in performance scores between the light settings. Rising alertness is commonly used as a measure for possible performance enhancements. There were however no correlations between light, cortisol levels and alertness found in the different settings. The de-briefing session (Appendix 13), following the experimental day, provides an explanation for the lack of differences, as it was shown that the participants experienced the lighting in highly personal ways. Moreover, the result is consistent with earlier research where office lighting could not be confirmed to affect performance (Boyce et al., 2003a; Boyce et al., 2003b; Boyce et al., 2006a). An additional possible reason for this lack of response is the VDT based instrument, where traditional visual acuity tests on paper are more susceptible to differences in lighting quality than tests on a VDT.

5.3.2 Well-being

The findings in Study II (Papers C, D and E) and Study III (Paper F) indicate a preference for a light setting with a variety of light sources as opposed to a monotonous light setting with only LEDs or fluorescent lighting. In general, both settings in Study II with low illuminances were felt to enhance well-being. In Study III (Paper F), the commercially available replacement LEDs at the time of the study only provided a colour rendering (CRI) of 60, which is below lowest standard for public environments. It was therefore not surprising that the criteria for lighting quality in this study overall were given higher ratings in the varied light setting than in the LED setting.

The review, Study IV, includes results that show ratings of the lit environment were enhanced after the participants set their own own preferred illuminance level (Newsham, Arsenault & Veitch, 2002). Additionally, high levels of bright light exposure were found to induce lower levels of fretfulness and higher levels of agreeableness and more positive affect (Aan het Rot et al., 2008). Comfort, pleasantness and impressions of relaxation increased with decreasing CCT (Viénot et al., 2009). The varied light setting in study II had a lower CCT than the fluorescent light setting, and was the room in this study that was found to enhance well-being the most, supporting these findings. The higher illuminance in the fluorescent light setting did not result in more positive affect, possibly due to impressions of monotony taking over.

5.3.3 Visual comfort

There are significant differences between the light settings in Study II in terms of the levels of visual comfort experienced, where the most visual discomfort was experienced in the fluorescent light setting. This is not in line with suggestions found in the reviewed studies, which suggest better visual comfort in a VDT setting might be achieved with ambient lighting of high CCT, and that high CCT improves well-being and performance. However, Study II, in keeping with Escuyer et al. (2001), also found that office workers with on-screen tasks prefer a low illuminance level. Study III (Paper F), indicates that the LED setting, characterized by a high CCT, low illuminance and poor CRI, is less supportive for on-screen work tasks. This result needs to be contemplated and evaluated as the LEDs that were used were commercially available replacement LEDs and these were, at the time, low quality. Moreover, the confounding results are possibly a consequence of the varying importance attributed to the VDT in the different studies. Study III involved a home office situated in a living room, where perceptions of spaciousness and brightness would be perceived as more important than visual comfort when using the VDT.

5.3.4 How well do LEDs compare to traditional light sources in an office setting?

Both Study II (Papers C, D and E), and Study III (Paper F), indicate that a variety of light sources are preferred to a design with only one type of light source. Parameters for lighting quality were, overall, given lower ratings in the LED light setting compared to an identical room with a variety of light sources. Due to the quality problems with the replacement LEDs, conclusions as to which type of light source is preferred cannot be drawn. The LEDs in the LED room had a CCT of 3000 K (warm white), used in public spaces but not homes in Sweden, and CRI 60, which is below the lowest standard for the public environment and on the lower side of energy savings replacement lamps with CRI>80. Consequently there was a visible difference between the light settings in the two rooms. The participants also considered the light in the room with LEDs to be cold or too cold. As both illuminance, CCT and CRI varied, the result cannot be attributed to a specific property of the LED, and even though visual comfort evaluations differed, a valid conclusion cannot be drawn. Additionally, the participants perceived the LED environment to cause more visual discomfort than the light setting in the adjacent room. The database search in Study IV (Paper G) only retrieved one study involving LEDs in connection with VDT based work tasks. This study did not uncover any differences in visual fatigue while working on a VDT that depended on the light source being an LED or a fluorescent light source (Mochizuki, 2009).

Moreover, other aspects of the LED light source should be considered. I found in Study IV (Paper G) that the efficacy of light sources with non-continuous spectra and a proportionally greater part of short wavelengths, such as LEDs, is affected by the properties of the ageing eye (van Bommel, 2010). Light sources thus characterised can result in a loss in efficacy because of spectral age effect of up to 48%. As the work force in the western society is ageing, consideration should be given to the spectral composition of the light source. The LED is unique in that it has a monochromatic light, offering the option of tailoring the radiation content. It also offers the option of designing a dynamic light setting where aspects such as CCT and CRI, as well as illuminance and biological triggers, can be taken care of.

5.3.5 Application of research

Still, uncertainties remain to be resolved before lighting design can be adjusted in accordance with contemporary research. The field is in dire need of research that can be applied to lighting designs, but Study IV (Paper G) shows that research is hard to evaluate. Many experimental studies provide scarce information on light setting layout, glare incidences and light source properties, thus obstructing evaluations of applicability. Additionally, technical advancements have shortened the lifespan of many studies.

Further to the above, it was noted that the number of participants in the reviewed studies covered a very wide range, but demographic information was often excluded, side-stepping considerations deriving from ageing, gender and culture. Furthermore, gender distribution in the reviewed studies was sometimes heavily skewed. Experimental studies offer the option of studying reactions to light settings in a simulated office setting where extraneous influence is controlled for, but for research to be valid and applicable to real life situations, not only issues concerning experimental settings need to be addressed, but also sample selection.

As energy issues occupy a prominent position on the agenda in Scandinavia it is expected that control systems will be implemented at an increasing rate, implying that lighting control and dynamic lighting will gain importance in lighting systems. Studies on switching behaviour (Moore et al., 2003a) and control usage (Boyce et al., 2003b) however show that options for personalising light settings are not used. Research guiding control manufacturers in the design of a more accessible interface is needed.

A specific lighting design invites certain patterns of movement and thus the design creates the experience in collaboration with the person interacting with it (Figure 5:5). Light is not a static experience but is ambiguous in its diffuse and changing shape depending on position and movement in the room. Research should advance into the field of personal experiences and perceptions, supporting an application of lighting design to a holistic view on life.

Figure 5:5; *Interaction with light. Foto Dept. of Lighting Science, JTH, Sweden*

6 Reflections on methodology

In all research, it is important to consider how well the methods apply to the questions, and if the results are valid. The following chapter presents a reflection on the applied methodology in relation to the individual studies.

6.1 Reflections on methodology used in Study I

The study called for a large number of respondents but the method of sample selection resulted in many questionnaires being sent to people who were not in the targeted group, with an ensuing low response frequency. This was at odds with the predicted advantages of an e-mail questionnaire, such as contact with a large number of people at a low cost, and the possibility of dialogue. There was also a precariousness in the contacts and a loss of respondents with limited computer experience. The questionnaire did possibly reach the targeted group, but scrutiny of the sample displayed different occupations as well as different education, not discounting that other groups were unintentionally included. The question of whether or not the results are relevant must be answered with the conclusion that the persons who answered the questionnaire were actually involved in the lighting design of offices. They would not all be described as lighting designers but their answers describe the process as it is today. Due to the high attrition however the external validity is low and a broad generality cannot be claimed.

A dichotomous framework, where values depending on measurements were separated from those depending on descriptions, was used to differentiate in the system of inquiry and to facilitate analysis. Unfortunately, the scales that were used proved to be difficult to analyse for clear differences, and in the future it could prove advantageous to use longer scales for more differentiation. A short scale was found to increase the risk of over-emphasising small differences.

The quantitative system of inquiry seeks to discover cause-and-effect explanations. It was found that this was not necessarily appropriate as the process of design in itself is simultaneous with mutually shaping criteria. The difficulty stemmed from the ontological assumption that the designer is separated from the design, thus inviting a quantitative research method. In retrospect, in can be concluded that the design process is a subjective process, and that the multiple and amorphous nature of lighting when criteria are manipulated possibly calls for a more qualitative research method.

Study I did not explicitly ask the respondents to describe the lighting design process, but the results are still informative on this aspect. Internal validity, whether the questionnaire was capturing the procedures of the lighting design process or not, can be discussed. The method carefully documented the “audit trail” to ensure that the same reality was being tapped with all respondents. However, a more truthful description of the design process could possibly be achieved using qualitative measures. Furthermore, in framing the research questions and constructing the questionnaire I cannot bypass possible personal bias in the formulation of the questions etc., so the external validity is therefore limited to the cultural sphere of northern Europe. The questionnaire combined with a qualitative method resulting in a ”thick” description of the design process would achieve transferability, enabling the conclusions to be applied to other lighting practitioners. The answer or “knowledge” proposed to answer the question of how the lighting design process can be strengthened, is only as strong as the base it is built upon, and explanatory considerations derived from the answers to the questionnaire are important when contemplating whether or not the goal has been reached. Elucidating common considerations helps to establish validity but they do not necessarily explain where the process is going to end, as one vision can result in many possible solutions (Fig. 6:1).

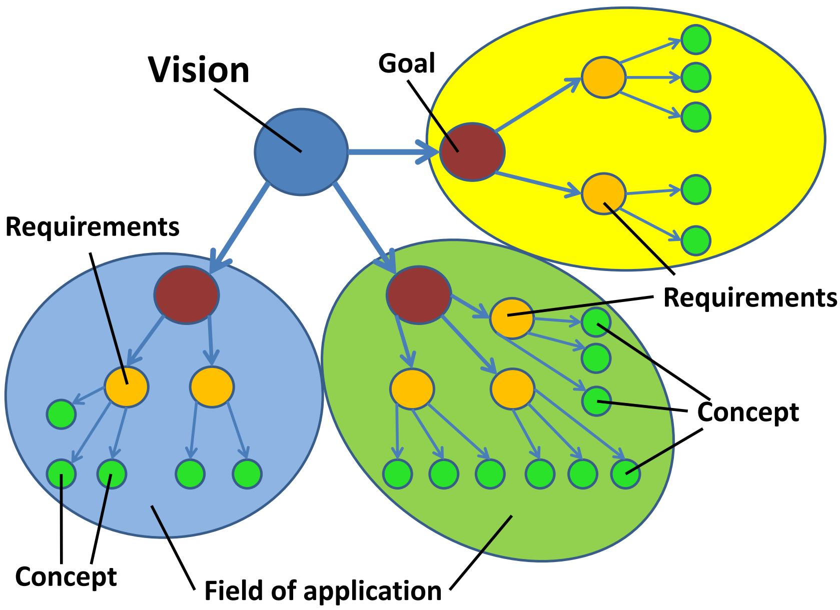


Figure 6:1; *Illustration of how the design process using one vision can result in many concepts (adapted from Duerk, 1993)*

6.2 Reflections on methodology used in Study II

Study II (Papers C, D and E) set out to map suitable office environments for computer based tasks. The study was set up as an experimental study using quantitative evaluation forms and a performance test.

I decided to use room settings that would be perceived as normal office settings with lighting qualities that can be found in an office. The colour scheme was neutral in order not to distort the lighting experience. However, an experimental setting is only one facet of the multiple interactions that are occuring as the visual experience is established, and it was not possible to prove a causal relationship between the actual setting and performance, visual comfort and well-being. It is possible that the variations in lighting qualities were too subtle to trigger traceable reactions.

The recruiting method procured participants representing a fair sample of community inhabitants. The age span was large and gender distribution equal. The loss of one age group was not seen as a problem as the group included both younger and older participants.

Previously validated instruments were deliberately chosen (Appendix 4-8, 10-12) but the concepts used to evaluate visual comfort, well-being and lighting experiences were not specifically defined for the participants in the study. This proved to be a disadvantage, as it included the option of positive interpretation by the participant, making the result more difficult to analyse. The difficulty can be exemplified with “good lighting” that has historically been defined as lighting promoting visual acuity in the near task area. The lighting that is most advantageous for visual acuity is not per se the most supportive lighting for peripheral vision, and situations that depend on peripheral vision do not benefit from this so-called “good lighting”. This differentiation was not clarified to the participants.

It proved difficult to use a quantitative approach in this research as the magnitude of influence of lighting on perception and well-being varies between individuals. To capture subtle variations in the visual experience, a qualitative method using personal descriptions should be added to the instruments.

Correlations between different aspects of lighting and performance have been discussed in earlier studies but these complex relationships intertwine with psychological factors and are yet to be established. The instrument used to measure performance (Appendix 8) proved to be useful, but the factors influencing the performance could not be established.

The procedures followed a set schedule but presentation order proved to have a substantial influence on the room evaluations, overriding possible influence by the lighting. Presentation order needs to be more carefully controlled to ensure validity. Moreover, the lighting experience is subjective and has temporal qualities, and cannot be fully replicated with other individuals or even with the same individual at a different time.

6.3 Reflections on methodology used in Study III

Study III (Paper F) set out to examine whether or not LEDs could replace traditional light sources in a home office environments for computer based tasks. The study was set up as an experimental study using quantitative evaluation forms.

I was offered the opportunity to perform my study as part of a larger study on LEDs in home environments. The room was set up as a home with appropriate furniture and visually appealing luminaires. The colour scheme was neutral so as not to distort the lighting experience. Nonetheless, the setting was not as strict and was less illuminated than with traditional office lighting. Unfortunately, the commercially available LEDs proved to be less satisfying from a quality point of view than the traditional light sources. The settings varied not only in CCT and CRI but also in all aspects included in a visual analysis. As the two light settings differed visually, a valid result could not be shown. When comparing two different light settings, the light sources need to be chosen with consideration, and variables that influence the result should be controlled, in order to procure results that are applicable to future lighting designs. The incentive to produce studies must not override the need for them to be carefully conceived to acheive thorough and successful studies.

In this study, a large number of participants was sought and consideration was given to age, gender and ethnicity. Only participants that took part in both room sessions were included in the study, resulting in a loss of participants, but this was esssential to secure the validity of the results.

The same instruments as in Study II were used and the same objections can be inferred in this study.

Procedures followed a set schedule with written and recorded instructions guiding the participants through the experiment. This form of instruction proved to be reliable and useful as all participants were treated in the same manner.

6.4 Reflections on methodology used in Study IV

The review, Study IV (Paper G), was based on a database search using keywords (Appendix 14). The keywords produced relevant articles and are considered to have been a satisfactory instrument.

Databases where the keywords were used were chosen from the available range at the University of Jönköping, based on the hits in the pilot search. In retrospect, it can be seen that all articles that were retrieved used quantitative research methods. In view of the results from the experimental studies included in this thesis, where more qualitative methods are missed, qualitative research needs to be included in a current office lighting review, to cover additional aspects of the impact of lighting on human beings.

The retrieved articles were screened by me, and three relevant categories for office lighting design were chosen, based on my experience and knowledge of office lighting design. This method does not exclude personal bias.

7 Conclusion

The overall goal for my research has been to procure results that are applicable to the field of lighting design. My experimental research is unique in the set up of the studies, study II where artificial lighting is compared to daylight and study III comparing the influence of LEDs to other light sources. Both studies were set up in an environment faithfully simulating a real setting. This has not been done before in a Scandinavian context. This thesis therefore contributes new knowledge within the field of office lighting research.

The psychological and physiological effects of electromagnetic radiation are interdependent and can be mutually strengthening. However, this research cannot verify that office lighting affects performance, even though it was shown that a varied light setting was perceived to enhance well-being more than a monotonous lighting solution.

My studies show that there is a need for lighting education within the group of lighting practitioners, as well as for research that is accessible and applicable to lighting designs. The findings further suggest that lighting design is not related to contemporary research. I show that the link between practitioners and researchers need to be stronger, and the field involved in ongoing research. The research field should strive to be informed about how lighting designs are drawn and executed, and about the difficulties and concerns experienced by lighting practitioners, in order to produce research that is applicable to field conditions.

Lighting recommendations are based on research, but it is obvious that the field of lighting has not been thoroughly investigated or even mapped. In this work I have discovered that there is a lack of mapping of preferred ranges for lighting criteria and their impact on human beings. Research is conducted in different ways depending on the research team and/or tradition, obstructing result comparison. One important contribution in this thesis is the unfolding of the inadequacy of the methodology. It is shown that quantitative measures alone do not possess the strength to explain the complex interactions between human perceptions, well-being, visual comfort and performance. Designs not only spur different reactions, they also appeal to people in an aesthetic sense. Measuring these perceptions requires sensitive methods, probing the participants to explain their experiences, suggesting that qualitative methods should be added to the quantitative. The impact of the light setting could then be further elucidated. Research related to planning issues is needed in a society where increasing demands are placed on the office staff, and where energy is seen as a valuable resource. To design a supportive and stimulating lighting environment with good quality lighting, an understanding of visual conditions and a sensitivity to the interaction of man and light with the environment and the set task is required.

7.1 Future research

Based on the results in this thesis, I would like to design and perform office lighting studies with a clear method, using suitable measures capable of establishing perceptions of, and reactions to, lighting in an office setting. The preferred ranges for lighting criteria, and their impact on human beings, needs to be mapped. This is research that needs to be done to form the basis for future research. Valid definitions of lighting quality, biological lighting and healing lighting etc. are still missing. Good explanations of visual perceptions can support the establishment of such criteria.

We also need to discuss the implications and definitions of different concepts and the size of the relevant measures. If the purpose is to relate to all human beings, the measurse will be too global to be of any use. It is possible to imagine a scenario in which the parameters that are most suitable to describe when a phenomenon occurs for a majority of the population is established, and in which photometric measurements are connected to specific experiences. This could constitute the elements included in a future model for the planning of the visual environment, where links between lighting quality and human reactions, based on multidisciplinary knowledge, are mapped.

There is also a need for repetitions of studies to substantiate earlier research. Additionally, technical advancements have shortened the lifespan of many studies, while new technologies are still to be looked into. The field is in dire need of research that can be applied to lighting designs. The most applicable research is the research that is carried out in the field. The setting and the participants represent the needs that have to be met, and the results can be immediately applied in a real life setting. It would be very interesting to further investigate the interaction of different lighting criteria with office staff in a field setting.

Lighting is of concern for all groups in society and it would be very interesting to study lighting applications for groups that are more vulnerable, with the intention of establishing solutions that are relevant to the users. Such groups might include children, old people and visually impaired people.

The final study, Study IV, made me curious about how lighting design research has been conducted in qualitative research environments. A review of office lighting design based on qualitative methods is, to my knowledge, not currently available.

This thesis is a stepping stone for future lighting design research. My hope is that future studies can benefit and develop using the studies included in this thesis. I hope that studying human perceptions and physiological reactions in interaction with the context will be more frequent, and that some of my discoveries will be applicable as lighting research advances.

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CIE 17.4-1987 International Lighting Vocabulary

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ISO 9241-7 Ergonomic requirements for office work with visual display terminals (VDTs)

ISO 8995:2002(E) / CIE S 008/E-2001 Lighting of Indoor Work Places

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APPENDICES

Appended Instruments

Appendix 1: General questions

Appendix 2: E-mail questionnaire, Study I

Appendix 3: Test protocol used in Study II

Appendix 4. Health screening for women,Study II and Study III

Appendix 5: Personality evaluation form, Study II

Appendix 6: Room evaluation form, Study II

Appendix 7: Mood evaluation form, Study II

Appendix 8: Description of the assessment of vigilance based on monotonous monitoring tasks, Study II

Appendix 9: On-screen work task used, Study II

Appendix 10: Ambient lighting evaluation form, Study II

Appendix 11: Work task lighting evaluation form, Study II

Appendix 12: Visual ergonomics evaluation form.Study II and Study III

Appendix 13: De-briefing guide, Study II

Appendix 14: Keywords, Study IV

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

The lighting of the office task area

I volunteer as a participant in the study "The lighting of the office task area"

Name:____

Address:____

Postal code:_______________ City:_____________________________

e-mail:____

Phone:_________________ Cell: _______________________________

Year of birth:_____________

Occupation:____

Glasses: ☐ no ☐ yes Contactlenses: ☐ no ☐ yes

Other vision impairments: : ☐ no ☐ yes

If yes, please describe your impairment_____________________________

Colour vision: ☐ good ☐ not good ☐ don´t know

Have you been unconscious
as a result of an accident, intoxication or epilepsy? ☐ no ☐ yes

Are you medicating regularly? ☐ no ☐ yes
If yes, please name your
medication____

At what time do you normally rise
in the morning? ____

Do you have any food allergies?
If yes, please describe
them____

Are you a vegetarian ☐ no ☐ yes

The study takes place Monday through Friday, 8 am - 4.30 pm, on the premises of Munksjö AB, Barnarpsgatan 39c. We will get in touch with you to schedule your participation.

RETURN THIS FORM IN THE APPENDED ENVELOPE!

School of Engineering, Jönköping University
Box 551 11 Jönköping

Department of Lighting Science
Phone: 036 - 101555

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

Please tick the appropriate box

1. Gender:
☐ female ☐ male

2. Age:

3. Work task:

4. Education:

5. Number of years in the occupation:

6. What characteristics do the offices you do the lighting design for have? Tick one or several alternatives.

☐ open layout solutions

☐ personal offices

☐ a combination of open layout and personal offices

7.What is your starting point for the lighting design? **Choose one** of the following alternatives and **tick in the appropriate box.**

☐ ambient lighting is the starting point for the lighting design

☐ work task light is the starting point for the lighting design

☐ a combination of ambient light and work task light is the starting point for the lighting design

8. How important do you consider the following information to be when choosing luminaire? **Tick in the boxes on the scales.**

Data	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Photo	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Price	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
References from collegues or sales persons alt. previous experience of the same luminaire	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Demonstrations	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Maintenance (flexibility, type of light source, exchange of light source, cleaning, mounting)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Operation (energy consumption, expected life of light source)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Possibility to recycle discarded luminaire	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Feedback from users	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Other, for example…	little	☐ 1	☐ 2	☐ 3	☐ 4	very important

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9b. To what degree do you consider the following criteria when designing **the work task lighting? Please tick in the appropriate box.**

Luminance (reflected light, dependant on illuminance and the reflectance of the surface)	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Glare	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Shadows	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Reflections (dependant on light treatment in the luminaire and the texture and shine of the illuminated surface)	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Direction of light (location of the most illuminated spot)	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Contrast (difference between illuminated surface and less illuminated surface)	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Illuminance (amount of light)	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Colour of light from the luminaire	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Colour rendering	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important
Position of luminaire in relationship to the work task area	little	☐ 1 ☐ 2 ☐ 3 ☐ 4	very important

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9b. To what degree do you consider the following criteria when designing **the work task lighting? Please tick in the appropriate box.**

Luminance (reflected light, dependant on illuminance and the reflectance of the surface)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Glare	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Shadows	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Reflections (dependant on light treatment in the luminaire and the texture and shine of the illuminated surface)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Direction of light (location of the most illuminated spot)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Contrast (difference between illuminated surface and less illuminated surface)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Illuminance (amount of light)	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Colour of light from the luminaire	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Colour rendering	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Position of luminaire in relationship to the work task area	little	☐ 1	☐ 2	☐ 3	☐ 4	very important

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10. When designing the lighting environment, how important do you consider the properties of the luminaire to be?
Please tick in the appropriate box.

Design	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Price excl. mounting	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Luminous flux	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Light modulation	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Light quality / Light colour	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Control /flexibility of the luminaire	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Mounting of the luminaire	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Heat impact on building construction	lite	☐ 1	☐ 2	☐ 3	☐ 4	mycket
Spatial demands in the building construction	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Maintenance	little	☐ 1	☐ 2	☐ 3	☐ 4	very important
Other, for example …	little	☐ 1	☐ 2	☐ 3	☐ 4	very important

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11. How much influence on the following do you consider yourself to have : **Please tick in the appropriate box.**

Choice of luminaire?	little	☐ 1	☐ 2	☐ 3	☐ 4	very much
Positioning of luminaires?	little	☐ 1	☐ 2	☐ 3	☐ 4	very much
Number of luminaires?	little	☐ 1	☐ 2	☐ 3	☐ 4	very much

12. Important aspects not previously mentioned in the questionnaire:

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Test protocol

Time	Duration	Task	Scale
8.00		Saliva sampling.	Cortisol nmol/L Melatonin ng/L
		Breakfast	
		Health screening questionnaire	nominal
Day one only		Personality type questionnaire.	Semantic 1-4
9.00		Experimental setting entered	
9.04	15 minutes	Environment evaluation	Semantic1-7
9.19	5 minutes	Mood evaluations	Likert 1-4
9.24	10 minutes Start-up-time for experimenter	Vigilance test	
9.34	25 minutes	Vigil, vigilance test	Reaction time / numb. of errors
10.00	1hour 45minutes	Read and modernize text on screen	
11.45		Saliva sampling	Cortisol nmol/L Melatonin ng/L
12.00	45 minutes	Lunch in experimental setting on ones own	
12.46	8 minutes	Total impression of lighting	Likert 1-7
12.56	8 minutes	Impression of task lighting	Likert 1-7
13.06	5 minutes	Mood evaluations	Likert 1-4
13.11	2hours 03minutes	read e-book on VDU	
15.14	15 minutes	Visual comfort	Semantic 0-3, Likert 1-5
15.30	5 minutes	Mood evaluations	Likert 1-4
15.35	10 minutes start-up-time for experimenter		
15.45	25 minutes	Vigil, vigilance test	Reaction time / numb. of errors
16.10		Saliva sampling	Cortisol nmol/L Melatonin ng/L Melatonin ng/L
		Debriefing	
16.30		End of day	

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

participant nr ☐

Date :__________

Please fill in this form
to help us understand how you feel today.

Health status, female

Are you an early riser?
( ) Yes ( ) No

Are you alert in the evening?
( ) Yes ( ) No

How is your sleep?
( ) Good ( ) Bad

Do you have recurring moodiness at a certain time of year?
( ) Yes ( ) No
If yes, at what time of year? ________________________

Have you been ill within the last two days?
( ) Yes ( ) No

Do you feel as if you are carrying an infection e.g. a cold?
( ) Yes ( ) No

Are you on any hormonal medication e.g. the pill, oestrogen plaster etc.?
( ) Yes ( ) No

Are you pregnant?
( ) Yes ( ) No

Where in your menstrual cycle are you? Mark with an X.

Menstrual bleeding

How many hours do you spend in front of a computer every day?______________

What is your most frequent task using the computer?___________________

Jönköpings Tekniska Högskola
Box 551 11 Jönköping

Avdelningen för Belysningsvetenskap
tel: 036 – 10 15 55

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participant nr

Cirkel the number that is most appropriate to you normal reaction.
Try to answer as swiftly and honestly as possible.

	Seldom	Some-times	Often	Fre-quent
1. I feel short of time.	1	2	3	4
2. I move swiftly as if in a hurry.	1	2	3	4
3. I do not like standing in line.	1	2	3	4
4. I get irritated at other car drivers.	1	2	3	4
5. I am high strung and push myself.	1	2	3	4
6. I get impatient with slow people.	1	2	3	4
7. I compete with myself and others.	1	2	3	4
8. I work with two or more tasks at the same time.	1	2	3	4
9. My state of mind is irritated and upset.	1	2	3	4
10. I speak quickly and with emphasis.	1	2	3	4
11. I catch myself being stressed when I really am not in a hurry.	1	2	3	4
12. I feel annoyed with clumsy and sloppy people.	1	2	3	4
13. I´m a fast eater and always the first to leave the table.	1	2	3	4
14. I like to have the last say and to convince other people that I am right.	1	2	3	4
15. I have tantrums.	1	2	3	4
16. I am unfocused in converations.	1	2	3	4
17. I have a hard time relaxing.	1	2	3	4
18. I interrupt other people.	1	2	3	4
19. Other people´s mistakes annoy me.	1	2	3	4
20. People around me tell me to relax and calm down.	1	2	3	4

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INSTRUCTION

It is possible to give a number of different evaluations to an environment. It is possible to perceive it to be large or small, more or less beautiful or more or less uniform.

This document consists of a number of evaluation scales. Please tick a box for how you perceive different aspects of the environment, where you are at the moment.

Here is an example of an evaluation scale:

	LARGE							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

Right on top of the scale is the quality of the environment that the scale is set to evaluate (LARGE). The scale has seven steps. The box to the left means that only a little of the quality is present in the environment and the box to the right means that a lot of the quality is present. Tick the box by moving the digital arrow to the box and press left on the mouse. Tick only one box. If you want to remove your tick, press left on the mouse again, while the digital arrow is on the box. Use the scroll bar to the right hand side of the screen to flip pages in the document.
All evaluations should be made while in the environment.

MODERN

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

VARIED

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

UGLY

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

STRANGE

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

COSTLY

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

MASCULIN

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

STIMULATING

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

ENCLOSED

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

FUNCTIONAL

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

GROOMED

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

ORDINARY

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

SECURE

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

STILISTICALLY PURE

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

BORING

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

FRAGILE

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

SUBDUED

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

				TIMELESS				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				OPEN				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				IDYLLIC				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				SURPRISING				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				SIMPLE				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				OLDFASHIONED				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				CONSISTENT				
a little	☐	☐	☐	☐	☐	☐	☐	a lot
				SPIRITUAL				
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	GOOD							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	LIMITED							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	POTENT							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	NEW							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	EXCLUSIVE							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	COMPLEX							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	COSY							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

	FEMININE							
a little	☐	☐	☐	☐	☐	☐	☐	a lot

WHOLENESS

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

BRUTAL

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

SPECIAL

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

AIRY

a little ☐ ☐ ☐ ☐ ☐ ☐ ☐ a lot

When you have completed all the evaluations **press** SAVE 🖫 at the top left of the screen. Close the document by pressing X to the top right of the screen.

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

INSTRUCTION

We experience many feelings over a day. Sometimes we are in a good mood, at other times we are unhappy. We might feel stressed, cross, uncaring, slack etc. Sometimes feelings invade us, but most of the time they are in the background, without us noticing them. If we stop to think, it is easier to recognise our present state of mind.

This form consists of a number of evaluation scales, where we would like you to mark the state of mind that you are in right now. This is an example of an evaluation scale:

☐ very tired ☐ pretty tired ☐ pretty rested ☐ very rested

This particular scale evaluates whether you feel tired or rested.
The scale has 4 steps. The box to the very left implies that you feel very tired, and the box to the very right that you feel very rested. The boxes in between are intermediate steps.
Tick the box by moving the digital arrow to the box and press left on the mouse. Tick one of the four boxes. If you want to remove your tick, press left on the mouse again, while the digital arrow is on the box.
On the following pages are several evaluation scales. Please use them to mark how you are feeling **right now**. Do not contemplate the answers but answer swiftly and spontaneously. Please do not bypass any scales.

I FEEL RIGHT NOW:

☐ very tired	☐ pretty tired	☐ pretty rested	☐ very rested
☐ very safe	☐ pretty safe	☐ pretty anxious	☐ very anxious
☐ very bored	☐ pretty bored	☐ pretty interested	☐ very interested
☐ very confident	☐ pretty confident	☐ pretty indecisive	☐ very indecisive
☐ very alert	☐ pretty alert	☐ pretty sleepy	☐ very sleepy
☐ very angry	☐ pretty angry	☐ pretty kind	☐ very kind
☐ very efficent	☐ pretty efficent	☐ pretty unattempting	☐ very unattempting

☐ very dependent	☐ pretty dependent	☐ pretty independent	☐ very independent
☐ very sleepy	☐ pretty sleepy	☐ pretty alert	☐ very alert
☐ very happy	☐ pretty happy	☐ pretty sad	☐ very sad
☐ very uninterested	☐ pretty uninterested	☐ pretty engaged	☐ very engaged
☐ very strong	☐ pretty strong	☐ pretty weak	☐ very weak

When you have completed all the evaluations **press** SAVE 🖫 at the top left of the screen. Close the document by pressing X to the top right of the screen.

VIGIL Vigilance

G. Schuhfried © SCHUHFRIED GmbH

The assessment of vigilance based on monotonous monitoring tasks is realistic, valid and highl reliable.

Application

Assessment of attention in the form of sustained vigilance in a low-stimulus observation situation; suitable for use with individuals aged 6 and over.

Theoretical background

Challenges involving vigilance are characterized by the following conditions:- a lengthy test requires uninterrupted vigilance of the subject; the signals which need to be attended to appear irregularly and do not automatically attract attention. The stimuli presented therefore need to be of relatively low intensity and critical events need to occur relatively infrequently. As a general principle a maximum 60 critical stimuli per hour is suggested. The decline in performance in vigilance experiments is explained by the lowering of the subject's activation level and the attendant increase in response latency. According to neurophysiological activation theory, stimulus poverty leads to the cortex bein insufficiently stimulated by the ascending reticular activating system (ARAS). The cerebral cortex therefore fails to receive the wake-up impulse needed to sustain particular activities; this results in psychological exhaustion and hence in a decline in performance efficiency. It is this situation which has given rise to the concept of being "overchallenged by understimulation".

Administration

A white dot moves along a circular path in small jumps. Sometimes the dot makes a double jump; when this happens the respondent must react by pressing a button.

Test forms

S1: The dots that make up the circular path are shown on the screen as small circles. This form differentiates only among performances that are well below average; it is intended primarily for use with patients whose vigilance is thought to be significantly impaired. Significant stimuli appear considerably more frequently than in forms S2 and S4.

S2: In this form the path is not marked out on the screen. The respondent must assess whether the white dot has made a double jump (=critical stimulus) or not.

S4: Identical to S2, but the length of the test is increased to 66 minutes.

Scoring

The following variables are calculated: Number of correct, Number of incorrect, Mean value of reaction time correct (sec.), Gradient of correct and Gradient of reaction time correct together with th associated measures of exactitude.

Reliability

Depending on the test version and the comparison sample, the following split-half reliabilities were obtained for the main variables: Number of correct: r=0.65 – r=0.95; Number of incorrect: r=0.69 – r=0.93, Mean value of reaction time correct: r=0.87 – r=0.99.

Validity

Criterion validity is given: all the criteria required in the most important theories for the measuremen of vigilance are met. Tests of extreme group validity found that patients with right-hemisphere cerebral lesions obtained significantly worse results than patients with comparable left-hemisphere brain injury.

Norms

S1: sample of adults N=292, sample of children/young people aged 6 – 17 N=619, Swedish job-seekers N=245, traffic-psychological clients N=143 and neurological patients N=51.

S2: Austrian norm sample N=271, sample of psychiatric patients N=111, Swedish job-seekers N=49 and Swedish applicants for technical occupations N=367.

S4: Comparison scores of N=114 patients with sleep apnoea are available.

References

Sturm W. & Büssing A. (1990). Normierungs- und Reliabilitätsuntersuchungen zum Vigilanzgerät nach Quatember und Maly. Diagnostica, 36 (1).

INSTRUCTION

Following is a text by Hjalmar Bergman from **Projekt Runeberg** (runeberg.org). This is a project where volunteers are working to create free electronic editions of classic Nordic literature, and to make them available over the internet. It started in 1992 at the computer club LYSATOR at Linköping university. Here you can find the largest internet based collection of Nordic literature.

Hjalmar Bergman was born on September 19, 1883, in Örebro, and died januari 1, 1931, in Berlin. Well-known novels are for example ”Farmor och vår herre” and ”Chefen fru Ingeborg”.

The text below is the first part of ”Chefen fru Ingeborg”. Your assignment is to modernize the text with new spellings, modern ways of addressing people and to add every day items that did not exist at the time when these events took place.

When the voice in the loudspeaker asks you to finish your work, please close up without hurrying and press SAVE 🖫 at the top left of the screen. Close the document by pressing X to the top right of the screen.

Here follows the text:

VÅREN

Hur börjar en händelse? Hur förlöper den? Var slutar den? Betyder den lidande eller löje? Och har den någon annan betydelse, en betydelse som faller utanför lidande och löje?

Denna händelses personer äro fyra. Därtill kommer några bipersoner, bland vilka märkas i främsta räckan fru Julia Koerner, en berömd skådespelerska. Hon är icke den viktigaste bipersonen, men hon är den mest talträngda.

Hattarna

Fru Koerner befann sig i huset Balzars spegelrum. Det var icke ett spegelrum, avsett för kunderna, utan ett sådant, där kringresande agenter brukade förevisa sina varor. Chefskontoret låg näst intill. Och bredvid fru Koerner stod mode- och konfektionsfirman Jacques Balzars chef och innehavare fru Ingeborg Balzar. Dessutom kringsvävades skådespelerskan av tvenne unga, vackra flickor, som insvepte henne i allehanda tyger, utsökta och rika. De betjänade henne som änglarna jungfru Maria med mjuka armrörelser, upprepade knäfall, böljande kroppsböjningar. Deras sköna och oskuldsfulla unga anleten strålade av……………..

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

INSTRUCTION

It is possible to evaluate the lighting in a number of different ways. It can be perceived as warm or cold, more or less subdued or more or less varied etc.

This form consists of a number of evaluation scales, where we would like you to mark how you experience **the ambient lighting** in the room .
This is an example of an evaluation scale:

strong ☐ ☐ ☐ ☐ ☐ ☐ ☐ weak

The scale has 7 steps. The box to the very left implies that the word "strong" is most in line with how you perceive the ambient lighting, and the box to the very right that the word "weak" is most in line with how you perceive the lighting. The boxes in between are intermediate steps.
Tick the box by moving the digital arrow to the box and press left on the mouse. Tick only <u>one</u> box. If you want to remove your tick, press left on the mouse again, while the digital arrow is on the box.
Use the scroll bar to the right hand side of the screen to flip pages in the document.

How do you perceive the **ambient lighting** in the room?

dark	☐	☐	☐	☐	☐	☐	☐	light
comfortable	☐	☐	☐	☐	☐	☐	☐	uncomfortable
colourless	☐	☐	☐	☐	☐	☐	☐	coloured
strong	☐	☐	☐	☐	☐	☐	☐	weak
dispersed	☐	☐	☐	☐	☐	☐	☐	concentrated
warm	☐	☐	☐	☐	☐	☐	☐	cold

unevenly distributed	☐	☐	☐	☐	☐	☐	☐	evenly distributed
hard	☐	☐	☐	☐	☐	☐	☐	soft
diffused	☐	☐	☐	☐	☐	☐	☐	focused
natural	☐	☐	☐	☐	☐	☐	☐	unnatural
clear	☐	☐	☐	☐	☐	☐	☐	murky
varied	☐	☐	☐	☐	☐	☐	☐	uniform
mild	☐	☐	☐	☐	☐	☐	☐	sharp

glary ☐ ☐ ☐ ☐ ☐ ☐ ☐ shielded

subdued ☐ ☐ ☐ ☐ ☐ ☐ ☐ brilliant

How do you think this ambient lighting influences your well-being?

deteriorates ☐ ☐ ☐ ☐ ☐ ☐ ☐ improves

How do you think this ambient lighting influences your work performance?

deteriorates ☐ ☐ ☐ ☐ ☐ ☐ ☐ improves

When you have completed all the evaluations **press** SAVE 🖫 at the top left of the screen. Close the document by pressing X to the top right of the screen

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

INSTRUCTION

It is possible to evaluate the lighting in a number of different ways. It can be perceived as warm or cold, more or less subdued or more or less varied etc.

This form consists of a number of evaluation scales, where we would like you to mark how you experience **the work task lighting** near the computer screen.
This is an example of an evaluation scale:

dark ☐ ☐ ☐ ☐ ☐ ☐ ☐ light

The scale has 7 steps. The box to the very left implies that the word "dark" is most in line with how you perceive the work task lighting, and the box to the very right that the word "light" is most in line with how you perceive the lighting. The boxes in between are intermediate steps.
Tick the box by moving the digital arrow to the box and press left on the mouse. Tick only <u>one</u> box. If you want to remove your tick, press left on the mouse again, while the digital arrow is on the box.
Use the scroll bar to the right hand side of the screen to flip pages in the document.

How do you perceive the **work task lighting** near the computer screen?

dark	☐	☐	☐	☐	☐	☐	☐	light
comfortable	☐	☐	☐	☐	☐	☐	☐	uncomfortable
colourless	☐	☐	☐	☐	☐	☐	☐	coloured
strong	☐	☐	☐	☐	☐	☐	☐	weak
dispersed	☐	☐	☐	☐	☐	☐	☐	concentrated
warm	☐	☐	☐	☐	☐	☐	☐	cold

unevenly distributed	☐	☐	☐	☐	☐	☐	☐	evenly distributed
hard	☐	☐	☐	☐	☐	☐	☐	soft
diffused	☐	☐	☐	☐	☐	☐	☐	focused
natural	☐	☐	☐	☐	☐	☐	☐	unnatural
clear	☐	☐	☐	☐	☐	☐	☐	murky
varied	☐	☐	☐	☐	☐	☐	☐	uniform
mild	☐	☐	☐	☐	☐	☐	☐	sharp

glary	☐	☐	☐	☐	☐	☐	☐	shielded
subdued	☐	☐	☐	☐	☐	☐	☐	brilliant

How do you think this work task lighting influences your well-being?

deteriorates	☐	☐	☐	☐	☐	☐	☐	improves

How do you think this work task lighting influences your work performance?

deteriorates	☐	☐	☐	☐	☐	☐	☐	improves

When you have completed all the evaluations **press** SAVE 🖫 at the top left of the screen. Close the document by pressing X to the top right of the screen

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

Visual ergonomics

When you are working in front of a computer screen you might perceive different physiological sensations. It is too warm or too cold, it itches or you perceive a diffuse discomfort.

This form contains a number of scales about visual ergonomics.

Mark with an X if you perceive yourself to experience or not to experience a discomfort. If you mark in the "yes" box, proceed to the right and mark how often and how severely you perceive the discomfort.

This is an example of an evaluation scale:

			Frequency during the day			**Severeness**		
	Yes	**No**	Odd times	Several times	All the time	trivial	moderate	severe
Stinging eyes	☐	☐	☐	☐	☐	☐	☐	☐

This scale is about stinging eyes. The scale has 2 steps. Tick the box to the left if you have stinging eyes, and the box to the right if you do not. The boxes further to the right tells how often and how severely you experience the discomfort.

Tick one of the boxes "yes" or "no" by moving the digital arrow to the box and press left on the mouse. Proceed to the right hand side boxes and tick them if you answered "yes" at the beginning. If you want to remove your tick, press left on the mouse again, while the digital arrow is on the box. Use the scroll bar to the right hand side of the screen to flip pages in the document.

On the next pages are several similar scales. Tick the scales to describe your presents status. . Do not contemplate the answers but answer swiftly and spontaneously. Please do not bypass any scales.

Do you presently experience any of the following discomforts to your eyes?

			Frequency during the day					
	Yes	**No**	Odd times	Several times	All the time	trivial	moderate	severe
Stinging	☐	☐	☐	☐	☐	☐	☐	☐
Itching	☐	☐	☐	☐	☐	☐	☐	☐
Gravel	☐	☐	☐	☐	☐	☐	☐	☐
Ache	☐	☐	☐	☐	☐	☐	☐	☐
Light sensitivity	☐	☐	☐	☐	☐	☐	☐	☐
Red eyes	☐	☐	☐	☐	☐	☐	☐	☐
Teary eyes	☐	☐	☐	☐	☐	☐	☐	☐
Dry eyes	☐	☐	☐	☐	☐	☐	☐	☐
Tired eyes	☐	☐	☐	☐	☐	☐	☐	☐
Headache	☐	☐	☐	☐	☐	☐	☐	☐

This question is only to be answered if you have ticked discomforts above, if not move on to the next question.

Do you consider the discomforts to be connected to your present worktasks?

- ☐ Yes, absolutely
- ☐ Yes, maybee
- ☐ Probably not, they result from ________
- ☐ No, absolutely not, they result from ________
- ☐ I don´t know

	Yes	No
Are you using glasses at the moment?	☐	☐
Are you using lenses at the moment?	☐	☐

What do you think of the lighting levels in this room?

Much too weak ☐ ☐ ☐ ☐ ☐ Much too high

I experience the lighting to produce shadows that are:

Much too diffuse ☐ ☐ ☐ ☐ ☐ Much too sharp

What do you think about the colour of light from the lighting?

Much too warm ☐ ☐ ☐ ☐ ☐ Much too cold

Are you bothered by strong light from the luminaires?

No, not at all	☐	☐	☐	☐	☐	Yes, very much

Do you perceive glints and reflexes on your screen?

No, not at all	☐	☐	☐	☐	☐	Yes, very much

How do you evaluate the lighting in the work task area?

Very bad	☐	☐	☐	☐	☐	Very good

How is the temperature in the room?

Much too warm	☐	☐	☐	☐	☐	Much too cold

How is the air in the room?

Much too dry	☐	☐	☐	☐	☐	Much too moist

Are you normally bothered by daylight glare from the window?

	During the light season	**During the dark season**
Very often	☐	☐
Pretty often	☐	☐
Sometimes	☐	☐
Seldom	☐	☐
Almost never	☐	☐

Do you experience one or several of the following muscular and skeletal discomforts?

If you answer “yes” to a discomfort, move on to the right and describe how often and to what extent you experience the discomfort.

				Frequency			Severeness		
Location		**Yes**	**No**	Odd times	Several times	All the time	trivial	moderate	severe
Hand	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐
Lower arm	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐
Elbow	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐
Upper arm	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐
Shoulder	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐
Neck	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐
Back	right	☐	☐	☐	☐	☐	☐	☐	☐
	left	☐	☐	☐	☐	☐	☐	☐	☐

When you have completed all the evaluations **press** SAVE 🖫 at the top left of the screen. Close the document by pressing X to the top right of the screen.

TEKNISKA HÖGSKOLAN
HÖGSKOLAN I JÖNKÖPING

participant nr

Date:

De-briefing check list

Let´s go into my office and talk about how you experienced the day.
(Sit down comfortably before starting the session)

How did it feel to be in the room all day?

Is there anything in the room that you would´ve liked to be different?

Has anything else except for the room and the lighting had an impact on you today?

Is there anything in the lighting that you would´ve liked to change?

How did the assignements work out?

Was screen visibility good?

Was there anything in the surroundings outside the room that you felt uncomfortable with?

Do you have anything else that you would like to discuss?

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Study IV Keywords used in data base search

Keywords			
Office lighting	Office space	Sensations	Related articles
Office work	VDU (computer screens)	Comfort	
Lighting	Performance	Fatigue	
Daylight	Glare	Well-being	
Window	Health	Melatonin	
Visual	Alertness	Ganglion cells	
Work task lighting	Biological clock	Flicker	
Ambient lighting	Circadian	iPRGC	
Illuminance	Spectral sensitivity	Acuity	
Luminance	Photo entrainment	Visual surroundings	
Spectral composition	Brightness	Illumination	
Light colour / color	VDT (computer screens)		

Appended Papers

Summary of appended paper

Paper A

"Criteria influencing the choice of luminaires in office lighting"
Conference paper

This paper provides the background to my studies with the practical application of criteria in the design process. The process of design includes a number of decisions focused on creating a successful light setting. In this study the different criteria influencing the design are rated by lighting practitioners in the field, using an e-mail questionnaire. The results show that experience is more influential on the design than education. The hypothesis that the perceptual criteria used in visual evaluations of the light setting would be given higher ratings by people with more education could not be proven.

Paper B

"Criteria influencing the choice of luminaires in office lighting"
Journal of Design Research, in press

This paper examines the role of the lighting designer and the different evaluations of criteria in the lighting design process. It identifies intrinsic processes in the lighting design process and discusses their impact. The purpose of the study is to establish the role of the lighting designer and to elucidate bias and wanting knowledge, further strengthening a lighting design process that is becoming progressively more complex and diversified. Earlier research has shown office lighting to be important for physiological and psychological processes in humans. Despite the importance of designing an environment supporting these processes, criteria were not evaluated according to how they related to these processes, but gender, personal knowledge and length of experience proved to have an impact on the evaluation of different criteria. These results indicate that an information filtering effect is at hand. The impact of personal factors when filtering the information is as high or higher than the influence of education and experience. Additionally, current research needs to be more readily available to practitioners to enhance differentiation of criteria and support lighting designs.

Paper C

"The influence of artificial lighting on performance and well-being"
Conference paper

The paper presented is a preview, focusing on the difference experienced between two artificial light settings. Earlier research has shown that the lighting set-up has an influence on comfort and well-being as well as personal preferences for illuminance. Additionally, there was a preference for smaller luminance ratios between VDT and background than those recommended. Based on this, it was hypothesised that illuminance and colour of light would influence well-being and alertness. Furthermore, it was presupposed that preferred luminance levels would be related to age and gender. Forty-eight participants spent one day in each of two rooms with simulated office tasks, room and lighting evaluation forms and a performance test. Results were not presented in this paper.

Paper D

"The influence of the lighting environment on performance and well-being in offices"
Conference paper

The influence of lighting on office staff well-being was investigated in three rooms with different light settings. Forty seven participants completed a three day study with tasks on a VDT. Artificial lighting in two of the rooms was contrasted to a light setting using only daylight. It has been suggested that visual comfort and high performance in office staff relates to the lighting set-up. This study sought to establish the lighting conditions that ensure good support for office staff in a VDT environment. Sampling of saliva for cortisol and melatonin variations followed performance tests and evaluations of visual comfort and state of mind. The impact of illuminance on alertness, suggested in earlier research, was hypothesised by this study to be traceable in cortisol variations and in self-assessed alertness scores, but this could not be substantiated. The impact of illuminance and spectral composition on cortisol levels was essentially the same in all three rooms, dismissing a link between illuminance, cortisol level and performance. Performance was better sustained over the day in the daylit room, indicating a possible correlation with the spectral composition of the lighting.

Paper E

"The influence of light settings on room perception, comfort and well-being"
Leukos, accepted with revisions

This paper re-analysed data from an earlier study. Three light settings were investigated as the participant was working with VDT-based office tasks.

The re-analysis hypothesised, based on an earlier study showing that colour temperature and illuminance changed the visual appeal of the office, that CCT and variations in the lighting set-up would influence room perception as well as perceived comfort and well-being, and that daylight on its own could well support VDT-based office tasks. However, the evaluation of perceived lighting quality, room perception and self-assessed well-being and comfort proved to be dependent on presentation order, and a relationship with variations in the lighting set-up could not be established. As a consequence of the presentation order impact, the study does not point at one of the settings as a better alternative, even though attention can be drawn to the preference displayed for a complex light setting that, combined with a lower illuminance, did improve self-assessed well-being. Difficulties also stemmed from the instruments not being sensitive to the subtle differences that the light settings presented, as very small changes in the combination of different variables are perceptible but hard to pinpoint. It is suggested that a combination of qualitative and quantitative methods could prove more fruitful in the pursuit of describing the experience of a lit environment.

Paper F

"The influence of light emitting diodes on well-being and comfort in home offices"

Conference paper

This study used two identical rooms, one with only LED light sources and the other with various light sources. Following an on-screen reading task, a survey evaluating visual comfort, the visual experience of the room and the lighting experience was completed by the eighty six participants. The results show that they experienced a higher degree of comfort in the room with various light sources than in the room with only LED light sources. Parameters for light quality were given higher ratings overall in the first room and the LED setting was experienced as less supportive to on-screen work tasks. The preferred light setting was significantly correlated to the preferred contrast relationship, indicating that contrast was in this case the primary defining factor of comfortable light. As the screen is luminous, ambient lighting is more important. The levels of illuminance comfortable for computer screen work tasks are not necessarily the same as those for paper work tasks but do influence the perception of lighting quality parameters, as shown in this study.

Paper G

"Review of office lighting research from a Scandinavian perspective"
Journal of Interior Design, in press

This paper presents office lighting research from around and after the year 2000. The research is related to a Scandinavian context, and relevance and problematic issues are discussed. Identifying areas that are lacking or missing from the research map and providing a basis for discussion of research methods were further objectives. The review is based on a database search using certain keywords. The search resulted in a large number of retrieved articles, and screening resulted in eighty six articles being chosen for inclusion in the review. The topics are presented in three main sections: 1) planning and the physical environment, 2) lighting quality and 3) light impact. Each section is complemented by a short summary and reflection. It can be concluded that there are a number of problematic issues in contemporary research, resulting in difficulties when comparing similar studies or studies claiming to study the same phenomenon. The research is difficult to apply in real life and an inter-disciplinary approach is missing.