THESIS FOR THE DEGREE OF DOCTOR OF TECHNOLOGY

Equilibrium
User centred lighting design

Towards the development of a lighting design that is individually psychologically, physiologically and visually supportive

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Department of Architecture
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ABSTRACT

Why and in what way should daylight and artificial light be designed for the indoor environment in order to fulfil goals about visual comfort and light-related health? When the outdoor and indoor interactions of man, light, colour and space (MLCS) are compared to one other, the spectral component plays the decisive role (Hollwich 1979, p. 90). Through empirical studies and theoretical surveys the knowledge about the interaction of MLCS in the indoor and outdoor environment is investigated. Patterns in responses and preferences of room and light settings are studied. The process of lighting design is investigated and the process that gives a PPV support from light for the individual user is described. Lighting design for the indoor environment should give the same input to melanopsin and ipRGC as can be seen in daylight outdoors, to be physiologically supportive. The pattern that can be seen in the studies performed in the Thesis, in responses and preferences to light in the indoor environment, concerns differences between individuals and changes during the day. Laws, recommendations and methods for lighting design are developed for a general visual support from a static artificial light. The use of EN12464-1:2011 do not fulfill goals of visual comfort set out in the standard or light-related parts of goals of health in EC Treaty 137 or WHO target 9 and 13-17. It is argued in the Thesis that the findings of melanopsin and ipRGC demonstrate the need to develop laws, recommendations and method for lighting design in a way that gives an individual support for visual comfort and light-related health. The computer calculated lighting design process (CCLDP) used in a majority of the lighting applications performed today is not done in contact with daylight, the user or the space, and by that it is not possible to support the individual user psychologically, physiologically or visually (PPV) by the use of the CCLDP. The user centred lighting design process (UCLDP), on the contrary, is done in contact with daylight, the user and the space and has by that the possibility to support the individual user PPV. Lighting quality (LQ) seen from the individual user's perspective is a well functioning PPV support from daylight and a daylight mimicking artificial light. When LQ is defined seen from the contractors or the clients perspective it is a general and theoretical approach, not related to the individual user's senses. Research in lighting design can be positioned around the lighting design process (LDP). This points out the cluster of topics that are related to lighting design, and their role is described in the research. The field of lighting science and design is theoretically delayed and a rapid development in the topic is valuable for the individual and for the society as well.

Keywords: User centred lighting design; Psychological, physiological and visual support.

PREFACE/ACKNOWLEDEGMENTS

In memoriam

This Thesis project is a part of Honorary Doctor in Engineering, Bertil Svensson's vision in the development of lighting science. With a numerous support Bertil Svenssson, one of the great pioneers in the Swedish Lighting Industry, took responsibility for the development of the topic and for a healthy use of artificial light of tomorrow that is unprecedented in Sweden.

The work is continued by the daughter of Bertil and Britt Svensson, Lena Gustavsson today the Head of the Bertil and Britt Svenssons Foundation for Lighting Technique. From the build-up of an education the foundation is laid out for research in the topic done in connection to the practical application. This will secure the development of methods for lighting design that, when used, fulfill important goals of visual comfort and light-related health. With this started the important development of support from light, not only visually, but also psychologically and physiologically. A positive contribution from lighting design to public health is established thanks to Honorary Doctor in Engineering Bertil Svensson and physiotherapist Lena Gustavsson.

By the support from the Britt and Bertil Svenssons Foundation for Lighting Technique, I have had an unique possibility to develop my knowledge in the topic during 13 years and the support has resulted in this first started Thesis project in the topic Lighting Science in Sweden. Being an educated lighting designer and go on with research is rare globally. The topic is underdeveloped theoretically and a lot of corrections in theory and practice are needed to fully use artificial light in a positive way. With these words I like to express my gratitude for being given this opportunity. It is a tough way to go being a free researcher in a new topic, many obstacles can be seen, but since I am devoted to the topic I will do as much as possible to contribute to a further development of the field.

The Thesis has been supported financially by the Bertil and Britt Svenssons Foundation for Lighting Technique and I wish to express my deepest gratitude towards Lena Gustavsson for giving me personal and financial support to carry on with the project. The Thesis project started at Lund University of Technology and continued at the Department of Architecture at Chalmers University of Technology. The Thesis is based on five studies performed in three room and light settings. The studies were planned and performed by the researcher and in cooperation with the staff at the Department of lighting science at Jonkoping University. Assistant professor in Environmental Psychology Thorbjörn Laike was responsible as supervisor during the initial part of the thesis and my second supervisor was Professor Monica Billger, interior designer and PhD in Architecture. I would like to express my gratitude for your ambition to support me in an open-minded way within the fields of environmental psychology and architectural research. Professor Catharina Dyrssen, Head of the Department of Architecture was my last supervisor. You gave me strong and inspiring support based on interest and an understanding for the project that I always will remember with the deepest gratitude. I have also been supported in many ways by Inger Lise Syversen, Head of the Doctoral programmes, and Director of PhD studies Lars Göran

Bergqvist. I also would like to acknowledge Full Professor Anders Liljefors; it is his work at The Royal Institute of Technology in Stockholm that is the origin of the thoughts that can be seen developed in the Thesis. In memoriam I acknowledge Assistant professor Bo Persson that together with Anders Liljefors are predecessors for the topic lighting science in Sweden. I also would like to express my gratitude to SIR, SID Håkan Fransson, who has shared all his lifelong knowledge about lighting with me. Anders and Håkan, you have both been my friends and mentors for a long time and I owe you so much. At last I would like to thank the staff at the Department of Lighting Science at Jonkoping University. Kharin Abrahamsson has done a great part of Studies 2, 3, 4, and 5 as a research leader, Mikael Pettersson has done a great part of Study 1 as a research leader and developed technical solutions for Studies 1, 2, 3, 4, and 5, Johan Röklander was research leader in study 3, 4 and 5 and developed technical solutions for Study 2, 3, 4 and 5, and Carina Adanko has been helpful with sample logistics. I also acknowledge the students that acted as subjects in the studies, especially those who stayed for three days. Thanks to your engagement valuable knowledge was gained. Finally, I am of course grateful to Ubbe and my sweet and patient daughters Mika and Sassa, who have allowed me to make my contribution to the topic lighting science for a long time.

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PUBLICATIONS

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Paper X. Säter, M. (2012). User centred lighting design and light-related public health. Design Studies. The international Journal for design research in engineering, architecture, products and systems. *Submitted.*

ABBREVIATIONS

ACTH- Adrenocorticotropin

BL- Baseline (A chosen value used as a reference)

BT- Burell´s test

CCLDP- Computer calculated lighting design process

CEN- The European Committee for Standardisation

CFL- Compact fluorescent light source

CIBSE- Chartered Institution of Building Services Engineers

CIE- International commission of illumination

CNS- Central nervous system

DEC OBL- Decrease over baseline

DEC UBL- Decrease under baseline

EMR- Electromagnetic radiation

HFOGS- High fulfillment of goals set out

INC OBL- Increase over baseline

INC UBL- Increase under baseline

IpRGC- Intrinsic photosensitive retinal ganglion cell

LA- Lighting application

LAN- Light at night

LDP- Lighting design process

LED- Light emitting diode

LFOGS- Low fulfillment of goals set out

LQ- Lighting quality

LRC- Lighting research center

LRPH- Light related public health

MLCS- Man, light, colour and space

MLT- Melatonin

NWFS- None well functioning support

OBT- Over mean for the Burell´s test

OOVCT- Over mean for level of light at the working table and over mean for the level of ambient light in the visual comfort test

OUVCT- Over mean for level of light at the working table and under mean for the level of ambient light in the visual comfort test

PPV- Psychological, physiological and visual

PS- Photon streams

SIS- Swedish Standards Institute

TAR- Transmission, absorption and reflection

TF- Theoretical framework

UBT- Under mean for Burell´s test

UCLDP- User centred lighting design process

UOVCT- Under mean for level of light at the working table and over mean for the ambient light measured in the visual comfort test

UUVCT- Under mean for level of light at the working table and for the ambient light measured in the visual comfort test

VCT- Visual comfort test

WFS- Well functioning support

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“Light needs to be designed supportive for humans and without harm to animals, plants and the ecosystem as well“
– S.M. Pauley 2004

“Better practice should start now”
-S.M. Pauley 2004

“Lighting and the building as a whole. Commodity, firmness and delight “
– Hopkinson & Kay 1969

“There is no visible electromagnetic radiation. Electromagnetic radiation has no color.
The human experience of light must be divided from the measurement of photons“
– Anders Liljefors 2012

“Despite millions of examples of visible light, visible spectrum, red and blue light in literature this is still an unscientific way to describe the invisible and uncoloured photonstreams and points out the need for theoretical development in the field globally“
– Anders Liljefors 2012

“Subsequent research concentrated on the brightest light at the lowest cost without raising the question of whether this different kind of light might have a harmful effect on the organism“
– Hollwich 1979

“We may, furthermore, conclude that the more the spectrum of the artificial light source differs from that of natural light the more the biological endocrine system in man will be disturbed, during short periods of time the disturbance of the endocrine system of man, induced by unbalanced artificial light, involves his comfort, his efficiency as well as fatigue“
– Hollwich & Dieckhues 1980

“We should therefore bear in mind that artificial light for the human individual at least, remains a mere substitute; it can never fully replace natural light, which as a vital element like water and air, forms the basis of our health“
– Hollwich & Dieckhues 1980

“To date, the scientific information in this field is incomplete, but progressively more researchers are becoming concerned about the potential path physiological consequences of light at the wrong time. Like most aspects of our environment, humans are clearly polluting the night with light. Only further research will clarify what light pollution means for human physiology; however, it would seem the effects will not turn out to be beneficial”
– Reiter et al. 2011

“The reason for WHO to choose the health theory of Pörn is related to the fact that the theory points out that health is an individual action and related to the environment”
– Edell-Gustafsson & Ek 1992

THE DEVELOPMENT OF THE PROJECT

The project has developed in the following two steps: 1) The project started with six studies. Only five of them are shown in the Thesis. The results of the sixth study will, for security reasons, not be published. This first phase concerned the five experimental studies and collection of data about user responses and preferences for room and light settings lit with daylight and artificial light. Also within the first phase, the three research questions were developed; 2) The second phase is the construction of the theoretical framework (TF). The TF investigates why and in what way light should be designed in order to fulfill goals of visual comfort and light-related health; the interaction of MLCS outdoor and in the indoor environment; the four steps of the lighting design process (LDP); the evaluation of the two typical processes used in lighting design; the computer calculated lighting design process (CCLDP) and user centred lighting design process (UCLDP); the recommendations for the UCLDP were developed within this phase and was investigated as well. The result, discussion and the conclusion follows the order of the three research questions.

Studies performed in the Thesis

Study 1: In the first study the lighting designer's visual preferences were investigated. It was questioned if it was possible for the lighting designer to use his or her own visual preferences in the design of light and get acceptance from a group of unknown users. The result showed that the group of subjects varied greatly in their preferences for visual comfort. The lighting designer's preferences for a low level of ambient light allowed the subjects, in a high extent, to find their own level of a visually comfortable light at the working table but not in the ambient light.

Study 2: The second study concerned responses and preferences to daylight and artificial light in the indoor environment. The highest level of individual alertness among the subjects was seen in both high and low levels of light and when the subjects had a high or low level of cortisol in the bloodstream.

Study 3**:** The third study mapped out preferences for light emitted from energy efficient light sources. The subjects preferred a combination of Halogen, compact fluorescent light sources (CFL) and light emitting diodes (LED) when compared to solely LED.

Study 4**:** The fourth study investigated preferences for visual comfort in level of light at the worktable and for the complementary ambient light. The level of light experienced as the most comfortable at the working table and for the complementary ambient light was measured with the use of visual comfort test (VCT). Two pair of subjects preferred the same combination, the other 314 subjects chose unique combinations of level of light at the working table and for the ambient light.

Study 5: Finally, two subjects were measured in the VCT test during a day. The result showed that the preferences for a visually comfortable light vary in a high extent during the day.

Complementary work done within the Thesis

The literature review: The reviews were from the beginning, focused on articles from 2000-2011. The theoretical framework (TF) was later completed with articles from 1928-1999 chosen as forerunners for the development in the topic about ipRGC and melatonin and a more physiological approach to research in lighting design.

The analysis of the interaction of MLCS in the outdoor and indoor environment: The interaction was analysed and basic parts were identified.

The investigation of the lighting design process LDP: The lighting design process was investigated and described in four basic steps.

The investigation of the CCLDP and the UCLDP: The two typical processes of lighting design were investigated and described in their basic steps.

The development of the UCLDP: The UCLDP was developed based on common knowledge in lighting design, analyses of the interaction of MLCS and the literature survey in the Thesis (Säter, Paper X).

The development of recommendations for the UCLDP: Recommendations for the UCLDP were developed based on common knowledge in lighting design, analyses of the interaction of MLCS and the literature survey in the Thesis (Säter, Paper X).

Evaluations of light-related goals set out for lighting design: Goals set out for visual comfort in EN12464-1:2011 were evaluated if fulfilled by the use of the standard. Goals set out about public health in EC Treaty 137 and WHO target 9, 13-17 was evaluated if fulfilled by the use of the CCLDP and the UCLDP.

Lighting design reflected: Lighting design is reflected from a comparison of the interaction of MLCS seen in the outdoor and the indoor environment and from the process of the LDP in general and the two types of the LDP (CCLDP and UCLDP) in specific.

CHAPTER 1

1. INTRODUCTION

I came across the research problems developed in the Thesis as a teacher in lighting design and Head of department of Lighting Science at Jonkoping University. I have experienced many years of frustration when light has been underestimated in importance and when users needs for a well-designed light have been neglected. I have seen the disappointment from students trained in user centred lighting design, not being able to work with design when lighting is seen merely from step 4, the technical part of the design process. Light is essential for humans and fundamental for life and of equal importance as water and air [Hollwich and Dieckhues 1980]. Humans get support from daylight for PPV processes. Artificial light is a replacement for daylight with a reduced spectral profile and restricted level of light compared to daylight. By unfavourable circumstances, the discovery of the physiological system behind daylight giving human's physiological support was not accepted until 2000. But already in 1928, the presence of an extra photosensitive cell was identified. During 40 years Fritz Hollwich wrote extensively about hormonal release as a result of light entering the eye and described the system that later was known as ipRGC and melanopsin. But it was not until David Berson managed to show pictures of the ipRGC that the discovery was accepted [Berson, Dunn & Takao 2001]. Ignatio Provencio et al. found the opsin in the ipRGC that absorbs EMR and contributes to action potentials to the brain [Provencio et al. 2000]. The human opsin was named melanopsin.

The discovery of melanopsin and ipRGC and the system behind the physiological support from daylight put focus on the fact that methods for measurement of EMR, methods for lighting design, recommendations for light and laws are developed with the ambition to give a general visual support. At the same time the findings of melanopsin and ipRGC show that the diurnal rhythm and human homeostatic balance is powerfully controlled by daylight and by artificial light (Brainard & Hanifin 2005). Daylight that enters the eye is important for the user´s ability to stay healthy. The interaction of MLCS seen in the outdoor environment is the role model for the man-made interaction in the indoor environment and for light-related hormonal release. Light-related hormonal release should not deviate from the one seen outdoors [Holwich 1979]. The physiological support from daylight differs due to individual differences in the ability to receive and respond to EMR [Ingvar 1981]. The senses are the utmost parts of the CNS and big differences can be seen in the individual sensitivity in the channels in to the CNS [Ingvar 1981]. At the same time the mediums in the eye for individuals differ in transparency, and big differences can be seen in human's ability to make visual performances and experience visual comfort (Säter Paper I). The time for onset and offset of the diurnal rhythm differs greatly among subjects. Subjects that wake up early, start the day at the same time as others go to bed. The spectral profile of daylight varies during the day and so do the levels of light and the light distribution. The spectral profile that supports diurnal rhythm and homeostatic balance at a certain time can be disturbing at another time of the day. If disturbances of the diurnal rhythm and homeostatic balance last for a long time this can be the start for light-related diseases. To avoid negative impact from EMR it is important to stay in daylight and a daylight mimicking complementary artificial light that is individually adapted. Architects, interior designers and lighting designers need to cooperate in the support of the individual user about the design of windows, shadings, daylight, daylight mimicking artificial light, colours and surfaces and in the work with setting the user in contact with the daylight at the place where the user lives. Laws, recommendations and methods for lighting design need to be developed to support the user individually and PPV.

The knowledge about the interaction of MLCS in the indoor and outdoor environment has been investigated through empirical studies and theoretical surveys. Patterns in responses and preferences of room and light settings are studied. The process of lighting design is investigated and the process that gives a PPV support from light for the individual user, is described. The Thesis investigates if goals for visual comfort and light-related health set out in European law and recommendations are fulfilled. A lighting design process that has the possibility to fulfill the goals for the individual user is described. This will hopefully contribute to a turning point in the use of EMR for lighting purposes and allow artificial light to be used to its full potential as PPV supportive.

Theoretically the Thesis project is part of a development that started in 1928. The scope and the starting point's origins from aspects of physiology related to man and light, linked to each other throughout history. These aspects can be found in connection to physiology and user centred design: 1) Cannon coined, in 1930 [Cannon 1932], the theory about homeostatic activity that we know today are linked to light [Brainard & Hainifin 2005; 2) in 1930, Luckiesh and Moss showed [Luckiesh & Moss 1931] individual variety in the visual functionality related to diurnal rhythm and light; 3) In 1928, Keller, Sutcliffe & Charifee presented the findings [Keeler, Sutcliffe & Charifee 1928] about a rodless and coneless mouse that responded to light and suggested a reason for the response; 4) in 1948, Hollwich reported [Hollwich 1948] about two suggested separate pathways for the light entering the eye: "The first serving vision, we designated as the "optical portion" of the visual pathway and the second one, stimulating endocrine function, we called the "energetic portion" [Hollwich & Dieckhues 1980 p. 190; 5]. In 1960, Gibson described [Gibson 1950, 1966, 1979] seeing and perception as one system with the purpose to collect information about changes in the outer world for corrections toward equilibrium (homeostatic balance); 6) in 1960, Hollwich showed [Hollwich & Dieckhues 1980] that daylight was essential to humans and pointed out the importance of diurnal rhythm; 7) in 1960, Norman developed [Norman1986] user centred design based on Gibson's theory of affordance; 8) Liljefors [Liljefors 2010] developed user centred lighting design based on seeing; 9) David Ingvar [Ingvar 1981] described that seeing is individual and is related to inter-individual differences in neurophysiologic disposition and that the sensitivity in the channels into the CSN differs in sensitivity among subjects; 10) in 1960, Ronchi [Ronchi 1970, 2009] showed the variability of the visual function related to light and diurnal rhythm; 11) Pörn, in 1980 [Pörn 1984, 1988, 1989] developed a health theory that is close to Gibson's theory about affordance and Norman´s user centred design related to individual equilibrium, diurnal rhythm, sleep and to light; 12) in 2000, Berson [Berson, Dunn & Takao 2001] was able to show pictures of the ipRGC that Keeler, Sutcliffe and Charifee looked for 1928; 13) in 2000 Provencio [Provencio et al. 2000] found melanopsin and 14) 1990, WHO used the Pörn health theory as a goal for WHO target 9 and 13-17 adopted by the Member States of European Region of health in the world. Pörn´s health theory that is based on support for diurnal rhythm and improved sleep is based on affordance and the use of the environment as a tool for health and is in that way space and light-related. The user centred perspective on lighting design is a health approach PPV to the use of light. The design of the light gives the individual a tool to shape the level of light at the indoor working place in an individual safe, comfortable and healthy way.

The user centred perspective also shows that a merely technical approach to lighting design as seen in applications based only on the recommendations from the standard EN2464-1:2011, for physiological reasons, do not lead to a fulfilment of goals about visual comfort or light-related health. The use of Pörn´s holistic health theory adopted by WHO has the possibility to imprint the process of lighting design to give the individual instruments to regulate daylight and artificial light in a visually comfortable way and for the use of the environment to entrain the diurnal rhythm to the daylight at the place where the user lives. The psychological, physiological and visual aspects of light need to be related to daylight, artificial light, colours and surfaces in the space. All of these factors need to be taken into account when designing light that supports the user to ensure that the users lives in a visually comfortable environment and in phase with and not against his or her biological rhythms. The individual user's light-related needs should be balanced together with other user´s needs when staying in the same room. The individual user´s light-related needs should, in the same way, be balanced between entrainment to the daylight and to an efficient working situation and to quality of life. The way light is designed is a key question for the fulfilment of goals set out for visual comfort, and light-related health in EN 12464-1:2011, EC Treaty 137 and for WHO target 9 and 13-17 of health adopted by the Member States of European Region. The tool used today for the way light is designed at indoor workplaces is EN 12464-1:2011. The level of 500 Lux is recommended in the standard to meet the great interindividual differences among humans and their need to live in rhythms. However, as demonstrated in the Thesis, the span of preferences for level of light at the working table is found to be 50 times in a group of 318 subjects [Säter 2011], and it is the insuffiency of the standards today that sets the starting point for the investigations described and discussed in the Thesis.

The research problems in the Thesis are of great importance since light is concerned basic human health. In the role of the teacher in lighting design I have worked with the ambition to educate in how to use light in a way that make the user more relaxed, vital and healthy. This has made me eager to see students get use of the methods they have been educated in at school, and it has been a daily reminder that the standard EN 12464-1:2011 is a problem according to visual comfort and light-related health. The standard recommends a static level of light on a specified level. As the standard EN 12464-1:2011, in the same way, is the tool for light-related health in EC Treaty 137 and for WHO target 9 and 13-17 adopted by the European region, it is frustrating to see that it is physiologically impossible to realise the goals of visual comfort, performance and light-related health by the use of the recommendations in EN 12464-1:2011. Recommendations for the user centred lighting design, on the contrary, has the possibility to do so.

The methododoly used in the Thesis is a combination of a theoretical investigation and design experiments, with self-evaluated instruments and evidence based methods such as testing through blood samples. Data is collected about the experience of the light in the room and light settings and of the physiological response to EMR and to visual preferences.

1.1 Scope and starting points

Why and in what way daylight and artificial light should be designed for the indoor environment to fulfill goals of visual comfort and light related health is a question of great importance for the society. Daylight is essential to humans and needs to be adapted to the individual user to give a well-functioning PPV support. The physiological system behind the support from daylight was not known until 2000. Measurement techniques for illumination, light sources, laws, recommendations and methods for lighting design have, according to the late discovery of melanopsin and ipRGC, been developed merely to give a visual support and collect data about the wavelengths that support humans visually. The interaction of MLCS seen in the indoor environment should not deviate from the one seen outdoors, and changes in light-related hormonal release related to the diurnal rhythm should be close to the one seen outdoors. Huge differences in preferences can be seen among subjects. Laws and recommendations need to be developed to give a PPV support for the individual user. Goals set out for visual comfort or light-related health are important but found not possible to fulfill by the use of the recommendations in the standard. It is a shortcoming if the light that is fundamental to life, and which powerfully controls almost all human behaviors and tissues in the body [Brainard & Hannifin 2005], is designed from recommendations in the standard, as the standard do not fulfill goals of visual comfort and light-related health for the workers in the European Union. When the most frequent method for lighting design, the computer calculated lighting design process (CCLDP), is investigated it is obvious that the light is not designed in contact with daylight, the user's senses or the specific space. The user centred lighting design process (UCLDP) on the contrary has the possibility to support the individual user psychologically, physiologically and visually and to set the user in contact with daylight at the place where the user lives, as well as to design the light related to the colours and surfaces in the space. There is a need to describe the LDP that give support to the individual user in order to build up recommendations for the design. The topic lighting science is underdeveloped theoretically. Around the four steps of the lighting design process, a cluster of light-related research areas can be identified. Seen from the perspective of the LDP, their role in the research of lighting design can be identified.

1.2 Aim and research questions

The aim of the Thesis is to investigate why and in what way lighting design should be designed for the indoor environment to fulfil goals of visual comfort and light-related health. It is also to put focus on the need for laws, recommendations and methods for lighting design that today is merely visual supportive to be developed PPV supportive and individually adaptive as well. The Thesis is oriented towards architects, interior designers and lighting designers and has the ambition to contribute to an increased dialogue between research areas that are related to the lighting design process. The aims with this Thesis are:

1. To investigate why and in what way daylight and artificial light should be designed for indoor environments in order to realise light-related goals of visual comfort and public health.

2. To investigate in what way recommendations and methods for lighting design can be developed to support users in a better way individually and PPV.

3. To investigate in what way a more qualitative research in lighting design can be developed in collaboration among different research areas and competences.

1.3 Identification of the problem area

Why and in what way daylight and artificial light should be designed for the indoor environment to realise goals of visual comfort and light-related health are central questions related to public health. Daylight that enters the eye and irradiates the skin supports humans psychologically, physiologically and visually [Reiter et al. 2011; Pechaceck, Andersen & Lockley 2008]. The spectral profile of daylight plays the decisive role [Hollwich 1979 p. 90] when the interaction of MLCS seen outdoors is compared to the one seen in the indoor environment.

Methods for measurement of illumination, light sources, laws and recommendations and methods for lighting design are developed merely to be visually supportive [Liljefors 2010]. As late as 2000 the human system behind the physiological support from daylight was identified [Berson, Dunn & Takao 2001]. The findings of melanopsin and ipRGC show that measurement techniques, light sources, laws, recommendations and methods need to be developed to give PPV support to the individual to fulfil goals set out about visual comfort and light-related health.

The senses are the outher parts of the CNS. Big differences can be seen among subjects in the sensitivity in the channels into the CNS [Ingvar 1981]. Due to the importance of light for basic health, it is argued in the Thesis that laws, recommendations and methods for lighting design, today mainly visually supportive, need to be developed in a way that gives an individual PPV support from light. Goals set out for lighting design are important to fulfil but goals for visual comfort in EN 12464-1:2011 and light related health in EC Treaty 137 and WHO target 9 and 13-17 are not fulfilled by the use of the recommendation in the standard. The most common method here for lighting design, the computer calculated lighting design process (CCLDP), does not set the user in contact with the daylight at the site where the user lives and is neither related to the individual user or to the colours and surfaces in the space. The user centred lighting design process (UCLDP), on the contrary, has the possibility to do so.

Lighting quality is a central theme in lighting science. A general perspective on the definition of lighting quality does not connect to the senses of the individual user. The user centred perspective on the other hand is based on the ambition to meet the individual user’s senses and by that design the light close to the user´s needs.

There is a need for a build up of a platform for research in lighting science. The LDP can be used to identify research areas around the process closely related to the four steps of lighting design. The range of diseases connected to the misuse of artificial light is a target for an intense research globally today in photobiology and medicine [Rollag & Zalatan; Cajochen et al. 2005; Cajochen 2007; Cajochen et al. 2011]. The effect of staying in EMR needs to be critically investigated by research associated to the LDP and its practical application. Artificial lightsources has a spectral profile that alters from daylight and that gives, by transduction through melanopsin and ipRGC, an altered input to hormonal release compared to when staying in daylight. Too little is known about patterns in user responses to, and preferences for, daylight and artificial light [Chang, Scheer & Czeisler 2011]. There is a need to develop the user centred lighting design process that give the user a visual comfort and a hormonal release close to the one seen outdoors and by that achieve goals in the reduction of light-related psychological, physiological or visual problems for the individual.

1.4 Research questions

1. Why and in what way should daylight and artificial light be designed for the indoor environment to realise light-related goals of visual comfort and public health?

2. In what way can laws, recommendations and methods for lighting design be developed to support the individual user in a better way PPV?

3. In what way can a more qualitative research in lighting design be developed in collaboration among different research areas and competences?

1.5 Research approach

The research approach is imprinted by the LDP and is empirical and theoretical in an interactive way. In a first step the approach was unprejudiced and idiographic, with the ambition to generate data linked to direct individual responses and preferences. This was later completed with a more nomothetic approach but still seen from the impact on the individual subject. Most of the methods used collected data on a quantitative level but the research can be seen as quantitative or qualitative, not on level of methods, but on level of data [Åsgård 2001]. I have, in the studies, looked closely to the individual subject’s experiences, responses and preferences and mainly collected data with the use of numbers. The applied methods can be divided into two main groups: empirical studies and literature reviews. Based on the results, lighting design processes have been developed and described. The literature reviews have been conducted in order to incorporate light-related topics such as physiology and photobiology into the research in lighting design. In order to reduce the amount of erroneous theoretical data, the reviews are mainly done on articles written after 2000 due to the findings of melanopsin and ipRGC at that time. A mathematical or statistical method is not used in the work with the Thesis. Data is analysed by the search for patterns in responses and preferences and by the use of means and frequencies. Methods used are well-known as SMB, BT and PANAS for instance but others are developed within the Thesis. No pre-determined hypotheses were used but clear research questions were developed gradually based on experiences from the former studies. The individual and idiographic perspective was completed with a more general and nomothetic perspective in a bottom-up research process including to examine if light-related goals were fulfilled seen from the individual subjects perspective.

Study 1. *User responses to lighting design:* Preferences for level of light at the working table and for the ambient light were measured and compared to the lighting designer's preferences. A study performed in three full scale rooms (See papers II, III and VI).

Study 2. *User responses to daylight and artificial light in the indoor environment:* Preferences for and responses to daylight and artificial light in the indoor environment. A study performed in three full scale rooms (See papers VII, VIII and IX).

Study 3. *User preferences for energy efficient light sources:* Preferences for light emitted from energy efficient light sources. European and non European subjects. A study performed in four (two of type 1 and two of type 2) full scale rooms (See papers IV and V).

Study 4. *User preferences for visual comfort in level of light at the working table and for the complementary ambient light:* Preferences for a visual comfortable level of light at the working table and for the complementary ambient light in a given contrast situation. European and non European subjects. A study performed in a full scale room (See paper I).

Study 5. *User preferences for visual comfort in level of light at the working table and for the complementary ambient light during a day:* Preferences for a visually comfortable level of light at the working table and for the complementary ambient light in a given contrast situation during a day. A study performed in a full scale room (See paper I).

1.6 Central concepts

Electromagnetic radiation: EM radiation or EMR is a form of energy emitted and absorbed by charged particles, which exhibits wave-like behaviour as it travels through space. EMR has both electric and magnetic field components, which stand in a fixed ratio of intensity to each other, and which oscillate in phase perpendicular to each other and perpendicular to the direction of energy and wave propagation. In vacuum, electromagnetic radiation propagates at a characteristic speed, the speed of light. [Wikipedia accessed 121002]. EMR is invisible and not possible to experience by the human visual sight in itself but can be measured by the use of a spectroradiometer or a Lux meter.

Holistic approach to lighting design: The lighting design process is seen as holistic when designed based on the four steps of the lighting design process described below.

Light: The human visual experience of the opposite to darkness. The concept light is only used in the Thesis for the human experience as a result of photon streams (PS) that enters the eye and make it possible for the brain to interpret a pattern of information. This process lies behind the experience of the room and the objects in the room being visible for us and for hormonal release.

Lighting design process: Step 1) Analyses of the space, colours, surfaces, daylight and artificial light in the room. The architects and the interior designer's intention with the room. Step 2) Analyses of the humans needs psychologically, and physiologically. Analyses of visual needs for support of activities in the room. Step 3) the design of daylight and artificial light in the indoor environment related to the colours and surfaces in the room and to the daylight at the site where the user lives. Step 4) the design of the lighting application technically and the development of a scheme for maintenance of the lighting application (LA).

Lighting quality: There is no existing accepted definition of lighting quality and there is no widely accepted method to measure it according to Veitch & Newsham [2006] and Boyce & Eklund [1995].

"Lighting quality may be the most talked about but least understood concept in lighting research" [Veitch & Newsham 2006, p.1].

"This would be straightforward if there existed a comprehensive, widely-accepted method for evaluating lighting quality. Unfortunately, this is not the case" [Boyce 1995, p.190].

"The definition that seems most generally applicable is that lighting quality is given by the extent to which the installation meets the objectives and constraints set by the client and the designer" [Boyce 2003, p. 188].

Lighting quality is a result of the use of the four steps in the LDP extended to the UCLDP and when the user experience a PPV support from the way the light is designed [Säter, Paper X].

Photon streams: In physics, a photon is an elementary particle, the quantum of light and all other forms of electromagnetic radiation. Photon streams are not possible to experience in themselves but are possible to measure with the use of a spectroradiometer or a light meter. When entering the eye, the photon streams carry information about the room and the objects in the room that are interpreted by the brain and start up action potentials to the brain.

User centred design: A design philosophy and a process in which the needs, wants and limitations of end users are given extensive attention at each stage of the design process.

Visual comfort: Visual comfort is experienced when the contrast situation in the visual sight is well functioning according to the individual subject´s sensitivity.

1.7 Delimitations

Related to the research questions formulated above, the following deliminations should be recognised:

1. The identification of reasons as to why and in what way daylight and artificial light should be designed for the indoor environment to realise goals of visual comfort and light-related public health concerns the result of the TF, common contemporary knowledge in lighting design and the empirical studies performed in the Thesis. The goals for lighting design can be found in EN 12464-1:2011, EC Treaty 137 and Pörn´s health theory adopted by WHO target 9 and 13-17.

2. The investigation of in what way laws, recommendations and methods for lighting design can be developed to support the individual user in a better way PPV is related to the TF and the four step of the LDP, CCLDP and UCLDP described in the Thesis. The law that regulates the design of workplaces is EC Treaty 137. Here EC Treaty 137 is used only as the highest goal for lighting design for workplaces.

3. The investigation of in what way a more qualitative research in lighting design can be developed in collaboration between different research areas and different competences is done related to the TF, LDP and the UCLDP.

1.8 Outline of the Thesis

Chapter 1**:** comprices a brief introduction to my starting points for the project. The topic lighting science is introduced in this chapter and the scope of the research is identified. Aims, research problems, research approach, methods, central concepts, delimitations and outline of the Thesis can be found here.

Chapter 2: holds an overview of theory, theoretical framework, relevant studies and the research problems. The approach to theory and research overview is described and structured by the questions used in the TF. A summary of discussion and conclusions can be found in this chapter.

Chapter 3: the methods used for collection of data are described in this chapter and the studies in the Thesis are compared to: 1) the first research in human temporary isolation by Wever [1979, 1992] in the Andech bunker ; 2) studies in action spectrum and hormonal release when staying in daylight and artificial light done by Hollwich & Dieckhues [1980] (Study 2); 3) sleep and wake up habits studied by Roenneberg et al. 2007 (Study 2); 4) studies in the variability in the preferences for light [Ronchi 2009] (Studies 4 and 5); 5) studies about level of light at the working table performed by Balder 1957, Bodman 1967, Saunders 1969 and Perry, Campbell & Rothwell 1987] (Studies 4 and 5); 6) studies 1, 2, 3, 4, and 5 are compared to the holistic health theory by Pörn [Pörn 1984, 1988,1989].

Chapter 4**:** observations and analyses in the studies are described in this chapter, with references to published papers [Säter Paper I-X];1) the first part of chapter 4 concerns why and in what way daylight and artificial light should be designed in order to realise aims of visual comfort or public health; 2) the second part concerns differences in the interaction of MLCS in the outdoor and the indoor environment; 3) the third part focuses on melanopsin and the ipRGC; 4) the fourth part discusses if patterns can be seen in the responses to photon streams (PS) and preferences for light when staying in daylight and artificial light in the indoor environment; 5) the fifth part concerns light-related goals seen in EN 12464-1:2011, EC Treaty 137 and Pörn´s health theory adopted by WHO target 9 and 13-17; 6) the sixth part concerns lighting quality (LQ) seen from the designers, end-users and the clients perspective; 7 and 8) lastly, in the seventh and the eighth parts, the results are shown about the development of and recommendations for the lighting design process that is done in contact with the individual user´s PPV needs and related to the colours and surfaces in the room and to the daylight at the site where the user lives.

Chapter 5: Reflections on results and methodology are given here. The findings from studies 1, 2, 3, 4, and 5 are reviewed and analysed. Final conclusions are drawn and future work is outlined.

Appendices and a summary of appended papers can be found at the end of the Thesis.

CHAPTER 2

2. THEORY

Theoretical framework and relevant studies and the research problems

This chapter aims to a) thoroughly map research that considers light quality and health; b) show how different researchers approach the topic of light and health; c) argue for a more differentiated, individually and spatially adapted mode to approach lighting design in order to develop adequate methods that strongly emphasise individual differences and health aspects.

The theoretical framework is built up around the three research questions in the Thesis and completed with other aspects found important for the research in lighting design and divided into TF part 1-10 concerning:

Research question 1:

- **TF part 1**) Why and in what way should daylight and artificial light be designed for the indoor environment to realise goals of visual comfort and light-related health?
- **TF part 2**) Can significant differences in the interaction of man, light, colour and space in the outdoor and indoor environment be identified?
- **TF part 3**) Which are the functions of melanopsin and ipRGC and how can a relation to lighting design and light-related basic health be formulated?
- **TF part 4**) Can patterns be seen in responses to PS and in preferences to light when subjects stay in daylight or artificial light in the room and light settings in the studies?

Research question 2:

- **TF part 5**) In what way can laws, recommendations and methods for lighting design be developed to support the individual user in a better PPV way? Will light–related goals according to visual comfort and health stipulated in EC Treaty 137, Pörn´s health theory in WHO target 9 and 13-17 adopted by the Member States of European Region and visual comfort in the European standard for indoor workplaces be fulfilled by the use of EN 12464-1:2011?
- **TF part 6**) Will the use of the CCLDP and the UCLDP fulfill goals about visual comfort and light-related health in EN 12464-1:2011, EC Treaty 137 and WHO target 9 and13-17 adopted by the member States of European Region?
- **TF part 7**) In what way does the end user, designer, or client perspective to LQ differ in PPV support for the user?
- **TF part 8**) How can the process of lighting design be described that support the user´s individual light-related PPV needs, and how is it related to the colours and surfaces in a specific space and sets the user in contact with the daylight at the site where the user lives?
- **TF part 9**) How can recommendations be formulated that guide the design of light toward being in contact with the individual user´s light-related needs, the colours and surfaces in a specific space and the daylight at the site where the user lives?

Research question 3:

- **TF part 10**) In what way can a more qualified research in lighting design be developed and different research areas be combined?

Relevant literature about humans and light can be found in a multidisciplinary cluster related to the four steps of the lighting design process. The steps concern the space, the user, the design and the technical part of the application. The literature used in the TF is light-related but not in all cases associated to the lighting design process. Literature about lighting design is often done with limited knowledge in basic human physiology and therefore often misleading. Here literature is chosen that connects light to physiology to give a foundation for a lighting design process that support users PPV. In the same way literature written after 2000 is preferred due to the findings of melanopsin and ipRGC at that time. Literature from before 2000 is used if being forerunners for the theoretical development about melanopsin and ipRGC seen after 2000.

In order to provide a consistent basis for further discussions, citations from sources are sometimes extensive, thereby they give a more coherent picture of central policies and contemporary discourse.

2.1 Approach to theory and research overview

Lighting design concerns all humans night and day throughout life and is essential for human health [Hollwich & Dieckhues 1980]. The research is centred to the room, daylight, artificial light, the user, the design of daylight and the complementary artificial light and the lighting application. A fruitful way to go into the topic is to use the LDP as a basis for the research. The LDP connects the research closely to the practical application and shows in an easy way where in the huge topic the research is situated and demonstrates a possible impact on the practical application.

Around the four steps of the LDP a cluster of research areas can be identified. Architecture and interior design research in daylight, artificial light, light distribution surfaces and colours are related to the first step of the LDP. Photobiology, physiology, medicine and ergonomics are related to the user and the second step of the LDP. Design and user centred design is related to the third step and lighting technology to the fourth. Step 2 is related to the user PPV and is the part of the process that step 1, 3 and 4 should support. When identifying psychological, physiological and visual reasons for the design of light, parts of these light-related topics that can be seen around the LDP is valuable for research. From this platform interaction models can be constructed and tested over and over again to find out if a design of light gives a positive PPV support. For the Thesis project architecture is mentioned mainly as a part of the LDP. Interior design as well as research in colours is in the same way mentioned mainly as a part of the LDP. Photobiology and medicine are investigated in the TF and studies connected to a PPV support from light are chosen and cited in central parts of the TF. The fourth step is not mentioned in the TF. The research overview for the Thesis project mainly concerns step 2 in the LDP. I have tried to find physiological reasons to use a specific method for lighting design then identified the LDP step 1-4 and the CCLDP and UCLDP. Finally I have investigated in what way the two different lighting design processes the CCLDP and UCLDP, fulfill goals set out from the individual user's point of view and from the perspective of the society. The Thesis project focuses on step 1, 2 and 3 of the LDP as well, but only in a limited way in step four. The questions that build up the TF are formulated in sections 2.2 to 2.9 in this chapter.

2.2 Research question nr 1.

***TF Part 1**. Research question 1. Why and in what way should daylight and artificial light be designed for the indoor environment to realise goals of visual comfort and light-related health?*

Light regulates diurnal rhythm: Ulla Edell-Gustavsson and Anna-Christina Ek mention the importance of sleep, circadian rhythm and lifestyle seen from the perspective of the health theory by Pörn. Here society and the individual´s relation to the environment are discussed. According to Pörn, health and diseases are not only medical problems but also depend on physiological, biomedical and psychological factors in the individual´s environment. The Regional Office for Europe of the World Health Organization worked 1993 with 38 Targets. Target 9 concerned reducing coronary disease and 13-17 lifestyle conductive to health [WHO, Health for all, 1993; Nordenfeldt 1987].

"Sleep is a physiological need. An individual´s will profile, repertoire and circumstances in the internal and external environment influence sleep, and are thus important factors for the individual´s good health. Sleep deprivation leads to an altered circadian rhythm, an early stage in psycho physiological and social poor health, independent of disease. This influences the individual´s behaviour and ability to adjust. Long-term disturbances lead to disease." [Edéll–Gustavsson & Ek 1992, p. 33].

"The holistic theory according to Pörn is an anthropological bias as regards the concept of health. It is a health concept not based on illness and thus differs from the traditional medical perspective. It describes an individual´s equilibrium that is between goal achievement and goals. [Pörn 1984, 1988, Nordenfeldt 1986]. That is to say, that the individual attempts to achieve his goals and to attain good health" [Edéll–Gustavsson & Ek 1992 p. 31].

The theory of Pörn is light-related since daylight and artificial light powerfully regulates the diurnal rhythm. If daylight and the complementary artificial light is not designed to support the user physiologically, diurnal rhythm will be affected and as Pörn states long-term disturbances in diurnal rhythm lead to diseases.

Light is fundamental to life and have biological effects: The knowledge about daylight and human diurnal rhythm increases [Stevens et al. 2007, p. 1357]. Through the diurnal rhythm, light has an impact on almost all tissues in the body, stated Brainard & Hanifin [2005, p. 314], [Brainard et al. 2001]. John Hanifin, (Manager of Laboratory Services, Thomas Jefferson University, Philadelphia, USA, a Collaborative PhD student) and George Brainard, Professor in Neurology, Biochemistry and Molecular Pharmacology at Thomas Jefferson University Jefferson Medical College Department of Neurology, describe the process of photo transduction, and that the light-induced changes subsequently evoke broader physiological responses within the organism**.**

“There is a basic principle shared by all species in their ability to respond to light stimuli: all photo biological responses are mediated by organic molecules that absorb light quanta and then undergo physical-chemical changes. These light-induced changes subsequently evoke broader physiological responses within the organism. This process is termed photo transduction and the specific molecular complexes are called photo pigment.” [Hanifin J. P & Brainard G. C. 2007, p. 87].

Theory behind in what way light should be designed from a health perspective can be found in photobiological literature.

“Sunlight is one of the most important elements in our environment. Plants harvest the energy of sunlight in order to grow, and thus to provide food for other organisms. Sunlight also provides information needed by organisms to trigger numerous biological responses. These are the beneficial wavelengths of sunlight. Sunlight also has its bad side. The shorter wavelengths (or the longer wavelengths plus photosensitizes) can kill plants and other organisms, and produce cancer and other debilitating conditions in man. Photobiology is the study of both the good and the bad effects of light. Studies range from the atomic level to the level of communities of organisms. Photo biologists use all of the tools of science to study the chemical and biological effects of light. Photobiology is an exciting and challenging field of science.”(Constitution of the American Society for Photobiology).

Kendrick C. Smith at Stanford University, School of Medicine, and the first president of the Northern California Photobiology and Chemistry Group from 1962-1966 describes that daylight should be used as much as possible to give information to the human body for the triggering of numerous biological responses. Photobiology is a topic with many branches and can be divided into 12 major specialty areas. Eleven of these concern the absorption of light in a biological system, and one concerns the emission of light by biological systems (Bioluminescence). The special areas are photophysics, photochemistry, photosensitisation, ultra violet (UV) radiation effects on molecules and cells, environmental photobiology, photomedicine, non-visual photoreception, vision, photo morphogenesis, photo movement, photosynthesis and bioluminescence. Relevant articles for research in lighting design can be found in the photobiological literature from these 12 subareas.

Living with light at the site where the user lives: Full Professor. Dr. Anna Wirz-Justice, a chronobiologist at the Centre for Chronobiology Psychiatric Hospital at the University of Basel, writes about the complementary ambient light and the need for entrainment to the light at the site where the user lives [Wirz-Justice & Fournier 2010]. The research of Lucia Ronchi PhD in physiological optics gives a theoretical background to the visual variability of the individual visual sight through the day [Ronchi 2009 p. 27, p.p. 28-32]. Badia et al. [1991] have investigated the relation between body temperature and light. Cajochen [2007] investigated alerting effects of light.

Daylight mimicking spectral profile in light for the production of vitamin D: Michael F. Holick the director of General clinical research center and professor in medicine, physiology and biophysics at Boston University Medical Center, argues that the generally low level of vitamin D in the bloodstream in the population of America is an epidemic disease and he recommends a supplementary dietary intake of vitamin D. MD and PhD David Servan-Schreiber comments Holick´s work in the following way; Dr. Holicks advice about vitamin D is possibly the single most important thing you can do to improve your health and save yourself from many chronic diseases, including cancer.

Holick relates a low level of vitamin D to Alzheimer, autoimmune diseases, heart diseases, multiple sclerosis, diabetes, cancer, flue, skeletal and teeth problems [Holick 2005-2011]. Dr.William Grant [2011a] writes about reducing the burden of diseases through adequate intake of vitamin D3. In publications about vitamin D, Grant and Michael F. Holick put attention on the reason to stay close to daylight and do a lighting design that is daylight mimicking and to use light sources with a spectral profile close to daylight [Holick 2005-2011; Grant 2011b].

Light at night: Stephen M. Pauley [2004] writes in the Journal of Medical Hypotheses about lighting for the human circadian clock and about recent research that indicates that lighting has become a public health issue.

"The hypothesis that the suppression of melatonin (MLT) by exposure to light at night (LAN) may be one reason for the higher rates of breast and colorectal cancers in the developed world deserves more attention. The literature supports raising this subject for awareness as a growing public health issue. Evidence now exists that indirectly links exposures to LAN to human breast and colorectal cancers in shift workers. The hypothesis begs an even larger question: has medical science overlooked the suppression of MLT by LAN as a contributor to the overall incidence of cancer?"[Pauley 2004, p. 588].

Pauley reports about research on animals regarding melatonin (MLT) and light at night (LAN) and cancer.

"The indirect linkage of breast cancer to LAN is further supported by laboratory rat experiments by David E. Blask and colleagues. Experiments involved the implanting of human MCF-7 breast cancer cell xenografts into the groins of rats and measurements were made of cancer cell growth rates, the uptake of linoleic acid (LA), and MLT levels. One group of implanted rats were placed in light–dark (12L: 12D) and a second group in light–light (12L: 12L) environments. Constant light suppressed MLT, increased cancer cell growth rates, and increased LA uptake into cancer cells. The opposite was seen in the light–dark group. The proposed mechanism is the suppression of nocturnal MLT by exposure to LAN and subsequent lack of protection by MLT on cancer cell receptor sites which allows the uptake of LA which in turn enhances the growth of cancer cells." [Pauley 2004, p.588].

Pauley reports on the negative effects LAN has on the production of MLT.

"MLT is a protective, oncostatic hormone and strong antioxidant having evolved in all plants and animals over the millennia. In vertebrates, MLT is normally produced by the pineal gland during the early morning hours of darkness, even in nocturnal animals, and is suppressed by exposure to LAN." [Pauley 2004, p.588].

Pauley presents that daily entrainment of the human circadian clock is one of the important charges of architectural light.

"Light needs to be designed supportive for humans and without harm to animals, plants and the ecosystem as well" *[Pauley 2004].*

"Daily entrainment of the human circadian clock is important for good human health. These studies suggest that the proper use…of indoor and outdoor lighting is important to the health of both humans and ecosystems. Lighting fixtures should be designed to minimize interference with normal circadian rhythms in plants and animals" [Pauley 2004, p. 588].

The quotations from Pauley imply that the use of artificial light has an effect not only on humans but on animals, plants and the ecosystem as well.

"New discoveries on…Light-sensitive retinal ganglion cell, light receptors that control the circadian clock and how those receptors relate to today's modern high intensity discharge (HID) lamps are discussed. There is a brief discussion of circadian rhythms and light pollution. With the precautionary principle in mind, practical suggestions are offered for better indoor and outdoor lighting practices designed to safeguard human health" [Pauley 2004, p. 588].

Pauley calls upon being preventive in everyday lighting practices.

"Until more research directly links exposure to LAN to increased rates of human cancers, it may be wise to consider preventive measures in the application of everyday lighting practices" [Pauley 2004, p. 592].

The use of artificial light has an impact on the production of human vitamin D and melatonin. Pauley places focus on how to cope with problems related to the use of artificial light.

"The best way to daily entrain (reset) our circadian clocks and have our body's produce a healthy dose of vitamin D is to get 15 min of natural sunlight exposure each morning [44]. At night we should sleep in total darkness. But in modern industrialized societies we see people with poor sleep habits. There are a growing number of people working both day and night shift jobs. Studies have shown that shift workers will phase-shift their circadian rhythms [56]. Disruption of normal night time MLT secretory rhythms due to shift work is likely harmful to human physiology" [Pauley 2004, p. 592].

Pauley points out important goals for a biologically friendly lighting.

"The two basic goals are: (a) to entrain the circadian clock during daylight through the use of bright, full spectrum white light; (b) at night to use non-glare, non-short outdoor and indoor lights [50], [53], [58] and [64]. Daytime office lighting in buildings without windows is often so dim that it is unable to entrain the circadian clock to suppress MLT, and therefore one is exposed to a "biological darkness" [74]. The best office daytime lighting source should be from natural daylight. Where windows in office spaces are not possible, non-glare, bright, full-spectrum white light should be used so as to entrain the circadian clock to daytime." [Pauley 2004, p. 593].

Pauley formulates a goal for a physiological well-functioning indoor lighting.

"Indoor night time lighting should be dim, reading by incandescent lights rather than fluorescent lights…Complete darkness during sleep is preferred. Televisions should not be left on during sleeping hours. Blinds should be closed if light from street lighting or flood lighting enters bedroom windows" [Pauley 2004, p. 593].

Internal homeostasis and being entrained to the light at the site where the user lives: Anna Wirz-Justice & Fournier argue that the design of architecture needs to take into consideration the biological effect that light has on different sectors of the population, for instance the elderly. [Wirz-Justice & Fournier 2010].

A misuse of light, a health risk: Lewy [1983] wrote in an early state about 2500 Lux at night that suppressed melatonin to near daytime levels. Buerley et al. [1989] wrote about Lewy and his findings about melatonin. He saw that the levels began to decrease after 10 to 20 minutes of light exposure. Lewy investigated 5 minutes of light exposure. They found that 5 minutes of bright light exposure slightly decreased level of plasma melatonin. It appears they stated that brief pulses of bright light do cause a stress response. Jasser, Blask and Brainard [2006] wrote in 2006 about breast cancer, an oncological disease partly related to increased exposure to light at night. They mention that developing breast cancer is up to five times higher in industrialised nations than in underdeveloped countries. Their results show that tumour growth respond to exposure of light during darkness, is intensity dependent and that the human nocturnal circadian melatonin signal not only inhibits human breast cancer growth but that this effect is extinguished by short-term ocular exposure to bright, white light at night [Jasser, Blask & Brainard 2006]. Badia et al. reported in 1991 about bright light effects on body temperature, alertness, Electroencephalography (EEG) and behaviour. They reported that under dimmed light conditions (50 Lux) the body temperature decreased but either increased or maintained under bright light (BL). Similar alertness, measured by EEG beta activity, was greater under BL, and night-time performance on behavioural tasks was also generally better. There were no differential effects on any measure during the daytime. These data indicate that light exerts a powerful, immediate effect on physiology and behaviour in addition to its powerful influence on circadian organisation [Badia et al. 1991].

Man and photon streams, the photobiological perspective: The interaction with PS that gives action potentials to the brain is a part of the unconscious, hormonal message system within the body described by Jens Hannibal [Hannibal et al. 2002].

"Rhythmic changes in physiology and behaviour within a 24 h period occur in living organisms on earth to meet the challenges associated with the daily changes in the external environment. The circadian pacemaker responsible for the temporal internal organization and the generation of endogenous rhythms of approximately 24 h is located in the hypothalamic suprachiasmatic nucleus (SCN) in mammals. The endogenous period generated by the pacemaker is close to, but generally not equal to 24 h and the biological clock therefore needs to be daily adjusted (entrained) by external cues. The daily alteration of light and darkness due to the rotation of our planet on its own axis in relation to the sun is the most prominent "zeitgeber" which adjusts the phase of the circadian rhythms to the astronomical day length, a process known as photo entrainment. In mammals, light is perceived only through photoreceptors located in the retina. Light information is mediated to the SCN via the retinohypothalamic tract (RHT) by activation of the classical photoreceptor system of rods and cones and a more recently identified system of intrinsic photosensitive retinal ganglion cells (ipRGCs) using melanopsin as a photopigment"[Hannibal & Fahrenkrug 2006, p. 1].

Man in the middle of the photon stream: Anders Liljefors, [1999], a Swedish architect and Full Professor in lighting science with a user centred and design based approach to lighting design, describes that humans are in a stream of photons that is transmitted through, absorbed in and reflected from (TAR) the surfaces in nature and in the indoor space and in the human eye as well. Liljefors has reported extensively about the misuse of the word light. Photons are invisible he argues, they have no colour but they have the capability to carry information to the human brain and this process lies behind the experience of being able to see where we are in the room. Despite millions of examples of the words visible light, visible spectrum, blue or red light in the scientific literature, he nevertheless claims this is an unscientific way to describe the invisible and colourless photons [Liljefors 2010].

Transmission, absorption and reflection (TAR): When living in the indoor environment humans stay in daylight and artificial light that interacts with the colours and surfaces in the room. Since PS are transmitted through, absorbed in and reflected from colours and surfaces in different percentages depending on the specific colour and type of surface, the way PS in the room affect users PPV will differ [Liljefors 1999].

The theoretical platforms of Gibson, Norman and Liljefors are pursued and completed by the photobiological perspective. This is described by Brainard and Hanifin. They picture at the same time the connection to architectural light [Brainard & Hanifin 2005, p. 314].

"A series of discoveries determined that light detected by the eyes was the primary stimulus that regulated pineal gland morphology, melatonin biosynthesis, and pineal-reproductive photoperiodic responses. Following those advances, a discrete, light-sensitive neural pathway extending from the retina into the suprachiasmatic nuclei (SCN) was elucidated for circadian regulation (Moore and Lenn 1972). These seminal discoveries showed that environmental light played a fundamental role in regulating homeostasis and circadian physiology. Together, these breakthroughs enabled investigators to begin using the tools of photobiology to explore circadian physiology." [Brainard & Hanifin 2005, p. 314].

Brainard and Hanifin describe the discovery of melanopsin as a turning point for the understanding of the human circadian photo transduction.

"The seminal discovery of melanopsin, the photopigment in intrinsically photosensitive retinal ganglion cells, has provided a turning point for understanding human circadian photo transduction" [Brainard & Hanifin 2005, p. 314].

Brainard and Hanifin link the findings to architectural light and point out the relation between photons and the nervous system.

"These findings open the door to innovations in light therapy for circadian and affective disorders, as well as possible architectural light applications" [Brainard & Hanifin 2005, p. 314].

Brainard and Hanifin, describe the interplay of photons with the nervous system.

"The interplay of photons with the nervous system often dominates our waking consciousness" [Brainard & Hanifin 2005, p. 314].

Brainard and Hanifin state that architectural light, in an unconscious way through the nervous system and the diurnal rhythm, has an impact on almost all tissues in the body [Brainard & Hanifin 2005 p. 314].

"Light profoundly impacts on human consciousness through the stimulation of the visual system and powerfully regulates the human circadian system, which, in turn, has a broad regulatory impact on virtually all tissues in the body" [Brainard & Hanifin 2005, p. 314].

"Subtly, almost always below the level of consciousness light also controls daily rhythms and hormonal tides with a regularity that is strongly linked to the daily progression of environmental light and darkness" [Brainard & Hanifin 2005, p. 314].

Brainard and Hanifin mention that all living organisms share the same fundamental principle in their ability to respond to light stimuli.

"All photo biological responses are mediated by organic molecules that absorb light quanta and then undergo physical-chemical changes. These light-induced changes subsequently evoke broader physiological responses within the organism. This process is termed photo transduction, and the specific organic molecules that absorb light energy to initiate responses are called chromophores" [Brainard & Hanifin 2005, p. 315].

"A chromophore´s pattern of wavelengths sensitivity, or its absorbance spectrum, is like a fingerprint, it is unique to that molecule within its photopigment complex. In the field of photobiology, an action spectrum is one of the principal tools for identifying the photo pigment that initiates a light induced response" [Brainard & Hanifin 2005, p. 315].

"Over the years, the photo biologists have evolved a set of refined approaches for determining action spectra that are applicable to all light responsive organisms (Horspool and Song, 1994)" [Brainard & Hanifin 2005, p. 315].

Brainard and Hanifin picture the process where photons in the architectural light induce a response to PS.

"In the past two years, studies have provided convincing evidence that melanopsin is a functional circadian photo pigment in ipRGCs. In blind humans with severe retinal disease, melanopsin expression was retained in the retina. [Hannibal et al. 2004]. These findings are congruent with earlier studies on blind humans who had intact circadian responses to light" [Brainard & Hanifin 2005, p. 319].

"These recent studies have shown that melanopsin is the photopigment responsible for phototransduction. When nonphotosensitive cells are transfected with the human or mouse melanopsin genes, these cells become sensitive" [Brainard & Hanifin 2005, p. 319].

Human response curve: The research of Prof. Dr. Christian Cajochen, head at the centre for chronobiology at the Psychiatric Hospital of the University of Basel, report about the human timing system´s sensitivity to ocular PS, a foundation for the human phase response curve**.**

"The human circadian timing system is sensitive to ocular light exposure. The effect of light depend on the circadian phase at which light is administered: light given after the core body temperature (CBT)

nadir advances the phase of circadian rhythms, whereas light given before the CBT nadir induces delays. This can be quantified by a so-called human phase response curve to light (1, 2). Besides the timing of exposure, the intensity of light (i: e irradiance) also play a crucial role in human circadian phase resetting [1, 2]."[Cajochen et al. 2005, p 1311].

"Besides circadian phase shifts, light also elicits acute physiological effects in humans such as rapid suppression of melatonin at night" (Brainard et al. 1997), an increase in CBT (8- 11) and heart rate (12), and an immediate dose-dependent alerting response, measured subjectively and objectively via the electroencephalogram (Cajochen et al. 2000). Brainard et al. (13, 14) have consistently shown that short wavelength at around 460 nm is most effective in acutely suppressing human melatonin levels. Furthermore, Hankins and Lucas (15) have recently shown that acute light responses in the human electroretinogram (ERG) are highly dependent on wavelengths, such that light at 483 nm elicited the strongest reduction in cone ERG b wave-implicit time. The acute effects of light, as well as the circadian effects, seem to be mediated by the eyes. Thus acute elevation of body temperature and suppression of melatonin are not observed when the eyes are covered (11, 16) or when light is administered to the skin" [Cajochen et al. 2005, p. 1311].

The variability of the human sight: In the indoor environment is the interaction of MLCS manmade. Lucia Ronchi´s research in the human visual sight shows the changes during the day in the visual functionality. In order to be experienced as visually comfortable, the interaction needs to be not only related to the indoor contrast situation that differs to a great extent from the one seen outdoors, but also support the sensibility of the individual user and the variability of the visual functionality across the day [Ronchi 2009, p.28-32].

"Of basic historical importance is the pioneering contribution of Luckiesh and Moss dated 1931. These authors have elaborated a research program devoted to Light Engineers, the traces of which were spread out over the subsequent decades. On the basis of their dataset of 100,000 visual measurements, they looked for the relative relationship between the level of illumination and seeing. They noted that all measurements on seeing are exceedingly irregular. The results vary widely both between different subjects and between successive operations by the same subjects from moment to moment in a day and /or from day to day. For the evaluation of the consequences of this variability, the authors recommend considering the relative change" [Ronchi 2009, p. 27].

Individual sensitivity to light: The variability during the day should be seen in addition to individual sensitivity for the visual sight she claims. David Ingvar (as mentioned earlier in the TF) supports the conclusion of Ronchis work.

"It is important to emphasize that already in the channels to the (Central nervous system) CNS can huge differences be seen in sensitivity. Because of this it is adventurous to define an ideal environment or light in absolute measurements. Retina is changing in size when displayed for varied amount of light. The central interpretation is also very different. It is important to have a plastic view of the nervous system capability to interpret the input from light on different levels of intensity" [Ingvar 1981, p.53].

"We know since a long time that we have a continuum between deep sleep and a high level of alertness." [Ingvar 1981, p.53]. The level of activity in the nervous system can vary and by that the consequences that the impressions have for us" [Ingvar 1981, p.53].

In what way, the lighting design process: Based on common knowledge in lighting design, analyses in the interaction of MLCS and the theoretical framework (TF) are two principal lighting design processes (LDP) identified and described in the thesis. The first process, the computer calculated lighting design process (CCLDP) has a general and visual approach to the user, and is done without being in contact with the user or being related to the colours and surfaces in the room or being in contact with the daylight at the site where the user lives. The second process is named user centred lighting design process (UCLDP). The UCLDP is specific and is done in contact with the user and the colours and surfaces in the room and related to the daylight at the site where the user lives. The two lighting design processes are described in their principal steps and according to their possibility to realise light-related goals (Paper X).

In what way, a general or specific approach to the user: In the book *Lighting of buildings* Hopkinson (1972), at that time a Professor in Environmental Design and Engineering at University College London, describes how to do lighting design for schools, hospitals, general offices, factories, and buildings. The text addresses the LDP in a careful way and expresses an approach to lighting and building design such as "lighting and the building design such as a whole–commodity, firmness and delight" [Hopkinson & Kay 1979, p. 23], but the user is not mentioned as an individual and the perspective to the user is merely general. In the same way Peter Boyce, a professor in Architecture (PhD in physics) at Troy, writes in his book *Human factors,* a general introduction and a description of how to do lighting design for offices, industry, escape lighting, lighting for driving, lighting and crime, light for the elderly, light and health. Boyce has a general approach to the user in the same way as Hopkinson. Boyce mentions special groups as premature babies, post-operative cataract patients, subjects with medical conditions that enhance photosensitivity and those who are exposed to certain chemical agents in the environment such as whiteners used in some household products. However, Boyce and Hopkinson do not focus on the individual user or subgroups of healthy normal sighted users, when writing about lighting design.

The work of Gooley et al. [2011] concerns sleep and implications on the diurnal rhythm. During the day high levels of melatonin can be seen as an opposite problem compared to low levels of melatonin during the night as reported here. When living in dimmed lighting conditions in artificial light, melatonin is not suppressed as in daylight in the outdoor environment.

"Daytime office lighting in buildings without windows is often so dim that it is unable to entrain the circadian clock to suppress MLT, and therefore one is exposed to a "biological darkness" [74]. The best office daytime lighting source should be from natural daylight. Where windows in office spaces are not possible, non-glare, bright, full-spectrum white light should be used so as to entrain the circadian clock to daytime" [Pauley 2004, p. 593].

"Compared with dim light, exposure to room light before bedtime suppressed melatonin, resulting in a later melatonin onset in 99.0% of individuals and shortening melatonin duration by about 90 min. Also, exposure to room light during the usual hours of sleep suppressed melatonin by greater than 50% in most (85%) trials" [Gooley et al. 2011].

Gooley et al. mention the hazard of being exposed to light at night and state a relation between the use of artificial light and disturbed internal glucose homeostasis [Gooley et al. 2011].

"These findings indicate that room light exerts a profound suppressive effect on melatonin levels and shortens the body's internal representation of night duration. Hence, chronically exposing oneself to electrical lighting in the late evening disrupts melatonin signalling and could therefore potentially impact sleep, thermoregulation, blood pressure, and glucose homeostasis" [Gooley et al. 2011].

Cajochen et al. report about high sensitivity of human melatonin, alertness, thermoregulation and heart rate to short-wavelength in light.

"Light can elicit acute physiological and alerting responses in humans, the magnitude of which depends on the timing, intensity, and duration of light exposure. Here we report that the alerting response of light as well as its effect on thermoregulation and heart rate is also wavelength dependent." [Cajochen et al. 2005, p. 1311].

Light and cancer: One of many physiological aspects of circadian rhythm and light is cancer. Rickard Stevens et al. reported about the need for research in environmental lighting related to circadian disruption in cancer and other diseases [Stevens et al. 2007, p. 1357].

"Light, including artificial light has a range of effects on human physiology and behaviour and can therefore alter human physiology when inappropriately timed. One example of potential light-induced disruption is the effect of light on circadian organization, including the timing of the circadian system such that internal rhythms can become desynchronized from both the external environment and internally with each other, impairing our ability to sleep and wake at the appropriate time and compromising physiologic and metabolic processes. Light can also have acute effects on neuroendocrine systems, for example, in suppression melatonin synthesis or elevating cortisol production that may have untoward long-term consequences" [Stevens et al. 2007, p. 1357].

Cajochen et al. published data about the effect of evening exposure to light-emitting diodes, (LED)-backlit computer screen, on circadian physiology and cognitive performance.

"Our data indicate that the spectral profile of light emitted by computer screens impacts on circadian physiology, alertness, and cognitive performance levels" [Cajochen et al. 2011, p.1432].

"Over 2 billion people use the internet, and this number is rapidly increasing. In 2010, 1.6 billion computers, television sets, and cellular phones were sold globally (www.worldometers.info), which illustrates the numbers of individuals who spend time in front of computer screens, video game consoles, or other video monitors. Newer computers and TV screens are now frequently equipped with light-emitting diodes (LED), which peak in the short-wavelength region" [Cajochen et al. 2011, p.1432].

"There is ample evidence that a novel, short-wavelength-sensitive photoreceptor system is primarily responsible for a variety of nonvisual light responses, in particular, resetting the timing of the circadian pacemaker, suppressing melatonin production, improving alertness and performance, and elevating brain activation, as assessed from EEG-derived correlates of arousal(...). Furthermore, bright light exposure and exposure to monochromatic blue light in the evening lengthens sleep latency and reduces initial EEG delta activity, a marker of slow-wave sleep" [Cajochen et al. 2011, p.1432].

In what way- harmonising daylight and artificial light: Thorington, Parascandola and Cunningham [1971] report about the action spectrum that comes from the spectral profile of daylight and how to get a better biological and visual support from artificial light sources. Han and Ishida [2004] focus on the design of daylight that should be used because of the spectral profile, timing and duration in daylight to which humans are adapted. Daylight should be complemented with artificial light in a harmonising way.

Human factors, interaction of MLCS: Relevant literature about human factors is written by Peter Boyce, earlier mentioned in the theoretical framework. Human factors concern man and the tool [Boyce 2003, p.162- 191]. When the interaction of man and light comprise MLCS and the subject´s PPV responses and preferences, the research is extended in complexity. It is difficult to find articles about the connections of MLCS in literature. Research in the interaction of MLCS is broadened in an extensive way, by the finding of the ipRGC.

Affordance-the origin to user centred design: James Jerome Gibson an American psychologist (1904–1979) was a pioneer in the idea of animals sampling information from the ambient outside world [Gibson 1950, 1966, 1979]. He coined the term affordance, originally introduced in his article "*The Theory of Affordances*" [1977] and explored it more fully in his book, *The Ecological Approach to Visual Perception* [1977, 1979]. He defined affordance as all "action possibilities" latent in the environment objectively measurable and independent of the individual's ability to recognise them but always in relation to the actor and therefore dependent on their capabilities. Donald Norman used the term affordance in the context of human–machine interaction to refer to just those action-possibilities that are readily perceivable by an actor. Norman, a cognitive scientist and usability engineer introduced the term affordance to the design of everyday things [Norman 1988]. He wrote about user-centred design, which he had previously referred to in User Centred System Design in 1986 [Norman & Draper 1986]. The concept of affordance has been influential in the field of design and ergonomics. Since light is needed for practical reasons and has a deep impact on humans, Gibson's term affordance and Norman's user centred design are important theoretical concepts for lighting design. Gibson´s theory about direct perception and direct realism is usable concepts in lighting design as well.

TF part 2*. Can significant differences in the interaction of man, light, colour and space in the outdoor and indoor environment be identified?*

Differences in the interaction of MLCS in the outdoor environment compared to the one seen indoors concern the wavelengths and rhythm of daylight. Reduced representation of specific wavelengths seen in daylight in the artificial light sources used indoors decrease the possibility for action potentials through photo transduction [Brainard & Hanifin 2005, p. 315] and the human's ability to produce vitamin D.

Vitamin D: Vitamin D is according to Carsten Geisler, Full Professor, Head of the Department of International Health, Immunology and Microbiology in Copenhagen. Vitamin D, related to regulation of the immune defence, cell growth and hormonal balance [Geisler 2004].

"*Vitamin D deficiency is now recognized as an epidemic in the United States. Vitamin D deficiency causes poor mineralization of the collagen matrix in young children's bones leading to growth retardation and bone deformities known as rickets. In adults, vitamin D deficiency induces secondary hyperparathyroidism, which causes a loss of matrix and minerals, thus increasing the risk of osteoporosis and fractures. In addition, the poor mineralization of newly laid down bone matrix in adult bone results in the painful bone disease of osteomalacia. Vitamin D deficiency causes muscle weakness, increasing the risk of falling and fractures. There is mounting scientific evidence that implicates vitamin D deficiency with an increased risk of type I diabetes, multiple sclerosis, rheumatoid arthritis, hypertension, cardiovascular heart disease, and many common deadly cancers" [Michael F. Holick 2005-11 p. 2739S-27341S]*

Spectral profile in light for the indoor environment: Full Professor Fritz Hollwich, a German opthamologist, found evidence about light entering the eye and acting as a trigger for hormonal release. In 1948 he wrote about a pathway to hypophysis [1948] that he called the "energetic pathway":

"*Different metabolic and endocrine effects on human subjects being due to the different spectral components of the lamps. In other words the spectral components play the decisive role" [Hollwich 1979, p. 90].*

"We may, furthermore, conclude that the more the spectrum of the artificial light source differs from that of natural light the more the biological endocrine system in man will be disturbed, during short periods of time the disturbance of the endocrine system of man, induced by unbalanced artificial light, involves his comfort [Hoefling 1973] his efficiency as well as fatigue [Hollwich & Dieckhues, 1972; Hollwich et al. 1975, 1977]." [Hollwich & Dickhues 1980, p. 194].

"S.O Mast in 1916 was the first to demonstrate the influence of light via the eye on a hormonal reaction. When the head of a plaice was put on a dark background, the plaice turned dark. When its head was put on alight background, the plaice changed to a light colour. The same reaction could be shown in an experiment with a frog. Furthermore, when we closed the lids of the frog with sutures, his colour no longer changed. In both animals therefore, the adaption of the colour of the body to the surroundings (dark or light) is induced by the light entering their eyes. These experiments show that the light entering the eye must travel along two different pathways; one pathway running from the retina to the visual center serves vision, the other one obviously goes to the hypophysis and endocrine gland which releases the specific melanophore hormone inducing the change of colours. Therefore, we suggested two separate pathways for the light entering the eye: The first, serving vision, we designated as the "optical portion" and the second one, stimulating endocrine function, we called the "energetic portion" [Hollwich 1948]" [Hollwich & Dieckhues 1980, p.188].

"We demonstrated the importance of radiations of different wavelengths on the development of a young duck. There was a twofold increase in weight compared to the control [Hollwich & Tilgner 1961]. Figure 7 shows the testes of 2 ducks of the same nest. The smaller one is the testis of a duck raised under normal conditions. Below is the much larger testis of a duck whose eye during 6 weeks was exposed for 5 h daily to long wavelengths" [Hollwich & Dieckhues 1980, p.190].

"Each duck is represented only by one testis. Irradiation with 632 nm enlarged 6 times and irradiation with 707 nm enlarged 16 times. 546 nm and 436 nm had no influence. (The irradiation exposure 2.45x10-4W/cm2 was 10 h daily during a period of 29 days" [Hollwich & Dieckhues 1980, p.191].

Fritz Hollwich and Dieckhues studied hormonal release in blind humans.

"We studied the biological rhythm of the ACTH, cortisol, HGH, testosterone and THS levels in totally blind people, in persons with defective light perception (all blinded by trauma as adults during World War II) and in a normal control group. The cortisol curve of the totally blind (bilaterally artificial eyes, no light perception) differs in its mean value significantly from the curve of normal subjects but also remarkably from that of people seeing hand movements or having light perception. Even so, in all the above-mentioned tests we found that the levels of those blind people with bilaterally artificial eyes or those with no light perception were the lowest ones" [Hollwich & Dieckhues 1980, p. 191].

Furthermore, they studied the Adrenocorticotropic hormone (ACTH) and cortisol levels in patients temporarily blind in both eyes by cataracts.

"We examined the levels before and after removing the cataracts. Before extraction we obtained approximately the same low level as found by the blind. After the cataract extraction we found normal levels of ACTH and cortisol" [Hollwich & Dieckhues 1980, p. 193].

The result showed that strong artificial illumination of 3 500 Lux increases the release of ACTH and cortisol.

"We also studied influence of another artificial light source, approximately of the same luminous intensity (3,300 Lux) but of different spectral composition. We compared the effect of a cool-white fluorescent lamp with a tube simulating sunlight" [Hollwich & Dieckhues 1980, p.194].

"Due to its reduced spectrum involves first of all the health of the child in school but also the man working in his office or in industry [Hollwich 1979]. We should therefore bear in mind that artificial light for the human individual at least, remains a mere substitute; it can never fully replace natural light, which as a vital element like water and air, forms the basis of our health. Comparing both lamps, we found that the stress-like effect of the cool-white tube was absent in the sunlight-stimulating tube. Therefore, since the luminous intensity was approximately the same, the different metabolic and endocrine effects on human subjects are due to the different spectral components of the lamp" [Hollwich & Dieckhues 1980, p.194].

Hollwich attended Commission *Internationale de l'Eclairage*, the International Commission on Illumination (CIE) conference in 1978 and revealed his findings for the researchers at the conference. In publication 1979 he stated that:

"subsequent research concentrated on the brightest light at the lowest cost without raising the question of whether this different kind of light might have a harmful effect on the organism" [Hollwich 1979, p. 89].

"The unpleasant effect of high intensity artificial light comes from the stressful reactions elicited by increased metabolic activity" [Hollwich 1979, p. 90].

About the effect of light on the human and animal organism, Hollwich emphasises:

“*that the numerous effects of light on the human and animal organism that have been cited do not only produce a beneficial “natural stimulation” of the pituarity gland and the adrenal cortex; if the stimulus becomes too strong, they bring about an unspecific stress reaction” [Hollwich 1979, p. 90].*

“Ever since Seyle conducted his experiments, it has been known that stress of any kind leads to increased secretion of the adrenal cortex and that a build- up of stress factors or prolonged stress can result in the appearance of abnormalities and pathological changes in the organism. Therefore, the sensory influx of environmental stimuli can only be accommodated by the regulatory systems. This influx must occur in physiological doses in order to keep the regulatory systems intact. On the other hand, an increase in the absorption of environmental influences via the sensory organs can lead to an overload in the regulatory system causing pathological reactions in the organism” [Hollwich 1979, p. 90].

Hollwich describes the importance of daylight and how to handle the complementary artificial light.

“In order to avoid light pollution we should therefore utilize daylight as long as the season permits, both in schools and other places of work. If artificial illumination is necessary, it should be subject to variation by a stage-selector and should not exceed an average value of 500 Lux for the school and 700 Lux for the average place of work. Artificial light should approach the spectral range of natural light as closely as possible” [Hollwich 1979, p. 90].

Hollwich points out risks with the use of artificial light especially for those who have unstable autonomic nervous systems.

“In contrast to natural light, artificial light has an unnatural and hence unphysiological stimulatory effect; the greater the intensity of the light involved, the greater this effect. This is true in special measure for windowless working areas whose only source of light is fluorescent lamps in the form of bands of light. Unnecessarily high intensity of artificial light leads to stress like changes of metabolic and endocrine parameters [Hollwich et al. 1977] traceable in the blood chemistry, as we were able to demonstrate in our experiments in addition to the, adults who work in a so called light cage [Höfling 1973] and whose autonomic nervous system is unstable by nature may undergo an increase in their symptoms” [Hollwich 1979, p. 96].

“Whereas natural daylight is subject to continuous fluctuations in brightness and colour because of cloud formation, sunrise, and twilight, artificial light evinces monotony in brightness and colour lasting from the moment the light is turned-on until it is turned off. But we know from experience that for the biological regulatory mechanism to work properly, continuous variations in the amount of stimulation are necessary to sustain its power function. The adverse condition of permanent monotony carries with it the danger that this regulatory mechanism may be restricted in its role of governing the normal functions of the orgasm, thereby inducing pathological disturbances” [Hollwich 1979, p. 91].

Hollwich conducted research during 30 years. He concluded that daylight is essential for human’s animals and plants as well as to stay healthy and that the artificial light should mimicking daylight to reduce risks of a pronounced reaction of stress hormones.

“In order to avoid light pollution we should therefore utilize daylight as long as the season permits, both in schools and other places of work. Artificial sources of light should approach the spectral range of

natural light as closely as possible. There are two ways to reach this goal; first as Meiners [1977] and Hollwich et al. [1978] stated, by a combined form of light (fluorescent tubes and incandescent lamps) and, second, as Wurtman [1975] proposed, by a broad spectrum fluorescent lamp with a tube simulating sunlight" [Hollwich 1979, p. 94].

Maas, Jayson and Kleiber reported about the effects from spectral differences in illuminance on fatigue [Maas, Jayson & Kleiber 1974]. They investigated the experience of fatigue after a period of studying. No significant differences in the subjects´ self-reported states were identified. However, objective measurements revealed less perceptual fatigue and better visual acuity under lighting which closely approximated the spectral quality of natural sunlight than under traditional cool-white lighting [Maas, Jayson & Kleiber 1974]. Martel reported in 2005 about the possibility of improvement of the workplace environment. He stated that 51% of the US workforce reports that sleepiness on the job interferes with their work, and 68 % of employees complain about light in their offices. Workplace productivity can be improved not only with a change in the direction of lighting, but also with enhanced short wavelengths and full-spectrum lighting. In 1971 Thorington, Parascandola and Cunningham reported on new criteria for interior illumination, corresponding to nearest colour temperature for global radiation between 5 500 and 6 800 K. This is the environmental light composition which has influenced all photobiological action spectra on the earth´s surface and in this sense analogous to air, which thought variable in its composition is definable over a reasonable range of composition which has provided the life supporting atmosphere for the earth [Thorington, Paranscandola & Cunningham 1971].

The interaction of man and light is also studied in photobiology [Kendrick 1982]. The topic is described on their website (access dec. 2011). Photobiology:

"Include all biological phenomena involving non-ionizing radiation. It is recognized that photo biological responses are the result of chemical and/or physical changes induced in biological systems by non-ionizing radiation."
*"Photobiology studies in a scientific way the interaction of light and living organism**.** Photo biological responses are the result of chemical and/or physical changes induced in biological systems by non-ionizing radiation"*

The goals of photobiology are:
***(1)** To understand the basic mechanisms of photobiology; this knowledge can then be used to: **(2)** Develop ways to control the beneficial effects of light upon our environment; **(3)** Promote ways to protect against the detrimental effects of light on biological organisms, including humans; and **(4)** Develop photochemical tools and techniques for use in research, medicine, and industry. *The division between ionizing radiation and nonionizing radiation is typically considered to be 10 eV, (the energy required to ionize an oxygen atom).*

"Photobiology is a large discipline that includes studies of both the beneficial and harmful effects of light. It covers topics from the atomic level to that of ecological communities. Photobiologists use all of the tools of science to study the chemical and biological effects of light and other non-ionizing radiation".

"Sunlight is one of the most important elements in our environment. Plants harvest the energy of sunlight in order to grow, and thus to provide food for other organisms. Sunlight also provides information needed by organisms to trigger numerous biological responses. These are the beneficial wavelengths of sunlight.

Sunlight also has its bad side. The shorter wavelengths (or the longer wavelengths plus photosensitizes) can kill plants and other organisms, and produce cancer and other debilitating conditions in man.

Photobiology is the study of both the good and the bad effects of light. Studies range from the atomic level to the level of communities of organisms. Photo biologists use all of the tools of science to study the chemical and biological effects of light. Photobiology is an exciting and challenging field of science" (Constitution of the American Society for Photobiology, homepage for American Society for Photobiology accessed 2012)

The research by Anna Wirz-Justice and George Brainard concerns light for the support of diurnal rhythm [Wirz-Justice & Fournier 2010, p. 49; Brainard & Hanifin 2005, p. 315]. They claim that lighting design and photobiology have the possibility to improve quality of life.

Lighting design for support PPV post ipRGC: The theoretical framework shows that research about responses to PS and preferences for light is today (post ipRGC) in a start up phase. The process of transferring knowledge from research in physiology into lighting design has recently started. The research in the human physiological responses to PS shows the importance of daylight [Hollwich 1979]. Hopkinson did research in design of daylight [Hopkinson 1963, 1969; Hopkinson, Petersbridge & Longmore 1966] and worked with the distribution of light in the space that supported the architect's idea about the space. 30 years later, Pechacek, Andersen & Lockley developed a preliminary method for doing a prospective analysis of the circadian efficacy of daylight with applications to healthcare architecture. The quotations show the change in the complexity regarding demands on lighting designers today compared to 10 years ago. Pechaceck, Anderson and Lockley point out the complexity of the lighting application of tomorrow.

"Recent studies have attempted to link environmental cues, such as lighting, with human performance and health, and initial findings seem to indicate a positive correlation between the two. Light is the major environmental time cue that resets the human circadian pacemaker, an endogenous clock in the hypothalamus that controls the timing of many 24-hour rhythms in physiology and behaviour. Insufficient or inappropriate light exposure can disrupt normal circadian rhythms which may result in adverse consequences for human performance, health and safety. This paper addresses the problem of prospective analysis of building architecture for circadian stimulus potential based on the state of the art in photobiology. Three variables were considered in this analysis: lighting intensity, timing, and spectrum. Intensity is a standard design tool frequently used in illuminating engineering. Timing and spectrum are not commonplace considerations, so the analysis that follows proposes tools to quantitatively address these additional requirements." [Pechaceck, Anderson & Lockley 2008].

"Light affects humans on physical (Bergman and others 1995), physiological (Lockley 2008, In Press), and psychological levels (Farley & Veitch 2001), though the results are not always conclusive (Knez

2001). As the relationship is complex, some level of simplification is necessary in order to make an objective assessment of the human health-light connection and we chose to pursue the human health-light connection from a physiological perspective." [Pechaceck, Anderson & Lockley 2008].

"The use of physiology as inspiration in architectural design finds precedent in the work of architects such as Richard Neutra [Neutra 2007]. By studying the relationship between human physiology and light, research in photobiology, especially circadian photoreception, has advanced to a point where specific lighting implications can be proposed. Previous research has reported dramatic healthcare outcomes in relation to the quality of daylight environments [Walsh et al. 2005][Beauchemin & Hays 19989 [Wilson 1972] although the mechanism and photoreceptor systems mediating these effects are as yet unknown."[Pechaceck, Anderson & Lockley 2008].

"This paper will build upon specific biological findings to propose methods by which circadian illumination may be considered in building design. From the literature, it appears that there are approximately five critical aspects to circadian rhythm: intensity, timing, duration/pattern, photic history, and spectrum [Lockley 2008, In Press] [Veitch and others 2004]. The timing and spectral requirements for circadian illumination differ enough from other forms of illumination, such general and task illumination, to warrant consideration of their impact upon lighting design" [Pechaceck, Anderson & Lockley 2008].

"The objective of this paper is to describe the characteristics of (day) light that may promote human health by providing lighting for the appropriate synchronization of circadian rhythms, and to use these findings to make specific (day)lighting recommendations, grounded in biological findings. Specific metrics and findings will be discussed but it is the relative evaluation and improvement in circadian efficacy which is of concern. In other words, these findings should not be taken as an absolute measure of circadian efficacy or health potential because the precise definition of the human circadian action spectrum C (λ) is still underway. For example, debate exists as to the extent of the contribution of rods and cones in addition to melanopsin, or whether non-visual photoreception exhibits spectral opponency, as demonstrated for vision. Similarly, there may be time of-day differences in the spectral sensitivity function, effects of prior photic history or inter-individual or inter-population differences that may have to be taken into account in applying these findings. Therefore, while we use a nominal definition of C (λ) in the current analyses, the findings of this paper are not specifically dependent on the curve presented, or any curve, and thus a consensus curve may be substituted into the process described here as knowledge advances. These data represent a starting point from which we can begin to address more practical and flexible solutions as needs inevitably arise" [Pechaceck, Andersen & Lockley 2008, p.1].

In the conclusion of their article Pechaceck, Andersson and Lockley points out the need of careful attention to the way daylight is designed in buildings [Pechaceck, Andersen & Lockley 2008].

"Little in the way of rigorous analysis exists in the emerging field of evidence-based design, however billions of dollars are committed to healthcare construction in the United States each year. This paper applies traditional scientific inquiry in an attempt to provide objective, quantitative analysis of specific health characteristics of light to arrive at specific recommendations for architectural design. Careful attention to the issues presented here should increase the circadian health potential of new building designs, and will likely contribute to improve patient outcomes pending validation through future research" [Pechaceck, Andersen & Lockley 2008 p. 1].

Other examples of research about physiological responses to PS are done by Vout J. M. van Bommel, a professor in physics.

"The effects of good lighting extend much further than we used to think. Recent medical and biological research has consistently shown that light entering the human eyes has, apart from a visual effect, also an important non-visual biological effect on the human body. As a consequence, good lighting has a positive influence on health, well-being, alertness, and even on sleep quality. Our better understanding of the diversity in lighting effects teaches us that new rules governing the design of good and healthy lighting installations are required. Thanks to the recent discovery of a novel photoreceptor in the eye and its probable distribution within the eye we can now begin to define these new rules. These will guide us to dynamic lighting installations: that is to say dynamic in lighting level and dynamic in tint of whiteness of the lighting colour. At the beginning of the industrial revolution, most people moved away from an outdoor daytime environment to an indoor daytime environment. The consequence of t his was 40–200 times less light for those not working very close to a window. We have now learned that this has a negative influence on health and well-being. However, thanks to the recent discovery of a novel photoreceptor in the eye and the understanding of the mechanism responsible for non-visual biological effects, we are now able to start defining lighting situations that ensure that healthy people remain healthy, even when having to work in a darker indoor environment. We do this by ensuring that they receive sufficient biologically active light at the moments when this is needed" [Van Bommel 2006].

The article written by Van Bommel [2006] along with the previously cited article written by Pechaceck, Andersen and Lockley [2008] are examples of research going into the complexity of the support of humans psychologically, physiologically and visually by the use of daylight and a daylight mimicking artificial light. Peter Boyce is another example of a lighting designer and researcher that widens the perspective of lighting design theoretically and goes into the new parts of lighting design, physiology and photobiology. In his book, *Human factors,* Peter Boyce writes about lighting design from a theoretical and practical aspect and about the visual system, the circadian system, light and health. Why bother, he concludes in *Human factors [Boyce 2003]*.

"In which case why is it necessary to continue lighting research at all, let alone attempt to improve it. There are two answers. The first is simply that the general standard of lighting could be better, particularly exterior lighting. Greater knowledge of how people respond to lighting will aid and encourage better practice. The second answer is that for most people is lighting important, although its value is often not appreciated until it is eliminated by a power cut. However for most people lighting is not an end in itself; it is a means to an end. The most widely recognized "ends" are increasing productivity, reducing energy consumption, enhancing health and improve the quality of life" [Boyce 2003, p. 520].

Interaction design: The research about the interaction of MLCS [Säter Paper I-X] is related to the ergonomic field. The process of the design that comprise the man, the tool and the space based on common knowledge and the theoretical framework is described in the TF by the author of the Thesis in steps 1-4. By the use of the lighting design process (LDP) steps 1-4 in a user centred way an interaction of MLCS is created that has the possibility to support the user PPV and to give the user an experience of lighting quality. Anders Liljefors and Bo Persson are precursors for this development in Sweden [Liljefors 2010; Persson 1996]. They have in common the human visual perception as the starting point for lighting design. They also use a clear vocabulary, dividing human experiences of light in the room from the measurements of the invisible PS. Since 2000, as previously mentioned, architectural light is related to an increasing extent to quality of life [Pechaceck, Anderson and Lockley 2008] and an increased concern about the subject. The post ipRGC research in lighting design has in common the need for a clear vocabulary dividing the human experience of the light in the room and the measured invisible and uncoloured photons [Liljefors 2010].

Light and colour: Colour is an important part of the interaction of MLCS. The chosen colours should keep a beautiful appearance and be comfortable to perceive in both high and low levels of daylight and artificial light. Research in colours and surfaces has an important role in the design of the well-functioning interaction of MLCS. Monica Billger, a Swedish interior designer and Professor in Architecture, has done research in colour appearance [Billger 1999]. Her studies concern in what way colours affect each other when seen in the same enclosed space. Paradigm shift in type of light sources put high demands on the adaption of colour and surfaces chosen for a space. Maud Hårleman, a Swedish architect, investigated the changes in colour appearance in rooms connected to south and north facades [Hårleman 2007]. The palette of colours used in the room need to be balanced together in a way that handles the daylight and artificial light on high and low levels and coming from south and north, without creating an unpleasant appearance or becoming visually uncomfortable. The research of Billger and Hårleman shows that colours affect each other and need to be chosen according to the light and the colours present in the space. The way that the space opens up for daylight imprints the experience of the room [Olsson 2004]. The colours and surfaces in the room interact with PS by transmission, absorption and reflection (TAR) [Liljefors 1999]. The way daylight appears in the room and is transmitted through, absorbed into and reflected from the colours and the surfaces, contributes to the way the room is experienced visually. Sven Hesselgren is an early example of the development of theory about the sensory experience of the room [Hesselgren 1969] not often seen in literature. Anders Liljefors and Sölve Olsson [Olsson 2004] share the same sensory approach to the light and the room as Hesselgren. The work of Malnar and Vodvarka is, in the same way, an example of theory about architecture with the ambition to increase the space related human pleasure from a sensory standpoint [Malnar & Vodvarka 2004]. Graciela Tonello reported in 2004 about to what extent variations in natural daylight as well as indoor lighting and decoration affected the mood of people working indoors. She investigated the impact from colours on decreasing the sensory deprivation. Throughout the study the participants reported a more positive mood in the colourful environment. The difference was consistent over the year but became significant only during autumn and winter. Tonello points out the importance of a colourful environment [2004]. Faber Birren worked with the same questions and related the colourful environment to decreased sensory deprivation among end-users. [Birren 1979, 1972]. Not only colour but also culture is related to light. Jan Garnert claims that light seen from an historical cultural aspect shows that technology and culture interact [2004]. This is an important aspect especially for elderly users.

***TF part 3**. Which are the functions of melanopsin and ipRGC and how can a relation to lighting design and light-related basic health be formulated?*

In 1923, three PhD students in medical genetics, Keeler, Sutcliffe and Charifee, made interesting findings from research about mice with degenerated retina [Keeler, Sutcliffe & Charifee 1928, p.477-481; Van Gelder 2008, p. 38-39]. Although possessing a lack of rods and cones, the mice still had visual reflexes. Keeler suggested that another unknown photosensitive cell must be present in the retina.

"In 1923, a first year Harvard graduate student named Clyde Keeler was given the assignment of comparing histological specimens from the eyes of several vertebrates. Keeler had caught some wild mice in his dormitory room at the Busey Institute and was breeding them as a hobby. He sacrificed one of these mice for his project. His advisor, Samuel Detwiler, was furious when he saw the sections, which were devoid of all photoreceptive rods and cones. Assuming that Keeler had badly botched the sectioning. Detwiler threatened to expel him from the graduate program [1]. Keeler, however, astutely realized that this was not a histological artefact; his mice had indeed lost their photoreceptors [2]. He soon showed that these mice inherited their retinal degeneration as a recessive allele of a single gene (which he called rodless*[3], allelic to the modern* rd *mutation). Keeler also realized these mice phenocopied the human disease retinitis pigmentosa. Three years later, Keeler published a remarkable paper, entitled 'Iris movements in blind mice', in which he demonstrated that the* rodless *mice — although apparently visually blind — continue to show pupil constriction in response to light [4]. Keeler wrote: "...we may suppose that a* rodless *mouse will not see in the ordinary sense. Nevertheless, we can imagine the possibility of other forms of stimulation by light, such as through absorption by pigment cells, the contraction of the iris, or direct stimulation of the internal nuclear layer of the rods" [Van Gelder 2008 , pp. 38-39].*

Hanifin and Brainard describe the way humans absorb photons [Hanifin & Brainard 2007].

"There is a basic principle shared by all species in their ability to respond to light stimuli: all photo biological responses are mediated by organic molecules that absorb light quanta and then undergo physical-chemical changes. These light-induced changes subsequently evoke broader physiological responses within the organism. This process is termed photo transduction and the specific molecular complexes are called photo pigment. As a rule, these photoactive molecules do not absorb energy equally across the electromagnetic spectrum. Photo pigments have their own characteristic wavelength absorption spectrum that depends on their atomic structure" [Hanifin & Brainard 2007, p. 87].

Despite 200 years of medical research on vision the findings of melanopsin and ipRGC came late [Berson et al. 2001]. It is a strange circumstance that the researchers were surrounded by the trigger (PS) and used the system (melanopsin and the ipRGC) while looking for it.

Homeostatic balance and light: Walter B. Cannon (1871-1945), an American experimental physiologist, had a holistic approach to the human body and coined the term homeostatic activity. He described how changes in the internal or external environment were counteracted to enhance the steady state and to improve likelihood for survival. Cannon [32] stated that "*it must be other triggers for hormonal release*"than known at the time. Keeler, Sutcliffe and Charifee were on the track for the knowledge Cannon needed, but the existence of melanopsin and ipRGC in the retina was not known until after 2000.

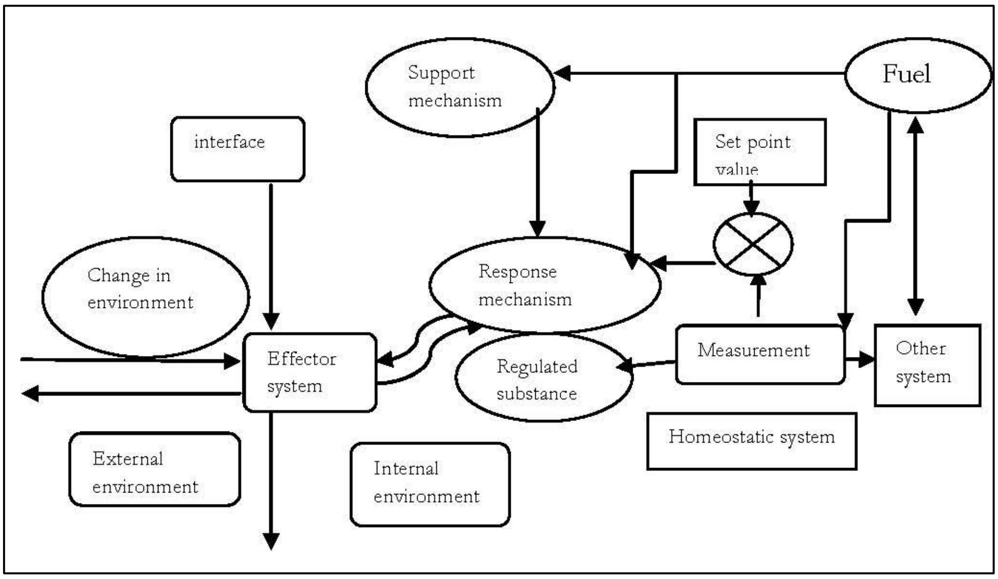


Figure1. Cannon´s model of Homeostasis.

Homeostasis is related to lighting science due to the fact that PS is a strong trigger for hormonal release and homeostatic balance. According to the following quote from Dr. Martin Winkler at the Center for Applied Medical Science at University for Applied Science in Luneburg published on their web page, web4help, every illness is a result of lost homeostasis:

"Just as we live in a constantly changing world, so do the cells and tissues survive in a constantly changing microenvironment. The 'normal' or 'physiologic' state then is achieved by adaptive responses to the ebb and flow of various stimuli permitting the cells and tissues to adapt and to live in harmony within their microenvironment. Thus, homeostasis is preserved. It is only when the stimuli become more severe, or the response of the organism breaks down, that disease results - a generalization as true for the whole organism as it is for the individual cell." [Robbins et al.1984].

"Homeostasis is an ideal state of equilibrium, when all the body´s different parts and subsystems is functioning in an optimal way and fulfil all needs of the individual, both psychologically and physiologically. When homeostasis is disturbed, the body tries to recover by, adjusting one or more of the body´s functions. This stress adapting process includes an activating of the HPA-axis (Hypothalamic-Pituitary- Adrenal Axis). A chain of events that control the release of Cortisol which is in a prosaic talk a part of the stressystem in the body that together with the autonomonys nervsystem and the endocrinological functions prepares the body for stress. Severe and long lasting stress can lead to an unbalance in the homeostasis. This can lead to not only psychological injury but also psychosomatic symptoms "[Martin Winkler 2008 Web4help, accessed 2012-01-11].

Martin Winkler mentions the importance of the triggers for hormonal release being balanced and not static during a long time. In nature static levels of light are not seen, instead levels of light always change. Stephen M. Pauley mentions the hormone melatonin (MLT) that induces sleep and regulates a balanced physiological state in humans.

"MLT is a hormone that has sleep-inducing properties and regulates a balanced physiological state in humans [59–61]. "MLT also has substantial free radical scavenging/antioxidant and anticancer activity in experimental systems [45, 60, 61, and 63]. This knowledge has obvious relevance to human health [22, 26, 54, 60, 61, 66, and 79]" [S.M. Pauley 2004, p.591].

Brainard and Hanifin mention that environmental light plays a fundamental role in regulating homeostasis.

"These seminal discoveries showed that environmental light played a fundamental role in regulating homeostasis and circadian physiology. Together, these breakthroughs enabled investigators to begin using the tools of photobiology to explore circadian physiology" [Brainard & Hanifin 2005, p. 315].

James Jerome Gibson, as earlier mentioned an American psychologist, did research in human perception. He saw perception as a co-operating system with the function to guide the human toward survival in a constantly changing internal and external environment. He developed an ecological approach to his research in psychology and pictured humans staying on earth surrounded by light, air and water. He saw the human senses in co-operation with each other, receiving information from the external or internal environment [Gibson 1950, 1966]. Today post ipRGC, it is possible to see that Gibson pictured a holistic interaction of man, light, air, water, sound and nature in the outdoor environment. This ecological picture of the human interaction with the external or internal world has, together with TAR, been developed further by Anders Liljefors, the precursor for the idea of the interaction MLCS seen in the indoor environment developed in the Thesis.

Seeing and light: Gibson considered human sight as the crown in the system of perception. Keeler, Sutcliffe and Charifee was in the beginning of revealing the information that Gibson needed to show the physiological mechanism behind the physiological response (direct action) to the scanning of the external trigger PS. The findings of ipRGC were not accepted until after 2000**.**

After World War II Fritz Hollwich, a German ophthalmologist, found evidence for daylight being essential to humans [Hollwich 1979] and light being related to hormonal release. Hollwich saw recovery after cataract surgery and similar diseases among his patients. He went on with research about the way artificial light sources affected the subjects´ hormonal levels in the bloodstream and compared this to when the subjects stayed in daylight. He found a higher release of stress hormones when the subjects stayed in artificial light and that the levels of hormones declined after two weeks in daylight. When Hollwich did animal research, he saw that birds became physically different when they grew up in a monochromatic artificial light for a short period of time during the day compared to birds from the same clutch that grew up in daylight [Hollwich 1980]. Light and health was not a common issue at the time. Methods for lighting design were not affected by Hollwich´s findings despite extensive publication.

ARAS and DRAS and light: Rickard Kuller (1939-2009), Full Professor, Ph.Lic in psychology, DSC in architecture, early found an interest in the topic light, health and environment [Kuller 1981]. Kuller worked with PS and the connection to basic human functions and systems. He investigated user's experiences and developed instruments such as semantic scales for the evaluation of the human experience of room and light settings (SMB). Kuller studied physiology to see in what way arousal through Ascending Reticular Activating System **(**ARAS) and decrease in arousal by Descending Reticular Activating System (DRAS) worked. He investigated the physiological impact from color and light in the environment on the human. Researchers working early with light, health and environment were not given full recognition for their work at that time. Today, the importance of their work is well known and is a part of light being designed to meet the human needs for PPV support.

Transduction, melanopsin and ipRGC: In the beginning of 2000, the physiological explanation came through the findings in 1923 by PhD students Keeler, Sutcliffe and Charifee, Cannon´s question 1932 and Hollwich´s findings after World War II. It was reflexes induced by phototransduction through melanopsin and ipRGC that Keeler noticed. It was daylight that by transduction through melanopsin and by action potentials to the brain cured Hollwich´s patients. PS was the agent for hormonal release that Cannon looked for. The work of Gibson that was criticised for seeing humans as animals could at last be seen from the perspective of the human transduction of PS in the environment giving hormonal release and a direct impact on the human PPV. Transduction through melanopsin in the ipRGC let through some of the wavelengths in daylight and from artificial light [Hanifin & Brainard 2007, p. 87]. PS alters melanopsin in charge and generates an action potential to the brain and reports information to the body clock. The phototransduction starts up a domino-effect of physiological processes in humans, not fully known today [Hanifin & Brainard 2007, p. 87].

"Key discoveries in human chronobiology are related to the impact of light. Recognition of the so-called 'biological effects of light' by lighting manufacturers has led to interest in developing new lighting systems that integrate this knowledge. Is it time for the medical mainstream to take notice of what neuroscientists know about the body clock? And is it also time for architects to do so? These questions were explored at a symposium for architects, lighting engineers and manufacturers, initiated by Society for Light Treatment and Biological Rhythms (www.sltbr.org), in order to develop approaches to bridge the gap between these disciplines." [Wirz-Justice, Fournier 2010, p.44].

The information from PS entrains the user to the light at the site where the user lives and withholds a rhythm of 24 hours. PS is let through melanopsin and ipRGC and adjusts the rhythm toward the 24 hour rhythm and reports information to the body-clock. [Hannibal & Fahrenkrug 2006].

"Ocular exposure to… has a range of neurobiological effects in humans, including resetting the endogenous circadian pacemaker, acute suppression of pineal melatonin production, elevation of core body temperature and heart rate and stimulation of cortisol" [Lockley et al. 2006, p. 161].

Steven Lockley, an associate Professor of Medicine at Harvard Medical School and Neuroscientist at the Division of Sleep Medicine Department of Medicine Brigham and Women's Hospital and colleagues, describes how the human physiological response to light has a range of neurobiological effects in humans including resetting the endogenous circadian pacemaker, acute suppression of pineal melatonin production, elevation of body core temperature and heart rate, and stimulation of cortisol in the early morning. [Lockley et al. 2006, p. 161]. The action spectrum in PS was investigated to find out the wavelengths related to hormonal release and to diurnal rhythm [Brainard & Hanifin 2005, p.p. 316-317].

Second sight, image forming ganglion cell: Hicks wrote about an article of Ecker et al. 2010 concerning melanopsin-expressing retinal ganglion-cell photoreceptors: cellular diversity and role in pattern vision. [Neuron 67 p.p. 49–60]. The article dated 2011 is called second sight reporting that ipRGC are involved in forming vision. He describes further ipRGC as involved in many common diseases today and that ipRGC projects to more parts of the brain than previous known. Hick's states that ipRGCs:

"Ever since the existence of directly photosensitive retinal cells distinct from rod and cone photoreceptors exploded onto the scene some 10 years ago, the field has been one of the most fertile and exciting in vision research. It took a long time to convince a skeptical academic establishment that light detection was present in mammals even in the complete absence of rods and cones, but the definitive proof was supplied a decade ago when directly photosensitive retinal ganglion cells were identified. This specialized sub-population, representing only 1–2% of total ganglion cells, expresses a newly discovered visual pigment termed melanopsin, distantly related to the classic visual opsins in rods and cones. To sum up the numerous groundbreaking discoveries concerning this class of cell, the idea grew that whereas rods and cones subserved "image-forming" vision, in contrast the "intrinsically photosensitive retinal ganglion cells" or ipRGC subserved "non-image forming" vision. That is, their characteristics (morphology, physiology, spectral sensitivity and target projection sites within the brain) indicated they were responsible for major functions such as synchronization of the circadian clock (located in the ventral hypothalamus) with external light cues, pupillary constriction, pineal melatonin secretion, and sleep/wake cycles. And even though it quickly became clear that ipRGC also relied upon input from the classical rod and cone circuits, these two aspects of visual processing—image forming and non-image forming vision —were considered as largely separate. But in such a rapidly evolving field of research, things are (still) becoming more complicated before they become simpler: recent papers such as the article by Ecker and associates [1] show that the range of functions attributable to ipRGC actually goes far beyond what was originally thought, and that use of light information on a systems level is far more pervasive than we imagined. Before going any further, let it be made clear for a medically-oriented readership that ipRGCs play important roles in health and disease, both directly and indirectly: melanopsin mutations segregate with seasonal affective disorder, some 40% of blind people have sleep problems (either insomnia or daytime somnolence), the ipRGCs have been linked to migraine and photophobia; and nightshift workers (i.e., exposed to non-natural lighting regimes) have significantly higher incidences of metabolic disorders, depression and cancer. Light exposure has even been shown to affect adrenal gland function (cortisol secretion).But coming back to the study in question, using a genetic strategy involving high amplification of the reporter gene (either green fluorescent protein or alkaline phosphatase) the authors showed that melanopsin-containing retinal ganglion cells were more diverse (five distinct sub-types compared to the previously identified three), far more numerous (some 3–

4 fold) and projected to many more areas in the brain than had been demonstrated previously. These newly described heavily innervated projection sites include the lateral geniculate nucleus, the principal relay centre for "conventional" retinal ganglion cells involved in image forming vision. This observation begged the question of whether ipRGC could also be involved in image forming vision" [Hicks 2011, p. 313].

Today, more is known about the complicated roles of the classical rods and cones and the ipRGC in the image forming process and the co-operation of the types of photosensitive cells [Hicks 2011; Ecker et al. 2010].

Sleep and wake up habits: Prof. Dr. Roenneberg at Institut für Medizinische Psychologie Ludwig-Maximilians-Universität München has, with fundings from the EU, performed research in the human diurnal rhythm. Being psychologically ill is often seen at the same time as an internal desynchronisation to nature's dark and light cycle. Roenneberg et al. demonstrated in a study of 55,000 subjects that humans show large inter-individual differences in organising their behaviour within the 24-h day [Roenneberg et al. 2007].

"Humans show large inter-individual differences in organizing their behavior within the 24-h day—this is most obvious in their preferred timing of sleep and wakefulness. Sleep and wake times show a near-Gaussian distribution in a given population, with extreme early types waking up when extreme late types fall asleep. This distribution is predominantly based on differences in an individual´s circadian clock. The relationship between the circadian system and different "chronotypes" is formally and genetically well established in experimental studies in organisms ranging from unicells to mammals" [Roenneberg et al. 2007, p. 429].

The physiological link to the sun: David M. Berson, Professor of Medical Science at Brown University provided the first electrophysiological recordings from intrinsically photosensitive retinal ganglion cells [Berson, Dunn & Takao 2001; Keeler 1928; van Gelder 2008; Hannibal et al. 2002]. Ignacio Provencio, an American neuroscientist and Associate Professor at the University of Virginia is the discoverer of melanopsin, the photo pigment found in specialised photosensitive ganglion cells of mammalian retina [Provencio et al. 2000]. The melanopsin in ipRGC that lets through some of the wavelengths in PS in the environment and by the development of an actionpotential reports to the body-clock, and starts up a domino-effect of processes in the human body [Hanifin & Brainard 2007, p. 87-88; Provencio et al. 2000, p. 600].

"Here we report the identification of a novel human opsin, melanopsin that is expressed in cells of the mammalian inner retina" [Provencio et al. 2000, p. 600].

The increased knowledge about melanopsin and action spectrum for wavelengths, and human diurnal rhythm are investigated from many aspects. Shanti et al. report that the circadian timing system is mediated by a multi-component photoreceptive system, consisting of rods, cones and melanopsin-expressing intrinsically photosensitive retinal ganglion cells (ipRGC) and assume that the melanopsin system is rather insensitive for lower levels of light [Santhi et al. 2011].

"Endogenous circadian clocks remain in synchrony with daily and seasonal changes in the external environment through sensitivity to the light-dark cycle [1–3], which until the introduction of artificial light, was determined solely by the Earth's rotation around its axis and the sun. The consequences of the widespread prevalence of artificial light in the evening may be considerable, given the rapidly growing evidence for the effects of light on brain function [4, 5], and the health consequences of light–induced disruption of circadian rhythmicity and associated sleep deprivation [6, 7]. The artificial light we are exposed to in the evening is assumed to have led to a delay of sleep onset relative to dusk, not only because this light allows us to engage in activities that require vision, but also because it suppresses the secretion of the pineal hormone melatonin [8, 9], thereby delaying its nocturnal rise [10], which is closely associated with the increase in sleep propensity and the timing of sleep onset [11, 12]. Surprisingly, the validity of this assumption has not been investigated in detail" [Santhi et al. 2011].

"The effect of light on the circadian timing system is mediated by a multi-component photoreceptive system, consisting of rods, cones and melanopsin-expressing intrinsically photosensitive retinal ganglion cells (ipRGC) [13–19]. This photoreceptive system, and in particular the melanopsin system, has unique intensity and wavelength-dependent sensitivity characteristics [20, 21]. Based upon basic studies in humans investigating the effects of monochromatic light, it has been estimated that the peak sensitivity of melanopsin is at approximately 480 nm, which is shifted considerably towards the short ...spectrum, compared with both the photopic (550 nm; cones) and the scotopic systems (505 nm; rods) [22]. In both humans and rodents, the melanopsin system is assumed to be relatively insensitive [19, 23, 24] and to only exert a significant influence on circadian physiology at relatively high intensity. In fact, whether melanopsin plays a dominant role in the effects of light on melatonin and sleep continues to be debated [24, 25]" [Santhi et al. 2011].

TF part 4. *Can patterns be seen in responses to PS and in preferences to light when subjects stay in daylight or artificial light in the room and light settings in the studies?*

Light and personality: Research in responses to PS and preferences to daylight and artificial light can be seen developed from many aspects. Level of arousal is basically a stress response and personality might affect the response to stress. Flaa et al. conclude that their study performed in 2007 demonstrates how certain personalities may be a threat against health and well-being, as exaggerated cardiovascular responses to stressful situations are well-known predictors of future morbidity and mortality [Flaa et al. 2007, p. 1751-59].

"Our findings indicate that cardiovascular and cathecholamine stress reactivity is dependent on different personality traits, without any single trait clearly dominant" [Flaa et al. 2007, p. 1755].

The Pörn holistic health theory, used by WHO target 9 and 13-17 of health and adopted by the Member States of European Union is related to heart and coronary disease and the environment seen as a tool for health.

"Pörn´s theory explains the relationship between sleep and health. Sleep is a basic need, important in physical and psychological recovery" [Edéll-Gustavsson & Ek 1992, p. 29].

Light and entrainment: The human diurnal system is shown affected by prior photic history [Chang, Scheer & Czeisler 2011]. Chang et al. show results on evidence for dynamic adaptive changes in the sensitivity of circadian ocular photoreception. This plasticity has important implications for the optimisation of light therapy for the treatment of circadian rhythm sleep disorders but needs also to be taken into account for indoor lighting.

"*Light is the most potent stimulus for synchronizing the endogenous circadian timing system to the 24 h day. The timing, intensity, duration, pattern and wavelength of light are known to modulate photic resetting of the circadian system and acute suppression of melatonin secretion. The effect of prior photic history on these processes, however, is not well understood. Although previous studies have shown that light history affects the suppression of melatonin in response to a subsequent light exposure, here we show for the first time that a very dim light history, as opposed to a typical indoor room illuminance, amplifies the phase-shifting response to a subsequent sub-saturating light stimulus by 60–70%. This greater efficacy provides evidence for dynamic adaptive changes in the sensitivity of circadian ocular photoreception. This plasticity has important implications" [Chang et al. 2011, p. 1095].*

Light, sympathetic nervous system and homeostatic balance: In a meta-analysis written by Goldstein and Kopin about human responses to stressors, the authors mention that Cannon, in the early 20th century, proposed that the sympathetic nervous system and the adrenaline function acted as a coordinated system maintaining homeostasis. The concept Cannon made regards rapid activating of the sympathoadrenal system preserving the internal environment by producing compensatory and anticipatory adjustments to preserve homeostatic balance and enhance likelihood of survival.

"The sympathoadrenal system is one of the major pathways mediating physiological responses in the organism. The sympathoadrenal system plays an important role in the regulation of blood pressure, glucose, sodium and other key physiological and metabolic processes. In many disease states, the sympathoadrenal system is affected and by corrective physiological responses the sympathoadrenal system preserves homeostasis; many therapeutic agents are either adrenergic activators or inhibitors. Therefore, measurements of the components of the sympathoadrenal system and the activity of the sympathoadrenal system have been of major interest for decades. Levels of plasma (p-) noradrenaline (NA), the sympathetic neurotransmitter, have been used to indicate activity of the neuronal sympathoadrenal component, while adrenaline (Adr) levels indicate activity of the hormonal adrenomedullary component of the sympathoadrenal system" [Goldstein & Kopin 2008, p. 112].

"In the early 20th century, the American physiologist, Walter B Cannon, proposed that the sympathetic nervous system (SNS) and the adrenal gland hormone "adrenin" (which came to be known as epinephrine (EPI) or adrenalin) function as a coordinated system maintaining homeostasis (a word he coined) during emergencies such as "fight or flight "situations (a phrase he introduced). According to Cannon´s concept, rapid activation of the sympathoadrenal system preserves the internal environment by producing compensatory and anticipatory adjustments that enhance the likelihood of survival. In 1939, Cannon formally proposed EPI as both the active principle of the adrenal gland and as the neurotransmitter of the sympathetic nervous system (Cannon and Lissak 1939) consistent with the functional unity of the sympathoadrenal system" [Goldstein & Kopin 2008, p. 112].

"Hans Seyle popularized stress as a scientific idea (Seyle1936, 1956). Seyle defined stress as the nonspecific response of the body to any demand imposed on it. (Seyle 1974)… It was later demonstrated that these changes were associated with, and to at least some extent resulted from, activation of the hypothalamic-pituarity-adrenocortical (HPA) axis. Steroids released into the circulation from the

adrenal cortex contribute to resistance but also be responsible for pathological changes. Selye´s concept that prolonged stress can produce physical diseases and mental disorders is now widely accepted. A third concept considered in these meta-analyses is that in response to situations that stimulate adreno-medullary secretion, there is concurrent activation of the HPA axis" [Goldstein & Kopin 2008, p. 112].

In an article, Davydov et al. [2007] report findings about homeostatic balance.

"The homeostatic hypothesis [34] predicts that a decrease or increase in any arousal factors (e.g. cortisol) improves mood if it shifts general arousal towards a homeostatic level, but a decrease or increase in an arousal factor disturbs mood if it moves general arousal away from a homeostatic level. Individuals that are not in a midarousal state will show fewer disturbances in their emotional state, whereas either downward or upward deviation from an optimal arousal level will be associated with greater disturbance. An optimal level of arousal is determined by the joint impact of arousal –related factors in which the higher or lower level of one factor is compensated for by the higher or lower level of another arousal factor. Although different arousal related factors may have different effects on arousal, a hyper arousal condition (e.g. complex of both higher and lower stress hormone levels) should be associated with negative mood states, and a hypo arousal condition (e.g. complex of two lower stress hormone levels) should also be related to negative mood states, whereas a midarousal *condition (e.g. complex of both higher and lower stress hormone levels) should be related to positive mood states" [Davydov et al. 2007, p. 322].*

Action spectrum and light: Research done by G.C. Brainard and J.P. Hanifin is concerned with (among many other aspects) a combinations of wavelengths that have an impact on the user. Research about detection of action spectrums and the way narrow bands in nm affects humans is a useful tool for the development of artificial light sources.

"In the field of photobiology, an action spectrum is one of the principal tools for identifying the wavelengths that initiates a light–induced response. Strictly defined, an action spectrum is the relative response of an organism to different wavelengths of…electromagnetic radiation" [Brainard & Hanifin 2005].

Brainard reported, in 2001 a peak sensitivity for plasma melatonin suppression at 464 nm (446-477 nm). In 2001, Thapan, Arendt & Skene reported peak sensitivity for melatonin suppression at 459 nm. (457-462 nm) [Brainard et al. 2001; Thapan, Arendt & Skene 2001]. Newman et al. showed, in [2003], that absorption spectrum for melanopsin is most strongly exited by short wavelengths, 420-440 nm. In 2011, Enezi a. J. et al. [2011] showed action spectrum for melanopsin**.**

"Photoreception in the mammalian retina is not restricted to rods and cones but extends to a small number of intrinsically photosensitive retinal ganglion cells expressing the photo pigment melanopsin. These ipRGCs are especially important contributors to circadian entrainment, the pupil light reflex, and other so-called nonimage-forming (NIF) responses. The spectral sensitivity of melanopsin photo transduction has been addressed in several species by comparing responses to a range of monochromatic stimuli. The resultant action spectra match the predicted profile of an opsin: vitamin A–based photo pigment (nomogram) with peak sensitivity (λ_{max}) around 480 nm. It would be most useful to be able to use this spectral sensitivity function to predict melanopsin's sensitivity to broad-spectrum, including "white,"

*lights. However, evidence that melanopsin is a bistable pigment with an intrinsic light-dependent bleach recovery mechanism raises the possibility of a more complex relationship between spectral quality and photoreceptor response. Here, we set out to empirically determine whether simply weighting optical power at each wavelength according to the 480-nm nomogram and integrating across the spectrum could predict melanopsin sensitivity to a variety of polychromatic stimuli. We show that pupillomotor and circadian responses of mice relying solely on melanopsin for their photosensitivity (*rd/rd cl*) can indeed be accurately predicted using this methodology. Our data therefore suggest that the 480-nm nomogram may be employed as the basis for a new photometric measure of light intensity (which we term "melanopic") relevant for melanopsin photoreception. They further show that measuring light in these terms predicts the melanopsin response to light of divergent spectral composition much more reliably than other methods for quantifying irradiance or illuminance currently in widespread use" [Enezi et al. 2011, p. 314]***.**

The light for an indoor working place based on recommended values in EN 12464-1:2011 has the same light and lighting application day and night. Reiter et al. [2011] report on research about cancer and light at night.

"Epidemiologists were the first to report that cancer incidence was exaggerated in airline hostesses [46] and in women who worked night shifts for prolonged periods [47]. The majority of these observations claimed an elevated incidence of breast cancer in women who commonly disturbed their circadian/melatonin cycles; these findings have been summarized in a number of thorough reviews within the last decade [48-51]. The outcomes of subsequent studies claimed that not only breast cancer in females but likewise prostate cancer was also exaggerated in males experiencing abnormal or irregular photoperiods which curtailed the total amount of melatonin produced and/or frequently caused unusual circadian rhythms [52, 53]. The prevalence of other cancer types, e.g., colorectal cancer, has also been reported to be increased in individuals who live in metropolitan areas where light exposure at night is common" [Reiter et al. 2011, p. 17].

"Experimental evidence is compelling that melatonin is an endogenously-produced oncostatic agent *[57-61] and as a consequence, its frequent suppression at night as a result of any means including excessive illumination, may increase the possibility of cancer initiation and/or exaggerate the rate of growth of established tumours in humans. A variety of mechanisms have been described by which a reduction in melatonin levels may stimulate tumour growth [62-70]. Moreover, melatonin may also reduce the likelihood of tumour metastases [67] because of its ability to modulate the cellular cytoskeleton [71] "[Reiter et al. 2011, p. 17].*

"Recently, it was proposed that circadian disruption and melatonin suppression may be associated with a generalized elevation of all cancer subtypes [54]" [Reiter et al. 2011, p. 17].

"With the advent of artificial light and the extension of the photoperiod into the night and, perhaps worse yet, the acute exposure to light at night, the biological clock receives misinformation and makes adjustments to physiology which are inappropriate for the time of day. When organisms are repeatedly exposed to these inappropriate periods of light, the accumulated time-inappropriate physiological adjustments should be expected to lead to pathologies" [Reiter et al. 2011, p. 19].

"To date, the scientific information in this field is incomplete, but progressively more researchers are becoming concerned about the potential path physiological consequences of light at the wrong time. Like most aspects of our environment, humans are clearly polluting the night with light. Only further research

will clarify what light pollution means for human physiology; however, it would seem the effects will not turn out to be beneficial" [Reiter et al. 2011, p. 19].

Light and individual sensitivity in the central nervous system (CNS): Research in preferences to daylight and artificial light can be seen developed from many aspects. Visual comfort is an individual experience. From a neuro-physiological standpoint David Ingvar wrote about the need for individual levels of light as a matter of an adaption to individual neurophysiologic sensitivity [Ingvar 1981 p 53]. Ingvar shows that individual sensitivity is a basic foundation for the experience of visual comfort.

"It is important to emphasize that already in the channels to CNS can huge differences be seen in sensitivity. Because of this it is adventurous to define an ideal environment or light in absolute measurements. Retina is changing in size when displayed for varied amount of light. The central interpretation is also very different. It is important to have a plastic view of the nervous system capability to interpret the input from light on different levels of intensity" [Ingvar 1981, p. 53].

Light and age: Light and age is an important variable in the user centered lighting design process. When a specific static level of light is recommended, the interindividual differences between subjects of the same age is not supported, and neither of older subjects, mentions David Ingvar.

"The older central nervous system especially the very old, senile and dement, cannot handle information in the same way as the young nervous system"[Ingvar 1981, p. 56].

Light and physiological optics: The research of Lucia Ronchi concerns physiological optics and human visual perception. Her result shows that the visual sight has a variability in the function during the day.

"Our results confirm that the diurnal variability enlarges the range of response, compared to the short-term variability. Now plotting our data versus the time of day the possibility of a diurnal rhythmical behaviour, modulated by an intradian 4-hour period variability (3; 5-6] is encouraged, and a possible influence on it of the SPD of the source seems to emerge" [Ronchi 2010, p. 6].

"In early textbooks on physiological optics the problem of the variability of the response to a constant stimulus has been widely discussed, calling into play the statistical treatment of data, the implications when formulating a standard, the underline data and so on" [Ronchi 2009, p. 25].

"In 1951 Graham [8] reported that "it has been known for a long time that the discrimination is influenced by the conditions of the organism at the time for the discrimination" [Ronchi 2009, p. 26].

Responses to and preferences for light and lighting quality: Research is more frequently seen in literature concerning what people in general prefer compared to an individual approach. J.E. Flynn worked with research related to end users´ preferences and technical systems in the building. He evaluated many aspects of the lighting systems seen in the room. The end user´s experiences were labelled subjective responses [Flynn 1977]. The research of Flynn is an early example of work with preferences for levels of light and light distribution. He collected data with semantic scales. Flynn found that light affected the user's behavior and the way that they used the space. In 1977, Flynn wrote about user responses to lighting applications and used semantic scales in order to collect data about the end users´ opinions [Flynn 1977]. In 1979, Hawkes, Loe & Rowlands wrote about lighting quality and did research in user preferences.

"It is perhaps to be regretted that the regular array of recessed luminaries the most common way of lighting offices, are the least preferred" [Hawkes, Loe & Rowlands 1979, p.111].

"But certainly the indications from this study are that subjects prefer other ways than regular recessed luminaries to light their offices. Complexity and brightness together: perhaps that is what people want in the lighting of their offices" [Hawkes, Loe & Rowlands 1979 p. 111].

"In recent years increasing attention has been paid to the complex problem of lighting quality. This is probably not because the problem of providing adequate light to maximize performance has been solved but because a number of techniques have been developed by psychologists which enable one to gain some understanding of the nature of lighting quality. With such techniques as semantic differentials, factor analysis, and multidimensional scaling available, it is no longer necessary to treat lighting quality as a totally unsolvable riddle, too subject to individual taste and the whims of fashion to be susceptible to scientific examination. Of course the techniques themselves will not solve the riddle, but sensitively used, they have shown that it is possible to remove some of the mystery attached to the vague and subjective term "lighting quality" [Hawkes, Loe & Rowlands 1979 111].

The quotes of Hawkes, Loe & Rowlands [1979, p.111] show their interest in finding out something that the users in general prefer. They call LQ vague and subjective but argue that it can be a target for research and by that become less vague.

Saunders wrote in 1969 about results from a study about user preferences for level of light. He mentions that the observers differed in preferences and preferred consistently a highly illuminated table before a table with a lower level of light. Saunders refers to previous studies of observer's preferences for level of light.

- Balders, 70% of the observers preferred 1770 Lux, and he reported that some felt the level too bright at 1000 Lux [Balders 1957].
- Bodman and his colleagues found that the observers preferred a level of 1000 – 2500 Lux [Bodman, Sollner& Voit 1963; Bodman 1967].
- Reimenschneider´s [1967] study obtained an optimum level at 2500 Lux.

The Thesis showed in study 4, 2007 Lux as a mean preference for level of light. These studies can be compared to Aguilars and Stiles study in 1954 that showed 4 subjects with a saturation of the rod mechanism at 120-300 Cd/m2. Translated into Lux this is 500 to 1500 Lux, Saunders claims [1969].

In 1987 Perry wrote about recommendations from Chartered Institution of Building Services Engineers (CIBSE)**.**

"The current edition of the CIBSE lighting code recommends a standard service illuminance for general office work of 500 Lux. This range log luminance lies reasonably close to the lower bound of Aguilar and Stiles´ rod saturation region" [Perry, Campbell & Newman 1987].

The names of the three subjects that are the origin of the here mentioned recommendation of 500 Lux are Miss P. Fowler, Miss S. Ide and Miss E. Kinrade. The fourth subject is not mentioned by name. The rod mechanism was saturated for the four subjects in this experiment between 500-1500 Lux. The reason for the use of the lower bound of the experiment is not found in literature by the author of the thesis nor the reason for the neglect of the results of studies performed 1931, 1957, 1963, 1967 and 1969 that show:

- *Luckiesh and Moss [1931]:* seeing is exceedingly irregular. The results vary widely both between subjects and between successive operations by the same subject from moment to moment in a day and/or from day to day. For the evaluation of the consequences of this variability, the authors recommend considering the relative change [Ronchi 2009 p.27].
- *Balders [1957]:* the maximum percentage for good lighting occurred for a task lighting of 365 Cd/m2 converted to Lux 1770 Lux. [Sanders 1969 p.42].
- *Bodman & Sollner [1963]:* a preferred range of task illumination levels occurred between 1000-2500 Lux [Sanders 1969 p.42].
- *Riemenschneider [1967]***:** an optimum illumination level of the order of 2500 Lux [Sanders 1969 p.42].
- *Perry [1987]:"The current edition of the CIBSE lighting code recommends a standard service illuminance for general office work of 500 Lux. This range log luminance lies reasonably close to the lower bound of Aguilar and Stiles´ rod saturation region. This conclusion does not answer why if given a free choice some people will select desk top illuminance of 1600 Lux or greater".*
- *Ronchi [2009]:* variability in the visual functionality across the day.
- *Säter [2011]***:** mean for preference for level of light at the worktable 2007 Lux. The subject´s preferences for level of light at the working table and for the ambient light are almost unique. Two pairs of subjects choose the same combination, the other 313 subject were unique in their choices of levels of light. It differed 50 times between the lowest and highest level of light for the work table and 58 times in preference for the level of ambient light. 2 subjects where measured for visual comfort during the day. They showed a difference of 3 [1030-3420 Lux] between the lowest and highest value during the day.

Recommendations of today: In 2012 is the European recommendation for level of light at the work place 500 Lux. This is the same as for CIBSE 1987 associated to the lower bound of the saturated rod mechanism of Miss P. Fowler, Miss S. Ide and Miss E Kinrade and the fourth subject not mentioned by name and a result of a study done in 1954. The study revealed that at 500-1500 Lux the subjects´ rods showed no reactions when the levels of light were raised. The European standard that is based on 500 Lux state "the standard meets the needs for visual comfort and performance of people having normal ophthalmic (visual) capacity" EN 14664-1: 2011. Other researchers investigating preferences for levels of light are Loe, Mansfield & Rowlands. They worked 1994 with the human experience of light and used semantic scales for measurement of the human experience.

"The purpose of this project was to examine the relationship between a subjective response to a lit environment and its luminance distribution as a contribution to improving lighting design. Observer subjective assessments were examined using factor analysis and this identified two main factors: "visual interest" and "visual lightness". The results suggest minimum values for these two parameters which are likely to be necessary for a lit environment" [Loe, Mansfield & Rowlands 1994, p. 119].

Here, Loe, Mansfield & Rowlands use their data about subject´s preferences for the visual appearance of the room as a tool for recommendations of how to do lighting design [Loe, Mansfield & Rowlands 1994]. Two years later, in 1996, Loe and Rowland wrote about human responses to lighting design [Loe & Rowlands 1996].

"This paper discusses the lighting design process and proposes an improved strategy which provides a holistic approach including human responses to the appearance of the whole visual environment. In particular, it considers the aspects of visual function and amenity, integration with the architecture and energy efficiency" [Loe & Rowlands 1996, p. 153].

"Both the art and science aspects, together with their inter-relationships, need to be regarded in the process, and a framework for design is proposed. An all embracing approach is necessary if both high qualities in lighting and high energy efficiency are to be achieved. However, if a more holistic approach is taken considering the pattern of light and lighting controls that allow the user to adjust the lighting for their particular need, it may be possible to relax the numerical criteria currently recommended" [Loe & Rowlands 1996, p.153].

Loe and Rowlands mentioned light entering the eye that affected both the visual and physiological human system [Loe & Rowlands 1996]. Houser et al. work in the same tradition as Flynn, Hawkes, Rowlands, Mansfield and Loe. Here they investigate subjective responses to linear fluorescent direct/ indirect lighting systems [Houser et al. 2002]. In their research they show an interest in the individual user and find the user able to discriminate different light settings. They found that the subjects were not seduced into reporting a change when a physical difference was not present.

"This paper characterizes human subjective response to spatial distributions of light resulting from different up light/ down light photometric distributions"[Houser, et al. 2002].

The result of the study shows the subjects´ preferences for lighting design [Houser et al. 2002].

"1. the walls and the ceiling contributed to the perception of overall brightness when the work plane illuminance was held constant, 2. The room appeared more spacious when more light was supplied indirectly, and 3. Light settings where the indirect component had a horizontal illuminance contribution of 60% or more were favoured."[Houser et al. 2002].

2.3 Research question nr. 2

***TF part 5**. In what way can laws, recommendations and methods for lighting design be developed to support the individual user in a better way PPV? Will light-related goals according to visual comfort and health stipulated in EC treaty 137, Pörn´s health theory in WHO target 9 and 13-17 adopted by the Member States of European Region and visual comfort in the European standard for indoor workplaces be fulfilled by the use of EN 12464-1: 2011?*

EC treaty 137: The health issue within the European Union should be seen as a part of maintenance of the competitiveness of the economy of the Community. In EU-Charter of fundamental rights article 31, it is stated about fair and just working conditions. EC 137 addresses every worker´s right to working conditions which respect his or her health, safety and dignity. The EC Treaty 137 (Title XI, Social policy, education, vocational training and youth. Chapter 1 social provisions 1) concerns improvement in particular of the working environment to protect workers' health and safety and the working conditions.

Charter of Fundamental rights. Access EU webpage dec. 2011:
The Charter of Fundamental Rights of the European Union: Definition 1. Every worker has the right to working conditions which respect his or her health, safety and dignity. 2. Every worker has the right to limitation of maximum working hours, to daily and weekly rest periods and to an annual period of paid leave.

Legal explanations 1. Paragraph 1 of this Article is based on Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work. It also draws on Article 3 of the Social Charter and point 19 of the Community on the rights of workers, and, as regards dignity at work, on Article 26 of the revised Social Charter. The expression "working conditions" must be understood in the sense of Article III-107 of the Constitution.
2. Paragraph 2 is based on Directive 93/104/EC concerning certain aspects of the organisation of working time, Article 2 of the European Social Charter and point 8 of the Community Charter on the rights of workers.

In the directive 89/391 health is protected both at work and at home.
*The aim of this **Directive** is to introduce measures to encourage improvements in the safety and health of workers at work. It applies to all sectors of activity, both public and private. Directive" Of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work" Directive 89/391-OSH"Framework Directive.*

***Objective:** The aim of this Directive is to introduce measures to encourage improvements in the safety and health of workers at work. It applies to all sectors of activity, both public and private, except for specific public service activities, such as the armed forces, the police or certain civil protection services.*

It is of fundamental importance as it is the basic safety and health legal act which lays down general principles concerning the prevention and protection of workers against occupational accidents and diseases. It contains principles concerning the prevention of risks, the protection of safety and health, the assessment of risks, the elimination of risks and accident factors, the informing, consultation and balanced participation and training of workers and their representatives.

On the basis of this "Framework Directive" a series of individual directives were adopted. The Framework Directive with its general principles continues to apply in full to all the areas covered by the individual directives, but where individual directives contain more stringent and/or specific provisions, these special provisions of individual directives prevail.

Definitions: *Definition of the terms “worker”, “employer”, “workers' representative with specific responsibility for the safety and health of workers” and “prevention”.*

Contents: *The Framework Directive contains basic obligations for employers and workers. Nevertheless, the workers' obligations shall not affect the principle of the responsibility of the employer. It is the employer's obligation to ensure the safety and health of workers in every aspect related to work and he may not impose financial costs to the workers to achieve this aim. Alike, where an employer enlists competent external services or persons, this shall not discharge him from his responsibilities in this area.*

The general principles of prevention listed in the directive are the following: avoiding risks, evaluating the risks, combating the risks at source, adapting the work to the individual, adapting to technical progress, replacing the dangerous by the non- or the less dangerous, developing a coherent overall prevention policy, prioritizing collective protective measures (over individual protective measures), giving appropriate instructions to the workers.

Employers’ and workers' obligations: *The employer shall evaluate all the risks to the safety and health of workers, inter alia in the choice of work equipment, the chemical substances or preparations used, and the fitting-out of work places implement measures which assure an improvement in the level of protection afforded to workers and are integrated into all the activities of the undertaking and/or establishment at all hierarchical levels take into consideration the worker's capabilities as regards health and safety when he entrusts tasks to workers; consult workers on introduction of new technologies; designate worker(s) to carry out activities related to the protection and prevention of occupational risks, take the necessary measures for first aid, fire-fighting, evacuation of workers and action required in the event of serious and imminent danger keep a list of occupational accidents and draw up and draw up, for the responsible authorities reports on occupational accidents suffered by his workers inform and consult workers and allow them to take part in discussions on all questions relating to safety and health at work; ensure that each worker receives adequate safety and health training The worker shall make correct use of machinery, apparatus, tools, dangerous substances, transport equipment, other means of production and personal protective equipment immediately inform the employer of any work situation presenting a serious and immediate danger and of any shortcomings in the protection arrangements cooperate with the employer in fulfilling any requirements imposed for the protection of health and safety and in enabling him to ensure that the working environment and working conditions are safe and pose no risks. Health surveillance should be provided for workers according to national systems. Particularly sensitive risk groups must be protected against the dangers which specifically affect them.*

In the EC Treaty 136 is stated as fundamental social rights, improved living and working conditions. In EC Treaty 137 is written: To be able to achieve the objectives of Article 136, the Community shall support and complement, the activities of the Member States, in the following fields:(a) improvement in particular of the working environment to protect workers' health and safety.

(b) working conditions” EC Treaty 137.

Article 136 and 137 from the EU webpage:

TITLE XI SOCIAL POLICY, EDUCATION, VOCATIONAL TRAINING AND YOUTH CHAPTER 1 SOCIAL PROVISIONS

Article 136
The Community and the Member States, having in mind fundamental social rights such as those set out in the European Social Charter signed at Turin on 18 October 1961 and in the 1989 Community Charter of the Fundamental Social Rights of Workers, shall have as their objectives the promotion of employment, improved living and working conditions, so as to make possible their harmonisation while the improvement is being maintained, proper social protection, dialogue between management and labour, the development of human resources with a view to lasting high employment and the combating of exclusion.

To this end the Community and the Member States shall implement measures which take account of the diverse forms of national practices, in particular in the field of contractual relations, and the need to maintain the competitiveness of the Community economy.

They believe that such a development will ensue not only from the functioning of the common market, which will favour the harmonisation of social systems, but also from the procedures

Provided for in this Treaty and from the approximation of provisions laid down by law, regulation or administrative action.

Article 137
1. With a view to achieving the objectives of Article 136, the Community shall support and complement the activities of the Member States in the following fields:
(a) Improvement in particular of the working environment to protect workers' health and safety;
(b) Working conditions;
(c) Social security and social protection of workers;
(d) Protection of workers where their employment contract is terminated;
(e) The information and consultation of workers;
(f) Representation and collective defense of the interests of workers and employers, including codetermination,
Subject to paragraph 5;
(g) Conditions of employment for third-country nationals legally residing in Community territory;
(h) The integration of persons excluded from the labour market, without prejudice to Article 150;
(I) equality between men and women with regard to labour market opportunities and treatment At work;
(j) The combating of social exclusion;
(k) The modernization of social protection systems without prejudice to point (c).
2. to this end, the Council:
(a) May adopt measures designed to encourage cooperation between Member States through Initiatives aimed at improving knowledge
(b) May adopt, in the fields referred to in paragraph 1(a) to (I), by means of directives, minimum requirements for gradual implementation, having regard to the conditions and technical rules obtaining in each of the Member States. Such directives shall avoid imposing administrative, financial and legal constraints in a way which would hold back the creation and development of small and medium-sized undertakings.

The Council shall act in accordance with the procedure referred to in Article 251 after consulting the Economic and Social Committee and the Committee of the Regions, except in the fields referred to in paragraph 1(c), (d), (f) and (g) of this Article, where the Council shall act unanimously on a proposal from the Commission, after consulting the European Parliament and the said Committees. The Council, acting unanimously on a proposal from the Commission, after consulting the European Parliament, may decide to render the procedure referred to in Article 251applicable to paragraph 1(d), (f) and (g) of this Article.
3. A Member State may entrust management and labour, at their joint request, with the Implementation of directives adopted pursuant to paragraph 2. In this case, it shall ensure that, no later than the date on which a directive must be transposed in accordance with Article 249, management and labour have introduced the necessary measures by agreement, the Member State concerned being required to take any necessary measure enabling it at
Any time to be in a position to guarantee the results imposed by that directive.
4. The provisions adopted pursuant to this Article — shall not affect the right of Member States to define the fundamental principles of their social security systems and must not significantly affect the financial equilibrium thereof,— shall not prevent any Member State from maintaining or introducing more stringent protective measures compatible with this Treaty.
5. the provisions of this Article shall not apply to pay, the right of association, the right to Strike or the right to impose lock-outs.

WHO- target 9, 13-17: WHO accepted the health theory of Pörn in 1990 because the theory points out the environment as a tool for the individual to maintain health [Edell-Gustafsson & Ek 1992]. Pörn´s health theory explains the relationship between sleep and health. Sleep is a physiological need. Sleep deprivation leads to an altered circadian rhythm, an early stage in psycho physiological and social poor health, independent of disease. This influences the individual´s behavior and ability to adjust. Long-term disturbances lead to disease. Total health care, according to Pörn, includes the conditions of will, environment, repertoire and health and is directed toward individual care. Health for Pörn is the relationship between an individual´s ability and goals. The “healthy” lifestyle is a result of the individual´s understanding of good health, lifestyle and sleep pattern.

EN12464-1:2011: EC Treaty article 153, related to the rights of the consumer, is mentioned in the standard for lighting at indoor working places. Health is not an issue here, but ergonomics and performance. In the European standard is stated that the recommendations “meet the needs for visual comfort and performance of people having normal ophthalmic (visual) capacity” *[EN-12464-1:2011]*.

Swedish standards Institute, SIS, published on their homepage: *This European Standard specifies lighting requirements for humans in indoor work places, which meet the needs for visual comfort and performance of people having normal ophthalmic (visual) capacity. All usual visual tasks are considered, including Display Screen Equipment (DSE).*
This European Standard specifies requirements for lighting solutions for most indoor work places and their associated areas in terms of quantity and quality of illumination. In addition recommendations are given for good lighting practice.
This European Standard does not specify lighting requirements with respect to the safety and health of people at work and has not been prepared in the field of application of Article 153 of the EC treaty, although the lighting requirements, as specified in this European Standard, usually fulfil safety needs.

Lighting requirements with respect to the safety and health of workers at work can be contained in Directives based on Article 153 of the EC treaty, in national legislation of member states implementing these directives or in other national legislation of member states.
This European Standard neither provides specific solutions, nor restricts the designers´ freedom from exploring new techniques nor restricts the use of innovative equipment. The illumination can be provided by daylight, artificial lighting or a combination of both.
This European Standard is not applicable for the lighting of outdoor work places and underground mining or emergency lighting. For outdoor work places, see EN 12464-2 and for emergency lighting, see EN 1838 and EN 13032-3. Accessed dec. 2011.

Treaty establishing the European Community (Nice consolidated version) Part Three: Community policies, from the EU webpage, accessed dec. 2011: *Title XIV: Consumer protection Article 153Article 129a - EC Treaty (Maastricht consolidated version)*
Article 153
1. In order to promote the interests of consumers and to ensure a high level of consumer protection, the Community shall contribute to protecting the health, safety and economic interests of consumers, as well as to promoting their right to information, education and to organize themselves in order to safeguard their interests. 2. Consumer protection requirements shall be taken into account in defining and implementing other Community policies and activities
3. The Community shall contribute to the attainment of the objectives referred to in paragraph 1 through: (a) measures adopted pursuant to Article 95 in the context of the completion of the internal market; (b) measures which support, supplement and monitor the policy pursued by the Member States.
4. The Council, acting in accordance with the procedure referred to in Article 251 and after consulting the Economic and Social Committee, shall adopt the measures referred to in paragraph 3(b).
5. Measures adopted pursuant to paragraph 4 shall not prevent any Member State from maintaining or introducing more stringent protective measures. Such measures must be compatible with this Treaty. The Commission shall be notified of them. [EN 12464:1- 2011].

***Recommendations for lighting design**:* It is hard to find research about the standard for lighting design or literature with a special intent on recommendations for lighting design. Studies made within the field of lighting quality goes into the same questions as for recommendations and are here reviewed. From an American lighting design perspective, Peter Boyce has described laws, regulations, and codes and guides [Boyce 2003 p. 491].

Säter, Paper X: A theoretical background to the development of recommendations seen from a Swedish horizon is described by the author of the Thesis [Paper X]. The text is based on an investigation about the process done in 2000-2012. Recommendations for lighting design developed by actors in the field additionally to CIE, CEN and SIS, are mentioned as well.

CIE, CEN, and SIS: "The way lighting design is performed is to a great extent regulated by recommendations. Until today lighting in the building process is mainly seen as a practical function needed for visual security and for work tasks. As a result of light being important merely from a visual point of view, light is planned with a predefined specific level of light and with an even light distribution. The static and even light is commonly seen as secure at work.
The Swedish Work Environment Authority is, together with SIS, the main actor in the field of construction

of regulations for lighting design in Sweden. The Swedish Work Environment Authority develops the decree for the work environment law. To promote a secure and healthy light in the work environment is the start for the work with light-related standards. CIE, CEN and the national standardisation committees (SIS in Sweden) write together the standard for lighting used in Europe. CIE has an agreement to deliver reports to CEN. The CEN group writes resolutions. The resolutions are forwarded to SIS for a voting process. The Swedish Work Environment Authority contributes to the creation of the standards within the SIS National Committee in cooperation with representatives for the companies working with production of luminaries and light sources. Since lighting design is a rather new skill, it is unusual that lighting designers have been involved in the development of recommendations about how to design light. Researchers in lighting design are rare both nationally and globally, so it is not common that researchers work with the development of the standard. It is those who can afford to travel that have the opportunity to contribute to the technical committees within CIE and CEN and to the national committees of standardisation. The national committees (SIS in Sweden) have no financial opportunities to secure the standards being scientifically proven or to invite researchers to join the work. They have to trust the expert group that joins the meetings at CIE, CEN and SIS. The expert group votes for acceptance of a new member. It is to a large extent the luminary and light source companies that are travelling to the different meetings and acting as lighting experts. The background for the expert group in CIE, CEN and the national standardisations committees can in this case to a great extent be commercial with a focus on control of the market for light sources and luminaries. If suitable, it is possible to use the voting process to control if a person will be accepted or not in the national standard committees within SIS and, in doing so, control the members in CEN. The development of the standard for lighting can by the voting process for new members in the national committees and CEN be controlled. If the work of CIE, CEN and the national committees for standardisation becomes directives, the commercial actors have a strong tool to control the market and decide in advance the way their products will be used. When researchers in lighting design are absent, there is a risk that the standard will be developed solely toward the interests of the producers and not toward the interests of health authorities and the users or the companies that are based on the work of lighting designers [Säter Paper X].

Swedish Energy Agency: *Good examples for energy efficient lighting applications. The ambition to reduce energy consumed for lighting purposes is another reason for the development of recommendations in the field of lighting and is performed by the Energy Agency in Sweden. It is seldom lighting designers or researchers trained in the four steps of lighting design that work as consultants to the Energy Agency when writing recommendations. It is more often engineers in general not trained in any of the four steps of lighting design and representatives for companies that are trained merely in the fourth step that are seen as experts and help out the authorities with the development of recommendations [Säter Paper X].*

Recommendations from the producers of luminaries and light sources: *Representatives from the industry have developed recommendations for the planning of light and described the planning process done by the computer. The text describes man and light and lighting quality. The predefined static levels of light in the standard EN 12464:12011 are added to the text [Säter Paper X].*

Hierarchy of recommendations: *The hierarchy of the Swedish national recommendations shows that the work environment department´s decree for the work environment law is of the highest range and mandatory at penalty all other recommendations developed by CIE, CEN, SIS, the Energy Agency and the producers of light sources and luminaries is voluntary to use. The only mandatory with a standard is if the standard is accepted it will be the only standard used for the purpose nationally. The standard can* *be used in the building process as a demand and a reference to if the lighting is satisfactory or not (at penalty). On a European level the EC Treaty 137 is of the highest range in law for light-related health for the working environment and the EN12464-1:2011 is the only standard (recommendation) in use for lighting for indoor workplaces within the EU [Säter Paper X].*

WHO- target 9, 13-17: Pörn´s health theory is related to the environment and to give the users the affordance (a tool) to protect their health.

"It is already established in research circles that a person´s lifestyle, environment, daily living and genetic background have a bearing on the development of, for example, arteriosclerosis and coronary heart disease"[Edell- Gustafsson & Ek 1992].

"Pörn´s theory of health relates to society and the individual´s environment. Pörn relates health problems not only to medical problems but also to physiological, biochemical and psychological factors in the individual´s environment. This is the reason for choosing Pörn´s health theory, the World Health Organization´s target 9 and 13-17 of health adopted by the member states of European Region, and their relationship to patterns of sleep and coronary heart disease" [Edell- Gustafsson & Ek 1992].

"The reason for WHO to choose the health theory of Pörn is related to the fact that the theory points out that health is an individual action and related to the environment" [Edell-Gustafsson & Ek 1992].

"Pörn´s health theory explains the relationship between sleep and health. Sleep is a physiological need. Sleep deprivation leads to an altered circadian rhythm, an early stage in psycho physiological and social poor health, independent of disease. This influences the individual´s behavior and ability to adjust. Long-term disturbances lead to disease. Total health care, according to Pörn, includes the conditions of will, environment, repertoire and health and is directed towards individual care. Health for Pörn is the relationship between individual´s ability and goals. The resulting "healthy" lifestyle is a result of the individual´s understanding of good health, lifestyle and sleep pattern" [Edell-Gustafsson & Ek 1992].

Through cooperation, the architect, interior designer and lighting designer have the possibility to give the individual the ability to adapt the use of EMR towards the individual PPV needs and by that give the user the tool to stay in balance with light and level of alertness.

***Research in legislation and recommendations of light*:** It is hard to find research directly related to the EC Treaty 137 or EN 12464-1: 2011 but underlying data for the research question can be found in literature about light and health, visual performance and visual comfort [Nordenfeldt 1987; Ronchi 1970, 2009; Stevens et al. 2007; Brainard & Hanifin 2005; Hannibal et al. 2002; Cajochen et al. 2005; Roenneberg 2007; Säter 2011].

TF part 6*. Will the use of the CCLDP and the UCLDP fulfill goals about visual comfort and light-related health in EN 12464-1:2011, EC Treaty 137 and WHO target 9 and 13-17 adopted by the member States of European Region?*

CCLDP: The computer calculated lighting design process (CCLDP) is done without contact with the user, the space or the daylight where the user lives. A computer calculation is done in relation to dimension PS toward pre-determined levels for light. This process is used to fulfil demands from (in this case) the standard EN 12464-1:2011. The lighting applications in Europe are more frequently done with CCLDP than the user centred lighting design process (UCLDP). CCLDP can be evaluated in the way it realises goals for visual comfort and light-related health set out in society by EC Treaty 137 and WHO Treaty 9, 12-17 in the following way; when the CCLDP is used, the approach is general and in a restricted way visual. No individually well-functioning connections are designed between the individual user and the light from the lighting application (LA). The process does not adapt the light from the LA toward the colours and surfaces in the specific space. The light sources used are developed to show 15 colours close to the way they are exhibited in daylight and are not developed to support humans physiologically. The process is focused on the realisation of predefined photometric values and is not connected to the user's preferences or physiological needs. Regarding this, the method when used has a low possibility to realise goals of visual comfort set out in EN12464-1:2011 and light-related health in EC Treaty 137 or WHO target 9 and 13-17 adopted by the Member States of the European Region.

The second process is called the user centred lighting design process (UCLDP): *UCLDP:* The process is done in contact with the user (if possible) with the space (if possible) and is based on daylight at the place where the space is situated. Analyses are made about the space, the user´s needs of light, the design of daylight and artificial light and about the site where the user is situated with the ambition to dimension PS in a way that creates individual visual comfort and an individual good performance and to set the user in contact with the daylight at the site where the user lives. The process is done to support the users toward the experience of visual comfort, a well-functioning diurnal rhythm, light-related homeostasis and fulfil individually the light-related parts of the goals of health stipulated in EC Treaty 137 and WHO 9, 13-17. A minority of the lighting applications done today are done with the use of a basic form of UCLDP. When the UCLDP is used the approach is space specific, user centred and supportive PPV. Well-functioning connections between the user and the lighting application (LA) are established. Concerning this, the method when used has a high possibility to realise the goals of visual comfort in EN 12464-1:2011, light-related health in EC Treaty 137 or WHO target 9 and 13-17 adopted by the Member States of the European Region. In this way the space becomes a tool for health as described in the health theory of Pörn.

The two processes can be described as abbreviations.
Process 1) CCLDP=LDP Step 4= (non well-functioning support) NWFS MLCS=NWFS PPV=NWFS LQ=Low fulfilment of goals set out (LFOGS).
CCLDP=LDP Step 4=NWFS MLCS=NWFS PPV=NWFS LQ=LFOGS.
Process 2) UCLDP= LDP Steps 1, 2, 3 and 4=well-functioning support (WFS) MLCS=WFS PPV=WFS LQ= High fulfilment of goals set out (HFOGS).
UCLDP=LDP 1-4=WFS MLCS=WFS PPV=WFS LQ=HFOGS.
The CCLDP and UCLDP are here described in their basic steps. The CCLDP is the most frequent used method for lighting design. The UCLDP is developed from knowledge revealed in

the theoretical framework and is used by trained lighting designers, but less frequent in use compared to the CCLDP.

TF part 7*. In what way do the end user, designer, or client perspective to LQ differ in PPV support for the user?*

Peter Boyce and Eklund stated in 1995 that:

"This would be straightforward if there existed a comprehensive, widely-accepted method for evaluating lighting quality. Unfortunately, this is not the case. A review of the literature shows a number of ad-hoc evaluations, undertaken to demonstrate, the value of new lighting equipment, or a new design approach". [Boyce & Eklund 1995, p.190].

Jennifer Veitch, a Canadian PhD in environmental psychology at the National Research Council of Canada / Institute for Research in Construction and Indoor Environment Research Program, and G.R. Newsham argues:

"Discussions about quality are complicated by its intangible nature". One cannot measure quality in the same sense as one measures length mass or lumen output. LQ is a hypothetical domain in the same sense as widely-known abstract concepts such as aggression, altruism, or political affiliation. In the language of social scientist, such intangible entities are constructs." [Veitch & Newsham 2006 p. 10].

"Members of the lighting community have long speculated about the effects of LQ on human performance comfort and well-being." [Veitch & Newsham 2006, p. 1].

"Past attempts to develop a metric for LQ even in the limited case of office lighting have largely failed" [Veitch & Newsham 2006, p.1].

Boyce adds to the discussion about LQ, why bother about the way we design the light? [Boyce 2003 p. 520]. The question can be read out as why bother about LQ? The answer to the question, he says, is because it is a matter of quality of life. Boyce mentions that lighting can have an impact on aims like improving non-life threatening health issues. Lighting can have an impact on users to perform work better although older, promote some aspects of health for people of all ages and give an attractive environment. Veitch and Newman characterise the research of LQ as a search for the Holy Grail. They give as an example that the perfect fit is an immeasurable ideal and, in that case, LQ has a utopian nature [Veitch & Newsham 1995]. Peter Boyce, Jennifer Veitch and Guy Newsham mention energy saving as a reason for the research in LQ. LQ is, according to Veitch and Newsham, seen as a multi-faceted concept that not should rest on a single measurement or a single measurements' technique. In the same way, they state that LQ is not measurable.

"The failure to reach agreement about lighting quality has been seriously impeded by difficulties to recognize the question as one part of the larger attempt to identify the nature of environmental quality provided to support human activity. The outcomes that benefit from good lighting quality are behavioural outcomes. Behavioural scientists have been remiss in not looking to the lighting literature for a different perspective on this issue. Lighting researchers have been remiss in not following the behavioural

literature and in particular its standards for research design methods statistical analysis and reporting. In consequence we know less about lighting quality than we would, after more than a century of lighting practice and ninety years of its professional organization"[Veitch & Newsham 2006, p.18, http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc39866.php access 2012 0101].

"Even with a research-based understanding of lighting quality in terms of the effects of luminous conditions on people lighting design will not become a simple "by the numbers" Boyce [Boyce 1995a] aptly described vision as a fairy story"[Veitch & Newsham 2006, p. 19, http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc39866 php. Access 2012 010].

Veitch and Newsham define determinants of LQ [Veitch & Newsham 2006]. They state that past events to develop a metric for LQ even in the limited case of office lighting, have largely failed. The reason for this is seen as poor science, poor research design as well as statistical analysis and reporting. They set out that the research related to LQ is a subset to environment-behaviour research and presents a behaviourally-based definition of LQ [Veitch & Newsham 2006]. They mention as a goal consensus based lighting design recommendations. Veitch and Newsham list methods that are used to specify LQ or aspects of LQ: 1) Visibility Level model, Blackwell 1959; 2) Equivalent Sphere Illuminate committee on recommendations for quality and quantity of illumination1970; 3) Visual Comfort Probability, RQQ 1966, LQ index, [Herst & Ngai 1978]; 4) Comfort, satisfaction and performance, CSP-index [Bean and Bell 1992]; Relative performance model [Rea& Oulette 1991]; An approach to a measurement of LQ [Miller, McKay & Boyce, 1995].

Peter Boyce and Nils Eklund wrote about evaluating LQ in the same year as Veitch and Newsham. They introduced a toolkit that provided a comprehensive and flexible multi-dimensional evaluation of LQ [Boyce & Eklund 1995]. Veitch, Newsham, Boyce and Eklund write here about the measurement and analysis of the human experience of the lighting application**.** If conducted in a more accurate and comprehensive way, they claim that data will improve.

Lighting quality (LQ) is a central term in lighting science: Despite many efforts to describe and measure LQ, confusion about what it is and how to measure it can be seen. LQ is mentioned as mystery, vague, subjective [Hawkes, Loe & Rowlands], intangible nature, hypothetical domain [Veitch & Newsham 1995; Veitch & Newsham 2006]. The words used to describe LQ by the mentioned researchers show a general approach to the user and can be compared to the UCLDP and the 4 steps of lighting design described in the theoretical framework (Säter Paper X), and which includes; *Step 1*) analyses of the space, colours, surfaces, daylight and artificial light in the room; *Step 2*) analyses of the human needs PPV and the visual needs for support of activities in the room; *Step 3)* design of daylight and artificial light in the indoor environment close to the user's needs, related to the colours in the room and to the daylight at the site where the user lives; *Step 4*) the design of the lighting application technically and development of instructions of how to maintain the application. This process is an example of the user-centred LDP that is specific for the user and the space. From this perspective and with cooperation between subjects if staying in the same room, LQ can easily be realised.

R.J. Hawkes and D. J. Loe (MPh in civil engineering) formulated in 1979 a note they called the understanding of LQ. They conclude the study with: complexity and brightness together: perhaps that is what people want in the lighting of their offices [Hawkes & Loe, 1979]. This quote shows the general approach often seen in literature about the LA when looking for the optimal solution, for everybody, all the time. LQ can be seen related to research in human factors. According to Peter Boyce [2003], the most widely accepted definition about LQ is that LQ is perceived when the designer or the client's expectations are fulfilled. The research of Hawkes and Loe and the statement of Boyce are examples of looking for LQ as a theoretical and as mentioned before general expectation.

User centred design: Light for the indoor environment is also a matter of research in interaction design and affordance [Redström, 2006].

"Research in design that used to be a matter of form seems to in an increasingly extent be about the user and her experiences" [Redström 2006, p. 123].

This overview of different aspects on LQ briefly mentioned here is done before 2011. It is obvious that LQ is seen from many aspects, and different methods are used to measure it but without a wide acceptance [Boyce 2003]. The findings of melanopsin and ipRGC rewrite the map for the identification of LQ. The new knowledge change the research approach from a manmade evaluation of the technical tool in the indoor environment toward an individual approach related to PPV support. Here the design of light is based on daylight in the outdoor environment, the design of daylight indoors and a daylight mimicking artificial light developed based on photo biological research, medicine and visual comfort [Brainard & Hanifin 2005; Roenneberg et al. 2007]. The principal approach to LQ mentioned by Peter Boyce [2003] can be compared with the individual perspective mentioned by Ingvar [1981] and Hollwich [1980]; LQ is perceived when the trigger PS is dimensioned to suit the individual subject's nervous system. Affordance by Gibson [Gibson 1977, 79] is applicable on lighting design since the individual user needs to adapt the lighting for the experience of pleasure during the day.

TF part 8. *How can the process of lighting design be described that supports the user´s individual light-related PPV needs and is related to the colours and surfaces in a specific space and sets the user in contact with the daylight at the site where the user lives?*

It is hard to find something written about lighting design seen as a user centred process based on the knowledge about melanopsin and ipRGC. This part is developed within the Thesis and the argumentation rests upon common knowledge in lighting design, analysis of the interaction of MLCS in the outdoor and indoor environment, the four steps of lighting design, the theoretical framework and results from the studies 1-5. The main arguments are listed below.

The ambient light: should be designed with daylight and a daylight mimicking artificial ambient light and be in contact with the light at the site where the subject lives. This will provide the subjects with a healthy light physiologically [Hanifin & Brainard 2007].

Task lighting: A glare free and flexible task lighting that has a range from low to high levels of light have the possibilities to support the subjects with the experience of visual comfort [Ronchi 2009; Paper VI].

The dimensioning of PS: When PS is designed to fit the visual needs of the user and the actual transmission, absorption and reflection in the room according to colour and surfaces, the room will be perceived as visually comfortable [Säter 2011; Paper VI].

Stay in contact with daylight: Daylight and a daylight mimicking artificial ambient light in contact with the light at the site where the subject lives will provide the subjects with a healthy light physiologically [Pechaceck, Andersen & Lockley 2008].

Support the individual visual needs: A glare free flexible task lighting that has a range from low to high levels of light will support the subjects in a visual comfortable way [Ronchi 2009; Säter 2011].

Designed related to the colours and surfaces in the room: When PS is designed to meet the actual transmission, absorption and reflection of the colours and surfaces in the space in a way that gives well functioning visual contrasts, the room will be perceived as visually comfortable [Liljefors 1999].

Designed to suit the subject's diurnal rhythm: The theoretical background for the identification of a lighting design that is done in contact with the subjects physiologically can be found in the work of Rutger Wever. He worked with subjects that stayed in light and room settings for 28-90 days. The bunker in Andechs was where the first extensive human experiments in temporal isolation were performed. Rutger Wever is the precursor for research in mapping out the human response to light related to diurnal rhythm.

"His was the energy and persistence that designed and carried out, alone or in collaboration, day and night from 1964 to 1989, 418 experiments in 447 human volunteers in the bunker under nearly every conceivable condition (211 free-running). He summarized his findings in a dense, carefully written book, The Circadian System of Man (Wever, 1979), with all the data laid out" [Wirz-Justice et al. 2005, p.1].

Rutger Wever writes about autonomous rhythms being psychological and physiological.

"The physiological rhythms are remarkably regular. The psychological rhythms however, the relevance of the rhythmicities mainly is based on the sharply decreased night values; the plateaus during daytime would hardly constitute reliable rhythms" [Wever 197, p. 25].

EU-clock project: The EU-CLOCK project is an example of research done recently about man and light and concerns 55 000 subjects´ sleep habits [Roenneberg et al. 2007].

Light and architecture: Part of their research by Anna Wirz-Justice and C. Fournier [2010] concerns the design of the environment for support to elderly end-user´s and their diurnal rhythm.

TF part 9*. How can recommendations be formulated that guide the design of light toward being in contact with the individual user´s light-related needs, the colours and surfaces in a specific space and the daylight at the site where the user lives?*

Since it is hard to find recommendations about goals that only can be fulfilled by the use of a user centred lighting design process and recommendations based on the knowledge about melanopsin and ipRGC, this part is developed within the Thesis and rests upon common knowledge in lighting design, analyses of the interaction of MLCS, the four steps of LDP and the theoretical framework (Paper X).

The ambient light: should be designed with daylight and a daylight mimicking artificial ambient light and be in contact with the light at the site where the subject lives. This will provide the subjects with a healthy light physiologically [Hanifin & Brainard 2007].

Task lighting: A glare free and flexible task lighting that has a range from low to high levels of light will support the subjects with the experience of visual comfort. Some subjects should be provided two luminaries to get the levels of light that they need [Ronchi 2009; Paper I].

The dimensioning of PS: When PS is designed to fit the user and the actual transmission, absorption and reflection in the room according to colour and surfaces, the room will be perceived as visually comfortable [Säter 2011, Paper VI].

Many users in the same room and still individual light: When many end-users share the same room, contradictory needs will be seen. This can only be solved by co-operation between the subjects. The users that need a low level of ambient light need to sit together as well as those who need a higher level. The ambient light is daylight in the first hand and the complementary daylight mimicking artificial light follows the daylight to a certain lowest level of security and pleasure. The shielding of daylight is important for all subjects but especially for the subjects that prefer low level of light but are situated close to the windows [Säter 2011; Paper VI].

Harmonising daylight and artificial light: Divide ambient light from task lighting. Let daylight as much as possible be the ambient light. Let the complementary ambient light follow the daylight in spectral profile, intensity, duration as close as possible to a certain lowest level of security.

Task lighting; Give the subjects the task lighting they feel at comfort with, according to being glare free seen from their level of sensitivity. Provide the level of light at the working table that the user needs during the day. Make sure the daylight and the artificial light do not meet the colours and surfaces in the room in a way that gives poorly functioning contrasts. Secure that onset and offset of the diurnal rhythm are not overruled by the use of artificial light. Extra task luminaries should be present at the workplace if needed for the users. Engage the users to find their own level of preferred light at the moment and to work in a visually comfortable environment [Säter, Paper, X].

2.4 Research question 3

***TF part 10**. In what way can a more qualitative research in lighting design be developed in collaboration among different research areas and different competences?*

Brainard, Lockley, Pauley, Wirtz, Holick and other researchers mentioned in the TF have deep knowledge in the physiological part of the research but limited knowledge in how to connect the breakthrough of ipRGC and melanopsin into everyday's practical lighting application. The researchers mentioned in the TF represent a cluster around the LDP and around the interaction of MLCS. New physiological knowledge about man and light needs to be tried out in the practical application to verify the impact on the user. If this is done in a multidisciplinary way and in connection to the practical lighting application quality of data will increase.

2.5 Summary of discussion of conclusion

Daylight is essential to humans and needs to be designed close to the individual users needs. This should be done by the use of UCLDP in order to be individual and flexible. It is discussed that lighting has been developed restricted visually until now but needs to be increased in support for the user psychologically and physiologically as well. If methods for lighting design are developed for a well functioning interaction of MLCS, goals set out for lighting design will be easier to fulfil. It is the use of the UCLDP that has the possibility to support humans and fulfil goals about VC and LRPH. It is discussed that the use of the recommendations in EN 12464-1:2011 and the CCLDP do not lead to lighting applications that fulfil goals set out in the standard for indoor lighting at offices or EC Treaty 137 or WHO Target 9 and 13-18. The UCLDP, on the contrary, has the possibility to do so.

Subjects that are distant in preferences and stay in the same room need to cooperate with each other to develope a visually comfortable light. Lighting design is discussed having an ethical aspect. It is more complicated to work with UCLDP compared to the CCLDP but seen from the perspective of the importance of light for humans it is an ethical issue to always support the user in the best possible way. The patterns seen in studies about visual preferences show large interindividual differences. Mean for preferred level of light at the worktable, on the contrary, are close to each other despite being different in subjects and methods. Studies performed between 1955-2011 shows 1500-2500 Lux as a mean for preferred level of light at the worktable. 500 Lux is found related to a study performed 1954 with four subjects (Miss P. Fowler, Miss S. Ida, and Miss E. Kinrade and a fourth subject not mentioned by name**).** The result of the study shows as a result a span for 500 to1500 Lux. 500 Lux is associated to results from this study performed by Aguilar and Styles and concern the rod saturation mechanism and the lower bound of the rod saturation mechanism for these four subjects. CIBSE recommend 500 Lux as an optimal level related to this study [Perry 1987]. The use of EN 12446-1:2011 is not found fulfilling goals of VC and LRPH in EN 12446-1:2011, EC Treaty137 or WHO target 9 and 13-17. EN 12464-1:2011 is not found giving visual comfort for the normal sighted workers of the population of Europe and do not fulfill aims of light-related health set out in EN 137 or WHO target 9 and 13-17. LQ is discussed from a general and a user specific approach and is related to the perspective of affordance and cooperation among subjects. The UCLD and recommendations for UCLDP is described and discussed as being limited in the number of details.

The process of lighting design that supports the user PPV is discussed and described from a general and static approach to an individual and flexible. The discussion of the recommendation for the LDP that supports users PPV is critically discussed being limited to adjustable task lighting, being in contact with daylight and to adapt to the colours and surfaces in the space. The PPV support from light is more complex and can and should be widened in details.

2.6 Summary of discussion about methods

The methods used in the studies are blood samples and self evaluated instruments. They are discussed being close to caring sciences that differ in methods from medical science in their being more complex and focused on the subjects experiences, preferences, responses and the environment instead of investigations of the impact from one single factor (for instance lethal dose). The fact is discussed that the methods chosen for investigation of the release of hormonal levels do not show the trigger for the hormonal release. It is not possible to identify the trigger for the specific response with the methods used in the studies, to do so other measurements need to be done to secure that, for instance, the release of cortisol is not a result of the camp and flight system being active. Diurnal cortisol and the release of extra cortisol as a response to a stressful situation need to be divided. Studies that do not use a synchronized start up for the diurnal rhythm do not have reliable data. If the hormonal levels from a subject with a late start on the diurnal rhythm are added to a study, the conclusions about diurnal rhythm will be wrong. Crucial for methods used in research in lighting design and of the interaction of MLCS is to handle the interaction as a totality and be done synchronised to diurnal rhythm. The individual user's diurnal rhythm and differences in receiving and responding to EMR make the exposure different for all users. To be able to do an evaluation of different room and light settings the need of being exposed visually for the room and light settings at the same time was discussed. Patterns in the responses and preferences to EMR were discussed. This is a methodological issue since the individual differences in diurnal rhythm, the variety in the ability to receive and respond to EMR differs among subjects in a way that it cannot be said that the subjects have the same input to melanopsin and ipRGC despite being exposed to EMR in the same way. Methods for the buildup of the TF were discussed. It can be wider and deeper within the different research areas and more areas of research than mentioned is related to the LDP steps 1-4.

CHAPTER 3

3. METHODS

The research is performed with a number of empirical studies that are shown in Paper I-X and a theoretical framework from research areas close to lighting design. The TF is build up around questions seen as important for the LDP and present research from light-related areas. The research is done theoretically and by empirical studies in an interactive way. It is a part of the research by design approach to indentify and discuss reasons for developing methods to give a better support for the user. Since the design of light in a majority of applications in Europe today is performed by a standard not only concerning the methods but also laws, recommendations and goals set out for lighting design, a critical examination and a constructive discussion of present conditions is part of the research. The main purpose of the Thesis is to question why an in what way lighting design should be designed in the indoor environment to realise goals of visual comfort and public health. The work is done in an interaction between an empirical and theoretical approach with the ambition to reflect lighting design from relevant aspects and discuss in what way recommendations and methods for lighting design can be developed to be PPV supportive and individually adaptive. The empirical studies are reflected on a background of light-related research and citation of researchers based on knowledge about PPV support. The survey results in an identification of and in recommendations for the UCLDP and a statement of the development of a PPV support from lighting design that is individually adaptive.

3.1 A comparison with existing studies

3.1.1 Andechs

Andechs: An early example of experimental full scale studies about responses to PS is the light experiment done in Andechs in Schwizerland from 1964-89. The studies in Andechs were performed in a cave prepared for the test of the impact from light on subject's diurnal rhythm. Researchers worked with subjects that stayed in light and room settings between 28-90 days. They stayed in a temperature of 7 Celsius and lived in tents. This was the first extensive studies done in human temporal isolation.

"Andechs bunker, where the first extensive human experiments in temporal isolation…and has become history. Jurgen Aschoff himself was the first free-running subject, and Rütger Wever his observer. The brief overview of his achievements below should remind the younger generation of one of the great pioneers of human circadian biology" [Wirz-Justice et al. 2005].

"As a physicist, his approach was mathematical, his analyses stringent; as an experimentalist, he was a never-tiring, ever curious collector of the myriad strange phenomena elicited by the particular conditions of temporal isolation. His was the energy and persistence that designed and carried out, alone or in collaboration, day and night from 1964 to 1989, 418 experiments in 447 human volunteers in the bunker under nearly every conceivable condition (211 fee-running) Wever's multioscillator concept regains pertinence in a molecular. [AnnaWirz-Justice, Serge D., Folkard S., Lewy A., Lund R., Zulley] JOURNAL OF BIOLOGICAL RHYTHMS / December 2005" [Wirz-Justice et al. 2005].

The studies done in Andechs were performed during between 4 weeks and up to 3 months [Wever 1979]. Other studies in temporal isolation have been made by Hallberg et al. 1965, Mills et al. 1964, Ghata et al.1964, Apfelbaum 1965, Chouvet et al.1968. These isolation experiments in natural caves lasted from 15 to 205 days [Wever 1979].

Comparison with the studies in the Thesis: The subjects that participated in the studies in the Thesis stayed from a few hours to a day. The design of the room and light settings were done to permit a systematic comparison between the data collected in the rooms in each study. The studies conducted in this project should be seen as pre-studies. The work of Wever in Andechs shows the time and effort that is needed to find out the impact from light. During the time that Wever worked he found out methods and procedures that increased the quality of the work. With the knowledge I have today the studies done in the Thesis should be performed for a longer time and with more precise developed instruments and be combined with interviews.

3.1.2 Early examples of research in action spectrum in PS from artificial light sources

Hollwich found evidence that light entering the eye act as a trigger for hormonal release. He reported about a suggested pathway to hypophysis 1948 that he called the “energetic pathway”. In 1980 he wrote that different metabolic and endocrine effects on human subjects are due to the different spectral components of the lamp. ”In other words the spectral components play the decisive role” [Hollwich & Dieckhues 1980].

“We may, furthermore, conclude that the more the spectrum of the artificial light source differs from that of natural light the more the biological endocrine system in man will be disturbed during short periods of time. The disturbance of the endocrine system of man, induced by unbalanced artificial light, involves his comfort [Hoefling 1973], his efficiency as well as fatigue [Hollwich and Dieckhues, 1972; Hollwich et al. 1975, 1977]” [Hollwich & Dieckhues 1980].

Fritz Hollwich studied blind humans.

“We studied the biological rhythm of the ACTH, cortisol, HGH, testosterone and THS levels in totally blind people, in persons with defective light perception (all blinded by trauma as adults during World War II) and in a normal control group. The cortisol curve of the totally blind (bilaterally artificial eyes, no light perception) differs in its mean value significantly from the curve of normal subjects but also remarkably from that of people seeing hand movements or having light perception. Even so, in all the above-mentioned tests we found that the levels of those blind people with bilaterally artificial eyes or those with no light perception were the lowest ones” [Hollwich & Dickhues 1980].

Additionally, Hollwich studied ACTH and cortisol levels in patients temporarily blind in both eyes by cataracts. They examined the levels before and after removing the cataracts.

“Before extraction we obtained approximately the same low level as found by the blind. After the cataract extraction we found normal levels of ACTH and cortisol” [Hollwich & Dieckhues 1980].

Fritz Hollwich did a study on the physiological impact from lighting applications in 1980. The result of the study showed that strong artificial illumination of 3500 Lux increased the release of

ACTH and cortisol in the group of subjects and that the short period of a fortnight of exposure to this condition suffices to create stress-like levels of ACTH and cortisol.

"We also studied influence of another artificial light source, approximately of the same luminous intensity (3,300 lx) but of different spectral composition. We compared the effect of a cool-white fluorescent lamp with a tube simulating sunlight" [Hollwich & Dieckhues 1980, p. 194].

"Comparing both lamps, we found that the stress-like effect of the cool-white tube was absent in the sunlight-simulating tube" [Hollwich & Dieckhues 1980, p. 194].

Comparison with the studies in the Thesis: The blind subjects that Hollwich studied lived for a long time without daylight entering the eye. The subjects in the studies in the Thesis project were normal sighted and stayed from a few hours to a day, or three days at the most, within the room and its lighting application in the study. In his research Hollwich used basically the same alternatives: daylight, artificial light mimicking daylight and artificial light deviating from daylight. Daylight and artificial light mimicking daylight worked well for the subjects, but in artificial light deviating from daylight there were differences seen in the response. The studies are not identical in wavelengths emitted from the lights sources, the subjects and the rooms used in the studies differ. The conclusions of the research performed by Hollwich and study 2 in the Thesis are close. The study number 2 shows that daylight and daylight mimicking artificial light initially show a more positive response from the subjects compared to an artificial light deviating from daylight. In the work of Hollwich [1979] daylight was used as a natural reference, and this reference was used in the work with the studies in the Thesis as well. The logical conclusions drawn by Hollwich about daylight being essential to humans and the associations to the way light should be designed are congruent with the findings in the Thesis [Paper VI, VIII, IX, X].

3.1.3 Research in sleep and wake up habits

Roenneberg et al. [2007] studied 55 000 subjects and their sleep and wake up habits. The result verified the large spread in their behaviour. The study shows that some humans go to bed when others wake up. This large scale study is an example of the work that needs to be done to be able to predict light-related patterns in responses to PS and preferences for light in order to show a normal distribution curve valid for the spread in the population.

Comparison with the studies in the Thesis: The subjects that participated in the studies in the Thesis stayed from a few hours to a day, and three days at the most. The design of the room and light settings was done to permit a systematic comparison between the data collected in the rooms in each study. The study of Roenneberg et al. [2007] shows that despite being exposed for the same 24 hour rhythm in daylight the subjects are in different phases of the diurnal rhythm when participating in the study. This was not controlled in the studies in the Thesis. But the studies compared if the subject's individual responses and preferences differed from each other when they stayed in the room and light settings? The result of Roenneberg et al. showed large differences . The same result was seen in study 4 [Säter 2011]. Despite the fact that the study by Roenneberg et al. [2007] concerned habits in sleep and wake up behavior and the result in study

4 concerned visual comfort, the studies have in common a pattern of interindividual differences, and a variety in the responses and preferences to light.

3.1.4 Research in the variability of the human visual function

Lucia Ronchi´s research in the cyclic variability of the visual responsiveness was performed by recording a given response for a number of tasks, in various successive trials throughout the day, from a number of normally skilled young adults. When she plotted her data versus the time of day, she discovered that the possibility of a diurnal rhythmical behaviour, modulated by an intradian 4-hour period variability, was encouraged and a possible influence on it from the spectral power distribution (SPD) of the source seemed to merge. For instance, she concludes that (in short wavelengths) the intradian oscillation seems to be damped and the amplitude decreases during the day, contrary to what happened in long wavelengths.

Comparison with the studies in the thesis: The results of Lucia Ronchi show variability in the performance related to the diurnal rhythm. In study 4 and 5 the subject's preferences for visual comfort show a pattern of a constant change in preference. In study 5 the result shows variability during the day when measured within a short period of time.

3.1.5 Research in health theory

"The holistic theory according to Pörn is an anthropological bias as regards the concept of health. It is a health concept not based on illness and thus differs from traditional medical perspective. It describes an individual´s equilibrium, that between goal achievement and goals [Pörn 1984, 1988; Nordenfeldt 1986]. That is to say the individual attempts to achieve his goals and so attain good health. Pörn theory of health [Pörn 1984, 1989] consists of three factors "will profile", repertoire and environment. Will profile (or goal profile) relate to an individual´s central and peripheral purpose in life, such as aims and means. A person's goals should be in tune with his or her plans. Does a person´s lifestyle leave room for 7-9 hours sleep or are his/her goals such that he/she experiences psycho physiological stress, sleep disturbance and bad health? A person's repertoire is his/her psychological and physiological capacity plus other internal resources. These functions are disturbed by sleep disturbances. In the concept "environment", Pörn [Pörn 1984, 1988] includes the individual´s internal and external environment. It is the actual circumstances in the environment that give us the opportunities for action. A person experiences good or bad health as a result of the relationship between these above mentioned three variables. The individual is dependent, making demands both upon himself and the environment [Pörn 1984, 1988]" [Edéll-Gustavsson & Ek 1992, p. 31].

Pörn's theory about health is not a specific study but an approach to the way environment can be used as a tool for health, and thus it can still be compared to the ideas behind the use of methods in the studies. The individual's equilibrium, will profile, repertoire and environment is close to the health approach that has characterized the work with the Thesis. The lighting designer has the possibility to encourage the will profile according to the individual user's needs and create a health supportive environment that strengthens the diurnal rhythm. Health is, according to Pörn, related to a well-functioning sleep and diurnal rhythm since long-term disturbances lead to disease. The goal for recommendations for lighting design developed in the Thesis is to increase the repertoire and the will among subjects to use light in a way that strengthens their diurnal rhythm and, in doing so, to improve their sleep and health.

When Pörn's health theory is compared to the design of Studies 1, 2, 3, 4 and 5, theoretical similarities can be seen in the approach. Study 1) the environment is seen as a tool for visual comfort. Visual comfort is in the same way the key for the design of a physiological supportive light [Paper IV]; Study 2) the environment is seen as the tool for hormonal release [Paper IX]; Study 3) the environment is seen as a tool for comfort (alertness) [Paper VIII]; 4) Studies 4 and 5 show the huge interindividual differences in the experience of visual comfort [Paper I]. The subjects need to be able to choose the most individually comfortable and supportive light for the specific the moment. It is the design of the daylight and artificial light that give the subject this opportunity [Paper X].

Comparison with the studies in the Thesis: The research by Pörn is theoretical and differ in methods from the studies done in the Thesis, but his investigations are close in the idea of the PPV impact from the environment on the subject and the possibility to use the room as a tool for the experience of individual equilibrium (perfect homeostasis). Pörn´s holistic health theory is based on lifestyle, society and the individual's environment and is concerned the environment used as a tool for the individual subject to stay in equilibrium and for a stable diurnal rhythm. This is a theoretical approach close to the one behind the development of the room and light settings in the studies.

3.1.6 VCT, method for investigation about level of light at the working table and for the complementary ambient light

The method used in the investigation of the level of light at the working table is developed with the purpose to collect data about user preferences in the combination of light at the table and in the ambient light. The method was developed by Bo Persson at KTH in Stockholm together with opticians and was further developed by the author of the Thesis and used at Jonkoping University for 10 years. In the study performed in the Thesis, there were no ambitions to use previous data or methods from earlier studies. The study is done without ambition to generalise about an optimal level, the purpose was only to demonstrate the variety of preferences in a group of subjects. After data was collected I started to read about previous studies to compare my result with others. I found that generalisations of 500 Lux as a well-functioning level of light at the working table goes back to M. Aguilar and W.S. Stiles 1954 and their work with the saturation of the Rod Mechanism of the Retina at High Levels of Stimulation [Aguilar, Stiles 1954].

"From the results obtained here by this method it is concluded that at a field intensity of about 100 scotopic trolands the sensitivity of the rod mechanism to stimulus differences begins to fall off rapidly and that at about 2000 to 5000 scotopic trolands (corresponding approximately to daylight luminances of 120 to 300 cd/m^2) the rod mechanism becomes saturated and is no longer capable of responding to an increase of stimulus." [Aguilar, Stiles 1954 p.59].

The first study performed by Stiles was done with one subject [Stiles 1939]. Aguilar and Stiles increased the number of subjects to four in the study performed in 1954 [Aguilar & Stiles]. Miss P. Fowler, Miss S. Ide and Miss E. Kinrade acted as subjects. Based on the results of these three subjects and a fourth subject not mentioned by name, 500 Lux is found optimal by Perry, Campell and Rothwell in 1987. In a study performed by M. J. Perry, F.W. Campbell and S.E. Rothwell in 1987, it is concluded: The current edition of CIBSE interior lighting code recommends as a standard service illumination of general office work of 500 Lux [Perry, Campbell & Rothwell 1987].

"Assuming an effective working plane reflectance range of 2.23-0.36, this equates to a log luminance range of 1.56-1.77. his range of log luminance lies reasonably close to the lower bound of the Aguilar and Stiles rod saturation region. Allowing some decrease in response time before it is deemed to affect performance, the present data show that, in terms of response times, these recommendations are optimal. Perry, Campbell & Rothwell 1987" [Perry, Campbell & Rothwell 1987].

"This conclusion does not answer the question of why given a free choice, some people will select desk top illuminations on 1600 Lux or greater. The lack of correlation between an apparently optimum luminance and the subject's free choice of luminance will require further investigation" [Perry, Campbell & Rothwell 1987].

"Previous studies of an observer´s preference for different task area luminance's and illumination levels are in reasonable agreement with the present results. Balder asked his observers to rate the acceptability of the luminance of a piece of white paper placed on a desk into one of the three categories too dark, good, too bright. Approximately 70 per cent of the observers considered that good lighting occurred for a task luminance of between 325 and 410 candelas per square meter, the maximum percentage occurring for a luminance of 365 candelas per square meter, corresponding to an illumination of 1770 Lux. In the present study such a luminance corresponds to a desk illumination level of 1.550 Lux, i.e., in the region where the preference rating is relatively constant" [Perry, Campbell & Rotwell 1987, p .42].

"Balder [Balder1957] also found that some observers found the task luminance to be too bright at levels above approximately 200 candelas per square meter (illumination level 1.000 Lux). Similar results were obtained by Bodman [Bodman, Sollner & Voit 1963] and his colleagues (10, 11) who concluded that a preferred range of task illumination levels occurred between 1.000 and 2.500 Lux. Riemenschneider (12) has obtained an optimum illumination level of the order of 2.500 Lux, although it seems possible that this relatively high level was due in part to a lack of control of the adaption conditions, similar to the effect found in the pilot experiment described in Section 2. In Balder and Bodman and the present studies the indications are that the mean observer´s preference for the lighting on a simple office type task, at least for normal task-surround conditions, is fairly constant for illumination levels between approximately 1.000 and 2.500 Lux, and that the maximum preference probably occurs in this range." [Perry, Campbell & Rotwell 1987 p.42].

"All three studies show that an increasing number of observers begin to find the lighting on the task too bright as the level is raised above 1.000 Lux, although such a comment is not associated with as low a preference rating as when the lighting is too dark" [Perry, Campbell & Rothwell 1987, p.42].

"In Balder´s, Bodman´s and the present studies the indication are that the mean observer´s preference is fairly constant "[Perry, Campbell & Rothwell 1987, p.42].

Comparison with the studies in the Thesis: Study 4 and 5 in the Thesis are hard to compare with Perry´s et al. and Balder and Bodman. They do not have the same subjects, contrast situation or light settings and work tasks. The ambition in the study performed in the Thesis was to let the subjects judge their visually comfortable level of light on the table when reading black letters on a white paper and to combine this with their preference for the preferred level of complementary ambient light. The preferred level of light for the working table was measured first and is used here for the comparison.

J.E. Saunders studies [1969] can be related to the result of Balder and Bodman.

"In Balder´s, Bodmans and the present studies the indications are that the mean observer's preference for the lighting on a simple office-type task at least for normal task-surround conditions, is fairly constant for illumination levels between 1.000-2.500 Lux and that the maximum preference probably occurs in this range" [Saunders 1969].

When comparing the result of the five studies, I find that, despite their being different, they point in the same direction for the most preferred level of light. Saunders,1969 (1550 Lux) Balder, 1957 (1770 Lux), Bodman, 1967 (1000-2500 Lux), Riemenscheder, 1967 (2500 Lux), Säter 2011 (M=2007 Lux). However, in order to be able to compare these five studies in an accurate way, they need to be reconstructed and used in the same way by the same subjects, as well as measured in the same way and this is not done here.

3.1.7 Summary

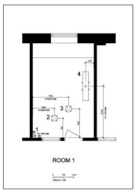
Self-evaluation with semantic scales and physiological markers are used in the studies. Those are the most frequent methods seen used today. They are restricted in many ways. The self-evaluation depends on if the subjects are naïve or trained and need to be related to the individual's disposition for receiving EMR, visual performance and diurnal rhythm. Methods can be compared in the way they are performed but also in the theory that lies behind the work with the development of the methods. I find the result of Wever, Hollwich, Ronchi and Roenneberg et al. important in many ways. They are usable for predictions of the public´s relation to light. It is difficult to imagine the effort needed for Hollwichs´ 30 000 blood samples, Wevers´ night and day shifts 1964-1989 and Roenneberg and his colleagues work with 55,000 subjects. Luckiesh and Moss 100,000 measurements and Ronchis´ work for 30 years. But this is the effort needed to be able to predict human responses to PS. The studies in the Thesis are done with the ambition to look closely on a small group of subjects and to see the actual individual response and preference. The studies performed in the Thesis are small prestudies far from the mappings for normal distribution curves done in the studies of Roenneberg et al., Wever and Hollwich. Lucia Ronchis´ studies since 1960 show the complexity in the visual function as a part of the human body in a diurnal rhythm going from deepest sleep to the highest level of alertness. The studies performed in the thesis and by Luckiesh and Moss, Wever, Hollwich, Roenneberg et al. and Lucia Ronchi share the knowledge about the importance of the light-related diurnal rhythm and show the differences between the individual users. This all fits in to the holistic theory of health of Pörn. The methods used are different in the way they are performed and are by that not possible to compare to each other. Despite this, the methods used have in common that they investigate the interaction of MLCS and the huge inter-individual differences among subjects when staying in the same interaction model.

3.2 Studies performed in the Thesis

3.2.1 Study number 1. Visual comfort

Visual comfort is a central theme in lighting design. Study 1 concerns the experience of visual comfort. The lighting designer´s and the subject's experiences of visual comfort are measured in a visual comfort test (VCT). The use of the VCT provides the possibility to make comparisons between the individual's preferences for the combination of level of light at the working table and for the complementary ambient light. The study was performed in room and light setting number 1. Three ordinary offices were used and equipped with a working and a reading area. The level of visual comfort and level of visual variation were designed close to, far from and very far from the lighting designer's visual preferences. The 36 subjects attended the study in a balanced order of presentation and got instructions through a loudspeaker. The subjects stayed during the day in all three room and light settings. They answered pre-formulated questions while staying in the room. After leaving the room, they described in a free formulated way how they experienced the room that they just left. The study is published in paper VI appended here**.**





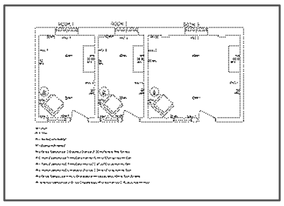
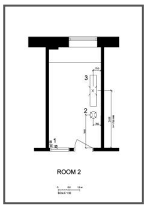


Fig. 2. Study1 R1. **Fig. 3.** Study 1 R1. **Fig. 4.** Floor plan. **Fig. 5.** Measurement points Study1.





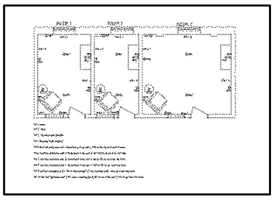


Fig. 6. Study 1 R 2. **Fig. 7. Study** 1 R 2. **Fig. 8**. Floor plan. **Fig. 5**. Measurement points Study1.



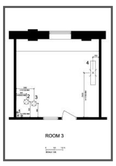
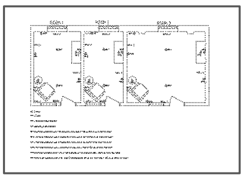



Fig. 9. St. 1 R 3. **Fig. 10.** St. 1 R 3. **Fig. 11.** Floor plan. **Fig. 5**. Measurement points Study 1.

Study design study 1, study 1

In order to find more information about user preferences to the design of artificial light for the indoor environment data was collected about 36 subject's experiences of three room and light settings. A second part of the study was the visual comfort study (VCT) where the lighting designer and 18 of the 36 subjects participated. They evaluated their visual preferences according to preferred level of light at the working table and for the complementary ambient light. The lighting designer´s measured preferences for level of light were then compared with the group of 18 students who were enrolled in the Lighting Design Program at Jonkoping University. The study was conducted at the School of Engineering at Jonkoping University in December 2005. Thirty-six (36) university students completed all segments of the main study. Test subjects for the study were recruited via e-mail messages which were sent to all students at the School of Engineering at Jonkoping University. Forty (40) of these were invited to participate. The remaining three were excluded because there was no space to accommodate them in the group. Thirty-six (36) people completed all sections of the study. Four (4) participants were excluded due to incomplete data. The 36 test subjects consisted of 11 men and 25 women (m=25.9 years). Within the group, 16 women and 6 men were students at the Department of Lighting Science at the School of Engineering at Jonkoping University. The others were enrolled in different departments at the School of Engineering. Each participant was allowed to order a book as compensation for their participation.

Instruments used in the study, study 1

PANAS: Emotional state was measured with ten five-grade semantic scales (PANAS scales), [Watson et al. 1988].

The perception of lighting quality: The ambient light was measured through a questionnaire, on which test subjects were asked to encircle on a paper the three words that best described their experience of the lighting in the room. In the test 34 words as a total were used, 21 positive and 13 negative and they were listed on one sheet of paper. Chosen as positive were the words shaded, comfortable, good, diffuse, subdued, absence of flicker, focused, even, and cold, clear, concentrated, bright, shiny, mild, soft, natural, uncolored, uneven, abroach, varied, and warm. Chosen as negative were glary, bad, uniform, flickering, colored, hard, sullen, dark, uncomfortably, unpleasant, unnatural, sharp, strong, weak. The words good, pleasant and comfortable were counted and given one point each. In the same way and by using the same instrument the light at the reading area and workspace was evaluated.

Positive room descriptive words: The subjects were asked when they left the study to describe the room they just left as carefully as possible. The positive room descriptive words were counted and were given 1 point each. No limit was set for the number of words that were counted. The test was developed by Monica Säter at the Department of Lighting Design at Jonkoping University in 2006. The instrument, positive room descriptive words, was used in Study number 1. The test was used and every free formulated positive room descriptive word was counted. No limit was set for the number of words counted.

Procedures in the study, study 1

The test subjects were welcomed and placed in one of the three rooms with a balanced order of presentation. Instructions to the test subjects were transmitted via MP3 players.
There was then a 15-second period of silence. They were asked to sit at the work table. This was followed by 10 seconds of silence. The test subjects were instructed to carry out Task 1, after which there was 5-minute period of silence. They were then instructed to proceed to Task 2, after which there were 2 minutes and 30 seconds of silence. The test subjects were asked to carry out Task 3. There was then a period of silence lasting 2 minutes and 30 seconds. The test subjects were asked to sit in the reading chair. This direction was followed by a 15-second period of silence. They were then asked to read newspapers for 3 minutes. The test subjects were asked to proceed to and carry out Task 5, which was to be followed by a 4-minute period of silence. They were subsequently instructed to proceed to Task 6. This was also followed by a 4-minute period of silence. The test subjects were instructed to carry out Task 7. This was followed by another 4-minute period of silence, after which they were instructed to leave the room. Once outside, they were instructed to carry out Task 8. Following this, the test subjects were assigned new room numbers and instructed to go to these rooms. These procedures were repeated a total of three times. The test subjects spent equal lengths of time and carried out identical tasks in each of the three rooms.

Statistics used in the study, study 1

Data was analysed with the use of mean values.

Instruments used for measurements in the VCT

A calibrated luxmeter was used to measure vertical and horizontal illuminance.

Design of Room 1, 2 and 3, study 1

The design of the room and light settings was done in a descending level of visual comfort and can be seen in figure 2-11 and is described further in table 1-6.

Fig. 2. Study 1 R 1

Fig 3. Study 1 R 1

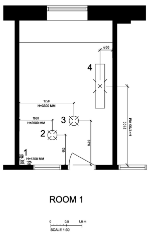


Fig. 4. Floor plan (se appendix B)

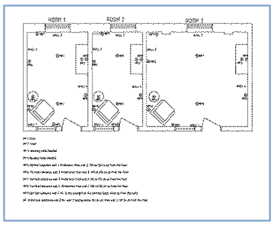


Fig.5. Floor plan (see appendix B)

Table 1. R1- L1L4

L1= Floor standing reading lamp, Halogen4clear restr. dimmable.
L2= Downlight, Halogen 100W clear

L3= Down light, T/E 26W/830
L4= Pendant worktask lum. TL 5 49W/830 restricted dimmable

Table 2. Room 1 HI = Horizontal illumination

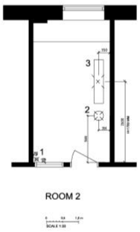
MP 1 Floor 1 190 Lux HI

MP 2 Floor 2 96 Lux HI

W- table 75-950 Lux HI

R- table 410 Lux HI





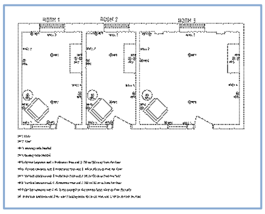


Fig. 6. R 2. W-place **Fig. 7**. R 2 R-place. **Fig. 8**. Fl.plan R 2 (see appendix B) **Fig. 5.** Wall 1-4, m p R 2 (see appendix B)

Table 3. Floor plan L1-L3**.**

L1= Floor standing reading lamp Halogen 100W opal and Halogen 50W. Dimmable

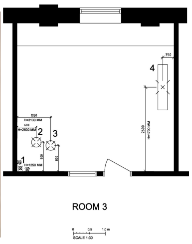
L2= White tubular cloth lamp, 3xa60 60 W.

L3= Table standing work task luminaire. 36W/840 Dimmable

Table 4. Horizontal illuminance

Mp 1 Floor	175 Lux	HI
MP 2 Floor	103 Lux	HI
W-table	53-3100 Lux	HI
R-table	900 Lux	HI





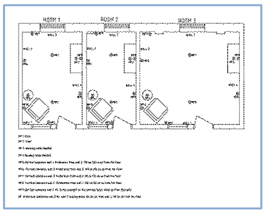


Fig.9. R3 **Fig.10.** R3 **Fig.11.** R3 (see appendix B) **Fig.5.** R 3 (see appendix B)

Table 5. L1-4

L1= Floor standing reading lamp, halogen 4 clear, restr. dimmable. L2= Ceiling mounted down light, halogen 100W clear.

L3= Ceiling mounted down light, PL-T 18W/830/4p L4= Pendant work task luminaries. Svitch dim, fluorescent PL-T 28W/830. Filter CTB

Table 6. Mp1-2. Wall1-4

Measurements point	**HI Lux,**		
	Room 1	Room 2	Room 3
Measure point 1. Floor	190 Lux (MP1Floor)	175 Lux	275 Lux
Measure point 2. Floor	95 Lux (Mp2 Floor)	103 Lux	105 Lux
Working table	75-950 Lux (Working table)	53-3100 Lux	41-520 Lux
Reading table	470 Lux	900 Lux	600 Lux

Room and light setting nr. 1-3, study 1

The walls in rooms 1, 2 and 3 were painted with white plastic paint, color code NCS 0500. The floors in Rooms 1, 2 and 3 were covered with linoleum with patterns in the following colors: NCS 2010-Y30R, 4040-Y30R and 3502-B. The ceilings in the three rooms were painted with plastic paint in color NCS 0500. All three rooms had workspaces consisting of a wooden table with black metal legs and a chair. The chairs had wooden frames, with seats made of leather. In addition, there was a linen-covered armchair in the reading area of each room. The threads in the fabric were in the colors NCS 5010-Y30R and 0500. In Room 2, the armchair was covered with a cotton fabric in color NCS-3070-Y90R. Beside the reading chair was a round pinewood table with white tabletop. There was a white woven wool mat on the floors of Rooms 1, 2 and 3. In Room 1, the window was decorated with a linen curtain in color NCS 4005-Y50R. In Room 2, the curtain was cotton and in color NCS 0500. The curtain in Room 3 was also linen and in color NCS 1010-Y20R. The Venetian blinds in Rooms 1 and 3 were covered with linen fabric in the color NCS 4005-Y50R. The blinds in Room 2 were not covered. The red band that held the wooden slats were of the color NCS 4050-Y70R. As a complementary feature to the décor, a piece of cloth was placed on the table beside the armchair. The cloth in Room 1 was made of cotton and was of the color NCS 1005-Y20R. The cloth in Room 2 was of the color NCS 4060-Y90R with traces of 0005-Y20R. The cloth in Room 3 was made of cotton and in color NCS 1005-Y20R.

3.2.2 Study number 2. Responses to daylight, artificial light mimicking daylight, artificial light deviating from daylight, in the indoor environment.

Study number two was performed in rooms designed in the same way but different in the choice of ambient light and task lighting. The study focused on responses to PS and preferences for the light in the three room and light settings. Daylight was used in Room 1 for ambient light and the room had no task lighting. Metal halide and Halogen (Halo par) was used for the ambient light in Room 2 and an incandescent light source for task lighting. In room 3 fluorescent tubes were used. The response to PS was measured with blood samples and the preferences for light with preformulated instruments. The study is published in Papers VII, VIII, IX appended here.

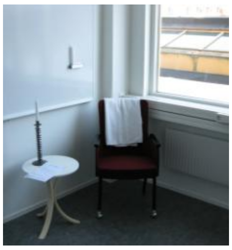


Fig. 12. Study 2 R 1.

Fig 13. Study 2 R1.

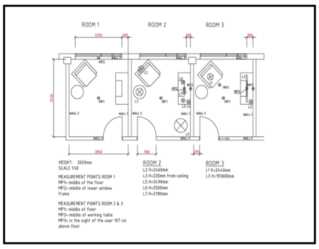


Fig. 14. Floor plan. Study 2 (see appendix B).

Fig. 15. Study 2 **R2**.

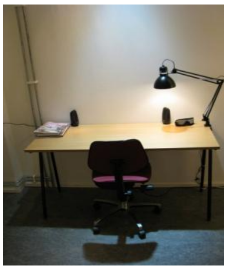


Fig. 16. Study 2 R2.

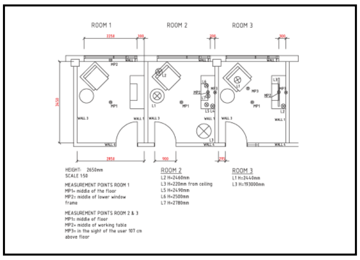


Fig. 14. Floor plan. Study 2 (see appendix B).

Fig. 17. Study 2, R 3.

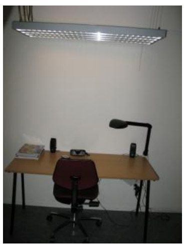


Fig. 18. Study 2, R 3.

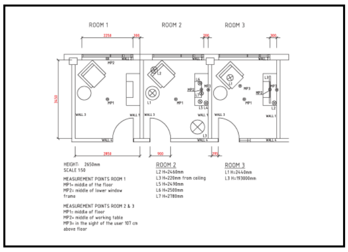


Fig. 14. Floor plan Study 2 .(see appendix B)

Study design, study 2

This study was performed in three room and light settings similar in architectural and interior design but different in light settings. The subjects stayed for one day in each room. Data about the subjects' experiences, responses and performances in the three rooms was collected with questionnaires about emotional experience and cognitive performance. Blood samples were collected at 8:00-8:15, 12:00-12:15 and 16:00-16:15. The subjects remained in the same electromagnetic radiation (EMR) during the day with an exception of 15 min. when the blood samples were taken. All blood samples were taken solely in daylight due to practical reasons.

Participants, study 2

The study was conducted at Jonkoping University in 2006. The test subjects were recruited by group mail sent to all students enrolled in the lighting design program at Jonkoping University. 20 people applied to participate in the study (m=24.6 years) and were chosen by convenience. The group consisted of 12 women and 8 men. Each participant received books worth 2000 SEK for their participation in the study.

Instruments used in the study, study 2

Gunilla Burells test: The subjects' personality and self-evaluated disposition to experience stress were measured by using *Gunilla Burrell's personality test* (BT). The subjects assign by 20 questions in a range of 1-4 points **(**20p=min, 80p=max**)** their disposition to experience stress in everyday life. (http://www.hjart-lungfonden.se/HLF/Aktuellt/Ar-du-stressad/).

I feel at the moment: The subjects´ experiences were measured with the test called *I feel at the moment.* The test measures the users experiences with a semantic scale from 1-4+. The test is based on contradictory feelings graded in very, rather and very (sleepy-alert goes from very sleepy, rather sleepy, rather alert, and very alert). The words very sleepy– very alert were used.

VCT: The test was developed by Bo Persson at KTH in Sweden. It was used to measure the preferred level of light at the working table. Bo Persson did the test with a white paper on a white table and repeated the procedure for three times. Then he did the same procedure with a white paper on a black table. The test was completed in 2006 by M. Säter to be used for measurement of both the level of light at the working table and for the preferred level of the complementary ambient light. A white paper on a black table was used in Studies 1, 2, 3, 4, and 5 in the Thesis.

Study number four focuses on the preferences for a visually comfortable level of light at the working table and for the ambient light. The study was performed in one of the rooms used in Study number 1 and in one room used in Study number 3. The visual comfort test (VCT) measures the subjects´ preferences in a given contrast situation. A white paper is placed on a black table. The test starts in the room which is dark and the level of light is taken up to maximum, down again, until the subject recognises their individual level of light experienced as visually comfortable. The preferred level of light is measured as horizontal (the table) and vertical (ambient light) illumination with a light meter. Then, the level of light for the working table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times and the third measurement is counted. The VCT test was used in the same way in Studies 1, 2, 3, 4 and 5.

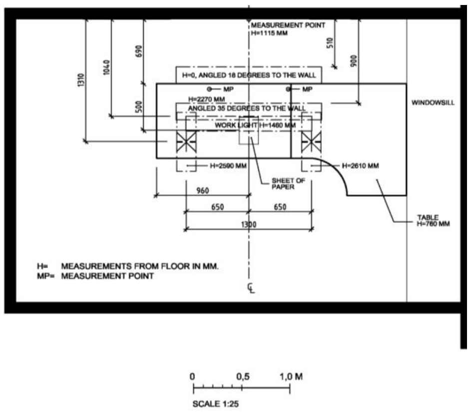


Fig.19. Plan visual comfort test (see appendix B)

Blood samples: The physiological response was investigated via tests for the hormones cortisol, adrenaline, noradrenaline, melatonin and oxytocin. A visual analysis was also applied. In order to gather data about the physiological responses to the three lighting environments, saliva and blood specimens were collected from the test subjects. These were used to measure the levels of cortisol, melatonin, adrenaline, noradrenaline and oxytocin in the participants. The specimens were collected by a biomedical analyst from the Ryhov County Hospital (*Länssjukhuset Ryhov*). The analyses were carried out by Ingegerd Thudén and Carina Tengham as described below. S-Cortisol: The test was conducted in 4 ml test tubes. The specimens were marked in accordance with normal routines. The tubes were allowed to stand for 30-60 minutes and then put in a centrifuge. Half of the serum was pipetted into a polypropylene test tube and marked with a barcode label. The specimens were then re-labelled and frozen. The primary test tube was refrigerated. P-cathecholamines: The test was conducted in three chilled 6 ml heparin test tubes. These were either placed in an ice bath or immediately in a cold centrifuge. The plasma was separated into two polypropylene test tubes, at least 1.8 ml in each tube. These were labelled with the name of the test subject and the time. One tube was labelled with “Cathecholamines back up”. The label was flagged and the tube placed in a freezer. P-oxytocin: The test was conducted in a 10 ml K3-EDTA test tube. It was then placed in an ice bath or directly in a centrifuge. The plasma was divided between two propylene tubes and labelled with the test being carried out and the time. One tube was labelled “Oxytocin, back up”. The labels were flagged and the tubes frozen.

Test conduction: Handling the tubes. The test tubes were transported daily to the Clinical Chemistry Department in carrying cases equipped with freezer clamps. Ice cubes and freezer clamps were available each day. Leftover material, centrifuge and waste were transported away at the end of the study. In the oxytocin test, the test tubes were frozen at -70 ºC. In the test for catecholamines, the tubes were frozen at -70 ºC. Cortisol tests were treated as routine tests, and the backup test tubes were frozen at -20 ºC.

Procedure, study 2, study 2

The subjects stayed outside of the test rooms before the experiment started and then entered in a balanced order of presentation. Instructions to the test subjects were transmitted via MP3 players. The test had the following schedule that was repeated three times during one day in the three test rooms: *7:15–8:15* Gathering at the school, anaesthetic cream, Emla was rubbed in to prevent pain from needles, specimen collection, and breakfast. Task 1, Completed before entering the room. 8:15– 8:30 Entering the room. 8:30–8:50 Task 2, SMB, 4 min. Task 3, Check list: 2 min 30 s. Task 4, Lighting experience: 4 min. Task 5, *I feel at the moment* : 2 min 30 s. Task 6, Pattern corrections: 5 min 30 s, Total 19 min. 8:50–12:00 Study for examination. 11:00 Reminder to take Emla and that there is one hour to go before the next round of specimen collection. No intake of food between 11:00-12:00. 12:00-12:15 Specimen collection: blood and saliva. 12:15- Lunch.13:00- Task 7, Lighting experience: 4 min. 13:15 Task 8, Checklist: 2 min 30 s. Task 9, I feel at the moment: 2 min, 30 s. Task 10, Letter correction: 5 min, 30 s. 13:15-16:00 Study for the examination: 2 hrs, 45 min. 15:00 Reminder to take Emla and that there is one hour to go before the next round of specimen collection. No food between 15:00-16:00. 16:00-16:30 Specimen collection: blood and saliva. 16:30 Task 11, Lighting experience: 4 min. Task 12, *I feel at the moment*: 2 min. 30 s. Task 13, Character correction: 5 min. 30 s. Task 14, Checklist: 2 min. 30 s. Task 15, SMB: 4 min., Total 18 min. 16:50-17:25 Study for examination: 35 min. Task 16, *I feel at the moment*: 2 min. 30 s. 17:30 End of test. The subjects went home and returned to the school to participate in days 2 and 3 of the test.

Analysis of data, study 2

Data was analysed with the analytic software SPSS. Mean and frequencies were used.

Design of the room and light settings, study 2

The three room and light settings, almost identical in architecture and interior design differed in the lighting equipment. (Figures12-18, Tables 7-20). In order to neutralise temporary differences in the level of daylight that only lasted for a short while, a mean daylight day was constructed. The mean daylight day was based on 4 and 10 March 2006. Horizontal illuminance was measured in the middle of the floor. The levels of light in Room 2 were designed close to the measured values of horizontal illuminance seen in the mean daylight day. Position of luminaries, light distribution and level of light differed in the three rooms. One room, Room 1, used only daylight as task and ambient light and was completed with two candles if needed during the day. Two of the rooms, Rooms 2 and 3 were darkened and were equipped only with artificial light. The light in Room 2 was designed mimicking daylight (to some extent, see methods). The light in Room 3 was designed to deviate from daylight (to some extent, see methods) (Figures 12-18, tables 7-20). The doors in Rooms 1, 2 and 3 were painted in a blue-reddish colour with NCS code 4060R70B. The walls in Rooms 1, 2 and 3 were painted with a neutral white latex paint with NCS code 0502Y. The floors in the three rooms were covered with a carpet of linoleum in beige with NCS code 6500. The ceilings in the three rooms were equipped with acoustic boards painted in white with NCS code 0502Y. The work space had a work table of birch with black metal legs, 1400mm x 600mm and 720mm. All three rooms were equipped with a reading place with an armchair in a wine red cloth with wooden legs, Ø450mm, and height 540mm at the reading place. The corridor outside of the three test rooms was screened off from daylight with black cloth and was equipped with two separate lighting systems. The first was equipped with incandescent light bulbs; the other had low energy light bulbs and was used as a complementary lighting system to enable the subjects to go to the restroom in the same light in which they stayed in the test rooms (Figures 12-18, tables 7-20).

Lighting conditions Rooms 1, 2 and 3, study 2
Data about the lighting applications in the three rooms can be found in table 7-20 and in figure 12-18.

Measurement points, study 2

Table 7. Measurement points Room 1, study 2

Room 1	**Measurement point**
Ambient light HI	Middle of the floor

Table 8. Measurement points Rooms 2 and 3, study 2

Rooms 2 , 3	Size cm			Measurement p			
	Length	Width	Height	Length	Width	Height	
Work table	140	60	72	70	30	0	Edge of table, 66 cm fr. wall 2
Floor	340	285	267	170	142	0	
Reading place				57	62	76	
				From wall 3	From wall 2		
Wall at the table				136 cm from wall		107 cm over the floor	
Wall at the door				80 cm from wall 1		110	80 from wall 1
Wall at the reading place				105 from 2			

2.6.3 Level of horizontal and vertical illumination and luminance, study 2

Table 9. Level of HI Room 1, 8.00, 10.00, 12.00, study 2

Mean day Lux	**8.00**	**10.00**	**12.00**
Floor HI	62	230	367
Window frameHI	749	1761	3290

MF= middle floor MLF= Middle lower window frame

Table 10. Level of HI Room 1, 14.00, 16.00, 17.00, study 2

Mean day Lux	**14.00**	**16.00**	**17.00**
Floor HI	184	114	50
Window frame HI	**2647**	**1303**	**531**

MF= middle floor MLF= Middle lower window fram

Table 11. Illuminance Room 2, 8.00, 10.00, 12.00, study 2

08.00 Illuminance					10.00 Illuminance				12.00 Illuminance			
	Lux	Lux			Lux	Lux			Lux	Lux		
Place	1*	2*			1*	2*			1*	2*		
Work table HI	170	171			1500	1490			1780	1780		
Floor HI	40	41			330	330			340	348		
Reading place HI	145	146			445	448			617	615		
Wall at table VI	44	44			326	325			480	470		
Wall at the door VI	55	53			414	410			433	435		
Wall at the reading place VI	120	128			255	260			340	330		

HI=horizontal illumination, VI=Vertical illumination, 1* =first measurement, 2*= second measurement

Table 12. Illuminance, Room 2, 14.00, 16.00 and 17.30, study 2

14.00 Illuminance					16.00 Illuminance				17.30 Illuminance			
	Lx	Lx			Lx	Lx			Lx	Lx		
Place	1 *	2*			1*	2*			1*	2*		
Work table HI	1180	1180			290	290			211	215		
Floor HI	237	239			70	74			38	38		
Reading place HI	364	364			185	188			148	149		
Wall at w- table VI	327	330			95	98			67	68		
Wall at door VI	350	347			168	163			69	68		
Wall at reading place VI	221	220			147	149			120	120		

HI=horizontal illumination, VI=Vertical illumination, 1* =first measurement, 2*= second measurement

Table 13. Illuminance Room 3, 8.00, 10.00 and 12.00, study 2

08. 00 Illuminance					10. 00 Illuminance				12. 00 Illuminance			
	Lux	Lux			Lux	Lux			Lux	Lux		
Place	1*	2*			1*	2*			1*	2*		
Work table HI	65	65			67	66			216	217		
Floor HI	20	19			18	17			56	55		
Reading Place HI	27	27			19	20			27	30		
Wall at table VI	22	21			21	21			82	81		
Wall at the door VI	8	8			8	8			27	26		
Wall at the reading place VI	10	10			8	8			20	20		

HI=horizontal illumination, VI=Vertical illumination, 1* =first measurement, 2*= second measurement

Table 14. Illuminance, Room 3, 14.00, 16.00 and 17.30, study 2

14. 00 Illuminance					16. 00 Illuminance				17. 30 Illuminance			
	Lux	Lux			Lux	Lux			Lux	Lux		
Place	1*	2*			1*	2*			1*	2*		
Work table HI	240	244			1340	1340			3500	3510		
Floor HI	43	42			349	347			1060	1090		
Reading Place HI	31	32			178	180			430	440		
Wall at table VI	58	58			533	534			1710	1730		
Wall at the door VI	17	17			148	147			470	470		
	16	16			120	119			360	360		

HI=horizontal illumination, VI=Vertical illumination, 1* =first measurement, 2*= second measurement

Design of the lighting application in Room 1, study 2

In Room 1, only daylight was used for task lighting and ambient light. The daylight fluctuated in a way that was evaluated as normal for the season (February-March) and as a result of the type of window opening in the room, as well as the cardinal direction at the location. No shielding of the window was used. Based on the measurements of two test days, a mean day of daylight was created (*Table 9-10,15-16*). The use of a mean day was done with a measure point placed in the middle of the floor collecting data of daylight based on the fourth and the tenth of March to get an overall, rough reference to ambient daylight (see discussion of methods). The light started low, increased, increased, decreased, decreased and decreased drastically (Table 9-10, 15-16). The subject received two optional candles as complementary lighting if needed. In order to enable visiting the restroom in the same lighting as in the present test room, candlelight was placed in the restroom. The collection of blood samples for all subjects was done during 15 minutes in daylight (*Figures 12- 18, Tables 7-20*).

Fig. 12. R 1

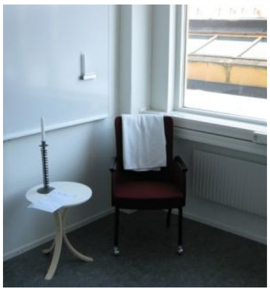


Fig. 13. R 1

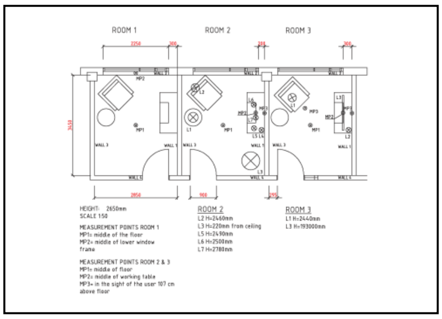


Fig. 14. Floor plan Room 1 (see appendix B).

Table 15. Horizontal illumination, daylight, study 2

Daylight Lux	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
4 March	65	158	353	282	390	378	246	169	98	40
10 March	59	207	106	182	343	320	219	198	130	59
Mean day	63	183	230	232	367	349	233	184	114	50

Table 16. Horizontal illumination, lower part of the window, study 2

	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
4 March	748	1688	2330	1595	3500	2970	2616	1891	1113	452
10 March	750	2320	1191	1873	3080	2990	2678	2250	1493	609
Mean day	749	2004	1761	1734	3290	2980	2647	2071	1303	531

The design of the lighting application in Room 2, study 2

The light in Room 2 was designed to mimic daylight (to some extent, see methods). The windows were covered and daylight shaded out. The light in the room consisted of only artificial light. The subjects had no possibility to dim the light. The level of light varied linearly during the day and from a low level increased, increased, decreased, decreased and decreased by the use of a lighting control system (Table 11-12, 17-18). In order to enable visiting the toilet in the same lighting conditions as in the present test room two incandescent light sources were placed in the restroom. The collection of blood samples for all subjects was done during 15 minutes in daylight (*Figures 12-18, Tables 7-20*). * to some extent and by the use of technique common on the market.

Fig. 15. R 2.

Fig. 16. R 2

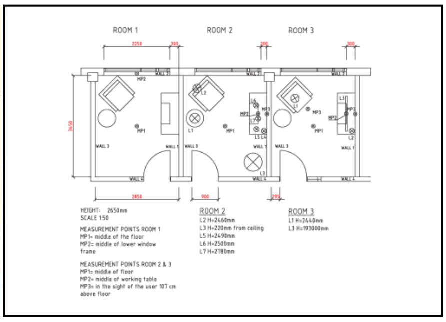


Fig. 14. Floor plan Room 2 (see appendix B).

Table 17. Horizontal and vertical illumination Room 2, study 2

		8.00	10.00	12.00	14.00	16.00	17.00
R 2. Artificial Amb.HI	Middle of the floor	40	330	340	237	70	38
R 2. Artificial Table HI	Middle of the table	170	1500	1780	1180	290	211

M.P= measuring point, HI=horizontal illumination, VI= vertical illumination

Table18. Lighting equipment Room 2, study 2

L1	Luminaire	Incandescent 40W E14 small globe	Floor standing table lamp at reading space	Reading area
L2	Luminary Par 20	Halo par 20 50W 10°	Light aperture 246 cm above floor	Reading area
			47 cm from wall 3, 44 cm from wall 2	Centre measurement
			6° from wall 3, 0° from wall 2	Centre measurement
L3	Cloth shaded luminary 222 cm high	Incandescent 4x60W E27 big bulb	47 cm from wall 1, 50 cm from wall 4	2^{nd} and 4^{th} lamp
			22 cm from ceiling, cloth shaded lamp Ø 31 cm	1^{st} and 3^{rd} lamp
L4	Luminary	Incandescent 60W	Attached to upper right hand corner of desk against wall 1	Work space
L5	Par 20	Halopar 20 50W 10°	Light aperture 249 cm above floor	
			36 cm from wall 1, 162 cm from wall 4	Centre measurement
			slanted 20° from wall 4	Centre measurement
L6	Par 20	Halopar 20 50W 10°	Light aperture 250 cm above floor	
			37 cm from wall 1, 243 cm from wall 4	Centre measurement
			slanted 5° from wall 3, slanted 6° from wall 2	Centre measurement
L7	Spotlight	Colour CDMT 70W 942	202 cm from wall 4, 30 cm from wall 1	Centre measurement
			278 cm from floor	Lamp mounted on roller Above inside ceiling Driver HID-PVC 070/G CDM 2 dimmers, Botex MPX 405
	Fan regulator Off/On Metal halogen lamp			

L= luminary

The design of the lighting application in Room 3, study 2

The light in Room 3 was designed to deviate from daylight; the windows were covered with cloth and all daylight shaded out and the light in the room consisted only of artificial light. The subjects had no possibility to dim the light. The level of light varied linearly during the day starting as low, decreased, increased, decreased, increased and increased drastically (Table 13-14, 19-20) by the use of a lighting control system. In order to enable visiting the restroom in the same lighting conditions as in the present test room, three compact fluorescents were placed inside the restroom. The collection of blood samples for all subjects was done during 15 minutes in daylight (*Figures 12-18, Tables 7-20*).

Fig. 17. R 3

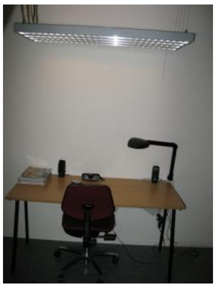


Fig. 18. R 3

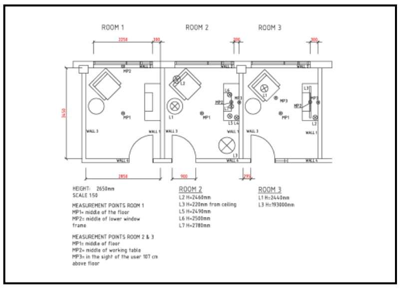


Fig. 14. Floor plan Room 3 (see appendix B).

Table 19. Level of illumination, Room 3, study 2

		8.00	**10.00**	**12.00**	**14.00**	**16.00**	**17.30**
R 3. Artificial light Amb light HI	Middle of the floor	20	18	56	43	349	1060
R 3. Artificial light W. table	Middle of the table	65	67	216	240	1340	3500

M.P. = measurements point, HI= horizontal illumination, VI= vertical illumination

Table 20. Study 2. Room 3. Lighting application, equipment , study 2

Table mounted work task luminary	PL-C 13W, 840, 4p	Attached to upper right corner of desk	Work space
Fluorescent luminary			
Closest to the wall, warm	TL5 HO 54W 830	193 cm from floor	Work space
3rd from the wall, warm	TL5 HO 54W 830	193 cm from floor	Work space
2nd from the wall, cold	TL5 HO 54W 965	193 cm from floor	Work space
4th from the wall, cold	TL5 HO 54W 965	193 cm from floor	Work space

Regulation via light board over DMX to addressed luminaries over a regulation system

3.2.3 Study number 3. Preferences for energy efficient light sources

Study number three was performed in four similar office rooms that were furnished in the same way. The study focused on the subjects´ preferences for energy efficient light.

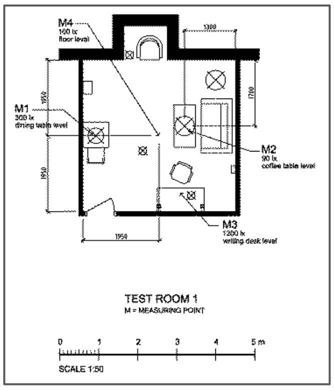
The subjects´ preferences were collected with pre-formulated instruments with semantic scales and free formulated instruments without a scale. The study is published in Papers IV and V here appended.

3.2.4. Room and light setting nr. 3, used in Study 3

Fig. 20. Study 3. R 1 and R 2.

Fig. 21. Study 3. R1 and R 2.

Fig. 22. Study 3. R 1 and R 2.



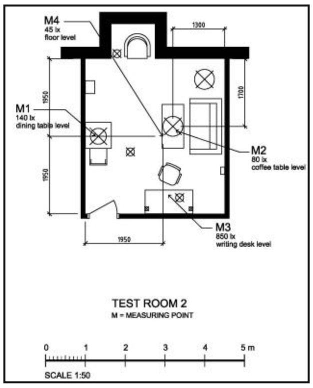


Fig. 23. St.3. R 1 Floor plan (see appendix B). **Fig. 24**. St. 3. R 2 Floor plan (see appendix B).

Methods, study 3:

Subjects

The test subjects were recruited by e-mail (due to convenience) which was sent to all students at the School of Engineering. From the group that expressed an interest in participating, 100 people were selected based on a desire to obtain as even a distribution in age and geographical origins as possible. 87 people from 23 countries completed all stages of the study. The group consisted of 43 men and 44 women. The average age was 31 years.

Formation of subgroups

The average values for the entire group's experiences were collected as a first step. The group was then divided into three subgroups: Scandinavians, Central Europeans and non-Europeans. Finally, the group was divided into men and women. The average values for the entire group of test subjects were compared with those of the subgroups. The average values obtained from each subgroup were subsequently compared with those of the other subgroups.

Procedure, study 3

The following is the procedure for conducting the study for the test subjects who began in Test Room 1. The allotted time was 50 minutes. The test subjects arrived and were each given a folder. They then carried out a test of visual comfort, after which they recorded the light sources they had at home on a questionnaire. They then received oral information about how the trial was to be conducted. An MP3 player in the room gave the test subjects information about the study's activity plan. Evaluation of the fixtures was carried out. Test subjects evaluated whether the light they were seeing in the room matched the light to which they were accustomed at home. They were then asked to state the way in which these two lighting conditions were similar, and to describe the differences if the light did not correspond with the type they had at home. The test subjects were then asked to record their feelings of alertness, fatigue and wellbeing using a scale from 1-5 (a little – a lot). The trial was concluded after approximately 50 minutes.

The following is the procedure for conducting the study for the test subjects who began in Test Room 2. The allotted time was 50 minutes. The test subjects arrived and were each given a folder. They then conducted a study of lighting quality by describing the light in boxes 1-5 in their own words. They were asked to evaluate the quality of the light by assigning a score on a scale of 1-10, where 1=low and 10=high. The study of visual variation in the light on the wall included the test subjects being asked to look at the light source on the wall for one minute and then describe, in their own words, whether they felt that the light had changed during the time they had been observing it. They were asked to describe how the light had changed. The test subjects then carried out a glare test. A box with five different filters was placed on the floor. The test subject stood in a marked square, looking at the light in the box. The test subjects were asked to describe their experience of looking at the five alternatively lit surfaces on a scale of 1-10, with 1=uncomfortable and 10=comfortable. The test subjects received oral information about how the trial was to be conducted. An MP3 player in the room provided the test subjects with information about the study's activity plan. Evaluation of the fixtures was carried out. Test subjects evaluated whether the light they were seeing in the room matched the light to which they were accustomed at home. They were then asked to state the way in which they were similar, and to describe the differences if the light did not correspond with the type they had at home. The test subjects were then asked to describe their feelings of alertness, fatigue and well-being on a scale from 1-5 (a little – a lot). The trial was concluded after approximately 50 minutes. The test subjects then continued to the next room, either Room 1 or 2, depending on where they had commenced the study.

Instruments used in study 3

VCT. *Visual comfort test*. Developed by Dr. Bo Persson KTH and completed by Monica Säter at the Department of Lighting Science, Jonkoping University.

The test was developed by Dr. Bo Persson at KTH in Sweden. It was used to measure the preferred level of light at the working table. Bo Persson did the test with a white paper on a white table three times. Then he did the same procedure with a white paper on a black table. The test was completed in 2006 by M. Säter to be used for measurement of both the level of light at the working table and for the preferred complementary level of ambient light. A white paper on a black table was used in Studies 1, 2, 3, 4, and 5 in the Thesis.

Study number four focused on the preferences for a visually comfortable level of light at the working table and for the ambient light. The study was performed in one of the rooms used in Study number 1 and in one room used in Study number 3. The VCT test measures the subjects´ preferences in a given contrast situation. A white paper is placed on a black table. The test starts in the room which is dark and the level of light is taken up to maximum, down again, until the subject recognises their individual level of light experienced as visually comfortable. The preferred level of light is measured as horizontal (the table) and vertical (ambient light) illumination with a light meter. Then, the level of light for the working table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times and the third measurement is counted.

Questionnaire that recorded the light sources they had at home: Developed by Monica Säter 2010 at Department of Lighting Science, Jonkoping University.

How many of the following light sources do you use at home?

Lightbulb

☐ **not at all**

☐ **a few**

☐ **several**

☐ **in most of the lamps**

Halogen lamp

☐ **not at all**

☐ **a few**

☐ **several**

☐ **in most of the lamps**

Low energy light bulb

☐ **not at all**

☐ **a few**

☐ **several**

☐ **in most of the lamps**

Questionnaires about the light and the fixtures in test Rooms 1 and 2: Developed by Monica Säter 2008 at Department of Lighting Science, Jonkoping University.

Task 1a. Dining area
Describe your opinion about the light from the pendant kitchen lamp in the dining area. (Free formulated, no limit, each positive or negative word counted as 1 point).

Task 1b. Pendant kitchen lamp.

Describe your opinion about the pendant kitchen lamp (Free formulated, no limit, each positive or negative word counted as 1 point).

Task 1c. Select a mark which light source you believe is used in the pendant kitchen lamp. LED, compact fluorescent lamp, fluorescent lamp, halogen light bulb, low energy light bulb (1 choice was marked).

Task 1 d. Pendant kitchen lamp
Select and mark the best word to describe the light from the pendant kitchen lamp.
Being interesting, cold, cosy, hard, soft, uncomfortable, comfortable, unpleasant, pleasant, and non well-functional, functional, uneven, even, ugly and beautiful.

Task 1 e. Large white lamp
Describe your opinion about the light from the pendant kitchen lamp in the dining area. (Free formulated, no limit. Each positive or negative word counted as 1 point).

Task 1 e. Large white wall lamp
Describe your opinion about the light from the large white wall lamp in the dining area. Free formulated no limit. Each positive or negative word counted as 1 point).

Task 1f. Large white wall lamp
Describe your opinion about the large white wall lamp (Free formulated, no limit. Each positive or negative word counted as 1 point).

*Task 1g***.** Large white wall lamp.
Select and mark which light source you believe is used in the large white wall lamp. LED, compact fluorescent lamp, fluorescent lamp, halogen light bulb, low energy light bulb (1 choice was marked).

*Task 1h***.** Large white wall lamp.
Select and mark the best word to describe the light from the large white wall lamp. Being interesting, cold, cosy, hard, soft, uncomfortable, comfortable, unpleasant, pleasant, and non well-functional, functional, uneven, even, ugly, and beautiful.

Task 2a-d, Task 3a-l, 4b-I, 5a-d, questioned the subjects in the same way about their opinion about the light from the luminaries in the area of the armchair for reading and at the workplace.

6a. The light in the room.
Describe if the light you see in the room is consistent with the light you are used to being around at home. Specify in what way it is the same. The question was evaluated as similar or unsimilar.

*Task 6 b***.** The light in the room.
Describe if the light you see in the room does not match the light you are used to being around at home. Specify in what way it differs. The question was not evaluated.

Task 6 c. The light in the room.
The light in the room.
Describe the room and the light in the room as close as you can.
The question was evaluated as positive or negative.

Task 7 a. What is your overall impression of the room?
Tick the appropriate box on each scale
Do you feel alert? A little-very much. A semantic scale in 5 steps
Do you feel tired? A little-very much. A semantic scale in 5 steps.
Indicate your level of comfort. Low-high. A semantic scale in 5 steps.
The test was developed by Monica Säter at Jonkoping University 2010.

*Instrument for the study of lighting quality***.**
Describing the light in boxes 1-5 in the subjects´ own words. They were asked to evaluate the quality of the light by assigning a score on a scale of 1-10, where 1=low and 10=high. The instrument was developed by Monica Säter at Jonkoping University 2010.

Test 2. Instrument about visual variation in the light on the wall. The test subjects were asked to look at the light source on the wall for one minute and then describe, in their own words, whether they felt that the light had changed during the time they had been observing it. They were asked to describe in what way the light on the wall was changed. The instrument was developed by Monica Säter at Jonkoping University 2010.

Test 3. Glare test. A box with five different filters was placed on the floor. The test subject stood in a marked square, looking at the light in the box. The test subjects were asked to describe their experience of looking at the five alternatively lit surfaces on a scale of 1-10, with 1=uncomfortable and 10=comfortable. The test was developed by Monica Säter at Jonkoping University 2010.

Test 4. Questionnaires about the light and the fixtures in test Rooms 2: Performed in the same way as for Room 1. Task 1a-h, 2a-d, 3a-l, 4a-I, 5a-d, 6a-c, 7a. The test was developed by Monica Säter at Jonkoping University.

Methods for data analysis, study 3
Data was evaluated by counting positive or negative words used for subject's opinion of the light emitted from the luminaries in Test Room 1 or 2. Data was compared between the subgroups. Data from the questionnaire used for collecting data about the subject's evaluation of the light sources in the luminaries in Test Room 1 and 2 was compared between the subgroups.

Design of the test rooms, study 3

All tests were conducted in six rooms. In two of these rooms, light colour, glare and individual preferences for lighting levels were evaluated with regards to levels of light on work surfaces and levels of ambient light. The additional four rooms will in this text be referred to as Test room 1 and Test room 2. They were completely identical as far as the furniture was concerned, however Rooms 1a and 1b were designed with the same luminaries as Test Rooms 2a and b, but were equipped with different light sources. The luminaries in Test Rooms 1a and 1b were fitted with LEDs, halogen bulbs and low energy efficient light bulbs, while Test Rooms 2a and 2b were fitted solely with LEDs (see figure 20-25, table 21-22. Figure 26 in Appendix B)

Fig. 20. Room 1.

Fig. 21. Room 1**.**

Fig. 22. Room 2

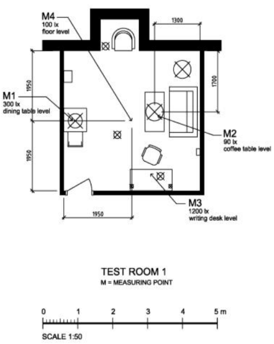


Figure 23. M.P. Room 1

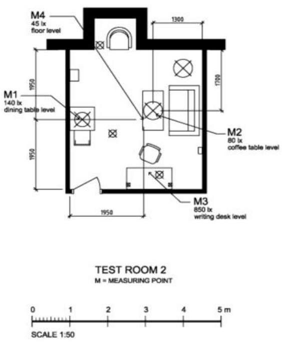


Figure 24. M.P. Room 2 (see appendix B).

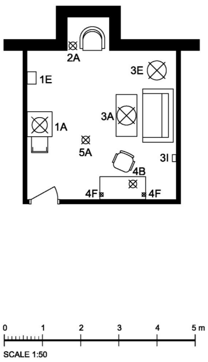


Figure 25. Coded floor plan R 1, 2.

Table 21. Lighting conditions in Test Room 1 and 2 (coded floor plan), study 3

Test Room 1		Test Room 2	
1A	Pendant luminaire. Compact fluorescent 11W E27, 2700K. Dining area.	1A	Pendant luminaire LED 8W E27.
1E	Wall luminaire. Dining area. Compact fluorescent 2x7W, E27, 2700K.	1E	Wall luminaire LED 2x4W E27.
2A	Reading luminaire. Compact fluorescent 7W, E14, 2700K. Reading area.	2A	Reading luminaire LED 1,6W E14 Warm white.
3A	Pendant luminaire Compact fluorescent 8W, E27, 2700K. At the sofa.	3A	Pendant luminaire LED 2W E27 Warm white.
3E	Floor luminaire. At the sofa. LED, 1,6W, E27, Warm white.	3E	Floor luminaire, LED 1,6W, E27, Warm white.
3I	Wall luminarie Halogen 42W 230V, E27. At the sofa.	3I	Wall luminaire LED 1,6W E27 Warm white.
4B	Reading luminaire Halogen 35W, 12V, GY 6.35. At the worktable.	4B	Reading luminaire LED 9W 18V 800 mA Warm white.
4F	2 Ceiling luminaires. Compact fluorescent 7W, GX53.	4F	Ceiling luminaire LED 3W, 700 mA.
5A	Ceiling luminaire Compact fluorescent 7W, E27, 825. Middle of the room.	5A	Ceiling luminaire LED 2W, E27, Warm white.

Table 22. Measuring points Test rooms 1 and 2, study 3

Lux				
Measuring p. 1, Dining table	Test Room 1	300	Test Room 2	140
Measuring p. 2, Coffee table	Test Room 1	190	Test Room 2	80
Measuring p. 3, Writing desk	Test Room 1	1200	Test Room 2	850
Measuring p. 4, Middle floor	Test Room 1	100	Test Room 2	45

3.2.5 Study number 4. Preferences for level of light at the working table and for the complementary ambient light

Study number four focuses on the preferences for a visually comfortable level of light at the working table and for the ambient light. The study was performed in one of the rooms used in study number 1 and in one room used in study number 3. The VCT test measure the subjects´ preferences in a given contrast situation. The test starts in the room which is dark and the level of light on the working table is taken up to maximum, down again, up again, until the subject recognises her/his individual level experienced as the most visually comfortable. The preferred level of light is measured in Lux as horizontal illumination with a light meter. Then the level of light for the work table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times, and the third measurement is counted. The VCT is used in studies 1, 2, 3, 4 and 5. The result from studies 4 and 5 is published in paper I here appended.

Method used: Visual comfort test (VCT), study 4

The test was developed by Bo Persson at KTH in Sweden. It was used to measure the preferred level of light at the working table. Bo Persson did the test with a white paper on a white table and repeated the procedure three times. Then he did the same procedure with a white paper on a black table. The test was completed in 2006 by M. Säter to be used for measurement of both the level of light at the working table and for the preferred complementary level of ambient light. A white paper was placed on a black table. The test starts in the room which is dark and the level of light is taken up to maximum, down again, until the subject recognises their individual level of light experienced as most visually comfortable. The preferred level of light is measured as horizontal (the table) and vertical (ambient light) illumination with a light meter. Then, the level of light for the working table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times and the third measurement is counted. The VCT test was used in the same way in Studies 1, 2, 3, 4 and 5 (Figure 19).

3.2.6 Study number 5. Preferences for level of light at the working table and for the complimentary ambient light during a day

In study 5 two subjects stayed in two rooms used in Study 3, for a day. The VCT test was used in the same way as in Study 4. The subjects´ preferences for visual comfort were measured every hour between 9:00-17:00. The result from the study is published in paper I here appended.

Method used: Visual comfort test (VCT)

The test was developed by Bo Persson at KTH in Sweden. It was used to measure the preferred level of light at the working table. Bo Persson did the test with a white paper on a white table and repeated the procedure three times. Then he did the same procedure with a white paper on a black table. The test was completed in 2006 by M. Säter to be used for measurement of both the level of light at the working table and for the preferred complementary level of ambient light. A white paper was placed on a black table. The test starts in the room which is dark and the level of light is taken up to maximum, down again, until the subject recognises their individual level of light experienced as visually comfortable. The preferred level of light is measured as horizontal (the table) and vertical (ambient light) illumination with a light meter. Then, the level of light for the working table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times and the third measurement is counted. The VCT test was used in the same way in Studies 1, 2, 3, 4 and 5 (Figure 19).

3.3. Methods used in the Thesis to collect data about psychological preferences

Methods used to collect data about the subjects´ preferences for light when staying in the room and light settings were pre-formulated instruments and instruments that allowed the subjects to formulated their own opinion.

3.3.1. Gunilla Burell´s stress test

To collect data about the subject's personality Gunilla Burell´s test of stress behaviour (BT) was used. The test collects data about if the subjects experienced themselves as stressed in everyday situations. The test uses 20 questions, and the answer is almost never, sometimes, often or almost every time. The answer is counted from 1-4+. The minimum and maximum point was 20-80p. Literature: Burell G. Testa ditt stressbeteende – Hjärt-Lungfonden www.hjartlungfonden.se/HLF/Aktuellt/Ar-du-stressad/Accessed 2011, Oktober 15. The Gunilla Burell´s stress test was used in Study 1 and 2.

3.3.2. SMB

Rickard Kuller´s SMB-test was used to collect information about the subject's experience of the room. The test uses 36 questions and measures the subject´s experience from little to much in a scale from 1-7+ or -. The SMB test was used in Study 1 and 2.

Study 1: In the study only the word comfortable was used, on a scale from little to much. It was seen as positive and counted as 1-7+.

Study 2: In the study only the word comfortable was used, on a scale from little to much. It was seen as positive and counted as 1-7+.

3.3.3. Checklist for the experience of the lighting conditions: (checklist för bedömning av belysningsförhållanden)

The test consisted of 34 words related to the experience of light. The subject chose three words that they assumed described the light in a good way. The test was developed at the Lund University, Department of Environmental Psychology. The test was completed by Monica Säter with the evaluation of the words being positive or negative. 21 words in the test were evaluated as positive. The positive words chosen were shaded, pleasant, good, diffuse, repressed, free from flicker, focused, even, cold, clear, concentrated, pale, shiny, comfortable, soft, natural, uncoloured, uneven, disseminated, varied and warm. The 13 words evaluated as negative were glary, bad, uniform, flickering, coloured, hard, sullen, dark, unpleasant, unnatural, sharp, strong and weak. The test that was developed at Lund University, Department of Environmental Psychology, was changed by Monica Säter in order to focus more directly on the positive and visually comfortable experience. The test checklist for the experience of the light was used in Studies 1 and 2. **Study 1.** The words chosen to be counted were: good, pleasant and comfortable and given one point each. A maximum of 3 points was given for the work task. **Study 2.** The words chosen to be counted were good, pleasant and comfortable and were given one point each. A maximum of 3 points was given for the work task.

3.3.4. Perception of the lighting quality. How do you experience the light at the workplace? (Hur upplever du ljuset vid läsplatsen, arbetsplatsen?)

16 pairs of contradictory words were used in a scale from 1-7. The words were dark-light, pleasant-unpleasant, uncoloured-coloured, strong-weak, spread-concentrated, warm-cold, uneven-even, hard-soft, diffused-focused, natural-unnatural, flickering-free from flicker, clear-sullen, varied-uniform, mild-sharp, glaring-shaded and repressed-shiny. As a complement, a question was added. How well do you think you can see in this lighting? The scale was from very bad to very good, and measured as 1-7+. Only the result from the last question was used. The test was developed at Lund University, Department of Environmental Psychology. The test, how do you experience the light in the room, was used in Study 1.
The value for the lighting quality at the *reading area* was counted as follows. The pair of words pleasant and unpleasant was used and counted, 1=3, 2=2, 3=1 and the other values =0. Only the positive part of the scale was used from 0-3+. This was called *perception of lighting quality, reading area*.
The value for the question, how well do you think that you see in this light at the reading area, was counted as follows. The value for very good was counted 5=1, 6=2, 7=3 and the rest was counted as 0. This was called *reading area light*, level of support for visual performance.
The value for the lighting quality at the workspace was counted as follows. The pair of words, pleasant and unpleasant, was used, and was counted 1=3, 2=2, 3=1 and the other values =0. Only the positive part of the scale was used from 0-3+. This was called lighting quality, *workspace light.*
The value for the question, how well do you think that you see in this light at the workspace was counted. The value for very good was counted 5=1, 6=2, 7=3 and the rest 1-4 was counted as 0. This was called *workspace light*, level of support for visual performance.

3.3.5. I feel at the moment (Jag känner mej just nu)

In order to get data about the subject´s experience of staying in the room and light setting, a test was used that was based on 12 pairs of contradictory words in a scale from 1-4. Going from very–rather-rather to very. The words used were very tired-very rested, very safe-very anxious, very bored-very interested, very decided-very undecided, very alert-very dozy, very angry-very kind, very efficient-very inefficient, very dependent-very independent, very tired-very alert, very happy-very sad, very negligent-very engaged and very strong-very weak. The test was developed at Lund University, Department of Environmental Psychology. The test, I feel at the moment, was used in Study 2. Data for the words very sleepy-very alert was used and was counted as 1-4+.

3.3.6. Positive room descriptive words

The subjects were asked when they left the study to describe the room they just visited as carefully as possible. The positive room descriptive words were counted and given 1 point each. No limit was set for the number of words that were counted. The test was developed by Monica Säter at the Department of Lighting Design at Jonkoping University in 2006. The instrument, positive room descriptive words, was used in Study number 1.

3.3.7. PANAS, Positive and negative affect schedule

10 questions going from negative to positive with phrases that describe different feelings. The test was developed by David Watson and Lee Anna Clark, at the University of Iowa. Literature: The PANAS-X, Manual for the Positive and Negative Affect Schedule-Expanded form, Copyright 1994 David Watson and Lee Anna Clark, The University of Iowa. The PANAS instrument was used in Study 1 and results for the words *inspired* and *interested* were used. Only the positive part of the negative-positive scale, was used. Data about if the subjects experienced themselves as inspired and interested was counted as 1-5+.

3.3.8. Future lighting

Describe your opinion about the light from the pendant kitchen in the dining area. Describe your opinion about the pendant kitchen lamp. Select and mark which light source you believe is used in the pendant kitchen lamp (LED, compact fluorescent lamp, fluorescent lamp, halogen, light bulb, low energy light bulb). Select and mark the best words to describe the light from the pendant kitchen lamp. Words counted as positive were: interesting, cosy, soft, comfortable, pleasant, functional, even, and beautiful. Words counted as negative were: boring, cold, hard, uncomfortable, unpleasant, unfunctional, uneven, and ugly. The same questions were used for the large white wall lamp, reading lamp at armchair, floor lamp, pendant lamp, small wall lamp, reading lamp on table, two ceiling lamps, ceiling lamp in the centre of the room. The light in the room: describe if the light you see in the room is consistent with the light you are used to at home. Specify in what way it is the same.
Describe if the light you see in the room does not match the light you are used to at home. Specify in what way it differs. Describe the room and the light in the room as close as you can. What are your overall impressions of the room?
Do you feel alert? A little-very much. A semantic scale of 5 steps (1-5+).
Do you feel tired? A little-very much. A semantic scale of 5 steps (1-5+).
Indicate your level of comfort. Low-high. A semantic scale of 5 steps (1-5+).

3. 4. The subjects experiences of the colour of the light

In the test five boxes were used, painted in white. The boxes were 72 cm in width, 50 cm in height, and 53 cm in depth. *Box number one* was equipped with a compact fluorescent light source13W(827), 2700 K. *Box number two* was equipped with LED, 22W, 2950K. Box number three was equipped with, LED, 9W, 3660 K. Box number 4 was equipped with LED, 15W, 4300K . Box 5 was equipped with LED, 12W, and 5350K. The subjects stood on a spot on the floor at a distance of 20 cm from the wall behind the box. The boxes were placed close to the wall. The subjects then answered the following questions about the light in the boxes. Questions: Describe with your own words your opinion about the light in boxes 1, 2, 3, 4, and 5. Describe the quality of the light with a marker on the ten degree range from low quality to high quality in a semantic scale (low=1, high=10). Nationalities within the subgroups were Scandinavians, Europeans, and Non Europeans. Subgroups of women and men were used in the study. The test about subjects´ experiences of colour of light were used in Study 3.

3.5 Opinion of level of visual comfort

Data was collected about the subject's experiences of visual comfort when looking at an illuminated surface. A box was placed on the floor close to a wall. The box (width 57 cm, height 50 cm, depth 53 cm) was equipped with LED 15W, 4300 K, lens10 degrees. The subject stood on the floor on a marked spot and viewed the box 20 cm from the closest part of the box. The subject got a questionnaire with the following question: Describe with your own words your experience of looking into the light in the box. Evaluate how pleasant-unpleasant your perception of the lit surface is with a marker at the 10 degree range. The surface was evaluated, when lit by a light source that was filtered by the use of 5 filters put in front of the light source. The surface was evaluated again after filter 1 was removed and filters 3-5 remained fixed on the light source. Then the surface was evaluated again after filter 3 was removed and filters 4 and 5 were still fixed to the light source. Finally, the wall was evaluated when only filter 5 was fixed to the light source. The subjects got the following instructions. Describe with your own words how it feels to look into the box. Evaluate how pleasant-unpleasant your perception of the lit surface is with a marker at the 10 degree range. The test was developed as a semantic scale from 1-10+. The test was developed by Monica Säter at the Department of Lighting Design at Jonkoping University in 2008. The test opinion of level of visual comfort was used in Study 3. Mean for the test was compared between the subgroups. The subgroups were Scandinavians, Europeans, Non Europeans, women and men.

3.6. Experience of visual variation when viewing light emitted on a wall from a LED replacement-light source

A LED spotlight, 30 degrees warm white E27/230V-2,7W, was put on a tripod and was directed toward a white wall. The tripod was placed at a distance of 120 cm from the wall and 160 cm above the floor. The subject stood on a designated spot on the floor at a distance of 150 cm from the wall. The lighting was switched off with a lighting switch on the floor. The subjects viewed the lit circle on the wall for one minute. A stop watch was used for the recording of time. The subjects answered the following question about the brightness on the wall: Describe with your own words if you feel that the light changes during the time you consider the light. If so, describe how the light changes. The test was developed by Monica Säter at the Department of Lighting Design at Jonkoping University in 2008. Experience of visual variation when viewing light emitted on a wall from a LED replacement-light source was used in Study number 3.

3.7. Use of light sources at home

The subjects answered a questionnaire about the type of light sources they used at home.

3.8 Methods used to collect data about physiological responses

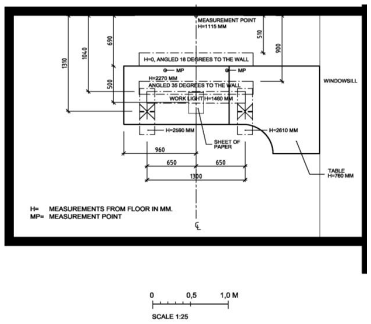
Methods used to collect data about the subjects´ unconscious physiological responses included blood samples. Level of cortisol, adrenaline, noradrenaline, oxytocin and melatonin in the subject's bloodstream was measured. Test with Blood samples was used in Study 2. Study 2: Blood samples were taken three times a day. See paper IX appended here for more information.

3.9. Methods used in the Thesis to collect data about visual preferences

Methods used for the collection of data about the subjects´ visual preferences for the working table and for the ambient light included the visual comfort test (VCT).

3.9.1. Visual comfort test (VCT)

The test was developed by Bo Persson at KTH in Sweden. It was used to measure the preferred level of light at the working table. Bo Persson did the test with a white paper on a white table and repeated the procedure for three times. Then he did the same procedure with a white paper on a black table. The test was completed in 2006 by M. Säter to be used for measurement of both the level of light at the working table and for the preferred complementary level of ambient light. A white paper was placed on a black table. The test starts in the room while dark and the level of light is taken up to maximum, down again, until the subject recognises their individual level of light experienced as most visually comfortable. The preferred level of light is measured as horizontal (the table) and vertical (ambient light) illumination with a light meter. Then, the level of light for the working table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times and the third measurement is counted. The VCT test was used in the same way in Studies 1, 2, 3, 4 and 5.



(see appendix B)

Figure 19. Visual comfort test used in Studies nr. 1, 5, 6. Coded floor plan for VCT
Lamp1, 1, 4 Wall washer 26W 830. Lamp 2, 1 Pendant 2x54W Fluorescent 830. Lamp 3, 2 Pendant 2x49W 830. Control dimmers on table, 1-10V converter Digi DIM 470. Lighting control, ATCO PCA 2/54 15XL one size LP. Lighting control: Sidelight, qt-t/e1x26/230-240 dim. Lighting control: PCA/49. Light source 80-3950 Lux. Working light gives 0 (80)-3950 Lux on the working table and 0 (10)-120 to the Ambient light. Ambient light gives 0 (10) - 550 Lux on the working table and to the Ambient light 0 (30)-1800 Lux. Total on the Working table 0(90)-4500 Lux. Total Ambient light 0(40)-1930 Lux.

The visual comfort test was used in Studies 1, 2, 3, 4 and 5.

CHAPTER 4

4. RESULTS

The results of the empirical studies and the TF are presented here. The disposition of the result follows the three research questions. The results of the questions in the TF are thematically put under the appropriate research question.

4.1 Results related to Rearch question 1.

TF Part 1. *Result of research question nr 1. part one.* The investigation about why daylight and artificial light should be designed for the indoor environment to realise light-related goals of visual comfort and public health can be answered by the TF and the empirical studies in the following way:

Photobiological research demonstrates that light is fundamental to life.

"Light is a potent biological and therapeutic force which is fundamental to life on our planet" [Hanifin & Brainard 2007, p. 87].

"Light profoundly impacts human consciousness through the stimulation of the visual system and powerfully regulates the human circadian system which in turn, has a broad regulatory impact on virtually all tissues in the body" [Brainard & Hanifin 2005, p. 314].

"Photons have a profound capacity to trigger biological change, from eliciting conscious vision to the subconscious control of hormonal secretions and biological rhythms" [Brainard & Hanifin 2005, p. 322].

"We should therefore bear in mind that artificial light, for the human individual at least, remains a mere substitute; it can never fully replace natural light, which, as a vital element like water and air, forms the basis of our health" [Hollwich 1980, p.194].

Since daylight is essential for humans and we live in the indoor environment in an increasing amount of time in artificial light that deviates from daylight, we need to use daylight as much as possible and design the light in a daylight mimicking way. If the complementary artificial light is designed in a daylight mimicking way in spectral profile, time, intensity and duration [Lockley 2006, p. 22; Pechacek, Andersen & Lockley 2008] and is related to the light at the site where the subjects lives, the biological rhythms will be supported and human health will improve [Wirz-Justice & Fournier 2010; Lockley 2006], (TF 2.2).

TF Part 1. Result of research question nr 1. part two: The investigation about in what way daylight and artificial light should be designed for the indoor environment to realise light-related goals of visual comfort and public health can be answered by the TF and the empirical studies in the following way:

TF Part 2. The significant differences in the interaction of man, light, colour and space in the outdoor and indoor environments was identified in the following way: The literature survey reveals that the most important light-related difference between the outdoor and indoor environment is the wavelengths and the rhythm of daylight. Artificial light in the indoor environment does not give humans the opportunity to produce vitamin D as the wavelengths that produce Vitamin D do not pass the window glass. The action potentials to the human brain for physiological processes when staying in artificial light is altered compared to when staying outdoors. The signals from daylight in the outdoor environment reach the user and entrain to the 24 hour rhythm. In the indoor environment the signals are present in room with windows but the signals and the rhythm can be overruled by the use of static artificial light [Brainard & Hanifin 2005, p. 315-322; von Rode et al. 2010], (TF 2.3).

TF Part 3. *The functions of melanopsin and ipRGC and the relation to lighting design and light-related health is here formulated as:* Melanopsin is a photopigment found in specialised photosensitive ganglion cells in the retina (ipRGC). The process when PS is absorbed by the eye into melanopsin in the ipRGC and undergoes physical and chemical changes is called photo transduction.

"These photoactive molecules do not absorb energy equally across the electromagnetic spectrum. Chromophores have their own characteristic wavelength absorption spectrum that depends on their atomic structure. A chromospheres pattern of wavelength sensitivity, or its absorbance spectrum, is like a fingerprint –it is unique to that molecule within its photo pigment complex. In the field of photobiology, an action spectrum is one of the principal tools for identifying the photo pigment that initiates a light-induced response." [Brainard & Hanifin 2005, p. 315].

Lighting design has the possibility to design daylight for the indoor environment and the complementary artificial light in a way that gives input to melanopsin and ipRGC close to the one seen in the outdoor environment, but adapted for the contrast situation in the indoor environment. If done in a orderly way lighting design have the possibility to support light-induced responses in a way close to the one seen outdoors (TF 2.4).

TF Part 4. *Patterns can be seen in responses to PS and in preferences to light when subjects stay in daylight or artificial light in the room and light settings in the studies.*

Responses

Study 1; the study was concerned with visual comfort. Only preferences were collected. *Study 2;* the study was focused on responses and preferences to daylight and artificial light in the indoor environment. Baseline (BL) is here the value measured at 8.00. Increase or decrease (INC or DEC) and increase or decrease over BL (INC O BL or DEC O BL) or decrease over or under baseline (DEC or INC U BL) is evaluated. The subjects´ (*n*=1-20) mean for level of hormones displays a similar pattern of increases and decreases during the day for cortisol in all three rooms when compared to the pattern seen in daylight. The changes in mean for adrenaline shows differences in the pattern during the day (Room 1, BL, BL, INC O BL, Room 2, BL, DEC, INC O BL, Room 3, BL, DEC, INC U BL), (*n*=1-20) when compared to the pattern of changes in mean seen in Room 1, daylight. The result of the changes in mean for noradrenaline in Room 2 and 3 during the day also reveals differences in the pattern (Room 1, BL, DEC, INC O BL, Room 2, BL INC, DEC O BL, Room 3, BL, INC, DEC O BL) when compared to the pattern seen in Room 1, daylight. When the patterns of mean for measured hormones during the day for the subjects are compared to the pattern seen in daylight only cortisol is changing in a similar way in the three rooms. The mean for adrenaline is decreased in Room 2 and 3 compared to in Room 1 daylight. The mean for noradrenaline is increased in Room 2 and 3 compared to in Room 1 daylight. Differences in mean for hormonal levels are small. (BL= Baseline value 8.00, INC O BL= increase over baseline. DEC O BL= Decrease over baseline, measurements 8, 00, 12.00, 15.00, 16.00) (Säter, Paper IX).

Study 2; Subjects individually alert on the highest level can be seen in 25/180 times when alertness is measured in the study. Alertness on level 4 is evaluated as natural if seen in the morning, at 12.15 or during the entire day. Alertness is viewed as unnatural if seen only at 16.00. 10 subjects evaluated themselves as being alert on the highest level at 16.00 in the three rooms. 7/10 subjects alert on the highest level is seen in Room 3, 16.00 (Paper IX).

Study 2; The highest number of subjects that increase in cortisol with the highest mean for the increase is observed in Room 3. Here, at the same time, is the lowest mean for cortisol detected at 12.15 and 16.00 for the group of subjects. The highest number of subjects being on level 4 of alertness is seen at the same time. 6/20 subjects increase in cortisol in room 3, 16.00. Only 1/7 of the subjects that was evaluated as on the highest level of alertness have simultaneously the highest level of cortisol during the day or for the three days, 5/7 increases in adrenaline, 2/7 subjects increase in noradrenaline and 2/7 subjects increase in oxytocin on the highest level observed for the day or for the three days (Paper IX).

Study 3; Was concerned with preferences for energy efficient light sources. Only preferences were collected.

Study 4; Dealt with preferences for level of light at the working table and for the complementary ambient light. Just preferences were gathered [Säter, Paper I].

Study 5; Covered preferences for level of light at the working table and for the complementary ambient light during a day. Only preferences were collected [Säter, Paper I].

Preferences

Study 1; The lighting designer´s preferences for levels of light on the working table and for the ambient light were compared in general to the 36 subjects participating in the study and to 18/36 subjects by the use of the VCT. The light in the three rooms was designed close, distant and very distant from the lighting designer’s preferences. The subjects evaluated the lighting design most close to the lighting designer’s preferences as the most comfortable. The reason for this is here suggested to be that the low level of ambient light allowed the subjects to stay in a general visually comfortable room. This gave the subjects a possibility to find their own preferred level of light on the working table, to a great extent, compared to in the other rooms. Taken together this gave the subjects an experience of visual comfort. The study puts focus on the importance of individual task lighting and a low level of ambient light that increase the possibility for the individual to stay in a preferred level of light in the working situation [Paper VI].

Study 2. Only responses were collected.

Study 3; Concerned preferences for energy efficient light sources. Preferences for light emitted from energy efficient light sources were evaluated in the study. A group of 87 subjects from 23 countries showed their preferences for light emitted from LED, Halogen and CFL compared to light emitted solely from LED replacements lamps. The combination of different light sources was evaluated as more like the light sources the subjects used in their homes and was preferred by the subjects [Säter, Papers IV, and V].

Study 4; Focused on the subjects (*n*=1-20) preferences for level of light at the working table and for the complimentary ambient light. 318 subjects were measured with the VCT-test. The subject's preferred combinations of levels of light for the working table and for the ambient light were widely distributed in a range from low to high levels of light.

Study 4; Exhibited a span of preferences for the level of light at the working table within 80-3940 Lux and for the ambient light within 30-1750 Lux for 318 subjects. Two pairs of subjects preferred the same combination of level of light at the working table and for the ambient light while the other 314 made unique combinations.

Study 5; Was related to preferences for level of light at the working table and for the complementary ambient light during a day. In study 5, 2 subjects were measured for their preferences from 9.00-17.00. The preferred levels of light varied during the day from 1030-3420 Lux for the level of light at the working table and 140-1010 Lux for the ambient light [Säter, Paper I], (TF 2.5).

4.2 Results related to Rearch question nr. 2

TF Part 5*. Research question nr 2:* The way laws, recommendations and methods for lighting design can be developed to support users in a better way individually PPV is by the use of the UCLDP. The user centred lighting design process set the user in contact with daylight and the user's individual sensitivity is the foundation for the way the room and light setting is designed and in relation to the colours and surfaces in the space.

TF Part 5. *Will light-related goals according to light-related health stipulated in EC Treaty 137, Pörn´s health theory in WHO target 9 and 13-17 adopted by the Member States of European Region and visual comfort in the European standard for indoor workplaces be fulfilled by the use of EN 12464-1: 2011:* The use of EN 12464-1:2012 do not fulfill goals of visual comfort in EN 12464-1:2012 and health stipulated in EC treaty 137, Pörn´s health theory in WHO target 9 and 13-17 adopted by the Member States of European Region since not connected to the individual users needs PPV.

TF Part 6. *Will the use of the CCLDP and the UCLDP fulfill goals about visual comfort and light-related health in EN 12464-1:2011, EC Treaty 137 and WHO target 9 and 13-17 adopted by the member States of European Region:*

To fulfill light-related parts of the goal of health stipulated in EC Treaty 137 and WHO 9, 13-17, the complementary artificial light should be designed in co-operation with the individual user psychologically, physiologically and visually and with the use of the UCLDP. This process makes it possible for the user to stay in a light that can be regulated toward the individual state of equilibrium (perfect homeostatic balance). Only the user knows when being in equilibrium and this state will always change in order to cope with the changes in the internal and external environment. The use of the LDP of four steps and increased to the UCLDP shapes the interaction of MLCS in a way that have the possibility to support the user PPV and that gives an individual experience of LQ. The process can be described as UCLDP Step 1, 2, 3 and 4=well-functioning interaction of MLCS=support of the individual PPV=individual experience of LQ. The process has the possibility to enhance visual comfort and support light-related health for the individual.

Both visual comfort (EN 12464-1:2011) and light-related health (EC Treaty 137; WHO target 9, 13-17 adopted by the Member States of European Region) is a central light-related goal for workplaces in the European Union. To achieve this, daylight should be the base in ambient light and a daylight mimicking artificial light should be added. The function of the visual sight is changing during the day and the lighting application needs to be flexible to be able to give support in an individually visual comfortable way [Ronchi 2009; Säter 2011]. In order to design not only a visually comfortable task lighting but also a visually comfortable sight in the working environment, the ambient light needs to be designed in relation to the colours and surfaces in the room [Hopkinson & Kay 1972, p. 23:Liljefors 1999]. If light is designed for the individual in a visually comfortable way and supportive for light-related health at the working environments, set out in EN12464-1:2011, EC Treaty 137 and WHO target 9 and 13-17, the possibilities to achieve the goals increases (TF 2.2).

Will goals according to light-related health stipulated in EC Treaty 137 and Pörn health theory in WHO target 9 and 13-17 adopted by the Member States of European Region and visual ergonomics in the European standard for indoor workplaces be fulfilled by the use of EN12464-1:2011? The standard EN 12464-1:2011 is the only allowed standard for lighting applications for work places in Europe today. The tool is said to give:

"This European Standard specifies lighting requirements for humans in indoor work places, which meet the needs for visual comfort and performance of people having normal ophthalmic (visual) capacity" EN 12464-1:2011.

When this statement is compared to Lucia Ronchi's results about the variability of the visual function during the day [Ranchi 2009] and to Studies 4 and 5 in the Thesis [Säter 2011], it is here revealed that EN12464-1:2011 and a static level of artificial light on one recommended level cannot meet the physiological needs for one single subject visually during a day, nor all normal sighted workers of the 502 million (2011) inhabitants in Europe. The standard is set out to be the tool for visual comfort for workers at the indoor working place but is in the same way the tool for light-related public health stated in EC Treaty 137 and WHO target 9, 13-17.

A level of static artificial light as recommended in the standard counteracts the adaption to the light at the site where the user lives. The light-sources recommended (through the current demand for pretend) are not synchronised with the human photo transduction through melanopsin and ipRGC or developed close to the wavelengths that humans use in daylight and because of that they do not support light-induced photo transduction and responses in a way close to the one seen outdoors in daylight [Hanifin & Brainard 2007]. The literature survey shows that the tool used by the society for the design of light at indoor workplaces (EN 12464-1:2011) counteracts goals for visual ergonomics in EN 12464-1:2011 and health in EC Treaty 137 and WHO target 9, 13-17. It is psychologically, physiologically and visually impossible that the standard as formulated today can support the ever changing needs for an experience of individual visual comfort and support human light-related health for one single subject during a day. In the same way the use of EN 12464-1:2011 does not give visual comfort and support for light-related health for all normal sighted workers in Europe at indoor workplaces. Daylight is mentioned for the first time today in the standard EN12464-1:2011. But since the standard does not recommend light sources that emit PS close to wavelengths emitted in daylight or adapt the artificial light to the rhythm of daylight, the recommendations in the standard of one level of static artificial light deviates from daylight. Since the artificial light designed from the recommendations in the standard is not designed close to daylight and the light at the place where the subject lives, it counteracts the fact that the user gets light-induced responses in a way close to the one seen outdoors. (TF 2.7)

TF Part 7. *In what way do the end user, designer, or client perspective to LQ differs in PPV support for the user*: The result of the investigation in the TF about in what way the perspectives of an end user, designer or client on LQ differs in PPV support gave the following result.

It was found out that there is no widely accepted definition of LQ. Boyce has a suggestion in the second edition of *Human factors*.

"The definition that seems most generally applicable is that lighting quality is given by the extent to which the installation meets the objectives and constraints set by the client and the designer" [Boyce 2003, p.188].

LQ can, according to Boyce, be seen from the aspect of the client´s or the designer's general expectations of the performance of the technique. Although the definition of lighting quality cited here is stated as generally accepted, the result of the literature survey shows that LQ is not a general experience and something good enough for everybody but to a greater extent it concerns the individual humans PPV needs for light [Hanifin & Brainard 2007; Säter 2011]. The interaction of MLCS seen outdoors that humans are adapted to, has a stronger relation to LQ compared to general expectations. When comparing the individual perspective of LQ to a general expectation of the client or the designer, I find that the individual perspective to LQ in a better way gives support to the individual human PPV. LQ is experienced when the lighting application gives support for the individual user PPV by a well-functioning interaction of MLCS based on daylight and related to the rhythm of daylight at the site where the user lives and designed related to the colours and surfaces in the room [Paper X].

TF Part 8. *How can the process of lighting design be described that support the user´s individual light-related PPV needs and is related to the colours and surfaces in a specific space and sets the user in contact with the daylight at the site where the user lives:* The UCLDP seen from the perspective of the interaction of MLCS; The lighting design process that leads to a well-functioning interaction of MLCS and supports the individual user´s PPV needs, is related to the colours and surfaces in a specific space and sets the user in contact with the daylight at the place where the user lives and can based on the empirical studies and theoretical survey, schematically be described in the following way.

- ***MAN:*** To support the end user with light PPV: 1) the lighting application should be designed in a way that keep the user in contact with daylight and the light at the site where the subject lives [Wirz-Justice & Fournier 2010]; 2) the design of the lighting application should be close to the individual user´s needs to stay in a well-functioning visual contrast situation [Ingvar 1981]; 3) the light emitted from the lighting application should be visually comfortable [Ingvar 1981]; 4) the lighting application should be able to adapt to the changed human visual function during the day [Luckiesh & Moss 1931; Ronchi 2009, Säter 2011].
- ***LIGHT***: To support the end user with light PPV: 1) the artificial light should be designed in contact with daylight at the place where the subjects lives through the design of the ambient light [Wirz-Justice & Fournier 2010; Boyce 2003 p. 118]; 2) the lighting application should be designed in a way that gives light-induced responses similar to the responses seen in the outdoor environment [Hanifin & Brainard 2007]; 3) To visually support the end user with light, the daylight should be designed visually comfortable [Han & Ishida 2004]; 4) the artificial light source should mimic daylight [Pechacek, Andersen & Lockley 2008] and be adapted to the indoor contrast situation; 5) the ambient light should be designed with a complementary daylight mimicking artificial light to a certain lowest level of security [Wirz-Justice & Fournier 2010; Boyce 2003, p. 118; Han & Ishida 2004]; 6) the amount of light for task lighting should be designed close to the user´s changing needs during the day [Ronchi 2009; Säter 2011]; 7) To support the end user with light visually, the task lighting should be visually comfortable and easy to use for the end user [Boyce 2003, p. 162; Säter 2011]; 8) the lighting application should be designed visually comfortable for the most sensitive user [Boyce 2003, p.472; Säter 2011]; 9) the lighting application should be designed flexible enough in the ambient light to be able to follow the increases and decreases in the natural light and the task lighting should be flexible enough to fully support the subject´s changing needs during the day [Ronchi 2009; Säter 2011]; 10) To support the end user with light visually, the amount of artificial light should be designed in a visually comfortable way [Ingvar 1981].
- ***COLOUR:*** To support the end user: 1) the colours should be chosen from their possibility to keep a comfortable and pleasant appearance in changing levels of daylight in the space [Ingvar 1981]; 2) the colours should be chosen from their possibility to keep a comfortable and pleasant appearance in changing levels of the specific light source in the space [Ingvar 1981].

- ***SPACE:*** To support the end user: 1) the space should be opened up for daylight [Han & Ishida 2004; Pechacek, Andersen & Lockley 2008]; the surfaces should transmit, absorb and reflect light in a visually comfortable way [Ingvar 1981]. (TF 2.8).

TF Part 8. *The UCLDP─ Seen from the perspective of the LDP step 1-4 and the UCLDP:* The result of the investigation of the lighting design process that supports the individual user´s PPV needs related to the colours and surfaces in a specific space and set the user in contact with the daylight at the place where the user lives seen from the UCLDP and LDP step 1-4, is here revealed.

- *Step 1: The space, analyses of the space, daylight and artificial light, the architects and the interior designer's intentions with the space.*
  -Analyses of the space. -
  Analyses of windows in size and position, colours and surfaces in the space.
  -Analyses of the architects and the interior designers intentions with the space.

- *Step 2: The human, the needs of light PPV.*
  -Analyses of the needs of the user to stay in contact with daylight.
  -Analyses about the user's needs of having a natural input to a stable diurnal rhythm and a hormonal release close to the one seen in the outdoor environment.
  -Analyses about the users need of staying in a visually comfortable environment.
  -Analyses of the user's needs of being effective in work, visually well oriented and at comfort.

- *Step 3: The design of the daylight and the artificial light related to the colours and surfaces in the room and connected to the daylight at the site where the user lives.*
  -Design of the daylight in a visually comfortable and pleasant way.
  -Design of the complementary artificial light in a daylight mimicking, comfortable and pleasant way.

- *Step 4: The design of the lighting application and the scheme for maintenance.*
  The design of a user-friendly, easy to maintain lighting application that in a flexible way follows daylight and the changing needs of the user in the ambient light as well as in the task lighting.

TF Part 9. *Recommendations for methods for lighting design*: The result of the investigation about the CCLDP and the UCLDP and if the use of the processes fulfill goals about visual comfort and light-related health in EN 12464-1: 2011, EC Treaty 137 and WHO target 9 and 13-17 adopted by the member States of European Region is here revealed**.**

The CCLDP done with a static level of predesigned light and done without contact with the user or the room cannot be visually comfortable, PPV supportive or promote light related health during the day. A direct contact with the user is needed to adapt to the individual users PPV needs.
The UCLDP done based on daylight and with a daylight mimicking complementary artificial light, designed in contact with the user and related to the colours and surfaces in the space have the possibility to be visually comfortable, supportive PPV and promote light-related health.

TF Part 9. *Recommendations for lighting design***:** The result of the investigation about the recommendations for lighting design that gives a well functioning interaction MLCS and a lighting design process that supports the individual user´s PPV needs, is related to the colours and surfaces in a specific space and sets the user in contact with the daylight at the place where the user lives, is here revealed.

TF Part 9. *Recommendations for the UCLDP seen from the perspective of the interaction of MLCS:*

- ***Man:*** To interact in a good way with the end-user: 1) the light should be designed based on daylight and in contact with the light at the site where the end user lives [Wirz-Justice & Fournier 2009]; 2) the light should be designed close to the subject´s changing needs visually during the day [Ronchi 2009].
- ***Light:*** To interact in a good way with the end-user: 1) the ambient light should be designed related to daylight at the place where the users lives; 2) the light should be designed with a complementary artificial light mimicking daylight to a certain lowest level of security for the ambient light; 3) the task lighting should be designed with the amount of light for task lighting close to the user´s changing needs during the day; 4) the task lighting should be designed visually comfortable and easy to use; the task lighting should be designed visually comfortable for the most sensitive user; 5) the task lighting should be designed flexible enough to follow the increases and decreases in the natural light and to fully support the subjects changing needs during the day; the lighting application should be designed with a light source that is mimicking daylight and the design be adapted to the indoor contrast situation; 6) the lighting application should be designed related to the colours and surfaces in the room and in a visually comfortable way; 7) the lighting application should be designed close to the interior designer´s and the architect’s intentions with the space.
- ***Colour:*** To interact in a good way with the end-user: 1) the colours should be designed with a pleasant appearance and in a visually comfortable way according to amount and character of daylight and artificial light during the day.

- ***Space:*** To interact in a good way with the space: 1) the lighting application should be designed close to the architect´s and the interior designer's intentions; 2) the lighting application should be dimensioned in a visually comfortable way related to the colours and surfaces in the space.

TF Part 9. *Recommendation for the UCLDP seen from the four steps of the LDP:*

- ***Step 1;*** The space, analyses of the space, daylight and artificial light, the architects and the interior designer's intentions with the space.
  -Analyse the space, daylight and the artificial light in the space.
  -Analyse the architects and the interior designer's intentions with the space.
  -Analyse the colours and surfaces in the room according to TAR.
- ***Step 2;*** The human, the needs of light PPV.
  -Analyse the users need of light PPV in the specific space.
- ***Step 3;*** The design of the daylight and the artificial light related to the colours and surfaces in the room and connected to the daylight at the site where the user lives.
  -Design the daylight in a visually comfortable and user-friendly way.
  -Design the complementary artificial light in a daylight mimicking, visually comfortable and user-friendly way.
- ***Step 4;*** The design of the lighting application and a scheme for maintenance.
  -Design a LA that follow the changes in daylight during the day and adapt easily to the individual users needs during the day.
  -Design a user-friendly lighting application that is easy to maintain.

4.3 Results related to Research question nr. 3

TF Part 10. *Research question nr. 3:* A more qualitative research in lighting design can be developed in collaboration among different research areas and different competences. The cooperation in research among architects, interior designers and lighting designers in combination with the knowledge from psychology, physiology, medicine, sleep research and visual ergonomics are important aspects on research in lighting design. When seen as a cluster around the four steps of LDP the different research areas and the role in the research can be identified.

CHAPTER 5

5. DISCUSSION, CONCLUSIONS AND FUTURE WORK

In this chapter methods used in the project and findings from the studies will be reviewed. The discussion follows the order of the research questions and the questions used in the TF can be found thematically associated to the appropriate research question. Conclusions and future work can be seen in this chapter.

5.1 Discussion related to research question nr. 1

TF part 1. *Research question 1***.** *Why and in what way should daylight and artificial light be designed for the indoor environment:* The results of the TF show that daylight is essential to humans and needs to be designed close to the individual user´s needs. The design of an individual light can be questioned on many levels. It is more likely that a higher number of subjects are robust in the sensitivity to stay in high and low levels of light than the opposite. Preferably young and healthy subjects may take less notice of the light that they are staying in. Subjects working in daylight, close to windows between 8-5 in the indoor environment might only recognize a restricted negative impact from the use of artificial light. The subjects that are tired, stressed or visually impaired by age and work too far from or too close to windows seen from the perspective of their sensitivity of the channels in to CNS, have another situation. If additionally the time they spend at work is in conflict with the diurnal rhythm, many negative factors can be accumulated and give a negative impact. The visual support from light is not enough for any subject. The support should be psychological and physiological as well. Since humans are different in the sensitivity in the channels in to the CSN they need to be respected in the different sensitivity for looking at lit surfaces. The supersensitive subjects need to be supported in their needs of staying in a low level of light to feel at comfort. The variety in preferences for visual comfort is of such a range that everybody needs special care to experience visual comfort.

TF Part 2. *Can significant differences in the interaction of man, light, colour and space in the outdoor and indoor environment be identified***:** The interaction of MLCS that is indentified in the Thesis is described without details. It takes a second to experience the room and light setting but it takes a long time to describe all the connections that exists between the subjects, the space and the lighting application. To create an interaction of MLCS that gives a physical input to melanopsin and ipRGC close to the one seen outdoors is a challenge for the lighting designer of tomorrow and has a great potential to improve light-related public health. The differences that can be seen in the indoor and outdoor interaction of MLCS can be ranked as more or less important for human health. Wavelengths in daylight and the rhythm of daylight are of the highest importance since these two factors have such a profound impact on diurnal rhythm and by that on almost all tissues in the human body. The vitamin D production that is triggered from 290-315 nm but does not pass the glass of the window is an example of daylight being of high physiological importance and essential to humans. In the indoor environment until today, light is developed by the producers of light sources for being visually but not physiologically supportive. If the light source shows 15 colours it is seen as having the highest quality. The light source post ipRGC that is physiologically supportive needs to mimic daylight to be of the highest quality.

TF Part 3. *About the functions of melanopsin, ipRGC and how a relation to lighting design and light-related basic health can be formulated:* Lighting design should mimic the lightrelated phototransduction through melanopsin and ipRGC from daylight in the outdoor environment in order to support a healthy input from light for hormonal release in the indoor environment. It is likely that we are only in the beginning of knowing more about the human visual sight, melanopsin and ipRGC. Rods and cones and ipRGC might co-operate in a way not fully known today. The development of knowledge about ipRGC, melanopsin, actionspectras and cooperation between human vision and ipRGC is fast and the lighting designer needs to be updated toward new knowledge.

TF Part 4. *About patterns that can be seen in responses to PS and in preferences to light when subjects stay in daylight or artificial light in the room and light settings in the studies*: Results show inter-individual differences, but the group of subjects is too small to reveal general patterns. The individual approach to the user is not frequent in contemporary literature. The result of the Thesis is congruent with the research of Lucia Ronchi and the work of Luckiesh and Moss. Ronchi has performed research during 30 years within this part of the topic. Vision is irregular and the performance changes related to the diurnal rhythm.

TF Part 4. *Can patterns be seen in responses to PS and in preferences to light when subjects stay in daylight or artificial light in the room and light settings in the studies:* Despite different subjects and methods used for the collection of preferences, the results of the studies mentioned in the Thesis are close to each other. Visual comfort: Study 1 shows that visual comfort is an individual need that cannot be fulfilled by the use of a method that lacks contact with the user's preferences or the colours and surfaces in the room. A standard with a given specified level of light does not support visual comfort during the day nor the lighting designer´s general care. It is to be able to stay in the individual subject´s changing preferences for comfortable contrasts in the visual sight that gives the experience of visual comfort. Recommendations of one level of static light do not strengthen the human biological rhythms going from deepest sleep to the highest level of alertness and back to sleep during the 24 hour period. The static light does not support the variability of the visual sight during the day. Only the individual subject has the possibility to feel the individual bodily rhythm and know how to take support from light in a way that enhances light-related homeostatic balance. In nature we go under the tree to get a decrease in level of alertness and eyestrain, while in the garden we go inside the house when the level of light is too strong for the eyes or for the level of alertness. In the same way, we go out in the spring when we feel weak and need to stay in the sunshine to be more alert. To be able to modulate the level of light toward your own light-related equilibrium gives the user pleasure and comfort. It is a basic need to follow your biological rhythms and to feel in homeostatic balance and at visual comfort. It is also the possibility to regulate the light that makes it possible to be reached by information from the daylight about onset and offset of the diurnal rhythm. The signals from the light that gives the wakeup call and the signal for time to go to sleep are overruled by the static light on one recommended level of artificial light. The daytime working environment with windows is from a light perspective well-functioning compared to the windowless environment and the work place for shift work at night.

When studies that show mean preferences for level of light at the working table such as Balder [1957] (M=1770 Lux), Bodman [1967] (M=1000-2500 Lux), Riemenscheder [1967] (M=2500 Lux), Saunders [1969] (M=1550 Lux), Säter [2011] (M=2007 Lux), are compared to the recommendation of the standard it is difficult to understand why the general recommendation is 500 Lux. According to Perry [1987] 500 Lux is recommended by CIBSE as an optimal level of the illuminance for the working table. Perry refers to Stiles´ study on one subject in 1939 and to Aguilar and Stiles´ study on four subjects' in1954 and to the lower bound of the rod saturation mechanism. Today 500 Lux is recommended to the normal sighted workers of 502 million (2011) living in Europe and the standard for indoor workplaces claims to "meet the needs for visual comfort and performance of people having normal ophthalmic (visual) capacity" EN-12464-1:2011. Seen from the studies of Luckiesh and Moss [1931], Balders [1957], Bodman [1967], Riemenschneider [1967], Saunders [1969], Perry [1987], Ronchi [2009] and Säter [2011], it is obvious that the recommended level of light in the standard is far away from the needs for level of light of the users in these studies. Luckiesh and Moss, [1931], Perry, Campbell & Rothwell [1987], Saunders [1969], Ronchi [2009] and Säter [2011] all report about large differences in visual preferences between subjects. Ronchi reports a variability of the visual functionality through the day. The mean preference is between 1500-2500 Lux. The recommendation of 500 Lux is not even correct from the measurement of the rod saturation of Miss P. Fowler, Miss S. Ide and Miss E. Kinrade and the fourth unknown subject in the study performed in 1954 by Aguilar and Stiles, since their individual rods where saturated between 500-1500 Lux. The studies here mentioned that investigate preferences for levels of light show that light should be designed for the support of humans visually. Light should also adapt to the changes of preferences during the day to give a well-functioning support.

A predesigned static level of light of 500 Lux will not support the normalsighted workers in Europe with a population of 502 million (2011) to the experience of visual comfort.
Daylight is the light that humans are adapted to and need to stay in to be healthy. [Brainard & Hanifin 2005; Hollwich 1979]. The rhythmical changes between a high level of light and absolute darkness in daylight drive the human body from the deepest sleep to the highest level of alertness and back to sleep. The results in Studies 2, 4 and 5 are suggested here to be affected by individual differences in the disposition to receive and to respond to light and in different onset and offset of the diurnal rhythm. Regarding this, as shown in Studies 2, 4 and 5 there are large inter-individual differences between subjects in preferences to light during the day. According to Brainard & Hanifin [2005] light is shown regulating diurnal rhythm and powerfully controlling daily rhythms and hormonal tides with a regularity that is strongly linked to the daily progression of environmental light and darkness. It is likely that we are only in the beginning of the understanding of the impact of light on the human body and the relation between common

diseases and light. In the same way, we are in the beginning of the design of the future lighting application. Daylight is the role model for light since we are adapted to the wavelengths and the rhythms in daylight through photo transduction and the production of Vitamin D. Individual support from light for light-related health is a tangible goal. It is up to the lighting designer's creativity to find the design suitable for the actual space that meets the individual user's needs. It is a matter of the design of a flexible lighting application that has the possibility to give the subject a visually comfortable working environment. It is a matter of a higher precaution for those who are supersensitive to look at contrasts in the visual field. The recommendation developed in the thesis is done without details. The recommendations should not be detailed because it is a burden for the designer since it is impossible to design a guide that suits every individual and every space. Lighting design is a handicraft that needs to be done in situ as for colouring and interior design. Without analysing the colours and surfaces in the room, it is not possible to design a visually comfortable room. Visual comfort is the (visual) limit that the physiologically supportive light not at any time should exceed.

5.2. Discussion related to research question 2

TF Part 5. *Research question 2. In what way can laws, recommendations and methods for lighting design be developed to support the individual user in a better way PPV*: Light needs to be designed close to the subject's visual sensitivity in order to be supportive? A general visual approach to the support from light is merely theoretical and of low value for the user. The user centered lighting design process on the other hand has the possibility to support the individual user in a visually comfortable way and psychologically and physiologically as well. Laws need to be followed by explanations about light- related public health. Recommendations need to be developed for user specific support and methods need to be verified scientifically in a positive impact on light-related public health.

TF Part 5. *Will the light-related goals of health stipulated in EC Treaty 137 and Pörn´s health theory in WHO target 9 and 13-17 adopted by the Member States of European Region and visual comfort in the European standard for indoor workplaces be fulfilled by the use of EN 12464-1:2011:* Studies 4 and 5 in the Thesis project show that the use of EN 12464-1:2011 does not give all normal sighted employees of the 502 million inhabitants in Europe (2011) an experience of visual comfort. This is hard not to debate since the 318 subjects that participated in study 4 varied 50 times between each other in preference for level of a visually comfortable light at the working table and almost 60 times in preference for level of a complementary comfortable level in the ambient light. The subjects were almost unique in their preferences for the combination of light at the working table and for the ambient light. The result of the 2 subjects in study 5 that was measured every hour between 9.00-17.00 varied 3 times (from 1000-3000 Lux) during the day between the lowest and highest level of light experienced as visually most comfortable. The variability of the visual function [Ronchi 2009; 2010] is not supported by a predesigned static level of light as recommended in the lighting standard. The impact of the use of the standard on the subject's health can be a target for discussion. The standard does not recommend in what way the artificial light should be used or be mixed with daylight at a specific workplace. It is a principal statement that a static level of light from a non daylight mimicking artificial light source is counteracting basic light-related health since we need to stay in daylight in the outdoor environment and in the rhythm of daylight to get a healthy input from light. The security aspect at work needs to be balanced together with the need of staying in the rhythm of daylight and to be alerted by changes in the environment. We are modern people that need light to be safe at work and for quality of life, but we cannot live a life to far from the daylight rhythm in a way that is negative for health. These contradicting needs should be balanced together. The subject that works in artificial light only, or is situated far away from windows, is more affected by the use of artificial light compared to those who sit nearby the window. Subjects that work to a high extent at night, early in the morning or late in the evening are the most exposed to the impact on diurnal rhythm from artificial light. The standard does not give recommendations about spectral profile, time, duration. The recommended static level of light seen in the standard can be carried out with different lighting techniques and in that way have a varied impact on the user.

TF Part 6. *Will the use of the CCLDP and the UCLDP fulfill goals about visual comfort and light-related health set out in EN 12464-1:2011, EC Treaty 137, WHO target 9 and 13-17 adopted by the member States of European Region:* The evaluation of the CCLDP not being PPV supportive is a logical conclusion based on common knowledge in lighting design, the analysis of the interaction of MLCS, the analysis of the lighting design process (LDP) step 1-4 and TF in the thesis. The CCLDP do not use the analyses that are needed to establish a supportive interaction of MLCS (TF 3.2-3.10). The evaluation of the UCLDP being PPV supportive is in the same way based on a logical conclusion, common knowledge in lighting design, and the analysis of the interaction MLCS, the analysis of the LDP step 1-4 and TF in the Thesis. The UCLDP uses the analyses that are needed to design a supportive interaction of MLCS (TF 2.3-2.10) and by that are the goals fulfilled in the way that is possible for the technical part of the shadings for daylight and the complementary lighting application for artificial light used in the space.

TF Part 7. *In what way does the end user, designer or client perspective to LQ differ in PPV support for the user?*
The perspective on LQ is important as the goal for ambitions in lighting design. Lighting quality cannot be defined by any other person than the user and at the time. Humans live in a rhythm going from very alert to deep sleep. The visual sight is no exception from that. [Ronchi 2009] Since diurnal rhythm changes the performance of the visual perception during the day, only the user knows when LQ is achieved. When the three perspectives on LQ, the designer, the client and the end user, are compared, only the actual end user knows the individual light-related needs at the time. The client and the designer perspective is a general approach to the use of light. This general perspective can only be put on the complementary artificial ambient light that has a role model in daylight. The task lighting, on the other hand, needs to be adapted during the day to the individual user. The evaluation of LQ from three perspectives shows two general approaches and one individual to the user. It can be argued if these are contradictory or complementary. A general perspective to light-related health is only theoretical and a matter of words with no

possibility to fulfil the individual subject´s changing light-related needs. But if the question about LQ is seen from the perspective of lighting design it is possible to describe a flexible lighting application that gives LQ to the individual user.

The results do not show LQ as general and vague; instead it is seen as a result of a triggering from PS in a way that gives a hormonal release close to the one seen outdoor and that suits the users nervous system and contributes to homeostatic balance, a well functioning diurnal rhythm and a visual comfortable contrast situation for the individual user in the indoor environment.

TF Part 8. *The UCLDP- Seen from the perspective of the LDP step 1-4 and the UCLD:* If the UCLDP and the LDP step 1-4 are used in the design of light the interaction of MLCS will be well-functioning and the light will be possible to adapt individually. It is hard to question the need of light for PPV support that is individually adaptable. Light has for a long time been seen as something practical that should be designed in a cheap way and be economical to use. We pay a high prize for using light as a product on the market of the same importance as shoes, candy or toys. Light is fundamental for life [Hainifin & Brainard 2007] and needs to be designed carefully to have a positive impact not only on the individual user but on animals, plants and the ecosystem as well. The use of the UCLDP changes the lighting design from general and static towards being individual and flexible. When many users work in the same space they need to cooperate about the level of the complementary ambient light. The UCLDP can be described with an increased amount of details and the use of UCLDP can be questioned by practical reasons. It takes time, it is more expensive to use and the light is often planned before the space is built. But lighting design is an ethical issue. It is important to as a lighting designer give the user the best possible support from light. A lighting designer should always strive for best practice since light is fundamental for life for the user. Maybe the use of UCLDP seems more complicated to use compared to the template. This is, of course, again an ethical issue. The goal for visual comfort and light–related health will not be fulfilled without the development of an individual approach to the user. With the UCLDP, it is easy to develop a user friendly and highly flexible lighting application instead of using mathematical formulas for calculations of levels of illumination to fit general recommendations with a static light.

TF Part 9. *How can recommendations for a lighting design process be formulated that supports the individual user´s PPV needs, is related to the colours and surfaces in a specific space and sets the user in contact with daylight at the site where the user lives?*
It can be discussed if the support of basic human health is more complex than being in contact with colours and surfaces in the room, with daylight and having ergonomic task lighting. The question can be widened and include spectral profile, timing and duration close to daylight and the way light is spread in the room as well as a part of mimicking daylight, but this is not described in detail here. However, lighting design is always a matter of balance of contradictory needs and is re-evaluated for every situation. Nevertheless, the recommendations have the possibility to enhance the support for the diurnal rhythm and give an increase in visual comfort for the individual user, which are the primary goals to fulfill.

5.3 Discussion related to research question nr. 3

TF Part 10. *Research question nr. 3*: *In what way can a more qualitative research in lighting design be developed in collaboration among different research areas and different competences*?

It is an unlucky circumstance that lighting design is developed to be merely visually supportive. The establishments of the development of a PPV support from light demands cooperation in research among the light-related areas around the LDP. Knowledge about the room, architecture, windows, shadings, interior design, daylight, artificial light, man and light PPV, design and technique is needed when designing the light-related research. The high complexity in lighting design makes multidisciplinary teambuilding important for the research project. The Thesis shows a limited part of the complexity in the topic and a restricted amount of details. The cooperation among the research areas and competences can be extended further.

5.4 DISCUSSION OF METHODS

Methods used in study 1-5
A general reason to question the methods is the use of references in the theoretical framework. Methods are not always precise and related to lighting design because those are hard to find, instead references are used for a support of logical conclusions that illustrate the theme described in the thesis. The exact quotations are shown by page. The result of the studies are insufficient and the group of subjects too small compared to the extensive studies that are needed to find normal curves for individual experience, response and preference according to light. It is Wever and Roenneberg that have the length of the studies and number of subjects that is needed to find human patterns in responses to and preferences for light. But on the contrary a small group can in an effective way show that the subjects are not similar in responses and preferences despite being triggered in the same way. That subjects vary to a high extent and the result can then be read out as a pattern that is valuable to investigate further.

Methods used for light-related interaction research
Methods used in the Thesis are developed as suitable for light-related interaction research. This differs in many ways from the tradition within medical and psychological research. The interaction research is close to caring science. In the medical and psychological research the focus is to investigate for instance lethal dose. This is a one factor research. If the research study is based on the investigation of one factor and a control group is used, the impact from the chosen factor can be verified. Since humans live in complex rhythms and have a mind that can start up the camp and flight system, increase level of stress, feel anger, be afraid and so on, the mind has an impact on hormonal release and to the response to the triggering from EMR. The caring science tries to collect data about, for example, the individual subjects experience of pain and about strategies in coping with diseases. In the caring science a holistic perspective is important and data is collected about the individual subjects experiences seen in the environmental context. Light-related interaction research is multidisciplinary and close to affordance, human factors ergonomics and caring science. But the perspective is extended and

includes man, the tool and the environment. The space is the scene where PS interacts with TAR through, into and from the colours and surfaces in the room and in the same way with the user's eyes in phototransduction.

Methods used for research in responses to EMR and PS

Studies about responses to EMR and PS need to describe in what way they have excluded other external or internal triggers for the camp and flight system and divided this from diurnal rhythm. Increases in cortisol during the day are a stress response and not a part of the diurnal rhythm, with Cortisol increase in the morning and decrease during the day. Since there is a variety in the individual time for on and offset for the diurnal rhythm, an increase in cortisol can be a normal increase by a subject that is in a late start up phase. The late increase in cortisol in the start up time of the diurnal rhythm among subjects or the extra released cortisol during the day as a result of the activation of camp and flight system should not be seen as a positive response to the trigger PS. If this is concluded in a study the researchers need to explain how they have divided cortisol release in diurnal rhythm from newly generated cortisol as a result of the camp and flight system. If the increase of cortisol during the day is concluded as being positive, the researcher needs to explain why a deviation from diurnal rhythm and a disturbance of the natural decrease in cortisol is seen as positive.

Methods used in the buildup of the TF

The methods used in the build up of the TF were initially an identification of the topics that can be seen around to the LDP step 1-3. The review is focused on light-related parts of the research areas related to these steps of the LDP. This review can be widened. The survey is done based on international literature from 2000-2011 since the breakthrough with melanopsin and ipRGC came at that time. This was completed with the forerunners for the devolvement seen from 1923-1999. In the TF the literature in the first hand concerns man, light and physiology. The literature before 2000 merely concerns man, light and vision. The articles chosen in the thesis are in the first hand concerned with physiology, with an ambition to create a link between man, light, physiology and lighting design that is congruent with the development seen after 2000. The interaction of MLCS of the outdoor environment was compared to the interaction seen indoors on a principal level. The result was translated into the LDP process. Two typical LDP processes were identified as CCLDP and UCLDP and were compared according to goals set out on visual comfort and light-related health. When the outdoor interaction is used as a role model for the design of light combined with the 4 steps of LDP and the UCLDP, the method used is natural and holistic. The literature survey done in the thesis can be widened and include more aspects of the contemporary literature.

Methods used to measure the experiences, responses and preferences are in the first hand self evaluations (semantic scales) completed with blood samples. The semantic scales are not ideal since they collect the experience but do not show the trigger for the experience, response or preference. Blood samples on the other hand show level of hormonal release but do not in a short period of time show the rhythm for the specific individual or are an objective response to one specified trigger. It takes time to collect data about the individual subject and the result reveals hormonal release in combination with individual disposition, photic history and all external and internal triggers present at the time. The result should not be seen as fixed or static. It is instead a general rhythm that should be displayed of increase and decreases related to the time of the day. Sometimes more, sometimes less and in a rhythm.

Responses: Homeostatic activity can be initiated by many factors. Internal or external triggers cannot be totally under control. By that, it is not possible to point out PS as the trigger for hormonal release by the specific methods used in the studies.

Preferences: Methods used for a systematic comparison between subjects responses to daylight and artificial light in the study are not ideal. Staying solely in daylight and in artificial light cannot be done at the same time. In the same way it is a problem that daylight will always provide a view through the window of some kind compared to the blacked out windows in the rooms solely lit with artificial light. The two optional candlelights were necessary to provide light if needed for the users to be able to do the work tasks in the room only lit with daylight in the afternoon. This can of course be questioned but it is not possible to know if the level of light late in the afternoon in February or March will be enough for the individual subject to read in. Daylight measured on a spot varies to a large extent. In the study a mean day for daylight was constructed. The focus spot in the room was chosen to be the lower frame of the window and not the view in front of the subject when sitting at the working table. The ambition was to find the average impact from daylight. The view of the window, the variability of daylight and the optional candlelight was necessary to handle when using daylight in the study. The daylight during the period of tests was normal for the season. The light was weak and grey in February and March as often seen during the wintertime in Sweden. The view was towards a white wall on a distance of 5 meters. The level of illumination on the wall in front of the subject was not used as a measure point in the daylight room. Instead the lower frame in the window was measured. The lower frame was the most lit part of the room and more relevant to use than the dark wall in front of the subject because of its alerting effect. To measure the preferences the BT test was used with the ambition to see if preferences were connected to a certain personality. It can be questioned if the subjects were honest in the way they answered the questions about being stressed, unpolite and egoistic. It is likely that some subjects might have denied the rudest parts of their personality. The instruments need to be developed more towards being free formulated and more specific into the experience of the daylight, the artificial light, the combination of daylight and artificial light and the ambient light as well as task lighting.

Literature: Literature in methods is found for PANAS and SMB. Most of the methods used are developed in the Thesis.

Methods used for the investigation of the EC 137 and EN 12464-1:2011

The method used to investigate EC Treaty137 and EN 12464-1:2011 was the literature survey and this can be broadened and more aspects can be investigated. My own experiences of participating in CIE, CEN and SIS in a limited number of meetings, were a part of the investigation. Here I reveal my own experiences and the way these three organisations cooperate with each other is further described by SIS at their homepage. The exact number of academic researchers and representatives for companies and lighting designers that actually have been participating in these organisations are not investigated. The text are based on the meetings I have participated in and is a first step in a deeper investigation about how recommendations for lighting design are built up that will be completed in a post doc. project.

Methods used to evaluate the CCLDP and UCLDP

The method used to evaluate the CCLDP is common knowledge in lighting design, logical conclusions based on TF and the analysis of the interaction of MLCS in the outdoor and indoor environment sorted into the four steps of the LDP. Based on this the CCLDP was found performed without contact with the user's needs and the colours and surfaces in the room. The UCLDP on the contrary is performed in contact with the users needs and related to the colours and surfaces in the room. The result is principal and the quality of the interaction of MLCS designed by the use of the UCLDP is a matter of the way the handicraft lighting design is performed by the lighting designer and the technique available on the market.

The method used to identify the UCLDP was as for the CCLDP, common knowledge about lighting design, the analysis of the interaction of MLCS in the outdoor and indoor environment sorted into the four steps of the LDP and the literature survey about humans need for light PPV done in the theoretical framework. *Literature:* TF 2.2-2.10.

The method used to develop recommendations for the UCLDP was in the same way common knowledge about lighting design, analyses of the interaction of MLCS in the outdoor and indoor environment sorted into the four steps of the LDP and the literature survey done in the theoretical framework about the human's need for light PPV. The recommendations are a logical conclusion of the literature survey and are based on the parts of the theoretical framework that was found relevant. The amount of details mentioned can be increased.
Literature: TF 2.9.

5.5 FINAL CONCLUSIONS

The result of the investigation about the three research questions are here finally concluded. The questions in the theoretical framework are associated thematically to the appropriate research question.

5.5.1 Research question nr. 1

TF Part 1. *Research question number 1. Why and in what way should daylight and artificial light be designed for the indoor environment to realise goals of visual comfort and light-related health:*

Light is fundamental to life and needs to be carefully designed [Hanifin & Brainard 2007; Wirz-Justice & Fournier 2010] since connected in a solid way to basic human health.
"Light profoundly impacts human consciousness through the stimulation of the visual system and powerfully regulates the human circadian system, which in turn, has a regulatory impact on virtually all tissues in the body" [Brainard & Hanifin 2005].

Daylight should be used as ambient light [Hollwich 1979] in the indoor environment and be completed with a daylight mimicking artificial light [Hollwich 1979; Hannibal et al. 2007] that supports humans PPV. The use of the UCLDP will increase the possibilities to fulfil goals set out for visual comfort in EN12464-1:2011 and light-related health in EC Treaty 137 and WHO Target 9 and 13-17.

TF Part 2. *Can significant differences in the interaction of man, light, colour and space in the outdoor and indoor environment be identified:* Significant differences between the interaction of MLCS seen in the outdoor and the indoor environment are the wavelengths and the rhythm of daylight [Hollwich 1979; Brainard & Hanifin 2005].

TF Part 3. *Which are the functions of melanopsin and ipRGC and how can a relation to lighting design and light-related basic health be formulated:* The chemical structure of melanopsin in ipRGC opens up for some wavelengths to reach the melanopsin and contribute to action potentials to the brain. Artificial light sources need to be developed to emit (safe) wavelengths that have the possibility to enter the eye and give action potentials close to the one seen in the outdoor environment. Melanopsin and ipRGC receive signals from daylight for onset and offset of the diurnal rhythm. Artificial light need to be designed in a way that do not risk interfere with the signals for onset and offset of the diurnal rhythm seen in daylight and to be adapted to the light at the site where the user lives [Brainard & Hanifin 2005].

TF Part 4. *Can patterns be seen in responses to PS and in preferences to light when subjects stay in daylight or artificial light in the room and light settings in the studies:*

- *Study 1:* Only preferences were collected.
- *Study 2:* Minor differences can be seen in mean for measured hormonal levels in the bloodstream when staying in the three room and light settings. Mean for cortisol follows the same pattern in changes in daylight and in artificial light. Changes in mean for adrenaline and noradrenaline differ slightly compared to the pattern of changes seen in daylight. More research is needed to find out if this is a systematic difference that can be related to the wavelengths emitted from artificial light.
  Study 2: Subjects being alert on the highest level is only seen at 25 of 180 occasions of self-evaluation. The highest number of subjects evaluated as alert on level four and seen as natural, was seen in daylight. The highest number of alertness on level 4 evaluated as unnatural was seen in Room 3 at 16.00. The result of the study does not show if this is a systematic difference that can be related to the wavelengths emitted from daylight or artificial light.
- *Study 3:* Only preferences were collected.
- *Study 4:* Only preferences were gathered.
- *Study 5:* Only preferences were collected.

Preferences

- *Study 1:* When the lighting designers preferences for visual comfort (close to, far from and very far from) seen in the room and light settings in the study, was compared to the measured preferences for visual comfort (VCT) for the subjects, the result shows that the most visual comfortable room according to the lighting designers preferences was preferred at the most by the subjects. The lighting designer's preference for a low level of ambient light shown in Room 2 made it possible for the highest number of measured subjects to have their own preferred level of light at the work table but not in the ambient light, compared to in the two other rooms. All subjects in the study preferred a higher level of light at the table compared to the level of ambient light. When associated to the ordinary lighting application it can be concluded that the study shows that it was an advantage to use a low level of ambient light. When daylight is used as ambient light (to a certain lowest level of security) it gives the user an opportunity to have the individually preferred level of light at the working table. Low level of daylight is here suggested appreciated as visually comfortable.
- *Study 2:* Only responses were collected.
- *Study 3:* When the 87 subjects from 23 countries in study 3 evaluated the light emitted from Halogen, CFL and LED and compared to the light from only LED it was found that Halogen, CFL and LED was found more similar to the light the subjects were used to at home. The light from Halogen, CFL and LED was preferred compared to the light emitted from only LED.
- *Study 4:* The study exhibited a span among the 318 subjects that participated in the study from 80-3940 Lux for the preference for a visually comfortable level of light at the table and 30-1750 for the ambient light in the group of subjects. The subjects varied 50 times in preferences for level of light between each other's and almost 60 times in preferences for level of a complementary ambient light. The subjects did almost unique combinations of level of light at the worktable and for the ambient light. Only two pairs of subjects had the same preferences, 314 subjects did unique combinations of levels of light.
- *Study 5:* The two subjects in the study varied widely in preferences for level of light at the work table and for the ambient light during 9.00-17.00. The subjects varied from the lowest value 1030 to the highest value 3420 Lux for the level of light at the work table and from 140 to 1010 Lux in the ambient light (TF 2.4).

5.5.2 Research question 2.

TF Part 5. *Research question 2. In what way can laws, recommendations and methods for lighting design be developed to support the individual user in a better way PPV:* Light is of high importance for human basic health? Laws, recommendations, and methods for lighting design need to be developed to give a user specific support PPV. Laws should not be detailed but the ambition with the law need to be explained related to lighting design. Recommendations need to be focused on flexibility of the lighting application that has the possibility to give the individual subjects a good visual support. Methods for lighting design need to be verified having a positive impact on the public health by health authorities.

The lighting design process can be described from the perspective of ; 1) the interaction of MLCS; 2) the LDP (in general) step 1-4; 3) and the UCLDP 1-4, that is user specific**.**

TF Part 5. *Will light-related goals according to visual comfort and health stipulated in EC Treaty 137, Pörn´s health theory in WHO target 9 and 13-17 adopted by the Member States of European Region and visual comfort in the European standard for indoor workplaces be fulfilled by the use of EN 12464-1: 2011:* No it is not possible to fulfill goals about visual comfort by the use of the recommendation in the standard. Visual comfort is a matter of adaption to the individual user's visual needs and to the colours and surfaces in the room and this is not done here. It is in the same way not possible to support human's needs for the wavelengths and rhythm of daylight by the use of a predesigned static level of light and an artificial light source.

TF Part 6. *Will the use of the CCLDP and the UCLDP fulfill goals about visual comfort and light-related health in EN 12464-1:2011, EC Treaty 137 and WHO target 9 and 13-17 adopted by the member States of European Region:* Goals for visual comfort and light related health by the use of CCLDP or UCLDP. CCLDP done without contact with the user, the colours, surfaces in the space or daylight do not meet the goals of visual comfort in EN 12464-1:2011 or light-related goals of health in EC Treaty 137 or WHO Target 9, 13-17. The UCLDP on the contrary performed in contact with the user and the colours and surfaces in the room and related to daylight at the site were the user lives have the possibility to give an individual experience of visual comfort and light-related health.

TF Part 7. *In what way does the end user, designer, or client perspective to LQ differ in PPV support for the user:* The experience of lighting quality goes through the user's senses. The designer or the client does not know the needs for light of the individual user**.** Lighting quality is a PPV support from light designed close to the individual users needs.

TF Part 7. *Three perspectives on lighting quality*
The two principal approaches to LQ that can be seen, according to Boyce [Boyce 2003], (evaluated as fulfilling the client´s and the designer´s expectations) are here suggested as being general and not in contact with the individual user´s light-related needs. This can be compared to a third approach to LQ seen in literature and here associated to the lighting design process by the author of the Thesis. LQ is seen as perceived when the individual subject´s needs and preferences for light PPV is fulfilled and daylight and the artificial light is designed related to the colours and surfaces in the room and connected to daylight in the outdoor environment. Examples of differences between these three aspects on lighting quality according to a PPV support of the user are:

- The designer's perspective on LQ is general and the designer has no possibilities to feel if the individual user is experiencing homeostatic balance or visual comfort. The designer does not have information about the group of users individually changed needs during the day.

- The client perspective if not the individual end-user is as general as the designers and the client does not have information about when the user experiences homeostatic balance or visual comfort.
- The end-user is specific and knows when the chosen light enhances homeostasis and visual comfort or not. The end-user is guided in the use of light by the experience of relief and comfort PPV in the striving towards equilibrium. The reason for the experience of comfort and relief is shown by research of photo biologists, sleep researchers, physiological optics and researchers in lighting and user centred design [Brainard & Hanifin 2005; Roenneberg et al. 2007; Ronchi 2009; Säter 2011; Redström 2006; Davydow et al. 2007].

TF Part 8. *How can the process of lighting design be described that support the user´s individual light-related PPV needs and is related to the colours and surfaces in a specific space and sets the user in contact with the daylight at the site where the user lives?*

Interaction of MLCS

- ***Man:*** Design the daylight in the room close to the users needs PPV. Design a complementary artificial light that is related to the colours and surfaces in the room and follows daylight to a lowest level of security. Use non glary task lightings and a light source that mimics daylight.
- ***Light:*** Analyse daylight and the artificial light in the room.
- ***Colour:*** Analyse the colours and surfaces in the room.
- ***Space:*** Analyse the space.

LDP 1-4.

- ***Step 1:*** *The space, analyses of the space, daylight and artificial light, the architects and the interior designer's intentions with the space.*
  Analyse the way the space is designed?
  Analyse the daylight and the artificial light in the space.
  Analyse windows in size and position, colours and surfaces in the space.
  Analyse the architects and the interior designer's intentions with the space.
- ***Step 2:*** *The human, the needs of light PPV.*
  Analyse the needs of the user to stay in contact with daylight.
  Analyse the user's needs of a natural input to a stable diurnal rhythm and a hormonal release close to the one seen in the outdoor environment.
  Analyse the user's need of staying in a visually comfortable environment.
  Analyse the user's needs of being effective in work, visually well oriented and at comfort.
- ***Step 3:*** *The design of the daylight and the artificial light related to the colours and surfaces in the room and connected to the daylight at the site where the user lives.*
  Design the daylight in a visually comfortable and pleasant way.

Design the complementary artificial light in a daylight mimicking, comfortable and pleasant way.

- ***Step 4:*** *The design of the lighting application and the scheme for maintenance.*
  Design a user-friendly, easy to maintain, lighting application that in a flexible way follows the changing needs of the user in the ambient light as well as in the task lighting.

UCLDP step 1-4

- Step 1: *The space, analyses of the space, daylight and artificial light, the architects and the interior designer's intentions with the space.*
  Analyse the way the space is designed?
  Analyse the daylight and artificial light in the space.
  Analyse windows in size and position, colours and surfaces in the space.
  Analyse the architects and the interior designer's intentions with the space.
- ***Step 2:*** *The human, the needs of light PPV.*
  Analyse the needs of the specific user or users to stay in contact with daylight.
  Analyse the specific user's needs of having a natural input to a stable diurnal rhythm and a hormonal release close to the one seen in the outdoor environment.
  Analyse the specific user's need of staying in a visually comfortable environment.
  Analyse the specific user's needs of being effective in work, visually well oriented and at comfort.
- ***Step 3:*** *The design of the daylight and the artificial light related to the colours and surfaces in the room and connected to the daylight at the site where the user lives.*
  Design daylight in a visually comfortable and pleasant way for the specific user.
  Design the complementary artificial light in a daylight mimicking, comfortable and pleasant way for the specific user.
- ***Step 4:*** *The design of the lighting application and the scheme for maintenance.*
  Design a user-friendly, easy to maintain lighting application that in a flexible way follows the changing needs of the user in the ambient light as well as in the task lighting.

TF Part 9. *How can recommendations that guide the design of light toward being in contact with the individual user´s light-related needs, the colours and surfaces in a specific space and the daylight at the site where the user lives be formulated?*
The recommendations for the process of lighting design that support the user PPV can be described from the perspective of ; 1) interaction of MLCS; 2) the LDP (in general) step 1-4; 3) and the UCLDP 1-4, that is user specific.

Interaction of MLCS

- ***Man:*** Design the daylight close to the users needs PPV. Design a complementary light setting of artificial light that is related to the colours and surfaces in the room and follows daylight to a lowest level of security. Use non glary task lighting and a light source that mimics daylight.

- ***Light:*** Analyse daylight and the artificial light in the room.
- ***Colour:*** Analyse the colours and surfaces in the room.
- ***Space:*** Analyse the space.

LDP 1-4.

- ***Step 1:*** *The space, analyses of the space, daylight and artificial light, the architects and the interior designer's intentions with the space.*
  Analyse the way the space is designed?
  Analyse the daylight and the artificial light in the space.
  Analyse windows in size and position and colours and surfaces in the space.
  Analyse the architects and the interior designer's intentions with the space.
- ***Step 2:*** *The human, the needs of light PPV.*
  Analyse the needs of the user to stay in contact with daylight.
  Analyse the user's needs of a natural input to a stable diurnal rhythm and a hormonal release close to the one seen outdoors.
  Analyse the user's need of staying in a visually comfortable environment.
  Analyse the user's needs of being effective in work, visually well oriented and at comfort.
- ***Step 3:*** *The design of the daylight and the artificial light related to the colours and surfaces in the room and connected to the daylight at the site where the user lives.*
  Design of the daylight in a visually comfortable and pleasant way.
  Design of the complementary artificial light in a daylight mimicking, comfortable and pleasant way.
- ***Step 4:*** *The design of the lighting application and the scheme for maintenance.*
  The design of a user-friendly, easy to maintain lighting application that in a flexible way follows the changing needs of the user in the ambient light as well as in the task lighting.

UCLDP Step 1-4

- ***Step 1:*** *The space, analyses of the space, daylight and artificial light, the architects and the interior designer's intentions with the space.*
  Analyse the way the space is designed?
  Analyse the daylight and artificial light in the space.
  Analyse windows in size and position, colours and surfaces in the space.
  Analyse the architects and the interior designer's intentions with the space.
- ***Step 2:*** *The human, the needs of light PPV.*
  Analyse the needs of the specific user or users to stay in contact with daylight.
  Analyse the specific user's needs of a natural input to a stable diurnal rhythm and a hormonal release close to the one seen in the outdoor environment.
  Analyse the specific user's need of staying in a visually comfortable environment.
  Analyse the specific user's needs of being effective in work, visually well oriented and at comfort.
- ***Step 3:*** *The design of the daylight and the artificial light related to the colours and surfaces in the room and connected to the daylight at the site where the user lives.*

Design of the daylight in the room in a visually comfortable and pleasant way for the specific user.
Design of the complementary artificial light in a daylight mimicking, comfortable and pleasant way for the specific user.

Step 4: *The design of the lighting application and the scheme for maintenance.*
Design a user-friendly, easy to maintain lighting application that in a flexible way follows the changing needs of the user in the ambient light as well as in the task lighting.

5.5.3. Research question 3.

TF Part 10. Research question number 3. *In what way can a more qualitative research in lighting design be developed in collaboration among different research areas and different competences?*
The research area around the LDP is wide. The interaction of MLCS seen in the outdoor environment is the first step in the mapping of the humans need for daylight. The next step is to identify the interaction of MLCS that is well functioning for the indoor environment and is designed based on the interaction seen outdoors. The man made interaction indoors should give the same patterns in balance of light-related hormonal release as can be seen outdoors. Then the LDP that gives the well-functioning interaction in the indoor environment for the individual user needs to be explored. The UCLDP should be developed in details. In the research of the interaction of MLCS and of the lighting design process is a collaboration needed among architects, interior designers and lighting designers photobiological research as well as psychology, physiology, medical research and photobiology. This group can together investigate human's needs physiologically and show in what way the technique used in the practical lighting application should be developed.

Finally

Finally it is concluded that light despite being fundamental for life is set out on the market as a goods like shampoo or shoes. The work in the National standardisation committees has as a goal to support the member organisations financially. The standard organization recommendations encourage a method for lighting of indoor workplaces that is based on the use of step 4 in the LDP and by 500 Lux and with no adaption to the user or the space. It is more costly to design light by the use of step 1-4 in the LDP and by the use of the UCLDP and adapt the light to the individual user, daylight and to the actual space. If the yearly costs of the society for medical treatment for light-related diseases are counted and compared to the costs for the use of the LDP step 1-4 and the UCLDP, it is likely that the costs for lighting design are seen as negligible.

In the same way it might be seen that light is to valuable for the society financially in the contribution to lower costs for light-related medical treatment and in making the workforces more productive to be designed without contact with the individual user henceforth. With the findings of melanopsin and ipRGC follows that laws, legislations and recommendations and methods for lighting design need to be rewritten with the ambition to reduce problems with visual discomfort and light-related diseases among the workers of Europe. If the law is interpreted to be more precise in goals for the design of light and recommendations is developed in a way that support the individual user PPV, this have a great potential to make Europe, the third largest population in the world, more competitive.

The result of the Thesis project can hopefully contribute to a design based research in lighting science close to the one of caring science and Pörns health theory. A research that have a focus on the user when staying in the room and to build in the tools for light-related health for the individual into the space.

5.6 FUTURE WORK

Research in goals for the process of lighting design seen from the perspective of the society: It is important to investigate if goals of light-related health that can be seen in laws and recommendations for lighting design are fulfilled or not and define the costs for a misuse of artificial light, not only for humans but for animals, plants and the ecosystem as well.

Research in the LDP: Research in parts 1-3 of the LDP has the possibility to increase the quality of the recommendations of future lighting applications and guide the technical development of lighting applications as well.

Research in education: Multidisciplinary research in lighting design based on photobiology, physiology, user centred design, lighting design, architecture and interior design has the possibility to improve education not only for the lighting designer but for the architect and the interior designer as well and by that the quality of the future lighting application.

Research in inter-individual differences according to man and light: More needs to be known about inter-individual differences according to man and light. The differences between subjects in the triggering from EMR need to be mapped out and put into a normal distribution curve.

User-centred lighting design: More research about the process of user centred lighting design and the realisation of individual light-related goals is of high importance. Research in the build up of recommendations for light is well motivated.

Multidisciplinary knowledge about man and light: Multidisciplinary knowledge about man and light needs to be put together by research and identify the PPV future supportive light in a detailed way.

Synchronise contradictory needs for light: Research in how to synchronise contradictory needs for light in society is needed. The design of energy efficient lighting applications needs to be synchronised with goals for health and be evaluated if contradicting vital aspects of light-related public health.

Light-related standards and directives: Research in how to develop standards and directives that lead to a fulfilment of light-related goals is of an urgent need as well as to by research secure that the goals set out are fulfilled and result in a reduction of diseases related to the misuse of artificial light.

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APPENDIX A

Positive room descriptive words.
Questionnaires developed for Study 2 in the thesis project.
Developed by Monica Säter at Jonkoping University.
Copyright Monica Säter 2004.

Describe with your own words and with as much details as possible the room that you just left.

……………………………………………………………………………………………………
……………………………………………………………………………………………

All words used that described the room in a positive way was counted and given 1 point. No limit.

Future lighting.
Questionnaires developed for Study 3 in the thesis project.
Developed by Monica Säter at Jonkoping University.
Copyright Monica Säter 2006.

Task 1a. Dining area

Sit down at the dining table.

Describe your opinion about the light from the pendant kitchen lamp in the dining area.

……………………………………………………………………………………………………
……………………………………………………………………………………………

Task 1b. Pendant kitchen lamp

Describe your opinion about the pendant kitchen lamp.

……………………………………………………………………………………………………
……………………………………………………………………………………………

Task 1 c. Pendant kitchen lamp

Select and mark which light source you believe is used in the pendant kitchen lamp.

LED, compact fluorescent lamp, fluorescent lamp, halogen light bulb, low energy light bulb.

Task 1 d. Pendant kitchen lamp.

Select and mark the best word to describe the light from the pendant kitchen lamp.

Boring, interesting, cold, cozy, hard, soft, uncomfortable, comfortable, unpleasant, unfunctional, pleasant, unfunctional, functional, uneven, even, ugly, and beautiful.

Task 1 e- 1h large white wall lamp

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 2a-2d Armchair for reading, reading lamp.

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 3 a-3d Sofa Floor lamp

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 3 e-3h Pendant lamp

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 3 i- 3 l the small wall lamp

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 4 b- 4 e Reading lamp

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 4 f- 4i the two ceiling lamps (above the desk)

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 5a Ceiling lamp in the center of the room (marked with 5)

Question 1e-h in the same way as for the pendant kitchen lamp.

Task 6 a. The light in the room

Describe if the light you see in the room is consistent with the light you´re used to being around at home. Specify in what way it´s the same.

………
……

Negative and positive words was counted and given 1 point each. No limit

Task 6b. The light in the room

Describe if the light you see in the room do not match the light you´re used to being around at home. Specify in what way it differs.

………
……

Negative and positive words was counted and given 1 point each. No limit.

Task 6 c. The light in the room

Describe the room and the light in the room a close as you can.

………
……

Negative and positive words was counted and given 1 point each. No limit.

Task 7 a. What is your overall impression of the room?

……...
....

Negative and positive words was counted and given 1 point each. No limit.

Tick the appropriate box on each scale

Do you feel alert?

A little ☐☐☐☐☐ very much

Do you feel tired?

A little ☐☐☐☐☐ very much

Indicate your level of comfort

Low ☐☐☐☐☐ high

This concludes your session. You may now step out of the room.

Questionnaires developed in the thesis project: Study 3. Type of light source used at home. Developed by Monica Säter at Jonkoping University.

Fp_____________

How many of the following light sources do you use at home**?**

Lightbulb

☐ **not at all**

☐ **a few**

☐ **several**

☐ **in most of the lamps**

Halogen lamp

☐ **not at all**

☐ **a few**

☐ **several**

☐ **in most of the lamps**

Low energy light bulb

☐ **not at all**

☐ **a few**

☐ **several**

☐ **in most of the lamp**

Visual comfort
Questionnaires developed in the thesis project:
Developed by Monica Säter at Jonkoping University.

Visual comfort **Fp___________**

Nr 1

Describe with your own words the experience of looking in to the light in the box

____

____

Indicate how pleasant-unpleasant it is to look in the light box with a marker at the 10 degrees range.

unpleasant pleasant

1	2	3	4	5	6	7	8	9	10

This question was repeated in the same way for the 5 boxes.

Light in boxes.
Questionnaires developed in Study 3 in the thesis project
Developed by Monica Säter at Jonkoping University.

Fp_________________

Evaluation of light color

Box 1

Describe with your own words your opinion about the light in box 1.

____

____

____

Negative and positive words was counted and given 1 point each. No limit.

Describe the quality of the light with a marker at the 10 degree range low
low high

1	2	3	4	5	6	7	8	9	10

This was repeated for the 5 boxes.

Lightspot on the wall.
Questionnaires developed in Study 3 in the thesis project.
Developed by Monica Säter at Jonkoping University.

FP_________

Look at the light from the light source on the wall in one minute.

Describe with your own words:
If you feel that the light changes during the time you consider the light. If so, describe how the light changes.

____

Visual comfort test (VCT)
Developed by Bo Persson, completed by Monica Säter at Jonkoping University.
The VCT was developed by Dr. Bo Persson at KTH in Sweden. It was used to measure the preferred level of light at the working table. Bo Persson did the test with a white paper on a white table three times. Then he did the same procedure three times with a white paper on a black table. The test was completed in 2006 by M. Säter to be used for measurement of both the level of light at the working table and for the preferred complementary level of ambient light. A white paper is placed on a black table. The test starts in the room which is dark and the level of light is taken up to maximum, down again, until the subject recognises their individual level of light experienced as visually comfortable. The preferred level of light is measured as horizontal (the table) and vertical (ambient light) illumination with a light meter. Then, the level of light for the working table is kept and the ambient light is added. The level of ambient light is taken up to maximum and then down until the most visually comfortable combination of level of light at the working table and for the ambient light is found by the individual subject. The procedure is done three times and the third measurement is counted. The VCT test was used in the same way in Studies 1, 2, 3, 4 and 5.

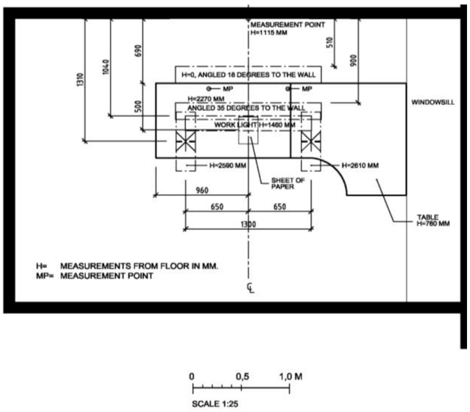

Figure 19. Visual comfort test used in Studies nr. 1, 5, 6. Coded floor plan for VCT
Lamp1, 1, 4 Wall washer 26W 830. Lamp 2, 1 Pendant 2x54W Fluorescent 830. Lamp 3, 2 Pendant 2x49W 830. Control dimmers on table, 1-10V converter Digi DIM 470. Lighting control, ATCO PCA 2/54 15XL one size LP. Lighting control: Sidelight, qt-t/e1x26/230-240 dim. Lighting control: PCA/49. Light source 80-3950 Lux. Working light gives 0 (80)-3950 Lux on the working table and 0 (10)-120 to the Ambient light. Ambient light gives 0 (10) – 550 Lux on the working table and to the Ambient light 0 (30)-1800 Lux. Total on the Working table 0(90)-4500 Lux. Total Ambient light 0(40)-1930 Lux.

The visual comfort test was used in Studies 1, 2, 3, 4 and 5.

APPENDIX B

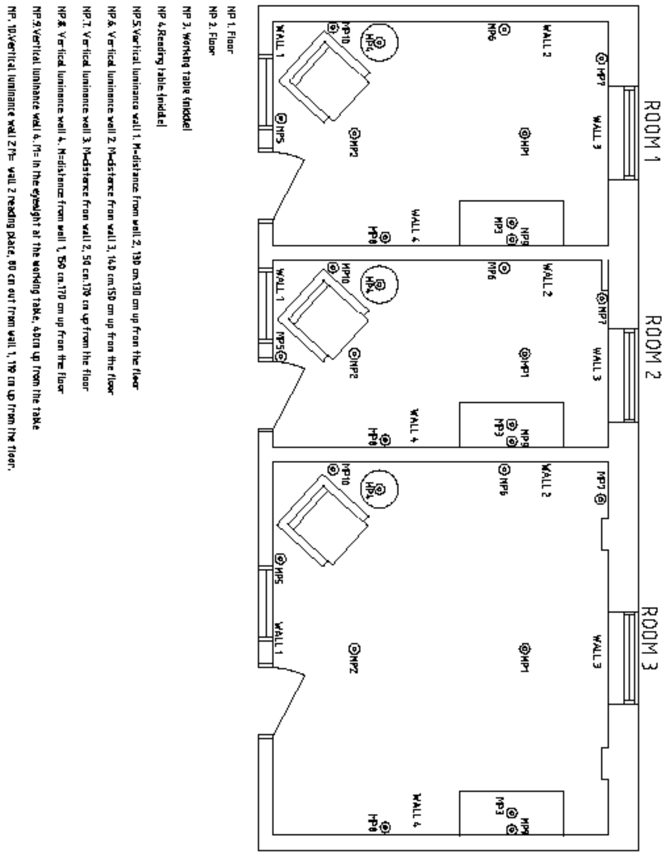

Fig. 5. Floorplan study 1.

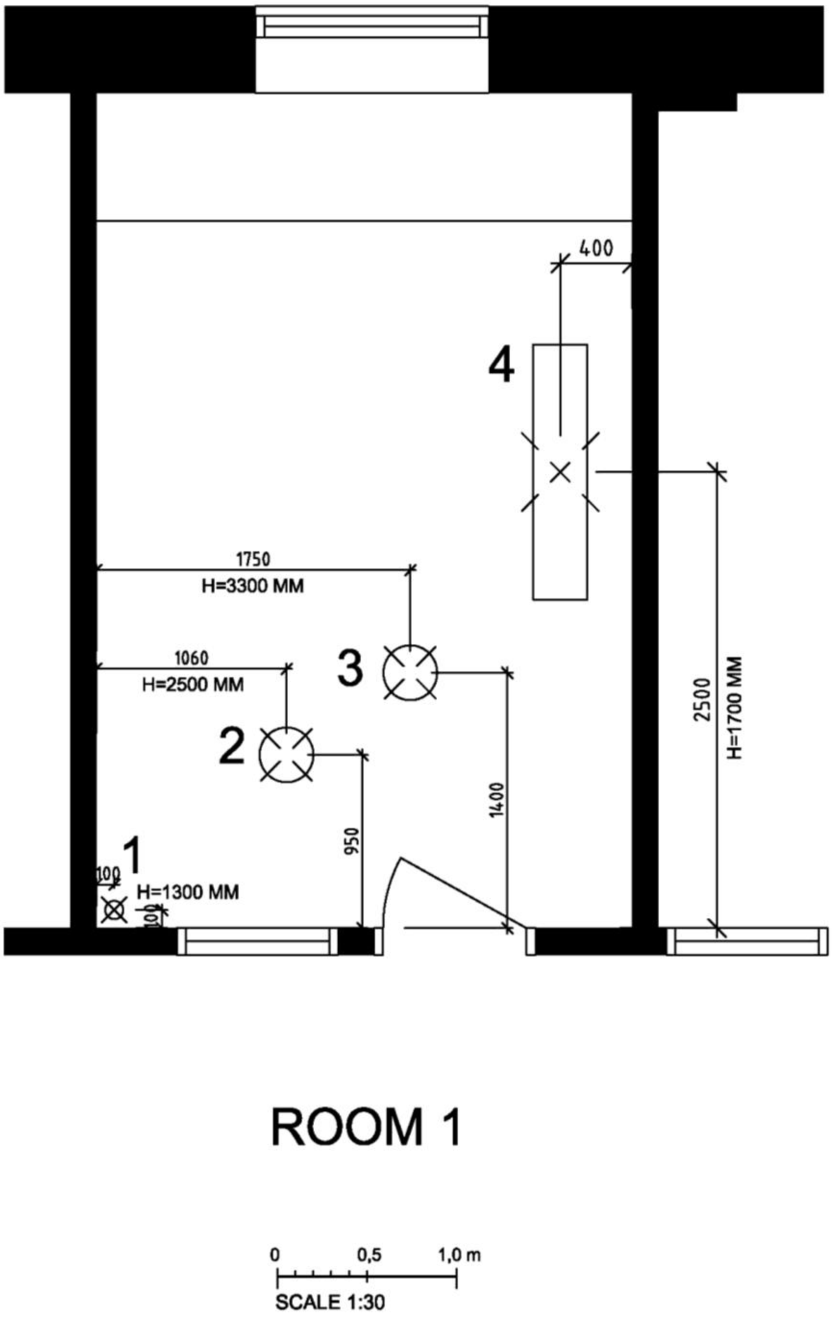

Fig. 4. Floorplan study 1.

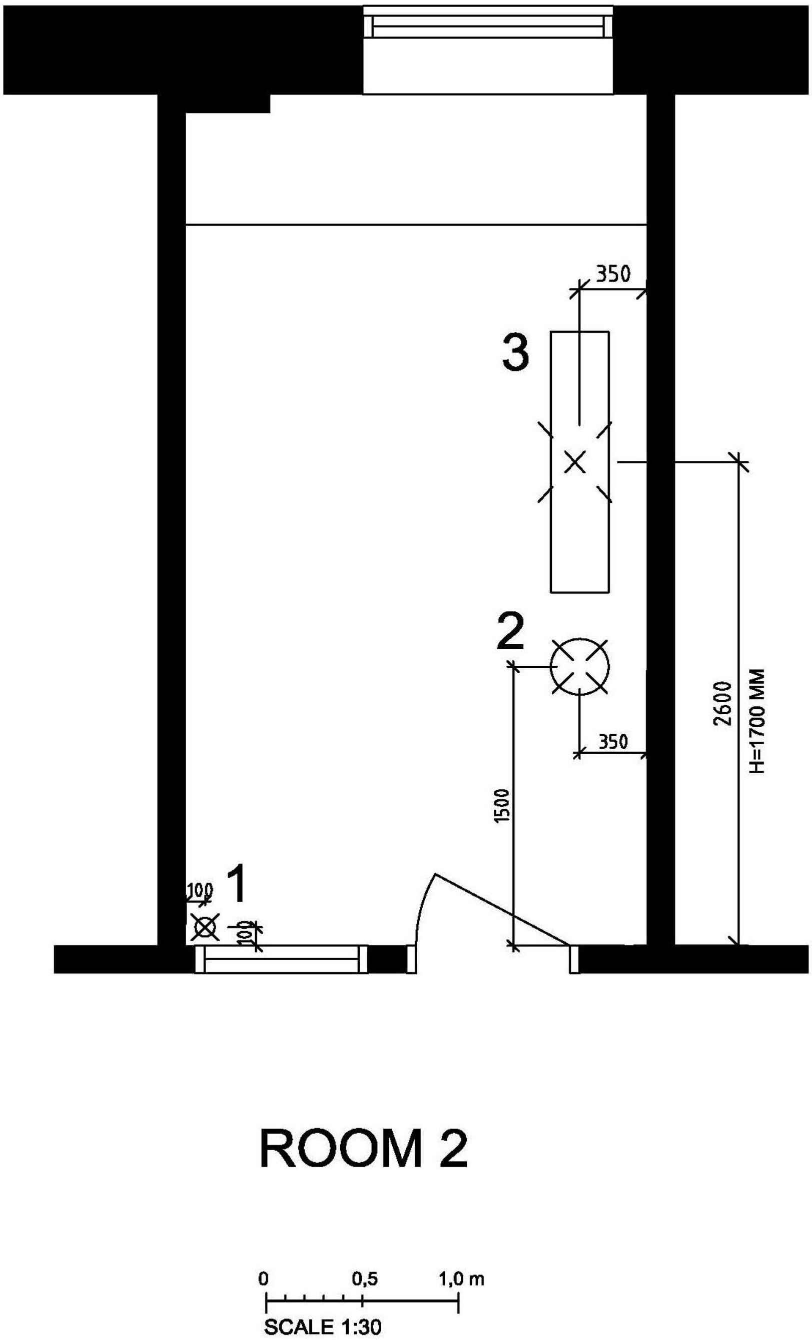

Fig. 8. Floorplan study 1.

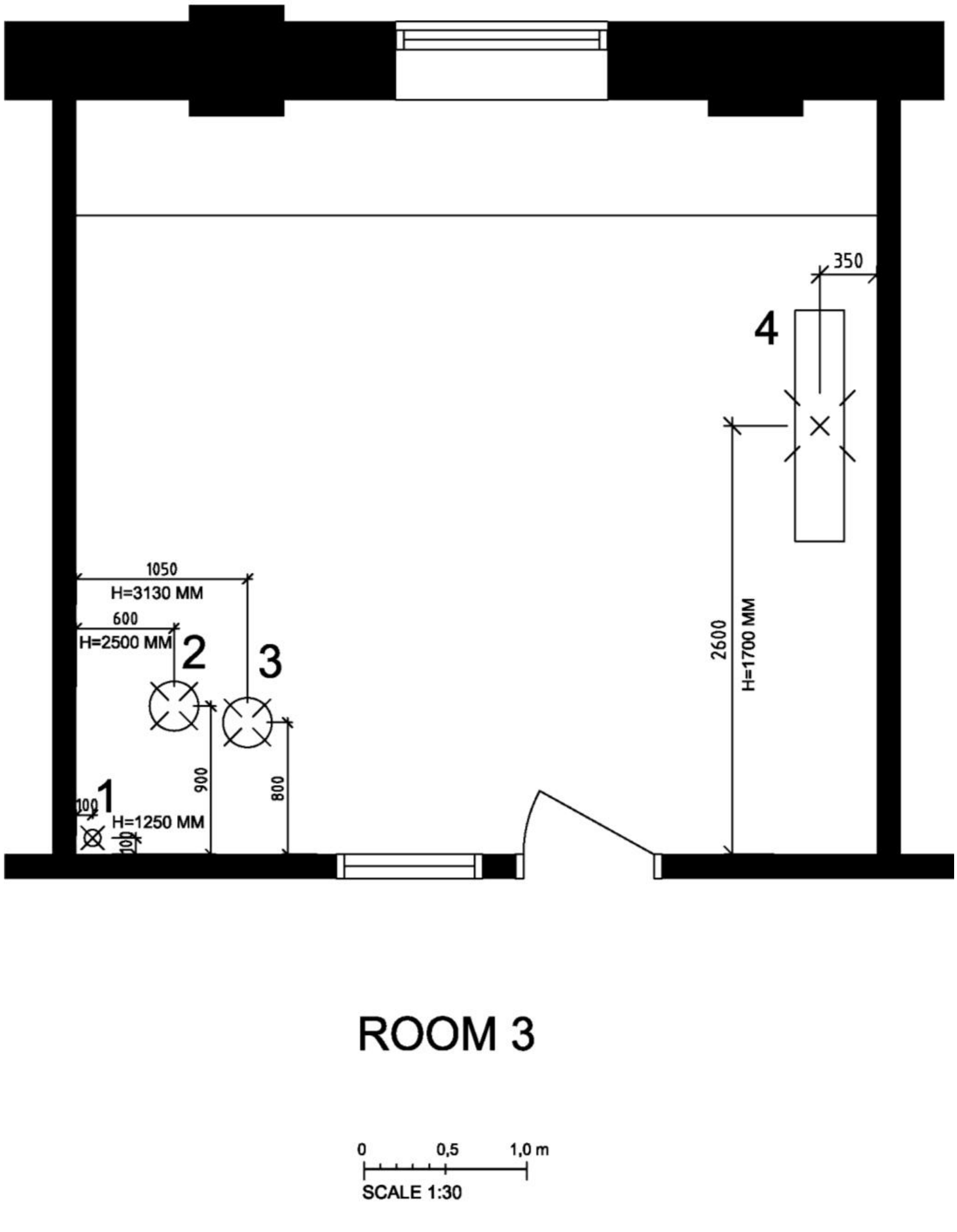

Fig. 11. Floorplan study 1.

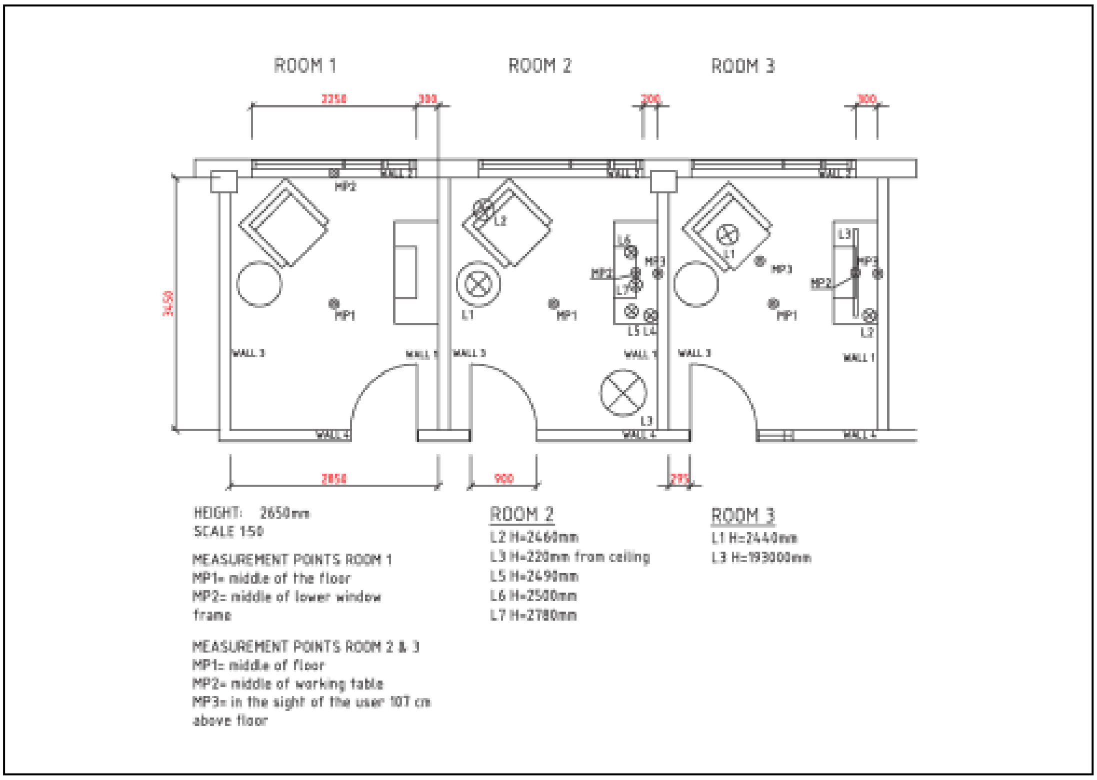

Fig. 14. Floorplan study 2.

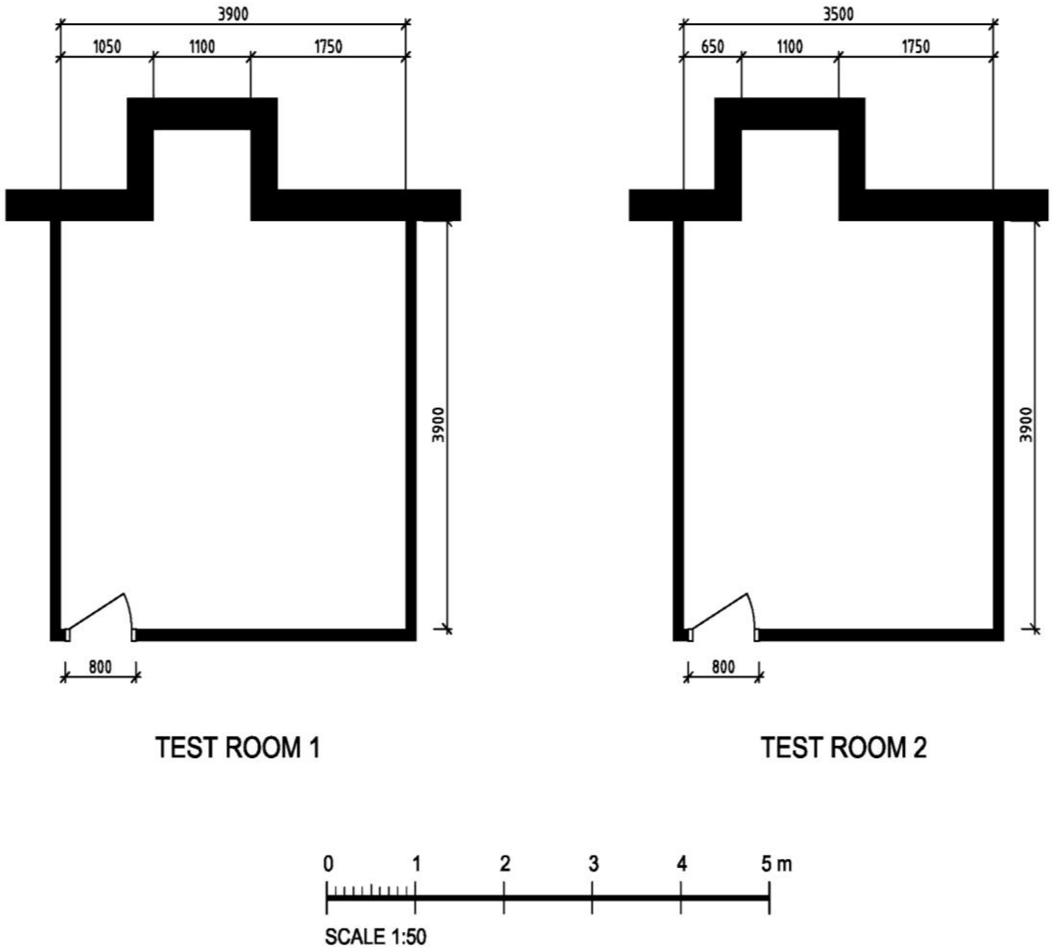

Fig. 26. Floorplan study 3.

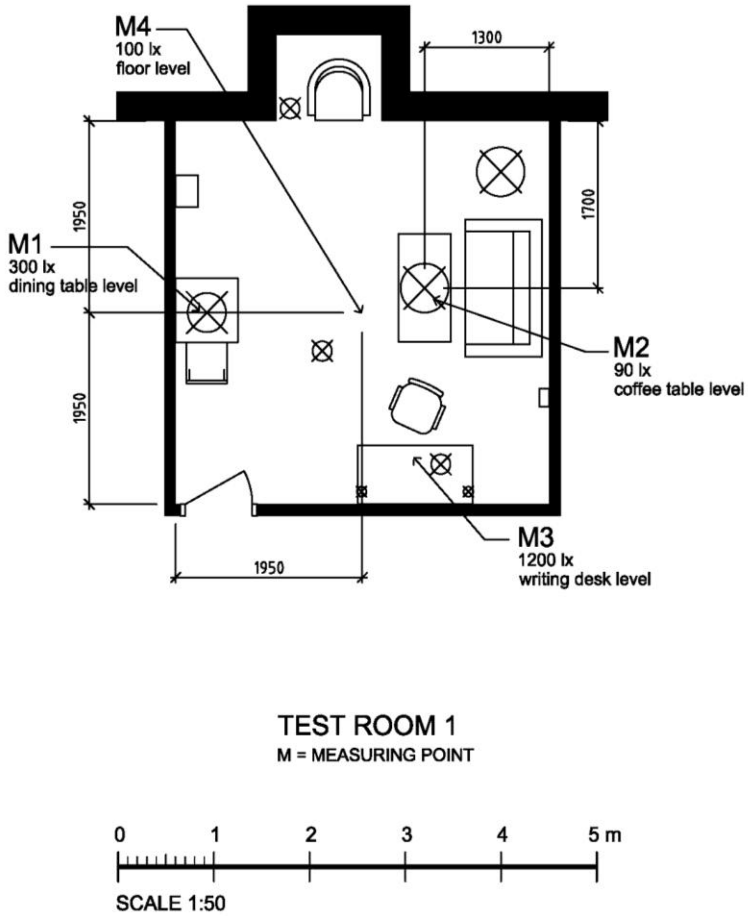

Fig. 23. Floorplan study 3.

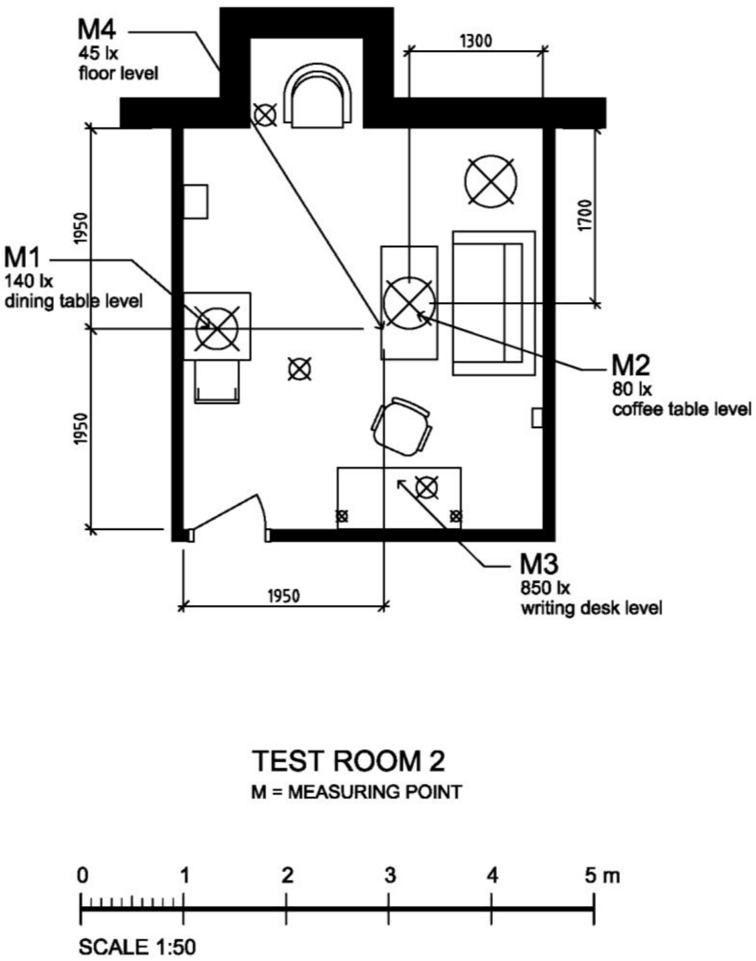

Fig. 24. Floorplan study 3.

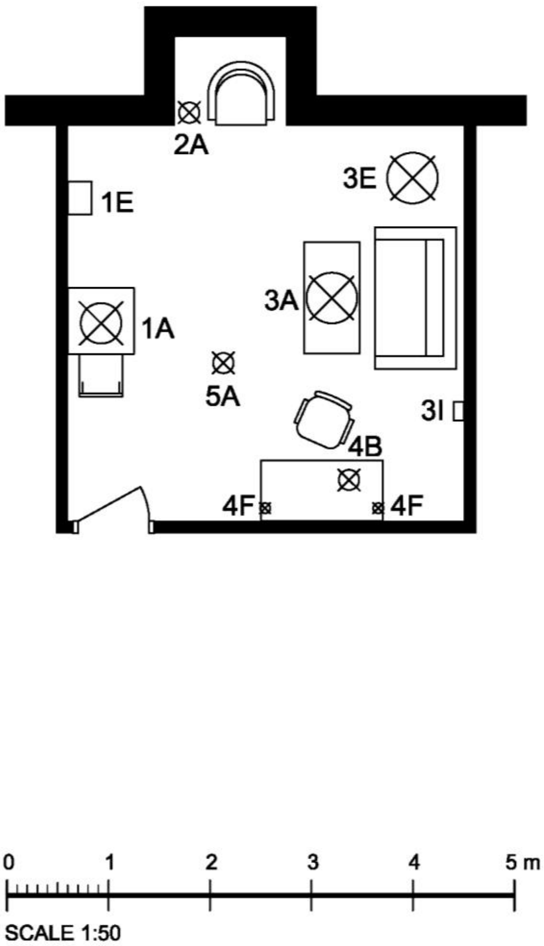

Fig. 25. Floorplan study 3

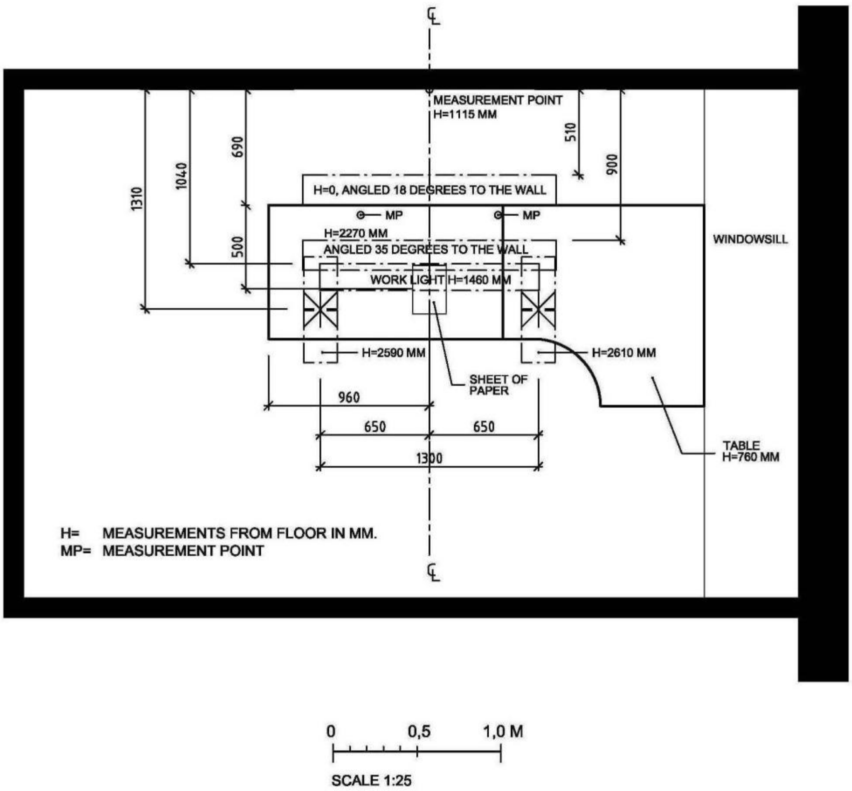

Fig. 19. Plan for the visual comfort test

SUMMARY OF APPENDED PAPERS

PAPER I.
Säter M. (2010). Preferences for level of light at the work table and for the complementary ambient light. CIE proceedings. 27th session the CIE South Africa 10-15 July 2011.

The conference paper concerns subjects preferences for levels of artificial light in a given contrast situation when staying in the indoor environment. Studies 4 and 5 were performed in the room designed for the VCT-test. The subjects got their preferences for a visually comfortable level of light at the working table and for the complementary ambient light recorded. The result shows that the subject's preferences vary in a high extent and are almost unique. Only two pair of subjects showed the same preferences for the combination of level of light at the working table, and for the complementary ambient light.

PAPER II.
Säter M. (2010). Colour and light and the human area for visual comfort. COLOUR AND LIGHT IN ARCHITECTURE. International conference – Venice 11-12 November 2010.

The conference paper is concerned if pattern can be seen in the subject's preferences for room and light settings when staying in the indoor environment. The study were based on study number 1 that was performed in room and light setting number 1, as well as in the VCT-test. The result provides a comparison between the lighting designer´s preferences for visual comfort and the subject´s preferences in the study. The room and light settings were designed close to, far from and very far from, the lighting designer's visual preferences. The subjects appreciated to a large extent the room and light settings in the same way as the lighting designer. Low levels of ambient light made it possible for 14 of 18 measured subjects to stay within their visual preferences for the light at the working table but not within their preferences for the ambient light.

PAPER III
Säter M. (2010). A holistic approach to lighting design in practical application - 2nd CIE expert symposiums on Appearance: When appearance meets lighting. 8-10 September 2010, Gent, Belgium.

The conference paper is concerned if pattern can be seen in the subject's preferences for room and light settings when staying in the indoor environment. The study were performed in room and light setting number 1, and the in the VCT-test. It concerns the interaction of man, light, colour and space, done by the lighting designer and is based on her individual preferences. The subjects evaluated to a great extent the room and light settings in the same way as the lighting designer indicating that despite differences in preferences in visual comfort there are similarities in the response for room and light settings. A well-functioning interaction of man, light, colour and space seems to be, appreciated by the subjects in general, despite their visual preferences for level of light.

PAPER IV

Säter M. (2010). User responses to LED as a guide for energy efficient lighting applications in Domestic Environments. Light and Engineering nr. 3 2010.

The article is concerned if pattern can be seen in the subject's preferences for energy effective light sources when staying in the indoor environment. The article is based on study number 3 performed in room and light setting number 3 and was performed in two similar room and light settings, only different in design when it comes to light sources. The subjects preferred to stay in a room that was lit with Halogen, CFL and LED, compared to a room solely lit with LED.

PAPER V

Säter M. (2010). User responses to energy efficient light sources in Home Environments. In: Linkoping University Electronic Press 2010. New Lightings-New LEDs. Aspects on Light-emitting diodes from social and material science perspectives. Editors Mats Bladh and Mikael Syräjärvi.

The article is concerned if pattern can be seen in the subject's preferences for energy effective light sources when staying in the indoor environment. The article is based on Study number 3 and room and light setting number 3. It concerns, data about 87 subjects, from in and outside Europe. In the study data was collected about the light sources used in the subjects´ homes. The subjects´ ability to evaluate the room lit with energy efficient light sources and predict the light source used in the luminaire was investigated. Data about the subject's sensitivity to view lit surfaces and their evaluation of the light in the room and light settings was also collected. The study confirms that the subjects was most familiar to the light from the incandescent and found the combination of Halogen, CFL and LED as more similar to the light they had at home compared to the light emitted from LED.

PAPER VI

Säter M. (2011). User responses to Lighting Design.

The paper is concerned if pattern can be seen in the subject's preferences for room and light settings when staying in the indoor environment. The paper is based on the first study and the interaction model number 1 and the VCT test. It provides a comparison between the lighting designers preference for visual comfort, and 18/38 unknown subjects measured values for the same experience. The study has the lighting designer's preferences for visual comfort as a starting point for the comparison. The VCT is a neutral reference that makes a comparison between the subject's preferences possible. The study verifies that the visual preferences vary in a high extent among the subjects. The lighting designer's preferences for a low level of ambient light made it possible to allow 14/18 subject to find their own preferred level of light at the working table. Submitted to: Design Studies. The international Journal for design research in engineering, architecture, products and systems.

PAPER VII

Säter M. (2011). User responses to lighting design with respect to gender, personality and visual preferences.

The paper is concerned if pattern can be seen in the subject's responses and preferences for daylight and artificial light when staying in the indoor environment. The paper is based on the second study and was performed in room and light setting number 2 with three rooms with the same interior design but with different lighting applications. Room 1 was lit with daylight only, Room 2 with a daylight mimicking artificial light, and Room 3 with artificial light deviating from daylight. The paper focuses on the formation of subgroups based on personality, gender and visual preferences for level of light and the build up of an individual light identity. Submitted to: Design Studies. The international Journal for design research in engineering, architecture, products and systems.

PAPER VIII

Säter M. (2011). User responses to lighting design with respect to level of alertness.

The paper is concerned if pattern can be seen in the subject's responses and preferences for daylight and artificial light when staying in the indoor environment. The paper is based on the second study, and room and light setting number 2 developed in three rooms, with the same interior design but with different lighting applications. Room 1 was lit with daylight only, Room 2 with a daylight mimicking artificial light, and Room 3 with artificial light deviating from daylight. The study focuses on the subject's level of alertness and is related to individual levels of hormones in the bloodstream. Submitted to: Design Studies. The international Journal for design research in engineering, architecture, products and systems.

PAPER IX

Säter M. (2011). User responses to lighting design with respect to psychological experiences and hormonal release among subjects of cortisol, adrenaline, noradrenaline in the bloodstream when staying in daylight and in artificial light.

The paper is concerned if pattern can be seen in the subject's responses and preferences for daylight and artificial light when staying in the indoor environment. The paper is based on the second study, and room and light setting number 2 developed in three rooms, with the same interior design but with different lighting applications. Room 1 was lit with daylight only, Room 2 with a daylight mimicking artificial light, and Room 3 with artificial light deviating from daylight. The study focuses on the subject's psychological experience and hormonal release of cortisol, adrenaline and noradrenaline in the bloodstream when staying in daylight and in artificial light. Submitted to Design Studies. The international Journal for design research in engineering, architecture, products and systems.

PAPER X

Säter M. (2012). User centred lighting design and public health.

The paper reveals a part of the literature review done in the Thesis project and is concerned lighting design linked to public health. The paper focuses on the two processes for lighting design that can be seen in use, the computer calculated lighting design process (CCLDP) and the user centred (UCLDP), the buildup of recommendations and if goals set out for light is fulfilled or not. Submitted to Design Studies. The international Journal for design research in engineering, architecture, products and systems.