VARIATION

Human Centric School Lighting

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Human Centric School Lighting

Evidence based design of light characters and automatic light variation, for a classroom in Malmö

Tove Karlsson, 2015

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It's impossible that all variation can cease; it must exist; without variation life must cease.

- Swami Vivekananda, 1897

We have at last realised that light is a foodstuff like normal food and, just as unbalanced diet makes us ill, wrong lighting can also make us ill and only correct lighting can preserve our health. Research in this field has made significant strides, but there is still a lot to do.

- Dr. John Nash Ott, Founder of OttLite, 1909-2000

Man has evolved in the diverse variation of the natural light. People are designed to seek for change and the visual system reacts primarily to contrast and changes.
It is vital to vary the light.

- Tove Karlsson, 2015

Abstract

The combination of today's SSL and the new scientific results about the effects of various kinds of light variations is starting to enable Human Centric Lighting that is considered to be significantly better for human health and wellbeing. However there is limited knowledge about how to make use of these possibilities to tailor the light and create variation patterns that's adapted to the individuals' specific needs, different parts of the day and for different activities.

The aim of this thesis is to develop a design principle for dynamic Human Centric School Lighting that enables appropriate variation of the light intensity and color temperature. The thesis suggests a set of light characters that clarify different kinds of lighting needs. The thesis presents case study of a dynamic light installation in a classroom in Malmö.

The major scientific breakthrough behind the work in this thesis is the accumulating work on how in particular the blue light influence the circadian cycles. This thesis interprets overviews of this scientific discourse in relation to analyses of the classroom and the daily activity patterns in the room. The results are combined via continual improvements to generate a concluding design suggestion. In a larger perspective this suggestion only is one possible example. It is fundamental to start to design and test explicit suggestions, but there is no single truth. The most important with this thesis may be the presented way of working with evidence-based design.

One main aspect of the suggested design is the automatic light variation scheme. The main ingredients are: a dose of bluish activating light in the morning, limit the strong activating light to 30 minutes, provide concentration supporting (more red) light after lunch, limit the amount of light to avoid stress and to avoid all rapid changes of the light. The automatic light variation scheme is combined with manual control buttons to give the teachers a toolbox to adapt the light to the educational situation, e.g. awakening or stimulating light when the pupils are tired. Another basic aim is to provide a restful light atmosphere, a sense of tranquillity e.g. when reading together with young pupils. One main aspect in the used environmental psychology discourse is that it is important to develop environments that support restoration of mental strength. The aim here is to make it natural for the mind to relax by supporting positive thoughts. The suggested light characters and the automatic light variation are inspired by lighting design, research on circadian effects and the environmental psychology theories about restorative effects and Grahn's characters.

It may appear as if it is sufficient to have tuneable white luminaires and a number of control buttons to be able to select different light characters whenever wanted. However the studies indicate that when one light setting has been turned on the teachers tend to leave it in that position. This is crucial because the observations also indicate that it is unsuitable to have the activating light on during a large part of the day, because then some pupils tend to get a headache. To get out of this contradiction there is a need for automatic variation of the light.

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1 INTRODUCTION

Various types of light have different effects on the human hormones and mood. We need different types of light before we go to bed than at a time when it is critical that we can concentrate. We have scientific knowledge about a number of aspects concerning the effect of various kinds of light. However there is limited understanding about how to make use of this knowledge and the new technical opportunities to tailor the light and create variation patterns that's adapted to the individuals' specific needs in a variety of occasions.

During the time that I have developed my interest in light; in the writing of my bachelor thesis, in the efforts to help with the compilation of a multidisciplinary light book, as a participant in a light course at LRC (Lighting Research Center), as a student in lighting design at KTH and as an employee at Lund University working in the EU project SSL-erate, I have many times been confronted with three different statements:

1. Blue light is activating.
2. People in the Nordic countries prefer warmer light, especially at lower illuminance.
3. From evolutionary point of view, we are adapted to and thrive in light that varies.

These claims have attracted a growing curiosity to find out what scientific knowledge basis there is behind the statements and what technical opportunities there are to create a lighting solution that can vary the lighting between those light characteristics in a real life environment.

I started to look for a possible case study for my lighting design master thesis. I found a number of people in Malmö City that are very interested in testing Human Centric School Lighting, see definition in section 1.2 below. They helped me with appropriate contacts and in the spring 2013 they suggested a classroom for the installation and promised to cover the cost for the new lighting. Parallel to this process, I started to look for a company that could provide a luminaire with appropriate color variation abilities.

The original plan for this thesis was to develop and assess the planned installation with human centric light variation in a classroom. However there were a number of delays, the commissioning was made in steps and took more time than expected. It was not possible to make the initially planned case study of a finalised installation. I changed the plan and started to work with smaller case studies as input to two loops of evidence based design in a continual improvement process.

This means that the thesis result includes a description of the initially planned light variations (appendix 2). In addition to the preparatory studies the thesis includes results from two case studies with surveys and interviews. The main accumulated result is summarised in the Resulting design suggestion, presented in chapter 9.

1.1 Lighting characters

Lighting design has its main focus in visual functionality and aesthetic considerations in relation to architectural circumstances. It has been unusual to make advanced lighting design for ordinary classrooms. The normal lighting solution for classrooms is to aim for an even and static light distribution. In recent years it has become common to consider dimming of the light to save energy and some are also thinking about which color temperature they should use. In some places the dimming has been automatized and a few places have control buttons for selection between different light settings.

To create a more activating work environment, is one aim for high light levels and to select daylight fluorescent tubes. One recent major scientific breakthrough is the knowledge about how different light intensities and colors influence the circadian cycles, different parts of the day. To achieve a positive synchronization there is a need for more and bluer light early in the day. It is relevant to say that this light has an activating character. Other kinds of light have other kinds of effects and are experienced in different ways. It has become more vital to characterise differences between different light settings in relation to different kinds of human needs.

The practical and economically reasonable possibility to change between different light characters and also the knowledge about in which ways this is important is rather new. The main focus in Human Centric Lighting is to provide activating/awakening light at the right time of the day. At the other end of this "scale" it is important to provide a light to calm down. Other subject areas focus on other aspects, for example to avoid negative stress. One main aspect in the environmental psychology discourse is that it is important to include environments that support the restoration of mental strength. For example there is a need for fascinating elements that catch the interest in positive ways and also to support the feeling of "being away" on a small excursion. The aim here is to make it natural for the mind to relax by supporting positive thoughts. The light characters and the automatic light variation suggested in this thesis are inspired by lighting design, research on circadian effects and the environmental psychology theories about restorative effects and Grahn's characters.

I have not found an obvious model for the needed development of lighting concepts. I have therefore used a model from Landscape Architecture as inspiration for my development of the "lighting character" words that I need for my dialogues, control panel buttons and this thesis.

One Landscape Architecture and Environmental Psychology suggestion is to use the following set of eight characters, to characterise different areas, e.g. parts of schoolyards (Grahn 2005):
Serene - Expresses the human need to find a place that provides peace
Wild - This is about a fascination for the wild

Rich in species – Expresses the human need for variation
Space - To enter into another world
The common – A place where common activities can be arranged
The pleasure garden – A safe place for socialisation
Festive – A place to meet new people
Culture – Traces from previous generations

A characterization of environments in such a way can be used to classify different kinds of light after the atmosphere that it creates. The characters may in turn be connected to the individual´s mental strength and type of involvement and can therefore be used to create rooms with different moods. Light can be used to activate (blue light) or to calm down (lower light level) and give support to be able to switch between different levels of mental activation. The pyramid (see figure 4) is used as a conceptual model. The goal is to describe the different levels that a human can be at mentally. The light characters are a conceptual tool for clarification the user values of different light settings. One perspective is that it is a set of "words" that describe a number of different light settings. This toolset is also intended as a framing for a new way of thinking about dynamic lighting.
Lighting should give support to be able to switch between different levels of mental strength. The lighting influences the atmosphere and thereby probably also the motivation to involve in different ways. A relation to Patrik Grahn and health gardens can be used to make analogies to understand the relation between lighting, health and wellbeing (Johansson & Küller 2005).

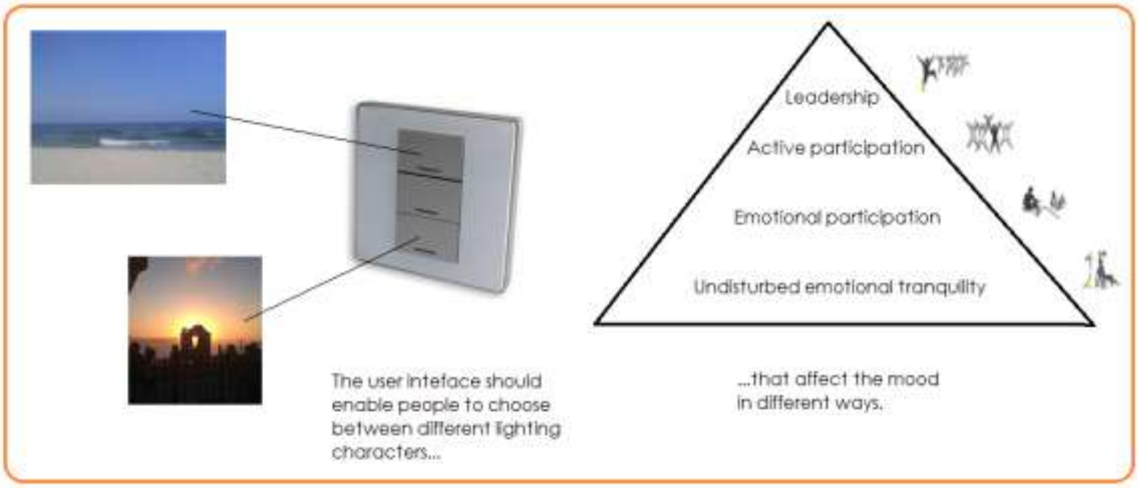

Figure 1 A conceptual model for the creation of lighting characters.

The present thinking about lighting includes visual, biological and emotional considerations. Still, also this perspective tends to focus on how various kinds of light influence the users. An alternative approach is to take a starting point in what the users need and want. This is one aspect of what is described as human centric lighting.

1.2 Human Centric Lighting (HCL)

Human Centric Lighting is a new popular term. It's often used for light that is supposed to have positive circadian effects. So far, different actors use this term in quite different ways. One definition is:

> *Human centric lighting is all kinds of light that improves the sum of the visual, biological and emotional aspects, compared to the kind of light that adhere to the traditional lighting perspective.*
>
> - *Definition formulated in the D2.6 SSL-erate report 2014*

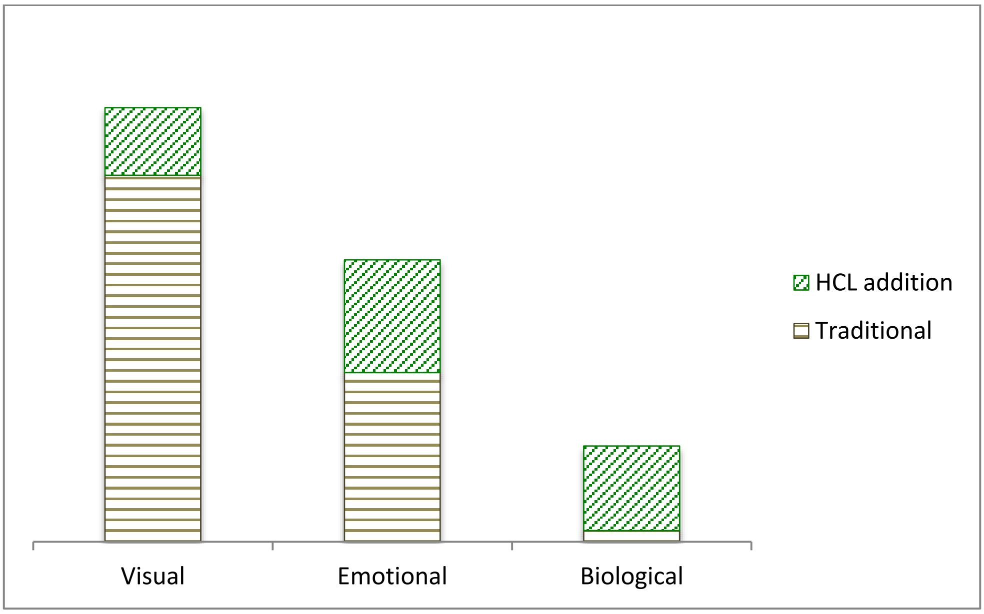

Figure 2 Change of perspective from traditional lighting to HCL. HCL improves the sum of visual, biological and emotional aspects.

Human Centric Lighting (HCL) is often conceptualised as lighting that focus on the circadian entrainment. It is also possible to use a broader framing that HCL is lighting that is adapted to the personal needs and preferences for as many as possible. This view is aiming to optimize the effectiveness of how lighting is used; to maximize the quotient Total human value/Total cost. This quotient ought to include both direct and indirect user effects and direct and indirect societal and environmental effects.

Some examples that are related to HCL improvements: optimization of the visibility, long- and short-term health and wellbeing effects (e.g. circadian entrainment), and minimization of light pollution, dynamic color control and new forms of dynamic user adapted design and control. HCL aim to make use of new scientific findings as soon as they evolve, e.g. by innovative demonstrations and testing (Karlsson et al 2014).

1.3 Aim

The aim is to develop design principles for dynamic Human Centric School Lighting that enables appropriate variation of the light intensity and color temperature.

The goal is to develop a set of light characters that clarify different kinds of lighting needs, in a classroom.

1.4 Overarching structure

The basic method in this thesis is evidence based design. The design suggestion in this thesis is developed based on the result from a scientific literature review and user interviews and surveys. The installed lighting has been evaluated via two rounds of case studies leading to a final proposal on how the light variations should look like. The test installations have been made in a classroom in Malmö and the evaluations are made with teachers and pupils in a 7th grade.

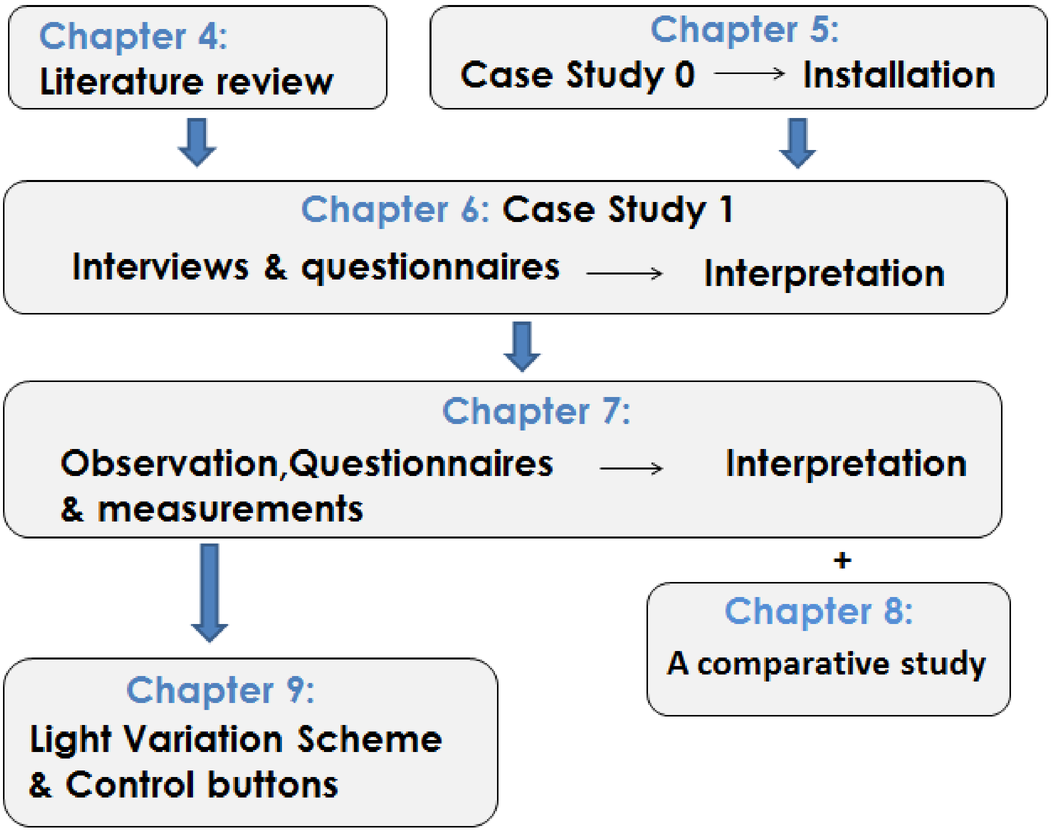

Figure 3 The results in this paper are based on evidence based design. The scientific literature review and the evaluations of the room and with the users lead to a final proposal of how to coordinate the automatic variation of the light and the manual control buttons in the classroom.

2 BACKGROUND

2.1 The evolution of lighting

The latest hundred years we have become accustomed to static, somewhat reddish, slightly flickering light environments where we essentially have been aiming for more lumens and the same light everywhere, all the time. However, the human sensory system is adapted to the varying light in nature, where the colour composition, the proportion of directional light and the intensity vary quite a lot. We know that sometimes we want functional light and sometimes we want cosy light, and also darkness. We know that the glittering light from moving water and in the forest feels good, many appreciate the play of light at sunrise and sunset, and we appreciate candlelight dinners.

- *Karlsson, 2014*

Human beings have evolved under the sunlight; a light that is varying in intensity, direction and Color Temperature. Eventually we started to make use of the fire which provides a low CT with a reddish glow.

The incandescent bulb is an example of early lighting technology and it has a red glow (about 2700 K). Eventually the fluorescent lamp was developed, which has a bluer light that is more similar to the outdoor light in its color composition, but that does not provide any opportunity for a redder light. The combination of incandescent and fluorescent lamps provided a possibility to vary between a bluer and a redder light. With the prohibition of the bulb we lost the ability to create a cosy character using a redder electric light. With the advent of LED lights, we regained the ability to create light with different kinds of character.

2.1.1 Light Emitting Diodes (LED)

A light emitting diode is a two-lead (one P-type and one N-type) semiconductor light source which emits light when activated. When a suitable voltage is applied to the leads, electrons will recombine with electron holes within the device and release energy in form of photons. The color of the light corresponds to the energy of the photon which is determined by the energy band gap of the semiconductor.

The output from a LED can range from red (approximately 700 nm) to blue-violet (about 400 nm). Some LED also emit infrared energy at 830 nm or longer. The LED area is less than 1 mm^2 and integrated optical components can be used to shape its radiation pattern (DiLaura 2011). That the source is so small also increase the risk of glare. The risk of glare can be reduced by reducing the luminance of the light source or increase the background luminance surrounding the light source (Rea et al 1993).

2.1.2 Intelligent systems

The new light technology enables a new level of possibilities to vary spectral distribution and dynamics. With the help of LED and intelligent systems the character can be adjusted so that the environment becomes more energizing or calming.

User adapted variations of context dependent lighting can be used to create more stimulating as well as more relaxing conditions. This is important to promote productivity and reduce stress which is particularly important for children, e.g. in preschools and classrooms. The new dynamic light technology offers the ability to create lighting that works better for the activities in the classroom, for the pupils to become less stressed and stay active when they need to be (Karlsson 2015).

The latest 15 years scientists have clarified new important aspects of how humans are affected by light. Different kinds of light characters, different light levels and their daily variations are vital for the synchronization of the circadian cycles, which is important for the human short- and long term productivity, wellbeing and health. The combination of today's Solis State Lighting (SSL) and the new scientific results about the effects of various kinds of light variations is starting to enable Human Centric Lighting that is significantly better for human health and wellbeing.

2.2 Light measurement

Two broad categories for light measurement exist: radiometry and photometry. Radiometry characterizes the physical properties of light: wavelength and energy. Photometry also takes into account the fact that biological photoreceptors are not equally sensitive to light at all wavelengths. A photometer uses a filter to weight the detector response to different wavelengths according to the spectral sensitivity of human vision; most commonly the v(λ)-curve. This photopic luminous efficiency function reflects the spectral sensitivity of long- and middle wavelength sensitive cones. In photopic conditions the eye sensitivity is highest at 555 nm. Once luminance reduces, shifts the sensitivity towards shorter wavelengths. The sensitivity, during scotopic (night vision) conditions, is greatest at 508 nm. Until now the basis for almost all the photometry has been the v(λ) - curve, which was established in 1924. The v'(λ) curve, eye sensitivity function in scotopic conditions was established in 1951, but has hardly been used in practical photometry (Halonen et al 2011).

Illuminance

Illuminance is a photometric quantity to measure how much a surface is illuminated, i.e. the amount of light incident on the surface. Illuminance is measured in lux (lumen / square meter) and is dependent on the orientation and distance from the light source (DiLaura 2011).

Luminance

Luminance is measured in candela (luminous intensity in a given direction) per square meter. It is the luminance distribution in the room that determines the eye's perceived idea of how bright a surface is. Luminance distribution is a product of the surface reflection properties and illuminance.

To give an accurate picture of a lit environment it is important that we can separate the luminance and illuminance. We normally measure the illuminance, which means that we do not take into account the areas that the light hits. The light sources are crucial for the flow of light in the room. The room design (color, shape, contrast) is also significant for how we perceive a lit environment (DiLaura 2011).

Color Temperature

Color Temperature (CT) is the hue of the light and is measured in kelvin (K). A source that emits white light, but with a higher percentage of the radiation in the red part of the spectrum than in the blue gives a feeling of warm white and mostly blue radiation creates a cold white light. Sources are usually called warm as the color temperature is below 3300 K and cold at color temperatures above 5000 K (DiLaura 2011).

Color Rendering

Color rendering (Color Rendering Index, CRI) is a quantitative measure of the ability of a light source to reproduce the correct colors of various objects in comparison with an ideal source or natural light. CRI is defined on a scale from 0 for monochromatic light sources to 100 for sources that emit a continuous visible spectrum (DiLaura 2011).

Spectral Power Distribution

A Spectral Power Distribution (SPD) graph shows the relative power of wavelengths across the visible spectrum for a given light source. These graphs also reveal the ability of a light source to render different colors. Daylight has a high relative power of all wavelengths and provides the highest level of color rendering across the spectrum (DiLaura 2011).

3 METHOD

The development process in this thesis builds on iterative improvements of the design with continual improvements and a basis in Evidence Based Design, see Figure 4. The major scientific breakthrough behind the work in this thesis is the accumulating work of how in particular the blue light influence the circadian cycles, via the intrinsical retinal ganglion cells and the melatonin related influence on the circadian cycles, see literature review. This thesis interprets overviews of this scientific discourse in relation to analyses of the classroom and the daily activity patterns in the classroom.

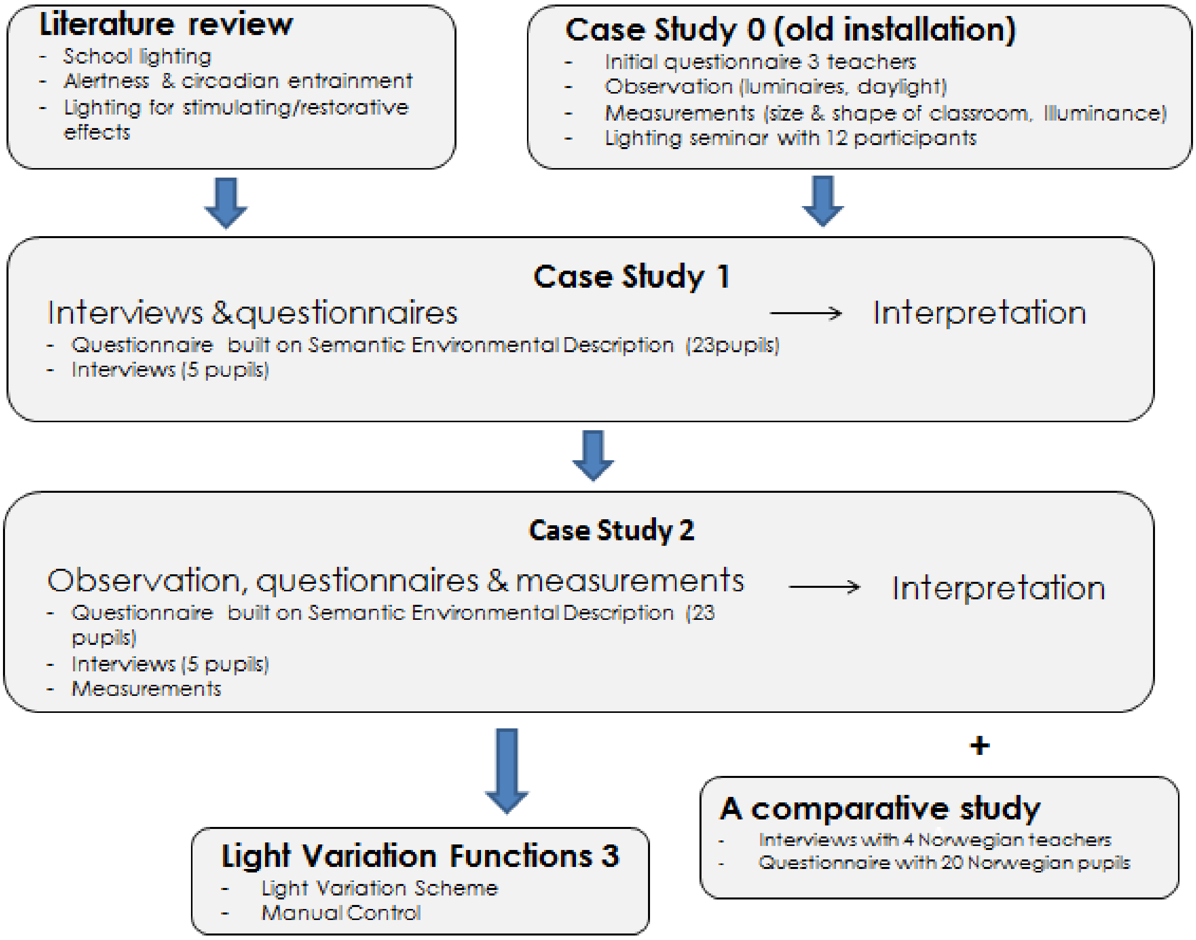

Figure 4 Main structure of the methodology in this thesis.

Measurement devices

Spectrometer AvaSoft 7.4, 2009 Avantes, for spectral distribution measurements borrowed from Environmental Psychology, Lund University

Oscilloscope PicoScope 6 with a MHz lightsensor, for flicker measurements borrowed from the flicker specialist Hillevi Hemphälä, Lund University

Lightmeter, Standard st-1300, for Lux measurements
own instrument from Clas Ohlson

Small tube spectrometer

Evidenced based design

The design process in this thesis focuses on development of "recipes" for automatic light variation in concert with control buttons for various settings of the tuneable white luminaires.

Evidence based means that the design is based on knowledge that has a basis in:

1. Scientific research
2. Measurements that are relevant for real-life use
3. Mapping of the user needs and wants, e.g. by interviews

To achieve a good design result it is often preferable to work in an iterative way, via a number of preliminary designs that are evaluated. One good structure for the work is to use the Deming Circle (spiral) Plan-Do-Check-Act.

Semantic Environmental Description

The SED method in a systematic manner examines how people perceive the environment. SED has a basis in environmental psychology. The aim is to "measure" and describe the experience of a working or living environment.

The main method is to use questionnaires with pairs of (contradictory) adjectives and a fixed number of choices in between the words, for each pair of words, e.g.

Reddish ________ ________ ________ ________ Bluish

In this thesis I use a simplified form of SED, I don't make a complete scientific evaluation.

3.1 Delimitations

This thesis focuses on the temporal variation of the light. This is not in contradiction to development of light environments with several levels of spatial light variations. However it has been a big enough task to work with the temporal variation and consequently this thesis hardly deal with the spatial light variations. The basic principle for the spatial distribution is that I have kept the ambition to have the same light level at all workplaces for most of the lighting characters. The new installation has another kind of luminaires, but the light distribution goal is the same as before.
The installation is inspired by new scientific knowledge and the case studies within the evidence based design process. I have made interviews and some measurements, but I've hardly been working with architectural drafting of aesthetic light characteristics.

For practical and economic reasons, no daylight related control of the lighting level has been included in the design or installation.

This thesis doesn't have any real ambition to contribute to the basic scientific knowledge on how non visual effects influence the circadian cycles.

To get a better effect, it would be desirable to strengthen with new furniture, plants, etc. but I do not bring this up in this thesis.

4 LITERATURE REVIEW

The possibility to vary the character of the light in the classroom has initiated a new level of attempts to improve the light environments in classrooms. The natural starting point has been to increase the light levels and also to use more advanced technology and vary the light level to save energy. This thesis does not discuss the energy saving priority itself. However the energy saving ambition makes it more important to understand which light and how much light that is needed at various points in time.

This chapter takes a starting point in new attempts to improve the visual light design in classrooms (4.1). This also brings to the fore that more intense light has awakening effects. The new knowledge about the physiological effects of different kinds of light variations is described in 4.2 and 4.3 describe how different light colors influence those effects.

4.1 New light design for schools

Lighting design focuses on creating functional and aesthetically pleasing lighting environments. In a classroom the main focus has been to have enough light on the work surfaces and the method of achieving this has been to strive for a uniform light distribution with at least 300 Lux on the benches.

In recent years it has been emphasized that the vertical light (ambient light) is important. Research (Raynham, Govén, Laike 2011) indicate that ambient lighting can have a positive effect on childrens' chronobiological system, subjective emotional status (mood) and academic performance. Direct light creates modelling shadows that facilitates the perception of distance and three-dimensional objects, but at the same time it throws shadows that can interfere with work. A more diffuse, indirect light reduces unwanted shadows and throws light on the walls and ceiling to increase the vertical illumination and thus improve the visual communication (DiLaura 2011).

The lowest recommended intensity in the classroom is 300 lux and 500 lux for evening classes. The wall lighting must be over 75 lux and the ceiling lighting 50 lux. In order to provide the very best conditions for visual communications a cylindrical illumination of 150 lux is needed. The color rendition should be high, at least R_a 80 (Ljuskultur 2010).

There is also a requirement that it should be possible to adjust the lighting, and this is something that recently has begun to be explored. The classroom is an environment where many different activities are performed: reading, writing, presentations, school plays, tests, and more. A flexible lighting solution should be able to support all the different activities.

Lighting design has focused on the static goal to have the right light, in the right place. The new knowledge about light non-visual effects of circadian cycles actualises that it is important to have the right light, at the right time. Put simply, so that you wake up in the morning and so that you can find rest at other times of the day. The following section brings up examples of recently installed controllable school lighting and how it has affected pupils.

4.1.1 Examples of recent dynamic School Lighting installations

In a study by Wessolowski (2014) seven different lighting scenes designed by Philips for school use were used: "Standard", that follow the conventional lighting situation in classrooms based on the DIN 5035 standard (300 lx, 4000 K); "Focus on board", where the board lighting is bright (1000 lx, 4000 K) and the room lighting low (300 lx, 3800 K); "Board only", the board is lit and the room lighting is switched off; "Concentrate", very bright, daylight white light for individual work that demands a high degree of attention/concentration (1060 lx, 5800 K); "Activate", slightly brighter and a significantly higher level of the blue component of the spectrum compared to standard lighting (625 lx, 11000 K); "Relax", slightly warmer compared with standard lighting (325 lx, 3500 K) and "Extreme Relax", a more extreme variation of programme 6 is used when no reading and writing is performed (275 lx, 3500).

This Variable Lighting (VL) programme is adapted to different work and social arrangements used in school. The seven VL lighting programmes were chosen based on current research and in coordination with lighting experts and the participating schools. During two tests on the pupils' performance and behaviour the researcher controlled the variation pattern, by switching the different buttons. During the period in between, the teacher controlled the settings.

The result show that the pupils made fewer errors on a standardised test of attention, reading speed rose significantly and that reading comprehension rose slightly under the VL "Concentrate" program. The reading speed and reading comprehension results improved under the VL4 "Concentrate" program. The motivation for learning and the classroom atmosphere did not change during the nine month test period. The pupils and teachers rated the Variable Lighting positively and found it useful during lessons. This study also indicates that a possibility to choose between different lighting scenes can help to shape the different lesson segments optically and illuminate the structure of the lesson.

Teacher logs during the test revealed that out of the seven predefined programmes, primarily "Concentrate", "Activate" and "Relax" were used. The teachers particularly liked the option of visually separating individual sections of the lesson. The teachers desired a smaller number of different programmes and a programme with even warmer light (3000 K).

Overall the pupils were positive. The concentration promoting effect of the lighting was emphasized by one in six children. Very few of the pupils reported negative experiences; one pupil desired less abrupt transitions, one reported that too frequent changes were distracting, one male and one female pupil in secondary school complained about headaches caused by VL4 "Concentrate" (Barkmann et al. 2012).

Tuv school in Hemsedal in cooperation with "UiB, Haukland Universitetessjukehus" and "Nasjonal kompetansetjeneste for sovnsykdommer" has made a Human Centric lighting installation with LED with four different settings: "Energilys" to be used in the first hour of the day (Automatic, 6500 K, 650 lx); "Fokuslys" during tests (Manual. 6500 K, 1000 lx); "Roliglys" for relaxation and calm activities (Manual, 2700 K, 300 lx) and "Standardlys" for ordinary activities (3500 K, 300 lx). The control board is controlled by the teacher. The study involves 27 pupils in grade 3 and 4. The teachers report about positive development for the pupils' concentration and restfulness in class and the pupils report about decreased sleepiness (Saxvig et al 2014).

4.2 Light for alertness and circadian entrainment

Light affects our health and well-being much more than most people realize. 80 percent of the information we receive about our environment is taken in through the eye and the visual system (Starby 2006). In the retina, light hits the *retinal cones* responsible for the perception of color and the *retinal rods* responsible for the perception of brightness. The impressions are transmitted through the ganglion cells and the optical nerve to reach the visual centre in the occipital lobe where the visual impression emerges (Wessolowski et al 2014).

Circadian rhythm is every process in our body that repeats within approximately 24 hours (circa = about, dies = day) and circadian entrainment refer to the possibility to affect the circadian system so that the circadian rhythm is moved forward or backward. The circadian clock has an important role in regulating the normal wakefulness and sleep, allowing day living animals to wake up at dawn and get tired when darkness falls, while nocturnal animals become sleepy at dawn and wake up at dusk. It is influenced by exogenous (generated outside the system) as well as endogenous (generated inside the system) processes. The internal process regulates our circadian rhythm and is able to do so even in a dark cave, but it runs with a period slightly greater than 24 hours, in humans average 24.2 hours. The exogenous processes can influence and change the timing of the endogenous rhythms. Light is the main synchroniser of our circadian rhythm to the local position on earth (Figueiro 2015). The light-induced phase resetting of endogenous circadian clocks brings a wide array of biological processes under indirect retinal control, e.g. suppression of pineal melatonin production, increased heart rate and core body temperature, stimulation of cortisol production (Barkmann et al 2012).

Those biological and behavioural effects of light *are*, in addition to conventional rods and cones, influenced by a distinct photoreceptor in in the eye, melanopsin-containing *intrinsically photosensitive retinal ganglion cells (ipRGCs)*. They cover the retina like a spider web and are directly linked to the suprachiasmatic nucleus (SCN). The SCN is the primary clock for all circadian body functions and control them through the hormones *melatonin* and *cortisol* and the proteins CRY and PER.

At night the pineal gland produces the sleep hormone melatonin, but when the eye is stimulated by light the production ceases, leaving the field open for different activity hormones, such as cortisol. Melatonin is the hormone that tells the body when it is night and time to sleep. The rhythm of cortisol is roughly opposite to that of melatonin release. Disturbances in the circadian rhythm can result in poor sleep, due to an underproduction of melatonin. Interference can also lead to indigestion and reduced attention and performance. Over time, these disturbances lead to serious diseases, such as cardiovascular disease, diabetes, obesity and cancer. Exercise, social activities and scheduled meals have been shown to synchronize the clock, but their impact on the circadian rhythms are weaker than light.

Very many people, up to 60%, detects problems during the dark season , difficulty falling asleep, feeling sleepy, reduced activity, depression and do not appreciate as much to socialize with other people. Length and quality of sleep has been linked to academic performance where sufficient amount of good sleep has a positive effect on memory, reduce daytime sleepiness, increase concentration and attention level during lectures and therefore result in better grades. Bad sleep quality can result in mood disorders (Figueiro 2015). We do not just learn things during the day, learning is a process that continues during sleep at night. Pupils who do not get enough sleep often fail in exams or receive bad marks compared to those who get a higher amount of sleep (Curcio et al 2006, Dewald-Kaufman et al 2013, Dewald et al, Gruber et al 2010, Hofman et al 1997, Johnston et al 2010, Kelly et al 2001, Meijer et al 2008, Taras 2005).

The early start in school is a difficulty for adolescents. Chronotype *refers to a person's propensity to sleep at a particular time during a 24 hour period. There are two main types of Chrono types; "eveningness" (delayed sleep period) and "morningness" (advanced sleep period).* When children age they undergo a change from early chronotype in Kindergarten to late type in their teens (Fallone et al 2005, Gruber et al 2012, Pagel et al 2007, Shin et al 2003, Wolfson et al 1998, Fransisco et al 2013, Escribano et al 2012). *To enhance the light exposure and its blue content during the first hours of the morning and to reduce the light exposure and its blue content in the evening will benefit the late chronotype. This will support their awakening on workdays and prevent their bedtimes from drifting too late (SSL-erate).*

4.3 Stimulating effects by different light colors

The spectrum of the light plays an important role in the appraisal of the environment. The spectral composition influences the appearance of the colors of the objects in the environment and can play a key role in visual tasks that require color detection and discrimination.

The daylight spectral distribution varies over the day, with more short-wavelength light in the morning and longer-wavelength light in the evening that set our circadian rhythm right. With the help of short-wavelength light the melatonin production is blocked and we will wake up. If we don't get this melatonin repressive light in the morning it may affect our ability to fall asleep at night and our sleep can be disrupted which in turn affects our ability to perform during the day. Not only the color, but also the intensity affects our alertness. Man has evolved under the sunlight and the natural light spectral composition and variation in the intensity and color during the day is the best model that we have for creation of a well-functioning light for people.

Figure 5 The daylight varies in colour and intensity over a day (Glamox 2015).

Many scientists agree that red and blue light have specific effects on the human well-being and alertness and the literature review in this thesis focuses especially on those colors of the light.

4.3.1 Blue light

In daily language the term "blue light" is used to describe bluish white light i.e. light with a high colour temperature. Scientifically; blue light is visible light in the wavelength range of 420- 490 nm. The higher relative part of wavelengths that a light source emits within this part of the spectrum, the bluer the light is perceived. In practice this means that normally, it is only a part of the light from a specific light source that is actually blue. In addition to the light coming from the light source, different parts of the light bounce (are reflected) on the walls in particular ways. Blue light bounces off a blue wall. This does not mean that we get more blue light in absolute measures, but that a relatively high percentage of the blue light is reflected. On a white wall (as in the classroom in this specific case), all wavelengths bounces equally. If the wall is not smooth, it will change the direction of the light, normally making the light more diffuse (DiLaura et al 2011).

Previous studies have indicated that light with a higher color temperature (4000 K) results in higher ability to concentrate (Küller & Lindsten 1992). Scientifically, light in the range of 460 – 500 nm has been proven to have an activating effect (Berson et al 2002). Alertness, activity, performance and mood can be improved with light of sufficient intensity and blue content during daytime and also affect sleep during the subsequent night. Sleepiness and aggressive behaviour can be reduced with bright light in the morning. Research has shown that blue enriched light can be experienced as bright compared to a lower CCT with the same illuminance level (Chellappa et al 2011; Iskra-Golec & Smith 2011; Iskra-Golec et al 2012; Wei et al 2014). Lighting with a lower CCT is often experienced as warmer, more relaxing and less tense (Boyce & Cuttle 1990; Davis & Ginther 1990; Fleischer, Krueger & Schierz 2001; Manav 2007; Viénot, Durand & Mahler 2009; Vogels & Bronckers 2009).

Exposure to blue light at night results in lower melatonin secretion (Brainard et al 2001; Thapan et al 2001). Several studies have also shown that exposure to blue light can suppress melatonin secretion, result in higher subjective alertness, core body temperature and heart rate compared to green light at night (Lockley et al 2006) and in the late evening (Cajochen et al 2005). Not only monochromatic or narrow band blue light but also blue-enriched white light result in larger melatonin suppression (Figueiro, Rea & Bullough 2006; Kozaki, Koga, Toda, Noguchi & Yasukouchi 2008).

4.3.2 Red light

Red light is visible light in the wavelength range of 650 – 750 nm and bounces of a red wall (DiLaura et al 2011). Previous studies have indicated that warmer (3000 K) light may enhance communication and decrease agitation and disturbance during lessons (Küller & Lindsten 1992)(Grangaard 1995). Empirical studies indicate that warm, dimmed lighting in work environments can improve communication and increase prosocial behaviours. In a study performed by Fleischer (2001) participants at an office preferred this kind of lighting for discussions at a table and more lengthy telephone calls. In a simulated office setting, participants were more likely to say they would respond co-operatively to a hypothetical conflict situation and to volunteer in helping the experimenter, if exposed to warm-white (3000 K) rather than cool-white (4200 K) (Baron, Rea & Daniels 1992). Job applications by imaginary employees were assessed more positively when the applications were reviewed in warm, dimmed lighting (Baron et al 1992; Knez & Enmarker 1998). A study by Küller and Lindsten (1992): a tendency toward improved communication and social behaviour was observed among pupils in warm light at low illuminance.

In a study by Wessolowski et al (2014) movement detector measurements confirmed a more rapid decline in motor restlessness with VL “Relax”, that is a warm-white lighting situation with reduced lighting compared to higher illuminance with colder lighting. One possible explanantion for the decline is psychology; dark warm light such as that of a fireplace or the VL6 “Relax”are more closely associated with cozy feelings and evoke a state of relaxation and reassurance (Baron & Rea, 1991). Other possible explanations are noncontrolllable group dynamics and situation-specific events that affect the entire class. The VL6 “Relax” also resulted in less aggressive behaviour. One possible explanation is that there is a positive correlation between stress and aggression, shown e.g. by Kruk et al (2004). This study indicates that warm-white lighting with reduced illumination can be applied to reduce restlessness, aggressive behaviours and disturbances during lessons (Barkmann 2012).

4.3.3 Stimulating light – a choice between red and blue

The Lighting Research Center in Troy, New York have found that red light has acute alerting effects through EEG (brain activity) studies on blue and red light respectively. 40 lx of light at the eye increased cognition and alertness and there was no significant difference between red and blue light. 40 lx of blue (470 nm) and 40 lx of red (630 nm) light increased performance and heart rate compared to dim light at night. Only short wavelength (blue) light affected melatonin levels at night. Blue and red light affected cortisol, but red light has a slightly greater effect when it came to increasing cortisol levels.

While melatonin is only suppressed under blue light both blue and red light (narrow band lighting) at relatively low intensity levels during daytime have been proven to have alertness-enhancing effects (Figueiro, Bierman, Plitnick & Rea 2009). A study by Sahin & Figueiro (2013) indicate that exposure to dim red light instead of dim blue light (both at 48 lx for 48 minutes) induced higher alertness as assessed with EEG compared to darkness. Thus, melatonin suppression is not needed to have an alerting effect.

In a test with 200-300 lx of red and white light respectively, both decreased reaction time but only white light supressed melatonin. Red light can be used to increase alertness without supressing melatonin and thereby shifting the time of sleep (Mariana Figueiro 2015).

4.4 Interpretation of literature review

The fundamental starting point for this project is the knowledge that various types of light have different effects and that we need different types of light in different situations. The basic initial idea is therefore to include an automatic light variation pattern in the lighting design.

The scientific foundation include research that indicate that blue light has an activating, concentration enhancing effect (Küller & Lindsten 1992) (Berson et al 2002). The automatic light variation should therefore include a period with intense blue lighting in the morning to help the pupils wake up and to sleep better the following night. The manually controlled light scenes should include "Activating light" (intense blue lighting) for tasks that require high concentration, e.g. maths.

Previous studies have indicated that warmer light may enhance communication (prosocial behaviors), decrease agitation and disturbance during lessons (Küller & Lindsten 1992)(Grangaard 1995) (Fleischer 2001) (Baron, Rea & Daniels 1992) (Küller & Lindsten 1992)(Grangaard 1995) (Baron et al 1992) (Knez & Enmarker 1998). The manually controlled light scenes should include a "Dialogue" mode with warm light.

Recent research indicate that red light can have alerting effects without affecting melatonin levels (Figueiro, Bierman, Plitnick & Rea 2009) (Sahin and Figueiro 2013) (Figueiro 2015). The automatic variation should include red light in the afternoon to keep the pupils' concentrated without affecting their ability to sleep at night.

5 ANALYSIS OF THE ROOM, ITS USAGE & OLD LIGHTING

5.1 Analysis of the space

Architecture

The building were the classroom is located is large, with quite a lot of rooms in different sizes. The room is entered through a narrow corridor and all the windows are located in the east. The main room is of a quite ordinary Swedish classroom size length 8,39; width 7,11 meters and height 3,17 m. There are supporting columns and cupboards in three of the corners. The room is entered through a narrow corridor and the windows are located in the eastern side of the room, see figure 6. The benches are placed quite evenly in the room, with two pupils at every bench and the teachers' desk in the front of the room, see figure 6.

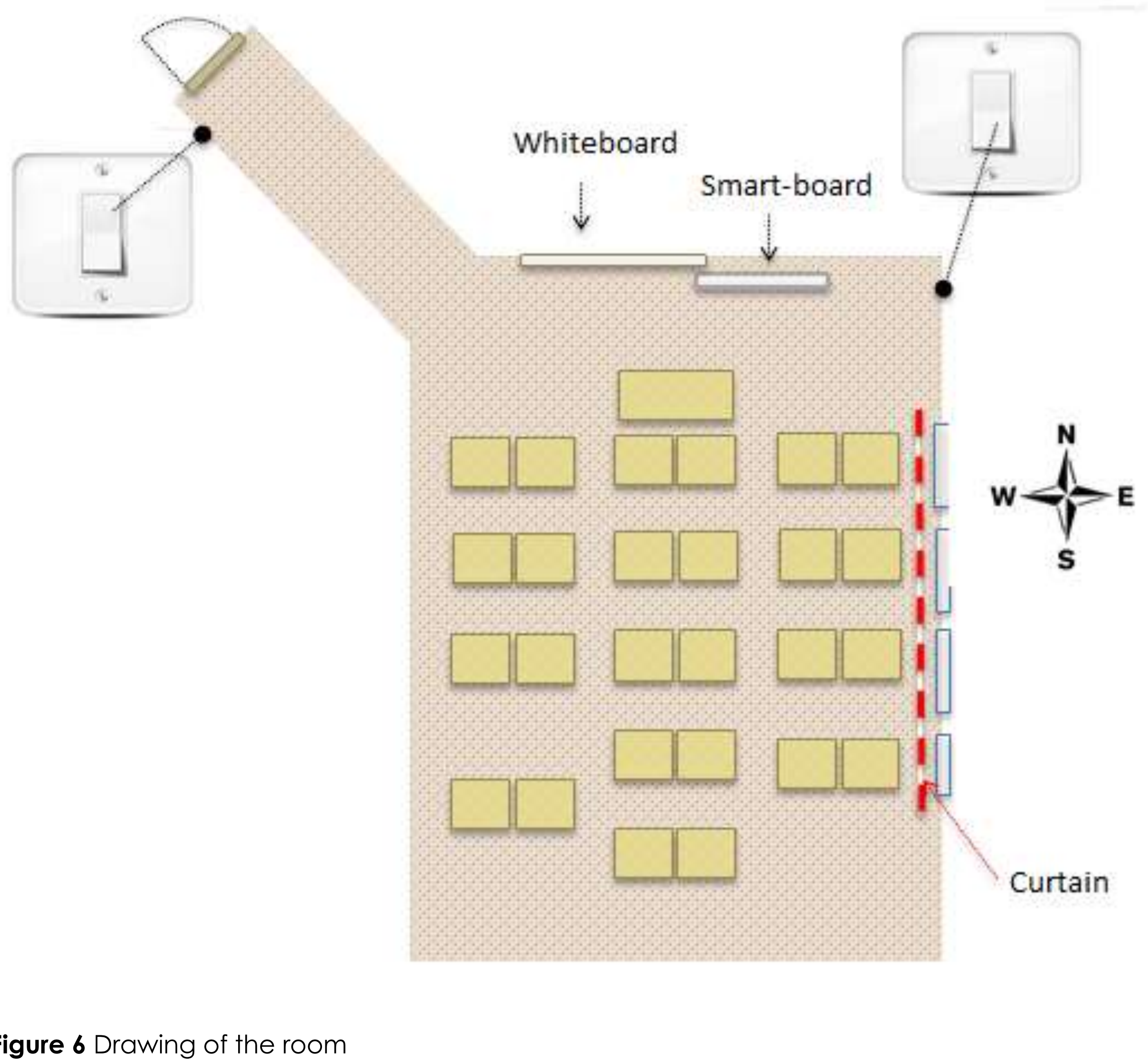

Figure 6 Drawing of the room

Material

The walls in the classroom are greyish white, not quite smooth. The floor is covered with a vinyl mottled (grey, black and yellow) surface. The ceiling is equipped with greyish ceiling tiles. The benches and tables are light coated wood with dark brown painted metal bars.

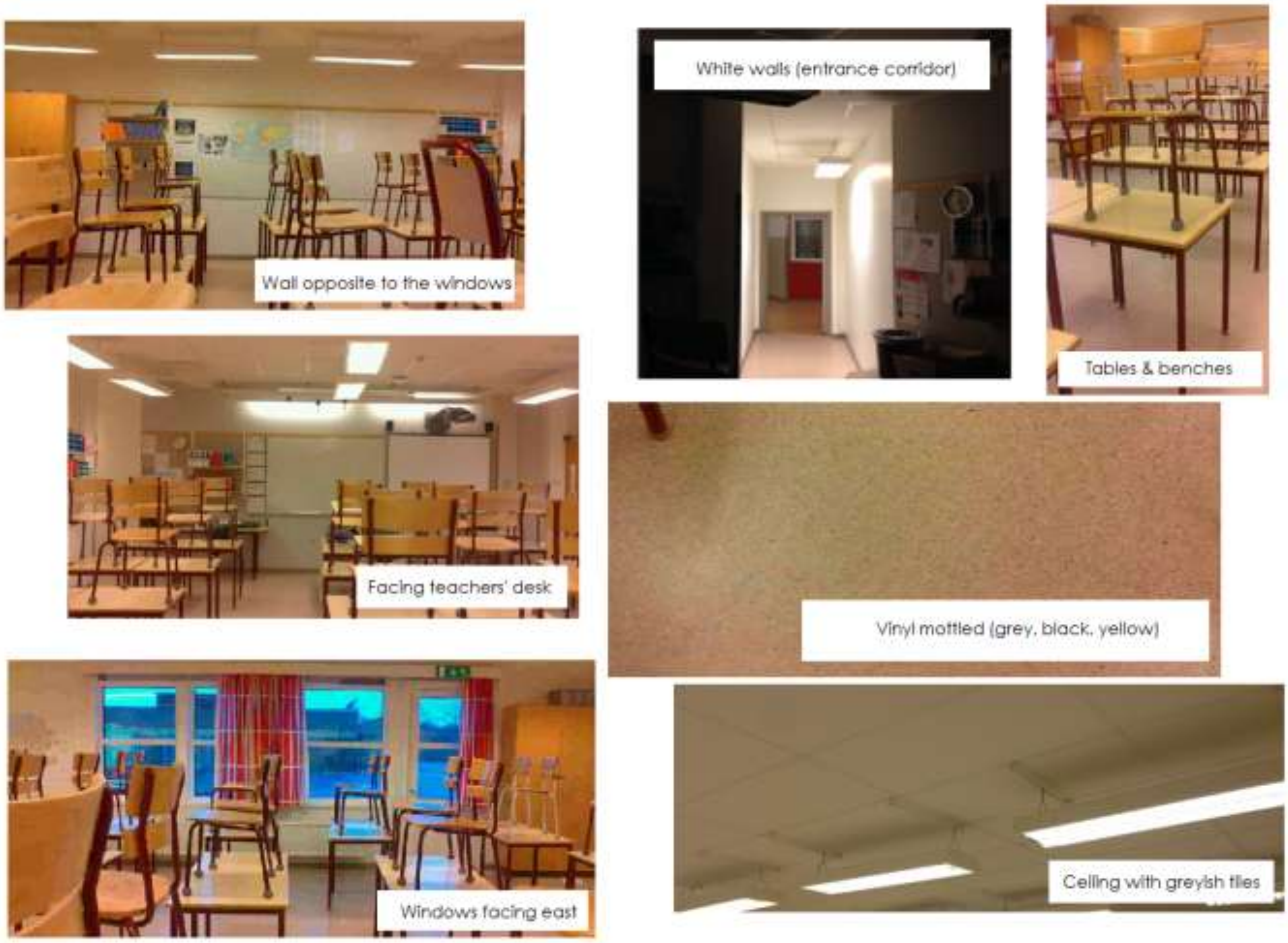

Figure 7 The left pictures show the inner, middle and window part of the classroom. The inner and back wall of the room is covered with books and paintings. The right pictures show the materials. The walls in the whole classroom are painted white (greyish) as in the picture of the entrance corridor. The tables and benches are light brown/dark brown and the floor mottled vinyl. The ceiling is covered with greyish tiles.

Influence of daylight

The classroom has rather large windows to the east. However there is a noisy schoolyard with a lot of activity just outside the classroom, so the teachers prefer to keep the blinds and curtains closed.

The Lux-values in table 1 illustrates how low the light levels are in Sweden in wintertime. This classroom has rather large windows and there are no major buildings or trees that reduce the light to the windows. The readings are taken a rather cloudy day, one hour before sunset.

Table 1 Distribution of daylight a cloudy day in November. No blinders and no curtains. All numbers in Lux. The first row is averages.

Situation	On benches	Front wall	Inner wall	Window	Rear wall
Daylight (14.30 20/11)	110	9	18	667	17
At the windows	300-400				
Middle row	30-60				
Inner row	18-25				

Lighting

The existing luminaires are placed in 3 × 4 rows, parallel to the windows. There is no automatic control. The light switches are placed at the entrance, to the right, and in the front corner.

Light sources: Aura, 36W, 830; A_5, T8
Philips master, TL-D, 36W/830

Luminaire: Fagerhult, 2 × 36W, 230V

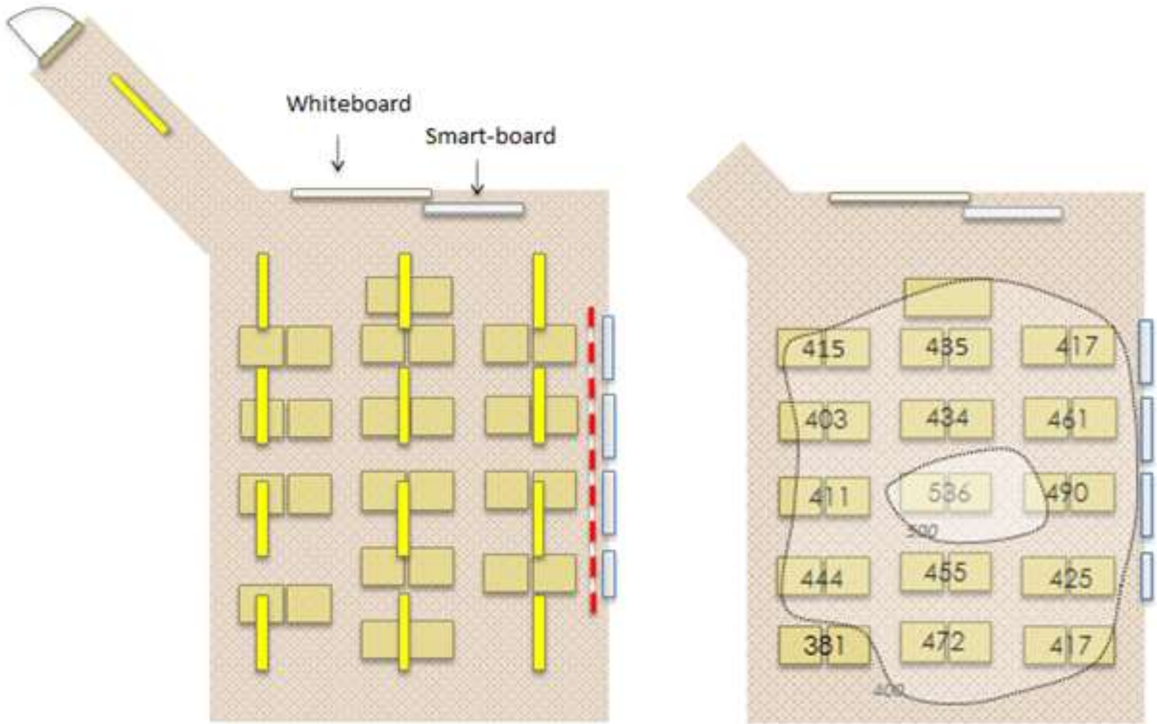

Figure 8 Luminaire position and resulting light distribution.

This old fluorescent tube luminaires did not have any up-light and not much side-light. The ceiling and the upper parts of the walls were relatively dark. The light distribution on the benches were fairly even, see figure 10.

The principal teacher describes the inner light switch as hard to reach. In the morning, in wintertime when you enter the room it is hardly possible to see anything. The light sources switch on little by little. No visible flickering. The light seems yellowish and the light coming from outside seem bluish (Observation made on a cloudy day, 8.45, 16/1). The principal teacher describes the light as harsh.

Use of the room

The classroom is used by pupils in grade 6-9 in the Swedish elementary school, age 12-16 years. Currently (autumn 2015) the room is mainly used by a 7th grade class for social studies, language lessons, maths, class gatherings etc. The schedule runs between 8.10-15.20 with a break for a few hours, a few times a week.

5.2 The teachers’ answers to the initial questionnaire

The information is based on the answers from a questionnaire (Appendix 9) that was given to the teachers who teach in the classroom, on the old installation.

Problems concerning the installation:

The light switches are placed at the entrance, to the right, and in the front corner. The teachers describe the inner light switch as hard to reach. In the morning, in wintertime when you enter the room it is hardly possible to see anything. Another problem is that the pupils get inside before there is any possibility for the teacher to turn the light on.
The teachers think it would be a good idea with motion sensors, as in the other classrooms.
When the smart board is on, the light must be turned off causing difficulties for the pupils to see what they write.

Concerning the pupils’ behaviour:

“How classes / groups function may vary. It may depend on what time of day it is. Morning lessons are often calm, messier before lunch and after lunch. It also depends on if something happened during the break. We also have the middle school schoolyard just outside the windows, which can disrupt a lot of times (noise and a lot of things happening). When it comes to fatigue, it manifests itself in different ways for different pupils. It happens that a pupil slept too little and is hanging over the bench. It can occur at any time. Some pupils become messy and noisy and unfocused when they are tired (either due to lack of sleep or lack of energy). This is more common before lunch. Some are messy after the lunch break, or other longer breaks.”

Wishes for the new installation:

“It would have been nice to have some different modes of brightness and perhaps another type of light (not too harsh). However, one must take into account that the pupils 'touch' everything. What guides the light should be placed so that it does not invite pupils to touch.”

5.3 Interpretation of initial questionnaire & space analysis

In the initial questionnaire, the teachers say that it's messy in the classroom before and after lunch. The automatic variation should therefore include periods with less intense, reddish light before and after lunch.

The teachers describe the inner light switch as hard to reach. The light switch should be moved. When the Smartboard is on, the light in the room needs to be turned off to enable the pupils to see the screen. A dark room raises difficulties for the pupils to read and write on their benches. A "Smartboard" mode should be included in the manually controlled light scenes with decreased light intensity in the front of the room.

5.4 Selection of new luminaire & light distribution

This thesis focuses on the automatic or user controlled temporal light variation. The basis for the possibility to vary the light color, i.e. CCT, is to make use of tuneable-white luminaries. The selection of those is discussed in this chapter and the luminaries were installed before the case studies in the next chapter. The light design goal for the positioning of the luminaries is to get an even light distribution (the same as for the old installation).

Installation requirements

The following specification of requirements was used as a prerequisite for the installation and choice of technology.

1. <u>Controllability of intensity and Color Temperature (CT)</u>
   <u>Specific requirement: Ability to change between a colder and a warmer CT</u>
   It is important to enable the pupils to read and write on their desks while the smartboard is on. This will be solved with different zones to provide the ability to dim the light in the front of the room (where the smartboard is placed).

2. <u>High colour rendering, Ra > 80</u>
   The standard for CRI (EN12464) is Ra 80, but in an art room they recommend above 90. This classroom will be used for teaching various subjects which may include short sequences of painting or crafts.

3. <u>Enough luminaires to provide:</u>
- A maximum of 700 lux on the work surface
- Ambient lighting

The standard (EN12464) requires 30 lux in the ceiling (recommended 50 lux) and recommend 50 lux in the ceiling and 75 lux on the walls. The standard also requires a cylindrical illuminance of 150 lux because it affects the ability to interpret faces, events and objects.

4. Good reflectors
   To distribute the light efficiently and prevent glare. Environments with monitor work, like this classroom, require a light that does not create glare and shadows on the screen. This classroom has a smartboard.

5. Light switch and control panel
   Easily accessible and easy to use.

6. Flicker free

The new luminaire

The installation was finalised with a 15 mm, 60 × 60 LED panel from Candelux, Art-nr: 440040. The luminaire is dimmable, offers the possibility to change from 3000 K to 6000 K, has a CRI of 85 (measured CRI 81-85) and give 3800 lm. The solution has 4 × 3 luminaires in the rectangular room and 1 luminaire in the entrance corridor.

Figure 9 The 40 W, 230 V luminaire from Candelux.

Figure 10 show the old and the new luminaire layout. The placement of the new luminaires has the same main goal as the old placement, to aim for an even distribution.

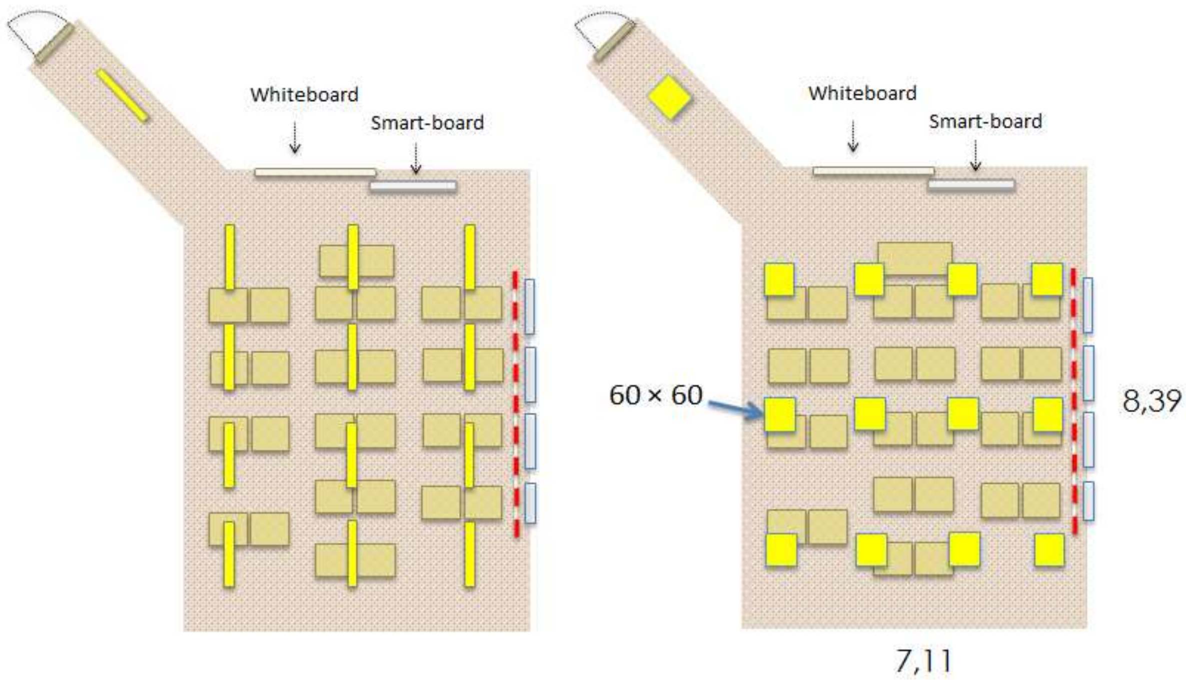

Figure 10 The plan to the left show the luminaire layout for the old fluorescent tubes. The plan to the right show the new luminaire layout for the 60 × 60 LED panels from Candelux.

The control system

The lighting installation in this classroom has a flexible standalone control system. The control system is based on a DIN Rail 2-Channel DALI Interface and a 5 '' TSW-752 Touch Screen from Crestron. At present the system does not include any sensors but it can be expanded with additional units like sensors. The user interface and the control unit are programmable in high-level language.

At present the luminaries are organized in two groups, the first row of luminaries and the rest. Those groupings are used for the Presentation and Smart-board characters. For all other characters all the luminaries (both groups) are controlled in the same way.

The new lighting system is started with the old light switch, at the door. After that all of the lighting control is made via the touch screen buttons and by the automatic light variation programme. It is easy to add new control buttons and possible to connect those to new settings, i.e. characters that also include the linear start-up and shut-down ramps, with different ramp times, for the different characters. In the automatic light variation setting the changes between the different characters are programmed as linear ramps for the intensity and the color temperature. The change of level is divided by the change-over time and then the control unit calculates and sends a new setting to the luminaire drivers quite often, e.g. a new setting each second. The same basic principle is used for the changeovers from automatic to a manual character and vice versa.

6 CASE STUDY 1

One goal for the case studies is to enhance the knowledge about the needs for various light characters and how those needs and characters ought to be specified, i.e. described to be able to talk about in mutually understandable ways.

6.1 Case study object

Due to technical start-up problems, the first installation was not working fully according to the specification (Light Variation Functions 1 in Appendix 3). Table 2 summarises the functions that were working properly and for this reason where used in the first questionnaire to the pupils.

Table 2 The manually controlled light characters that were evaluated in the first questionnaire to the pupils.

Manually controlled light character	Intensity	CT
"Activating light" The starting point is that more light with higher color temperature is activating. This light can be used when it is important that the pupils concentrate on an individual task or listen to the teacher.	700 lux	6500 K
"Calming light" This character is based on research which shows that red light enable us to calm down (with less agitation as a result) and has a positive effect on communication.	350 lux	2700 K
"Smartboard" Avoid glare and enable the pupils to read & write on the benches while the smartboard is on.	Dim light in front when smartboard is on. Solved with different zones. Automatic control so the light dims down in front when the smartboard is turned on.	

6.2 Results

6.2.1 The pupils' answers to the questionnaire

The first questionnaire to the pupils can be found in Appendix 5. The main method was to use questions with pairs of (contradictory) adjectives and four choices in between the words, for each pair of words, e.g.

Reddish _________ _________ _________ _________ Bluish

The same kind of "scale" is used on the x-axis in the following diagrams that show the number of answers, for each of the four positions. The questionnaires did not have any words for the positions in between the end points and the same principle is used in the result diagrams. The questionnaires had scales with four positions (lines), an even number and not an odd one to avoid the tendency to put the answer in the middle. Still some pupils put their mark (X) in the middle, between the lines and for the questions where this happened I have five positions on the x-axis in the result diagrams.

In general the pupils are positive to the new kind of light. 87 % of the pupils responded that the lighting is important for how they feel/ are able to work in a room. The first version of the automatic light variation made sudden jumps between different intensities and color temperatures. 9/23 pupils spontaneously expressed that the sudden changes were distracting.

There are also some indications that it might be problematic to switch between different rooms with different intensities and CCT. One pupil (with migraine) thinks that the light is working all right when he comes to school, but he gets a headache when he gets back to the classroom after the breaks. A few of the pupils experience the activating light as disturbing, one example: "Intense blue light gives me a headache" (comment made by pupil with migraine).

Diagram 1-6 summarise the number of pupils that has various preferences and perceptions of different kinds of light.

Diagram 1 summarise which kind of concentration light the pupils prefer. It includes information from answers to different questions.

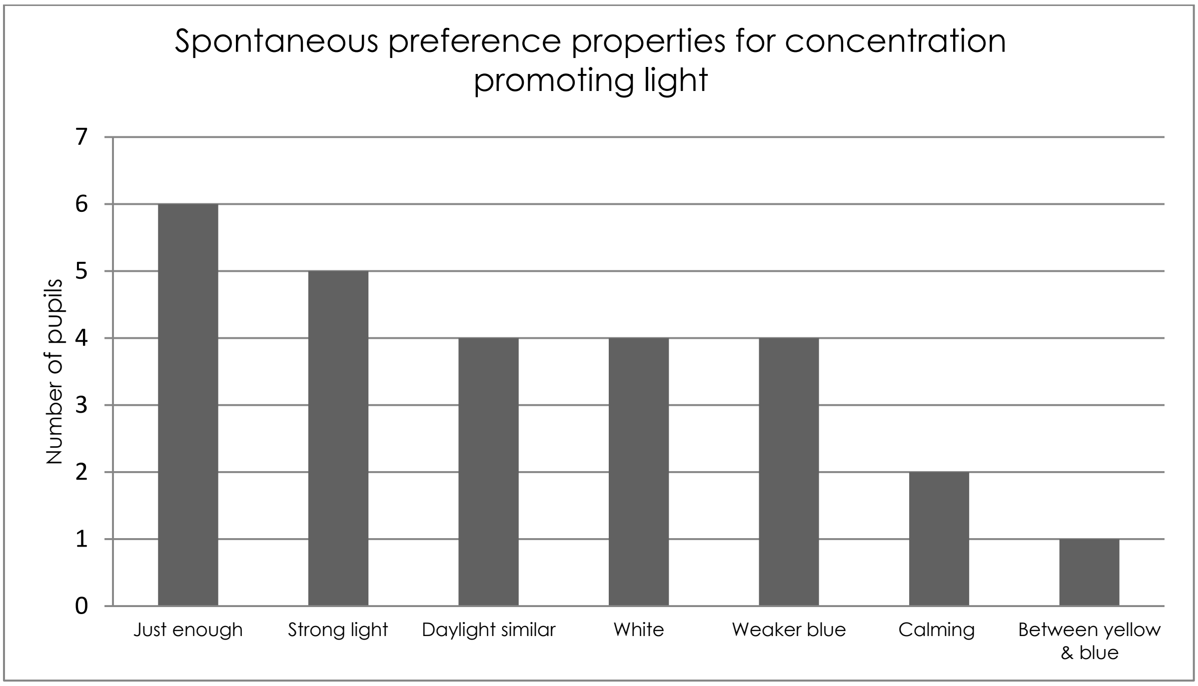

Diagram 1 Numbers of pupils that have mentioned the different properties. 1 pupil prefers white light between the blue (6500 K) and the red (2700 K). 2/23 pupils say that they want "light that is calming because so many of the other pupils are disturbing the lessons" and also "calming light for exams and tests". 4/23 pupils prefer the blue light (or as they call it "ice blue") but they don't want it to be as strong as in test installation 1. 4 pupils prefer white light. 4/23 pupils respond that they prefer daylight or daylight –like light. 5 pupils prefer strong light. 6/23 pupils say that too strong or too weak light decreases concentration.

Each of the diagrams 2-6 summarise the distribution of the pupils selected positions for one of the SED scales, between the two adjectives mentioned, on the questionnaire and in the diagram.

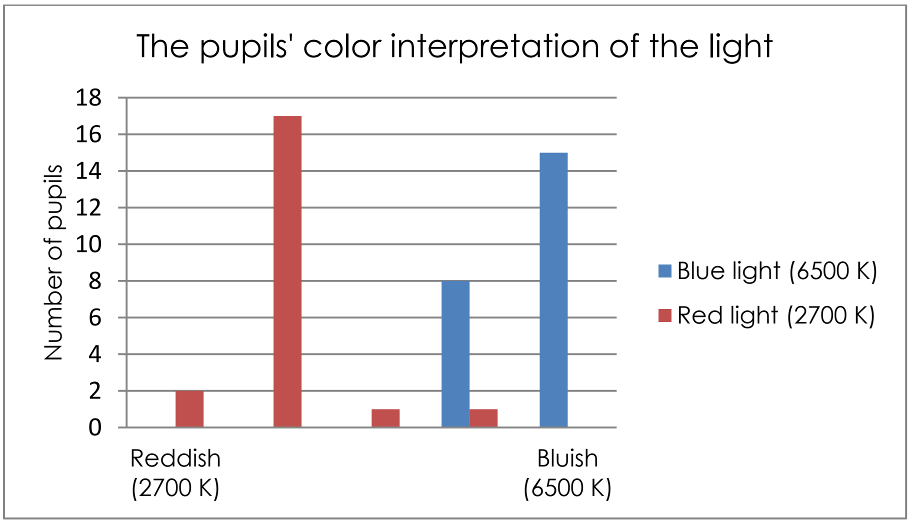

Diagram 2 The 6500 K light, the "activating light", is perceived as blue by the majority of the pupils. The 2700 K light, the "calming light" is perceived as quite reddish, but quite few of the pupils comment that it is "yellow", "very yellow" or "greenish". The scale for the x-axis is explained at the start of 6.2.1

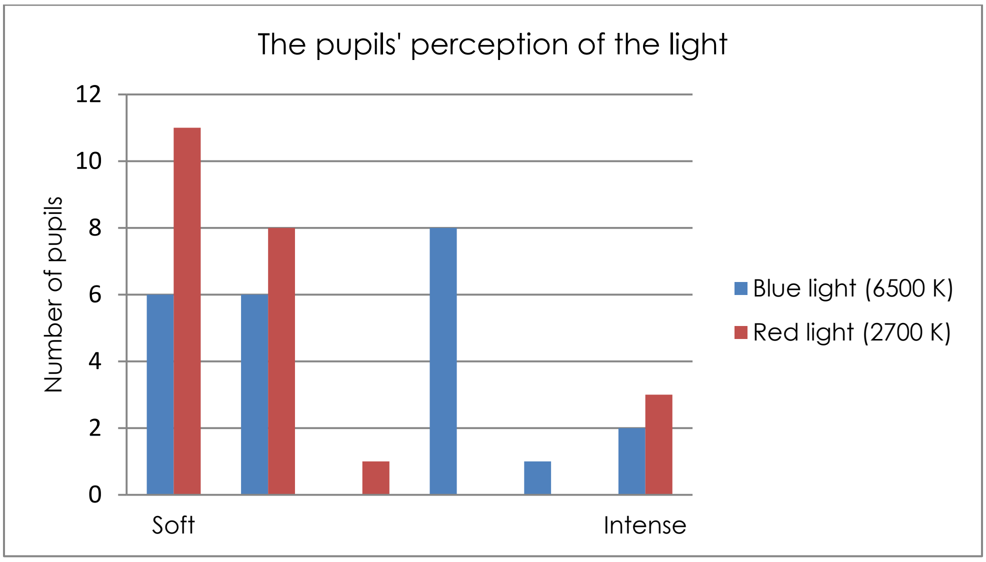

Diagram 3 The red light is perceived as soft by a majority of the pupils.

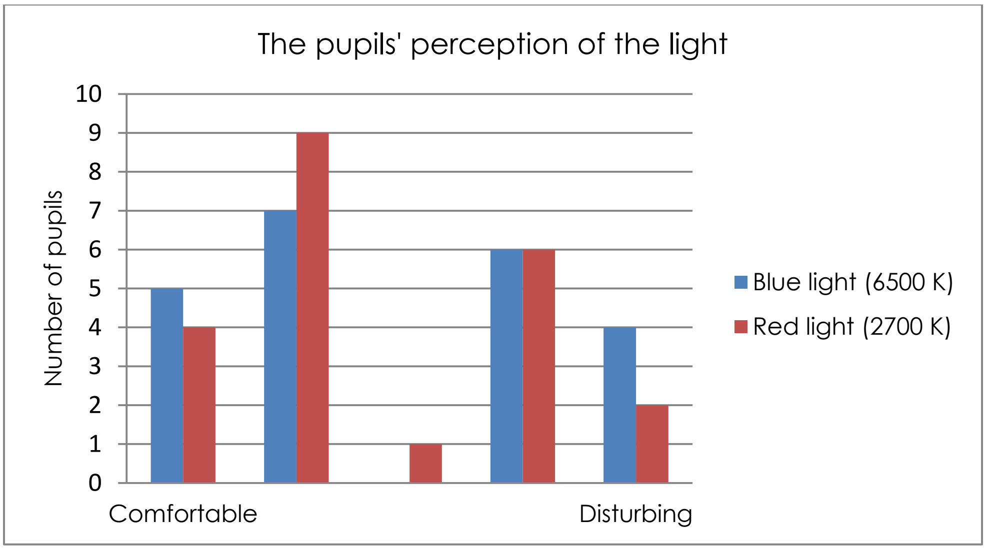

Diagram 4 Some of the pupils perceive the blue light as comfortable, some perceive it as disturbing. A slightly larger proportion of the pupils perceive the red light as comfortable.

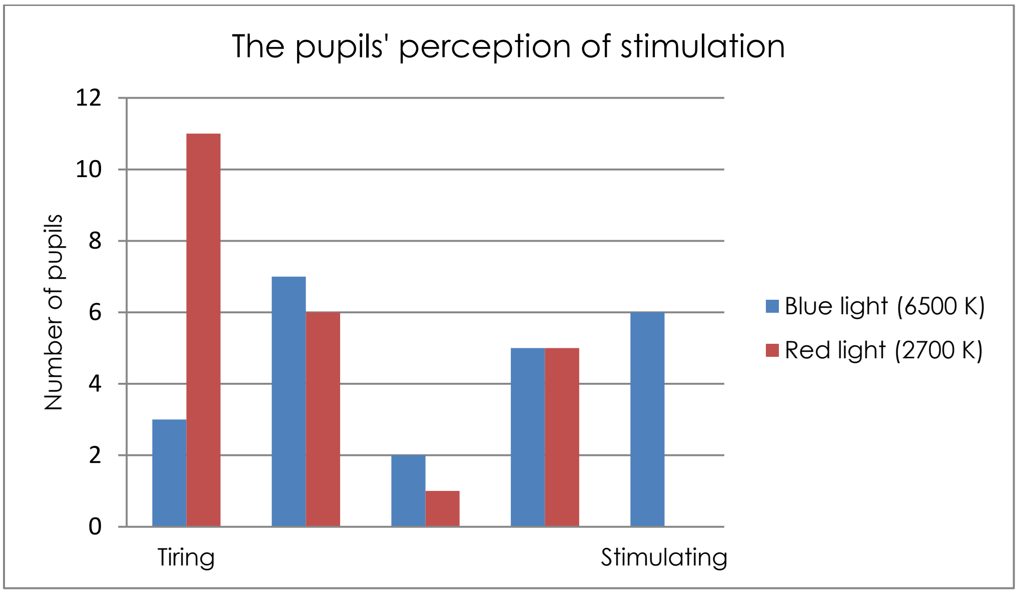

Diagram 5 Blue light is perceived neither as tiring, nor as activating. Red light is perceived as tiring by a majority of the pupils.

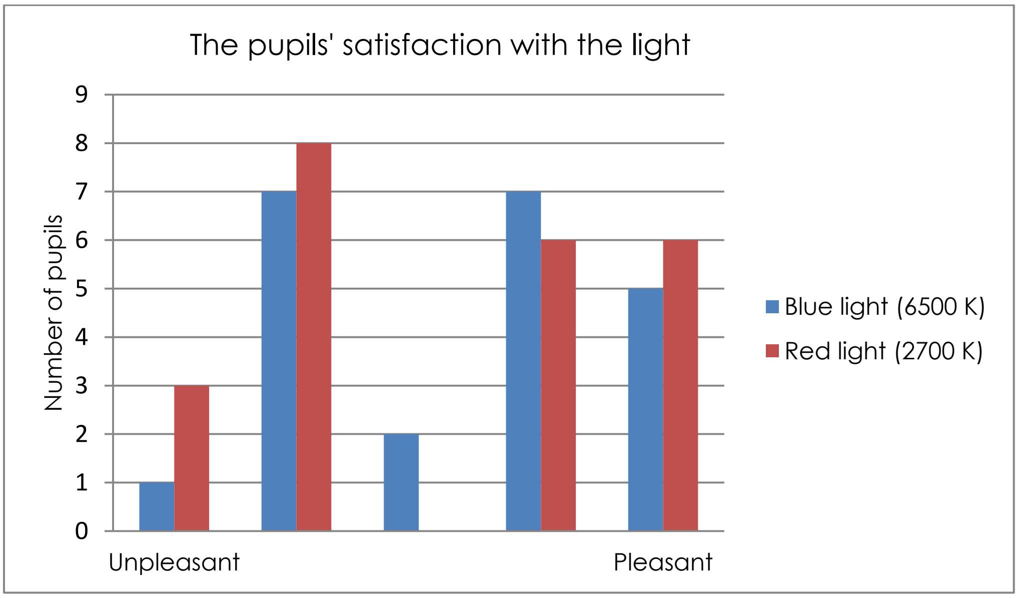

Diagram 6 Some of the pupils prefer the blue light, some of them prefer the red light. Most of the pupils say that they prefer a color of the light that is between the red and the blue. One of the pupils says that the blue light reminds of the "light at the dentist".

6.2.2 Teachers' answers to questionnaire

The questionnaire to the teachers can be found in Appendix 9.

In general, the teachers are satisfied with the lighting: "I think it's good if the light is similar to "Daylight". Unfortunately, we have two pupils who expressed that they get headache from the light. Otherwise, I think the lighting is good."

The teacher like the possibility for variation, but have primarily used "activating light" and "Smartboard": "I think that it is good that the lighting gives opportunity to vary and that it gives a good light, but during my lessons so far we have only used the "active mode", *"We have tried different settings, but almost exclusively used "active mode". We've tried the smart board sometimes"*, *"I think that it is primarily active mode that works in class. And of course SmartBoard, when we use it, and likewise Whiteboard."*, "I find it difficult to see when I should use "calming light" during lessons. If the teacher, for example, talks and the pupils listen it might have been good if we could have more light in front, at the teachers' desk, and less light in the rest of the room."

The automatic variation was not working properly: "At 14.00 the light suddenly changed and we wondered what was happening. We cannot have it like that, when we have a lesson the light suddenly starts to fluctuate. The pupils noticed it as well and wondered what was happening."

6.2.3 Pupils' answers in interviews

The second questionnaire to the pupils can be found in Appendix 6.

5/5 pupils are satisfied with the light installation: "I think the light is a bit more comfortable, you concentrate better.", "The lighting is better now. One can change the lighting whichever way you want to match what you are doing and that is not possible with this light (the old lighting in the room where we are sitting).", "What I think is better is that you become more alert and that it is better light. And that it does not blink as much because that is disturbing.", "I think it's cool, that it's possible to do different kinds of light." "It's better."

5/5 pupils say that it is good that there is a possibility to vary the color of the light: "It's good because then you can choose the brightness you want after how you feel", "I would like it if the light could change invisibly, like five or seven different kinds of light and then it goes without one noticing anything. I would like that."

5/5 pupils prefer daylight or daylight like light: "The best is when there is no (artificial) light at all and that the light is coming from the windows. But only half open with the curtain and the light coming through. Then it is most comfortable… It's better when it's sunny.", "I would like to have daylight. But that is the purpose of the bluish light, isn't it?"

4/5 pupils would like the color of the light to be somewhere in between the orange and the blue: "I think it has been quite good, even though you know that blue and orange light? I think it should be somewhere in between."

5/5 pupils appreciate "Smartboard": "When we are using the Smartboard now, there is no need to turn off lights, but just switch to Smartboard position.", "It works well with the Smartboard. Then you see those who are out there in front, and then you can see when you are writing too.", "If we use the Smartboard and take notes at the same time we don't want to turn off the lights completely because you don't see what you are writing and if the light is on you can't see what's on the Smartboard."

5/5 pupils like the new luminaires: "They are cool", "They look nice"

2/5 pupils say that the old luminaires where flickering: "I just feel that they don't blink like these (the old lighting in the classroom where we are sitting) because sometimes they blink and it's disturbing.

1/5 pupils experienced more headaches after the installation: "I thought it was fun when we got it but then I noticed that I got a headache almost every day, in school. But I did not think of it then of course. But then my mother said that when she arrived at the parental meeting her head started to hurt directly and she said that it could be the reason.", "With the blue light I get very strong headache. With the red light it is not as much but still headache.", "the headache is worse before and after lunch" Strong light induces the risk of headache: "I prefer darker light. Rather the reddish-yellow, than the blue."

6.3 Interpretation

A pupil with headache complains about strong headache before and after lunch. The automatic light variation should therefore include a period with warm light in the afternoon to maintain concentration without raising melatonin levels.

A majority of the pupils are disturbed by intense blue lighting which indicates that it is important to decrease the exposure to intense blue lighting. The time with intense blue lighting in the automatic light variation should be limited, the time with blue lighting in the manually controlled "Activation" mode should be limited and the intensity for the "Activating" light should be decreased.

One pupil (with migraine) thinks that the light is working all right when he comes to school, but he gets a headache when he gets back to the classroom after the breaks. In the morning he has been exposed to daylight while later in the day he has been spending time in the yellowish, less intense corridor lighting. This indicates that it is important to avoid sharp transitions. The classroom light should start from a light that is more similar to the light in the corridor to avoid sharp transitions and slow transitions should be included also in the manually controlled modes.

The teacher finds it difficult to see how "calming light" can be used during lessons. The names of the manually controlled light scenes are important for the usage. The “Calming light” mode should probably be renamed.

The teacher suggest a setting with more light at the teachers’ desk: “If the teacher, for example, talks and the pupils listen it might have been good if we could have more light in front, at the teachers’ desk, and less light in the rest of the room.” A setting conversely to “Smartboard” should be introduced, with more light in front and less in the back of the room, e.g. “Lighting for Presentation”.

A majority of the pupils prefer neutral lighting between the blue (6500 K) and the red (2700 K) and several of the pupils agree on that, too strong or too weak light decreases concentration. The use of white light (4000 K) at a lower intensity, e.g. 0 % should be increased

7 CASE STUDY 2

7.1 Case study object

Due to technical start-up problems, it's unclear if the installation is working fully according to the specification (Light Variation Functions 2 in Appendix 4). Table 3 summarises the functions that were used in the second questionnaire to the pupils (Appendix 6).

Table 3 The manually controlled light characters that were evaluated in the second questionnaire to the pupils.

Manually controlled light scene	Rise time
Activating 500 lux, 6500 K	2 min
Dialogue 500 lux, 2700 K	2 min
Presentation Light on the teacher (500 lux, 4000K) and whiteboard and more dialogue adapted light further back (350 lux, 3000 K)	2 min
Smartboard The light in the front of the classroom is dimmed to 300 lux, 4000 K to avoid glare while using 500 lux, 4000 K in most of the classroom	2 min
Neutral light 500 lux, 4000 K	2 min

7.2 Results

The main ambition for this questionnaire was to assess the perceptions of the automatically varying light. However there were problems with the automatic variation so I had to adapt the questionnaire process while I was doing the questionnaire. The intended questionnaire is shown in Appendix 6 but I could only use some questions. On the other hand I got some more spontaneous and broad comments.

7.2.1 Pupils' answers to questionnaire

The second questionnaire to the pupils can be found in Appendix 6.

Spontaneous comments to the open question about "Other remarks":

"When the light is intense you become alert. When the light feels comfortable you get very tired."

"I think the light is good but I get a little headache from it and I don't get very alert from it. But it is better light than we had before."

"The yellow light is not so good but the calm blue is very nice."

"It is very good light. I would like the light to be stimulating in the core subjects and then calmer in the ordinary subjects."

"It is good that it is possible to change light so that one doesn't need to have the same light all the time."

"I like that the light can shift after how you feel, e.g. stimulating."

Diagram 7 shows how many pupils it is that prefer a more rapid start up (decrease) and how many it is that would like a slower start up (increase). It can be noted that 6/23 pupils would prefer a longer start up time than 2 minutes and that only one pupil would prefer a more rapid start up. This is noticeable because the light changes are much more rapid when somebody presses a control button in a traditional lighting installation.

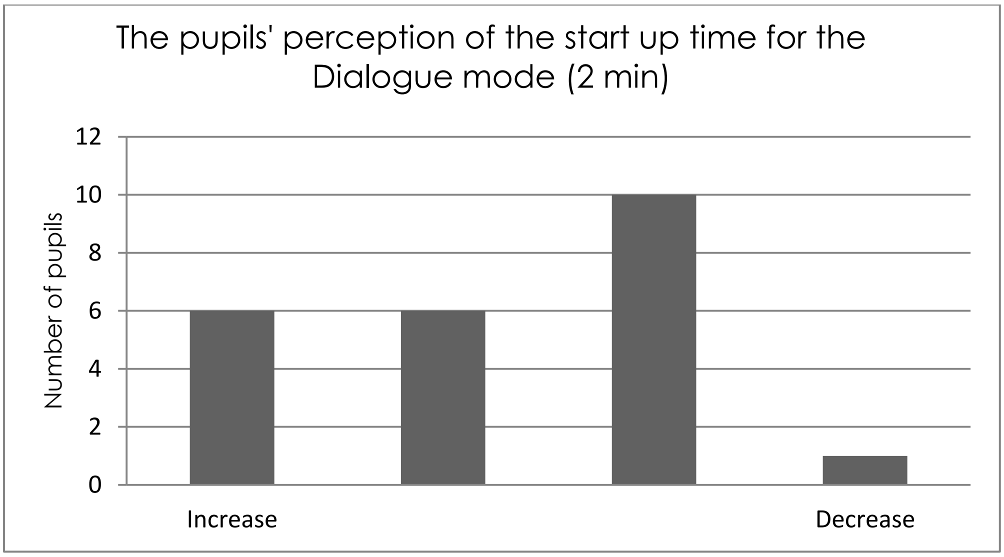

Diagram 7 When someone press the "Dialogue" button, it takes 2 minutes for the system to change to 70 %, 2700 K. The scale for the x-axis is explained at the start of 6.2.1

7.2.2 Light distribution measurements

November 20, 2015 I made measurements of the Illuminance patterns in the room. First I made two sets of measurements with only daylight and then one set for each of the characters Neutral, Dialogue and Activating. The measurements were made when the light had stabilized. Table 4 shows the averages for all work places and for 3 x 3 measurements for each of the walls. The work place measurements of the vertical light were made with sensor lying on the pupil's tables.

The wall measurements aim to describe the circular vertical illuminance. During these measurements I held the sensor approximately 40 centimetres from the wall with the sensing side pointing towards the wall. This means that I measured the light that is reflected from the wall. I made the measurements this close to walls to avoid inclusion of direct light from the luminaries. My own impression and also interpretation of the results is that the walls look bright and that there is sufficient vertical ambient light in the room.

Table 4 Average illuminance levels.

Situation	On benches	Front wall	Inner wall	Window	Rear wall
Daylight (14.30 20/11)	110	9	18	667	17
Baseline (14.35 20/11) Only daylight, Curtains & blinds	2,4		1,3		
Neutral (70 %, 4000 K) Curtains & blinds	375	94	197	123	150
Dialogue (70 %, 2700 K) Curtains & blinds	535	139	283	179	216
Activating (70 %, 6500 K) Curtains & blinds	589	143	289	181	223

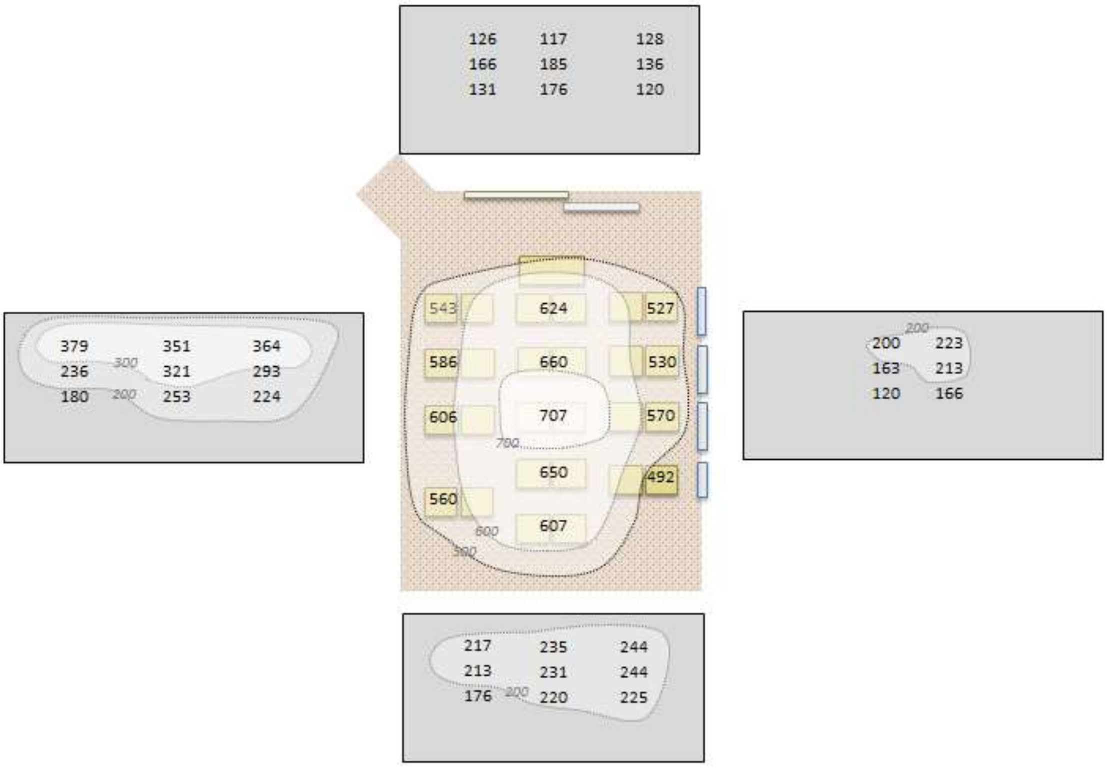

Figure 11 Light distribution in the Activating character.

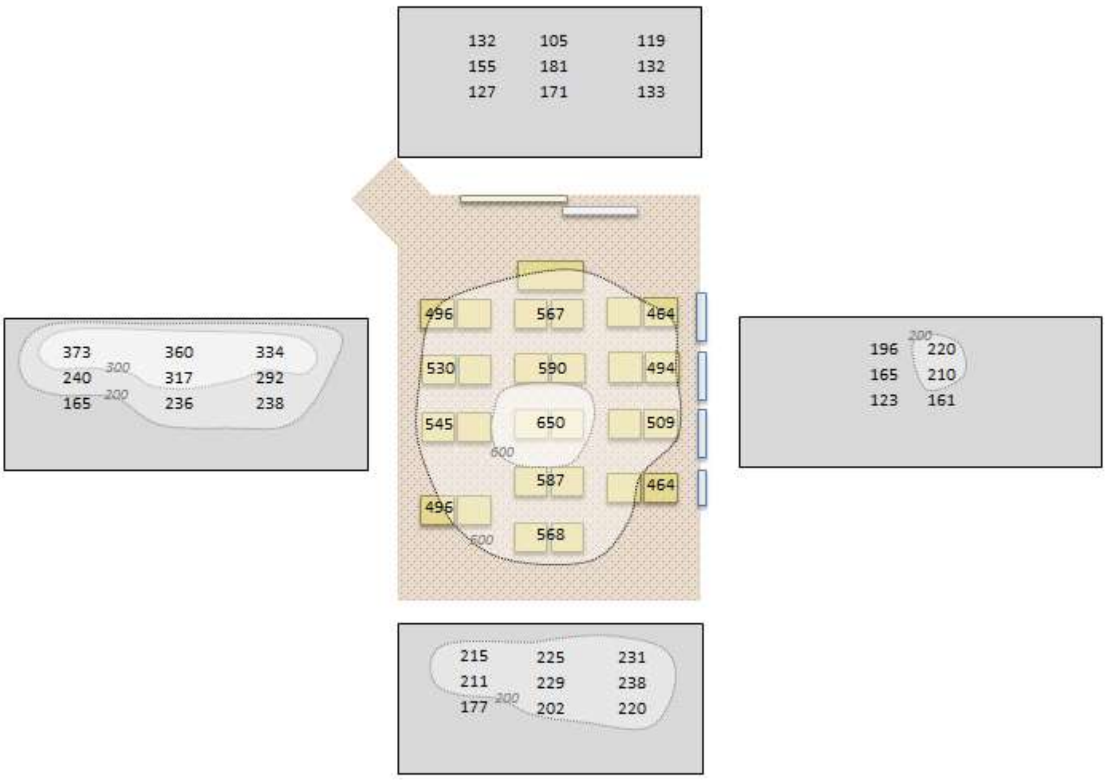

Figure12 Light distribution in the Dialogue character.

7.2.3 Authors evaluation of the various atmospheres in the room

The old pendant fluorescent light fittings gave a messy cluttered impression to the room. The new recessed LED light fittings give an open impression to the room. They look like as if it was openings through the roof.

The main colors of the furniture and walls in the room are white, grey, yellow, brown and red. The only clearly colored part is the red curtains.

The lighting atmosphere in the "Neutral" character

This setting has a significantly lower light level than dialogue and activating. It doesn't feel as bright. It feels as if it is enough light, for example to be able to read and at the same time the atmosphere feels comfortable. It does not feel stimulating as the activating light, in an awakening sense. In a way the room looks fairly gloomy, probably due to the low light level.

The luminaire surfaces look as if it was a window were one sees the sky with rather thin white clouds. The color looks natural.

The lighting atmosphere in the "Dialogue" character

This is the light setting that makes the human faces look most alive and the red curtains are also nice in this light. In my own opinion this light feels more stimulating than the neutral light, probably because the light level is about 40 % higher. The light color seems to match many interior parts, for example the yellowish table surfaces and the almost orange old wooden parts.

The luminaire surfaces looks a bit strange in this light, like if there was a cloudy day above but with a somewhat reddish tone as if the clouds were a little bit red. This feels somewhat unnatural.

The lighting atmosphere in the "Activating" character

This light atmosphere is bright and feels stimulating. In a way everything looks a bit cleaner, for example the upper part of the upper wall looks clearly white, almost a bit luminous. But on the other hand the atmosphere feels a bit unnatural, a bit greyish, which also influence the color of human faces. The wooden parts and the table surfaces are rather orange and they look rather brownish in the activating light.

The bright luminaire surfaces look like something in between a blue sky and a sky with thin white clouds. Thinking critically about the color it looks as if it was light from a blue sky coming in through clouds, which feels a bit unnatural.

Seven dimensions of the light atmosphere

The following seven paragraphs describe the light environment in accordance with the 7 parameters of light that has been defined by Liljefors (2003).

Level of lightness – how light or dark it is in a room

Neutral: The luminance level in the room feels comfortable and calm with just enough light. The luminance level is about 40 % lower and does not feel as stimulating, in an awakening sense, as in the dialogue and activating characters. On the other hand, the pupils are young with good vision and in general they seem to prefer a lower illuminance.

Dialogue: The Dialogue character gives a brighter impression than the Neutral character, probably because the luminance is higher, see table5.

Activating: The Activating character gives a bright, stimulating impression. It is the character with the highest luminance, see table 5.

Table 5 Average illuminance levels.

Situation	On benches
Neutral (70 %, 4000 K) Curtains & blinds	375 Lux
Dialogue (70 %, 2700 K) Curtains & blinds	535 Lux
Activating (70 %, 6500 K) Curtains & blinds	589 Lux

Spatial distribution of brightness – where it is darker/brighter

The luminous surface is quite large, 60 × 60 cm, and appear to have an almost 180 degrees light distribution which generate a diffuse, even light distribution in all the three different characters; Neutral, Dialogue and Activating.

November 20 I made measurements of the Illuminance patterns in the room. My own impression and also interpretation of the results is that the walls look bright and that there is sufficient vertical ambient light in the room.

Shadows – Where they fall and their character

This luminaire has a quite large luminous surface, 60 × 60 cm, which generates a diffuse, even light distribution and in this kind of environment there are shadows with diffuse borders, see figure 13.

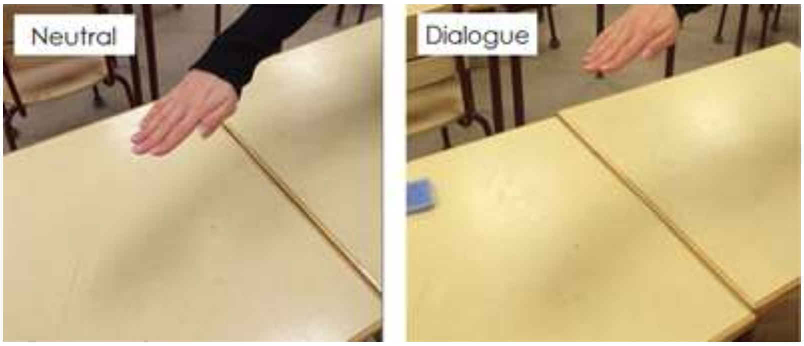

Figure 13 There are hardly any shadows in any of the characters Neutral, Dialogue and Activating.

Reflections – Where they occur and their character

This large luminous surface, 60 × 60 cm, generates a diffuse, even light distribution and in this room with 12 such luminaires in a rectangular room there are hardly any noticeable local reflections. Figure 14 show the most visible reflection and the reason for this is that there is only one luminaire in the entrance corridor and also that it is close to the wall.

In my opinion the evenness create a somewhat lifeless atmosphere in the room and it would be a good idea to add different layers of light, e.g. with spotlights. There is hardly any dramatic ingredient in the light and the mimics of the faces is hardly visualised.

Figure 14 In general, there is almost no noticeable local reflection in the room. The wall in the entrance corridor in the picture is the most reflective spot in the room.

Glare – Where it occurs and how noticeable it is

The large luminous surfaces minimize the risk of glare and looking at a computer screen or a white A4 paper there is no disturbing glare.

A simple glare test is to stand directly under a luminaire and hold your hand above the eyes. If the visibility is better with than without the hand, there is glare from the ceiling luminaires. I did not notice any visible glare effect with this test method so I asked an older person to take a look.

Neutral: The simple glare test was conducted with a 60-year old and in the Neutral character the visibility was a bit better with the hand blocking the light.

Dialogue: The simple glare test with the 60-year old showed that the Dialogue character was a bit less glary than the Neutral character.

Activating: The simple glare test with the 60-year old revealed more glare than for the Neutral and Dialogue characters.

In summary, the risk of glare is low.

Colour of light – The color experience of the light

Neutral: The light from the luminaire seem white with a very light, red tone.

Dialogue: The impression of the light from the luminaire is warm white with a reddish tone.

Activating: The impression of the light from the luminaire is cold white with a bluish tone, a bit unnatural.

Colors – If they look natural or distorted

Neutral: In general, white lights is the most versatile color of light because it can be reflected by any color. My impression is that red, green and blue colors seem just as prominent under this light, see figure 15.

Figure 15 The colors seem just as prominent under the light in the Neutral light.

Dialogue: The yellow light in the dialogue mode is a flattering one for the skin. It looks bright, because it has a lot of white in it but also warm due to the prominence of red wavelengths. The red colors in the room seem a bit more prominent and blue colors seem darker, see figure 16.

Figure 16 The red colors in the room seem a bit more prominent under the Dialogue light.

Activating: Most facial colors, except for red tones, can reflect blue light. Orange will absorb the blue light and darken significantly. The facial color seems somewhat grey/blue/purple in the activating mode. Green and blue colors seem a bit more prominent, see figure 17.

Figure 17 The green and blue colors seem a bit more brilliant under the Activating light.

Figure 18 shows a comparison of how red colors look in Neutral, Dialogue and Activating light.

Figure 18 The red colors in the dialogue light seem more vivid. The red colors in the activating light becomes darker and not as prominent.

Looking at the color compositions with the spectrometer it is obvious that the basic principle is that all the characters have the same kind of peaks, one rather narrow for blue light and broader with green and red light. The difference between the characters is that those peaks have different relative sizes for the different characters, see figures 19 and 20. One noticeable detail is that there is a dip in the spectral distribution around 480 nm.

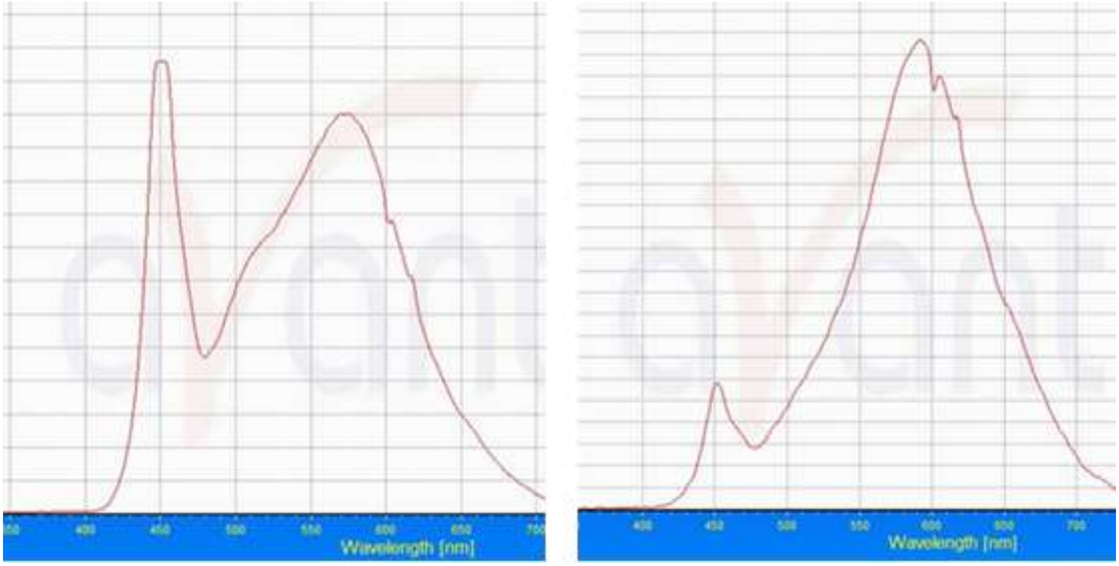

Figure 19 Spectral distribution for the Activating light to the left (The spectrum has a top at 450 nm) and the Dialogure light to the right

7.3 Interpretation

One conclusion that can be drawn from attempts to measure the light environment for the different characters is that it is very difficult to find a measurement method that provides a reasonable opportunity to describe the total experience of the different environments. Because of the difficulty to measure, there is room for frauds in sales of dynamic light environments. It is important with calibrated instruments.

The measurements also gave insight on how important it is to think about the lightings' interaction with the physical space; colors, shapes and surface textures.

The observations of the atmosphere in the room has made it clear that an even light distribution can create a somewhat lifeless atmosphere and that it would be a good idea to add different layers of light, e.g. with spotlights. There is hardly any dramatic ingredient in the light and the mimics of the faces is hardly visualised.

Most pupils appreciate the slow variations.

The following quote from a pupil summarises my own impression: "When the light is intense you become alert. When the light feels comfortable you get very tired." The quotation makes it clear that the environment that feels good, is not always the one that gives a revitalizing effect.

8 A COMPARATIVE STUDY

8.1 Case study object

One installation of Human Centric School (HCL) Lighting that is catching a lot of interest is the Glamox Luxo installation at the new Kongsgårdmoen school in Kongsberg, Norway. Kongsgårdmoen is a new school with 230 pupils, age 7-13 that opened in 2015. The school has Human Centric Lighting installed in the classrooms and in a number of rooms for meetings and special subjects. I observed HCL-lighting in 9 different rooms (2 classrooms, 4 subject rooms, 1 group room with smart-board, 1 lecture hall and 1 meeting room).

The recessed luminaire, Modul R 600 LED Premium (R_a: > 90) is a tuneable white luminaire that can be changed from warm white to cold white. It is installed in all the classrooms and is controlled with KNX to DALI.

Figure 20 To the left, cold white light to be used in the morning and during tests. To the right, warm white light to be used e.g. during story time.

The following settings have been installed at the Kongsgårdmoen school:

Morning level of the awakening light: E m = 650 lux, CCT 6.500 K

Awakening light: E m = 1.000 lux, CCT 6.500 K

Neutral light: E m = 300 lux, CCT 3.500 K

Restful light: E m = 300 lux, CCT 2.700 K

The purpose of this study is to assess whether the lighting system is working properly and how pupils and teachers experience the light and light variations.

The authors' evaluation

My own perception is that the Activating light is more intense at the Kongsgårdmoen school than it is in Malmö, which is consistent with the values presented above. The activating light at Kongsgårdmoen seems to give a better color rendition than the activating light in Malmö (which is also consistent with the value presented above).

The choices of wall, ceiling and floor colors seems to be adapted to a higher color temperature. Kongsgårdmoen use a lot of blue and white which is represented well in a higher color temperature. It is a new house so the paint looks fresh and there are many white surfaces.

The wooden details are also new, fairly beige and I had a positive impression of this also in the activating light. The intensity in the Dialogue light appears to be similar in both the schools, which is consistent with the intensity measurements at Lindeborgsskolan. This light feels more comfortable in Malmö, probably because it matches the furniture. However the Dialogue light seems to be more appreciated in Kongsgårdmoen, possibly because their activating light is perceived to be so intense.

8.2 Results

Pupil questionnaire data and analysis

90 % of the 20 pupils responded that the lighting is important for how they feel/ are able to work in a room. Most of the pupils appreciate the new light. This is illustrated by some spontaneous comments: "It's really cool that our school have activating, dialogue and neutral light" , "I think activating light is a good idea but I cannot focus as much as the teachers had hoped for." "I think LED is good. At the old school, I quickly got headache." "This light is much better than before, since it provides variety in everyday life."

The pupils' perception of the speed of change

The pupils were asked their opinion on the manual shifts between the light modes, e.g. going from a standard light to a focus light. The manual shifts are programmed to take less than a second. The focus and relax light settings have an automatic switch back to standard light after 30 minutes, in case the teacher forgets to turn these light modes off. The transition period takes 10 minutes.

Most of the pupils perceive the changes as sudden and most of them would also like the changes to be more gradual, see Diagram 8 and 9.

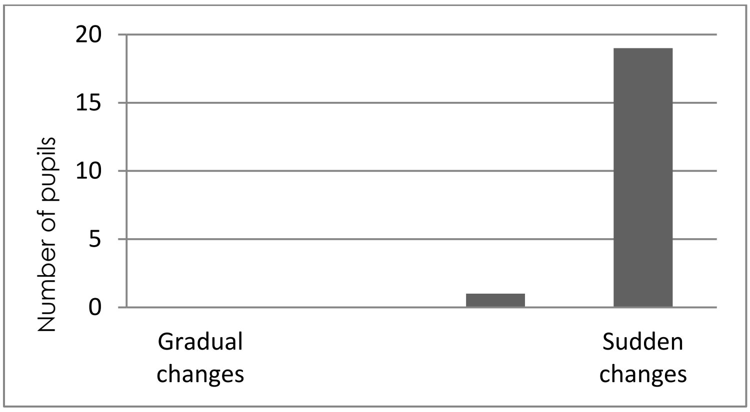

Diagram 8 The pupils perceive the changes as quite sudden.

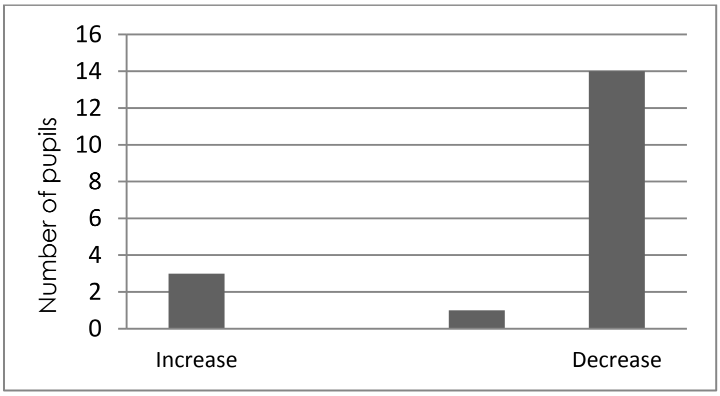

Diagram 9 Most of the pupils (14/20) would enjoy decrease the speed of the changes.

The pupils' perception of the intensity

A majority of the pupils would like to decrease the intensity of the focus light, see Diagram 10. 2/20 pupils spontaneously say that they want less intense light: ”I would like the light to be less intense.”, “I want to have dimmer light.”

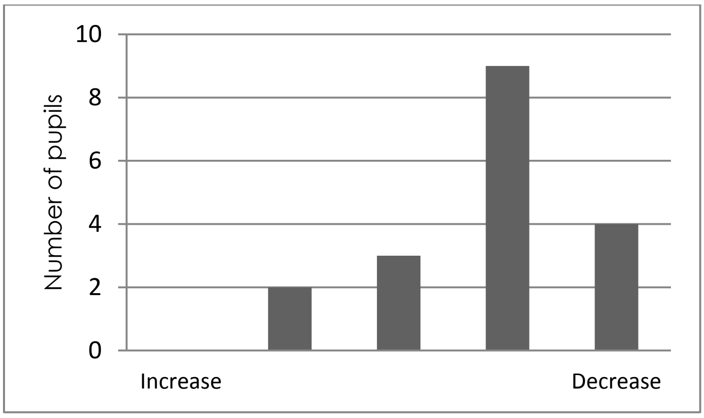

Diagram 10 A majority of the pupils would like to decrease the intensity of the light.

The pupil's perception of the focus light

"I do not notice much difference but I cannot relax in focus light. I have to work, in a way. "

A majority of the pupils perceive the focus light as too intense, quite disturbing and not stimulating nor tiring, see Diagram 11-16. 4/20 pupils expresses spontaneously that they don't like the activating light: "My eyes hurt from the focus light.", "I think the focus light is bad.", "The focus light quickly gives me a headache.", "Focus light is a bit annoying."

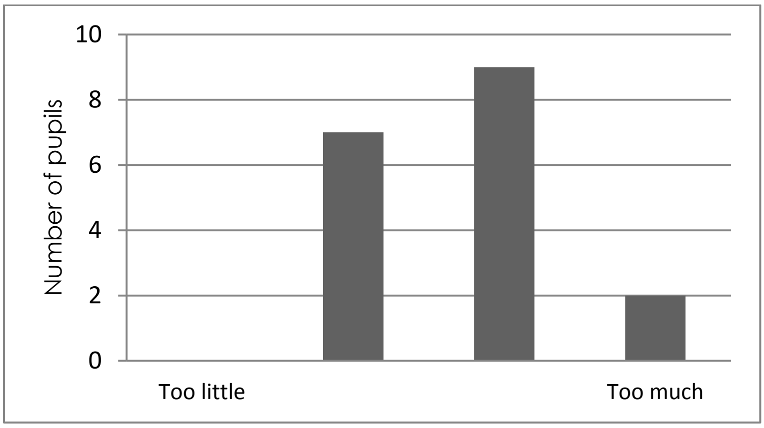

Diagram 11 A majority of the pupils perceive the activating light as too intense.

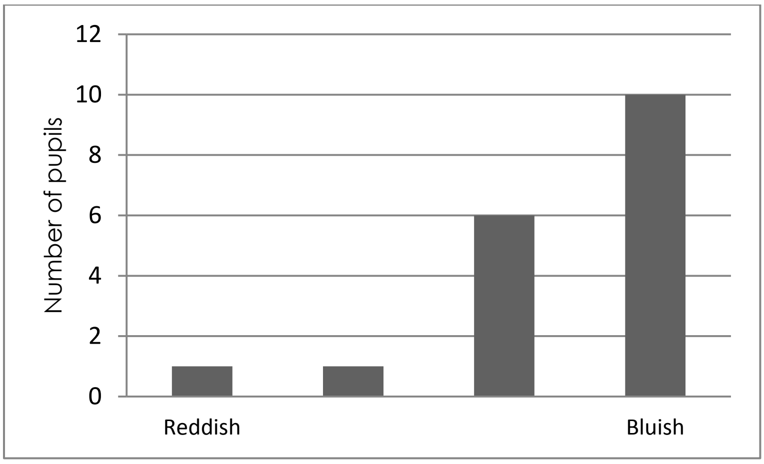

Diagram 12 A majority of the pupils perceive the activating light as bluish.

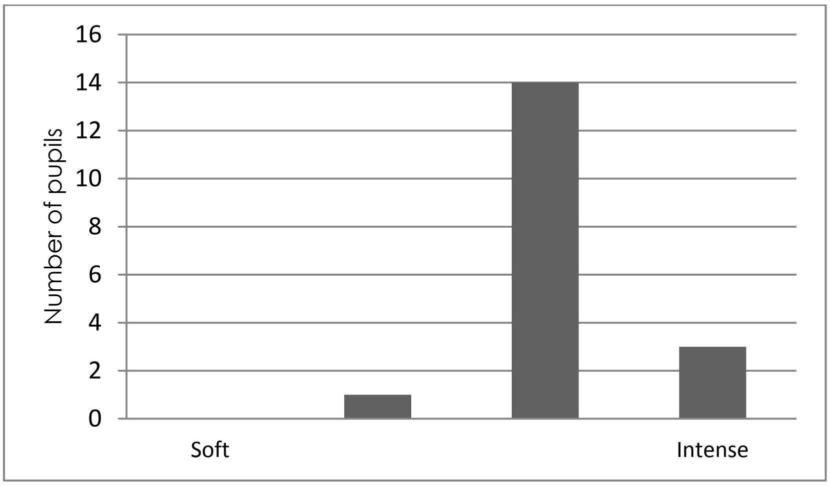

Diagram 13 Most of the pupils perceive the activating light as intense or quite intense.

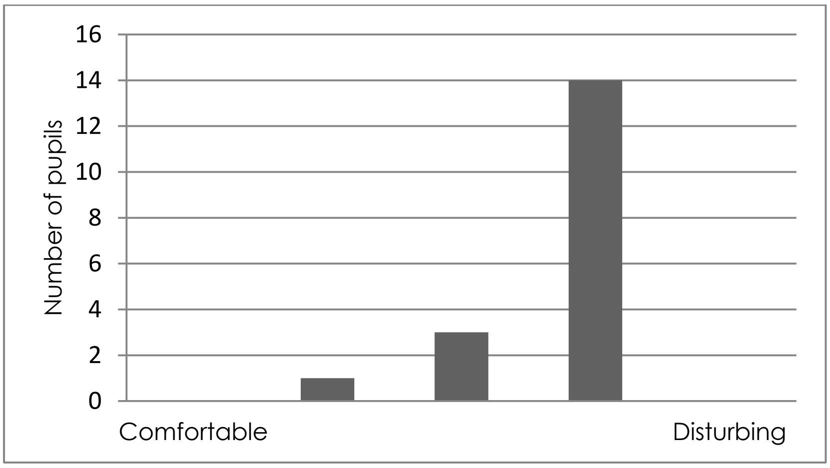

Diagram 14 A majority of the pupils perceive the activating light as quite disturbing.

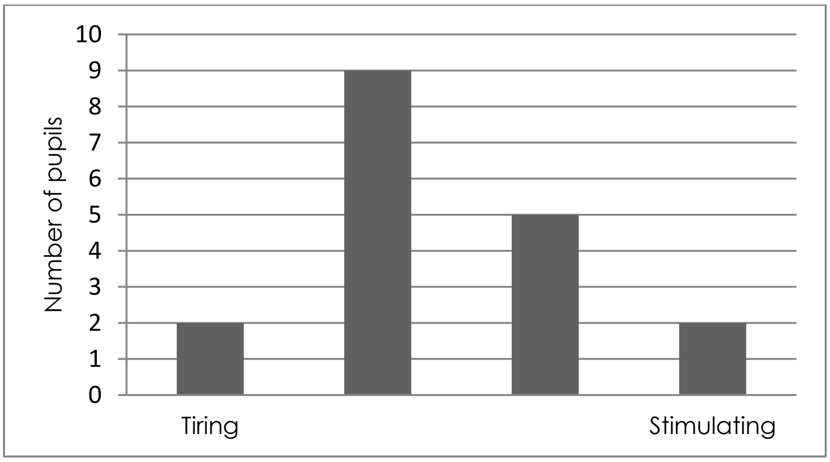

Diagram 15 The pupils' opinions are divided regarding whether the activating light is stimulating or tiring.

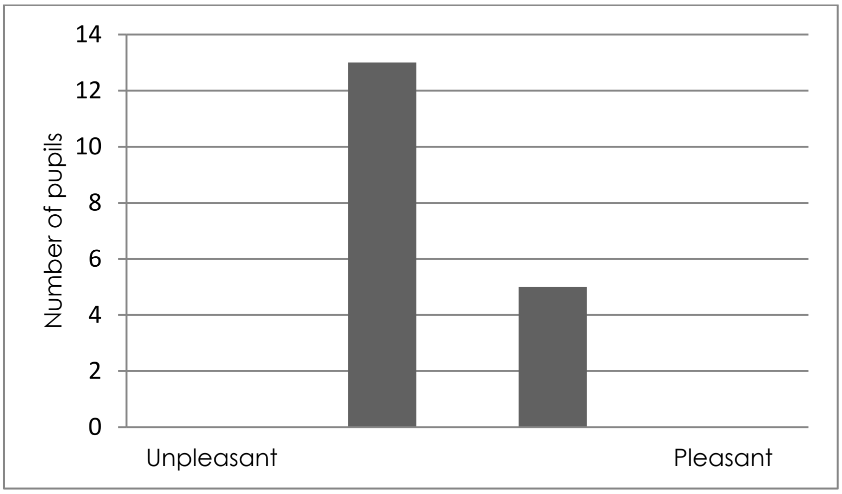

Diagram 16 The activating light is not perceived as unpleasant nor pleasant.

The kind of light the pupils prefer

3/20 pupils spontaneously express that they appreciate the natural light: ”Sunset is good.”, ”I think daylight is the best.”

7/20 pupils say that they would like green or water-colored light: “I would like to have a little turquoise-like light”, “I want water-colored light.”, “Dark blue, or greenish.”, “The light should be light green. Because that is a color of light and I think that would be good for me.”

11/20 of the pupils prefer “neutral light” or “dialogue light”: ”I would like the light to be a bit like the ”dialogue light” at the school.”, “I would like “dialogue light” and “neutral light”, “I might want to have “dialogue light” all the time because it is so nice to work in.”

7/20 suggest focus light or neutral light for theoretical tasks and dialogue light for cooperation tasks: ”I think the focus light is good for math”, ”The focus light is good for tests”, ”The focus light is good on tests. But not for too long.”, ”The focus light is good for a test. Dialogue light is good for cooperation tasks”, ”I like dialogue light when we are reading, but otherwise I like neutral light the best.”, ”Neutral light is good for tests”.

Dialogue with the pupils

My overall interpretation of the dialogue was that the pupils really like the new lighting and the possibility to vary the light, between the base setting, activating light and dialogue light.

3 pupils were talking about hurting eyes or head, one said it's annoying when the focus light is turned on. The pupils describe the pain from the "focus light" as centred above the eye.

One of the pupils says that when the focus light is turned on, the eyes hurt and then it hurts in the head and you get tired.

Interviews/dialogue with the teachers

Overall the teachers are very positive to the new lighting and the possibility to vary the light, between the standard light, activating light and dialogue light. Before the installation, the teachers had very little knowledge about Human Centric Lighting. They were surprised that they needed an introduction to the new lighting. Now they are positively interested, but some still hardly know how to use it and also the interested teachers find it a bit difficult to know how to talk about the new lighting.

One of the teachers says that the focus light may be a problem for 20 % (the hypersensitive ones) of the pupils. Most of the other pupils seem more focused and less tired now. The "normal pupils" complain less about headaches than before. Many of the pupils ask for focus light when it's time for "heavy theoretical subjects". The teachers themselves feel less tired and have fever headaches now.

How the teachers switch between the different lighting modes

- Neutral light goes on when they turn the light on in the morning.
- Focus light is used during limited time periods, mainly in the morning.
- Focus light is used during tests and dialogue light during massage and when the teachers are reading to the kids (according to a teacher in grade 4).
- Dialogue light is used during the morning assembly (only a few minutes) and then neutral light (acc. to a teacher for 6-year olds)

The teachers never switch the light mode without preparing the pupils. One of the teachers use focus light as a pedagogic tool: "Now it's time to concentrate!". The teachers talk about the effects of light also as placebo effects and those might disappear in this sense when the changes are unnoticeable.

8.3 Interpretation

Four pupils talk about headache in relation to the focus light and quite a few say that this light hurt their eyes or that it is disturbing or distracting. One of the teachers says that the focus light may be a problem for 20 % (the hypersensitive ones) of the pupils. This is consistent with the investigation in Malmö, where two of the pupils expressed that the intense, blue light gave headaches.

The interviewed teachers say that they find it a bit difficult to know how to talk about the new lighting which is a clear argument for why the new concepts, the lighting characters, are so needed. One of the teachers uses the light as a pedagogic tool, especially the focus light which is something that needs to be considered in the control system and lighting character design. The pupils prefer slow (unnoticeable) transitions, but as a pedagogic tool, the shorter transitions are more effective. The teachers talk about the effects of the light also as placebo effects and those might disappear in this sense when the changes are unnoticeable.

9 RESULTING DESIGN SUGGESTION

This suggestion focuses on an automatic light variation pattern and control buttons for different light characters. Those suggested automatic light variations and control buttons for different light characters are not yet in full operation. The spatial distribution of light is hardly assessed in this thesis. The choice of luminaries is presented in chapter 5 and the same new luminaries have been in operation from their installation, through the case studies.

This chapter presents the concluding descriptions of the suggested light characters, which includes the accumulated insights that have resulted from the process described in this thesis. The conceptual foundation is presented in chapter 1 and the characters are interpreted in relation to this framing.

9.1 Design intention

The traditional thinking about classroom lighting is that it should be a functional light that enable the visual aspect of various intellectual activities like reading, writing and math. The modern Swedish education includes a more diverse set of activities, for example a lot of project work and dialogues that are supported with tools like the smartboard. This means that there is a need for a broader set of lighting characters to support various dimensions of the diverse activities in the classroom.

One particular concern is that the smartboard is used quite a lot. This means that there has been a need to keep the blinders closed almost all the time and to turn the light off a significant part of the time. Consequently the average light level in the classroom had decreased the years before the new installation. This is problematic in relation to the new knowledge about the need for higher light levels that support alertness and circadian entrainment.

The first four points in the following intention focuses on visual light design objectives. The fifth intension relates to non-visual effects and to some extent there probably are some non-visual effects for all the five points.

The main intentions with the different light characters are to support:

1. A feeling of leadership, being on stage.
2. Alertness and intellectual activity
3. Dialogue and social interaction
4. Serene, aiming for a calm and peaceful environment
5. Circadian entrainment

Those five points summarise the core idea behind the suggested light characters. The resulting light characters are described in section 9.1.1. The core idea is inspired by environmental psychology as illustrated in the mental activity pyramid in figure 1 in section 1.1. This perspective is intended to clarify the need for variation between different lighting characters. In addition to the four levels that are shown in the figure 21, there also is a restorative need for sleep, i.e. circadian entrainment. To avoid stress there is a need to have some restorative support for all the shown activity levels. The light variations should enable people to climb to higher levels of mental activity and also to climb down to lower levels of mental activity.

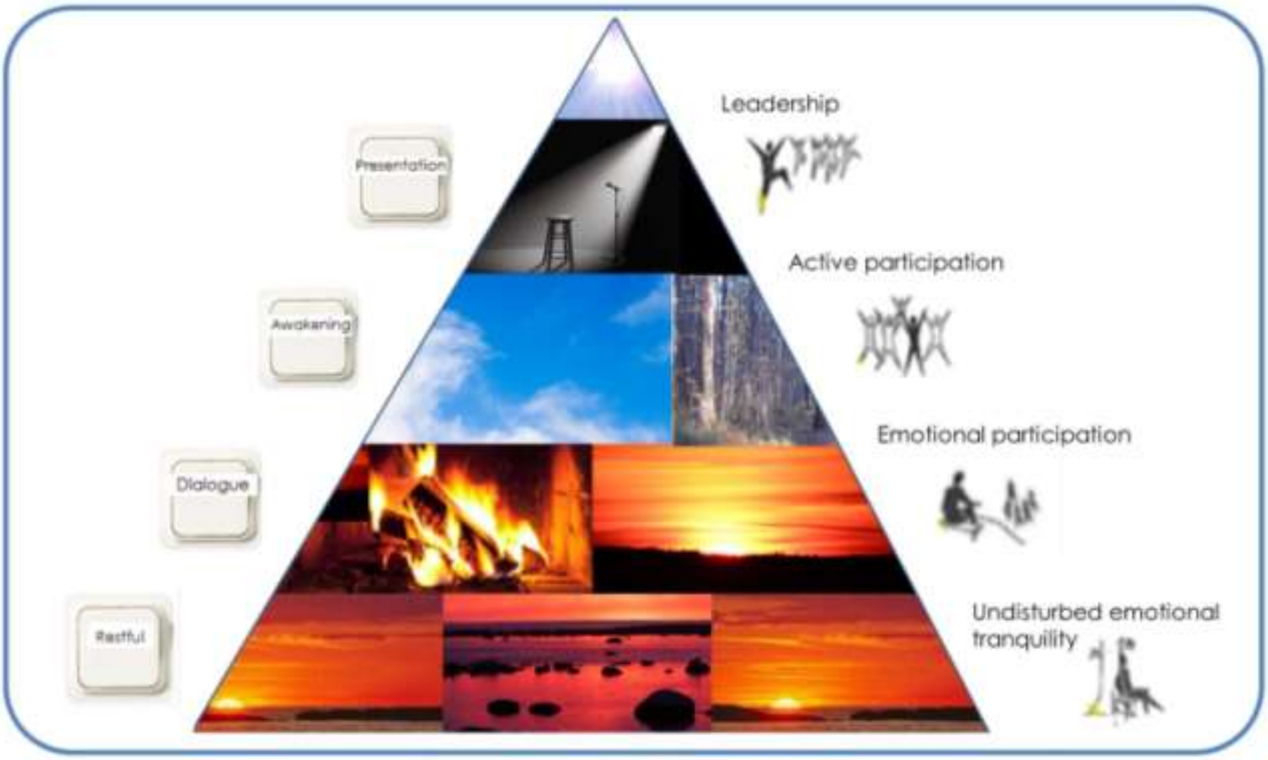

Figure 21 Light-related mental activity pyramid. The buttons to the left illustrate four of the suggested light characters and concepts to the right relates to the environmental psychology pyramid for landscape architecture, suggested by Grahn.

9.1.1 Lighting characters

Awakening

This character is based on recent scientific research which shows that blue light is activating as well as it inhibits the production of melatonin (Berson et al 2002). The color temperature and the intensity are high; 6500 K, 600 Lux and the light distribution is even. The goal is to promote circadian entrainment in such a way that the pupils feel that the light helps them to wake up and that it's time for school work. At the same time it is important that the intensity is not so high that the pupils perceive the light as stressful.

Figure 22 The goal is to provide a stimulating environment, but it is important that the light is not so intense that it becomes distracting or disturbing for the pupil.

Dialogue

Recent research has shown that also red light has an activating effect, but without affecting melatonin levels (Figueiro, Bierman, Plitnick & Rea, 2009) (Sahin and Figueiro 2013) (Mariana Figueiro, 2015). In this character, a high intensity, 600 Lux and an even light distribution is maintained; because the goal is still to keep the pupils alert to enable them to concentrate on the schoolwork.

Figure 23 A low color temperature helps us to see the difference between different nuances in the facial color which enable us to interpret the emotional state of the individuals we have around us.

Another starting point for this setting is the sensitivity of the color cones in our human eye. Human beings have three color cone types; S, M and L. M and L have very similar sensitivities, maximum sensitivities about 535 nm and 562 nm respectively. Those are also the wavelengths that give us the best ability to read minute changes in skin color. It is vital to enable us to see the difference between different nuances in the facial colour (oxygenated/not oxygenated blood) to enable us to interpret the emotional state of the individuals we have around us. Redder light often provide good conditions for dialogues with the essential elements of social contact. (Changizi 2009). For this reason, the color temperature is quite low; 3000 K.

Restful

The main goal with this character is to provide a restorative environment that provides space for the pupils not only to calm down but more importantly to gather strength. The color temperature and the intensity are low; 2700 K 250 Lux and the light distribution is even. This character does not focus on the visual needs for school work and it is therefore less sensitive if the environment is a bit glary. A candle light can help the pupils to enter a restorative feeling.

Figure 24 This restful character creates a restorative environment.

Neutral

This character aims to be somewhat restorative and at the same time sufficiently stimulating to support an active mindset. The old standard for required illuminance on the benches is met, 300 Lux. The light distribution is even and white, 4000 K.

Figure 25 The neutral character creates a soft atmosphere with sufficient light for visual work and also a light environment which allows the mind to settle down.

Presentation

The goal for this character is to create a more dramatic environment. The lighting in the front of the classroom is more intense (500 Lux) than further back in the classroom (350 Lux), to give a feeling of being on stage and for the pupils focus to be directed towards the one who is presenting. The color temperature is quite neutral, 4000 K.

Figure 26 The presentation character has different light levels in different parts of the classroom. This aims to create a more dramatic light environment.

Smartboard

The main goal is to reduce the light level around the smartboard in such a way that the pupils can read the information on the smartboard. It is important to avoid glare and enable the pupils to read & write on the benches while the smartboard is on. The light in the front row is dimmed down (200 Lux) with more light in the back (400 Lux). The color temperature is quite neutral, 4000 K.

Cleaning

This character does not affect the pupils. The goal is to provide a high visibility with high intensity white light; 650 Lux, 4000 K.

9.2 Control system design

The following light variation functions 3 have a basis in the three earlier suggested light variation functions 0, 1 and 2, shown in Appendices.

This suggestion builds on the experiences that are presented in this thesis. One reason for the selection of the color temperature range 2700-6500 K is that there seems to be economically feasible tuneable white luminaires that can handle this range.

Automatic light variation

One main ambition with the suggested light variation scheme is to provide an awakening light that synchronise the circadian cycles in the morning: the time period from 8:50 to 9:10 in figure 27. To avoid overstimulation this time period is limited. Around lunch the light level and also the color temperature is reduced to get a restful atmosphere. After lunch the intensity is increased to get a stimulating effect, keeping the low color temperature, i.e. a high red content as suggested by Figueiro to avoid a delaying the circadian cycles. At the start of the day and at the end of the day the light intensity is rather low.

The automatic variation is intended to provide a functional light in concert with the scientific knowledge about how various kinds of light affect the circadian cycles. This is intended as a basic normal functionality that is running most of the time, without any need for intervention from the teachers.

The variation curve in Figure 27 has linear ramps between the different set points. My reason to suggest the linear ramps is that it seems to be the most straightforward way to enable flexible programing and specification. Some slopes may appear to be steep but for example the slope 8:30-8:50 has 20 minutes transition time, which is a slow hardly noticeable change.

The automatic variation could be initiated and shut down with the normal light switch or a presence detector. The initial start of the lighting should be as quick as possible up to 100 Lux, to enable the entering persons to see.

The possibility to vary the light can also be used as a pedagogical tool, by means of manual changes between different light characters.

Table 6 Automatic light variation.

	Illuminance lx	CCT °K
08:00	350	3000
08:30	385	3200
08:50	700	6500
09:10	700	6500
09:50	490	4000
11:00	490	3800
11:30	350	2800
12:30	420	2800
13:00	665	2700
14:00	560	3500
15:10	490	3000
16:00	420	3000

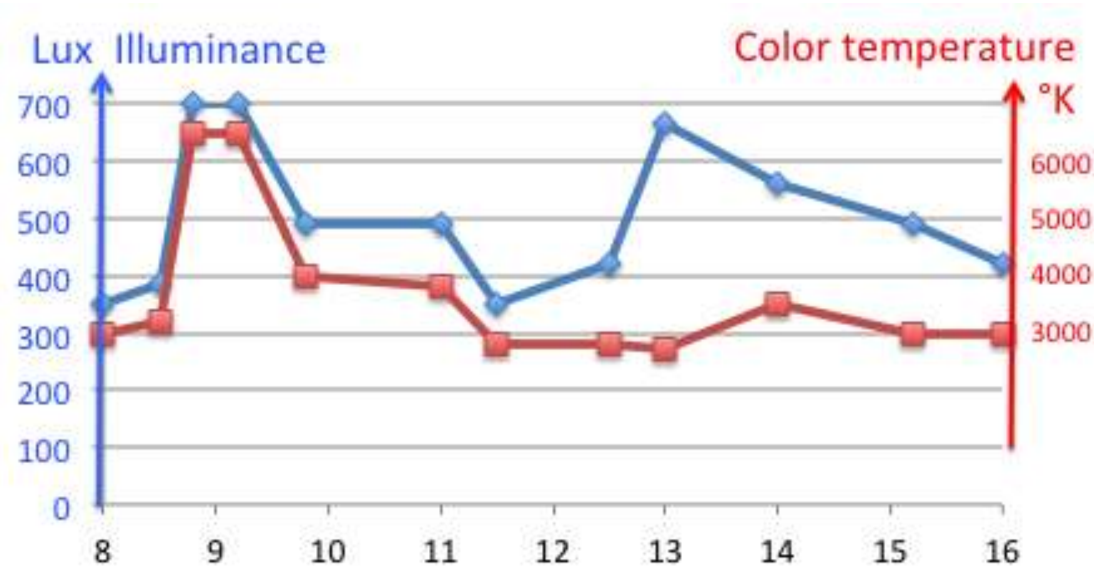

Figure 27 Automatic light variation.

Manual control

The motive for the assortment of light characters in table 7 is to give the teachers a toolbox to adapt the light to the educational situation. One basic possibility is to provide awakening or stimulating light when the pupils are tired. Another basic aim is to provide a restful light atmosphere, e.g. a sense of tranquillity when reading together with young pupils. The ambition is to provide tools for various attempts to influence the pupils level of mental activation, e.g. as described by Grahn, see pyramid in figure 1.

Table 7 also includes a number of characters for various practical purposes. The on-times for the Awakening and Stimulating characters is limited to 20 minutes and then there is a 300 second change over to automatic variation. The other manual selections stay on until another character is selected. The on/off for the smartboard character is intended to later be connected directly to the on/off of the smartboard.

The basic idea in table 7 is that when one character is running and another is selected the change over to the new setting should be fairly quick, 30 seconds for most cases. The background idea is that when the teacher selects a new character it should start without delay. One special case is that when "Automatic" is selected the changeover should have the "normal" non-disturbing rather slow appearance.

Table 7 The light starts from the prevailing lighting situation and then take 30 seconds to switch to the set point 30 seconds after the current time. 100 % intensity refers to 700 Lux on the workspace.

	Start-up	Start-up time (s)	CT (K)	Intensity (Lux)	Time (min)	Change over time (s)	Comment
Awakening	Linear ramp from the present light to the selected light character	30	6500	600	30	300	Linear ramp from the present to automatic after the specified time
Dialogue		30	3000	600	40	300	
Restful		30	2700	250	*	120	Linear ramp to automatic when selecting automatic
Neutral		30	4000	300	*	120	
Presentation Front row Back		30	 4000 4000	 500 350	*	60	
Smartboard Front row Back		30	 4000 4000	 200 400	*	30	Linear ramp to automatic when the smartboard is shut down.
Cleaning		10	4000	650	*	120	Linear ramp to automatic when selecting automatic

* Continues until another character is selected. Most characters start according to their specified rise time. The changes to automatic follow a linear ramp with the specified change over time.

Combined use of automatic and manual controls

The changeovers between different manual settings should follow a linear ramp, from the present setting to the selected character. In this case the end point is clearly defined and the start-up times are shown in table 7. The changeover to the automatic variation is more complicated. In this case the end point for the linear ramp has to be calculated, as shown in figure 28. The transition time is suggested to be 120 s and the end point setting for the transition ramp is calculated as the automatic variation goal value 120 s after the initiation of the transition to the automatic variation.

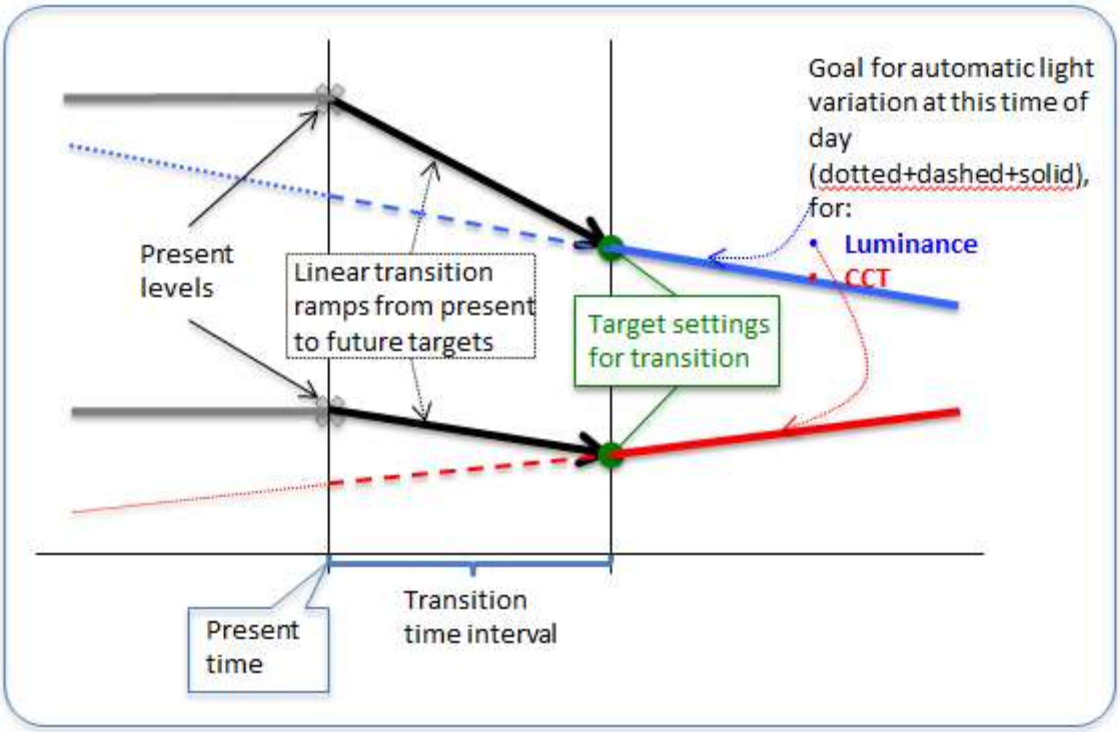

Figure 28 The changeover between different characters.

10 DISCUSSION

Teachers as well as pupils have shown great interest in the light installations. It is clear that the opportunity to experience the new light in a real-life installation has opened their eyes to how much they are affected by light and that it is possible to create many different kinds of atmospheres with light. The light can create stimulating or calming effects, and because of the significant impact on our wellbeing, there are also risks, such as headaches. In order to provide a reasonable assessment of the effects, it is important to be aware of other aspects affecting the users, such as visual connections to the yard, noise level in the room, air quality, social relations and mood related to the specific situation for each pupil. This study does not intend to prove how this particular light affects the pupils' health, wellbeing and performance. The thesis summarizes previous research on the effects of light on health and wellbeing, and examines how the users experience the light and provides a unifying proposal on how dynamic light can be used in a classroom environment.

Numerous comments from both pupils and teachers indicate that they perceive the natural daylight as a positive example for how the indoor lighting ought to be. The 60 × 60 plates are appreciated because they look like ceiling windows.

The thesis is built on the hypothesis that variation is good for humans. The thesis conclusions are based on research on light and health and experiences from an experimental light installation in a classroom. The installation focuses on creation of temporal variations of spectrum and intensity. In a classroom the main focus has been to have enough light on the work surfaces and the method of achieving this has been to strive for a uniform light distribution with at least 300 Lux on the benches. This thesis focuses on the automatic or user controlled temporal light variation. The light design goal for the positioning of the luminaries is to get an even light distribution. The spatially uniform and temporally varying lighting is only one aspect in achieving a good lighting design. A significant deficiency in relation to that it is important to get enough (blue) light in the eye seems to be that the resulting installation provides relatively little light in the front of the classroom. If we focus on horizontal light into the pupils' eyes it may be most effective to add wall washers in the front of the classroom.

A light environment that we share

On average, grown up persons need and want much more light than children (DiLaura 2011). This is one reason why I think the automatic light variation is so important in a classroom. When the teacher manually controls the light there is a risk that the pupils have to live with a higher light level than they need and want. Another aspect of the difference in visual ability is that it would be preferable to have more light at the teachers' work place than at the pupils' desks. I've not included this in my design suggestion, for practical reasons.

The pupils' perception of the speed of change

Most pupils would prefer slower variations than the two minutes slopes that have been operating during most of the tests. This is relevant for the slopes at the manual changes. However, the interviews at Kongsgårdmoen show that at least two teachers are using the manual control possibility as a pedagogical tool and for this case there should be clearly visible connections between the control actions and the change of the light in the room. Consequently I've suggested a more rapid on-set for the manual control of the various characters.

Stimulating and restorative properties

The activating light is appreciated by most. However, several pupils have written, said and shown that they feel that the activating light is very intense. This is the main reason why I have reduced the lux level for the manually started activating light, compared to the initial proposal. For the automatic variation I have kept the high level because the initiation of this character is slow and less noticeable.

The environmental psychology discourse does not say much about a need for activating environments, but quite a lot about the need for restorative environments. In relation to the fact that today's school pupils find it so difficult to settle down and work it is perhaps even more important that the classroom environment provides restorative properties than focusing on how we can create a more productive environment through high-pitched stimuli. It is important that we take the pupils' desire for a lower intensity and a softer environment seriously. We should think about how we can create stimulating environments, which also offer restorative properties.

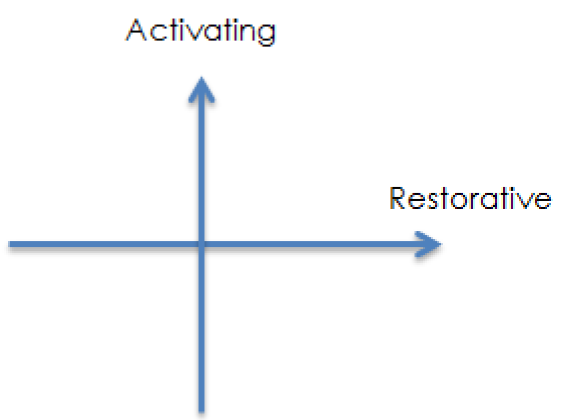

Figure 29 A stimulating environment can also contain restorative properties.

Several pupils express that they want a possibility to get restful light, at least some parts of the day. On the other hand, the classroom teacher in Malmö showed limited interest in the initial kind of restful light character. However, at least one teacher at Kongsgårdmoen is very fond of the restful setting, to get a good atmosphere for her reading and singing with the younger pupils. One background scientific result is that a high intensity of reddish light is stimulating and this also corresponds with the traditional idea that a higher light intensity is more stimulating, for all color temperatures. Consequently I've selected to suggest two different light characters with low color temperature, dialogue light with high intensity and restful light with low intensity.

Sensitive individuals are important messengers

Fairly soon after the first installation was completed, teachers and pupils informed me that one or two of the 23 pupils in Malmö, had an increased rate of headaches. Those pupils had earlier problems with migraine and the symptoms occurred in the Dialogue as well as the Awakening light, with a somewhat higher occurrence in the Awakening light. This was true for about 7 percent, which is far from the majority of the group. Initially those pupils where very positive to the new dynamic light installation, but their interest decreased when they noticed that the light influenced their tendency to get headaches in a negative way.

The majority of the group, pupils as well as the teachers are very positive to the new lighting and the possibility to vary the light. The classroom is shared by many and we must take into consideration the group as well as the individual preferences. One possible way is to use several layers of light and control reflectance and distribution through the choice of materials and colors, e.g. by dark colors on the furniture to reduce the reflectance in one corner of the room. A different way of thinking might be that what is good for the sensitive individuals is probably also good for the majority of the group. The first time I started to formulate this thought in connection to a light environment was when I conducted a study of the lighting environment at a facility for children with autism. Those children reacted very strongly to the sudden change of light intensity that was connected to presence detectors.

Gentile, Laike and Dubois (2014) found that presence sensors systems have been designed to decrease lighting electricity consumption and that the occupants' experiences fairly often has been neglected which is why people often perceive them as distracting. Through the interviews and questionnaires that were conducted in this Human Centric School Lighting report I also got some indications that sudden changes in intensity and/or color temperature, within the automatic variation in the room and through movements between rooms with very different light characteristics, was disturbing and also induced a higher risk for headaches.

The autistic children in my earlier observation clearly showed that the sudden change in light intensity was unappreciated. Most people hardly notice this effect until they are specifically asked about it. I see this as an indication that it is important to listen to the sensitive individuals. The individual problem that was perceived with the activating light led me to the conclusion that it's probably important to limit the exposure to intense blue lighting and that also the manual buttons should include a slow variation.

The importance of a user-adapted design

To create a good lighting environment for each individual there is a need for some kind of continuous assessment of the needs and possibilities in each situation. During this project I have realised that a successful Light Variation design should be simple, and only include the light variations that have been scientifically proven. The parts that are related to the pupils' schedule or activity pattern are better if the teacher is controlling and should therefore be included in the manual control. For the teachers and pupils to be able to use the light in an appreciated way, it is important to develop a user-interface that is easy to use.

A lot of the result of an installation is related to usage and therefore the lighting designer cannot alone be responsible for the end result. To begin with, the design must be adapted to the facilities and also meet the requirements for lighting in a classroom environment, e.g. 300 Lux on the benches. The result of a dynamic light installation is highly dependent on the user. It is therefore important that the operator, in this case the teachers, get knowledge about how the control system works, and how light with different properties affect us. Several of the teachers in Kongsberg expressed that they do not really know how the control works, but above all that they feel that it is difficult to know how to talk about the new light. Lighting characters gives us a tool in the use of and communication about the light.

The need for a conceptual foundation

During the two years I have been working on the planning for and realisation of the presented installation I have met numerous sales peoples and inventors that say that it now is easy to make dynamic lighting. However there have been several delays in the actual deliveries and I have realized that it has been rather difficult to make a lighting solution with automatically varying lighting. In the spring 2013 the City of Malmö accepted to make a test installation. The installation of luminaries and initial controls took place in September 2015 and the installation is still subject to continuous improvements.

Gentile, Laike and Dubois (2014) found that the entry-level products on the market today often are unable to achieve good performances and that one reason for this might be a communication problem between business people and technical staff. It is important that suppliers as well as facility caretakers and installers, together with light designer, assess new products and system solutions at an early stage to avoid misunderstandings that lead to deficiencies and delays.

In the process with this installation I have experienced repeated assertions that the installation of the new technology is a simple process that does not need any special preparation. It is important to improve the communication between the designer, producer, installer and programmer and that we learn to ask critical questions to avoid misunderstandings. To improve the communication, there is a need to develop a common language for the new properties that are being introduced.

I started this project with the ambition to find out what impact the installation would have on the health and well-being of the pupils. Due to technical start-up problems I got the opportunity to revise the design proposal based on the users' experiences. This process has given me important experiences, e.g. that to achieve a really good design result it is often preferable to work in an iterative way, via a number of preliminary designs that are evaluated.

How to make things happen

The dialogues about the complete thesis indicate that the presented way of working is useful as a tool to mobilise real-life utilisation of the scientific knowledge on Human Centric Lighting. The light characters and the automatic variation scheme can be used as guidance for design and installation. They also enable a more concrete dialogue among various actors. This is important to clarify the more advanced level of needs that Human Centric Lighting is aiming to support.

To mobilize the new technical potential and the new scientific knowledge about human centric lighting it is important to get started with demonstrations of the new advantages. There is no direct way from the present availability of knowledge to real life application in new more advanced lighting solutions. One basic method is to translate the new knowledge into new forms of lighting specifications and standards. To accelerate this process there is a need to build interest. It is also important to make demonstrations and experimental installations as a base for mutual learning among the various actors that are involved in the value chain in figure 30. One key to open up for demonstrations is to make a recipe for what it is that ought to be demonstrated. This thesis focuses on the green parts of figure 30.

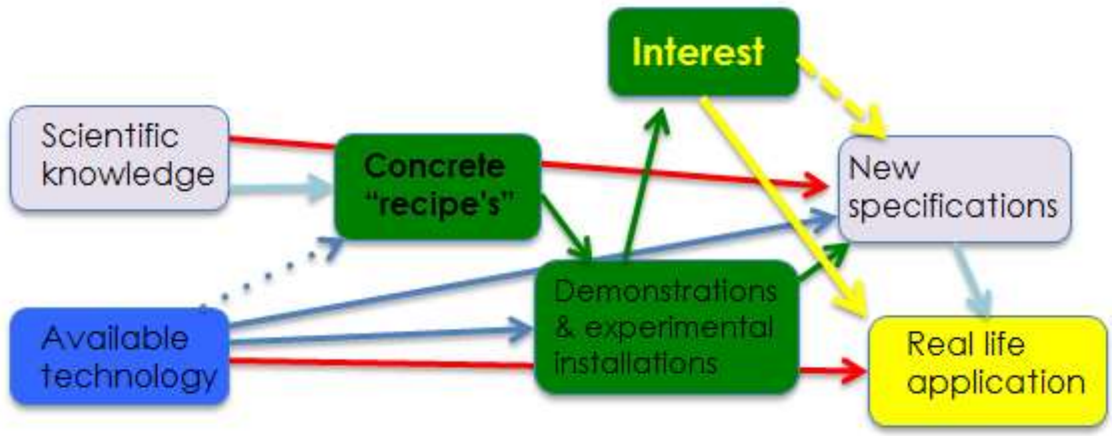

Figure 30 Value chain to enable more advanced usage of the new technical potential and the new scientific knowledge.

Suggestions for further research

A majority of the pupils and teachers expresses that it would be preferable to have slow unnoticeable changes of the intensity and color temperature of the light. It would be interesting to study the speed at which the pupils begin to detect a change.
A majority of the pupils experience the onset of high intensity bluish light as disturbing. It would be interesting to study if the light is experienced as disturbing, also with a slower start-up.

For practical and economic reasons, no daylight control has been included in the design or installation. It would be interesting to research the practical implementation and appreciation of daylight adaption in the control of a Human Centric Light installation. During my light measurements, I noticed a large rapid (400 Hz) variation on the oscilloscope screen. The light as measured with the MHz sensor varied quite considerably and in a rather irregular way, see appendix 12. This is an important area for further research.

During my work I have found ever more scientific results that show that different light characters have different effects on the circadian cycles and alertness. During the spring a new main compilation of numerous results was published via Lighting for People. The latest months I have noted that the interest in Human Centric Lighting is growing very rapidly and it seems as if the GlamoxLuxo installation in Kongsberg is catching a lot of interest. My own interviews and surveys show that most of the users are positive to the possibility to vary the lighting and to be able get more activating light. The combination of the new knowledge and the interest in the possibilities indicate that there are strong reasons to try to make more advanced demonstrations.

10.1 Conclusion

The installation of the automatic light variation has been more complicated than I expected and it has taken a lot of time. But the positive side of this process is that I have learnt a lot. I had not intended to make so many different kinds of observations and measurements. My work has been like a living lab environment and I have become more curious about new aspects like the risk of negative effects of flicker. The dialogues about the basic start-up disturbances have brought new ideas to my attention. I am convinced that the temporal variation of the light is important for human health and wellbeing. It seems as if it now also is becoming easier to find serious suppliers that can deliver automatically varying lighting.

It may appear as if it is sufficient to have tuneable white luminaires and a number of control buttons to be able to select different light characters whenever wanted. However the studies indicate that when one light setting has been turned on the teachers tend to leave it in that position. This is crucial because the observations also indicate that it is unsuitable to have the activating light on during a large part of the day, because then some pupils tend to get a headache. To get out of this contradiction there is a need for automatic variation of the light.

Acknowledgement

It's a bit unusual to work with both design and evaluation of a full-scale project in a master's thesis in lighting design and I would like to thank all of you who helped me make this project possible. It has been a long journey and I want to express my gratitude to my parents and to my supervisor Isabel Dominguez, who supported me when I almost gave up.

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Tove Karlsson

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Symposium

Chronobiology & non-visual effects of light, Mariana G. Figueiro, Light Symposium,Stockholm 2015

Webinar

Webinar: Shining a light on health and wellbeing, Presented by Mariana Figueiro, LRC
file:///C:/Users/tove/Desktop/Light%20on%20health%20and%20wellbeing%20-%20Philips%20Lighting.html

Education

Utbildningsdag "Epilepsi Halvdag I samarbete med Christina Hansson, Limhamn, 2015-10-14, Utbildningsansvarig Maria Granqusit, Sydassistans

Appendix 1

VOCABULARY

Light that is visible to the human eye is electromagnetic radiation with a wavelength of approximately 380-780 nm (DiLaura, 2011).

Circadian rhythm is every process in our body that repeats within approximately 24 hours (circa = about, dies = day). It is influenced by exogenous (generated outside the system) as well as endogenous (generated inside the system) processes. The internal process regulates our circadian rhythm and is able to do so even in a dark cave, but it runs with a period slightly greater than 24 hours for humans, average 24.2 hours. The exogenous processes can influence and change the timing of the endogenous rhythms. Light is the main regulator of our circadian rhythm (Webinar by Mariana Figueiro, 2015).

Circadian disruption can lead to poor sleep and higher stress, increased anxiety and depression, cardiovascular disease, type 2 diabetes and higher incidence of breast cancer among other things. The circadian system has its peak sensitivity at 460 nm, it is a blue sky detector.

Melatonin is a hormone that we produce at night, a hormone that makes us sleepy, and the amount of melatonin with the right conditions, starts to increase in the evening. Melatonin is used as a marker of circadian phase.

Cortisol is a stress hormone that tells the body to transfer from inactivity to activity and has a very sharp peak about 15-45 minutes after waking up.

Illuminance is a photometric quantity to measure how much a surface is illuminated, i.e., the amount of light incident on the surface. Illuminance is measured in lux (lumen / square meter) and is dependent on the orientation and distance from the light source (DiLaura 2011).

Luminance is measured in candela (luminous intensity in a given direction) per square meter. It is the luminance distribution in the room that determines the eye's perceived idea of how bright a surface is. Luminance distribution is a product of the surface reflection properties and illuminance.

To give an accurate picture of a lit environment it is important that we can separate the luminance and illuminance. We normally measure the illuminance, which means that we do not take into account the areas that the light hits. The light sources are crucial for the flow of light in the room. The room design (color, shape, contrast) is also significant for how we perceive a lit environment (DiLaura 2011).

Color Temperature (CCT) is the hue of the light and is measured in kelvin (K). A source that emits white light, but with a higher percentage of the radiation in the red part of the spectrum than in the blue gives a feeling of warm white and mostly blue radiation creates a cold white light. Sources are usually called warm as the color temperature is below 3300 K and cold at color temperatures above 5000 K. (DiLaura 2011)

Color rendering (Color Rendering Index, CRI) is a quantitative measure of the ability of a light source to reproduce the correct colors of various objects in comparison with black body radiation or a standardised daylight. The color rendering is often measured as R_a value. 100 means that the spectral distribution is the same as for the reference source (DiLaura 2011).

A Spectral Power Distribution (SPD) graph shows the relative power for each wavelength across the visible spectrum for a given light source. These graphs also reveal the ability of a light source to render different colors. Daylight has a high relative power of all wavelengths and provides the highest level of color rendering across the spectrum (DiLaura 2011).

Solid State Lighting (SSL) refers to a type of lighting emitted by solid-state electroluminescence, e.g. semiconductor light-emitting diodes (LEDs), organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED). SSL creates light with reduced heat generation and less energy dissipation, compared to incandescent lighting. SSL in itself saves energy, but it is the controllability that causes the greatest opportunities to reduce energy consumption as well as to create more people-centred environments (DiLaura 2011).

Blue light In daily language the term "blue light" is used to describe bluish white light i.e. light with a high colour temperature.

Scientifically; blue light is visible light in the wavelength range of 420- 490 nm. The higher relative part of wavelengths that a light source emits within this part of the spectrum, the bluer the light is perceived. In practice this means that normally, it is only a part of the light from a specific light source that is actually blue.

In addition to the light coming from the light source, different parts of the light bounce (are reflected) on the walls in particular ways. Blue light bounces off a blue wall. This does not mean that we get more blue light in absolute measures, but that a relatively high percentage of the blue light is reflected.

On a white wall (as in the classroom in this specific case), all wavelengths bounces equally. If the wall is not smooth, it will change the direction of the light, normally making the light more diffuse (DiLaura et al 2011).

Previous studies have indicated that light with a higher colour temperature (4000 K) results in higher ability to concentrate (Küller & Lindsten 1992). Scientifically, light in the range of 460 – 500 nm has been proven to have an activating effect (Berson et al 2002).

Red light is visible light in the wavelength range of 650 – 750 nm and bounces of a red wall (DiLaura et al 2011).

Previous studies have indicated that warmer (3000 K) light may enhance communication and decrease agitation and disturbance during lessons (Küller & Lindsten 1992)(Grangaard 1995).

Tuneable white A luminaire that enables the user to select different color temperatures for "white" functional lighting (not decorative lighting).

A **Light Emitting Diode (LED)** is a two-lead (one P-type and one N-type) semiconductor light source which emits light when activated. When a suitable voltage is applied to the leads, electrons will recombine with electron holes within the device and release energy in form of photons. The color of the light corresponds to the energy of the photon which is determined by the energy band gap of the semiconductor.

The output from an LED can range from red (approximately 700 nm) to blue-violet (about 400 nm).Some LED also emit infrared energy at 830 nm or longer.

The LED area is less than 1 mm^2 and integrated optical components can be used to shape its radiation pattern. It can also be combined with other semiconductors and other solid-state components, products and software systems to develop lighting as a part of smart system solutions (DiLaura 2011).

Light characters The words that I use to characterise different kinds of lighting settings and functionalities. I have developed the "words" (concepts) because I need them for my dialogues, control panel buttons and this thesis.

Light Variation Functions A concept that I use in this thesis. The Light Variation Functions include both automatic light variation schemes and also user control possibilities for selection of various light characters. The term dynamic lighting is sometimes used with a similar meaning. I have avoided this term because it is used also for other dynamics than temporal variations of the light.

Appendix 2

This design of the light variation functions was made for a solution with LEDEngins LuxiTune Generation 3.0. that offers a Color Temperature interval of 1400 K to 4500 Kelvin. *The installation was never finalised.*

Light Variation Functions 0

This dynamic light installation will be provided in a classroom for 12-16 year old pupils at Lindeborgsskolan in Malmö.

The installation will be dynamic which means that it will be controllable and shifting throughout the day. The control panel will give two different choices: automatic control and manual control. In the automatic control mode the light will vary throughout the day without any requirements on the user to control it. The manual control offers the user (the teacher) to choose between different lighting scenes depending on the particular task at hand.

100 % correspond to 700 Lux at the table surface.

AUTOMATIC CONTROL:

The lighting will be automatically changing throughout the day, to enable the teacher to invest all energy in the children. The aim is to use presence control in the sense that when someone comes into the room the light is turned on at the intensity and the CT that matches the present time of the day, see table 2. E.g. at 09.00 the light intensity will be at 100 % and CT 4500.

Table 8 Automatic variation of the light throughout the day.

Time	Intensity	CT
07:00	50 %	2700
08:00	50 %	2000
08:40	100 %	4500
09:00	100 %	4500
11:00	70 %	3000
11:30	50 %	2400
11:50	70 %	3500
12:20	80 %	4000
13:00	50 %	2400
13:20	90 %	4500
14:00	80 %	3000
14:20	60 %	2500
15:00	70 %	3000
16:00	50 %	2700
17:00	50 %	2700

<u>Overarching schedule and thoughts around dynamic light:</u>

1. Warm light and lower light intensity until around 8.30 am for the pupils to calm down and sit down
   E.g. Jonas Kjellander who got "Svenska ljuspriset" for the lighting of Matildelunds preschool says that lower light intensity makes us lower our voice, (CEEBEL. Nyhetsbrev, Nr 7,Årgång 2, November 2010)

2. Gradually higher colour Temperature and higher intensity lowers the melatonin content and has a wake up effect to stimulate the pupils to wake up and have energy to work
   Previous studies have indicated that light with a higher colour temperature (4000 K) results in higher ability to concentrate (Küller & Lindsten 1992). Scientifically, light in the range of 460 – 500 nm has been proven to have an activating effect (Berson et al 2002).

3. Warm light for the pupils to calm down before lunch
   The pupils are very active and restless before and after lunch (Questionnaire and personal conversation with the main responsible teacher, December & January 2014).
   Articles *(e.g. Küller & Lindsten 1992) and p*ersonal conversation (e.g. with Kai Piippo, ÅF ljusdesign, December 2014) indicate that warm light has a calming effect.

4. Warm light for the pupils to calm down after lunch (around 2500 K).

5. Gradually colder light and then 30-60 minutes of cold light to stimulate the pupils to work (around 4500 K).
   Previous studies have indicated that light with a higher colour temperature (4000 K) results in higher ability to concentrate (Küller & Lindsten 1992). Scientifically, light in the range of 460 – 500 nm has been proven to have an activating effect (Berson et al 2002).

6. Gradually warmer light before the end of the day (down to around 2700 K).
   To enable the pupils to calm down before the end of the day. Articles *(e.g. Küller & Lindsten 1992) and p*ersonal conversation (e.g. with Kai Piippo, ÅF ljusdesign, December 2014) indicate that warm light has a calming effect.

Any change from one mode to another should be soft.

Daylight control:

If possible, the automatic control will also consist of daylight control to lower the light level when there is more light outside and to get more light in the inner part of the classroom where there is less sunlight.

MANUAL CONTROL:

The manual control offers the user (the teacher) to choose between different lighting scenes depending on the particular task at hand. This choice can made based on research/knowledge on the effect of light on health and wellbeing or the user can choose a light scene that he/she feels particularly comfortable with. E.g. during the seminar one of the teachers expressed a dislike regarding light with a higher CT, regardless of the intensity. It is important that the users feel comfortable with lighting atmosphere.

Table 9 Manually controlled light scenes, depending on the users' preference

Manually controlled light scene	Intensity	CT
"Activating light" The starting point is that more light with higher color temperature is activating. This light can be used when it is important that the pupils concentrate on an individual task or listen to the teacher. *This character is based on late scientific research which shows that blue light is activating, e.g. Berson et al 2002.*	100 %	4500 K
"Lighting for communication" The starting point is that light with lower colour temperature is calming. Previous studies have indicated that higher colour temperature result in higher ability to concentrate and that warmer light may enhance communication (Küller & Lindsten 1992). Another starting point for this setting is the sensitivity of the color cones in our human eye. Human beings have three color cone types; S, M and L. M and L have very similar sensitivities, maximum sensitivities about 535 nm and 562 nm respectively. Those are also the wavelengths that give us the best ability to read minute changes in skin color. It is vital to enable us to see the difference between different nuances in the facial colour (oxygenated/not oxygenated blood) to enable us to interpret the emotional state of the individuals we have around us. *This character is based on research which shows that red light enable us to calm down (with less agitation as a result) and has a positive effect on communication e.g. Sandström et al 2002.*	50 %	1400 K
"Lighting for cleaning" High colour temperature, high intensity. This setting will not affect the pupils.	100 %	4500 K
"Smartboard" Avoid glare and enable the pupils to read & write on the benches while the smartboard is on.	Dim light in front when smartboard is on. Solved with different zones. Automatic control so the light dims down in front when the smartboard is turned on.	

Appendix 3

This design of the light variation functions was made for a solution with a 60 × 60 LED panel from Candelux that offer a Color Temperature interval from 2700 to 6500 K.

This design is very similar to the first design, but CT interval has been adapted to the luminaire.

In the installation that was made the automatic control did not work as intended.

The manual control buttons was used in Questionnaire 1, 2015-09-10.

Light Variation Functions 1

100 % intensity corresponds to 700 Lux at the table surface.

AUTOMATIC CONTROL:

Table 10 Automatic variation of the light throughout the day

Time	Intensity	CT
07:00	50 %	2700
08:00	70 %	2700
08:40	100 %	6500
09:00	100 %	5000
11:00	70 %	3000
11:30	50 %	2400
11:50	70 %	3500
12:20	80 %	4000
13:00	50 %	2400
13:20	90 %	4500
14:00	80 %	3000
14:20	60 %	2500
15:00	70 %	3000
16:00	50 %	2700
17:00	50 %	2700

MANUAL CONTROL:

Table 11 Manually controlled light scenes, depending on the users' preference

Manually controlled light scene	Intensity	CT
"Activating light" The starting point is that more light with higher color temperature is activating. This light can be used when it is important that the pupils concentrate on an individual task or listen to the teacher. *This character is based on late scientific research which shows that blue light is activating, e.g. Berson et al 2002.*	100 %	6500 K
"Lighting for communication" The starting point is that light with lower colour temperature is calming. Previous studies have indicated that higher colour temperature result in higher ability to concentrate and that warmer light may enhance communication (Küller & Lindsten 1992). Another starting point for this setting is the sensitivity of the color cones in our human eye. Human beings have three color cone types; S, M and L. M and L have very similar sensitivities, maximum sensitivities about 535 nm and 562 nm respectively. Those are also the wavelengths that give us the best ability to read minute changes in skin color. It is vital to enable us to see the difference between different nuances in the facial colour (oxygenated/not oxygenated blood) to enable us to interpret the emotional state of the individuals we have around us. *This character is based on research which shows that red light enable us to calm down (with less agitation as a result) and has a positive effect on communication e.g. Sandström et al 2002.*	50 %	2700 K
"Lighting for cleaning" High colour temperature, high intensity. This setting will not affect the pupils.	100 %	5000 K
"Smartboard" Avoid glare and enable the pupils to read & write on the benches while the smartboard is on.	Dim light in front when smartboard is on. Solved with different zones. Automatic control so the light dims down in front when the smartboard is turned on.	

Appendix 4

This design of the light variation functions was made for the same luminaires as described in appendix 2, ie. a solution with a 60 × 60 LED panel from Candelux that offer a Color Temperature interval from 2700 to 6500 K. This design proposal was implemented and used in Questionnaire 2, 2015-11-05.

Light Variation Functions 2

The control-command basic logic is that any changes should be made as a slow linear increase or decrease from the currently prevailing situation to the started feature. In particular, for the "activating light", the light should slowly return to the automatic variation pattern after a certain time. The time intervals for each function and variation are described in the tiny tables below.

100 % correspond to 700 Lux at the table surface.

Automatic variation When the pupils come in from the corridor, it is desirable to start in a light similar to the light in the corridor, 70%, 3000 K, and then with a continuous change go to the setpoints for the current time + start time. The pupils have expressed that a quick change to a bluish light can cause headaches. Therefore, it is important to prepare the sensory system.

Table 12 The light starts from the prevailing lighting situation and then take 20 minutes to switch to the set point 20 minutes after the current time. The automatic variation continues until the user presses a new command.

	Start	Rise time
Automatic	Current	20 min

Table13 Automatic variation patern.

Time	Intensity	CT
08:00	70 %	2700
08:40	100 %	6500
09:00	100 %	5000
11:00	70 %	4000
11:30	70 %	3000
12:00	70 %	2700
12:20	80 %	4000
13:00	90 %	5000
13:20	70 %	4000
14:00	70 %	3500
14:50	70 %	3500
15:20	60 %	2700

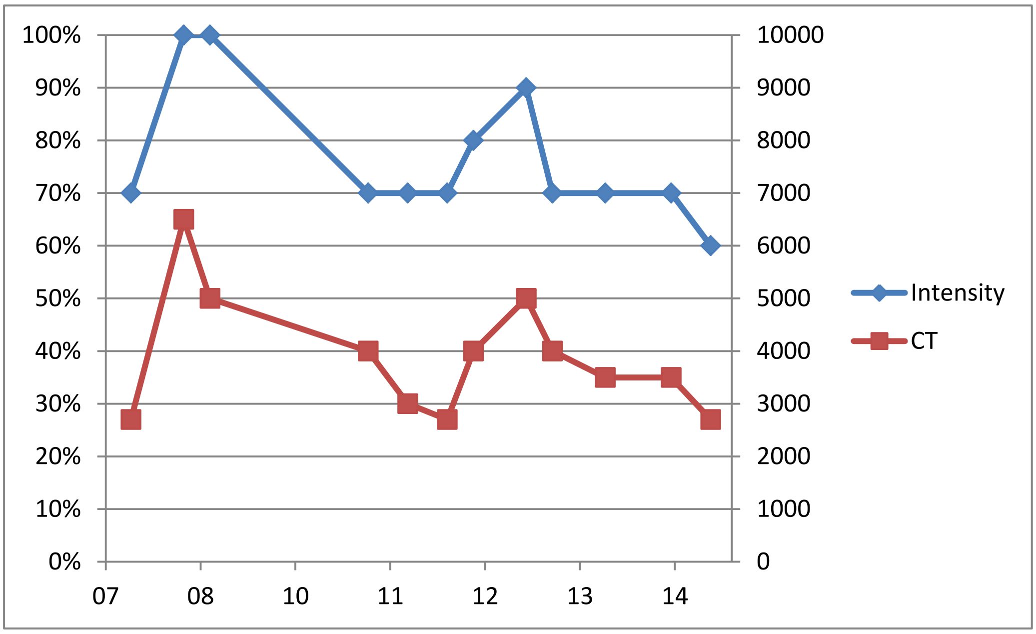

Figure 1 Continuous changes of intensity and color temperature. The straight lines have the same slope all the way between a particular pair of adjacent control points i.e. a continuous gradual change. The goal for this automatic control is to avoid sudden changes.

Activating To provide an activating light dose, while avoiding that the light gets stressful, it seems appropriate to limit the intense light to a limited time. The set point for the activating light should be 70%, 6500 K. The time interval for the pitch, activating and return is listed in Table 2.

It is scientifically proven that intensive and blue light (higher color temperature) is energizing and it is something that more and more lighting people highlights. More intensive bluish light is probably good when it is important that students can concentrate on an individual task or listen to the teacher. The activating light should not be used for too long, as it can cause headaches.

Table 14 The light starts from the prevailing lighting situation and then takes 20 minutes to switch to the activating light. This light is on for 20 minutes and then the system takes 20 minutes to return to the automatic variation.

	Start	Rise time	Time	Return	End
Activating	Current	20 min	20 min	20 min	Automatic

Dialogue 70 %, 2700 K

Many Swedes prefer a redder light (lower color temperature), especially in the evening dimmed down bulbs have been used. Light with a lower color temperature is less stressful and more relaxing. Studies have shown that more red light can help us to learn from each other's facial color. It is important that we can see the difference between shades of facial color (oxygenated / non oxygenated blood) in order to be able to interpret the emotional state of the individuals around us. Redder light often provide good pre-conditions for talks with the essential element of social contact.

Table 15 The light starts from the prevailing lighting situation and then takes 5 minutes to switch to dialogue mode. This light is used for 40 minutes and then it takes the system 10 minutes to return to automatic variation.

	Start	Rise time	Time	Return	End
Dialogue	Current	5 min	40 min	10 min	Variation

Presentation Light on the teacher (70%, 4000K) and whiteboard and more dialogue adapted light further back (50%, 3000 K). The aim is to calm down and focus the pupils' attention to the teacher.

Table 16 The light starts from the prevailing lighting situation and then takes 5 minutes to switch to smart board position. SmartBoard State will remain until the user presses a new command.

	Start	Rise time
Presentation	Current	2 min

Smartboard The light in the front of the classroom is dimmed to 30%, 4000 K to avoid glare while using 70%, 4000 K in most of the classroom to enable the pupils to read and write on the benches while the Smartboard is on.

Table 17 The light starts from the prevailing lighting situation and then takes 5 minutes to switch to smart board position. SmartBoard State will remain until the user presses a new command.

	Start	Rise time
Smartboard	Current	1 min

Neutral light 70 %, 4000 K.

Table 18 The light starts from the prevailing lighting situation and then takes 5 minutes to switch to the neutral light. The neutral light mode remains until the user presses a new command.

	Start	Rise time
Neutral light	Current	5 min

Lighting for cleaning 100 %, 4000 K

Table 19 The light starts from the prevailing lighting situation and then takes 30 seconds to switch to lighting for cleaning. The light will remain until the user presses a new command.

	Start	Rise time
Lighting for cleaning	Current	30 sek

Table 20 Summary table

	Start	Rise time	Time	Return	End
Activating	Current	20 min	20 min	20 min	Variation
Dialogue	Current	5 min	40 min	10 min	Variation
Presentation	Current	2 min			
Smartboard	Current	1 min			
Neutral	Current	5 min			
Cleaning	Current	30 sek			

Appendix 5

This questionnaire was given to the pupils after the first installation and focuses on the lighting functions with the manual control buttons. The result of the questionnaire was used to improve the design the light variation functions.

The questionnaire is built upon the Environmental Psychology method Semantic Environmental Description. The SED has been simplified and adapted to enable a quick evaluation of a real life variable light environment.

Frågeformulär kring ljusinstallationen 2015-09-10

Tycker du att belysningen är viktig för hur man mår/trivs/kan arbeta i ett rum?

Ja ☐ Nej ☐

Ge exempel på belysning som du tycker är bra eller dålig vid olika tillfällen

Har du sett den automatiska ljusvariationen som var igång förraveckan?

Ja ☐ Nej ☐

Om ja, hur upplevde du den?

Den nya ljustekniken ger stor möjlighet att variera ljuset. Om du kunde få bestämma precis hur ljuset skulle se ut, hur skulle det vara då?

Skulle du vilja ha någon speciell typ av belysning vid något särskilt tillfälle i klassrummet?

____

____

____

____

Demo 1. Sätt ett kryss på skalan där du anser bäst beskriver hur du uppfattar ljuset.

Rödaktigt ________ ________ ________ ________ Blåaktigt

Mjukt ________ ________ ________ ________ Intensivt

Komfortabelt ________ ________ ________ ________ Störande

Tröttande ________ ________ ________ ________ Uppiggande

Otrevligt ________ ________ ________ ________ Trevligt

Demo 2. Sätt ett kryss på skalan där du anser bäst beskriver hur du uppfattar ljuset.

Rödaktigt ________ ________ ________ ________ Blåaktigt

Mjukt ________ ________ ________ ________ Intensivt

Komfortabelt ________ ________ ________ ________ Störande

Tröttande ________ ________ ________ ________ Uppiggande

Otrevligt ________ ________ ________ ________ Trevligt

Appendix 6

This questionnaire was given to the pupils after the second installation, which included automatic light variation and control buttons. The result of the questionnaire was used to evaluate the childrens' experience of the light variation functions.

The questionnaire is built upon the Environmental Psychology method Semantic Environmental Description. The SED has been simplified and adapted to enable evaluation of a real life **variable** light environment.

Frågeformulär kring ljusinstallationen 2015-11-05

Hur upplevde du ljusvariationen under föregående lektion?

Varierande __________ __________ __________ __________ Konstant

Harmonisk __________ __________ __________ __________ Stimulerande

Komfortabel __________ __________ __________ __________ Störande

Tröttande __________ __________ __________ __________ Uppiggande

Otrevlig __________ __________ __________ __________ Trevlig

Gradvisa ändringar __________ __________ __________ __________ Plötsliga ändringar

Skulle du vilja Öka________ ________ ________ ________Minska hastigheten på förändringen?

Kommentarer:

____

____

____

Demo 1
Har ni märkt att ljuset har förändrats de senaste 20 minuterna?

Inte alls __________ __________ __________ __________ Mycket

Skulle du vilja Öka________ ________ ________ ________Minska hastigheten på förändringen?

Vilka tre ord anser du bäst beskriver ljuset som är i klassrummet nu?

____________________ ____________________ ____________________

Demo 2 Vilka tre ord anser du bäst beskriver ljuset som är i klassrummet nu?

____________________ ____________________ ____________________

Demo 3 Vilka tre ord anser du bäst beskriver ljuset i klassrummet just nu?

____________________ ____________________ ____________________

Sätt ett kryss på skalan där du anser bäst beskriver hur du uppfattar ljuset.

Rödaktigt __________ __________ __________ __________ Blåaktigt

Mjukt __________ __________ __________ __________ Intensivt

Komfortabelt __________ __________ __________ __________ Störande

Tröttande __________ __________ __________ __________ Uppiggande

Otrevligt __________ __________ __________ __________ Trevligt

Demo 4 Hur bra ser du läraren?

Bra __________ __________ __________ __________ Dåligt

Demo 5 Hur bra ser du att arbeta på bänken?

Bra __________ __________ __________ __________ Dåligt

Appendix 7

Frågeformulär kring ljusinstallationen på Kongsgårdmoen skole

Tycker du att belysningen är viktig för hur man mår/trivs/kan arbeta i klassrummet?

Ja ☐ Nej ☐

Hur upplever du belysningen och ljusvariationen i klassrummet?

Harmonisk ______ ______ ______ ______ Stimulerande

Komfortabel ______ ______ ______ ______ Störande

Tröttande ______ ______ ______ ______ Uppiggande

Otrevlig ______ ______ ______ ______ Trevlig

Varierande ______ ______ ______ ______ Konstant

Gradvisa ändringar ______ ______ ______ ______ Plötsliga ändringar

Skulle du vilja Öka______ ______ ______ ______Minska hastigheten på förändringarna?

Skulle du generellt sett vilja Öka ______ ______ ______ ______ Minska ljusstyrkan?

Kommentarer:

____

____

____

____

Hur upplever du det aktiverande ljuset?

För lite	____	____	____	____	För mycket
Rödaktigt	____	____	____	____	Blåaktigt
Mjukt	____	____	____	____	Intensivt
Komfortabelt	____	____	____	____	Störande
Tröttande	____	____	____	____	Uppiggande
Otrevligt	____	____	____	____	Trevligt

Ge exempel på belysning som du tycker är bra eller dålig vid olika tillfällen

____

____

____

Den nya ljustekniken ger stor möjlighet att variera ljuset. Om du kunde få bestämma precis hur ljuset skulle se ut, hur skulle du då vilja ha det?

____

____

____

____

Vad tycker du om LED för belysning?

____

____

____

Appendix 8: Light seminar

Välkommen till en presentation av ljusets betydelse i skolan

När: 11 februari 2015 kl. 15.00 - 16.30

Var: Sal 33 på Lindeborgsskolan

Belysningen påverkar vårt välbefinnande och vår hälsa mycket mer än de flesta inser. Ljuset är viktigt på många sätt och FN har proklamerat 2015 som ett internationellt ljusår, www.light2015.org
På följande sida finner du utbildningsmaterial för grundskolan:
http://www.light2015.org/Home/HandsOnInvolvement/Kids-and-Optics.html

Den nya dynamiska belysningstekniken ger nu möjlighet att skapa belysning som fungerar bättre för de aktiviteter som sker i klassrummet, så att eleverna blir mindre stressade och kan hålla sig aktiva när de behöver vara det. Den nya belysningstekniken är ett viktigt medel för att förbättra hälsa och välbefinnande på skolor, i vård och äldreomsorg.

Under Sportlovet kommer en ny dynamisk belysning att installeras i sal 33 på Lindeborgsskolan. Tove Karlsson, masterstudent i ljusdesign vid KTH, står för designen och installationen kommer att utföras av Elektrolanz (http://elektrolanz.se/). Klassrumsinstallationen är en av många ljusrelaterade aktiviteter som sker under 2015. Inside Light vid Lunds universitet arbetar tillsammans med Sydsvenska städer och företag för att Sydsverige skall ta en synlig roll i FN:s internationella ljusår. Se också bifogad inbjudan till ett internationellt ljusseminarium i Lund 5 februari.

Inside Light bjuder nu också in till detta seminarium kring framtidens skolbelysning. Seminarieledare är Thorbjörn Laike, Professor i miljöpsykologi vid Lunds universitet, föreståndare för CEEBEL (Centrum för energieffektiv belysning) och en ledande forskare på ljusets betydelse för människans hälsa och välbefinnande. Thorbjörn leder flera forskningsprojekt om belysningens inverkan på hälsa och välbefinnande.

Seminariet inleds med en kort presentation av projektet samt en föreläsning kring (skol)belysning, hälsa och välbefinnande och avslutas med produktdemo, diskussion och möjlighet att ställa frågor.

I installationen kommer vi att använda oss av ljuskällan LuxiTune™ gen 2.0. Vid seminariet kommer vi att ta med ett demokit av LuxiTune™ gen 3.0 för att få möjlighet att titta och känna på.

Anmälan sker till: tove.karlsson@luopen.lu.se

Vänliga hälsningar

Tove Karlsson & Thorbjörn Laike

KTH & Lunds universitet

Table 21 Participant list

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Thorbjörn Laike, Professor i miljöpsykologi vid Lunds universitet	thorbjorn.laike@arkitektur.lth.se; Tel: +46462227078
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”The importance of light in school”

Meeting notes from a seminar at Lindeborgsskolan 2015-02-11

The main objective of the seminar was to explain the potential user value of dynamic lighting and to create a coherent awareness among users, buyers, sellers and installers.

To be able to start a positive learning spiral around a demo installation of new light, it is important to attract a positive interest among the users. To do this, it is important to take their ideas seriously and to integrate them in the installations of the new light.

This seminar about the classroom installation at Lindeborgsskolan aroused great interest. It was introduced by a short presentation about dynamic light and the specific product; LEDEngins LuxiTune Generation 3.0, by Tove Karlsson. Thorbjörn Laike, Professor in Environmental psychology at Lund University held a presentation about the non-visual effects of light. Thorbjörn supported that is it is a good idea to have a higher content of red to get a more harmonic atmosphere and addressed the importance of bright bluish ambient light for students to become alert.

At the end of the seminar LEDEngin’s demo Light Engines was demonstrated and the colour distribution was measured with Thorbjörn’s advanced spectrometer to show the variation in spectral distribution and be able to discuss the possible variations that LuxiTune can provide.

The participants; technical managers, city representatives as well as schoolteachers, showed a positive interest in the potential user advantages of dynamic lighting.

One of the teachers said that she does not like the bluish LED light in general, not only when dimmed but also at full effect. She thought that the possibility of manual control is definitely needed (ability to choose the warm colour of the light).

The main responsible teacher of this classroom considered the placement of the light switch as a main concern. In current situation it is very inaccessible.

Magnus Rosberg from Grontmij proposed a solution with additional ambient lighting on the walls. His main concrete proposal is a light source from Zumtobels Tunable White assortment: http://www.zumtobel.com/tunablewhite/en/index.html#

Luminaire suggestion: http://www.zumtobel.com/com-en/products/product_popup.html?42182193

Helena Bendz, Beijer Electronics, proposed a control panel to control the lighting: iX HMI SoftControl file:///C:/Users/tove/Downloads/iX%20HMI%20SoftControl%20brochure_130528_low%20(1).pdf The installation is possible until week 12. After that the National exams will start and it will be hard to get access to the classroom.

Appendix 9: Questionnaire on the old solution

The following questions were sent to the teachers who teach in the classroom before I started planning the installation. I wanted to get an idea about how the teachers appreciate this room. The questions are written in Swedish to simplify for the teachers to answer the questions.

<u>The questions were sent to the following teachers:</u>

Anna Milstam is the responsible teacher of this room. Teaches german in this room.
Andreas Palmqvist teachers 6th graders in SO in this room.
Charlotte Jörme 6th graders in mathematics.
Agneta Lexholm a large group 6th graders in spanish.
Camilla Ohlsson 9th graders in german once a week.

<u>The questions:</u>

Trivs du med att undervisa i sal 33?

Upplever du några specifika problem med utformningen av salen?

Är du nöjd med belysningen i salen?

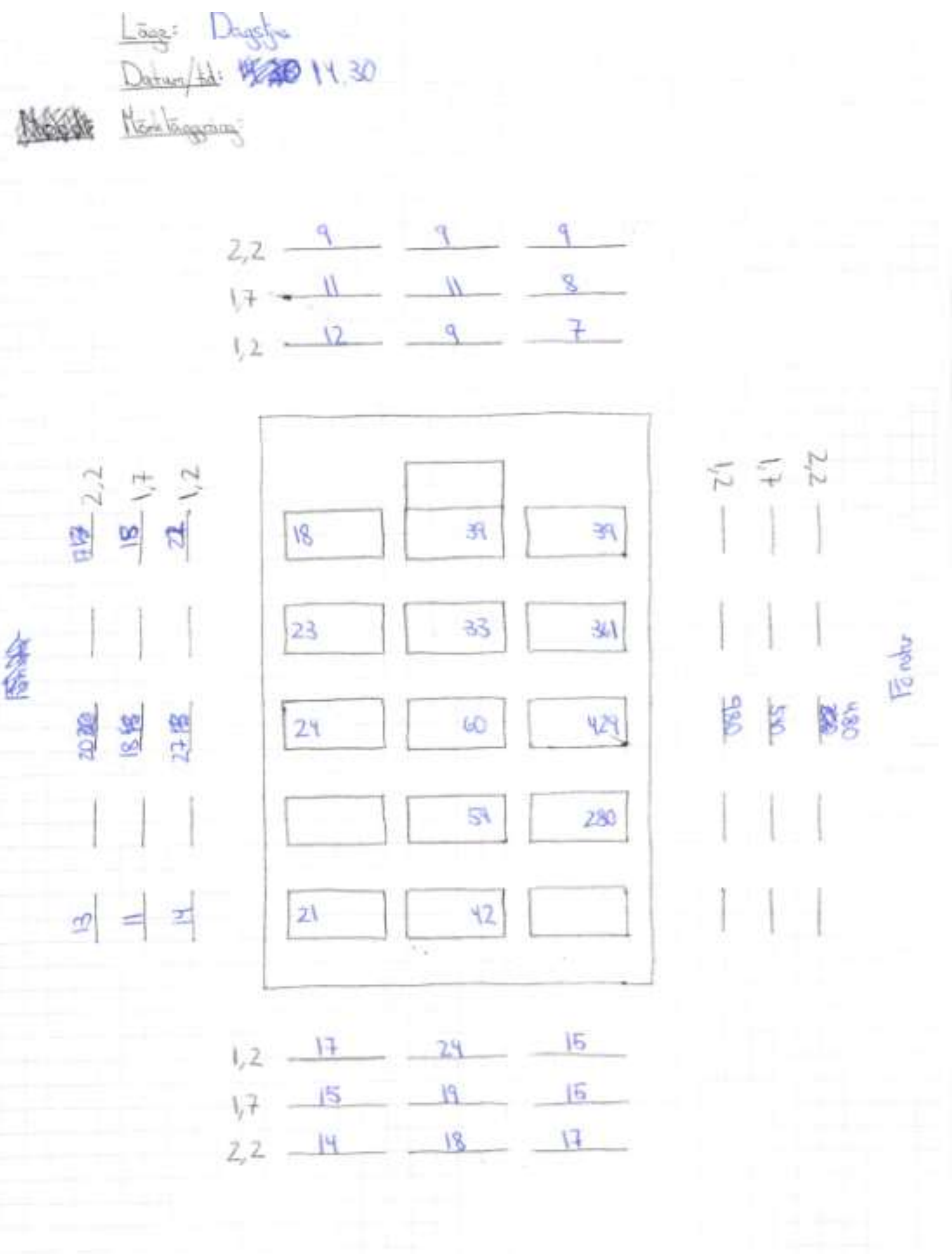
Upplever du några specifika problem i klassen du undervisar? Är det t.ex. höga ljudnivåer eller är eleverna särskilt trötta eller uppvarvande under någon specifik tid på dagen?

Tror du att dynamisk belysning kan förbättra arbetsförhållandena i klassrummet?

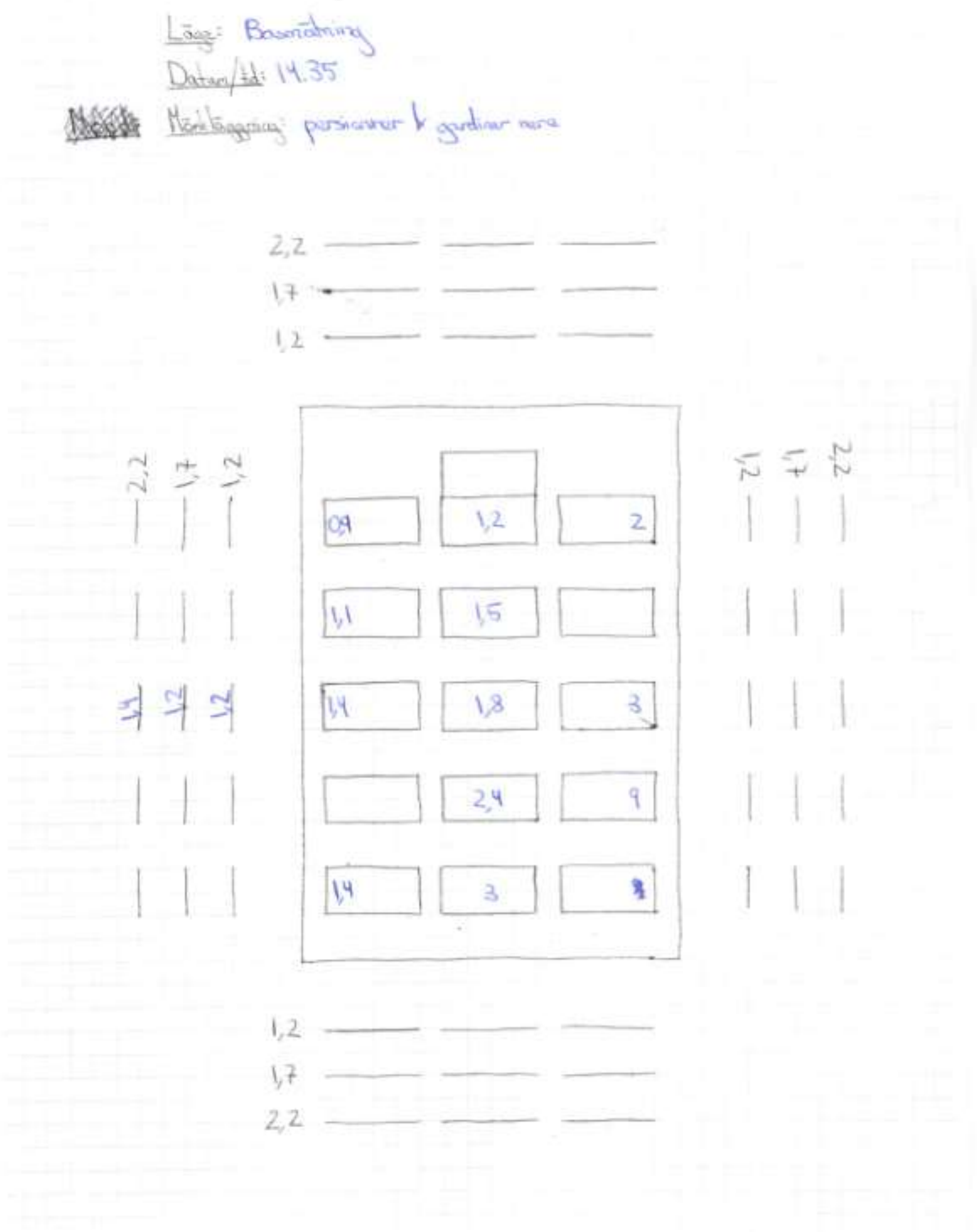
Hur skulle du vilja att belysningen i klassrummet förändras?

Appendix 10

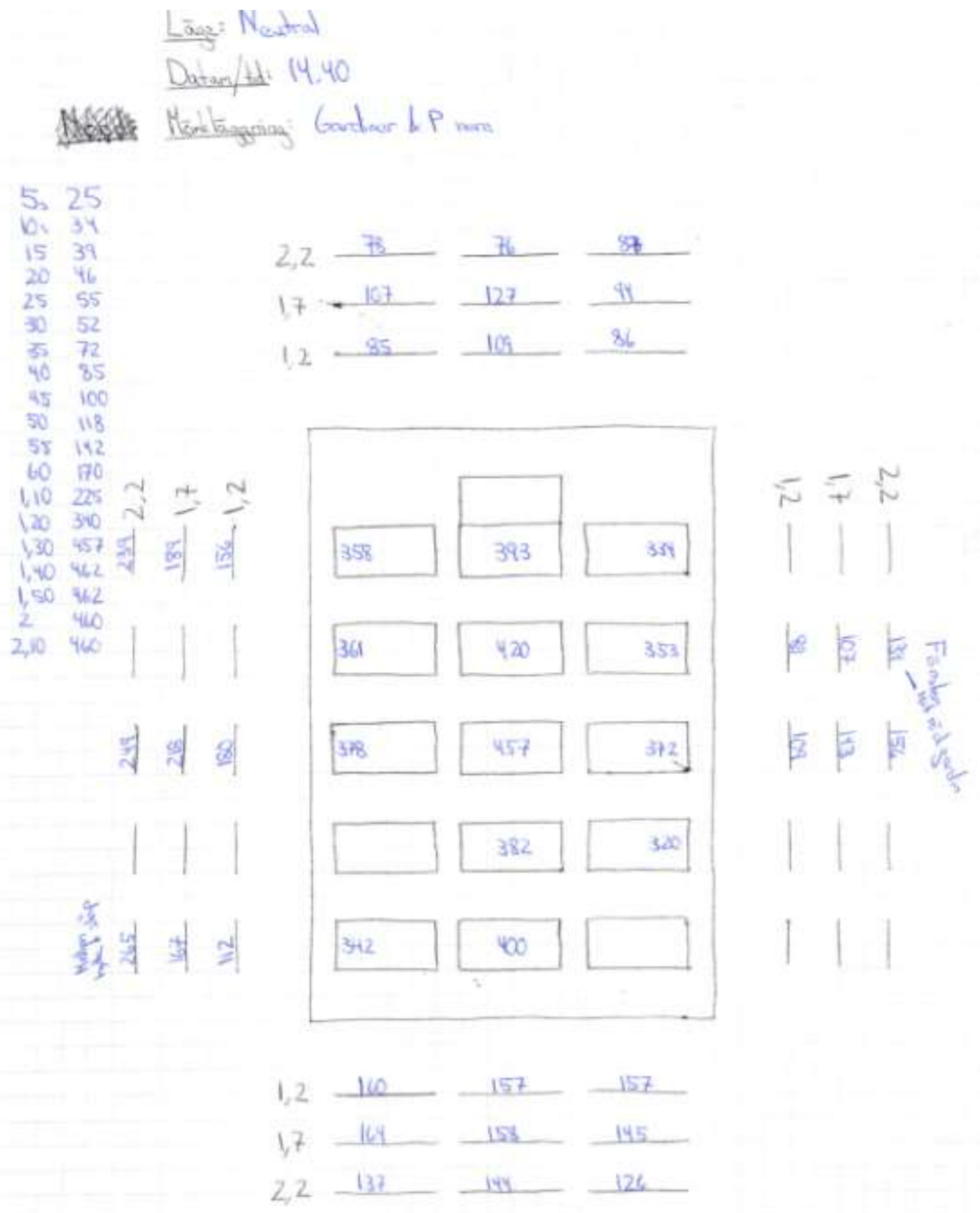
Light distribution with only daylight



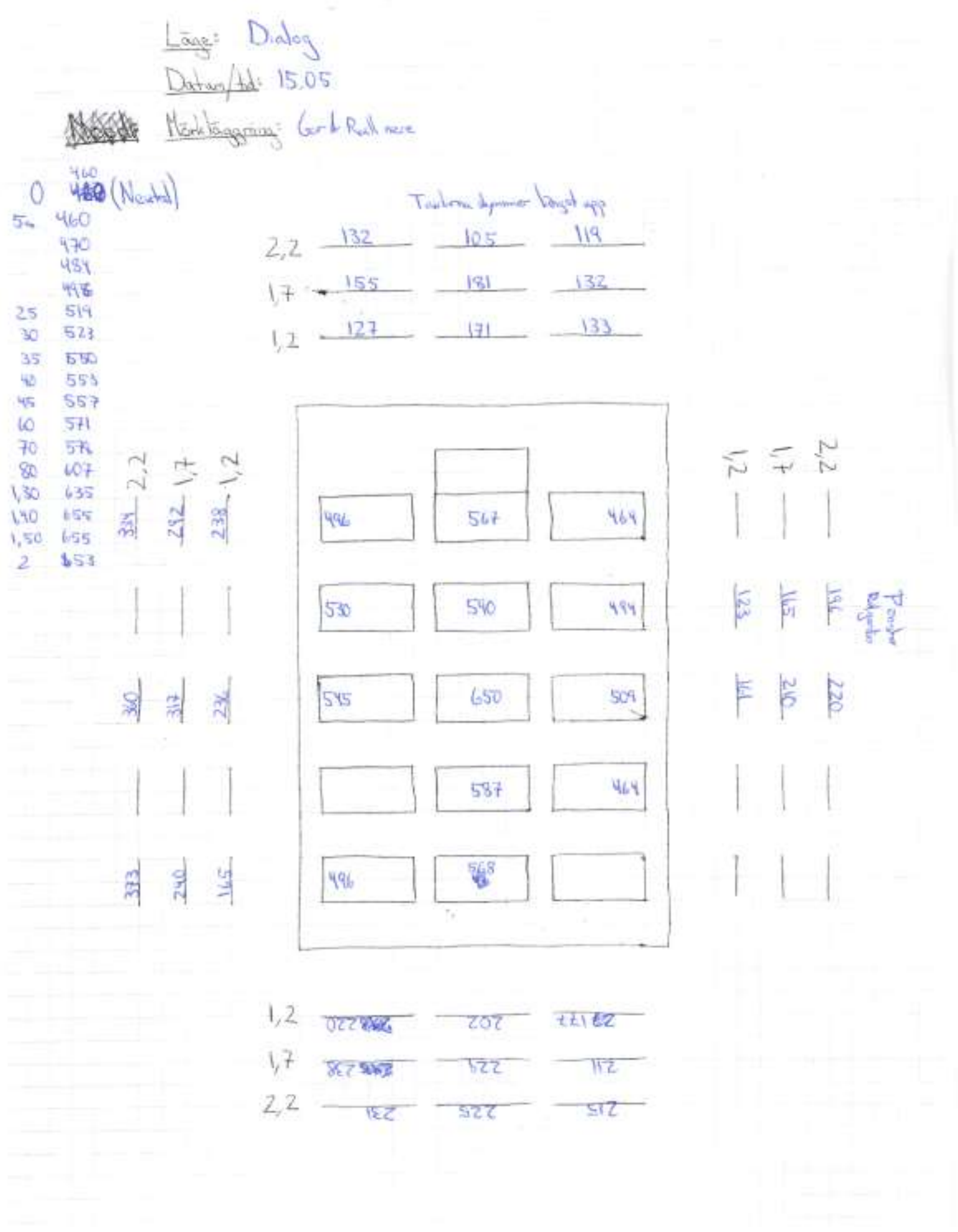
Light distribution in the baseline measurement (only daylight, blinds and curtains down)



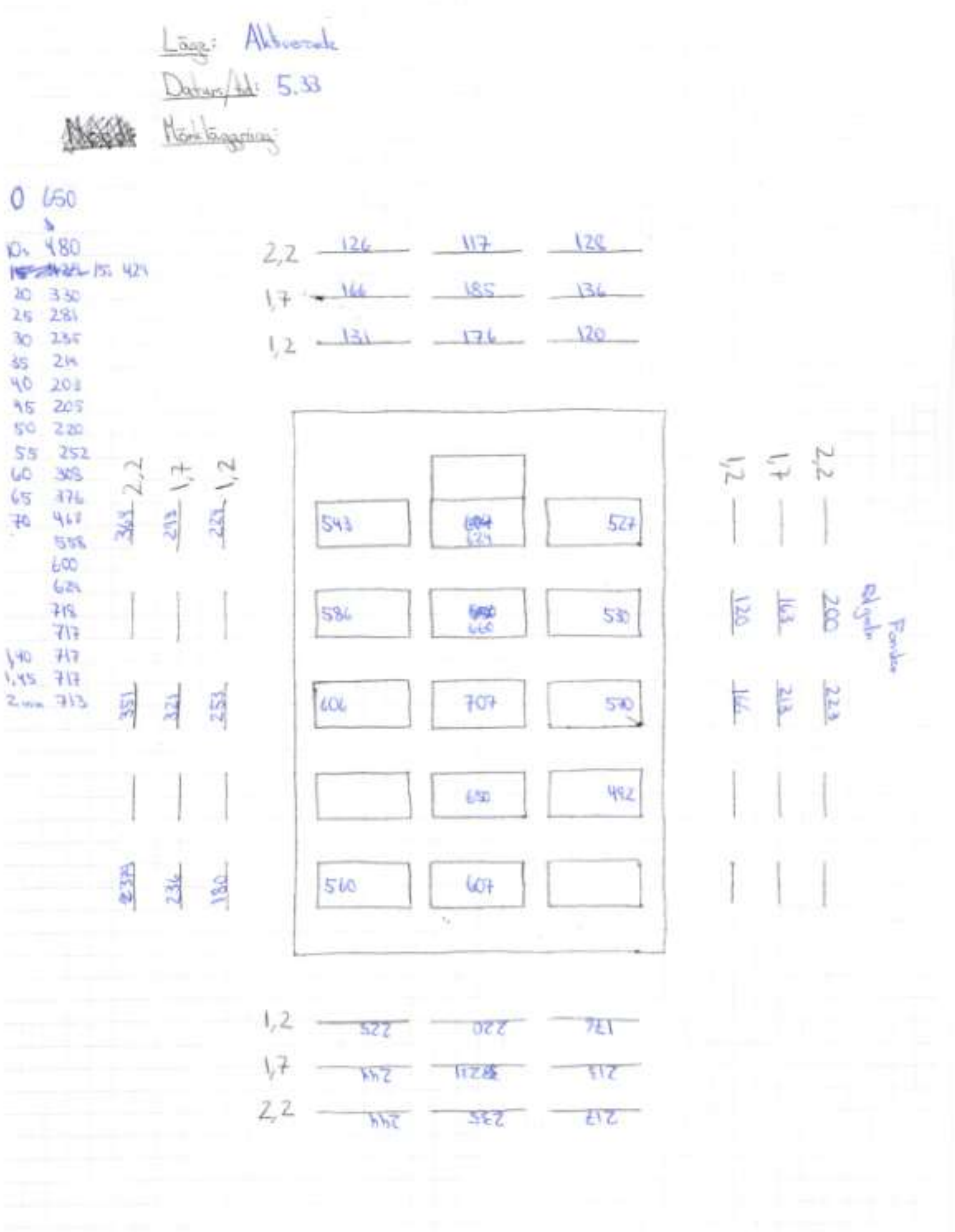
Light distribution in the Neutral character



Light distribution in the Dialogue character



Light distribution in the Activating character



Appendix 11

As a final check I had intended to make measurements to verify the automatic light variation. I have seen that the light varies and the supplier tell me that the automatic light variation is working. But there have been so many other disturbances to consider that I have not been able been able to verify if the automatic light variation works as specified. I borrowed instruments and made one set of measurements of spectral distributions, light variations and flicker November 10. Some curves are included in Appendix 10 However the specific results that caught my main attention was the variation patterns in illuminance and colour temperature after the manual start of the various characters. Table 6 and Table 7 show the variations after the starts of the Dialogue character and the start of the Activating character. The problem is that there is a significant dip in illuminance during the first minute. I suppose that this only is a technical start up problem.

Table 22 CCT variations after the start of the Dialogue character.

Start of dialouge character

Time s	CCT Kelvin	Illuminance Lux	
0	5700	(480)	Activating
15	5350	260	
30	2870	170	
45	3070	225	
60	3500	400	
75	3900	550	
90	3700	540	
105	2870	542	
120	2830	540	Dialogue

Table 23 CCT variations after the start of the Activating character.

Start of activating character

Time s	CCT Kelvin	Illuminance Lux	
0	4030	440	Neutral
10	2900	330	
20	2800	230	
30	3070	184	
40	4700	166	
50	5950	230	
60	5900	480	
75	5600	530	
90	5760	590	
105	5560	593	
120	5700	596	Activating

November 20 I made new measurements, but this time only with my own Lux-meter. The Dialogue character had a normal start up. However, there still was a dip during the start of the Activating character, see Table 24.

Table 24 Start-up for "Neutral".

Time (s)	Illuminance (Lux)		
	Start of Neutral	Start of Dialogue	Start of Activating
0	0	460 (Neutral)	650 (Dialogue)
5	25	460	480
10	34	470	429
15	39	484	330
20	46	496	281
25	55	519	235
30	52	523	214
35	72	550	203
40	85	553	205
45	100	557	220
50	118	571	252
55	142	578	308
60	170	607	376
70	225	635	468
80	340	655	558
90	457	655	600
100	462	655	629
110	462		718
120	460		717
130	460		717
			717
			713

Appendix 12

Spectral distribution and flicker measurements at Lindeborgsskolan

2015-11-10

Those measurements have been done as a small part of a Master thesis in Architectural Lighting Design. The thesis focuses on the human experiences of various light environments. The measurement of spectral distributions is extra thesis information and the measurement of flicker was only intended to be an additional check-up. The aim for the flicker measurement was to check if there is any 100 Hz flicker. I did not find any significant 100 Hz flicker.

However, I noticed another strange light variation on the oscilloscope screen. The light as measured with the MHz sensor varied quite considerably and in a rather irregular way. The first screen dump I managed to do shows an approximately 400 Hz variation with a Peak to peak light variation that is 86 % of the Maximum value, see Figure 1.

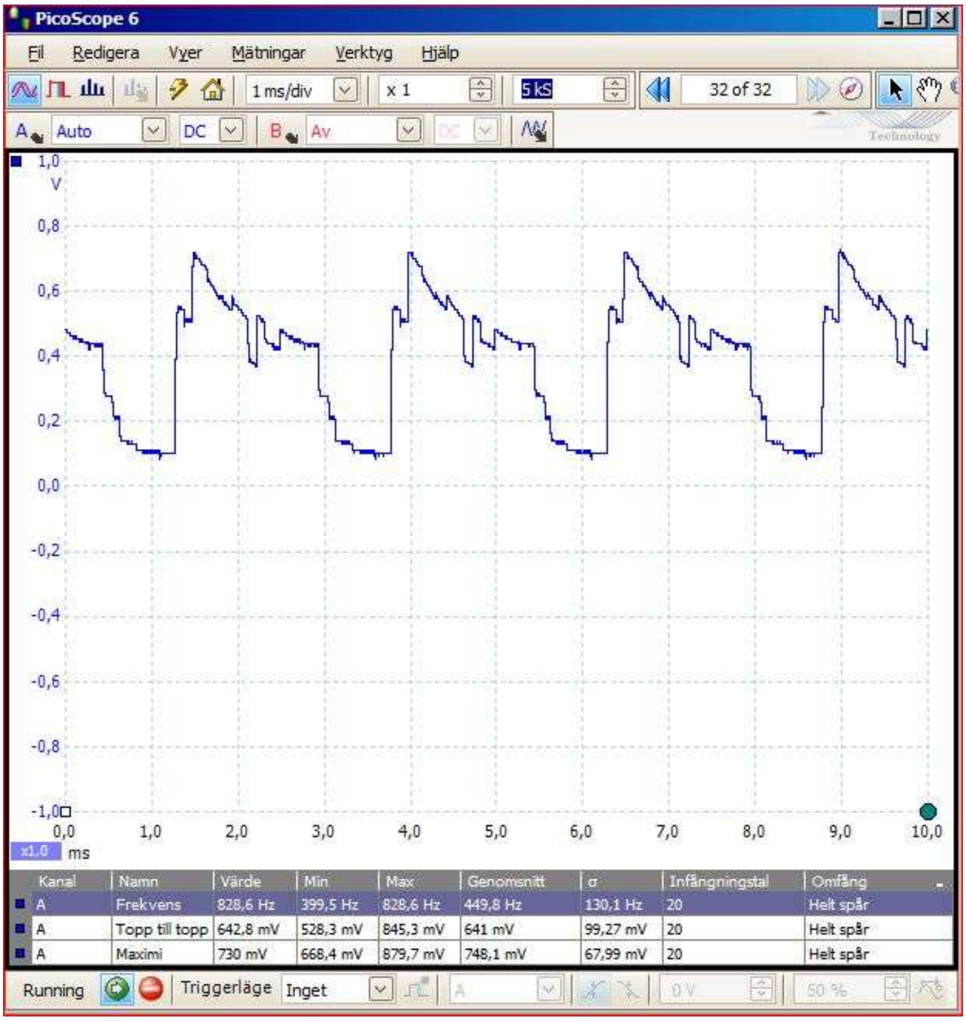


Figure 31 Light variation pattern for one luminaire. Screen dump with time scale 1 ms/division and relative variation of the illuminance, on the y-axsis.

Figure 1 shows one example of light variation. Figure 2 include two other examples in screen dumps were also the spectral distribution simultaneously was shown on the same screen. The reason that this picture could be generated in this way is that both the spectral distribution measurement software and the flicker measurement software ran in the same PC.

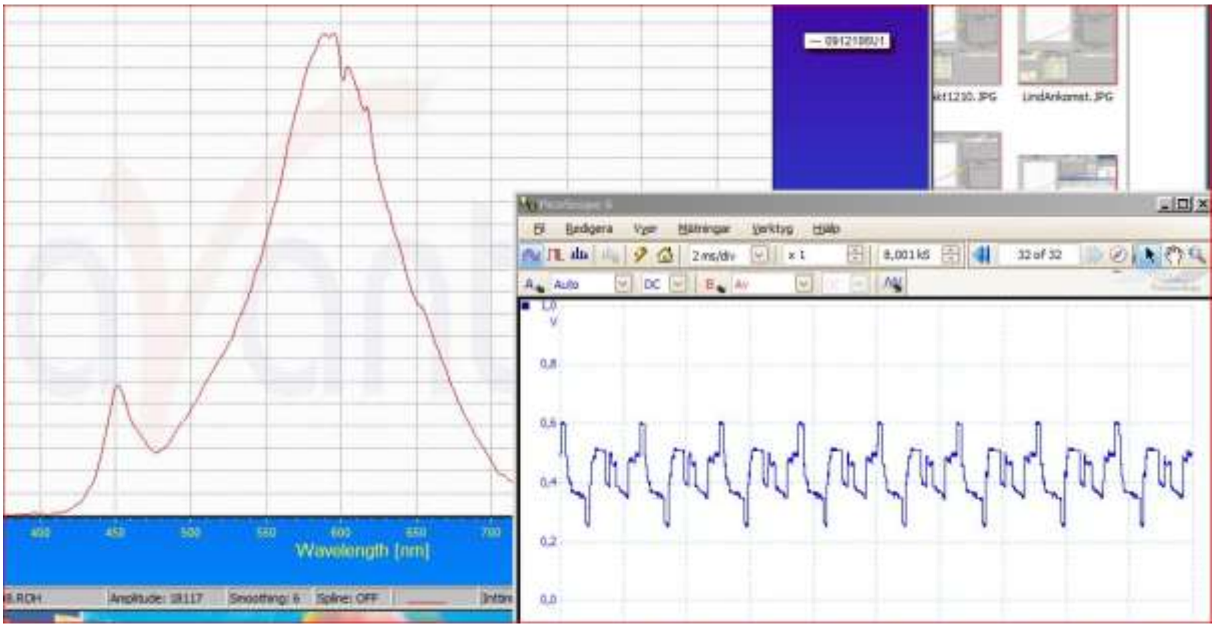


Figure 22 Simultaneous measurement of spectral distribution and ms light variation.

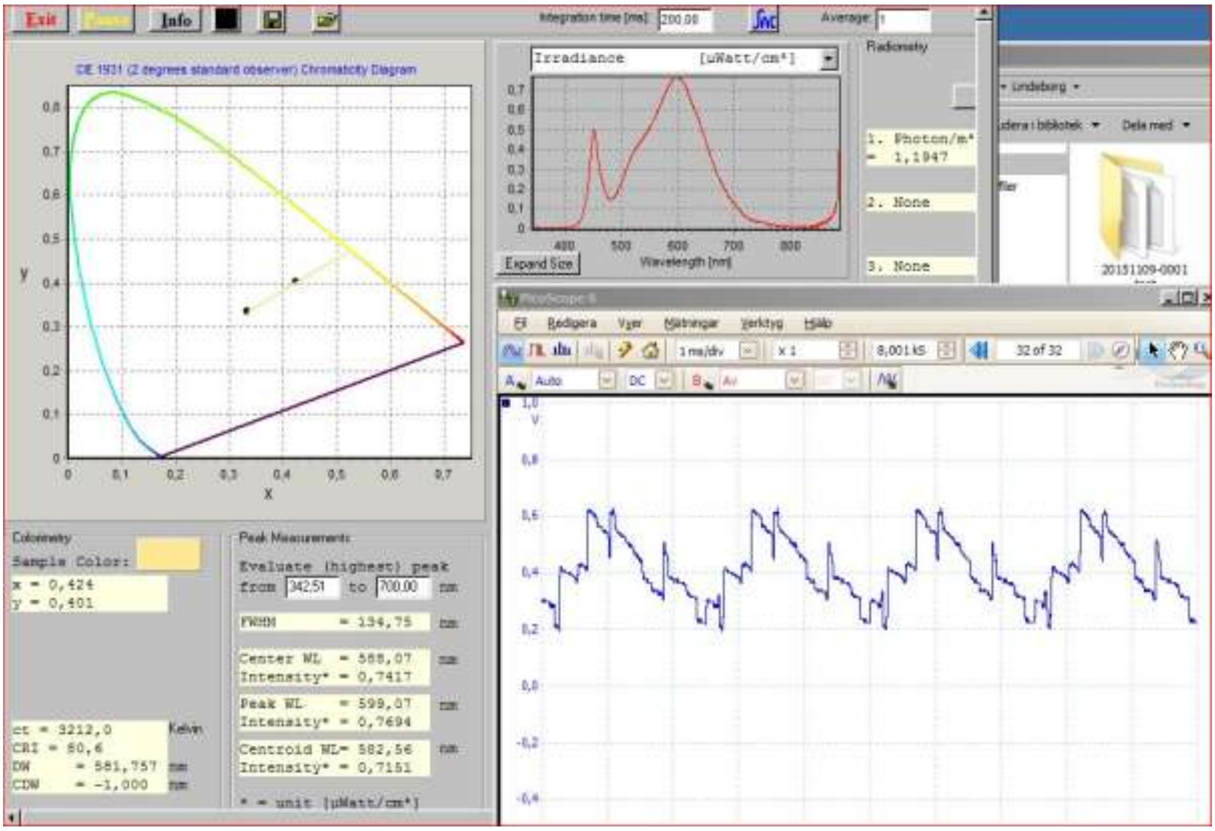


Figure 33 Simultaneous measurement of calculated light parameters, e.g. colour temperature (ct) and Colour Rendering Index (CRI), and ms light variation.