Is Human Centric Lighting Really Human Centric in a Classroom?

A holistic evaluation of a HCL-system in a classroom

Architectural Lighting Design

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IS HUMAN CENTRIC LIGHTING REALLY HUMAN CENTRIC IN A CLASSROOM?

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Master Thesis, Architectural Lighting Design
KTH, Royal Institute of Technology
Lighting Laboratory, 2017
ABSTRACT

The purpose of this study is to evaluate Human Centric Lighting in a classroom. Previous studies tend to focus primarily on the biological, non-visual, effects of the HCL. In this study, a more holistic approach to HCL is applied, including both the non-visual aspect as well as the visual and emotional aspects.

In order to fulfil the aim of the study, the three aspects - visual, emotional and biological - will be investigated through five different methodologies; observation and analysis of lighting distribution and behavioural analysis of lighting system as a visual aspect, surveys about the mood and emotions as an emotional aspect and visual performance and visual acuity as a biological aspect.

The evaluation took place in the elementary school Sturebyskolan in Stockholm, where a classroom with a HCL-system is to be found. The system includes three lighting settings; 800 lx and 6000 K (energy light/focus light), 500 lx and 4000 K (standard/normal light) and 300 lx and 3000 K (calm/relaxed light).

Results show positive effect on visual performance and better visual acuity in focus lighting than in relaxed lighting. Focus lighting was perceived as a cold and hard lighting for tests, while the relaxed lighting was perceived as a warm and calm lighting for a cosy feeling. The lighting characteristics are suited for a typical classroom. The ignorance of the lighting system can be a problem for the experience and usage of the lighting in the classroom.

In summary, to denominate a lighting system as HCL and only consider the altered colour temperature and light intensity is not comprehensive enough. A HCL-system needs to consider the visual, emotional and biological aspects, and the biological aspect is explicitly considered in this lighting-system, whilst the emotional and visual aspects are however not carefully considered.

As a proposal to consider all three aspects, several layers of light could be added in order to strengthen the visual aspect and create a vivid and interesting atmosphere. Moreover, conscious arrangement of luminaires and luminaires with flexible characteristics could simplify and broaden the opportunities in the classroom and facilitate the use of light layers.
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INTRODUCTION
Since the discovery of the third photoreceptor in the eye and the evidence of the biological influence from light, the term Human Centric Lighting (HCL) has become more popular in the lighting industry. Overall, HCL tends to focus too much, or only, on the non-visual effects of the lighting where tunable white-luminaires in some cases has been equated with HCL.

HCL is still a quite new concept in the lighting industry and still mostly used in office and health care environment. A large area of application could be schools and educational environments. Due to my previous experience as a teacher, I find it interesting to investigate the effects of lighting in school environment. At an elementary school in Stockholm, Sturebyskolan, there is a classroom with Human Centric Lighting luminaires which are automatically controlled and vary light intensity and colour temperature according to the time of day. A few other schools or classrooms have tested different kinds of HCL solutions, but there is still more research to be done in this field.

Previous studies tend to focus on the biological, non-visual, effects of the HCL. In this study, a more holistic approach to HCL is applied, including both the non-visual aspects as well as the visual and emotional aspects. The purpose of this study is to emphasize the visual aspect of lighting design and broaden the view of HCL.

AIM
The aim of this study is to evaluate Human Centric Lighting in a classroom from a visual, emotional and biological aspect. Another objective is to propose a suitable lighting design with the use of Human Centric Lighting in a classroom.

HYPOTHESIS AND RESEARCH QUESTIONS
My hypothesis is that HCL needs more consideration than a tunable white luminaire with varying light intensities and colour temperatures. The research questions are as follows:

- Are varying colour temperatures and light intensities enough to call a lighting system Human Centric Lighting?
- How can a Human Centric Lighting design that considers both the visual and the non-visual aspects look like in a classroom?
BACKGROUND

VISUAL PERCEPTION
In his V/P Lighting Theory, Anders Liljefors makes a distinction between visual and physical entities and he believes that the physical radiation is not the starting point in a lighting context, but the visual experience of a space. Liljefors means that even if the measurement of two lines are equal, but we perceive them visually as different lengths, the visual perception is not wrong, only different from the measurement. “The horizontal lines look different as a result of the vision’s remarkable ability to perceive the visual experience of space.” (Liljefors, 1999) Furthermore, Liljefors means that “It is fully possible to methodically describe a reliable knowledge of the visual world, based on common visual experiences, in terms which make it possible to specify basic relations visually-physically.” In V/P Lighting theory the visual experience of a space is described by seven terms;
- level of lightness, how light or dark it is in a room
- spatial distribution of brightness, where it is darker or lighter in a room
- shadows, where they fall and their character
- reflections, where they occur and their character
- glare, where it occurs and how noticeable it is
- colour of light, the colour experience of the light
- colours, if they look natural or distorted. (Liljefors, 1999)

Seeing is an active information-seeking process where visual sensory data are coordinated with contextual information from other senses, past experience etc. According to Lam, we have three aspects of perception; the attributive (matching patterns and classification), the expectant (associations with sequences and expectations due to previous experience) and the affective (how stimuli affects our emotional or evaluative responses), which in reality are hard to separate because they are intimately interrelated. In addition, because our visual attention seeks the most interesting thing in the visual field, our focus selector directs our attention to a bright spot or another interesting object which can be information (light on a sign or stage) or a distraction (when illuminated elements are unrelated to our needs). (Lam, 1992)

However, by fully illuminating spaces with a uniform light that makes everything visible, nothing is emphasised, which may create a lack of visual interest with no support for orientation and spatial understanding. (Wänström Lindh, 2013)

Madsen has developed the term light zones to describe spatial units made up of light within the space as a tool for analysis. Light zones can be grouped into three categories: A) a single or separate light zone, B) light zones in close connection with each other, and C) light zones that overlap each other to create a compound, illuminated area. Madsen’s observations became the starting point for viewing illuminated fields in the scale model study. Madsen study only examined natural light, but it is possible to analyse artificial light sources with the same tool. (Madsen, 2004).

In 1992, Ejhed did a full scale study to investigate if it was possible to create a grammar for lighting and environmental design. As a method he used, among other, semantic differential scales where the test subjects would evaluate different rooms by making notes in 31 different semantic scales. In order to make the abstract answers more tangible, the semantic scales were supplemented by questions about associations and characteristics of the room. The
evaluation responses were processed in a matrix program on a computer which determined the meanings of and relations between the semantic scales/pairs of words. (Ejhed, 1992)

In 1952 Richard Kelly established a terminology and principles as a theoretical foundation in lighting. He presented three elements in the perceptions of visual design; focal glow, ambient luminescence and play of brilliants. These three elements later became a point of reference in the field of lighting design. (Neumann, 2010)

**NON-IMAGE FORMING EFFECTS OF LIGHT**

Both humans and animals have a circadian rhythm, or inner clock, which for example controls our sleep cycle. For a long time, it was assumed, but not proven, that light had a great impact on the circadian rhythm. The discovery of the third, non-image forming, photoreceptor (NIF) in 2002 confirmed that the receptors in the eye not only have a visual function, but also a biological function (Berson et. al., 2002) (Hattar et. al., 2002). The third receptors, intrinsically photosensitive retinal ganglion cells (ipRGCs) work similar to rods and cones, except that it does not transmit information to the visual cortex, but directly to the suprachiasmatic nuclei (SCN) and further on to the pineal gland where the hormone melatonin is synthesized depending on the light conditions. This discovery expanded the knowledge about how light influences our circadian rhythm and our biology through hormones. Hence, the light can influence alertness (Sahin and Figueiro, 2013) (Teixeira et. al., 2013), sleep-cycles (Santhi et. al., 2008) and behaviour (van Hoof et. al., 2009). These discoveries were the start of the non-visual approach in the lighting industry and led to research and tests on the impact of timing (Santhi et. al., 2008), colour temperatures (Sahin and Figueiro, 2013) etc.

Since the responses by the visual and the circadian systems are different to optical radiation, a calculation procedure to measure circadian light (CL_a) and circadian stimulus (CS) were developed and presented in a report (Rea et. al., 2010). In order to measure the circadian stimulus many researchers from several countries and Universities have proposed a new measuring system for circadian light. “The discovery of ipRGC photoreceptors, and our growing understanding of their role in setting physiological and behavioural state, has revealed that current methods of light measurement are incomplete. We propose methods of light measurement that quantify effective irradiance for each of the photoreceptive inputs to this system independently”. (Lucas et. al., 2014)

Furthermore, in a report on metric to quantify biological light exposure doses it is found that “the currently used lux (photopic irradiance) is not the most appropriate unit to describe how much light is needed to generate the biological (NIF) effects of light. Lux is characterizing light only with respect to vision, not with respect to its biological NIF effects. In contrast to this, α-opic irradiances and the melanopic daylight equivalent illuminance are useful metrics to support light designers to decide, which light conditions can be used to promote, or avoid, certain biological (NIF) responses. These metrics are expected to be particularly effective, when designing light conditions with narrow spectral bands or different color temperatures.” (Giménez, 2013)
Human Centric Lighting

In the lighting industry, the term Human Centric Lighting (HCL) is frequently used in several different contexts. HCL has no general definition and it is up to the user to define it. Boyce explains: “What the people who talk about human-centric lighting mean is lighting that considers both the visual and non-visual effects of exposing humans to light and that widens the range of possible effects from visual performance and comfort to sleep quality, alertness, mood and behaviour with consequences for human health, learning and spending.” (Boyce, 2016)

In several cases, the biological, non-visual, part has become the most important one. In terms of artificial lighting, HCL is often translated into a fixture with tunable white where it is possible to change colour temperature and dim the light intensity from high to low. HCL is mostly used to enhance or improve the circadian rhythm, for example in offices, retirement homes and health care. For example, “the new use of light is made possible because of the new knowledge on the biological effects of light, and because of recent innovations in lighting technology. With the introduction of LEDs, or Light Emitting Diodes, tuneable white light can be achieved in an energy-efficient manner, which is easy to control with advanced control systems.” (Glamox Luxo, 2017) and “…the right light at the right time and in the right location. Also, biologically effective, dynamic white light with a brightness- and light colour sequence according to the course of daylight. This supports the natural biological rhythm to increase our well-being and improve our capacity to perform.” (Osram, 2017)

In this study, the definition of HCL is taken from a recently published report from IALD, where HCL is defined as “…the concept describing the connection between lighting, health and wellbeing. Lighting that focuses on people should balance visual, emotional, and biological benefits of lighting and promote good vision while satisfying the emotional and biological needs of the users.” (Ladopoulos & Shaw, 2017)

Lighting in Schools

In a study carried out in Sweden, in 2015, 26 percent of the respondents thought the lighting in schools were uncomfortable. (Belysningsbranschen, 2015) Through history, the opinions have varied on what signifies good lighting, and this is also visible in school buildings built in different decades. For example, the size, position and orientation of the windows and the amount of daylight have had different importance in different decades. In the early 20th century the windows in Swedish schools were supposed to be big and facing south in order to obtain as much light as possible. Later, this was reconsidered due to energy savings and heating. (Swedish National Heritage Board, 2000) Between 1900-1960, it was recommended to have high ceilings with large windows up to the top of the wall, and the size of the windows to be equivalent to 15-20 % of the size of the floor. In the 1960th the ceiling heights were lowered down and in the 1970th daylight was considered unnecessary and the classrooms were made to be deep and with small windows (Holm & Alm, 1990). One thing that regulates the lighting in Swedish schools today is the law of working environment where it is determined that the light should have appropriate distribution and aiming. Also, the colour rendering should be suited for the task, the light should be flicker free and there have to be daylight with view in classrooms and staff rooms (Arbetsmiljöverket, 2009). In addition, the lighting in the school areas are regulated by the lighting standards for work places
EN12464-1 (in Sweden SS-EN12464-1:2011) with different demands due to what kind of room it is. For example, in a classroom it is necessary to have 300 lx, 19 UGR, 0.60 Uo, 80 Ra. (Swedish Standards Institute, 2011)

SISAB, the property maintenance company for all municipal schools in Stockholm, has their own guidelines for lighting in schools; the light source should be LED, the lighting should be controlled with presence and daylight sensors in order to save energy and classrooms should have pendant luminaires with both indirect uplight and direct downlight. Further on, a recommendation about the lighting quality is stated: “Research also shows that vertical light (on walls) and ambient light are important for the work environment and affect the performance” (SISAB, 2017, translation from Swedish by the author)

Research has proven that daylight is important both for results and well being in a school environment. In a study with classrooms without windows the cortisol levels were higher in the mornings which had a negative effect on the concentration, body growth and sick leave. In the conclusion, a recommendation not to have classrooms without windows was proposed. (Küller and Lindsten, 1992). Furthermore, another study found that students with most daylight in their classrooms progressed 20 percent faster on mathematics and 26 percent faster on reading than students having less daylight in their classrooms. (Loisos, 1999)

Different light sources have been popular during the history and full-spectrum fluorescent lighting was common before today’s LED technology. The full-spectrum fluorescent lighting was used in order to mimic daylight and gain the positive health effects that we can attain from daylight. But there is no evidence that the full-spectrum fluorescent lighting is better for your health or can mimic the daylight, concluded in a study from 2001. (McColl & Veitch, 2001) Today, almost all new lighting is LED. In a Swedish study, LED fixtures were compared with T5 fluorescent tubes over a whole academic year in different classrooms with 72 students aged 17-18. The light environment, electricity consumption, and students’ mood, light perception and saliva cortisol concentration were monitored. The classrooms with LED fixtures were slightly preferred. (Gentile et. al., 2016)

The school environment is also of interest for HCL, but research about the effects of HCL are still limited. In a study funded by Philips, an evaluation of their HCL-system SchoolVision was conducted. Two classrooms, each in two separate schools, with variable lighting (VL: lighting that is variable in illuminance and colour temperature) were studied over a period of nine months. The results showed that students made fewer errors, particularly fewer errors of omission, on a standardized test of attention under the VL “Concentrate” program. Reading speed, as measured using standardized reading tests, rose significantly. In contrast, the achievement motivation of the students and the classroom atmosphere did not change over the nine-month period. Overall, the students and teachers rated VL positively and found it useful during lessons. (Barkmann et. al., 2012)

Furthermore, eighty-four third graders were exposed to either focus (6000K) or normal lighting. Focus lighting led to a higher percentage increase in oral reading fluency performance (36%) as oppose to control lighting (17%). (Mott et. al., 2012)
Another paper evaluates the effect of lighting conditions, carried out in three experiments, (with vertical illuminance between 350lux and 1000lux and correlated colour temperatures between 3000 and 12 000K) regarding the concentration among children in elementary school. In the first two experiments, a flexible and dynamic lighting system was used in quasi-experimental field studies using data from 89 pupils from two schools (Study 1) and 37 pupils from two classrooms (Study 2). The third experiment evaluated two lighting settings within a school-simulating, windowless laboratory setting. The results indicate a positive influence of the lighting system on pupils’ concentration. The findings stress the importance of lighting for learning. (Sleegers et. al., 2011)

Moreover, a non-published study made by Osram in 2011 examined the effect of light in performance capability of pupils. With the new lighting designed to simulate daylight, participating pupils achieved better results in standardized tests for concentration capability than the comparison group. Performance speed also increased significantly. (Helbig, 2011)

In another study, the near visual acuity (400 mm distance) of 27 children aged 10-11 years was measured under two common fluorescent lamps of CCT 3600 K and 5500 K. Acuities were measured for three lighting conditions. The results showed that visual acuity was significantly better under the higher CCT lamp with 24 of 27 children having better acuity. (Berman et. al., 2006)
**METHODOLOGY**

In order to answer the research questions and to fulfil the aim of the study, the three aspects - visual, emotional and biological - will be investigated through five different methodologies; observation and analysis of lighting distribution and behavioural analysis of lighting system as a visual aspect, surveys about the mood and emotions as an emotional aspect and visual performance and visual acuity as a biological aspect.

**VISUAL ASPECT**

**LIGHTING DISTRIBUTION**

The evaluation of the lighting distribution was realised by means of Liljefors V/P Lighting theory. (Liljefors, 1999) The classroom was evaluated and analysed with the seven terms as tool. The evaluation of the lighting distribution was made in terms of semantic lighting scales from 1-5. The scales are based on the V/P Lighting Theory, with modification of Favero (see appendix 4), and are as follows;

- Level of lightness (level of light): 1= very dark, 5= very bright
- Spatial distribution of brightness (light distribution): 1= uniform, 5= very dramatic
- Shadows: 1= very vague, 5= very marked
- Reflections: 1= none, 5= very marked
- Glare: 1= none, 5= intolerable
- Colour of light: 1= cool/cold, 5= warm
- Colours (appearance of surface colour): 1= natural, 5= deteriorated

The analysis was carried out on the 24th of April 2017 and the weather conditions at the time for the analysis were a bright day with overcast sky and white, light clouds. Four different observations were made; one with only daylight, one with relaxed lighting and the curtains closed, one with normal lighting and the curtains closed as well as one with focus lighting and the curtains closed. The analysis was made by the author of this study and can be perceived as subjective. Hence, the analysis tool is meant to be used by professionals, not by common people in a survey.

**BEHAVIOURAL ANALYSIS**

The two main teachers in the HCL-classroom were interviewed on 24th of April 2017 and 8th of May. They were asked about their use of the HCL-system, how they perceive the functionality of the system, how they experience the user-friendliness of the system etc. In addition, two other teachers that teach in the HCL-classroom were briefly asked about how they use the lighting system. The language in the interviews were Swedish, which was later translated into English.

**EMOTIONAL ASPECT**

**PERCEPTION OF MOOD**

A survey was distributed to all pupils’ in the class with HCL, and were answered on the 15th of May during mentorstid (30 minutes of information from the form teachers). The pupils were the same as in the visual performance test, why this survey was carried out after the second visual performance test in order to not influence the results or thoughts about the lighting in

...
the visual performance test. The survey is divided into four parts, the first part includes general questions about pupils' mood and their perception of lighting. Part two, three and four all consist of the same questions, regarding their mood and their perception of the lighting. The questions about their perception of space are selected and taken from Ejhed's study *Ljus och rum* (Ejhed, 1992), which includes semantic differential scales with one word in every end of the scale. Not all semantic scales from Ejhed's study are included in this study, the ones which had most relevance and were suitable for the target group (14-year-old pupils in elementary school) were chosen. In order to analyse answers from an entire class, the scales have nine markers which can be summarized according to the average numbers.

The respondents should write a cross somewhere on the scale which should correspond to their spontaneous perception of the room. The pupils were instructed to place the cross in the middle of the scale if they did not understand the words or the scale. During part two, three and four of the survey, the lighting in the classroom was changed, so the pupils responded to questions about the lighting that was actually in the room. Hence, in part one and two normal lighting (500 lx, 4000 K) was turned on, in part three; relaxed lighting (300 lx, 3000 K) and in the fourth; focus lighting (800 lx, 6000 K). The pupils were requested to stop after each page in order to have the current and correct lighting for the whole class at the same time. At the time for this survey, the curtains in the classroom were closed in order to decrease the influence of daylight and enhance the effect of the different lighting settings. In addition, selected volunteer pupils were asked some follow-up questions about the survey and the lighting. This was made as a complement to the answers in the survey in order to make the answers more tangible. Semantic differential scales are frequently used for researchers interested in human responses to the qualitative aspects of lighted environments. (Tifler and Rea, 1992) In this study, the semantic differential scales are a suitable tool for evaluating the perception and emotions connected to the different lighting setting in the classroom.

**BIOLOGICAL ASPECT**

**VISUAL PERFORMANCE**

In order to test the visual performance and concentration in different lighting conditions a matrices IQ test was used. A matrices IQ test is a non-verbal ‘culture fair’ multiple choice IQ test, which measures your fluid intelligence, your reasoning and problem solving ability. In each test item, the subject is asked to identify the missing element that completes a pattern of shapes. The patterns are presented in the form of a 3×3 matrix.

In the first test, pupils received 14 matrix questions with five multiple choices to solve in five minutes. In the second test, pupils were given another 14 matrix questions, with corresponding difficulty level, with five multiple choices to solve in five minutes. The tests were carried out with paper and pencils. The first test occasion was on the 24th of April 2017, where the lighting was calm light for relaxed activities (300 lx, 3000 K). The second occasion was on the 8th of May 2017 and the lighting was focus light for test activities (800 lx, 6000 K). Both tests were carried out on a Monday at 9.45 in mentorstid. The furnishing was different during the two tests (see analysis for details).
A control group in another classroom with regular lighting (recessed fluorescent tubes) was also tested with the same questions at the same dates. Both tests were carried out on a Monday at 14.00 in an English lesson. The reason for having a matrices IQ test was to carry out a culture fair test where prior knowledge and subject knowledge should not influence the results considerably. Furthermore, the test was well suited for a full class with approximately 30 pupils, was fast to carry out and easy to understand. In addition, the test tested concentration, reading and visual ability which is similar to common school work in the classroom.

The procedure of the test was:
- pupils were informed about the test and usage of the results. They were however not informed about the purpose of the test or the objectives and subject of the study, in order not to influence them.
- pupils examined two examples questions on the front page of the test
- the five-minute test started when all pupils were done with the examples and answered affirmative on the question if they were ready to start
- pupils were informed about the time remaining every minute and when the five minutes ended (including 15 seconds before the end)

**Visual acuity**

Visual acuity refers to the ability to discern the shapes and details of the things you see or sharpness of vision, in terms of the size of detail which can be detected by the eye at a given distance. A visual acuity test is an eye exam that checks how well you see the details of a letter or symbol from a specific distance. Different alphabetical and symbolical charts are available as methods of measuring the visual acuity.

In this study, the Monoyer test was used, which is a chart of letters in different sizes and arranged in rows and columns, viewed from 5 meters. During the test, the pupils, one by one, stood at a 5 meters’ distance from the chart and covered one eye. The test leader pointed at a letter and the pupils read, out loud, the letters they could see with their uncovered eye. The procedure was then repeated with the other eye. The test was carried out in 2\textsuperscript{nd} of June 2017 where ten volunteer pupils were chosen to proceed the test, five during relaxed lighting (300
Ix, 3000K) and five in focus lighting (800 lx, 6000K). During the visual acuity test, the curtains in the classroom were closed in order to decrease the influence of daylight in this test. The reason for using the French Monoyer test is because it is a standardised test for visual acuity, but not commonly used in Swedish classrooms which decreases the chance of reiteration.

![Picture 3, Monoyer Chart, Visual Acuity Test]

**LIMITATIONS**

Many different tests and evaluations are possible to carry out in order to evaluate lighting. Due to the limited amount of time, it was necessary to leave out some tests and focus on the ones that was possible to fulfil during the time for the study, in spring 2017.

In addition, the amount of data collected can be said to correlate to the disposable time. Because of this, there is a bigger risk of coincident and lower validity. To measure the effects and the perception in the classroom, it would be preferable to carry out tests regularly during a whole academic year. In a longer period of data collection, it would also be possible to compare different seasons.

Furthermore, the study and the tests were completed in a season with a lot of daylight, which made the artificial lighting not as influencing as it is in winter time with dark mornings and afternoons. Because of this, the effect of the lighting system is probably lower than it would be in winter time. However, the daylight changes during the year is nothing we can regulate and in a way it is interesting to see the results in the bright time of the year as well.
ANALYSIS

LIGHTING SYSTEM
In the elementary school Sturebyskolan in Stockholm, the property maintenance company SISAB, has provided a classroom with a HCL-system. The system was installed in December 2016 and the HCL classroom is primarily used by a class in 8th grade. The luminaires in the system are provided by the manufacturer Glamox Luxo, and are pendant luminaires with direct and indirect light called Reed, hanging at the height of 2,20 meters. Eleven luminaires, in a pattern of three times three plus two whiteboard luminaires, are connected to the system. The luminaires only have one driver and it is not possible to control the indirect and direct light separately. All luminaires in the classroom are connected to a control system with a clock that changes the colour temperature and light intensity according to time. The different settings in this system are:

- 800 lx, 6000 K (energy light/focus light), this is used in the first hour of school, from 8.00 to 8.51, as energy light. It can also be manually switched on during special activities, like test etc. as focus light. When it is manually switched on, it is automatically switched off maximum 30 minutes after activation.

- 500 lx, 4000 K (standard/normal light), this is used as standard light for common activities, normal lessons etc. Except for the first hour of school, this lighting is automatically used during the remains of the day. It is not possible to manually activate during the first hour of school.

- 300 lx, 3000 K (calm light), can be manually switched on for relaxed activities and is then automatically switched off maximum 30 minutes after activation. It is not possible to manually activate during the first hour of school.

The system is manually dimmable and the settings are manually controlled through a control panel in the classroom. In the top panel, you can choose the three settings; focus, normal and relaxed. The fourth button switches off the luminaires. In the bottom panel it is possible to dim the light manually and create your own setting. A manual is made by the manufacturer, but so far, the manual is still at the property maintenance company SISAB, and not available for the teachers at this school. On the the manufacturers webpage, it is possible to read about HCL solution in education;

During the early morning hours, the right light can help to wake up with less sleepiness. A better light environment can improve alertness and concentration during lessons. Lighting systems that give higher light intensities and colour temperature at the right time can help to improve duration of sleep and quality of sleep and thus improve learning effects. With biologically optimized lighting systems in educational environments, natural lighting conditions can be achieved more effectively. Simply said it is possible to imitate natural lighting inside the classroom. (Glamox Luxo, 2017)
CLASSROOM
The classroom is situated on the bottom floor in one of the main buildings of the school. The room is a former library which has been divided into two classrooms. The shape of the room is rectangular and the windows, which are covering a large part of one wall, are facing north east. There are four windows which are each 1.30 m wide and 2 m high, the size of the room is 8.80 m long, 6.50 m wide and 3.05 m high. There are also windows on the opposite wall where you can see into the main hall/atrium, the size of the windows is 4 m wide and 1.30 m high. The material of the floor is a dark grey linoleum, the walls are painted in a light grey colour, the ceiling consists of white 60x60 panels and the furniture is mostly light wood material. On the 24th of April 2017, during the first visual performance test, the furniture was situated in groups of 4-6 desks with a total of 28 desks with appurtenant chairs. On the 8th of May, during the second visual performance test, the furniture was situated in lines along the walls and a group of desks in the middle of the classroom.

CONTROL GROUP CLASSROOM
The ordinary classroom, which were the location for the control group in the visual performance test, is located at the second floor in the main building of the school. The shape and size of the classroom is similar to the HCL-classroom but the ceiling height is lower and the windows are facing the opposite direction, south west. The lighting in this classroom is ceiling mounted fluorescent tubes with a colour temperature of 3000 K and not possible to dim. The furniture was situated in pairs of desks and appurtenant chairs, a total quantity of 28 desks.

DAYLIGHT
During the daylight analysis the curtains were covering 1/3 of the windows (which was the ordinary setting) and the artificial lighting was switched off. Time for analysis was at noon on the 24th of April. The large quantity of windows on the outer wall contributed to large amount of daylight in the room. There were differences in the levels of light, were the distance from the window wall determined the illumination. On the desks far from the windows, the illumination was approximately 100 lux, on the desks in the middle of the classroom the illumination was approximately 170 lux, on the desks close to the windows the illumination was between 600-1200 lux and on the window-ledges the illumination was more than 6000 lux. An analysis of the lighting distribution, showed that the daylight gave a very uniform light, completely without sharp shadows and was perceived as cold and medium bright. No glare was perceived, the reflections were medium marked and the colours were perceived as natural.

FIGURE 1, ANALYSIS OF DAYLIGHT
RESULTS

VISUAL ASPECT

LIGHTING DISTRIBUTION
The findings in the observations of the artificial lighting include none reflections and glare, generally uniform lighting as well as overall natural colours. The levels of light and the colour of light differed according to the different settings with cold and very bright light in focus light, medium cold/warm and bright in normal light and warm and dark in relaxed lighting. The shadows were vague in the relaxed lighting and medium vague in the normal and focus lighting. The observation of the daylight showed similar findings to the artificial lighting conditions, with uniform light without shadows and glare, natural colours and cold but medium bright conditions. The greatest difference between the artificial light and the daylight was the reflections, which was clearly presented in the daylight but not in the artificial light.

In this study, the levels of light are not viewed as a scale from total darkness to extreme brightness, and the analysis of light levels is based on, and compared to, a common classroom with ordinary lighting, which for example means that result 1, out of 5, is considered as a dark classroom, not a totally dark room. The result varies from dark to very bright depending on the lighting settings; in the relaxed lighting the level of light is considered low, in the normal lighting it is high, and in the focus lighting it is considered as very high.

Artificial lighting, curtains closed, focus lighting setting

Artificial lighting, curtains closed, normal lighting setting

Artificial lighting, curtains closed, relaxed lighting setting

FIGURE 2, ANALYSIS OF FOCUS LIGHTING

FIGURE 3, ANALYSIS OF NORMAL LIGHTING

FIGURE 4, ANALYSIS OF RELAXED LIGHTING
**Behavioural analysis, interviews**

In this section, two teachers, A and B, have been interviewed. Two other teachers, C and D, were also interviewed, but not as thoroughly as A and B.

Teacher A never uses the different settings in the control system, only on and off and never uses the dimmer. Teacher A has noticed the different settings, especially when the light is dimmed down, and prefers the brightest light (focus light) and perceive it as good work lighting as well as the best lighting to use in general. The pupils occasionally change the lighting settings, however, not too often. The pupils prefer darker settings and want it more dimmed down and cosy, according to the teacher.

Teacher A does not think the control system/key pad is easy to use and only uses the function on and off. The key pad is divided into two switches and the one where you can dim down and chose settings is behind the whiteboard, and that is the strongest reason for not using the key pad. Teacher A has not been introduced or educated in the new lighting system and does not know the purpose of the lighting system. In general, the teacher is very satisfied with the lighting system and thinks that the lighting is better than in ordinary classrooms, both for teachers and pupils. If it would be more user-friendly, with all settings on one key pad, the teacher would wish for it in every classroom. Sometimes when teacher A is alone in the classroom and works/reads, the presence detectors are not activated and the lighting turns off, which can be annoying, but this is simply a minor aspect. Compared to other classrooms, the lighting is better and never out of order.

Teacher B rarely uses the different settings, but did so more in winter time when it was dark outside. During the winter, teacher B changed the settings approximately one or two times a week, but now, when it is brighter outside, the teacher only changes the settings occasionally. It happens that pupils change the settings, mostly from focus light or normal light to relaxed light, but this was also more common during winter time. Teacher B experiences a difference between the different light settings and likes the focus light, even though it is a bit harsh. Teacher B says that the focus light is better now than in winter time, but is unsure whether it is because the contrast is not that great now with much daylight or because s/he is simply used to the present light.

Furthermore, teacher B thinks the control system is easy to use, but has not been educated or introduced to the lighting system except for an explanation of its purpose from a colleague. Teacher B is satisfied with the lighting system and believes that the lighting in the test classroom is better than in other classrooms and that the light is better as work lighting than in older classrooms.

Teacher B suggests that the system could be different in winter time when it is dark outside and in summer time when it is brighter outside in order to decrease the great contrast. In addition, teacher B would like to have the HCL-system in all classrooms.

Teacher C and D were briefly asked about their using of the lighting system, and they were both unaware of the lighting system and did not know how or why to change lighting settings.
EMOTIONAL ASPECT

PERCEPTION OF MOOD

The survey was answered by 21 pupils. In the general questions, over 95% of the pupils said that they were aware of the lighting system and that the lighting settings vary during the day. In an oral follow-up, some pupils said that they did not know that the lighting changes automatically during the day, only that it was possible to change lighting settings manually. The most notable perceived difference was the different light intensities, a few pupils also noticed different colour temperatures. Furthermore, over 95% of the respondents answered that they would like to control the light at their own desk. In the follow-up, a few pupils mentioned that it would be irritating if everyone could control their own light at all times and that it would probably not be the best solution for the overall lighting in the classroom. The average mood was 4.27 of maximum 5 at this point.

In the questions about the normal lighting, 13 pupils, or approximately 60%, thought that their mood was affected by the lighting. A common answer to when the pupils want this lighting was at tests and math lessons. The mood at this time was lower than at the first question, 4 out of 5. Most of the answers were in the middle of the scale and had an average of 4-6 of 9. The brightness was perceived as bright, in average 3 out of 9, and half of the respondents perceived the conditions as very bright and answered 1. The colour temperature was perceived differently where almost half of the respondents perceived the colour temperature as 1 or 2, but the average result was 4.4 because several answers were close to warm on the scale. Also, the question about active-passive was differing, almost half of the respondents answered 1 or 2. In the follow-up, several pupils were confused about the normal lighting and the focus lighting and thought they were the same. Several comments about the normal light in the survey were actually meant for the focus lighting. In Figure 5, the average result for every question is presented.

FIGURE 5, PERCEPTION IN NORMAL LIGHTING
In the part with relaxed lighting, 16 pupils, which corresponds to 76% of the participants, thought that their mood was affected by the relaxed lighting. The pupils prefer to have this lighting during calm lessons and when they read, and several answers indicated that the pupils always want this lighting. The average mood in this lighting was the highest measured, 4,5 out of 5. With this lighting, it was only two of the questions that gave a medium result with an average between 4-6; varied-uniform and active-passive. This lighting was perceived as positive (7,2 out of 9), calm (8 out of 9), dark (7,5 out of 9) and soft (2,8 out of 9). Further on, the relaxed lighting was perceived as pleasant (3,7 out of 9), restful (3,7 out of 9) and safe (7,1 out of 9). In the follow-up, pupils talked about this cosy lighting as similar to other lighting at home, and that they sometimes change the lighting to relaxed during lessons, especially when it is dark outside. In figure 6, the average result for every question is presented.

In the questions about focus lighting, 14 pupils, or 66%, answered that their mood was affected by the lighting. The pupils want the focus lighting on when they have a test and need to concentrate extra. Several pupils also wanted this lighting in the afternoon, and others specifically never wanted this lighting to be on. The average mood, 4,1 out of 5, was lower than in the first question and in the relaxed lighting but equal to the normal lighting mood. The pupils had mixed opinions about negative-positive (4,3 out of 9), unsafe-safely (4,7 out of 9) and active-passive (4,2 out of 9), where for example, 11 pupils perceived the lighting as very active (answered 1 or 2) and 9 pupils answered 1 on the question about negative-positive. Focus lighting was clearly perceived as hard (8,5 out of 9) and bright (2 out of 9). In addition, the lighting was perceived as boring (7,1 out of 9), uniform (7,5 out of 9), tiresome (6,5 out of 9), cold (3,2 out of 9) and quite lively (3,9 out of 9) in average. In the follow-up, pupils talked about this lighting as the “dentist lighting” and that it is too bright and sometimes gives you a headache. Several pupils also mentioned this light as a test-light and that they know it is serious when this light is switched on. In figure 6, the average result for every question is presented.
BIOLOGICAL ASPECT

VISUAL PERFORMANCE

At the first test occasion in 24\textsuperscript{th} of April, 26 pupils participated in the HCL-classroom and 25 pupils in the control group in an ordinary classroom. At the second test occasion in 8\textsuperscript{th} of May, 24 pupils participated in the HCL-classroom and 26 pupils in the ordinary classroom.

In the first test in the HCL-classroom, 364 questions were answered and 190 of them were correct, which gives a result of 52\% correct answers. The average score was 7,3 out of 14 and the median result was 7. The highest score at this occasion was 12 out of 14.

The first test in the ordinary classroom included 350 questions and 205 of them were correct, which resulted in 58,5\% correct answers. The average score was 8,2 out of 14 and the median result was 8. The highest score at this occasion was 12 out of 14. The control group scored better in all categories in the first test occasion; percentage, average and median.

In the second test in the HCL-classroom, 336 questions were asked and 184 of them were correct, which means 54,76\% correct answers. The average score was 7,66 and the median score was 8, both slightly better than the first test. The highest score at this occasion was 11 out of 14, one less correct answer than in the first test.

The second test in the ordinary classroom included 364 questions and 205 of them were correct, which means 56,31\% correct answers. The average score was 7,88 and the median score was 8. The highest score at this test occasion was 12 out of 14. The highest score and median score were the same as in the first test, but both the percentage and average score were lower in the second test.
VISUAL ACUITY

Ten volunteer pupils participated in the test on 2\textsuperscript{nd} of June 2017. Five pupils carried out the test in focus lighting, and the other five carried out the test in relaxed lighting. During the focus lighting, one pupil used lenses and during the relaxed lighting one pupil used glasses, the other pupils had no known visual defects. The Monoyer chart consists of 77 letters divided into ten lines. During the relaxed lighting, the pupils had in total 187 incorrect answers, 89 with the left eye and 98 with the right eye, which generates an average of 18,7 incorrect answers per pupil. In the focus lighting, a total of 135 answers were incorrect, 71 with the left eye and 64 with the right eye, which means 13,5 incorrect answers per pupil. Two pupils, one in relaxed lighting and the other in focus lighting, had no incorrect answers at all. Furthermore, four pupils had four or less incorrect answers, two in relaxed lighting and two in focus lighting. Four other pupils had 50 or more incorrect answers, two in relaxed lighting and two in focus lighting. In order to make a comparison between the two lighting conditions with the exact same eyes, one pupil carried out the test in both relaxed lighting and focus lighting. The result in the relaxed lighting showed 108 incorrect answers (Relaxed 5\* in the table) and 72 incorrect answers in the focus lighting.

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<td>16</td>
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<td>54</td>
<td>108</td>
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<td>Focus 3</td>
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</tr>
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<td>Average</td>
<td>14,2</td>
<td>12,8</td>
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\* Glasses  
\** Lenses

FIGURE 10, VISUAL ACUITY, NUMBERS OF INCORRECT ANSWERS
DISCUSSION

The perception of mood and emotions connected to the different lighting settings were, as expected, mixed. The personal experience can differ a lot from someone else’s opinion and experience which make the individual perception, and partly ambiguous results, understandable. Many people have countless experience and opinions about different kinds of light and lighting. However, the findings have some clear results where more or less all pupils had the same opinion. The clearest results were the perception of focus lighting as hard and bright, as well as the relaxed lighting as warm and calm. The relaxed lighting also had a clear average perception of positivity at the same time as it was perceived as dark. If it is the colour temperature or the light intensity that is perceived as positive is not clear, probably a combination. Children and adolescents does not need as much light as adults to have good vision, which can be one explanation for the positive results in the relaxed lighting with lower light intensity. The follow-up also confirmed that many pupils prefer to have lower light intensity and perceive the higher light intensities as disturbing. Some pupils explained the calm, warm light as similar to the lighting at home, which probably is connected to a cosier feeling than the school environment. Almost everyone in the class wanted to have the possibility to have individual lighting control in the classroom, in the follow-up some of them were more sceptic and also considered the negative aspects with individual control. It would probably be confusing and lack of coherency in the room with totally individual control. By contrast, parts of the classroom/sections of luminaires could be separately controlled in order to create different scenarios or lighting settings in different parts of a room. It could also be interesting to have pre-set supplementary lighting settings in order to broaden the use of the classroom and choose additional scenarios. On the other hand, the system can not be too complex and it is good for the end users that the settings are few and clear. Furthermore, the results from the surveys show that many pupils associate the cold and hard focus light to test and concentration. Perhaps the perception and emotions of having the focus lighting affects the results and concentration like a habitual behaviour.

Some of the answers in the survey tend to show that the questions and the words in the semantic differential scales were hard to understand. As the instruction was to put the cross in the middle if they were hesitant, quite many scales tend to show a result in the middle of the scale. The intention was to only use scales with word that 14-year-old pupils could understand, but in retrospect, some of the scales could be replaced or removed. To many scales/questions also has a negative effect on pupils’ involvement and can lead to random and hasty answers. Some of the questions were clarified during the follow-up and it was then obvious that several questions got other answers or substantial additions. The follow-ups fulfilled their purpose and were important for the understandings and analysis of the surveys, but it would probably be even better with interviews where it easier to control if the question is understood or not. In addition, when it comes to personal experiences, emotions and perception of the lighting conditions, there is always a risk that the answers could be influenced by temporary mood and distractions.

According to the results of the behavioural analysis, the ignorance of the lighting system can be a problem for the experience and usage of the lighting in the classroom. None of the consulted teachers did know neither the purpose nor the application of the lighting system. Some of the teachers used the system obviously wrong and none of the teachers used it consistently correctly like it should. When the system is used incorrect, all three aspects,
visual, emotional and biological, run the risk of failing their purpose. For example, if a teacher finds the focus light best and uses it during all lessons, the visual aspect will be influenced (very bright all the time), the emotional aspect will be influenced (pupils experience it as hard and negative dentist lighting etc.), as well as the biological aspect (the system is pre-set for changes during the day, and if the focus lighting interrupt every lesson, the biological impact will be lower or even negative). According to the analysis of the perception, the pupils perceive the focus lighting as a test-lighting, but if the test-lighting is always on, the pupils will most likely adapt to the lighting and consider it as normal and the effect of the different lighting settings will be reduced. It is hard to estimate how much poorer the lighting system is with incorrect application, but having wrong light at wrong time instead of right light at right time is most likely not good. As the system is automatic, and only changes if you manually push the button on the control panel, the risk of ruining the system is quite low though. Passive users, that only switch on and off, are no real danger for the system because the system can then be totally automatic. Active educated users would be the optimum, users that know when and why to manually control the system. The worst users are the active, non educated ones, that know how to control the system, but does not do it correct and do not know the purpose of the lighting changes. The key to having correct usage of the system could be more involved end users (teachers and principals, as well as the property maintenance company) and better communication between the developer/manufacturer, property maintenance company and end user. A short introduction and education about the purpose of the lighting system and how to use it would probably improve the application and the result of the system substantially. Right know, the information about the lighting system from the manufacturer is still at the property maintenance company, and not provided to the end users, the staff at the school. In addition, in order to facilitate the use of the system the control panel should be more user friendly and clear for the users how to apply it and where to find it. When the control panel is hidden behind a whiteboard and according to the interviews with the teachers, it is not totally clear how to use it. Because of this, the usage of the lighting system in the test classroom of Sturebyskolan, tends not to be as indentent.

The results of the visual performance test verify the results from (Barkmann et. al., 2012) (Mott et. al., 2012) (Sleegers et. al., 2011) (Helbig, 2011) and shows that the focus lighting has positive effect on pupil’s performance. The test group had better results in the second test with focus lighting, both percentage-wise, median-wise and average-wise. In contrast, the control group had better results than the test group in both the first and the second test. However, the control group had better results in the first test than in the second, which could prove that the first test was a bit harder than the second test. Since the tests include different questions, even though it is the same kind of questions with the same difficulty level, it is possible that they are not perceived as equally hard. If the fact that the second test is perceived as harder, the results of the visual performance test in this study confirms the previous research even more because the test group had better results in the second “harder” test. In contrast, it is small differences in the results and even though it is clear that correct answers increased in the focus lighting, and at the same time decreased in the control group, the causation is not explicit. For example, the number of pupils in the first and the second test was not the same, neither in the test group nor the control group, and with the small margins in the result, one pupil can be crucial for the result, both in positive and negative sense. The results from the test group showed that the highest score had decreased in the second test from 12 to 11, but the overall result was better in the second test with
higher average, increased percentage of correct answers and median result was also better in the second test, which implies that the focus lighting helped pupils with low result in the first test to perform better in the second test. Hence, the focus lighting is particularly good for weak pupils and can help them to focus and concentrate.

Moreover, the tests in the test group and the control group was not carried out at the same time, of practical reasons, which also can influence the results. The test group performed during morning time and the control group performed in the afternoon, which could be an explanation of the higher results in the control group. The different types of classrooms, window orientation and amount of daylight are other factors that could have influenced the results. In the test classroom, the windows to the atrium could have been a distraction which in that case could have influenced the results negatively. In addition, the furnishing in the test classroom was different during the first and the second test which also could be a consideration for the increased results. Furthermore, according to the analysis of the perception of mood in the different lighting settings, the pupils are influenced by the lighting emotionally and the fact that they perceive the cold and hard focus lighting as a test-lighting or lighting where you should concentrate and be focused, could be the reason for the increased results during the focus lighting in the test classroom. In addition, lighting is one possible reason for the results, but there are plenty of other reasons that could influence the outcomes of the tests. As said in the limitations, this study has a limited time frame and thus limited test and time period. To do a more profound analysis whether the results are caused by lighting, and in that case due to the biological aspect or due to the emotional/psychological aspect, the study needs analysis from more tests during a longer time period, preferably one whole academic year. More tests to derive the biological effect is probably also necessary to clarify the reason for the increased results in focus lighting, such as measurements of melatonin levels etc. According to previous research, the photometric measurements (lux, photopic irradiance) are not well suited for circadian stimulus, and to clarify whether the results are of biological or emotional reason it could be necessary to measure with circadian lux (α-opic irradiances). (Rea et. al., 2010) (Lucas et. al., 2014) (Giménez, 2013)

The results of the analysis of the lighting distribution showed that the lighting is suited for a typical classroom where it is important to have no reflections, no glare, uniform distribution and vague shadows. All these characteristics are individually positive and necessary to fulfil the standards of classroom lighting, but put together, these characteristics creates a quite static and boring lighting. It is of course important to have good lighting conditions in the classroom in order to see and communicate, both for pupils and teachers. On the other hand, in a classroom it is also important to have a safe and inspiring atmosphere so that pupils and teachers feels motivated to learn and teach. The lighting has a big impact on the atmosphere of a room, and too many standard fulfilling characteristics can contribute to create an insipid and uninspiring room. As Lam mentioned about the focus selector (Lam, 1992), we always seek for the most interesting visual experience, and if the classroom is very uniform illuminated, the focus will perhaps be on the wrong things. In addition, according to Wänström Lindh, a uniform lighting where nothing is emphasised, can create a lack of visual interest with no support for orientation and spatial understanding. (Wänström Lindh, 2013)
Of practical reasons, the analysis of the lighting distribution was made during certain time limitation (when the classroom was empty during daytime), which contributed to changes of the lighting settings while being in the classroom. The fast changes between the lighting settings (normal, relaxed and focus lighting) were noticeable and probably affected the results of the analysis. The contrast between the focus lighting and the relaxed lighting are large, and especially when you, during a short time, are staying in the same room and have short time to adapt. The results of the analysis of the lighting distribution would probably be a bit different if the analysis was made during a longer session with pauses between the different settings. It would quite possibly be less contrasts between levels of light and colour temperature. The analysis could also have been made several times, in different times of the day and in different weather conditions and seasons, in order to make the analysis more reliable.

The limitations of this study includes the big influence of daylight in spring, which probably reduces the biological effect of the artificial lighting. This is a matter of consideration since the seasons and daylight will not change and during spring and autumn, daylight will interfere with the artificial lighting and influence the people inside the classroom. In accordance to previous research about daylight in classroom (Küller and Lindsten, 1992) (Loisos, 1999), daylight is always better than artificial lighting and during late spring/summer/early autumn we are, in Sweden, exposed to daylight all day long. An artificial lighting system that tries to mimic daylight and the variation of it is not better than real daylight, but the different settings is impossible to achieve with only daylight. For example, the effect of the relaxed lighting will be very decreased in combination with strong daylight like it is in late spring and early autumn. Also, the effect of the focus lighting will probably decrease because the daylight is even brighter and colder than the focus lighting, which reduces the contrast between daylight and artificial light and creates a more natural feeling, and less test feeling.

The results from the visual acuity test showed more correct answers in focus lighting than in relaxed lighting. The test can not give evidence to the fact that the lighting is the reason for the results, but it could be a contributory factor. In a test with only five participants per lighting setting, there is a risk that one pupil influences the results strongly. For example, if four of the pupils would have all correct answers, but the fifth pupil get none correct answers, it will be 154 incorrect answers in total and an average of 30,8 incorrect answers. In this study there are two pupils in the relaxed lighting and two pupils in the focus lighting that stands out with a high rate of incorrect answers. The weakest result was 108 incorrect answers, which was carried out in relaxed lighting, and contributed much to the total result. The pupils were just randomly placed in order, the first five carried out the test in relaxed lighting and the last five in focus lighting, and it could be a coincident that the weakest pupil ended up in the relaxed lighting. Because of the risk of letting coincident determine the result, the weakest pupil also got the chance to do the test in focus lighting and got a better result. In order to increase the reliability of the test, it would be interesting to test all pupils in both relaxed lighting and focus lighting to see if the difference is general or only personal for the only tested pupil. In addition, it would also be preferable with more test pupils in order to have a considerable selection of results. Anyway, the results tend to show that pupils with weaker vision are helped by focus lighting, but focus lighting is no guarantee for good vision. A presumable factor for the results is the difference in light intensity between the relaxed lighting (300 lx) and focus lighting (800 lx). According to previous research, also the colour
temperature could be a reason for the difference between the two lighting settings. (Berman et. al., 2006)

In summary, to denominate a lighting system as HCL and only consider the altered colour temperature and light intensity is not comprehensive enough. According to the definition used in this study (Ladopoulos & Shaw, 2017), a HCL-system needs to consider the visual, emotional and biological aspects. The biological aspect is explicitly considered in this lighting-system, whilst the emotional and visual aspects are however not carefully considered. The different lighting settings that can provoke altered emotions and moods could be considered as an emotional consideration. According to the findings in this study, the emotions connected to the artificial lighting could be an argument for the lighting system as emotionally considering. On the other hand, the lighting setting that are most appreciated by pupils in this study, relaxed lighting, is the least used in the lighting system and are never activated in the automatic settings. Even if the intention of the lighting system could be to provoke different feelings in the different lighting settings, it is not explicit and hence not clearly an emotional aspect. The text about the HCL-system on the manufacturers webpage indicates that the purpose of the system is solely biological. (Glamox Luxo, 2017)

Further on, the visual aspect is partly considered with the pendant direct/indirect luminaire that provides two different layers of light. In the manufacturers webpage it is said that the indirect light cast light both on the walls and the ceiling which increases the vertical illuminance and improve the visual communication. (Glamox Luxo, 2017) The visual aspect in this lighting tend to focus just on the visual communication to ensure good working conditions in the room; right amount of illuminance (on working plane, vertical and cylindrical), uniform brightness that provides right light level on every desk and avoid sharp shadows and glare. However, the total visual perception of the space is not really considered and as discussed earlier, too much focus on the visual communication related to the working conditions can negatively implicate the atmosphere. When it comes to the visual aspect the overall perception and atmosphere have to be considered as well as the visual communication and working conditions, which can be a difficult thing to balance. Overall, the visual perception of the atmosphere in a room has to be more important than it is in this lighting system in order to see it as carefully considered.
PROPOSAL

From the results of this study an evolved lighting design that considers all three aspects; visual, emotional and biological, are proposed.

The analysis of the lighting distribution showed that the lighting in the classroom was uniform which could lead to a static and boring atmosphere. In order to create a more vivid and interesting atmosphere a variety of layers of light would be preferable. Like Kelly’s three elements (Neumann, 2010) it could be layers with focal glow, ambient luminescence and play of brilliants. In a classroom that could for example be; highlighted objects or stage/front of classroom where teachers usually stand, wallwashing effect on walls without windows and one or several small detailed brilliants of light on the front wall or at the front desk. In the budget of a school, there is seldom space for extravagance and in the lighting planning of a school, there is usually a limited type of luminaires in order to reduce the cost of maintenance and purchase. In order to create different layers of light with these preconditions, it is desirable to use luminaires with several areas of application. For example, a luminaire that both could work for general lighting in the classroom, and as a wallwasher or spotlight to bring other layers to the lighting would be functional in order to maximise the use of every luminaire. In that case, it is important to arrange the positions of the luminaires in the classroom in order to be able to use them with different characteristics for different occasions. For example, place luminaires close to walls that need wallwashing and luminaires that can work as spotlights in positions where highlighting is needed. With flexible luminaires and conscious planning, it would be possible to create different layers of light with only one or two different kinds of luminaires. The backside of creating luminaires with more functions is the cost of the luminaire, which will increase. For instance, if the luminaire should be able to control the indirect and direct light separately, a second driver is needed and the cost of the luminaire will increase substantially. However, even if there is only a standard classroom luminaire, it is still possible to create different layers of light if the arrangement of the luminaires is conscious and suited for the different needs of the lighting in a classroom. Furthermore, the use of an advance control system, like the one in Sturebyskolan, could also be a way to broaden the use of the classroom with several different lighting scenarios. The possibility to control the lighting in different parts of the classroom could be a good opportunity both to easier create a good atmosphere with different layers of light, as well as to divide the classroom into different areas with different purposes. For example, if it is possible to control every row of luminaires separately, two or three different lighting scenarios can be applied, one for reading and one for group work or creative work etc. In addition, the different rows can operate with different characteristics as a way of creating layers of light.

Furthermore, as discussed earlier, the daylight has a vast influence during parts of the year which decreases the effect of the artificial lighting. In order to adapt the system to the daylight, it would be preferable to change the settings during the year so the artificial lighting corresponds to the daylight. This would be positive both for the lighting part, including all three aspects, but also for the energy consumption which could be reduced with a more adapted system. For example, if the system has sensors to measure the light intensity, the illumination from the luminaires can be reduced during the brightest part of the year. This will both save energy and enhance the daylight, which have positive influence on performance and health. (Küller and Lindsten, 1992) (Loisos, 1999) As it is now, the artificial focus lighting
illuminates the classroom with 800 lx like it would be a dark room, even though the daylight adds 100-1200 lx (in different part of the room). To use the daylight as an extra light source could also be an opportunity to add another layer of light into the classroom. If the daylight is considered as a general light source, the artificial lighting could be more adjusted to bring highlights, washes and sharp details into the room. On the other hand, in the dark part of the year, the daylight is very limited and can not be used as a general light source during all hours of school. However, if the luminaires have the capacity to include several purposes/characteristics, the general light could come from artificial luminaires during the dark period of the year and from daylight during the bright part of the year.

In addition, an important part of the lighting system is the application of it. As mentioned before, if the system is not used as it is supposed to, none of the three lighting aspects will be fulfilled. To prevent incorrect application, it is by great importance that the system is visible, easy to understand and simple to use. To achieve this, it is recommended that all users are being informed about the purpose and educated in the lighting system, as a suggestion by the lighting designer or manufacturer that is responsible for the lighting system. In municipal schools, like Sturebyskolan, the property maintenance company could be the responsible part, but according to the case in Sturebyskolan, it is better to decimate the numbers of concerned parts in order to streamline this task. A suggestion is that introduction and education to the lighting system is a part of the product. The education is valuable both for the end-users, so they can apply the lighting system correctly and be benefitted from that, but also the manufacturer which can be assured that their product is used as it should be and can accomplish the effects that the manufacturer pledges.
CONCLUSIONS

The aim of this study was to evaluate a HCL-system in a classroom by the means of the three aspects; visual, emotional and biological. Results shows that different lighting settings were perceived differently, where the focus lighting was perceived as a cold and hard lighting for tests, while the relaxed lighting was perceived as a warm and calm lighting for a cosy feeling. In addition, the results tend to show that the lighting affects the performance as a habitual behavioural factor, where the concentration increases connected to the focus lighting.

Further on, the lighting characteristics are suited for a typical classroom with uniform lighting, no glare and vague shadows. Despite positive lighting characteristics individually, put together, the lighting and the atmosphere can be perceived as static and boring. In addition, during parts of the year, the daylight influences the light in the classroom which have a great impact on the artificial lighting which decreases the effect of the lighting system.

Moreover, the function of the system depends on correct application of the users, and ignorance among users becomes a problem. In order to have a system that works properly, it is important that the system is user friendly and that the end users are educated.

Results show positive effect on performance in focus lighting, similar to previous research. Focus lighting seems to be particularly good for weaker pupils, even though it is not clear if the results are caused by the lighting or not. To assure if the results depends on the lighting or not, and whether it is caused by the emotional or biological aspect, more research is required. Results also show better visual acuity in focus lighting than in relaxed lighting and pupils with weaker vision seems to be helped by the focus lighting.

In summary, the HCL-system is considering the biological aspect explicitly, the emotional and visual aspects are however not enough considered to denominate the system as human centric. As a proposal to consider all three aspects, several layers of light could be added in order to strengthen the visual aspect and create a vivid and interesting atmosphere. Moreover, conscious arrangement of luminaires and luminaires with flexible characteristics could simplify and broaden the opportunities in the classroom and facilitate the use of light layers. A development of the control system could lead to a variety of scenarios and more opportunities in the classroom, which could strengthen the emotional aspect. In addition, education could be a part of the product in order to assure that the lighting system is used correctly. In that case, the end users can be benefitted from all functions, whilst the product is used as it should be and can accomplish the effects that the manufacturer pledges.

In this study, weaker pupils seemed to be more benefitted from the focus lighting both in visual performance and visual acuity. According to these findings, more research need to be done about how HCL affects different pupils with different knowledge/grades etc. If the research would go on, more investigation is needed about how to create the pre-set lighting settings, including which colour temperatures, light intensities and characteristics of the luminaires. In addition, research about how HCL-systems in schools with and without education for the end users works, could be an important supplement in future research.
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Appendix 1
Survey about perception, pupils

Enkätfrågor om belysningen i klassrummet

Jag är intresserad av din spontana upplevelser och vill gärna att du svarar omedelbart på frågorna utan att tänka för mycket.

Hur är ditt humör just nu?

<table>
<thead>
<tr>
<th>Ledsen</th>
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<th>4</th>
<th>5</th>
<th>Glad</th>
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Känner du till att belysningen i ditt klassrum ändras under dagen?

|       | Ja | Nej |

Har du märkt någon skillnad på de olika belysningsinställningarna?

|       | Ja | Nej |

Om ja, hur upplever du de olika inställningarna?

______________________________________________

______________________________________________

Skulle du vilja ha möjligheten att kontrollera ljuset på din egen bänk?

|       | Ja | Nej |

Vänta med att gå vidare med resten av frågorna, hela klassen behöver svara samtidigt.
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<tr>
<th>Ledset</th>
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<td>Hur är ditt humör just nu?</td>
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<tr>
<td>Påverkas din sinnesstämning/humör av belysningen?</td>
<td>Ja [ ]</td>
<td>Nej [ ]</td>
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<tr>
<td>Finns det särskilda tider/stunder/ lektioner då du vill ha den här belysningen?</td>
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<tr>
<td>Vilka tider/lektioner brukar ni ha den här belysningen?</td>
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Markera med ett kryss (X) på respektive skala det ord, som du tycker mest överensstämmer med *din spontana upplevelse* av rummet. **OBS!** Försök att bestämma dig fort, fundera inte, även om du tycker något ord är konstigt.

<table>
<thead>
<tr>
<th>Mjukt</th>
<th>Trevligt</th>
<th>Omväxlande</th>
<th>Negativt</th>
<th>Viljamt</th>
<th>Osäkert</th>
<th>Ljus</th>
<th>Kallt</th>
<th>Livligt</th>
<th>Aktivt</th>
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</table>

35
Appendix 2
Survey questions in English

English
- How is your mood right now? Sad 1-2-3-4-5 Happy
- Are you aware of the changing lighting system in your classroom?
- Have you noticed any difference in the lighting settings/properties?
- If yes, how do you perceive the different settings?
- Would you like to control the light on your own desk?

Normal lighting/Relaxed Lighting/Focus Lighting:
- How is your mood right now? Sad 1-2-3-4-5 Happy
- Is your mood affected by the lighting?
- Are there specific times/lessons when you want this lighting?
- At what times/lessons do you usually have this lighting?

Soft -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Hard
Restful -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Tiresome
Unsafe -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Safely
Bright -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Dark
Cold -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Warm
Lively -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Calm
Varied -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Uniform
Beautiful -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Ugly
Sharp -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Diffuse
Pleasant -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 – Boring
Active -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 – Passive
Negative -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 – Positive
Harmonious -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 – Inharmonic
Normal -1 - 2 - 3 - 4 - 5 - 6 - 7 – 8 - Strange
Appendix 3
Interview questions, teachers (in Swedish and English)

Swedish
- Hur ofta ändrar du inställningarna på belysningen i klasrummet?
- Ändrar någon annan än du inställningarna under dina lektioner?
- Upplever du någon skillnad mellan de olika inställningarna? Om ja, vad?
- Upplever du kontrollpanelen/strömbrytaren som enkel att använda?
- Har du fått någon utbildning/introduktion till belysningssystemet?
- Känner du till syftet med belysningsanordningen?
- Märker du någon skillnad på elever/dig själv i HCL-klasrummet och andra klassrum?
- Om du skulle få ändra/förbättra något med det nuvarande belysningssystemet, vad skulle det vara?
- Skulle du vilja ha detta belysningssystem i alla klassrum? Varför?

English
- How often do you change the properties of the lighting in the classroom?
- Is anyone else than you changing the properties during your lessons?
- Do you perceive any difference between the different properties? If yes, what?
- Do you find the control panel easy to use?
- Did you get any education/introduction to the new lighting system?
- Do you know the purpose of the new lighting system?
- Do you recognize any difference in your/your pupils’ behaviour in the HCL-classroom and in other classrooms?
- If you had the chance to change/improve something in this HCL-system, what would it be?
- Would you like to have HCL-system in all classrooms? Why?
Appendix 4
7 factors with modification by Favero. From lecture “Research and writing method” in C3 2016-11-07 by Federico Favero

7 descriptors of light (Eijhed, Liljefors 1990)
The visual experience of light in a space can be described by seven terms in a semantic differential scale, characterizing noticeable entities of the visual experience as a whole.

- evaluation will be performed by professionals

<table>
<thead>
<tr>
<th></th>
<th>very dark</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>very bright</th>
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<tr>
<td>Level of light evaluation</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>poor</td>
</tr>
<tr>
<td>Light distribution uniform</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>poor</td>
</tr>
<tr>
<td>Shadows very vague evaluation</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>poor</td>
</tr>
<tr>
<td>Reflections none evaluation</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>poor</td>
</tr>
<tr>
<td>Colour of light cool/cold</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>poor</td>
</tr>
<tr>
<td>Appearance of surf. colour natural</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>poor</td>
</tr>
<tr>
<td>Glare none evaluation</td>
<td>good</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<td>poor</td>
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Notes