SHADING SYSTEMS AND THE SUPPORT BY DYNAMIC LIGHTING TO IMPROVE LEARNING ENVIRONMENTS

THROUGH TWO CASE STUDIES IN DENMARK

by

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Abstract:

The project will present an investigation on shading systems supported by dynamic lighting to improve learning environments. In schools, students are facing problems regarding glare and occupant's discomfort with direct sunlight. Shading systems are used to avoid these problems but, creates darkness in the space and therefore it must be supplemented with artificial lighting. In order to improve occupant's visual comfort, this project is adding a new approach. The method for the project is to work with dynamic lighting by creating different scenario's based on shading systems. This project introduces a lighting scenario, when the shades are down how we can compensate the sunlight atmosphere inside the space with the support of dynamic lighting.

The project was carried out in 2 educational facilities: Herstedlund skole and Aalborg University, Copenhagen. The main aim is to investigate how can dynamic lighting can support daylight intake when using shading system to prevent glare. One of the targets is to investigate the fact that when shadings are drawn you actually loose some of the potentials of the daylight and I want to find out how I can compensate for this through dynamic electrical light and thereby can assist in creating a natural light atmosphere. In order to improve the learning environments, five experiments was conducted using physical mock ups as well as digital simulation. Qualitative and quantitative methods were applied in order to create and validate the final design proposal.

Acknowledgements

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Table of Contents

TABLE OF FIGURES

Structure of the Report

This report is structured in a way, which gives a short description of each chapter throughout the process. The following section provides an overview of the project from the introduction to the final design proposal.

1. Introduction

Chapter 1 gives an introduction to the topic, which will be supported by background from previous projects and raises an initial research question.

2. Survey

Chapter 2 describes the investigation of different shading systems, which can support the topic and literature review was made in order to find out what research has been done on this topic and what knowledge can be added in the process.

3. Analysis

In chapter 3, the Quantitative and qualitative methods will be applied in the analysis through measurements, photos, and observations. Two final research questions are formulated.

4. Success Criteria

In chapter 4, in order to support the final research questions, three success criterion have been formulated, which will help to find a solution for the final design proposal.

5. Testing

Chapter 5, presents different experiments with the shading system and compensated through dynamic lighting.

6. Final Design Proposal

In chapter 6, a final design proposal will be chosen based on the findings from the experiments.

7. Discussion of the further process

In chapter 7, the discussion will focus on the findings from the conducted experiments, and provide reflections on what could have been done differently. Following with suggestions for future work will be presented, which can improve learning environments.

8. Conclusion

Chapter 8 summarises the entire project with the support of three criteria's and provides an answer to the two final research questions.

1.0 Introduction

Daylight is one of the major factors in human life. Daylight is considered as the main light source and it is valued for its quality and variations of colour temperature. Natural light is used as the primary light source in buildings. Daylight provides exceptional light quality, which offers physiological benefits (Bellia *et al.*, 2011). Daylight provides visual comfort, which affects the health and well-being of occupants indoor. In the modern era, most of the buildings have glass facades, which provide a view to outside environment however at the same time causes excessive heat and glare issues. By controlling the facades with solar protection and allowing a limited amount of daylight reduces the energy consumption and provides visual comfort for the occupants. Research on daylighting systems has become one of the primary goals to ensure human comfort (Xiong *et al.*, 2015) (Hansen & Horoczi, 2014).

On the other hand, use of dynamic lighting has been increased in educational environments. Intensity, direction, distribution and colour temperature are the variables of artificial lighting, which plays a major role indoors. Each variable can create different atmospheres, that might to improve the learning environment and thereby the performance of students. This raises an important question for lighting designers in choosing different light settings and fixtures for educational environments (Mott *et al.*, 2012) (Georgieva *et al.,* 2017).

The topic of this paper is 'Shading system and the support by dynamic lighting to improve learning environments'. Why this topic is interesting is that daylight is the primary light source in human life. Daylight changes its intensity and colour temperature throughout the day. It depends on the orientation of the building and time of the day. Daylight is the full-spectrum of light that is most suitable to the human visual response and it can contribute to human health, performance and productivity (Inan, T. 2013). It has both psychological and physiological benefits but, at the same time, it has issues regarding glare and occupant's discomfort with direct sunlight and heat. In order to optimise the daylight intake, different shading systems are investigated. One of the problems is to find out when you draw the shadings you actually loose some of the potentials of daylight and I want to investigate how to compensate the light you don't get transmitted through the shading system through dynamic electrical light.

Challenges

There are challenges regarding the lighting conditions indoor. Based on shading systems, dynamic lighting should compensate with the outside conditions. There have been a lot of research studies on shading systems and supplementing with artificial lighting for visual comfort and energy (Shen, Hu and Patel, 2014) (Konstantoglou and Tsangrassoulis, 2016). Most of the projects do not provide information on shading and dynamic lighting in, which this project is adding with a new approach. The project aims to work only with sunlight conditions and supported by dynamic lighting. When we have direct sunlight, how can we avoid glare issues and with dynamic lighting how can we compensate to create the same outside sunlight conditions in the space? Here are some challenges that will investigate in the process.

- How to compensate the sunlight conditions indoor when shades are down?
- How to avoid sharp shadows and contrast on objects with Dynamic lighting?
- How can we improve the perception of the space?
- How to create a better view to outside?

1.1 Background

Daylight intake depends on the angle of the sun, which varies differently around the world, the day and year. As I come from India, I have experienced the angle of the sun is much higher, which allows excessive heat indoor and a different daylight intake through the windows. Based on the position of the sun, the design of schools is different when compared to Danish schools. Most of the schools in India are built with fewer windows to allow significant daylight and control heat. In Denmark, the position of the sun is low and lack of daylight has resulted in large window areas. Most of the classrooms are made with big glass areas to allow as much daylight intake as possible. According to the Copenhagen weather forecast, Denmark has 63% of overcast days and 37% of sunny days (Climatemp.com). Old schools, which were designed decades ago use blinds to control the glare and heat issues.

As a part of the "Lighting Metropolis" Light & Learning (lightingmetropolis.com) projects in Denmark and Sweden, a sub-project focusing on the impact of light on learning environments was carried out at Herstedlund Skole in Albertslund with project partners Tridonic, Albertslund, Sweco and AI Architects. I have worked with Herstedlund skole, Albertslund for my 3rd-semester project. The topic was 'double dynamic lighting to improve learning environments' where the main focus was controlling glare issues with shading system and supplementing with dynamic lighting. The classrooms that I was investigating for the project were 5X, which is facing west & 5Y facing east with big glass windows. The school was using curtains in east and west facing classrooms to control the glare and heat issues. I want to find out when it is necessary and how much the blinds need to be drawn to avoid glare. After observations and measuring the classrooms, I made a study investigating when to draw the curtains. Investigations were focussed on two issues: how necessary was the shading in the classrooms with east and west facing windows and how can this issue be solved in order to improve the learning environments by making three lighting scenarios (Kunta, R. R, 2016).

The first issue has shown that when the shading is needed for east and west facing classrooms. The school was facing issues with glare and heat in the east facing classroom. Investigations were done using the simulation software's, Velux Daylight Visualizer and Dialux Evo to find out what time of the day east facing classroom had issues and, which shading system could solve them (View Figure 1). In the process, stakeholders (clients, consultant, architects and lighting engineers) assumed that it would require the same kind of shading in east and west facing classrooms. After investigating, I found out at this time of the day the shading is needed for East and you don't need shading for West. As the project was only concerned with the school hours 08:00 – 15:00, the west facing classroom do not need any shading. This finding was essential for the project since the project team expected that there was a need for external automatic blinds at the west facing windows and this could be reduced and save money for better lighting.

Figure 1: Simulation of East facing classroom 5Y with direct sunlight on left and translucent shades on right

The second finding has shown that how to improve learning environments by making three lighting scenarios: watching a video, focusing on teacher and task lighting. Investigations were done using the Dialux Evo simulation software with the use of dynamic lighting to support the lighting scenarios. The main focus was to supplement the light with the use of dynamic lighting and at the same time meet the Danish standards for classrooms. These requirements were met by using the dimming options to supplement with the dynamic electrical light.

Experience gained in this previous project gives me an opportunity to take the further step in this project. By investigating the shading system, I want to go more in depth to find out what kind of light we expect to have indoor when it's sunny outside. What colour temperature can provide the sunlight atmosphere indoor, when shades are down? And what kind of light level is good for the perception and visual comfort? And finally be able to answer the question 'how can daylight intake through shading system be compensated with the dynamic lighting to create a natural light atmosphere in an east facing classroom'? Based on these findings, what scenario can we have and test it in the simulation validation to find out the light level? This is leading me to my initial research question.

How can Dynamic lighting support daylight intake when using shading system to improve learning environments?

The current project is dealing with the school at Albertslund, which is a case in Lighting Metropolis, Light & Learning. The project is focussing on a specific classroom 5Y located on the 1st floor of the building (View Figure 2). The room is facing east and has direct sunlight entering the classroom for the morning sessions. The daylight conditions vary based on the weather conditions and time of the day and year. When it is a clear sky, the direct sunlight entering the room is causing glare and overheating. Therefore the school implemented a solution with black and white curtains to avoid direct sunlight. It is controlling glare issues but, they could not solve the heat issues and at the same time, the room becomes darker, which forces them to turn on the electrical lighting. Even after the sun moving to the south, they do not draw the curtains back again when there is no need of them (View Figure 2). Therefore, the school management is willing to solve the issue by using the automatic external shading systems as part of the renovation of the classrooms. The simulations of the need for sun protection defined that the shading will be used 50 % of the time. In this period the light is affected since a limited amount of the light is transmitted through the shading system. To optimise the light when the shades are drawn this project will try to find a solution by utilising the shading systems and use of dynamic lighting to create a daylight atmosphere, when the shading are down, and thereby will improve learning environments. Different colour temperatures will be tested in the simulation software to find out, which will compensate with the daylight that we don't get when using shading. In order to find out the right solutions, different shading systems were investigated in the process.

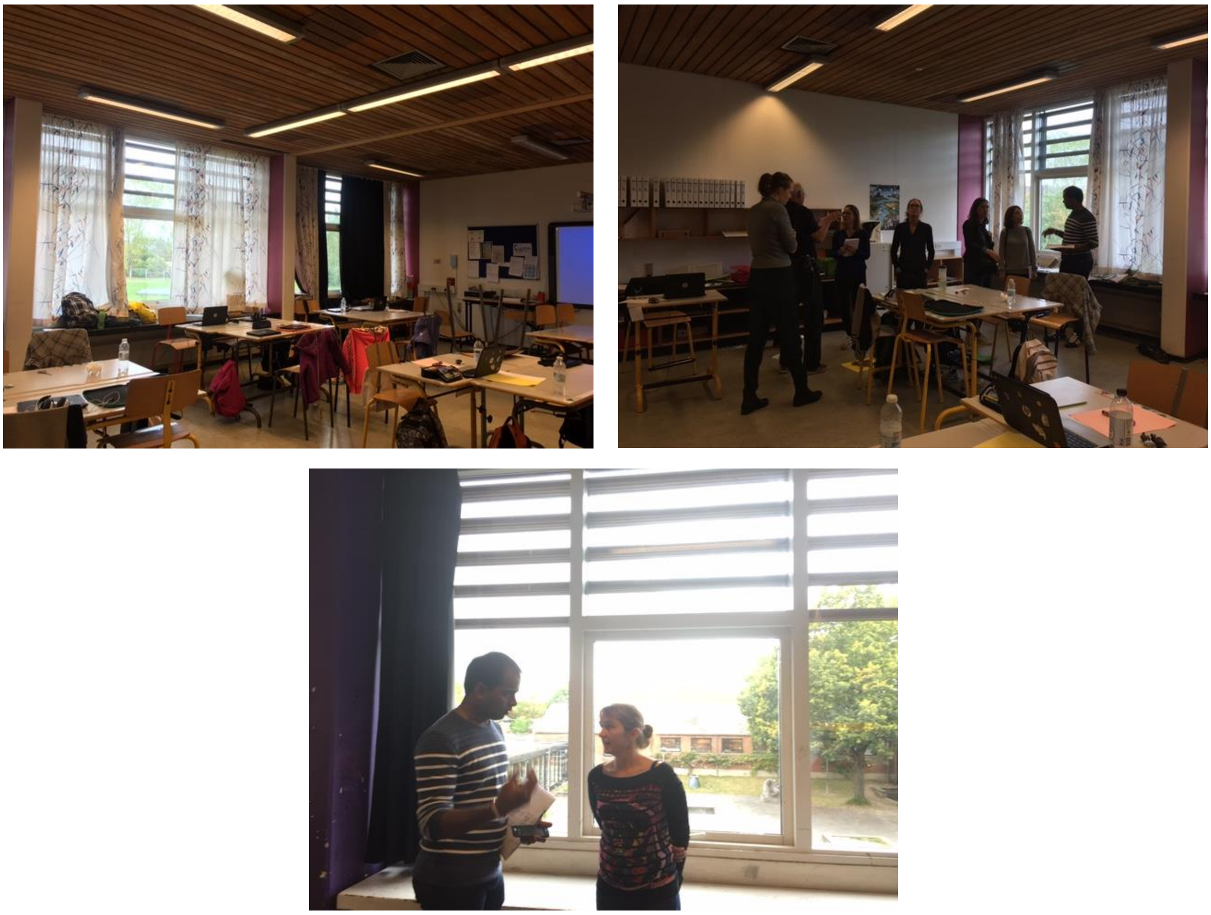


Figure 2: East facing classroom 5Y on Top and West facing classroom 5X on Bottom with Curtains

2.0 Survey

2.1 Shading systems

Shading systems play a significant role in buildings by blocking direct sunlight, preventing glare and controlling excessive heat. In order to find out the importance of shading systems, different shading devices are investigated. I am investigating different devices based on the parameters: transmittance, the direction of light and view to outside. These will help me to find out, which shading device can transmit the daylight into space. These investigations will help me to find out the right shading systems for implementing in the design. There are a significant amount of shading devices, which have been used in buildings for decades. In this investigation, I am going to work with Venetian blinds, roller shades and solar screens.

2.2 Venetian blinds

Venetians blinds are used in both residential and commercial buildings to control the heat, glare, energy and visual comfort. There are two kinds of Venetian blinds, which are horizontal and vertical blinds. These are used both interior and exterior and in between the glazing. The placement of blinds is based on the orientation of the buildings. The blinds are mainly based on the slat angles, which varies light distribution in the space. There are three cut-off angles, which are used to control the sunlight, 0˚ where slats are closed towards down, 45˚ where slats are half open and 90˚ where slats are closed upwards. These slats are controlled manually to adjust the angle based on sunlight and automatic slats work only with open and closed angles. These blinds have a benefit in redirecting the light into the depth of the room but still, there are glare issues for the occupants with the 'cut-off angle control'. The reflected rays could directly fall on the occupants, which are glary (Chan and Tzempelikos, 2013). The materials used for these blinds are fabric, wood, plastic and metal.

2.3 Roller Shades

Roller shades are mainly used in commercial buildings. They are used with a roller that rolls up and down by spinning, manually operated and motorised with electric motors. The light transmittance through shades depends on the material properties. Roller shades come in different materials, which are assigned for privacy, preventing glare, view to outside environment and controlling heat (Xiong *et al.*, 2015). Transmittance and colour have a direct impact on the indoor daylighting and comfort on the occupants.

2.4 Solar Screens

Solar screens are used to control the solar access in the buildings. These screens can balance daylight, glare and visual comfort in the interior space (Sabry *et al.*, 2014). The solar screens are mostly designed with translucent materials. These materials can get most of the diffuse light in and control the glare issues. These screens are controlled manually and motorised with the electric motors.

Based on the survey of the shading devices, each device has the capability of controlling daylight issues. A part of this project is working with controlling glare issues and providing daylight intake into space, solar screens fulfil the requirements. In order to support my initial research question, a survey needs to be done to compensate for dynamic lighting to improve learning environments

2.5 State of Art, Literature Survey

First, in the process, I have made a literature review to find the projects based on my topic. The survey machines that I used were the databases from Aalborg University Library web page and google scholar. When I started searching for shading systems and colour temperature as one topic, the results that I found were some of them are on shading systems and some are on dynamic lighting. There were no projects based on my topic, which is a combination of shading system and colour temperature. So I searched for the keywords shading systems, dynamic lighting and colour temperature.

In this research, the investigations were done on topics on optimising daylight through different shading systems and dynamic lighting. A number of articles have been reviewed on the topics to find out the relation between shading and dynamic lighting. Most of the articles were focusing on daylight intake through shading systems and supplement with dynamic lighting. I am doing it based on knowledge of dynamic lighting and shading and combining both to create a design to support my topic.

In research project published in 2001, on the impact of solar shading devices on daylight quality (Dubois, M. 2001). The author explains daylight quality through a research study, which was performed in Danish building and urban research Institute, Hørsholm, Denmark. The study was carried out entirely through measurements of illuminance and luminance in two identical south-oriented office rooms. The study performed on ten solar shading screens and one venetian blind to find out the daylight quality. The study was carried out with 3 groups of shading systems. The author assessed the daylight quality by five performance indicators to find, which shading device can provide better daylight quality. This research project can support my initial research question to investigate the screens.

In another article, based on an experimental study on the effectiveness of internal shading devices (Ye *et al.*, 2016). The author explains through an experimental study by comparing internal and external shading systems to find out, which system is better in all aspects. In this paper, external shading system is replaced by internal shading system with the use of high reflective materials, which were studied through experimental tests and simulation validations. Based on the findings, the author supports internal shading system by explaining that it is as effective as external shading systems and to consider them during the design process.

An article was published on the topic of illuminating the effects of dynamic lighting on student learning. The author explains how variables of colour temperature and illumination can influence the physiological effects on students' performance. The different colour temperatures can be assigned to different tasks to improve the performance. The author provides four discrete settings, which were designed for classroom environments. The findings argue the need for future research on electrical light and learning (Mott *et al.*, 2012).

A scientific article was published based on a study of luminance distribution patterns and occupant preference in daylight offices. The paper explores methods for analysing and evaluating the luminance quantities and distribution patterns in an office space under daylight conditions. Three existing luminance threshold analysis methods (scene average based luminance threshold, predetermined absolute luminance, and task average based luminance) are described to explain luminance variability. A test was carried out in an office space with quantitative measurements to study the occupant's preferences in daylighting conditions. The findings will support my topic to investigate further with the shading systems (Wymelenberg and Inanici, 2009).

A journal was published on the luminaire window – combining LED light and daylight, to meet biological needs and architectural potentials (Hansen & Horoczi, 2014). The authors explain how to supplement the natural light by combining daylight and dynamic LED light in the window construction. A qualitative experiment was conducted with dynamic LED light in a window in a mock-up at Aalborg University. The paper demonstrates how a luminaire window can support the daylight intake during the transmission from daylight to darkness. The author concludes that by combining a window and LED light can improve the quality of light indoor. This paper supports my topic to investigate daylight intake and quality of light.

Based on the literature survey, I can conclude that there is a need for additional research into the state of the art in shading and how this can best be combined with dynamic lighting. Previous research focuses on the use of shading to control glare, supplemented with dynamic lighting to meet the visual acuity standards. The focus of this thesis will not only be on visual acuity but, also to support learning. This implies a focus on research related to light and learning, and how the use of shades and dynamic lighting can best be combined to achieve this. Based on the knowledge from the literature survey, this thesis will contribute by focusing on sunlight conditions with respects to the use of shading and dynamic lighting.

3.0 Analysis of Shading systems and Light

In order to support my initial research question, investigations are done through the analysis.

How can Dynamic lighting support daylight intake when using shading system to improve learning environments?

This report is based on two case studies at Aalborg University, Copenhagen and Herstedlund skole, Albertslund. A real test will be carried out at Aalborg University, Copenhagen at frederikskaj 12, 3rd floor in the service system design studio, room no 3.12. The room will be used as a lab where the screens will be measured and tested in the space. Based on the measurements and tests from the lab will be used on Herstedlund skole with the use of Dialux Evo simulation software. The lab room is facing south-west and has an area of $12m^2$ with a ceiling height of 2.7 meters. The overall window has 2 small size windows and a big middle window. The windows are double-glazed clear with wooden frames, which starts at a 1-meter height from the floor. The test will be carried out for a big middle window with a height of 150 centimetres and width 96 centimetres. The 2 small windows, which are side to the big middle window will be blocked with the cardboards to get the precise results for the big middle window. The sample screens, which were gathered from Blendex Company will be used to find out the daylight intake ('Blendex products', 2017). There are three different screens, which will be tested in the space. The idea is to work with different screens to find out the light that comes through the screens and how it affects the interior space. Based on the measurements, how can we compensate with dynamic lighting to create a better learning environment? The findings from the lab will be implemented in the Herstedlund skole, Albertslund project.

The project at Herstedlund skole is located at Nyvej 11 in Albertslund. The building is constructed in 1960's with 2 floors and the orientation of the building is 339˚ north. The project works with the fifth-grade classroom 5Y, which is facing east. The classroom is located on the first floor of the building. The classroom has an area of $75m^2$ with a ceiling height of 3.07 meters. As the building was constructed 50 years ago, the design of the room was different compared to the present designs. The classroom has different reflecting materials, which plays a key role when working with the light. In the present picture, the ceiling is made of wooden beams and columns painted pink. Due to the dark materials, the school decided to change them to bright materials. The renovated classroom 5Y has a ceiling painted white and the columns are painted with a light blue colour. The classroom has double glazing windows with a height of 2.1 meters. The windows occupy 90% of the façade, which gives a good view to the outside environment. They use curtains to avoid direct sunlight and to watch the video on a smartboard.

Figure 3: The Research Setting in the studio facing south-west at AAU

Figure 4: East facing classroom at Herstedlund skole, Albertslund

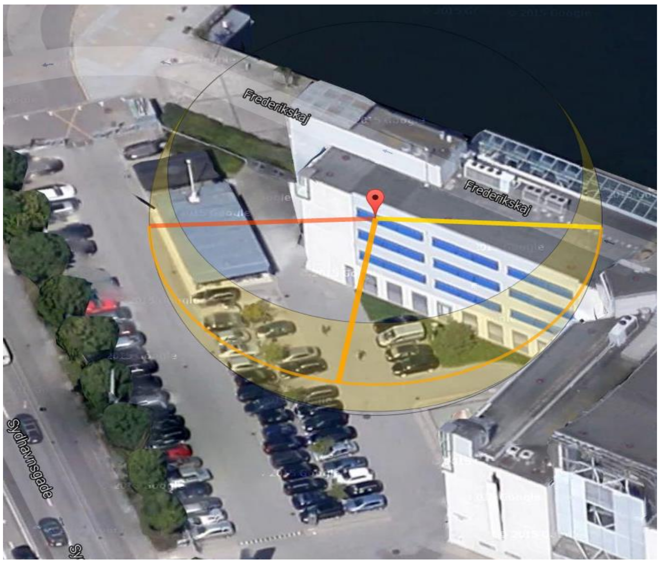


Figure 5: The sun position in relation to the building at AAU on March 15 2017, 13:00

3.1 Field Measurements

Quantitative and qualitative methods will be applied in the analysis through measurements, photos and observations. This methods has been conducted in the lab at Aalborg University, which is facing South-West. The measurements were conducted for different screens that can help implementing in the school at Albertslund.

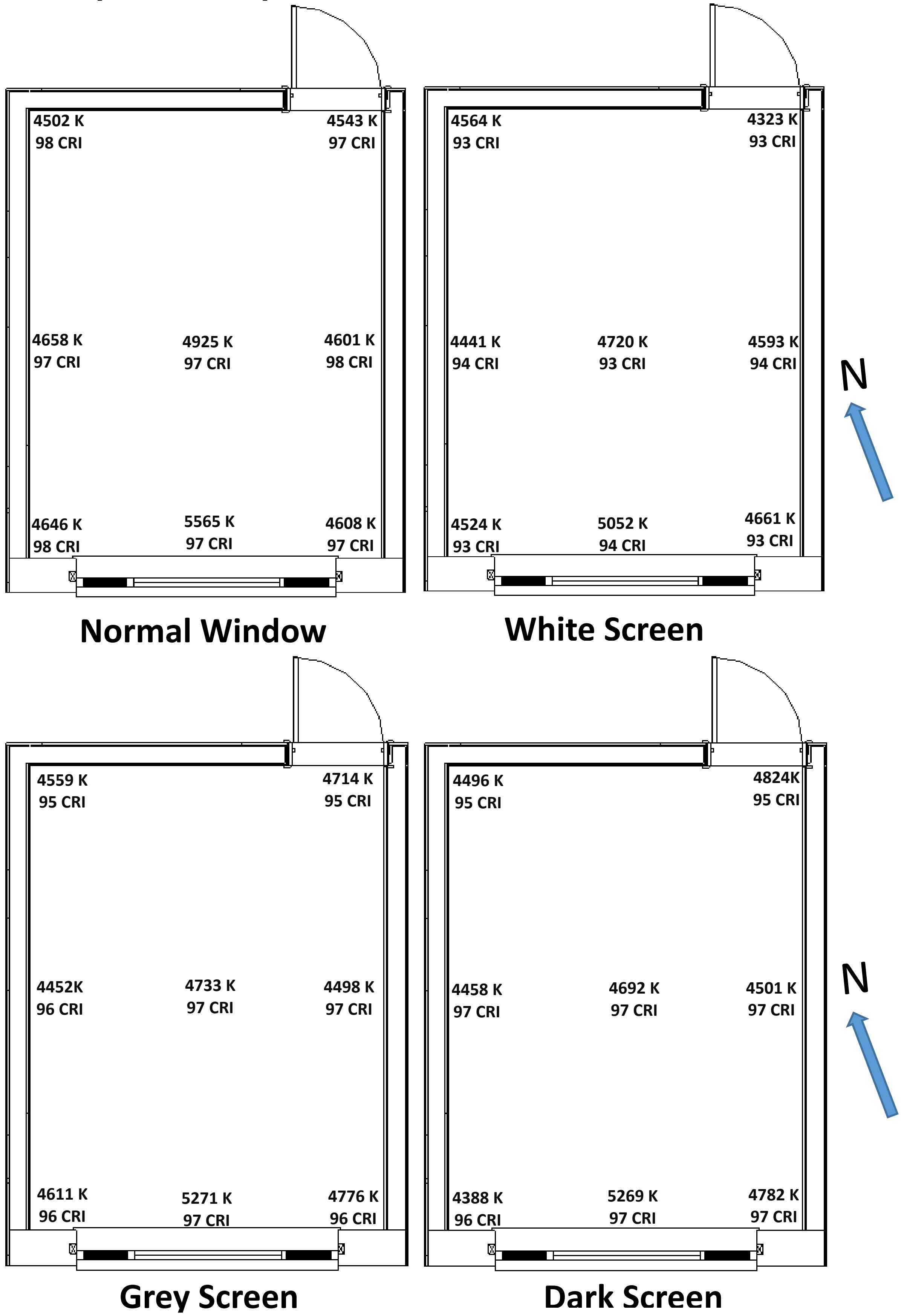
3.2 Quantitative parameters

Measurements were conducted for daylight intake in the space. The measurements will help to develop a test in the next phase to optimise daylight intake and supported by dynamic lighting to create a natural atmosphere. The tests are conducted in two different weather conditions: Sunny and Overcast. The measurements were conducted with and without sample screens to find the daylight intake in the space. Three photometric devices were used for measurements, a Spectrometer AsenseTek ALP-01 and 2 lux meters Hagner EC1. A professional camera with fisheye lens will be used to take the photos.

The measurements were conducted with Normal Window and the screens (white, Dark and grey) to find out **colour temperature, light distribution, light transmittance and daylight factor**. The measurements were carried out only for the big middle window with blocking the small windows to get the precise values in the space. These measurements will help me find out the issues regarding sunlight conditions and support the experiments that will drive to the final design proposal.

3.2.1 Colour temperature with and without screens

The measurements were conducted by using a spectrometer in order to find out the variations of different colour temperatures in the room. The measurements were carried out for three different screens and a normal window at a standard height of 0.8 meters. As the project was based on shading systems, it was measured on a sunny sky condition to find out the issues with colour temperatures in the space.

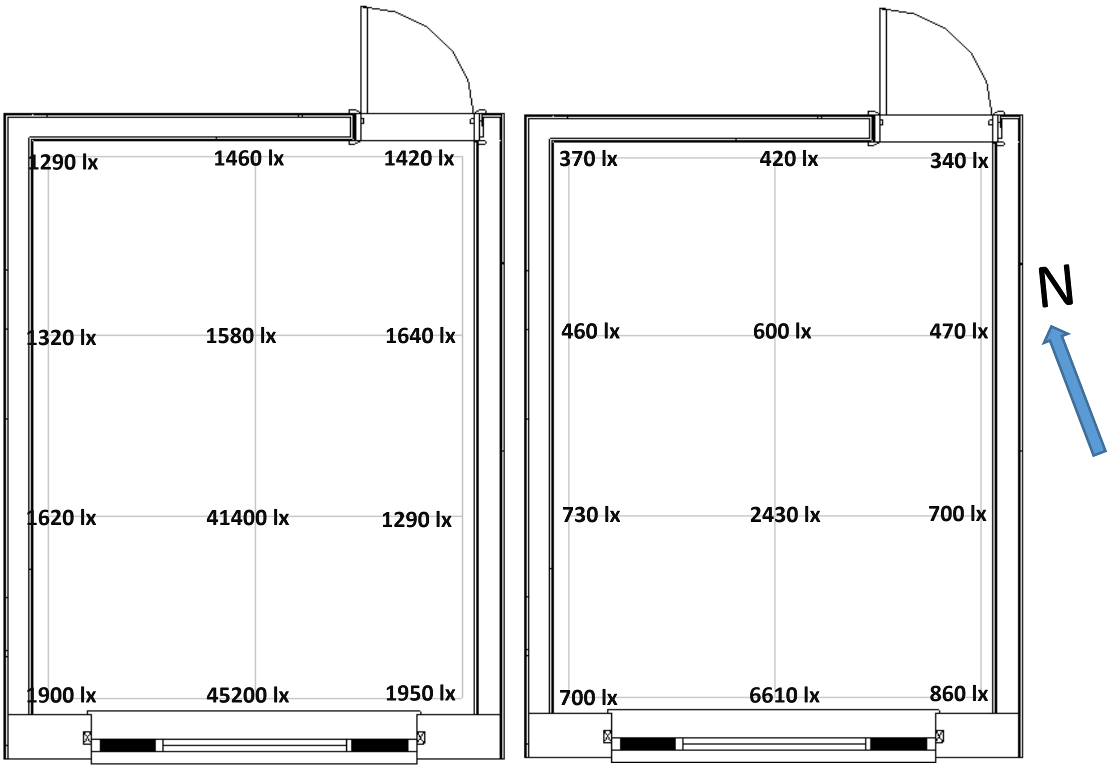


Measurements for colour Temperature on a sunny sky condition at AAU

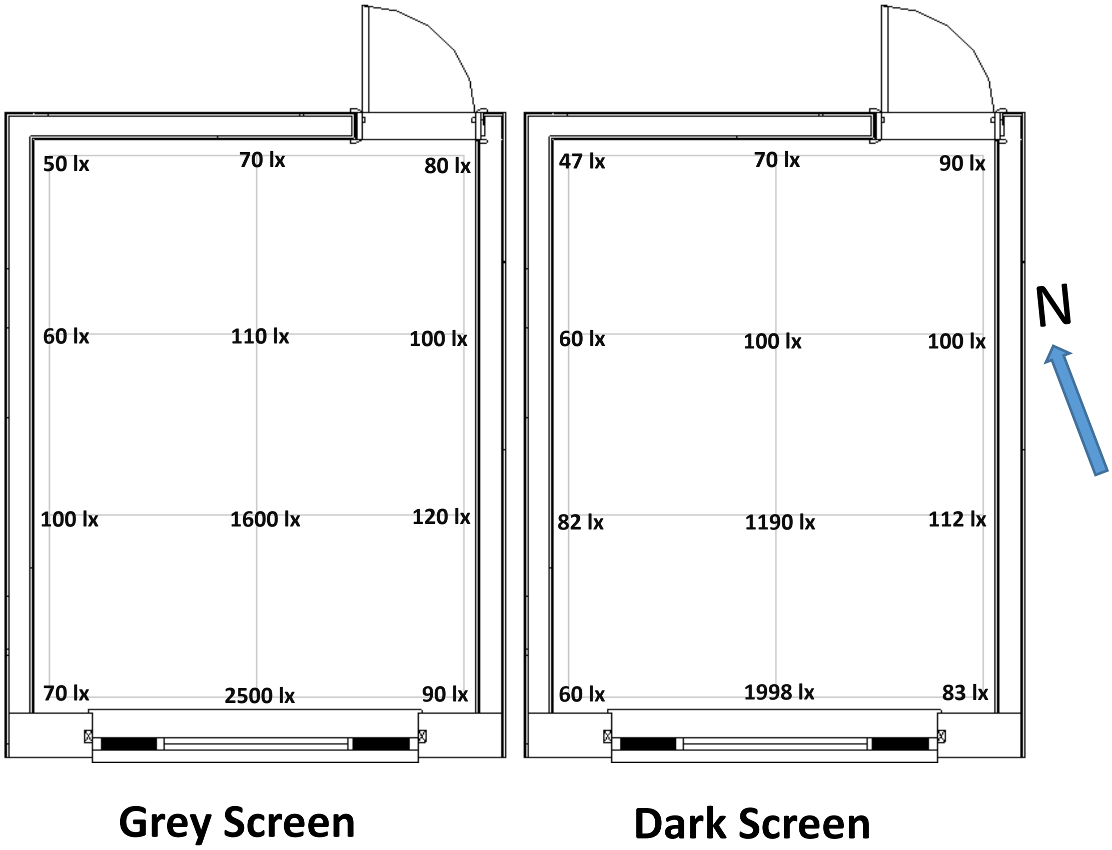
The measurements show a slight variation in colour temperature for the normal window and different screens. For the normal window, the colour temperature is high with 5271 K near the window where the sunlight falls directly and this continues for the rest of the screens as well. In the space, the colour temperature varies with 200-300 K, which is not a big difference. The findings from this measurements show that variation of colour temperature is not a big issue for the screens but, dynamic light needs to compensate with the screens by assigning the ideal temperature to create the sunlight atmosphere in the space.

3.2.2 Light Distribution with and without screens

The measurements were carried out by an illuminance meter mounted on a tripod at a standard height of 0.8 meters. The measurements were conducted for every one meter for the normal window and the screens to find out the difference with light distribution in the space. The light distribution was measured on a sunny sky condition. The approach to measuring the light distribution is to find out what happens when you get different light like the light area and dark area in the space with shading. This measurements will also help me to calculate the glare ratio in the space.



Normal Window **White Screen**



Measurements for Light Distribution on a sunny sky condition at AAU

The measurements conclude that light distribution varies significantly for the window and the screens. For the normal window, the light distribution is very high with an average of 43,300 lux near the window where the sunlight falls directly and then decreased to an average of 1547 lux, which is indirect light. For the white screen, the direct light near the window has 4520 lux and an average of 565 lux with indirect lighting. For the grey screen, the direct light near the window has 2050 lux and an average of 85 lux with indirect lighting. For the dark screen, the direct light near the window has 1594 lux and an average of 80 lux with indirect lighting.

One of the aims of the project is to avoid the glare and get the sunlight indoor. Based on the measurements, there is a significant difference with lux values in the space. This raises a question about the glare ratio, which creates a discomfort glare in the space. According to Osterhaus (Osterhaus, W. 2009), the comfortable glare ratio for visual comfort could be 1:3 and should not exceed more than 1:10 for the daylit work environments. Though, there are no specific glare ratios for educational environments. If we compare the average glare ratios for normal window and screens, except white screen none of them is achieving the ratio's that can be comfortable for the visual comfort. For the normal window, the glare ratio is 1:28, white screen 1:8, and grey screen 1:25 and dark screen 1:20. Even though, screens are avoiding the glare but, the light distribution is changing significantly, which can create discomfort for the occupants indoor. The findings from the measurements will help to find out the right screen to compensate with dynamic light and qualities of direct sunlight and uniformity in the space.

3.2.3 Light transmittance with and without screens

The transmittance was conducted with two **illuminance** meters placing both inside and outside at the same time to get the precise values. The **lux** meters were placed with one meter away from the window on both sides. The measurements were carried separately for the normal window and the window plus screens. The approach to measuring the transmittance is to find out the exact values to see the light that transmitted with different screens. This values will help to apply for the school in Albertslund when designing the classroom in a simulation software to create a natural atmosphere.

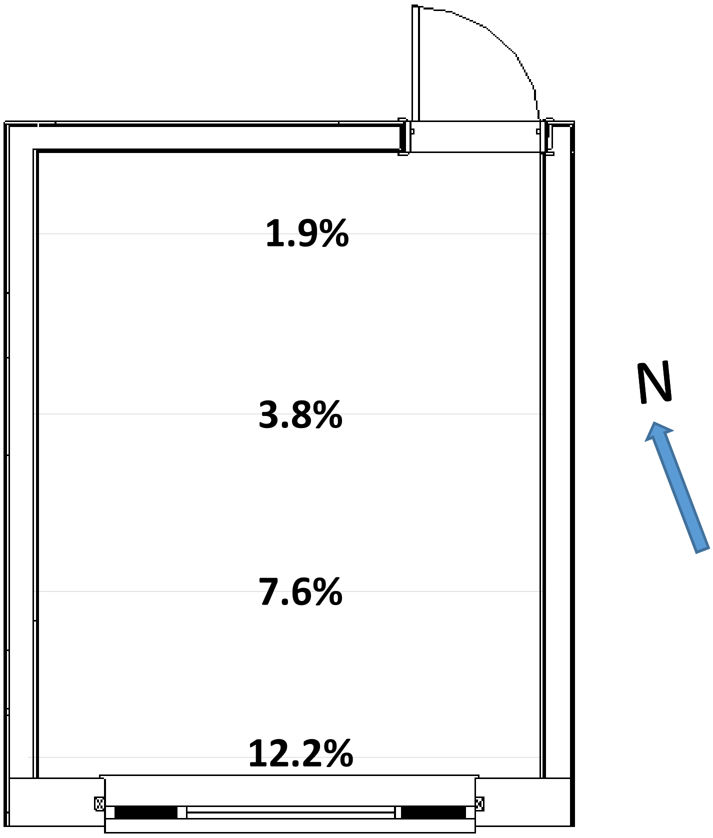
Transmittance	**E (indoor)** **Illuminance/Lux**	**E (outdoor)** **Illuminance/Lux**	**T= (Ei/Eo)*100**
Normal Window	69,100	90,800	76
White Screen + Window	12,500	80,000	15.6
Grey Screen + Window	4700	84,350	5.6
Dark Screen + Window	3000	83,500	3.6

Measurements for Transmittance on a Sunny sky condition at AAU

The measurements conclude that transmittance value for the normal window is 76 percent, which is good for a double glazing window but, the values for screens have a significant difference. As the values for screens includes a window as well, which makes the difference and the material colour as well. This is one of the reasons for the variation in light distribution between the screens. The findings will be applied in the testing phase to see the difference in lighting conditions in the space.

3.2.4 Daylight Factor with and without screens

The measurements for daylight factor was conducted simultaneously inside and outside with two illuminance meters both mounted on a tripod. The measurements were taken on an overcast sky condition at a standard height of one meter. To make sure, illuminance meter was placed outside on an open space where shadows could not interact with the device. The measurements were taken for every one meter of the space to find out the daylight intake in the space.



Measurements for Daylight Factor on a Overcast sky condition at AAU

The measurements conclude that the daylight near the windows is 12.2 percent and eventually decreases to 1.9 percent. Even though, the room is too small but, still it decreases below 2 percent. According to the standards, the daylight factor should be a minimum of 2 percent and a maximum of 5 percent.

3.3 Qualitative Observations

The analysis was conducted in the lab at Aalborg University, Copenhagen. A professional camera with Nikon D800 camera + full-frame fisheye lens was used to take the photos. The approach with the qualitative analysis is to work with the screens and compare them with the sunny sky conditions. The reason behind taking photos is to give an overview of the lighting conditions in the space. The main idea in comparing the pictures is to achieve the same colour temperature when the shades are on to create a natural atmosphere.

3.3.1 Solar Screens

In order to investigate the shading systems, three sample screens were used from Blendex Company. The screens used in the project were white, grey and dark colours. The reason behind using three different screens is to find out the lighting conditions, glare issues and view to outside environment. The screens have a height of 150 centimetres and a width of 100 centimetres. Screens are made of fabric materials with a thickness of 0.55 millimetres (BLX-u525-1010, 0101, 0202).

White Screen

BLX-u525-0202

Grey Screen

BLX-u525-0101

Dark Screen

BLX-u525-1010

Figure 6: Sample Screens from Blendex Company

3.3.2 Fisheye lens pictures

A professional camera with Nikon D800 camera + full-frame fisheye lens was used to take the photos. The approach for this analysis is to take the photos with direct sunlight and with the screens in order to find out the sunlight intake in the space and how is the perception of the space?

Normal

White Screen

Grey Screen

Dark Screen

Figure 7: Fish eye lens pictures for a window and Screens on a Sunny sky condition at AAU

Based on the test, the colour temperature for three screens are similar to the normal window but, the perception of viewing the space is different with the screens. For the white screen, the light in the space is much brighter than the normal window. When the direct sunlight hits the white screen, the reflection from the material is diffuse light with fewer shadows but, creates the brighter atmosphere and at the same time, it creates glare. For the grey screen, the lighting condition in the space is totally different from the white screen, as the material is dark grey it can transmit only 5.6 percent of light into space. The screen is avoiding the glare issues by blocking the sharp shadows and perception of viewing the space is different with bright areas near to the window and dark areas in rest of the space. The dark screen has same properties as the grey but, due to its transmittance value of 3.6 percent, it is slightly darker than the grey screen. The findings from the pictures provide the data regarding lighting conditions and glare issues, which will help me to find out the right screen in the experiments phase that can compensate with the sunlight atmosphere.

3.3.3 View to outside environment

The view has become one of the major parts of educational environments. View to the outside can improve health and well-being of occupants indoor (Hellinga, 2013). One of the aims of this project is to create a view to outside environment when shades are down. A professional camera Nikon D800 was used to take the photos for different screens. To get an overview, pictures were taken for the screens from near the window and from a distance of 3 meters to compare the quality of the view.

View from White screen, Far way (Left) and Closer (Right)

View from Grey screen, Far way (Left) and Closer (Right)

View from Dark screen, Far way (Left) and Closer (Right)

Figure 8: View from Screens on a Sunny sky condition at AAU

Based on the findings, quality of view varies within the screens. For the white screen, the quality of view is less due to its diffuse material, which takes away the view access. The contrast of the material creates glare that generates discomfort for the occupants indoor. For the grey screen, the quality of view is better than the white screen and gives an advantage to the occupants to enjoy the nature. The dark screen has the best view compared to the grey screen. As we can see from the figure. 8, quality of the view is more clear and satisfying for the viewers. In the dark screen, we can even see the change of weather better by viewing the sky. The findings conclude that screens have different quality of view to the outside, which will help me to find the better screen to propose for the final design that can also improve the learning environments.

Based on the findings from the analysis, this project attempts to answer two final research questions:

How can we improve the lighting in the classroom considering the daylight intake through shading systems?

How can dynamic lighting support daylight intake by considering light distribution, colour temperature and view to outside to create a better environment?

4.0 Success Criteria

Based on the findings from Quantitative parameters, Correlated colour temperature, distribution and light level are used to define the light with and without screens. Findings from the qualitative observations, quality of view and perception of the space are essential for the health and well-being. In order to support my final research questions, three success criteria's have been formulated to support the project. Different experiments will be conducted in order to test the criteria.

Creating outside sunlight conditions inside the room when screens are down.

Based on the quantitative analysis, the measurements with the colour temperature has proven that there is not much variation with the normal window and the screens but, the light distribution changes the perception of the space. Choosing colour temperature as the base, working with dynamic lighting can create the sunlight atmosphere. Three parameters: colour temperature, light distribution and light level, will be used as sub criteria's. In order to achieve, three questions should be answered with the support of dynamic lighting.

- What kind of light do we expect to have indoor when it is sunny outside?
- How can we achieve similar lighting conditions like outside without glare?
- Can we define this lighting through CCT, Distribution and intensity?

Creating a better view to outside environment.

By analysing the qualitative observations, quality of view is different for the screens. The colour of the materials plays a major role to be in contact with nature. If we compare the three screens, the dark screen gets the best view to outside and the grey screen has the good view and white is blocking the view due to its diffuse material.

Human perception can improve learning environments.

Based on the quantitative and qualitative analysis, the lighting conditions can affect the human perception. Colour temperature, light distribution and light level are three variables, which can influence the space. In order to improve the human perception, different experiments will be conducted with different objects concerning reflections, colours and visibility in the space. Dynamic lighting will support daylighting conditions, which can improve student learning.

5.0 Testing

The main approach of the project is to work with dynamic lighting with different colour temperatures to compensate with the daylight that you don't get in when using shading systems. Based on field measurements, there are issues with the daylight intake through shading systems. In order to find the problems regarding shading systems and to support through dynamic lighting, investigations need to be done to create a daylight atmosphere. Three parameters will be investigated in the testing face. They are colour temperature, light distribution and view. Through the testing phase, it attempts to answer two final research questions.

Overview of Tests

In order to provide an overview of the tests, experiments were described below in the table.

Experiments	Question	Where	Tool
Experiments 1	When do we need the shading and where?	Herstedlund skole, Albertslund	Velux Daylight Visualizer software
Experiments 2	How is the light in the classroom when using shading?	Herstedlund skole, Albertslund	Dialux Evo Simulation Software
Experiments 3	Testing with different colour temperatures to compensate with sunlight when shades are down	AAU Lab (practical test with Zumtobel fixture)	Nikon D800 camera + full-frame fisheye
Experiments 4	Testing with different objects to reduce sharpness and contrast of shadows when shades are down	AAU Lab	Nikon D800 camera
Experiments 5	Testing different colour temperatures and glare issues	Herstedlund skole, Albertslund	Dialux Evo Simulation Software

5.1 Experiments

In order to support the research questions, five experiments will be conducted using Velux Daylight Visualizer, Dialux Evo simulation software and a 1:1 test set up at Aalborg University, Copenhagen. This experiments will help to create a design proposal to improve lighting in learning environments when using shading systems.

5.1.1 Experiment 1

When do we need the shading and where?

In the 1st experiment, I was working with the direct sunlight in the classrooms at Herstedlund skole, Albertslund. In order to define the sunlight in the classroom, I have worked with Velux Daylight Visualizer simulation software to find out when is the direct sunlight entering the classroom and where. Based on direct sunlight, I want to find out when it is necessary and how much time you need to draw them. The main approach of this experiment is to find out the usage of shading systems, which will help me to argue about the view to outside environment. The contact with nature can improve the health and wellbeing of students, which motivates to improve their performance. The simulations were made according to the position of the sun and time of the day when the sunlight is needed. As the classroom is facing east, where the sun rises and the sun's position depends on different seasons of a year. In the winter, the angle of the sun at 12.00 is at 10.5˚ and in the summer it is at 57.5˚ (Mathiasen. N, 2015). So the daylight quality in the classroom is dependent on the orientation of the building and the season. The experiment was tested in Daylight Visualizer for an overview of six months, as the other six months will be similar. The calculation was set to the sunny sky condition on 21st of each month at 9 am to see the direct sunlight entering the classroom.

Figure 9: An overview for 6 months on 21st of each month, 9:00 am, Sunny sky condition

Based on the simulations from Velux Daylight Visualizer, the position of the sun varies throughout the day. The results show that sunlight entering the room also varies throughout the seasons. If we see the figure 9, the angle of the sun changes from January to June. In the winter season, the angle of the sun is low, which shows that sunlight enters into the depth of the room. In the summer season, the angle of the sun is high where the sunlight enters only to the half of the room. The findings from the simulations provide some data about the sunlight entering the room. These findings also raise a question about how many hours in a day, do we have direct sunlight in the space.

The calculations were done in Velux Daylight Visualizer to find out the hours on a day where the direct sunlight is entering the space. Figure 10, gives an overview of the hours annually with direct sunlight in the classroom. The data will be used in the final design proposal in order to optimise the screens when they are needed.

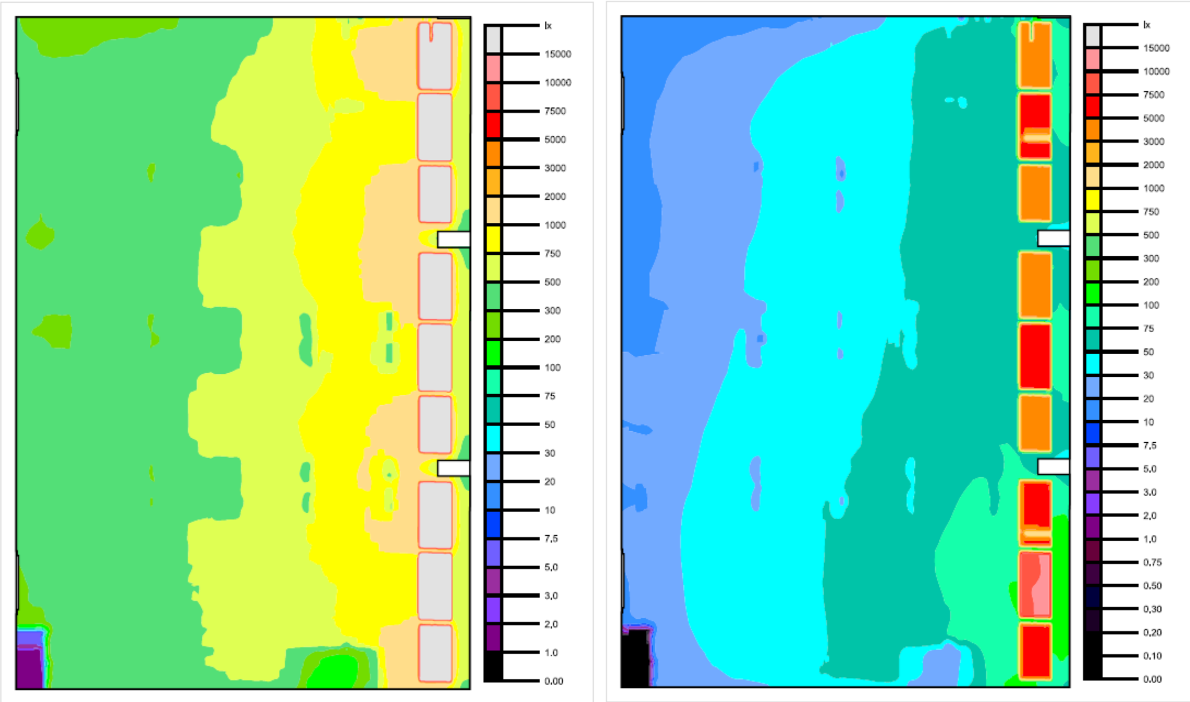
January	8:30 – 11:30
February	8:00 – 11:30
March	8:00 – 11:30
April	8:00 – 11:30
May	8:00 – 11:30
June	8:00 – 11:30
July	8:00 – 11:30
August	8:00 – 11:30
September	8:00 – 11:30
October	8:00 – 11:30
November	8:30 – 11:30
December	9:00 – 11:30

Figure 10: Annual overview of possible sunlight

5.1.2 Experiment 2

How is the light in the classroom when using shading?

The 2nd experiment was carried out in Dialux Evo simulation software in order to find out the lighting in the classroom with direct sunlight when shades are down. When using shading, some of the potentials of daylight will be lost. One of the aims is to find how different shadings will affect the amount of light distribution, colour temperature and view to outside. It is also important to see the light level in the space. When using shading systems, the amount of light is different. For example, the same space can have dark areas and bright areas depending on the shading. Overall, how do they influence the daylight and experience of the space? The calculations are done for the direct sunlight with the normal windows and screens on June 21st 9 am.



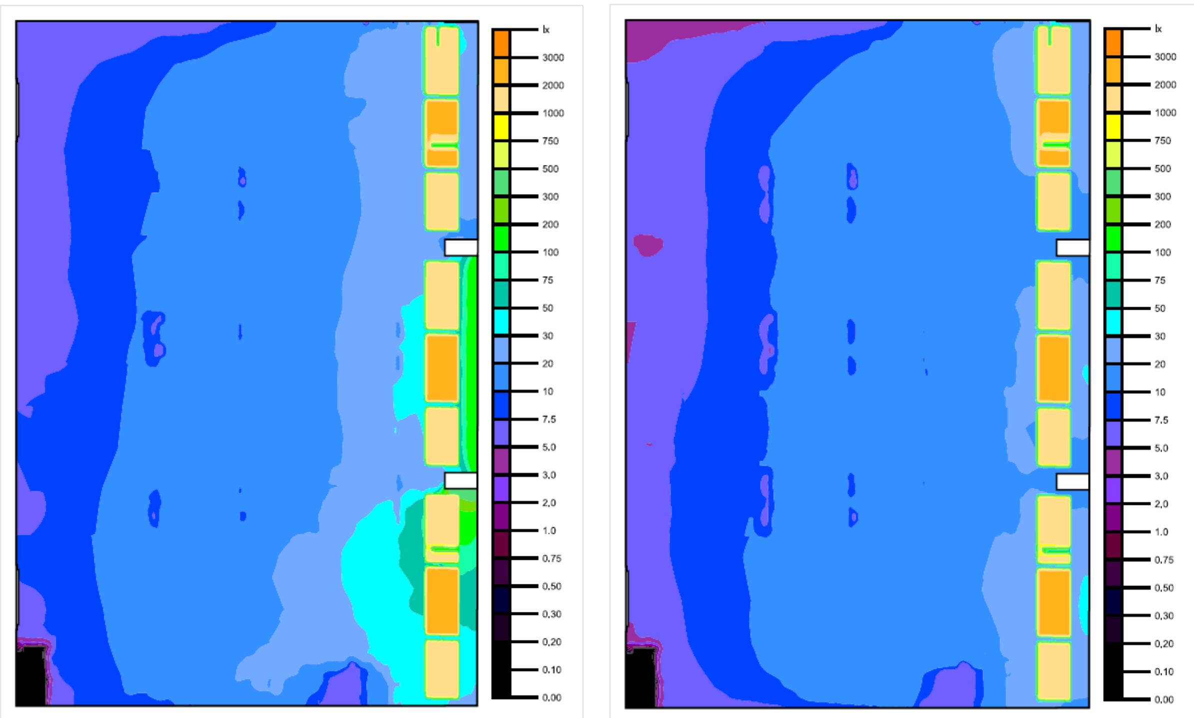
Scale: 1 : 75

Perpendicular illuminance (Surface)
Mean (actual): 2390 lx, Min: 1.06 lx, Max: 48148 lx, Min/average: 0.00, Min/max: 0.00
Height: 0.800 m, Wall zone: 0.000 m

Scale: 1 : 75

Perpendicular illuminance (Surface)
Mean (actual): 337 lx, Min: 0.00 lx, Max: 10013 lx, Min/average: 0.00, Min/max: 0.00
Height: 0.800 m, Wall zone: 0.000 m

Figure 11: False colour of direct sunlight on left and white screen on Right



Scale: 1 : 75

Perpendicular illuminance (Surface)
Mean (actual): 118 lx, Min: 0.00 lx, Max: 2801 lx, Min/average: 0.00, Min/max: 0.00
Height: 0.800 m, Wall zone: 0.000 m

Scale: 1 : 75

Perpendicular illuminance (Surface)
Mean (actual): 99.3 lx, Min: 0.00 lx, Max: 2484 lx, Min/average: 0.00, Min/max: 0.00
Height: 0.800 m, Wall zone: 0.000 m

Figure 12: False colour of Grey Screen on left and dark screen on Right

Based on the findings from Dialux Evo, the sunlight entering the space is different for a normal window and for the screens. In order to compare the sunlight entering the space, three different screens are calculated individually. If we compare with the normal windows, the white screens are reducing the light level near the windows from 15000 lux to 700 lux, which is better but, there are still soft shadows, which is 7500 lux near to the window. Even though, the sunlight is gradually decreasing when it reaches to a depth of the room but, there is still a strong contrast near the windows due to its diffuse material, which creates glare. Grey screens have a light level of 300-500 lux near the window but the rest of the room gradually decreases to 20 lux in depth of the space. The shadows that transmit through the windows from direct sunlight has got softer shadows compared to the white screen, which is 2000 lux. The dark screen was the last one that was calculated to find the sunlight entering the space. The dark screen has a light level of 100-200 lux near the window and gradually decreases to 20 lux in depth of the space. Dark and grey screens are mostly similar with the light level because the transmittance from both the screens has a difference of two percent. The difference is due to its material colour, which varies in light level throughout the space. These findings give an overview of the lighting conditions in the space. If we compare, there is a significant difference in lighting with and without screens (View Figure 7). In the next experiment, with the use of dynamic lighting how can we boost the experience of sunlight in the room, when screens are down?

5.1.3 Experiment 3

How can a light scenario support daylight intake through dynamic lighting?

One of the aims of the project is to work with dynamic lighting with different scenarios. Based on my previous literature review from last semester, three light scenarios have been tested in Dialux Evo software. Considering the scenarios, I would like to introduce a 4th lighting scenario, when the shades are down how we can compensate the sunlight atmosphere inside the space with the support of dynamic lighting.

The 3rd experiment was carried out practically in the Lab at Aalborg University, Copenhagen in frederikskaj 12, room 3.12. The test was conducted on a sunny sky condition on 6th of May, 2017. In order to test in the lab, a tunable white LED fixture with the control system was borrowed from Zumtobel Company, Copenhagen (Zumtobel group, 2017). The fixture is **Light Fields Evolution** (**LFE A 50W LED830-60 Q LDO SRE TTT**), a surface mounted luminaire. As the fixture was tunable white LED, it has three pre-set options for correlated colour temperature from 3000 K – 6000 K. The size of the fixture is 60x60 with a weight of 10-15 kilogrammes. First, the fixture was planned to mount it on the ceiling and test it but, due to the size of the fixture and weight, it was unable to mount it on the ceiling because it was an overhanging ceiling with the light weight of gypsum boards. There was only one option to

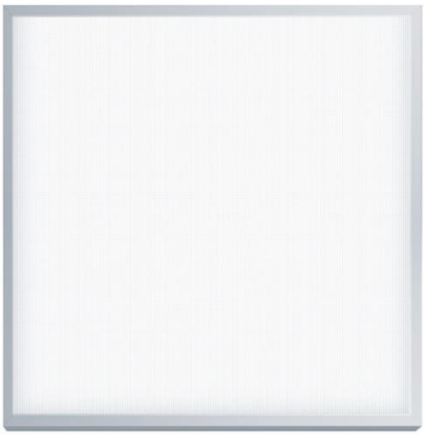


Figure 13: Light Fields Evolution, Tunable white LED, Zumtobel

mount the fixture, which was with scaffolding truss made of steel. There are three steel trusses with a height of 2.4 meters. The test setup has two trusses on both sides of the space and the third truss is assembled between the two trusses and fixed with screws to make it stable. A metal wire of 5mm thickness is used to mount the fixture in the middle of the truss.

Figure 14: The test setting in the lab

In this experiment, the approach was to work with the dynamic lighting with different colour temperatures. Three colour temperatures warm, neutral and cool were tested in the lab on a sunny sky condition when screens are down. To get an overview, each screen was tested with different colour temperatures. Intensity and dimming options were used to adjust the colour temperature to meet the criteria of creating a sunny atmosphere. Meanwhile, to make sure, a spectrometer was used to calculate the colour temperature. Pictures were taken with a Nikon D800 camera + full-frame fisheye lens to compare different light scenarios with sunny sky condition. The approach was to find out, which colour temperature can provide sunny sky atmosphere indoor when the screens are down by avoiding glare. The reason to work with this test is to create same colour temperature indoor, as you don’t have the screens down.

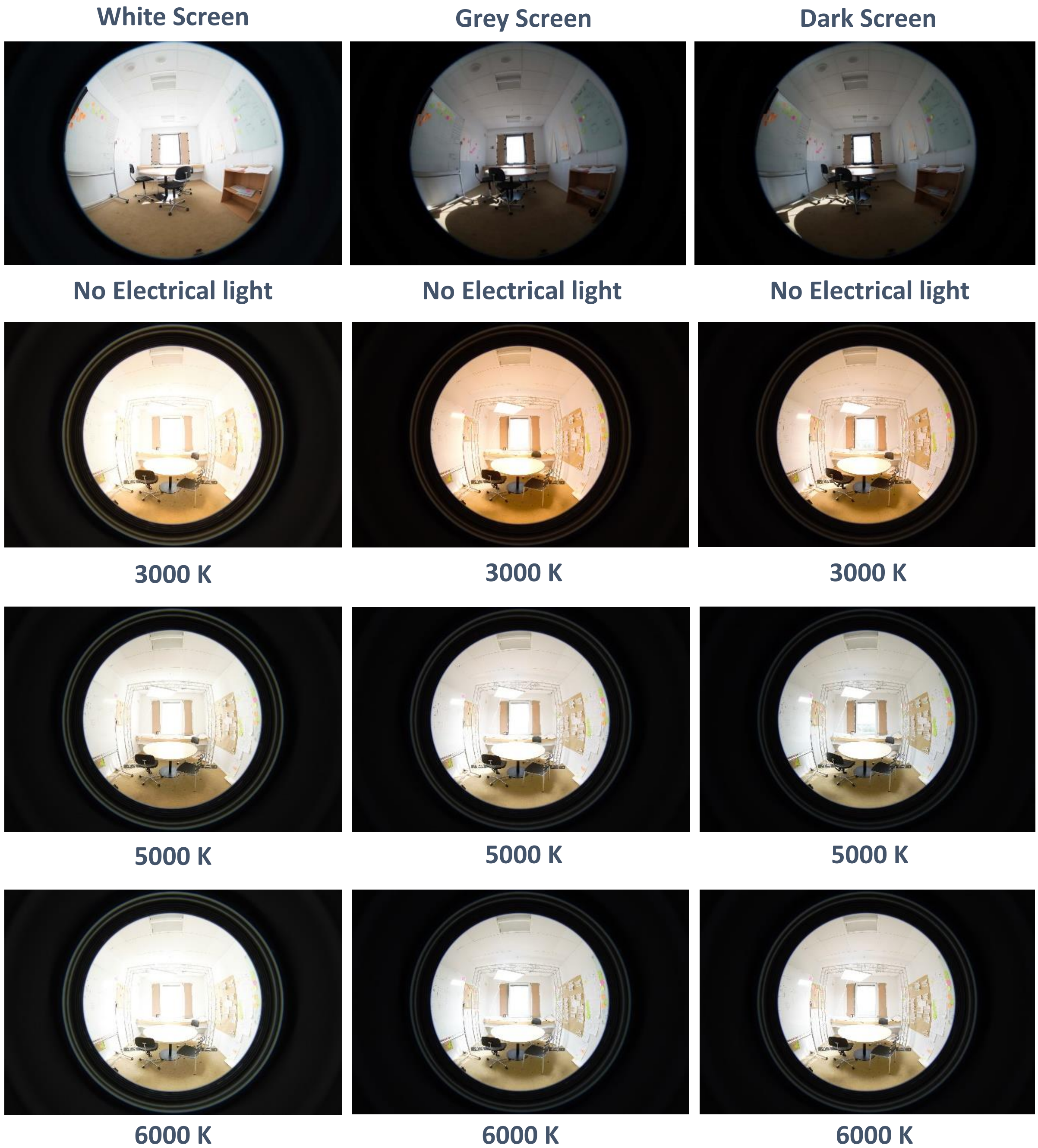


Figure 15: Test with 3 colour temperatures Warm, Neutral and Cool

Based on the observations of the photos from the experiment, different colour temperatures of the lighting changes the perception/experience of the space and “feeling of sunlight”. For the white screen, if we compare the normal and different colour temperatures, the perception of the space does not change much due to the diffuse material and colour of white screen. Space looks much brighter in the space but, the intensity near the window creates glare issues. For the grey and dark screens, the sunlight that transmits through the screen creates bright and dark areas in the space. The perception of the space is dark but, the screens avoid the glare issues. When the different colour temperatures are used, the perception of the space is better with all the three pre-sets but, the aim of this experiment is to find the colour temperature, which can create sunlight atmosphere indoor. In order to support the criteria of creating outside sunlight feeling indoor when screens are down, three pictures were chosen from each screen with an ideal colour temperature of 5000 K, which is close to sunlight atmosphere. The comparison between the normal window and the screens below fulfils the first criteria regarding sunny conditions indoor, which can improve the learning environments.

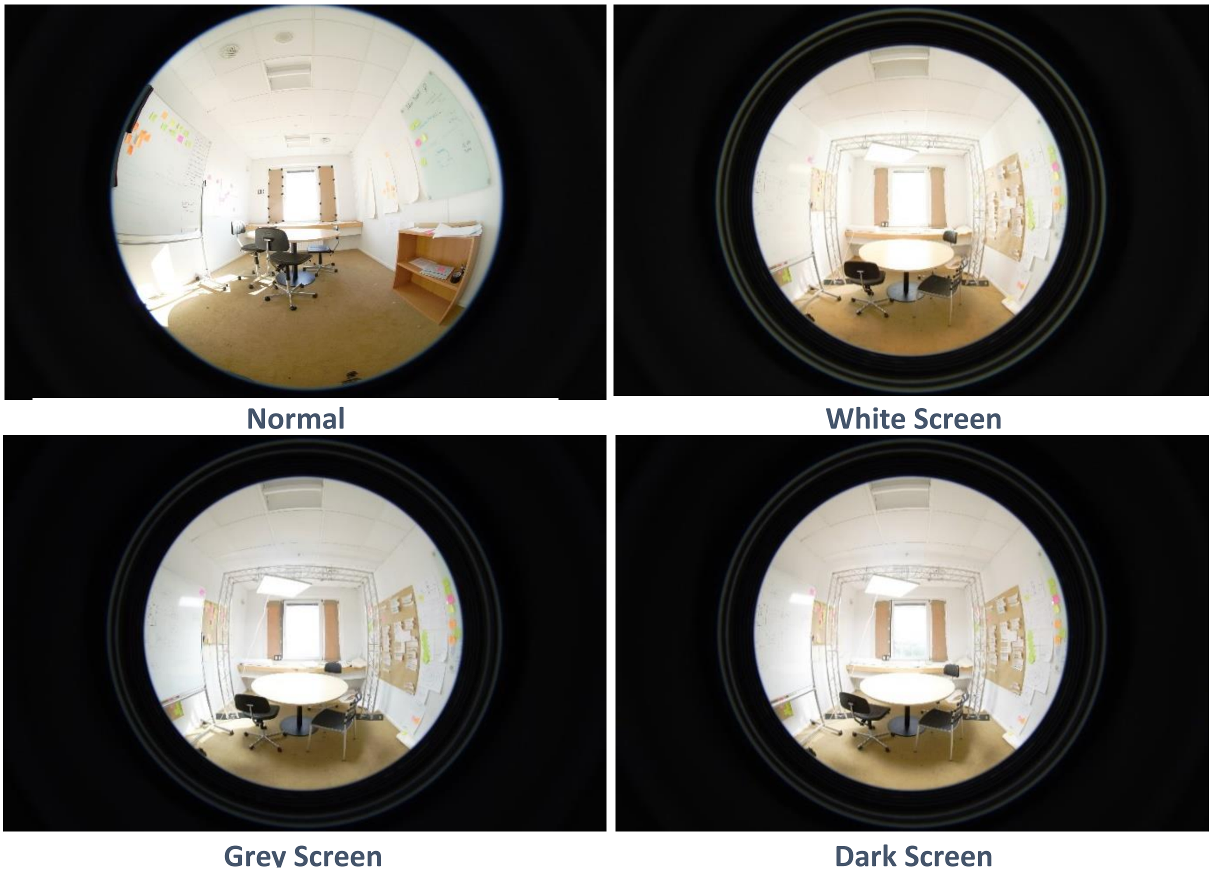


Figure 16: Comparison of ideal colour temperature 5000 K for Screens

5.1.4 Experiment 4

How can dynamic light be used to support sunlight in order to reduce the sharpness and contrast of the shadows, when the shades are down?

The 4th experiment was carried out practically in the Lab at Aalborg University, Copenhagen in frederikskaj 12, room 3.12. The test was conducted on a sunny sky condition on 13th of May, 2017. The test was conducted with tunable white LED fixture from Zumtobel mounted on a scaffolding at a height of 2.4 meters. The test was carried out with five different spherical objects with different textures on each of the objects. The test was inspired by a book **'The Design of Lighting'**, where author demonstrates through four different objects (Tennis ball, table tennis ball, orange fruit, and Christmas tree ball). The author explains how a texture and glossiness can increase a visual separation of objects and background. The author demonstrates through the modelling effect of different light sources. The test was done only by using artificial light to compare the difference between objects and background and how it create different shadows based on the objects. The artificial lighting used was diffuse illumination, single spotlight and a combination of key light and fill light (Tregenza and Loe, 2014 - p.116).

Based on the experiment from **the book**, I was inspired to test the objects with direct sunlight and supporting with the **fill** light to reduce the sharpness and contrast of shadows from objects. The objects used for this test were a tennis ball, a ping pong ball, an orange fruit, a specular object and a Matt object. The approach for this test is to compare different objects, which influence the space with shadows and contrast that affects the human perception in the space. The objects were placed on a desk, which has a standard height of 0.8 meters. The desk was placed near to the big middle window to get the direct sunlight falling on the objects. The test was conducted for three screens with the support of dynamic lighting. For each screen, different colour temperatures were tested in order to get an overview about the difference in texture and background (View Appendix 6). As the approach for this project is to work with the sunny sky conditions, neutral white light with an ideal colour temperature of 5000 K is compared with the direct sunlight, with screen and a fill light to create a natural atmosphere. Light level is measured for screens as well in order to have same lux values. A professional camera Nikon D800 was used to take the photos for different screens. The pictures were taken from a height of 1.5 meters to show the objects shape, shadows and texture in a precise way because there may hide important information in the shadow areas.

Based on the findings, it is quite interesting to see the objects interact with the direct sunlight and how it changes the perception of the background. The approach in this test is to demonstrate how the objects react to different lighting conditions in the space. First, a picture with direct sunlight is taken to give an overview about how objects react to it. We can see, there are sharp shadows from the objects, which are good in a way because it is the symbol of daylight but, it can also be distractive and specular objects can affect the visibility. At the same time, we can see little shadows on the objects as well, which may hide some details about the objects.

Normal Window

White Screen

White Screen + Neutral White (Fill light)

Figure 17: Comparing objects with different scenarios for white screen

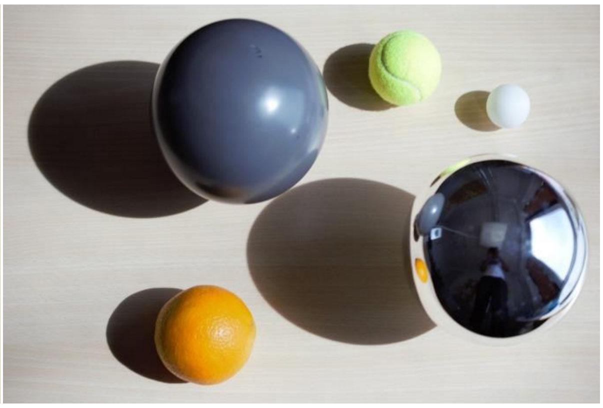
If we compare with the white screen (View fig 17), it takes away the sharp shadows from objects due to its diffuse material and it changes the texture and creates a smoother feeling on the objects. If we consider the specular object, the glossiness increases in the white screen. Even the background changes to a different colour, which is less bright than the original one. In order to take away the sharp shadows completely and illuminate the shadow areas without destroying the model of the objects, a fill light is mounted on top of the objects with the support of scaffolding truss. The third picture in the bottom is a combination of direct sunlight with a white screen and neutral white light (fill light), illustrates the visual separation of objects and background. It takes away the sharp shadows and improves the visibility to see the details of the object. The illuminance was measured for the white screen and the combination of white screen and Neutral white light. The illuminance value for the white screen is 3810 lux and with the neutral white light, it was 4200 lux. The values are higher because it was measured near to the window, which has the direct sunlight transmitting through the white screen that falls on the table. But, if we consider only dynamic light then it has 390 lux in the space. I am aware that the lux level should not exceed above 500 lux, which meets the standards for a classroom (DS/EN Standard, 2011).

Normal Window **Grey Screen**

Grey Screen + Neutral White (Fill light)

Figure 18: Comparing objects with different scenarios for Grey screen

For the grey screen (View fig 18), three scenarios were compared with the direct sunlight, grey screen and grey screen with neutral white light (fill light). If we compare the grey screen with the direct sunlight, the screen is taking away a bit of sharp shadow from the objects but, due to the material colour, the perception of the scene is changing totally. The scene looks much brighter than the normal one. First, the textures have a significant difference when the light falls on the objects. If we see the objects, the Matt object texture is changed from dark grey to purple. The other objects look brighter on the textures. The background as well changes from a brighter material to a softer one. (Tregenza and Loe, 2014), illustrates that “differences in texture and glossiness can increase the visual separation between object and background”. For the third scene in the bottom, which is a combination of grey screen and neutral white light takes away the sharp shadows and changes the texture and background. The fill light also takes away the shadows on the corner of the objects and makes it visible completely. The illuminance was measured for the grey screen and the combination of grey screen and Neutral white light. The illuminance value for the grey screen is 1910 lux and with the neutral white light, it was 2330 lux. The values are higher because it was measured near to the window, which has the direct sunlight transmitting through the grey screen that falls on the table. But, if we consider only dynamic light then it has 420 lux in the space.

Normal Window **Dark Screen**

Dark Screen + Neutral White (Fill light)

Figure 19: Comparing objects with different scenarios for Dark screen

For the dark screen (View fig 19), if we compare with the direct sunlight, the texture colour is changing totally to a different one. The background is much brighter than the normal one. The dark screen is almost similar to the grey screen but, there are small changes in the texture and background due to the material colour. Observing the specular object, the reflection of the material is changing based on the activity of the screen and dynamic lighting. The illuminance was also measured for the dark screen and the combination of dark screen and Neutral white light. The illuminance value for the dark screen is 1850 lux and with the neutral white light, it was 2300 lux. The values are higher because it was measured near to the window, which has the direct sunlight transmitting through the grey screen that falls on the table. But, if we consider only dynamic light then it has 450 lux in the space.

Overall, this experiment fulfils the criteria regarding the perception of the space and avoids sharp shadows, which improve the visibility of the objects. If we compare with the direct light when the shades are not down, it meets the feeling of sunlight with the support of ideal colour temperature 5000 K, when the shades are down. The illuminance level is also set to the same level, which does not exceed 500 lux, which meets the DS/EN Standards 12464-1(2011).

5.1.5 Experiment 5

Testing the light scenario in Dialux Evo to compare colour temperatures and avoid glare.

Figure 20: Light Fields Evolution, Tunable white LED, Zumtobel

The 5th experiment was carried out in Dialux Evo simulation software. The calculation was conducted for herstedlund skole, albertslund on a sunny sky condition at 9 am on June 21st. The approach for this test is to compare different colour temperatures and at the same time to avoid glare issues. The findings from the measurements are implemented for screens when calculating in Dialux Evo. The lighting fixture used for the test is **LIGHT FIELDS evolution (LFE E LED5000-830-60 M600Q LDE KA SRE) from Zumtobel** with tunable white LED and the colour temperature ranges from 3000 – 6000 K (Zumtobel group, 2017). Based on my findings from previous semester, the idea was to supplement the daylight intake with the dynamic lighting, But in this test, I was using it in another context, which is closer to real atmosphere. In the earlier phase, I was using quantitative and qualitative methods and mix them with the experiments with 1:1 set up and simulations and renderings to create a sunlight atmosphere indoor. The reason behind this test is to get an overview about the perception of the space when screens are down. As space is big, three same kinds of screens will be applied on three windows to see how space could react with different screens. Different colour temperatures will be tested in order to find out, which screen can provide sunny sky atmosphere indoor. One thing would be interesting when it is a sunny day outside, after shading I want to make it look like sunny inside with the ideal colour temperature and avoid glare.

Figure 21: Renders for Direct Sunlight on left and Ideal Colour temperature 5000 K with White Screen on right

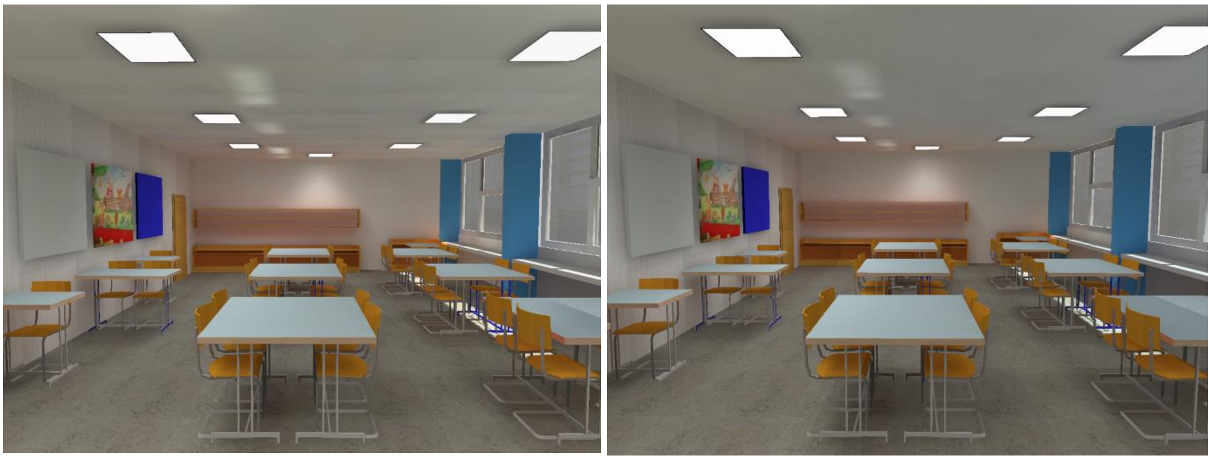


Figure 22: Renders with Ideal Colour temperature 5000 K for Grey Screen on left and dark Screen on right

Based on the findings, the calculations are done for Warm, Neutral and cool white colour temperatures. In order to create a sunny sky condition indoor, an ideal colour temperature has chosen to work with the screens. If we compare with the normal window (view Figure 21), space looks much brighter due to reflections from ceiling, walls and floor. As the classroom is facing east, the sunlight is much sharper that the shadows from the floor reflect on the ceiling. If we see the light distribution, there is 15000 lux near to the window with direct sunlight and decreases to 500 lux with indirect lighting in the space. Due to higher light level, the screens has to be down in order to avoid glare and maintain the uniform light distribution. When each screen was tested, with the colour temperature, light distribution has taken into consideration as well because when I measured in the lab, there is a significant difference with the light distribution for screens. If the room has uneven distribution then it changes the perception of the space and the eye cannot adapt to space quickly because of light and dark areas. If we compare with the screens, with the ideal colour temperature 5000 K with neutral white light gives the closer feeling to sunny sky atmosphere. Due to the contrast from the white screen, the perception of the space is different from grey and dark screens. Grey and dark screens are avoiding the glare issues to some extent by creating soft shadows near to the windows. The findings from this test will feed into final design proposal.

6.0 Final Design Proposal

The main idea regarding this project is to create a sunlight atmosphere indoors with the support of dynamic lighting when shades are down to improve learning environments. Based on the findings from the lab at Aalborg University, there are issues with colour temperature, light distribution and view when screens are down. Each screen reacts to the sunlight in a different way based on its transmittance value and material colour. Nevertheless, all the three screens avoid the glare issues: for a white screen, when the sunlight interacts with the screen, it creates a brighter contrast near the window due to its diffuse material. With the grey and dark screens, it takes away most of the glare issues but, space becomes darker in the depth of the room and brighter near to the windows. It could affect the perception of the space but, according to the findings, with the support of dynamic lighting space creates the natural atmosphere. Based on the success criteria's, one screen will be chosen as final design proposal, which fulfils the requirements. Three parameters colour temperature, light distribution and view, which are part of criteria's will be considered to choose the final design proposal.

Based on the experiments, dark screen fulfils the three success criteria's, which can improve learning environments. The findings suggest that dark screen is better to use for schools and universities. It can improve visual comfort, provides a better view to outside environment and the experiment with the spherical objects prove that it can improve the perception of the space.

For the 1st criteria, **creating outside sunny conditions inside the room when shades are down:**

The qualities that we get with the dark screen are a colour temperature, which is similar to outside conditions but, the perception of the space looks darker due to the screens transmittance. The glare ratio was much higher due to the variation of light level in the space. In order to compensate for the sunny sky condition, an ideal colour temperature of 5000 K is used to create the natural atmosphere. The light distribution is adjusted to a certain level of the intensity to create a uniform distribution. The glare ratio was decreased below 1:3 ensuring the visual comfort that can improve learning environments (Osterhaus, W. 2009). The dark screen avoids most of the glare issues, which improves the visual comfort for the occupants indoor.

Normal Window with Direct Sunlight

Dark Screen

Dark Screen with Ideal colour Temperature 5000 K (Neutral White)

Figure 23: Final Design Proposal of Dark Screen with Ideal Colour temperature 5000 K

For the 2nd criteria, **creating a better view to outside environment:**

Most of the researchers argue that view to the outside environment can influence well-being, productivity and health (Hellinga, H. 2013). The findings from the experiments showed that dark screen can avoid glare and it performs best at providing a view to the outside environment. The view looks natural and gives a feeling that there are no screen, by making the sky texture visible.

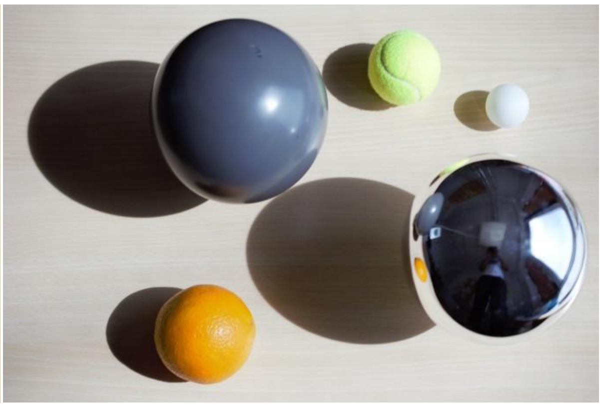
View from Dark screen, Far way (Left) and Closer (Right)

Figure 24: Final Design Proposal of Dark Screen with View to outside

For the 3rd criteria, **Human perception can improve learning environments:**

Our perception of a room is affected by different materials in the space. Even the reflection of a matt surface and specular surface can differ greatly. If we look at the experiment with the spherical objects for the dark screen, there is a significant change in textures for all the objects. The picture with direct sunlight gives an overview of different objects, which affects the visual appearance with sharp shadows. The dark screen changes the perception of the objects with a significant variation in texture and background, which affects the eye adaptation. In order to create a smoother visibility, fill light is added with an ideal colour temperature of 5000 K to take away the sharp shadows, which also avoids distraction. With the fill light, visibility is improved and is created a natural atmosphere that can help focus on activities in the space. This test can be used as a recommendation for educational facilities when designing the space.

Normal Window with Direct Sunlight



Dark Screen

Dark Screen + Neutral White (Fill light) with Ideal colour temperature 5000 K

Figure 25: Final Design Proposal of Dark Screen with different objects

7.0 Discussion of the further process

As mentioned, the interest in daylighting in the context of health and well-being has been increased significantly over the years**.** The need for daylighting in buildings has become the first preference for the occupant's indoors. But, the angle of the sun varies differently all over the world. Based on the angle of the sun, there are benefits and problems for the occupants indoor. The problems that occur with the sun are glare and heat issues, which occupants prefer to avoid the use of shading systems. In northern countries due to lack of daylight, manufacturing companies are developing dynamic lighting, which can compensate the lack of daylight. They are designing dynamic lighting especially for educational institutions and work environments. When we say 'good daylighting' conditions, often the implementation does not work the same way. In this thesis, many methods have been evaluated in order to find the best way to compensate daylight with the support of dynamic lighting when using shading system.

The angle of the sun in Denmark varies for different seasons (view Appendix 2). The evaluations are done for the specific season with quantitative and qualitative methods regards to shading system and how it affects the space. The results show that screens avoid the glare issues but, it changes the perception of the space, which affects the students learning. Even with the support of dynamic lighting, not every fixture can provide the daylight atmosphere. In this thesis, experiments were done in order to create sunny sky conditions indoors. The experiments were conducted with two different methods: a practical test and a simulation test. The experiments that were done with the practical test using screens and dynamic lighting shows some good results regards to sunny indoor atmosphere. The fixture that was used in the practical test is a fill light, which is a tunable white light. The fixture that was borrowed from Zumtobel Company is a surface mounted luminaire. Even though, we could achieve the results that were expected a fixture with an overhanging of 0.5 meters could provide more efficient results due to its direct and indirect lighting in the space. For this experiment, the results were still similar to sunny sky conditions except for a few soft shadows through the screens from direct sunlight in the space. As the screens are made of fabric, it still allows the soft shadows in the space. Even though, it does not affect the occupants indoors but, with the use of translucent screens it could have avoided the sunlight completely, but still, the view to the outside environment makes the screens a better choice. The practical test with the spherical objects gave me an opportunity to work with the materials in order to see the difference with the textures and background. The results confirmed that it can affect the perception of the space (Tregenza and Loe, 2014). The final results of the practical tests create the feeling of sunny sky condition with a quality of view that can improve learning environments.

The experiment with the simulation software Dialux Evo was conducted with the same screens and fixture. In order to achieve the outcome of the practical test, the findings from the measurements (transmittance, colour and thickness) were applied in the simulation software on a sunny sky condition in order to test different light scenarios. The results from the simulation software depend on the values and materials that are assigned during the calculations. Dialux Evo has a drawback with the reflections of materials, which changes the perception of the space because some of the material colours do not look realistic. But, the software is good for calculating the lighting conditions according to standards and there is an advantage of being able to choose fixtures from different companies for testing light scenarios. As Dialux Evo has a limited amount of shading systems from companies, it is hard to find the right shading to work for the projects. It could be really useful if the software has a library of shading devices from different companies would provide good results for the daylighting projects. Overall, the outcome from the simulations creates a sunny sky conditions indoors, which are closer to the feeling of the sunny atmosphere that can improve learning environments.

If we compare the results from both the tests (view figure 26), there is a significant difference with simulation because the software does not give the perception of the space similar to a professional camera.

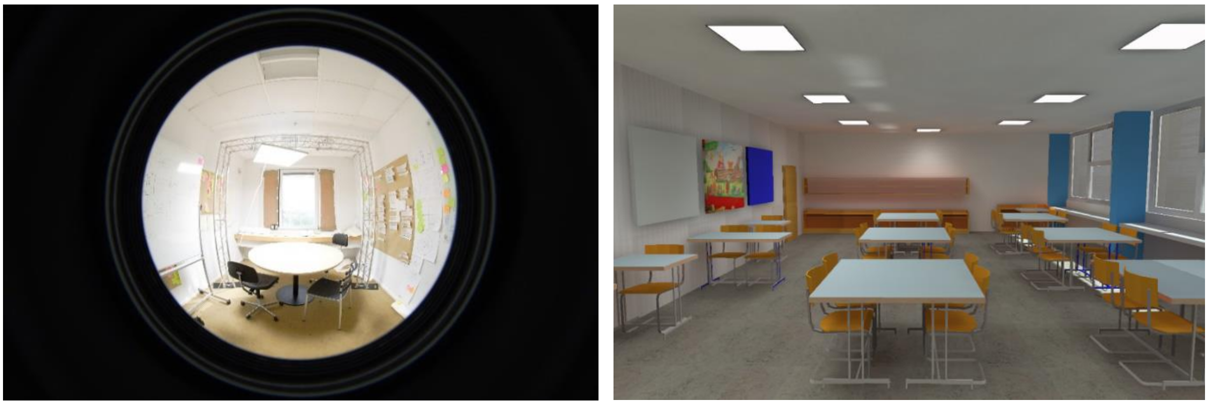


Figure 26: Comparison with the practical test on Left and Simulation test in Dialux Evo on Right

For the future works, I would like to work with the angle of the sun for different seasons because the low morning sun changes colour every hour (View Figure 27). So, it could be interesting to work with the dynamic lighting that can meet the daylight conditions. For my future work, I could try to meet the scenario, which is similar to outside conditions

Figure 27: Low morning sun changes colour every hour

In future works, it could also be interesting to work with the fixture that has characteristics of sunlight, which can create a sunny sky atmosphere indoors. For now, there is a Company that manufactures the fixtures, which look like a skylight window with a beam angle of 30˚, 45˚ and 60˚ (Coelux.com). The fixture can be mounted on ceilings and walls, which create a sunlight shadows inside the space. This fixture can give a feeling of sunny atmosphere with the shadows that can improve health and well-being of the occupants. At present, these fixtures are used in all kinds of fields except educational institutions, but it would be great to see them in educational institutions due to the qualities it can offer to the learning environment.

8.0 Conclusion

As the project was focussing on different solar screens with the support of dynamic lighting that can improve the learning environments. This project was investigated based on two case studies: a test room at Aalborg University, Copenhagen and Herstedlund skole, Albertslund regarding sunlight conditions in the space. Through analysis, experiments and final design, I have explored how we can create a natural indoor atmosphere. This project aimed to create sunny sky conditions indoor with the use of screens and supported by dynamic lighting to improve learning environments. To fulfil the criteria's, different experiments were done when screens are down and how we can compensate with dynamic lighting to create a better learning environment.

Firstly, the aim was to create outside sunlight conditions indoor when screens are down. In order to find out, the test was conducted in the lab at Aalborg University with the solar screens through measurements. The findings have concluded that there is a significant difference with light distribution and light level in the space. Even though, the colour temperature was similar for the screens but, the perception of viewing the space is different from the screens. Based on the findings, a tunable white LED fixture was used to compensate the sunlight atmosphere with an ideal colour temperature of 5000 K and at the same time created a uniform distribution in the space. Overall, it concludes that through colour temperature, light distribution and light level the aim of creating outdoor sunlight conditions indoor has been achieved, which can improve the student learning in the space.

Secondly, the project aimed to create a better view to the outside environment when screens are down. In comparison with the three screens, the dark screen provides a better quality of view that keeps in contact with nature. By creating a better view, it concludes that dark screen can improve health and well-being of occupants indoor, which can lead to improvement in performance of students. However, for the validated results a real test with the occupants needs to be investigated in the future.

Lastly, one of the aims was to improve the perception of space, which can provide better learning environments when screens are down. In order to support the success criteria, an experiment was conducted with different spherical objects when screens are down. The findings showed that objects can vary based on the material of the screens and the reflections from the objects could create glare problems. The objects can influence the behaviour and activities of students in the space. Overall, it concludes that by avoiding the shadows and contrast of the objects can improve the perception of the space, which can improve their performance.

Based on the findings from the experiments, this project answers the two final research questions.

How can we improve the lighting in the classroom considering the daylight intake through shading systems?

How can dynamic lighting support daylight intake by considering light distribution, colour temperature and view to outside to create a better environment?

Considering the daylight intake through screens, it avoids glare and improves the lighting conditions in the classroom. Dynamic lighting can improve the learning environments by considering light distribution and colour temperature. The quality of view can provide direct contact with nature, which can improve the students' performance. Overall, this tests can be used as a recommendation for educational facilities when designing the space.

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10.0 Appendix

1. Average Sunny and Cloudy days, Copenhagen, Denmark

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Sunlight Hours/ Day	01:09	01:56	03:48	05:22	07:54	08:10	07:42	06:40	05:14	02:48	01:08	00:36	04:23
Average Daylight Hours & Minutes/ Day	07:44	09:33	11:47	14:10	16:16	17:26	16:54	15:02	12:43	10:20	08:15	07:08	12:00
Sunny & (Cloudy) Daylight Hours (%)	16 (84)	21 (79)	33 (67)	39 (61)	49 (51)	48 (52)	46 (54)	45 (55)	42 (58)	28 (72)	14 (86)	9 (91)	37 (63)
Sun altitude at solar noon on the 21st day (°).	14.5	23.8	34.6	46.2	54.5	57.8	54.7	46.4	35	23.5	14.4	11	34.7

Figure 28: Annual overview of average sunny and cloudy days in Copenhagen, Denmark. (Climatemp.com).

2) Altitude of Sun, Denmark

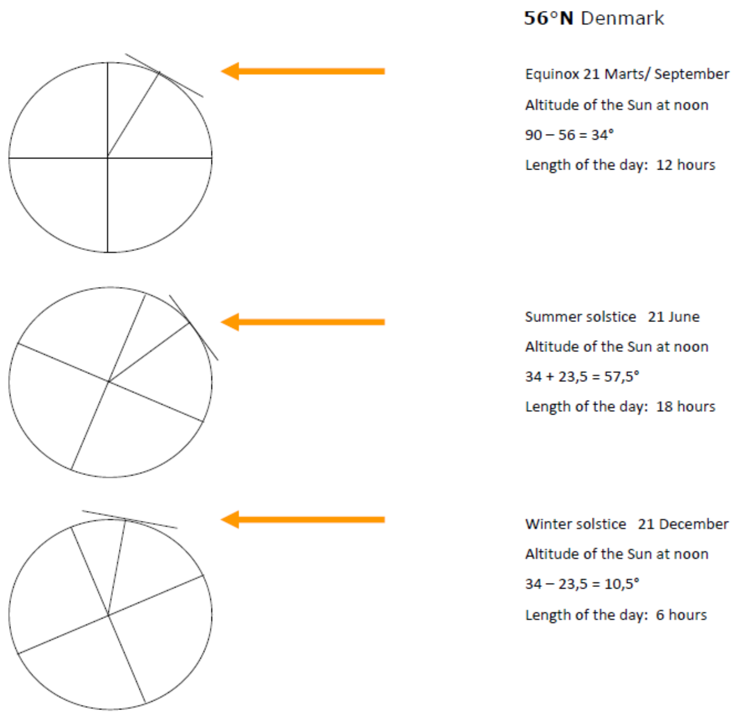

Figure 29: Altitude of the Sun at noon in Denmark. (Mathiasen. N, 2015)

3) Renders in Dialux Evo for normal window and screens

Figure 30: Renderings of Direct Sunlight on left and White Screen on right

Figure 31: Renderings of grey Screen on left and Dark Screen on Right

4) Renders in Dialux Evo with different colour temperatures for screens

Figure 32: Render in Dialux Evo for White Screen with 3000 K on left and 6000 K on right

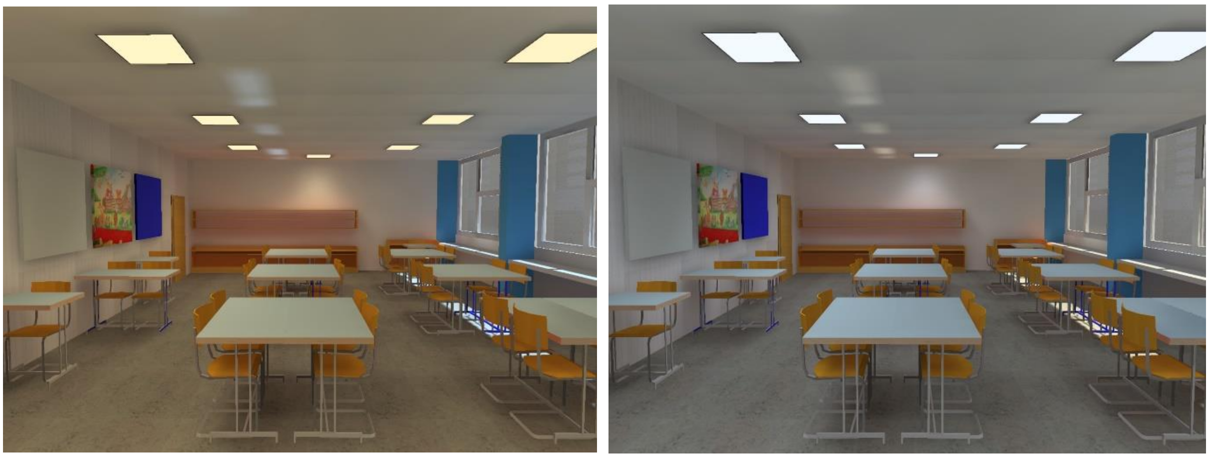

Figure 33: Render in Dialux Evo for Grey Screen with 3000 K on left and 6000 K on right

Figure 34: Render in Dialux Evo for Dark Screen with 3000 K on left and 6000 K on right

5) False colour images for screens with dynamic lighting showing light distribution

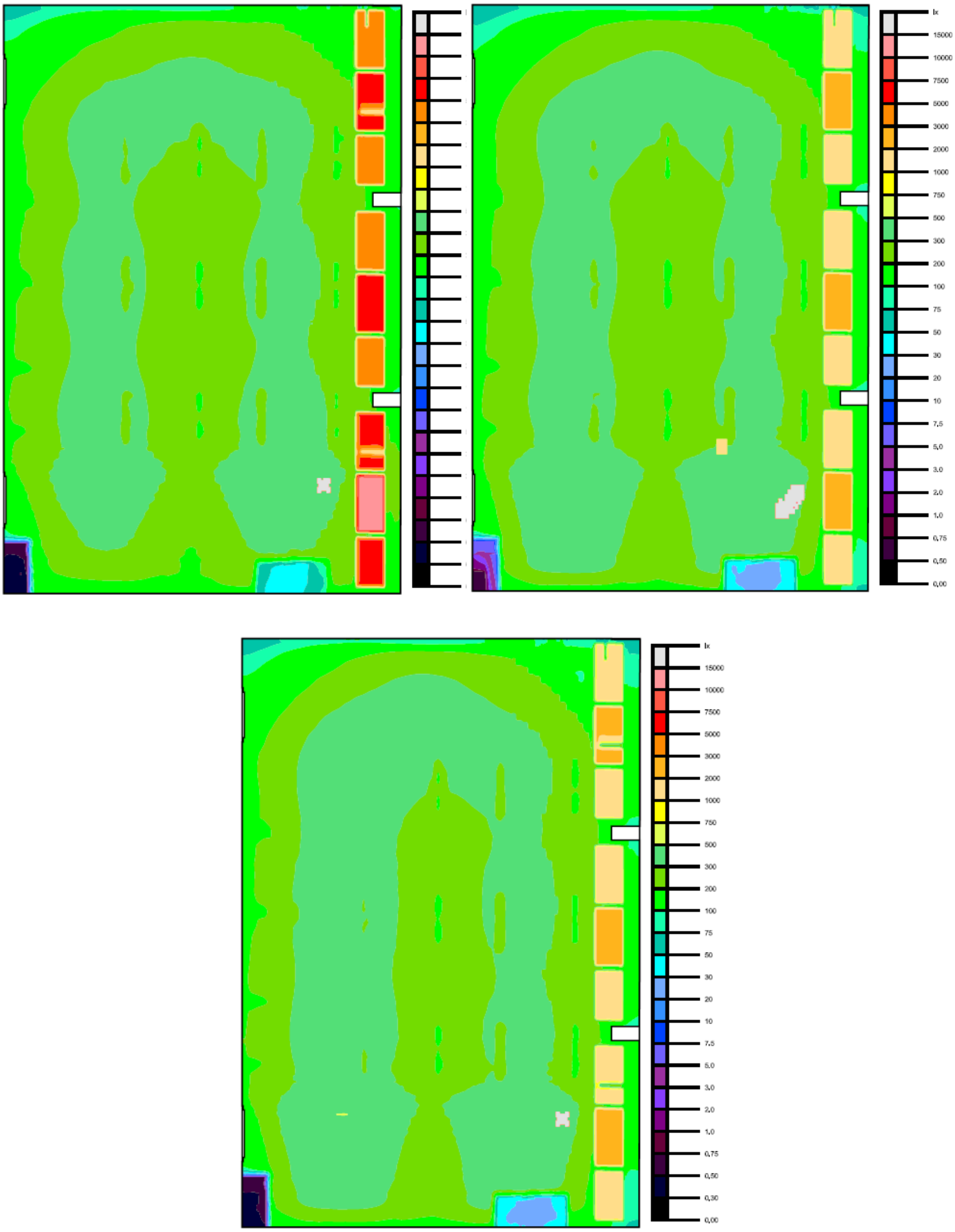

Figure 35: False colour images with light distribution for White screen (top left), Grey screen (top right) and Dark Screen (bottom)

6) Testing Spherical objects with a combination of screens and colour temperatures

Figure 36: Comparing Spherical objects with different Colour Temperatures for screens

7) Specifications of the Zumtobel fixture from Dialux Evo

Project 03/10/2016

Site 1 / Building 5 / Storey 7 / ZUMTOBEL 42 182 181 LFE E LED5000-830-60 M600Q LDE KA SRE 1xLED-Z42182181 / ZUMTOBEL - LFE E LED5000-830-60 M600Q LDE KA SRE (1xLED-Z42182181)

ZUMTOBEL 42 182 181 LFE E LED5000-830-60 M600Q LDE KA SRE 1xLED-Z42182181

Modular LED ceiling-recessed luminaire with MPO+ micropyramidal optic. Total power: 52 W, DALI controllable luminaire with LED converter DT8 2012 DALI system; LED service life lasts 50000 h before luminous flux is reduced to 80% of the initial value. Chromaticity tolerance (initial MacAdam): 4. Luminaire luminous flux: 4900 lm, Luminaire efficacy: 94 lm/W. Colour rendering Ra > 80, colour temperature 3000 K to 6000K. Despite maximum quality control, recognisable colour differences between luminaires with the predefined tight binning may occur with cluster applications. To achieve a uniform appearance despite this, we recommend consulting a lighting consultant with intended cluster installations. Luminous flux constant over the defined colour temperature range. Light guided via backlit multilayer MPO+ micropyramidal optic with seamless look and defined light emission for glare-free light distribution with UGR < 19 and L65 < 1500 cd/m² to EN 12464-1; reduced luminance at steep angles specifically designed to cut glare on tilted displays and allow maximum flexibility in positioning of luminaires; evenly spaced LED light points; LED modules include high reflection 3Dprotect® reflector as protective cover to prevent damage from electrostatic discharge, smooth outer diffuser of high grade PMMA for a brilliant appearance, low dirt sensitivity and simple cleaning; flat aluminium luminaire housing of sheet steel enamelled; high quality, silver eloxal optic surround made of Aluminium; inner 5-pole connector terminal (von außen anschließbar); can be installed as a single luminaire or in a cluster; designed to fit in cut ceiling apertures and in modular ceilings with concealed or visible grid system; please order fixing kit separately; Luminaire wired with halogen-free leads; Modul: 600; Dimensions: 597 x 597 x 100 mm, weight: 9 kg.

Order No.: 42 182 181

Light output ratio: 100%
Lamp luminous flux: 4900 lm
Luminaire luminous flux: 4900 lm
Power: 52.0 W
Luminous efficacy: 94.2 lm/W

Colourimetric data
1xLED-Z42182181: CCT 3259 K, CRI 84

Luminous emittance 1 / Polar LDC

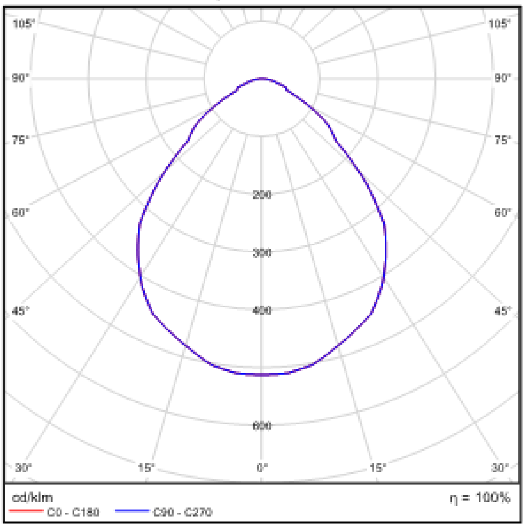

Figure 37: Specifications of Light Fields Evolution from Dialux Evo