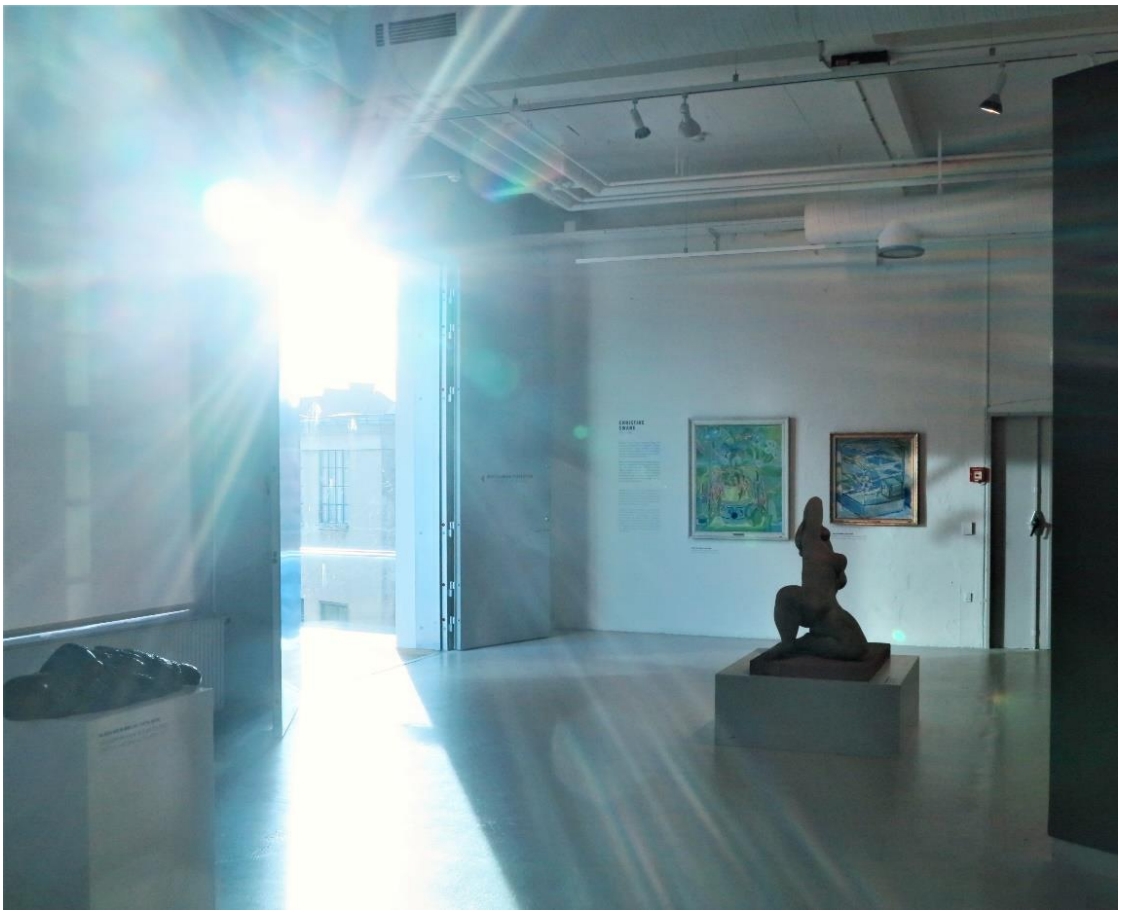
AALBORG UNIVERSITY
COPENHAGEN



DAYLIGHT IMPROVEMENTS IN MUSEUMS SITUATED IN HISTORICAL BUILDINGS

Aalborg University Copenhagen

4th Semester Master thesis, Msc Lighting Design, LID 4.

Student: Arthur van der Zaag, study nr. 20153041

Supervisors: Nanet Mathiasen and Marc Fontoynont

Secretary: Lisbeth Nykjær

2 June 2017

There will also be natural propriety in using eastern light for bedrooms and libraries, a western light in the winter for baths and winter apartments, and the northern light for picture galleries and other places in which a steady light is needed; for that quarter of the sky, grows neither light nor dark with the course of the sun, but remains steady and unshifting all day long.

Vitruvius (around 80 – 15 B.C)

Dagslys er det bedste lys, punktum.

Daylight is the best light, period.

Christina Augustesen, giving a guided tour at Novo Nordic headquarters in 2016.

Abstract

Many museums are placed in historical buildings that are not designed for the purpose of being a museum. Those buildings create an atmospheric environment for art exhibitions. Because those buildings are not designed to exhibit light sensitive works, often the solution is to block daylight and use stable electrical light. With this solution, the positive elements of daylight, which electrical light does not have, are lost. Daylight has positive elements that include the appearance of the space, the orientation to the surroundings outside the building, and human well-being, all of which contribute to positive experiences of the museum visitor.

In this case study, a series of interviews conducted with staff members at a museum determined the issues they experience with both electric light and daylight, as well as their needs and preferences for the use of the space in regard to the light situation. The input from the interviews and an analysis of the space provided information that was used to make specifications for a design solution.

The design solution reduces the daylight intake through the side lit windows with the use of light filters and with adjustable black out blinds that reduce the geometry of the window aperture. Three exhibitions layouts are presented that use partition walls that are placed in order to block or reflect light and make advantage of the reduced amount of daylight still entering the room. Additional elements of the design solution consisted of a new design of the lighting grid. The presented solutions made it possible to show light sensitive works that require reduced light levels at zero - 50 and 200 lux.

Table of Contents

1 Introduction

The Bible starts with these words:

> *In the beginning, God created the heavens and the earth. Now the earth was formless and empty, darkness was over the surface of the deep, and the Spirit of God was hovering over the waters. And God said, "Let there be light," and there was light. God saw that the light was good, and he separated the light from the darkness.*

What is striking is that when God saw the light, he determined that it was good. Ages have passed since that day, and much knowledge has been gained. All this knowledge from generations of observers emphasizes that the light that we receive from the sun, which is almost 150 million kilometers away, has unique qualities and is the reference source for "good" light. It is also this light our ancestors lived with for thousands of years. Through evolution, our eyes are perfectly adapted to this type of light.

Manmade light started approximately 400.000 years ago, when Homo sapiens started to make and control fire. Fire provided people with warmth and offered a somewhat controllable form of light. Many centuries passed before a further development was made. The next step advancement was the oil lamp, which was in use starting from roughly 400 B.C. Gas lighting was introduced around the year 1800, and almost a century later, the electrical bulb brought artificial light to the general public. Fluorescent light tubes were developed around 1940. The most recent major development in lighting is the LED light source, which was introduced around the start of the 21st century.

This means that apart from the daylight there is a wide range of light sources that can be used when designing lighting schemes. But one thing is sure, when lighting is being designed for museums and art galleries, the lighting must be of the best quality, because most of the artworks must be experienced or understood through their visual information.

1.1.1 Introduction to the qualities of daylight

Daylight is recognized to have many qualities that are not easy to accomplish with electrical light. Clegg (2014) describes the reasons for working with daylight improvements in buildings as following:

- Reduced energy consumption.
- Benefits to human health and well-being.
- Better appearance of the space.
- Provides a connection to the location, the weather outside and time of the day.

To this can be added:

- Good colour rendering

Good colour rendering is an obvious element to emphasize when evaluating museum lighting. Some more subtle elements related to the use of daylight include the appearance of the space, the orientation to the surroundings outside the building, and human well-being, all of which contribute to positive experiences of the museum visitor.

Research shows that people prefer offices with windows instead of offices without windows (Ruys, 1970) and that good daylight conditions reduce sick leave for employees, (Boubekri, 2014). Classrooms with windows have been shown to have a positive influence on reducing the stress levels of children (Küller & Lindsten, 1992).

Human well-being is one of the non-visual effects of daylight. Daylight influences our circadian rhythm through the human hormone production (more specifically the suppression of melatonin production) and this influences our level of alertness. (Figueiro et al. 2004). Another non-visual aspect of daylight is that the colour of the light and the position of the sun gives us references to the time of the day and the weather conditions outside.

Daylight is recognized to have both visual and non-visual effects. With a good use of daylight, the museum experience can be improved for both museum guests and museum employees.

1.1.2 Introduction to top lit and side lit rooms

The way in which the daylight enters a room can be divided into two different categories. Top lit (roof windows or “sky lights”) or side lit. Top lit rooms receive more light than side lit rooms with the same window size. The character of top lit windows is that they face the light source, the sky, at a 180° angle. That gives more light and a very even horizontal distribution of light throughout the space.

The distribution of top lit daylight onto the wall is characterized by more light on the upper part of the wall than on the lower part of the wall. With proper design a very even light distribution can be achieved at “exhibition height” (one to two meters above the ground). Rooms on the top floor of a building can be provided with roof windows.

Side lit windows can be made in any room facing at least one of the facades of the building. The depth of a building has a major influence on the penetration of the daylight into the building. Side lit rooms are characterized by greater amounts of light close to the windows and less light that reaches the core of the building. Side lit rooms have an uneven distribution of light on the horizontal surface in the room.

The geometry of the windows is also of great importance. The size of the windows has influence on the amount of daylight entering the room. The height of the window and the window sill, have influence on how deep the daylight is penetrating the building (Meek and Wymelenberg, 2015).

There are many examples of museums specially designed with the purpose of using the qualities of daylight. Architects and lighting designers have put a great deal of thought into the orientation of the building and the placement of the apertures such as windows and glass doors. Top lighting is a strategy typically used when buildings are specially designed for the purpose of housing a museum. Other techniques used are the orientation of the building and the use the qualities from the northern light. As previously mentioned in the quote by Vitruvius, northern light is stable and indirect daylight is suitable for picture galleries.

1.1.3 Background for the subject of the thesis

Many museums have been established in buildings that are not originally designed to be museums. Quite often, those museums are placed in historical buildings. These buildings create an atmospheric environment for art exhibitions, which can be of great value for the visitors and the museum, and can be used in relation to the exhibition design.

Many historical buildings are not designed for exhibiting, and therefore, the lighting conditions are often not suitable. The intensity of daylight entering the building is too high for light sensitive objects, such as paintings, drawings, and photographs. Those objects and artworks deteriorate over time when they are exposed to light, especially when exposed to great amounts of light. Historical buildings used as museums need to be redesigned for the specific purpose: viewing the objects on display in a visually optimal way while at the same time taking light regulations for light sensitive works into consideration.

In such buildings, fulfilling contemporary museum lighting requirements for light sensitive works is a challenge. Regarding side lit rooms, Hefferan (2008) states: “Windows are the most problematic daylight introducing building form.” He continues, “From my perspective there is no practical way to maintain favorable viewing conditions at conservation light levels in a gallery with windows” (page 24). Often, blacking out the daylight is the simple solution, and stable electric lighting is used instead. This enables light levels to be controlled, but the positive qualities of daylight that cannot be produced by the electric light are lost.

There is a need to find lighting solutions that would help create a more dynamic museum. Improvements in lighting would enable visitors to better enjoy the entire museum experience and still be aware of the time of day and the seasons outside. Better lighting

design would satisfy conservators regarding controlled light levels. Curators could have more flexible solutions and a livelier atmosphere inside the exhibition spaces, as well as the ability to create surroundings in which the artworks are presented in optimal conditions.

1.2 Research question

The purpose of this thesis is therefore to investigate how the qualities of daylight can be used in exhibitions spaces inside buildings that were not originally designed for the purpose of being a museum, and more specifically, buildings which have side lit windows, and in which the electrical lighting design must be taken into consideration, in regard lighting up light sensitive objects. The research question is therefore:

How is it possible to optimize the use of daylight and integrate electric lighting, in a side lit historical building, while still fulfilling museum standards for protecting light sensitive works?

1.2.1 The qualitative and quantitative part of the research question

With the research question determined, the next step is to organize how this question is going to be answered. A case study is introduced in chapter 1.4. This case features Brandts, an art museum in Odense. Using this museum as a case provides a focus point for the investigations, as well as the physical surroundings in which to carry out the quantitative and qualitative research.

The sub-question related to the research question is, "What is the optimum use of daylight?" Architecture professor Mohamed Boubekri (2014, s.12) stated: *"*Daylighting is about the judicious quantitative and qualitative control of daylight inside a building*."*
To find answers to the sub-question; "the optimum use of daylight", must be divided into quantitative and qualitative parts.

The qualitative part of the question can best be answered by the people who work at the site of the case study. To determine the answer to this question, the perceptions and opinions of the people who work at Brandts had to be obtained. To gain a broader perspective on the qualitative subject, literature and other research on the subject must be investigated. "What is the optimum daylight solution?" The quantitative part of the question will be answered by finding tables or other sources of information available that give certain minimum, maximum or possibly optimum values for daylight.

1.2.2 Terms related to the research question

To provide a clearer understanding of the research question, four terms used in the research question will be specified.

What is daylight?

In this thesis, the definition of the natural light put forth by Boyce (2014) will be used. "The natural light is light received on the earth from the sun, either directly or after reflection from the moon" (page 28). Although natural light is a more precise phrase, whenever the term daylight is used in this context, it is the equivalent of natural light as defined above.

What is a museum?

The word museums seem obvious to most museum guests. But an essential part of being a museum is having a collection. Typical art halls do not have their own collections. In this thesis, the phrase **museum** describes any space that is used permanently or temporarily to show art or cultural history objects to an audience, no matter if the objects shown are owned by the exhibiting place or not.

What are museum standards?

There are several different organizations defining light standards for museums. To mention a few, there is International Council of Museums (ICOM), Illuminating Engineering Society (IES), the British organization The Society of Light and Lighting, and there are the European standard DS/EN 12464-1.

In Denmark, there is the Danish Agency for Culture and Palaces, under the Ministry of Culture, which states guidelines for lighting at museum who are financially supported by the Danish state. The guidelines they use refer to research by Thomson (1986).

In most office buildings, there is a need for light levels in task areas between 50 and 5000 lux according to DS/EN 12464-1. Those light levels are too high to fulfill preservation requirements. For museum standards, light levels are restricted to between 50 and 200 lux for light sensitive works. Thomson (1986). Furthermore, restrictions are given for the amount of time light sensitive works are exposed to light.

What are light sensitive works?

Light sensitive works are any artifact that can be exhibited and that is changed in appearance by photochemical deterioration due to light exposure. (Conn, 2012)

According to Shaw (2015), typical categories include:

Irresponsive to light: stone, metal, enamel

Low responsive to light: painted surfaces, ivory, wood, lacquer

Medium responsive to light: paper works, photos, fabric

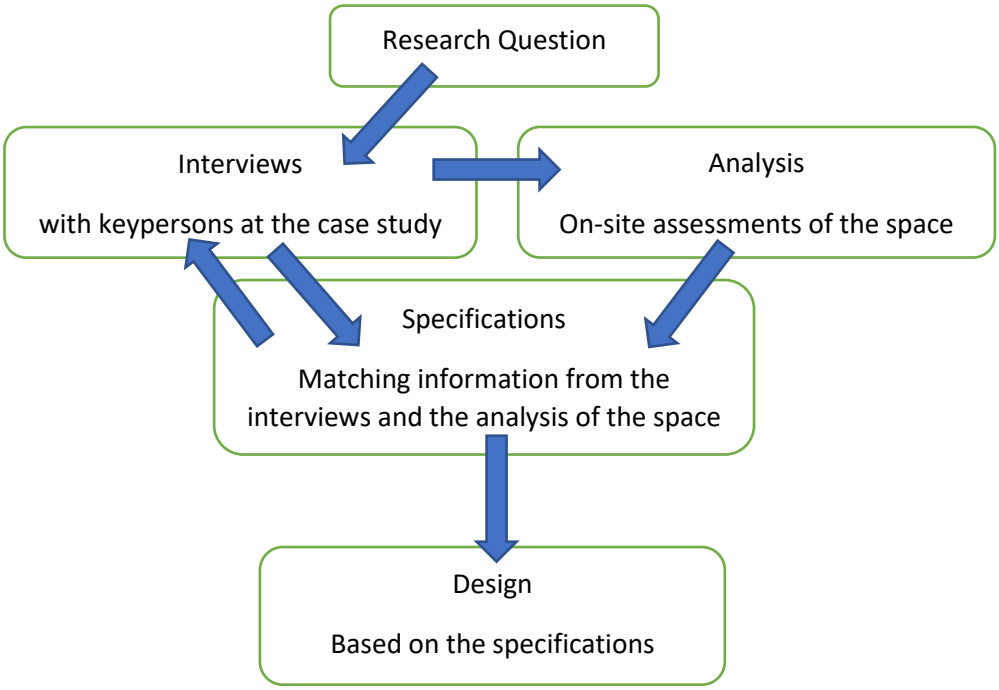
High responsive to light: watercolors, silk, newspaper

1.3 Methodology

The goal of this thesis is to find an answer to the research question:
How is it possible to optimize the use of daylight and integrate electric lighting in a side lit historical building, while still fulfilling museum standards for protecting light sensitive works?

In the thesis by Augustesen (2009), she investigates whether the use of daylight meets expectations at six international art galleries. The investigation shows that 4 out of the 6 galleries are not satisfied with the outcomes of daylight usage. Furthermore, there is no optimal strategy or golden solution that ensures the successful use of daylight. One important finding was that a close communication between the designer of the daylight solution and the gallery is essential.

User Centered Design, (Norman, 1986) is a method that was formulated originally in 1986. Later it was used in numerous ways when designing solutions based on user needs and expectations. This approach fits very well with one of the conclusions from Augustesen. The combination of the outcomes of Augustesen's thesis and the method of the User Centered Design lead to the following method:



1.3.1 The interviews

In the Brandts case study, two series of interviews were planned - one at the beginning of the project and one after the analysis of the space had been carried out. The purpose of the initial round of interviews was to gain better understanding of the issues that the key persons at Brandts experience in their work. The staff described the problems they experience with lighting in general, both electrical and daylight. Their answers provided insight into the qualities they consider to be beneficial or bothersome, as well as information about what they would like to improve.

Statements from the staff at Brandts were used to determine which issues to prioritize, and further analysis determined whether the issues could be solved or diminished through changes in the lighting. Input from the first round of interviews was also used to find out which room or area would best serve as the object of the case study.
The people interviewed are key staff members at the museum who have influence on the final presentation of the museum and the exhibition. For this reason, both the curators and exhibition designers are labeled as key persons in the interviews. There are also technical aspects to controlling the light and the amount of time that was required to be invested in maintaining/improving the lighting. Therefore, people from the technical staff are also among the key persons.

In this investigative process, the light designer has specialized knowledge about electric light and daylight. With a proper set of tools, the light designer can determine the actual light situation. Many factors have influence on the actual light situations. This means that possible solutions could relate to all factors that influence the actual light situation: the type of artificial light sources used, shading systems and the types of filters used on the windows. Also, the view of the outside surroundings can be taken into consideration, as well as the way partitions walls can be placed inside the room.
To determine the optimum daylight solution for this specific case, we use qualitive data based upon the wishes and needs from the key persons at the museum and quantitative and qualitative date from the analysis. The electrical light and the daylight intake are design elements under the control of the key persons at the museum. However, it must be noted that the well-being of the visitors and their experiences at the museum were evaluated by the key persons at the museum and were not expressed by the visitors themselves.
In the first round of interviews, two curators were interviewed together, a curator and a registrar were interviewed together, and the technical manager was interviewed alone. The interviews were semi-structured. There was a list of questions and when answers were given or explained, this sometimes raised new questions.
The semi-structured method was chosen because it offers greater flexibility. In addition, because the interviewer was a new person at the museum, the semi-structured interview form in the first round of interviews has a social aspect in that it presents the project and encourages the interviewees to reflect on the subject.
The second round of interviews was planned as a group interview. At this interview, the results from the analysis were discussed and questions about priorities as well as which

elements to address could be discussed. Both rounds of interviews provided more insight into the quantitative and qualitative elements as related to lighting. The goal from the analysis and the second interview was to be able to make user-based specifications for the lighting. After the first round of interviews, the analysis of the space and the surrounding contexts was carried out through on-site assessments of the building, geometry and photometry for both the electrical light and the daylight.

1.3.2 Quantitative data

Fontoynont (1999) uses the quantitative data of the daylight factor as a key to describe the use of daylight in different rooms and buildings. Daylight factor is the ratio between the light level at a particular spot in the room and the light outside. Daylight factor is measured when the sky is overcast. A measuring grid on the floor makes it possible to make an accurate description or a visualization of the light distribution in the room.

The partition walls that are currently in the space that was analyzed take up so much space that it was not possible to do an actual daylight factor measurement on site. Dialux (version 7.0) was used to make daylight factor calculations.
Doing this required access to the original drawings of the surrounding buildings which were obtained at the municipality. Those drawings were redrawn in SketchUp and then imported to Dialux. Brandts had drawings in SketchUp with more details of the investigated space.
Both drawings were used in Dialux to model the building, including the surrounding buildings. Room details such as radiators, the ceiling beams, ventilation pipes and light tracks were also modeled (according to on-site measurements), in order to be able to use the model, increase accuracy and visualize future changes and improvements in the room.

1.3.3 The tools

The technical tools used to do the different assessments are:

Light measurements *Windows, fixtures*	Asensetek Lighting passport, together with an iPad.
Light measurements (Handhold)	Testo 540 (calibrated in 2016)
Lux logs	Elsec 7650C Office Excel 2016 was used to make diagrams
Daylight factor	Dialux (version 7.0)

1.4 Introducing the case study

1.4.1 Introduction of Brandts

Brandts is located in the old city center of Odense. Odense is the third biggest city in Denmark and rounded 200.000 inhabitants in 2016 ([1]).

Brandts is the biggest museum on the island of Fyn both in size and number of visitors. The total exhibition capacity of Brands is 2000 m2 and in 2016, there were 93.400 visitors ([2]). Around 40 people are employed at the museum.

Brandts has its own collection of more than 15.000 works and also shows changing exhibitions. Works that are shown include national and international artists with a focus on contemporary art.

Brandts promotes itself as a museum for art and visual culture, so the scope includes paintings, drawings, sculptures, videos and photographs. Beside classic art exhibitions, Brandts also shows works that are related to design or popular culture (e.g. Tattoo, Disney). At present, they have a show featuring paintings by Vilhelm Lundstrøm and they are working on a show featuring film director Lars von Trier that opens September 2017.

1.4.2 Why use Brandts as a case study?

Brandts was chosen as a case study because it is one of the major art museums in Denmark.

The building is a typical for those built in the late 1800s, when daylight still was the main source of light. There are many large windows to maximize daylight intake in this building that was originally designed to be a fabric factory and is now used as a museum.

Another aspect of the research is that the improvements in the space should be based on the needs of the users.

After the initial contact was made, it was clear that the staff at Brandts were also interested in this research project; this was important because the staff had to be involved in order to make user-based investigations. So, the second condition - a staff that was willing to help or assist throughout the process was also fulfilled.

---

[1] http://www.odense.dk/presse/pressemeddelelser/pressemeddelelser-2016/odense-runder-200000-indbyggere

[2] Tine Jørgensen, PR and Marketing responsible at Brandts

The first meeting about this project was held in December 2016 with Brandts director Mads Damsbo, facility manager Arne Møller, supervisor Nanet Mathiasen, and the author of this thesis.

Mads Damsbo related that there are several rooms or parts of the building where there are issues with the daylight. The primary issue was determined to be too much daylight entering the building. Mads Damsbo suggested four possible locations for the project:

- Two different rooms at the fourth floor currently used by the Fynske Kunstakademi
- Brandts 13 (=B13)
- Det Søjle Frie Rum (=SF room)

The SF room on the second floor at the main building was selected. The reasons for choosing this space are:

- At the first meeting, Mads Damsbo related he thought it was a pity that all of the blinds in this room were closed in order to preserve the quality of the artworks. He explained that he would like the public to be able to look outside while ensuring that the lighting requirements for preserving the artworks were fulfilled.
- It is anticipated that in the future, Brandts will probably take over the third floor (currently the Mediemuseet) and the fourth floor (currently the Fynsk Kunstakademi). However, at present, it is not possible to do research experiments on those floors on a weekly basis. The second floor has the same dimensions (including window sizes) as the third floor. Analyses from the second floor can be used to design lighting solutions that both can be used on the second and third floors. Knowledge gained can also potentially be applied on the fourth floor as well, where the floor plan is the same but the ceiling and window heights are lower.

1.4.3 Introduction to the building

Brandts has two addresses located in the oldest part of Odense. The main exhibitions hall and the administration offices are situated at Brandts Torv 1. This building was formerly known as Brandt Klædefabrik. The other exhibition hall, B13, is located in a former museum building at Jernbanegade 13. Before 2014, it was an independent museum called “Fynske Kunst Museum” which featured art from 1750 until the present.

Brandts, main building B13

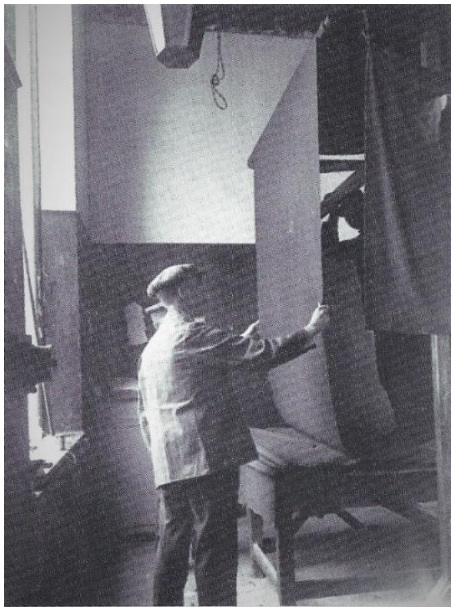
(Photographs by the author)

The next chapter will provide more information about the history of main building. More information about the history of the building can improve understanding the original design of the buildings, and this knowledge can be applied in the process of producing the final lighting design solutions.

1.4.4 History of the main building

Brandts Klædefabrik was the name previously used for the museum that is now known as Brandts. The old name refers to the original function from the main building. “Klædefabrik” means clothing factory.

In 1771, the site where the factory is located was being used as place where fabric was dyed. The new factory opened in 1869 and has a total area of 15.000 m2, divided between four floors. The building was designed for the fabrication of woven materials and a high visual acuity was essential. Thus, Brandts Klædefabrik was fitted with many large, high windows that allowed for a maximum daylight intake with a deep daylight penetration into the building.



(Photograph: Nationalmuseet Brede) (Photograph: Herluf Lykke 1944)

As it peaks Brandts Klædefabrik employed around 350 people. Production covered the entire process from carding the wool, weaving and dying it until it resulted in finished fabrics. The fabrics produced in this building were ready to be distributed throughout Denmark and internationally.

Beside the production of cloths, the factory was also known locally for the many social activities for the workers that took place there.

During World War II, regulations required the use of blackout curtains in the evening and limitations on the use of electricity. These restrictions were problematic for maintaining the production and dispensation was given for the use of blackout curtains, but all lights had to be turned off whenever an alarm was sounded.

In the 1960s, the exportation of fabrics declined. The flow of fabric started to move in opposite direction, towards Europe. This change eventually resulted in the closing of the factory in 1977.

Architect Kristian Isager took the industrial building that was constructed in the late 1800s and made a great effort to maintain its characteristics in his design. In 1987, the old factory reopened as a cultural center that kept the original name - Brandts Klædefabrik. Bolving (1995), Jensen (1993)

1.4.5 From Brandts Klædefabrik to Brandts

In the 1990s, it became apparent that there was a need for more space and new facilities. In 2000, Kjær & Richter won an architecture competition and designed two new extensions to the existing building. A new administration building of 800m2 was physically connected to the old factory with three glass bridges across the middle floors.

(Photographs by the author)

A second building was designed specifically to have the capacity to display very large artworks. A new exhibition space called "Det Dobbelthøje Rum" was made with 400m^2 of floor space and a ceiling height of 6,4 meters.
This space is equipped to fulfill current safety requirements, maintain a good interior climate and has the ability to control lighting. At the same time a new main entrance was constructed on the site on Grønnegade. The new building opened in 2004. The following year, its name was changed from Brandts Klædefabrik to Brandts, to better indicate the independence of the art museum at Brandts Klædefabrik, since the building also houses other cultural institutions.

In 2013, three of the major art institutions on the island of Fyn - Kunsthallen Brandts, Museet for Fotokunst and Fynsk Kunstmuseum - were merged. Together they are called Brandts, and Mads Damsbo became the new director. ([3])

[3] www.brandts./historien/ retrieved 13 May 2017

1.4.6 The use of the floors in the main building

The main building is divided into five floors. The museum Brandts is situated on the ground, first and second floors.

(Photograph by the author)

Ground floor

Museum entrance and shop

(Photograph by the author)

First floor

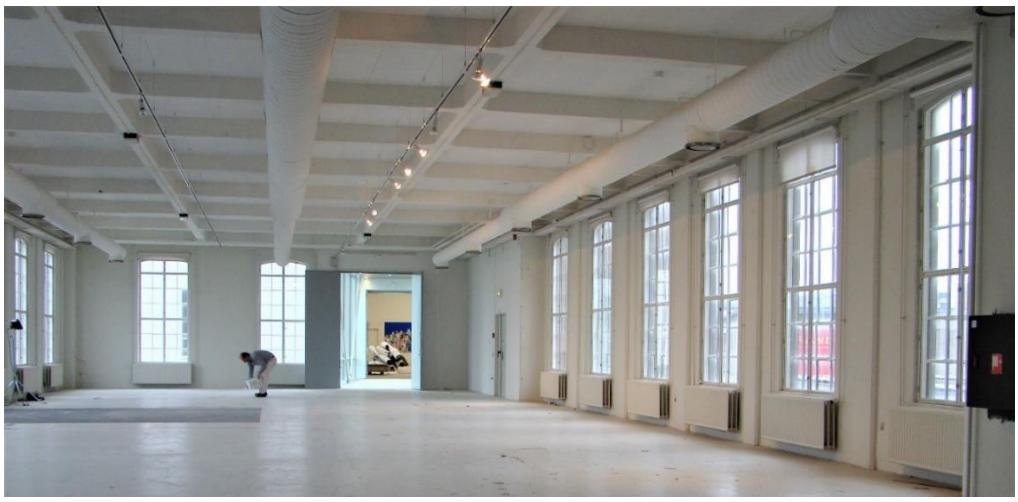
Exhibition space Brandts

Although the first floor and the second floor have similar dimensions, the spaces have different appearances. The first floor has pillars and the installations on the ceiling for acoustic regulation and climate control, are aligned with the ceiling beams.

(Photograph by the author)

Second Floor

SF room



(Photograph by Brandts)

The room also known as the “Søjle Frie Rum” (=SF room). This is the space that was used for the case study. This room has no pillars and that is why it is called the “Søjle Frie Rum” (translated as “pillarless room”).

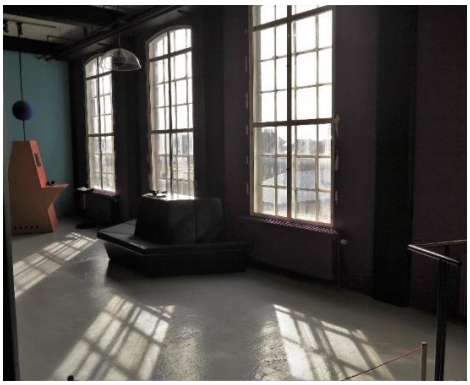
The exhibition room has 19 side-lit windows, no top lit windows, and an entrance on each end of the room. One entrance is from the central hall with staircases, and on the other end of the SF room, a window aperture has been transformed into a glass bridge, which allows

access to the new exhibition area the “Dobbelt Høje Rum”. In Chapter 3, an analysis of the light related aspects of the SF room is presented.

Third floor

Media Museet

The third floor houses a media museum, which features a permanent exhibition that relates the history of Danish television and newspaper media. It is anticipated that the media museum will be relocated, and that Brandts will eventually take over the exhibition area.



(Photograph by the author)

Fourth floor

Det Fynske Kunstakademi

At present, the fourth floor is being used by Det Fynske Kunstakademi. The room above the SF room and the media museum has same floor dimensions, but has a lower ceiling height and smaller windows. The room on the other side of the building has many qualities that work well for an exhibition space, as it has both top lit and side lit windows.
In 2018, Brandts will take over the fourth floor; its potential as exhibition space requires further investigation.

(Photograph: Det Fynske Kunstakademi)

2. Interviews

In February 2017, a series of interviews were conducted with a select group of professionals at Brandts.

The intention to create a daylight solution based on the user needs was inspired by Augustesen's finding that one significant reason that half of the galleries in that study were not satisfied with the outcome of the architecture and/or the use of daylight was due to a "lack of understanding of the needs and requirements." (page 91)

The goal for this project was to get more information about what the keypersons at Brandts expect or require regarding the lighting inside the museum, and more specifically, about the role of the daylight.

The first series of interviews was conducted with the following persons.

Anna Krogh (AK) curator, Liberty Paterson (LP) curator

Ellen Egemose (EE) curator, Bent Hesby (BH) registrar

Mads Damsbo (MD) director

Arne Møller (AM) facility manager

Anna Krogh (AK) curator, Liberty Paterson (LP) curator.

In response to the general question, "What do you think about the actual light situation?"

LP answers: "I haven't thought that much about it, but although we like to use the daylight, it is often blocked out because we have to build extra walls or we have video projections in the exhibition, so we have to block the natural light."

AK complains about the electrical light in B13, "It is completely inflexible." This is due to the lack of a track system and the fact that they nearly only have wall washers to work with. She also states, "I prefer the daylight; I think it is the best light to use for art." She also commentated that "… daylight is best for viewing paintings and sculptures, and it can be difficult for photographs because it has to be dimmed so low. For video works, normally you don't want daylight."

In B13 some rooms have top light system with daylight through diffused glass. AK says: "It is preferred that we do not work with them {the top lights}", so there is no flexibility in the daylight intake from the top light system.

In the main building, AK says that the electrical light situation is much more flexible than in B13. The daylight situation is also much better than B13 because "there is hardly any direct sunlight coming into the rooms." For this reason, she prefers to build extra exhibitions walls in the middle of the room and not in front of the windows.

In the “Tattoo” exhibition, a system of walls was used, in which the walls with or around the windows had openings so the light could travel further into the room. “This worked very well,”

(Photograph: Liberty Patterson)

According to LP, “Everything looks better in daylight.” When asked about favorite rooms LP an AK both like the SF room; LP refers to it as the ‘room with the concrete floor’ and because it has no pillars, she really appreciates its flexibility. AK mentions the “visual noise” produced by the three ventilation pipes that run through the ceiling as a disadvantage. AK’s favorite room is the new “Dobbelt Høje Rum” that was built in 2004. “This room works very well.” The room has both side lit windows and top light windows. The top light windows can also be lit with electrical (fluorescent) light. AK is very pleased with the flexibility of lighting in the room, because daylight can be blacked out, there is an option of using artificial daylight from the ceiling, and there is an additional exhibition spot in the track system on the ceiling.
Regarding the quality of the view outside the main building - LP and AK do not regard the view as having any specific quality other than being “a light source.” LP calls it a normal city landscape, and sees it more as ‘visual pollution’.

Curator AK does not consider the view outside of Brandts to have any special quality, but she adds that the closed windows (with translucent blinds) in the “old collection” give a bit a claustrophobic feeling

(Photograph: author)

LP refers to an exhibition featuring work by Henrik Vibskov, at which all rooms were blocked off from daylight; she believes that the lack of daylight made visitors move through the exhibition more quickly.

Climate control is not an issue in the Dobbelt Høje Room, which has options for controlling climate and humidity, but it still is an issue inside the other spaces at Brandts. AK mentions specifically that B13 is very hot in the summer and very cold in the winter. The same issue occurs in the SF room where the "old collection" is exhibited.

Referring to the lighting at other museums, AK mentions the Glyptotek "It is so welcoming," and "light comes from all directions" at the new Henning Larsen building.

LP referred to a Tal R exhibition at Aros in 2013; the artificial lighting worked very well in the cellar of Aros, which is completely blacked out (photograph to the left).

(photograph: Tal R: The Virgin, 2013, Installation view, Aros, Ole Hein Pedersen)

Regarding the atmosphere inside a building or museum, AK says, "It is only recently that we have started to create an entire environment around the exhibition." As an example, she mentions "hiring an architect for a Lundstrøm exhibition." In the past, funds were limited and there was just enough to build an extra wall, and she describes the way in which exhibitions were presented at Brandts and other museums in the past was "boring."

AK refers to staging, a movement, that she believes started at the cultural history museum and has become a new way of presenting the works and themes. As examples, she mentions the Maritime Museum and Moesgaard museum. (see photograph to the left)

(Photograph by the author)

LP adds, “There was a time when “staging” was frowned upon by the art crowd, because it was seen as being disloyal to the artworks. It was an aesthetic they did not want to be a part of, but I think this is changing very much now.”

Speaking about the dynamic character of daylight, both AK and LP consider this to be a positive aspect. AK stated, “Nothing is static outside the museum, so why should it be like that inside?” She added that staging “adds to the sense of atmosphere.”

When asked if they would like to have complete freedom in showing light sensitive works wherever they want or have it designated to specific areas installed for showing those types of artworks, AK replied that artists who show their work there seem to accept that “at B13 we don’t build an extra wall; we accept the spaces the way they are.” She continues, “We invite the artist and say this is what you have and we don’t have the option of building a white cube into the room.” So, the artists accept the elements of the current setting. From AK’s experience, it seems as if the less freedom artists have, the better the results, “because then you work with what you have.”

From this interview, the conclusions can be drawn that (at the time the interview took place) LP and AK believe that:

- Daylight is a very good or even the best light source, especially for paintings and sculptures. It is a problem for video works, photographs and works on paper.
- Highly flexible rooms are preferable.
- The view outside of Brandts has no peculiar aesthetic quality.
- The SF room has climate issues during summer and winter seasons-
- The ceiling of the SF room has a visual disturbance. The ventilation pipes are mentioned in particular.
- The SF room is appreciated as an exhibition space.
- Building staged scenes around the exhibitions is considered to be a very positive option.
- On the one hand the staff would like maximum flexibility in the exhibition room, however, they also believe that being restricted to the existing elements of a room that cannot be changed and making the best out of a given situation has its advantages.

Interview 2 February 2017

Ellen Egemose (EE) curator, Bent Hesby (BH) registrar

In answer to the question of what they think about the lighting at Brandts in general, BH replies “It is better than it has been, but we still have issues with reducing light in the places where direct sunlight enters the building.” BH thinks that lighting is an issue because protecting and preserving the works of art is an important responsibility.

As an example, he mentioned the Disney exhibition that is currently showing. The lender asked for a maximum level of 50 lux and Brands was not able to reduce the light to that low

level for two reasons. The first was that with so little light, the space was simply too dark. The other was that it was not possible to dim the new LED light to such low levels, so the light technician's solution was to put darkening filters over the lamps to further reduce the light output.

Another way to avoid problems with too high lux levels is the use of exhibition copies. BH commented, "At the last photo biennale, we produced all the works ourselves. The artist just sent us the files and we destroyed the exhibition copies after the exhibition. In that way, we don't have to worry about light levels on the pieces during the production, mounting and while the exhibition is showing."

EE says that light levels are more or less under control during special exhibitions, but agrees that there are still issues with high light levels in the SF room with the "old collection", even though the blinds are pulled down. "This gives curatorial restrictions." She elaborates with an example from an upcoming exhibition she is working on - "Lundstrøm". The museum would like to show Lundstrøms works together with works by the designer Poul Henningsen (also known as PH). He represents the Functionalistic period. Ideals for this period are clean spaces, clear lines and the use of a lot of light. "And that is just not possible because of (the need to preserve) the paintings."

Ideally EE would like to be able to use more light and still be able to remain within the maximum light requirement, "but I don't know what kind of magic could be used there."

BH replies, "You could make it interactive, so there is only light when there is audience in the room."

Regarding satisfaction with the lighting in general, BH thinks it has really improved in the exhibitions areas, but there are still issues in the hallway areas.

EE tells that three or four years ago the museum received 300,000 DKK, which was invested in new LED lighting for the department with the permanent collection.

In the "Dobbelthøje Rum", EE is not so fond of the artificial roof light in the evening. "Somehow it looks strange in the evening," she says, and continues, "The light is cold, but I think it is a matter of taste..."

EE thinks that there is something wrong with the lighting at Brandts in the evening hours in general. The light is "hard" she says. BH understands EE, and in his opinion it has something to do with the colour of the light.

BH mentions is that there is too little light in the newly opened photography exhibition, and the grey walls also darken the space.

The next question is whether they can give examples of other Danish museums which have good light situations. BH likes it at Randers art museum.

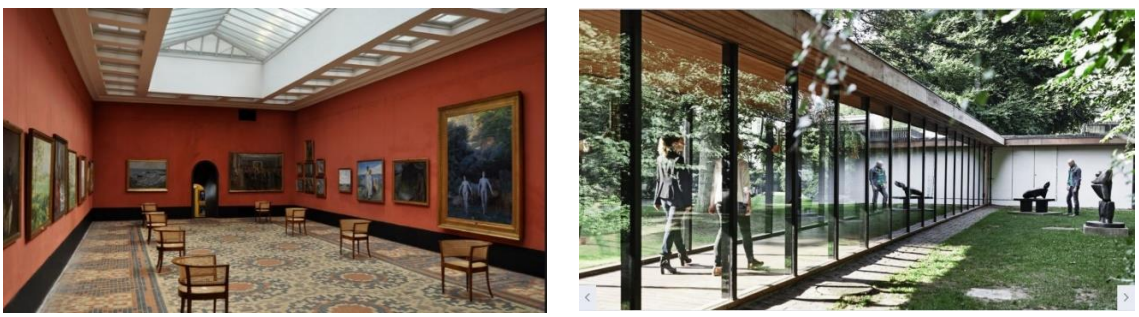
(Photograph: Randers Kunstmuseum)

EE likes both closed rooms with no daylight and very open rooms. She uses The David Collection in central Copenhagen as an example of a space with rooms that are completely blacked out and compares them to a "treasure chest." The focused light on the objects is "magical" she says. "I don't miss any daylight there."

The dynamic character of daylight is not seen as a positive factor by EE and BH. BH says, "We like it best when we can control it." EE admits that she really likes the dynamic character of the daylight, but from the perspective of a preservationist, it is a disadvantage, which is why she does not perceive the ever-changing daylight as being positive.

EE comments that institutions that lend works for exhibitions do not normally write specific lux/hour values but merely request a simple maximum lux value. She says that in Denmark it is not normal for lending museums to ask about opening hours or request graphs of annual light exposure.

EE mentions that Faaborg Museum has two PhD students. One of them is doing research about the 'atmosphere' there. "They have a relatively high amount of daylight, but I don't think it is only that. It has also something to do with the walls and floors at Faaborg Museum. "Some buildings just have more atmosphere than others, and that gives more options to work besides with just the lighting."



Photographs of Faaborg Museum (left) and Louisiana (right)

Referring to Louisiana Museum of Modern Art, EE says, "You can have this sense of purification when you are there."
One way to reduce light levels is to build light sensitive works into the walls. EE has seen this at an exhibition with Isaac Dahl at the Nationalmuseum in Stockholm.
BH refers to the blue lighting on the staircase at Brandts as "porno light", and adds, "It does not belong here."
From a conservational point of view, EE think the biggest challenge at Brandts is the daylight situation. "Because we decided not to block all of the windows, we just get too much daylight inside, even when they are covered with blinds."

They have been working with colour filters both on the lamps and also on the roof windows. According to EE, "When it was Kulturnat (Culture Night), there was a completely brothel-like atmosphere." The change in lighting was too much, and it also ruined the look of the paintings completely, because it changed the colours. She added, that it is still fine for her to stage an exhibition.

Based on this interview, the conclusions that were drawn by EE and BH at the time of the interview were as follows:

- There are issues with the dimming of the lights to low levels.
- Preservation of the artworks is essential.
- The ever-changing character of daylight is regarded positive, but from the perspective of a preservationist, direct sunlight is a problem.
- There are issues with the quality of the light that is present in the evening.
- Experiments with coloured light have been carried out, but were not perceived positively.
- Issues with too much daylight are recognized but have not been solved.
- Light levels outside opening hours are not an issue for lending institutions, according to EE.

Interview with Arne Møller (AM), facility manager

A member of staff at Brandts for many years, AM has been and has rational, clear answers to the questions. During the interview, he relays that power consumption is not an issue that influences decisions regarding the light situation, because the power bills are paid by the municipality, not the museum.

The buildings used by Brandts are owned by the municipality and Brandts only rents them. The artificial fluorescent tubes in the roof lights in the Dobbelte Høje Rum also belong to the municipality.

"Cleaning light" (= lights that are not pointed at the exhibited works and can be used while the room is being cleaned and for other reasons, outside of opening hours) is used, but only

in rooms that are completely dark; otherwise the cleaning staff could not see well enough to do their work. “Cleaning light hasn’t been used in rooms with light sensitive works.”

In the Dobbelte Høje Rum it is possible to do a complete blackout after opening hours, but at present this is not being done.

AM thinks it is fine to be flexible with light regulations for two reasons - because “those paintings do not have to be preserved for 3000 years,” and “there is nothing worse than entering a completely dark museum.”

Based on this interview, the conclusions drawn at the time of the interview indicate that AM thinks:

- Power consumption is not a factor when decisions about lighting are made.
- Being flexible with lux standards for museums is an acceptable practice.
- Light regulations could mean that museums (the interior spaces) are too dark for the well-being of guests and staff.

Based on the interviews with the curators, the technical staff and the director, the overall conclusions are:

- Power consumption is not a factor when decisions about lighting are made.
- Daylight is recognized as a very good or even the best light source, especially for paintings and sculptures. It is however considered to be problematic for video works and photographs as well as works on paper.
- Issues with too much daylight are recognized but have not been solved.
- Special attention should be given to preserving light sensitive objects, however low lux levels in rooms are often perceived as making the space dark or gloomy.
- Some of the interviewees consider that the view outside of Brandts has no peculiar quality. However, museum director Mads Damsbo has emphasized from the start of this project that he would like visitors to be able to look outside from the exhibition rooms.
- The preservation of the works of art is regarded as being essential to the work of the museum.
- The ever-changing character of daylight is seen as a positive, if and when excessive amounts of daylight can be avoided.
- There are issues with the SF room being warm in the summer and cold in the winter.
- No correlation between the light and temperature fluctuations has been determined.
- The SF room is an exhibition space where the curators really like to work because there are no pillars and there is the floor is made of plain concrete. There is an issue with the ventilation pipes which create a “visual disturbance” in the ceiling.
- There are issues with the dimming of the lights fixtures to achieve 50 lux light levels on the artworks.

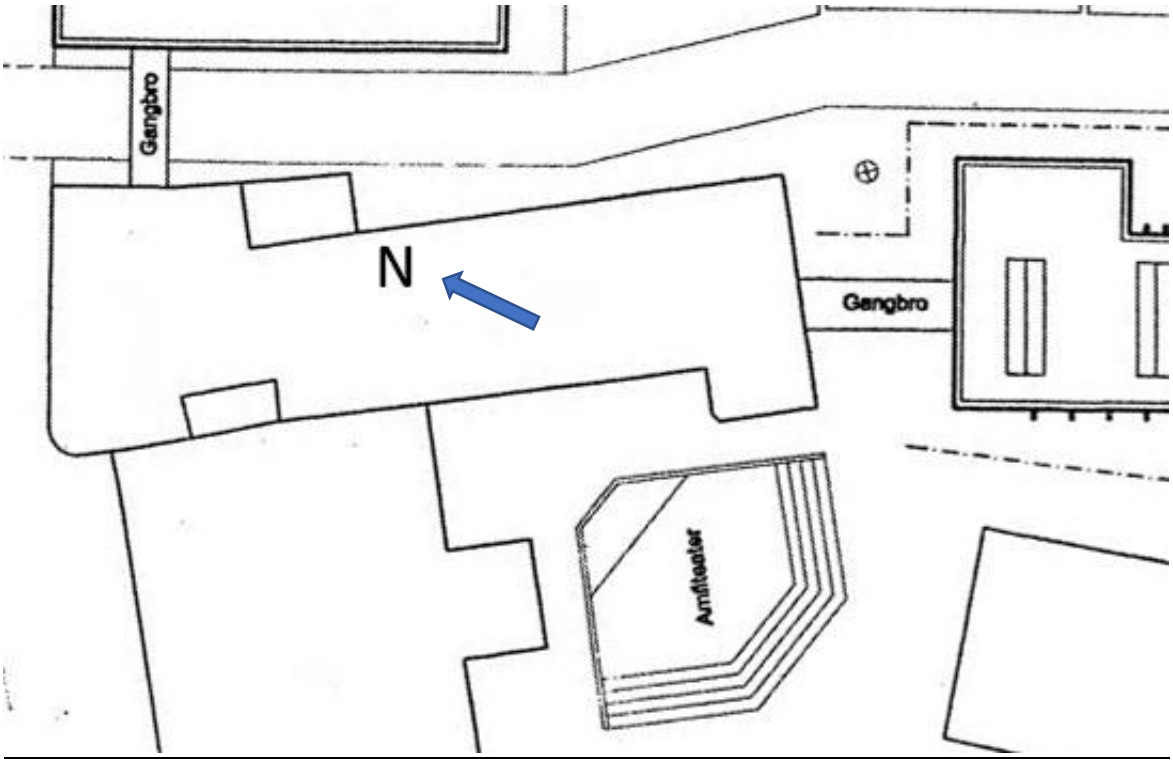
- There are issues with the quality of the light that is present in the evening.
- Experiments with coloured lighting have been carried out, but were not perceived positively.
- The museum staff would like to have highly flexible rooms that can be used to exhibit works that require maximum lux rates from zero, 50 and 200 lux.
- Light levels outside opening hours are not an issue for lending institutions at the time being.

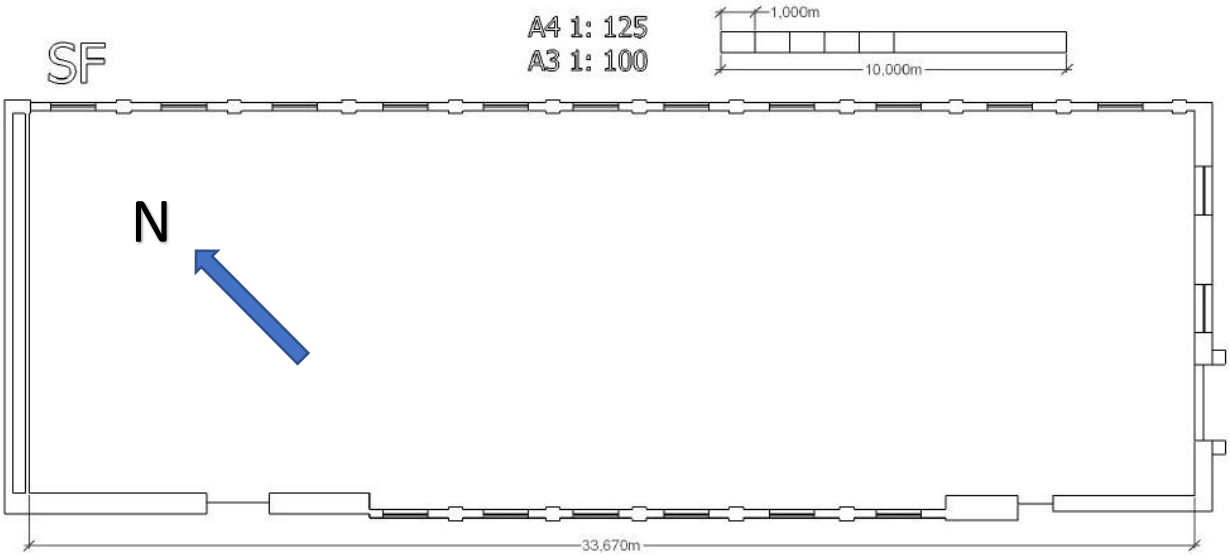
3. Analysis

3.1 Assessments on geometry and photometry

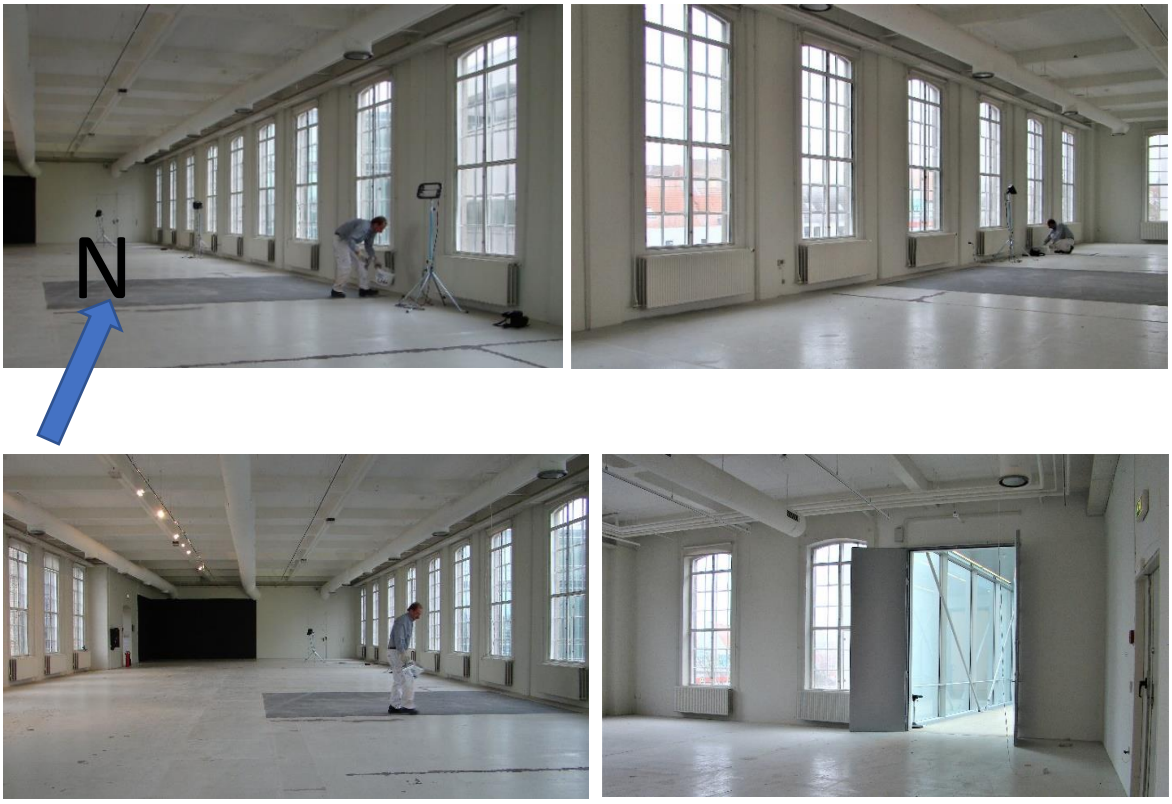
3.1.1 Geometry and photometry

It was necessary to determine how the building is situated according to its geographical position and in relation to the other buildings that surround it. This information is essential in order to establish the sunlight and daylight influence on the light situation inside the spaces. The placement and the shape of the windows and other openings in the building also provide information used in the assessment.
This information can be used to determine whether there are any peculiar lighting characteristics within the room that should be left as is or concealed/reduced.



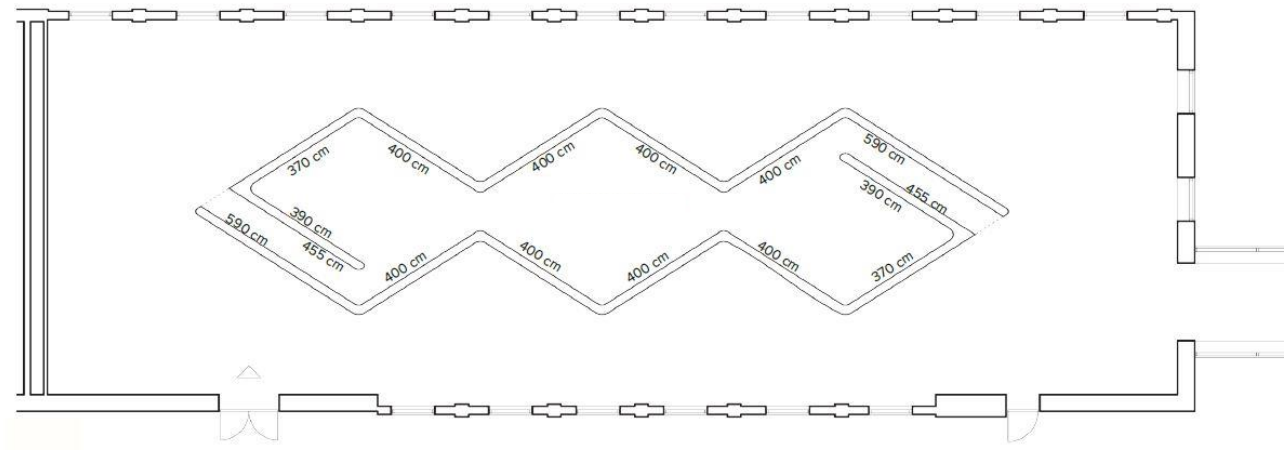


The room measures 33,67 x 8,5 m² and the ceiling height is 4,3 meters. There are 19 large windows. The SF room has an entrance from the central hall way. The new extension to the museum (2004) added a glass bridge on the other side of the room. The glass bridge that connects the two buildings. In relation to the lighting, this glass bridge can be considered to be the 20th window in the room.



(Photographs: Brandts)

All walls are painted with matte white wall paint, and the floor has a light grey finish. The ceiling has three ventilation pipes and four rows of 3-phase lighting tracks by the brand, Staff.
The ventilation pipes are diminished along the way. The lowest level of the pipes is at a height of 3,36 m.
The partition walls in the SF room have been in place for two years now and will remain there at least until the end of 2017. These walls are 3,07 meters high and create an inner space that is used for showing artworks on paper.



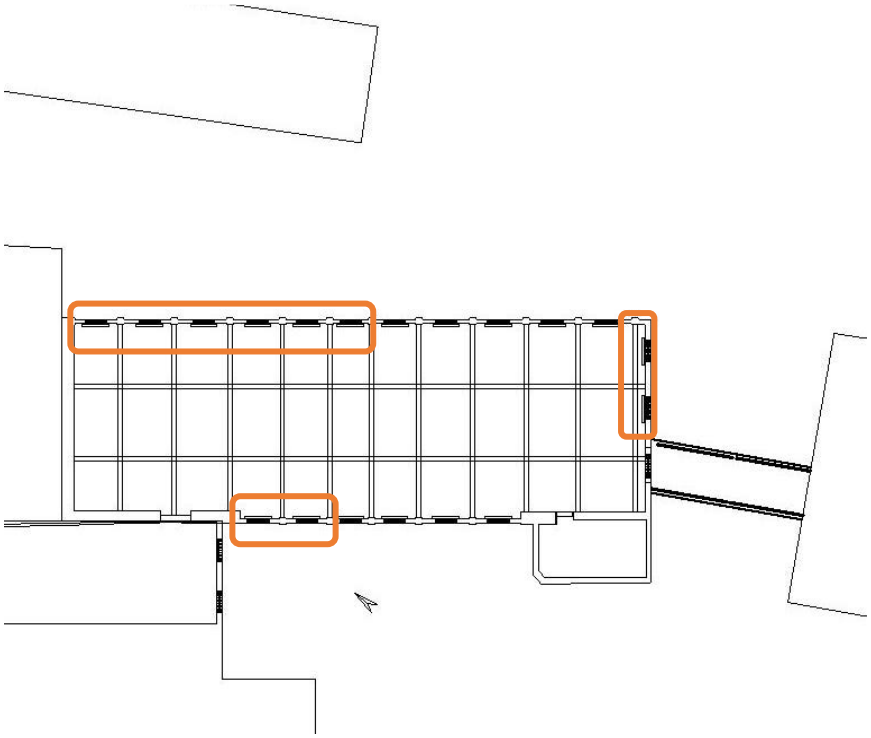
The window surface on the northeast façade is:

33,67 x 4,3 = 144,8 m²

11 windows of 2,95 x1,3 total 42,2 m²

Window percentage 29,1%

The windows marked in the diagram have an obstructed view because of surrounding buildings.



The room has a symmetrical appearance. The same type of windows and radiators are used throughout the room. Whether to maintain this symmetry or not must be taken into account when considering potential lighting solutions.

3.1.2 Conclusions

- The visual disruption from the ventilation pipes mentioned in the interviews needs to be addressed. As obstacles in the ceiling, the pipes have an influence on the placement of the light grid, so the second round of interview should be used to determine whether the ventilation pipes should be taken in account when designing a new lighting grid. In the assessments of the electrical lighting, the placement of the lighting grid has to be examined.
- The northeast facade has 29 % window coverage. This relatively large amount of interior wall space is not used to its fullest extent in the current outline for photographs, paintings or other 2D artworks because of the lack of wall space.
- The quality of the view varies widely. Several windows have a view directly facing another building. Those windows could be selected for a more permanent blockage.

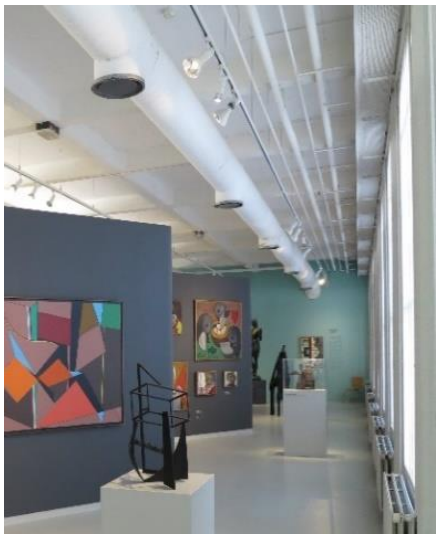
3.2 Assessments on electrical light installation

It is necessary to determine the exact dimensions of the current light grid. What is the range of options and what are the limitations? What quality of light does the current system have at present? Is the current system reusable or able to be salvaged in part? What are the options for making adjustments to the lighting system?

3.2.1 Light grid

The light grid consists of four 3-phase tracks (by the brand Staff). The tracks hang from wires in the ceiling, at 3,45-3,75 meters from the floor. Each track has its own on/off switch, no separate external dimming device is connected to the tracks

The distance between the tracks has some variation (3,02- 2,77 and 3,13 m) with an average of almost three meters (2,98 m). The tracks cover 1,5 m. on each length of the floor area and 1,25 m. towards the windows. With the current exhibition, a total of 50 lamps are use, yet only one of them is dimmable.



(Photographs by the author)

In addition to the light tracks, fluorescent tubes are placed above of the partition walls. According to the light technician at Brandts, Ole Mammen, the tubes were mounted there for the last photo exhibition, when they were used as a form of indirect lighting to fulfill the low lighting levels of 50 lux. So, their current placement is not intentional nor is it intended to remain in place; at some point, they should be taken down.

With the current placement of the partition walls, the ventilation pipes block the track lighting. There is no alignment of the track lighting with architectural elements, other than that they are parallel to the windows. With this set up, the obvious choice is to place partition walls parallel to the light tracks, however, if art works are framed in glass this will cause reflections from the windows

The emergency lighting is mounted on the support beams of the ceiling, and this might serve as inspiration for the placement of a newly designed light grid.

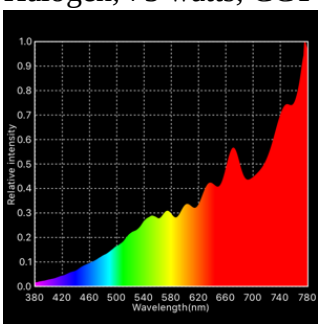
(Photograph by the author)

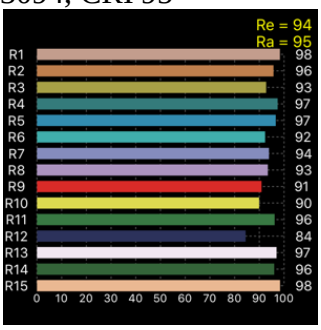
3.2.2 Fixtures

Five different light sources in the SF room were compared. The measurements were taken on 16 March 2017 between 11.30 and 12.30. The measurement tool was the Asensetek Light passport combined with an iPad.

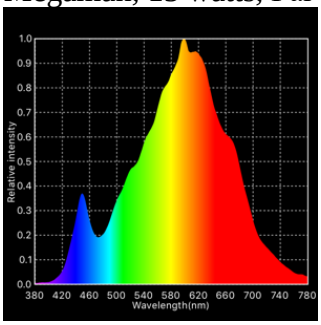
A variety of lamps are used, with different angles of the light beam. No wall washers are used. A few of the lamps are halogen lamps, but most are retrofit LED bulbs. The LED bulbs are from different producers (Sylvania, BLTC, Megaman, Samsung).

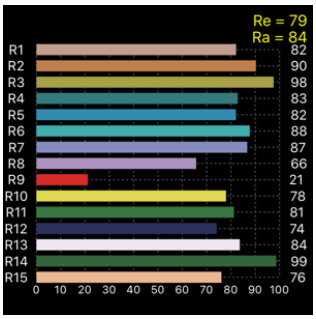
Halogen, 75 watts, CCT 3094, CRI 95



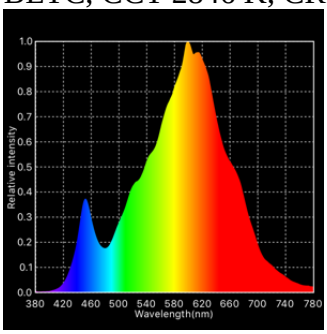


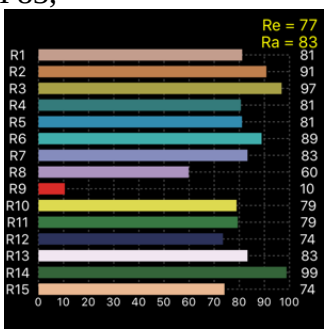
Megaman, 15 watts, Par 38, “warm white” CCT 2967, CRI 84



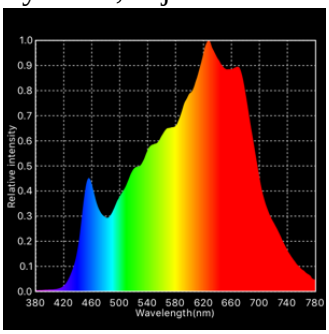


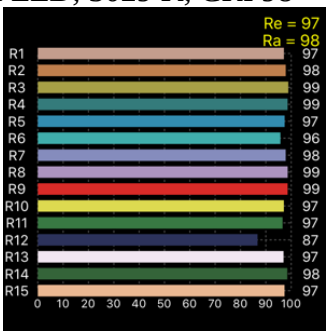
BLTC, CCT 2846 K, CRI 83,



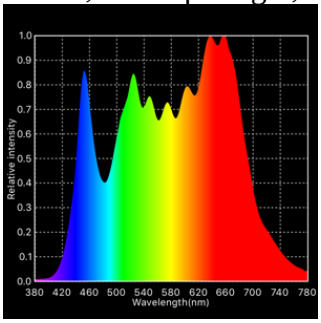


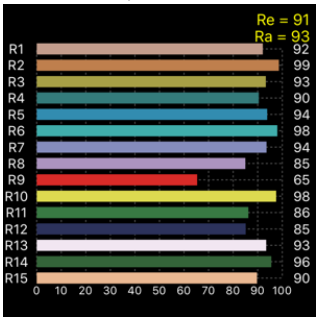
Sylvania, adjustable zoom LED, 3029 K, CRI 98





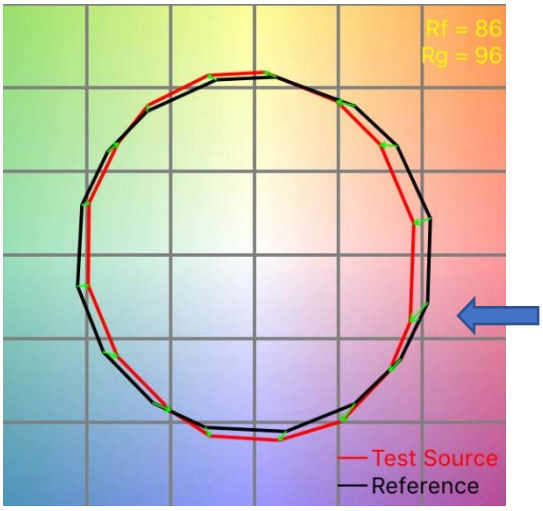
BLTC, LED spot light, CCT 4266K, CRI 93



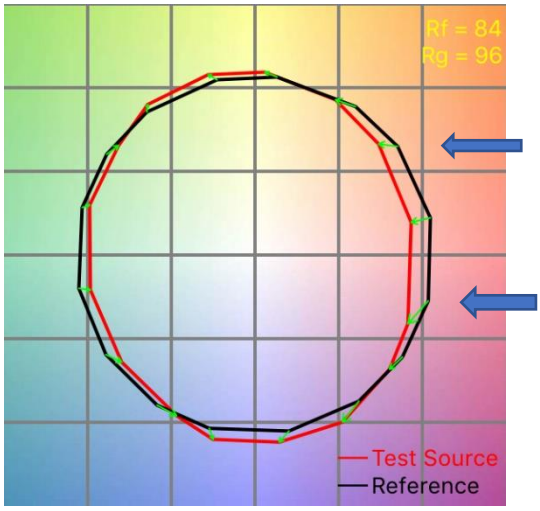


Using only the CRI value is a poor way of describing the quality of LED lighting. Hauser (2016) demonstrates that the TM-30 method gives a better insight in lighting qualities from light sources. Two lamps with a relative low CRI value used in the SF room, are compared with using a TM-30 diagram.

Megamen

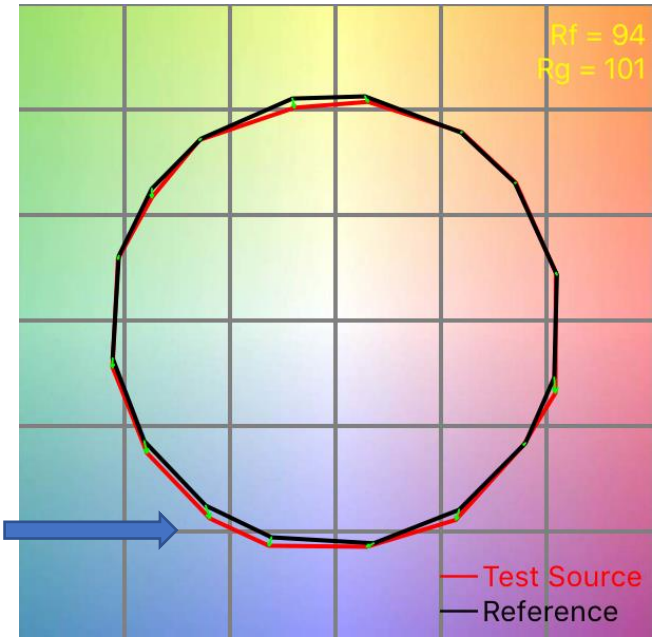


BLTC



Both lamps give off some colour distortion, especially in the red/yellow colour range. On the other hand, the results of the Sylvania lamps are very good. There is only a minor distortion of the gamut in the blueish area.

Sylvania



According to the technicians at Brandts, several of the Sylvania fixtures have a dimming control that is out of order. Besides that, these lamps cannot dim to real low values. As an alternative solution, ND (natural density) filters are applied on the lamps (this is an example from the Lundstrøm exhibition at Brandts). It is observed that the tape used for this purpose does not stick properly, and as a result paintings are exposed to excessive light amounts.

(Photographs by the author)

3.2.3 Conclusions light grid

- The light grid is made up of relatively simple elements (medium class track system hanging from wires).
- The light grid is not aligned with architectural elements in the room. Fitting the light grid in accordance with other room /ceiling elements, more specifically the ceiling beams, would reduce the visual disturbance.
- The light from the lighting tracks closet to the windows is partly blocked by the ventilation pipes.
- The lighting tracks closest to the windows hang 30 cm. lower than the tracks in the middle of the room. This is probably done with the intension to avoid blockage of the light by the ventilation pipes.
- The only lighting control connected to the light tracks is an on/off switch for each track. There is no external dimmer connected to the light tracks.

3.2.4 Conclusions for the fixtures

Conclusions drawn from comparing five light sources:

- Two different “basic” sources are being used: CCT 3000 and 4000K
- At 3000K there is a variation of 8,6% from 2850-3100 K (2848 K- 3094 K)
- The variation of the colour rendering index (CRI) ranges from 84 to 98.
- Two light sources have a CRI <90 (83 and 84).
- There is a lack of lamps with good dimming properties, specially at low light levels

3.2.5 Overall conclusions about the electrical lighting:

- At least two types of lamps have a CRI <90. This cannot be considered as high-quality lighting.
- There is an unmotivated use of different CCT values.
- With the current light set-up, it is hard to achieve 50 lux on the artworks exhibited.
- With the current lighting system, dimming of the light is not possible for the lamps at phases L1, L2, L3 of the track lighting system nor with individual control on the fixtures themselves.
- The only light control is an on/off switch.
- The Sylvania lamps have a very good light quality but a dimming unit of inferior quality.

3.3 Assessments of the daylight

In order to be able to control or adjust the daylight, it is necessary to know how much/little daylight enters the room. To determine this, an actual lux log must be conducted and a daylight factor will be calculated.

It is essential to establish which elements of daylight can be controlled. What is the nature of the relationship between the daylight and the artificial light?

The quantitative analysis of the SF rum was carried out by measuring the transmission of the glazing, the window filters and the blinds. Lux loggings of the movable partition walls must be carried out. Furthermore, the quality of the view outside must be investigated.

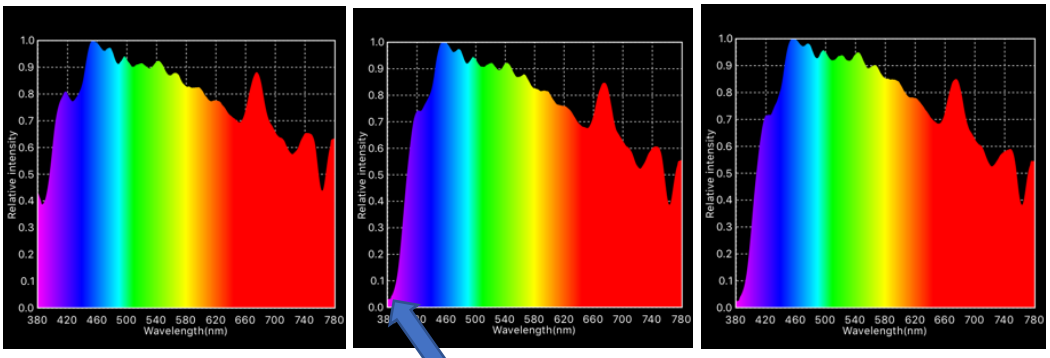
3.3.1 Daylight and windows

The 19 windows are the original cast iron windows, which measure 1,37 m x 2,95 m. The windows have a filter on the inside. There is a second layer of removable windows (=forsatsvinduer), made of polycarbonate. The third layer is the manual blind.

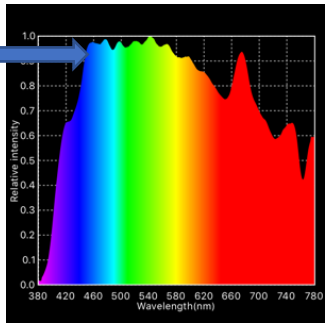



(Photographs by the author)

Outside 1 layer of glass with filter polycarbonate “removable window”



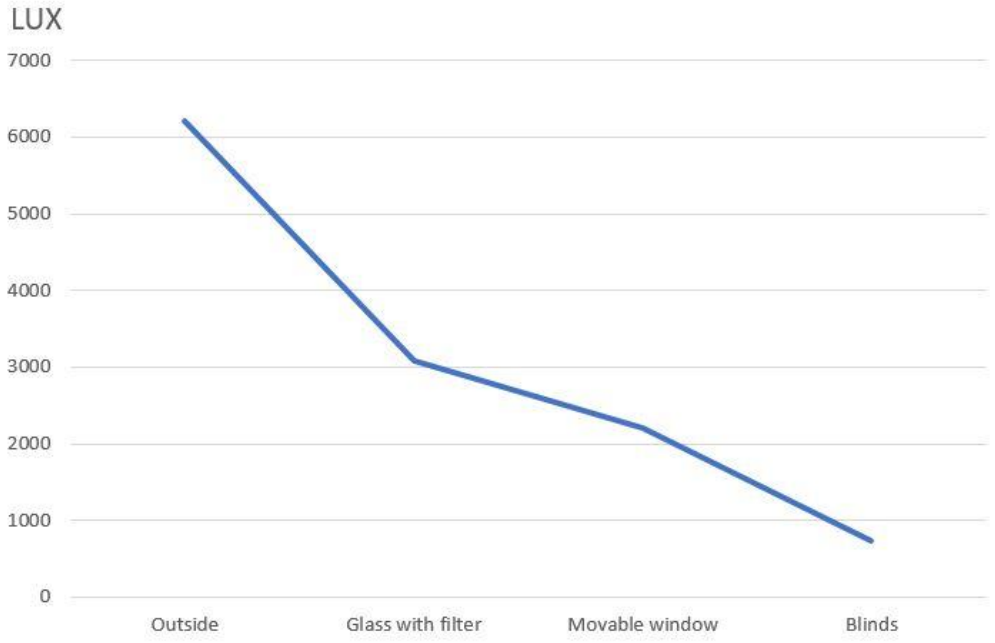
Blinds down



The glass with filter reduces the UV light significantly (on the left side of the spectral power distribution). A slight change on the blue spectrum can be seen when the blinds are down. No reduction of the IR light (e.g. sun heat) can been seen, as is shown in the diagrams above.

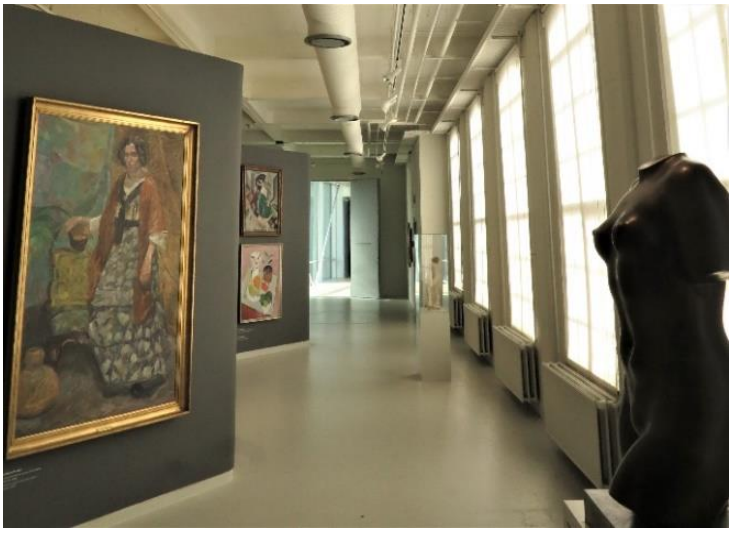
Measurement results

-	LUX	% lux decrease	rel. % lux decrease	CCT	CRI	CRI (R15)
Outside	6219	100	100	6168 K	100	100
Glass with filter	3081	50,5	50,5	6198 K	99	99
Removable windows	2214	64,4	28,1	6061 K	98	97
Blinds	734	**88,2**	66,8	5621 K	97	96



When all of the layers are closed or down, the reduction in light is 88,2 %. This was measured on the northeast side, which does not have direct sunlight. When light levels outside increase to 30.000 lux, for example, 3540 lux will still enter from the edges of the blinds.

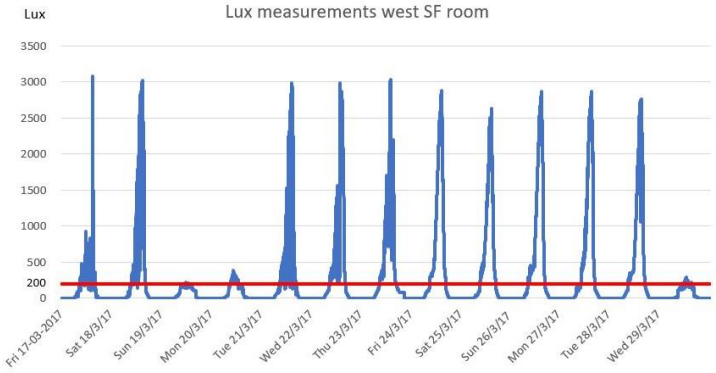
At 14.45 the same day, light measurement on a painting on the south side of the room was taken under conditions with bright sunlight outside. Light levels between 1800-2000 lux were measured on the painting, with light coming through/around the edges of the blinds and the from electrical light combined.



(Photograph by the author)

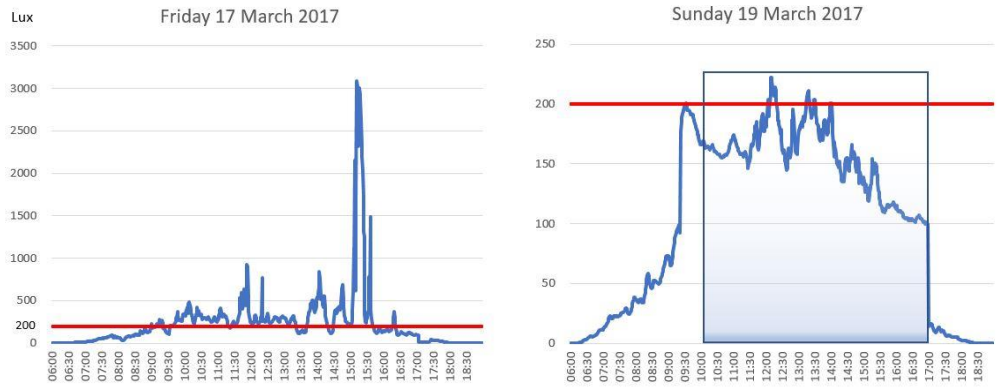
An Elsec 7650C log of the lux levels was carried out on the west side at a height of 2,30 meters.

Lux values were measured with one-minute intervals over a one-week period at each of the four geographical directions. This was done on the current exhibitions walls to get more precise information about the actual light levels throughout an entire day. Information was gathered about light levels both during and outside of opening hours.



The graph shows extremely high lighting levels for a museum room with light sensitive works. The high levels appear especially in the afternoon when direct sunlight hits the south-east facing windows. On the graph from 17 March 2017, light levels that reached 500 lux (2,5x times maximum values) and higher were measured between 10.00 and 15.45. The same kind of light levels were also recorded on other days. The electrical lighting is always switched on during opening hours.

In addition, the high light levels also occur on Mondays, when the museum is closed.



The graph of 19 March 2017 has the lowest lux measurements due to the weather conditions that day. The square in the middle represents the official opening hours from 10:00 to 17:00. The lack of a proper blackout of the windows can be seen on the light penetration between 6:00 and 10:00, and after 17:00 as well. Furthermore, the strong increase of the light level at around 9:20 is due to the electrical light being switched on at that time. The museum guards meet half an hour before the official opening and it is their habit to switch on the lights when they arrive at the museum.

The Danish Guidelines for Cultural Heritage Institutions (Retningslinjer for Kulturarvbevarende Institutioner) follow the international standards, and recommend maximum values as follows:

- 200 lux for objects of ordinary sensitivity, however, highly sensitive objects may only be lit with a maximum of 50 lux ([4])

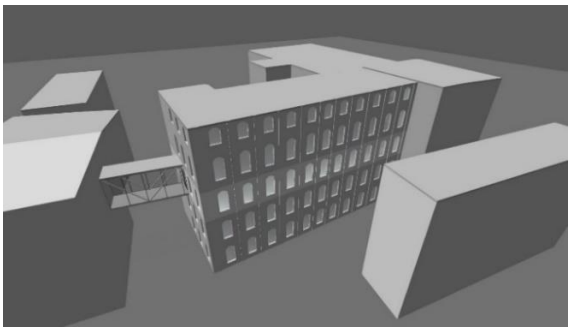
In the study by Augustesen (2009) five reasons for less successful use of daylight are described. Two of them can be related directly to the SF room:

- The gallery space was not designed to meet today's conservation requirements, and daylight control systems were implemented in the gallery after the building was taken into service.
- The gallery was designed without a daylight control system able to block out daylight during non-public hours. (page 89)

[4] http://slks.dk/museer/museernes-arbejdsopgaver/bevaring/bevaring-og-haandtering/retningslinjer-for-lys-paa-kulturarvsbevarende-institutioner/

3.3.2 Daylight factor

In a major European research project, Fontoynont (1999), several buildings were investigated, including nine museums. A general quantitative value is given for the daylight factors at museums in Europe of 1,5% in the winter and 0,6% in the summertime.



Daylight factor in %

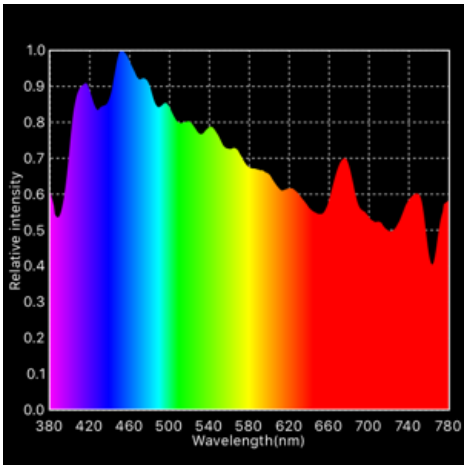
3.3.3 Daylight at the glass bridge

The glass bridge consists of almost full-size side lit windows that run along both the northeast side and the southwest sides of the structure. The window frame is made of medium reflective aluminum. The glass bridge has an aperture into the SF room that measures 2,05m in width x 3,3 m in height. A pair of metal double doors separates the SF room from the glass bridge. The doors are equipped with an automatic system that keeps them open once the museums guards open them in the morning. With the way the current automatic system works, it is not possible to close only one of the doors. If one door is closed, the other closes automatically. During opening hours, the doors are always open.

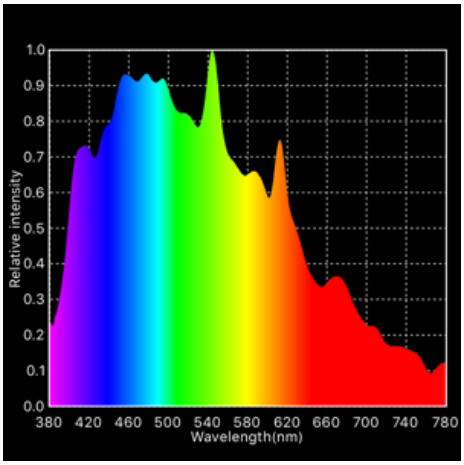
The glass bridge can be considered as the 20th window into the SF room since both daylight and direct sunlight enter the room.

(Photograph by the author)

The windows have no external filters but the spectrum of the daylight graph shows that the glazing reduces both the UV and the IR radiation.



Outside



Inside

There are no blinds or external shading mounted at the windows of the glass bridge. Direct sunlight can enter the glass bridge on both sides, but because of the geographical position and shading of the Dobbelt Høje Rum, direct sunlight enters the SF room only in the afternoon while the sunlight has its highest intensity.

The ceiling of the glass bridge is equipped with fluorescent tubes that are always switched on during opening hours.

3.4 Overall conclusions of the daylight and the electric light

A. Six windows are placed on the southwest side and need blocking of the direct sunlight in the afternoon.
B. The general daylight level is too high because windows sizes are very big and a reduction of the geometry should be applied.
C. There is a total of 19 windows. Ten windows have an obstructed view. Four windows with a good view are orientated to the southeast side and have direct sunlight in the afternoon. Five windows on the northeast side have a non-obstructed view and no/almost no direct sunlight. One window on the northeast side has a semi-obstructed view.
D. The glass bridge functions as the 20th window in the room and both daylight and direct sunlight from the southeast side should be reduced or blocked.

E. The current light grid is mounted parallel to the windows. With this set-up partition walls should ideally face the windows. If the view of the outside is kept open, this causes reflections in exhibited artworks mounted behind glass.
F. The ventilation pipes block the light from the light tracks closest to the windows when the light is pointed toward the middle of the room.
G. At least five different types of lamps are used in the SF room. Those lamps have different CRI and CCT values. Two types of lamps have CRI values below 90.
H. The light filter applied on the window has a UV filter but not a UV block. There is no reduction of IR radiation.
I. The existing solution of the window filter, removable blinds, let significant too much light enter the room.
J. Light enters the room during non-public hours.
K. Museum guards switch on the electrical light up to 40 minutes before opening hours.

4. Specifications

Tuesday 9. May 2017 a group meeting with the keypersons at Brands was planned. Everyone from the first round was invited, and it was planned that both curators, the registrar and the technical manager would be part of the group interview. Unfortunately, the technical manager and the registrar were unable to attend the meeting. To minimize the effect of the lack of participation at the second interview, the lighting specifications were sent to all invited key persons prior to the final review.

With the information from the interviews and the analyses of existing situation already completed, the group meeting was held to find out which priorities should be made when defining the specifications of the lighting design solutions. The meeting was also used to determine how to address some of the issues.

Architectural:

A daylight solution must be placed in the interior of the building (no outside mounting because the appearance of the facade should not be changed)

- Daylight reduction techniques can be applied directly on the windowpanes and also on the structure around the window
- The arched top of the window does not have to be respected, and it has been suggested to black out the arched top of the window so a more standard blackout system can be installed
- The existing ventilation system does not have to be considered when designing a new lighting grid (it is hoped that an entirely new climate system will be installed at some point).

Light levels:

- Light levels should meet standards from the Ministry of Culture and other international standards (200 lux for paintings and 50 lux for paper works)
- The exhibitions that are planned for the SF room are photo exhibitions and exhibitions with works on paper. But the SF room should be flexible. Both video works, works on paper and painting should be able to be shown at the same time in order to have maximum flexibility.

Daylight:

- Light from the glass bridge can be regulated at the glass bridge.
    - A view outside from the glass bridge should still be possible
    - An undisturbed view from the SF room to the “Dobbelt Høje Rum” should be maintained
- A view outside from the exhibition rooms is important.

Electrical light:

- There was a request to have two proposals - one reusing the existing lamps, and one requiring new lamps.
- New lighting should have daylight quality.
- New light should not be automatic controlled.

An overview of the design specifications and how they will be addressed

Specifications	Design
Windows	
A daylight solution cannot be placed on the outside of the building.	No outside blinds or shading system will be considered.
It should be possible to have a view to the outside from the exhibition room	A reduction of the aperture or window size with a 100% light proof (or a close as possible) blinds must be used.
The goal is to fulfil museum standards for light sensitive object. E.g. max light levels of ranging from 50-200 lux should be possible inside the room	Adjustable blinds will make it possible to have different daylight levels in the room. The height of a standing person will be used as a measure for the ability to look outside. A new light filter will be recommended with 50 % transmission and a good UV filter, and without changing the visible light. A light reduction of the glass bridge will be made with manually adjustable venetian blinds. This allows for the reduction of the afternoon sunlight from the southwest side.
Reducing the gain of solar heat	The light filter should also have an IR filter.
Maximum flexibility	All blinds should be individually adjustable.
The original iron cast windows should not be altered except for the arched upperpart	Because the removable windows are almost in line with the walls, it is not possible to mount blinds in the window aperture. A decision is made to look for blinds attached on the wall beside the windows. This would make it possible to see the entire window aperture when the blinds are rolled up.
A full black out should be possible outside of opening hours to reduce the lux per year amounts.	The blinds should close properly and snug around the windows. This would also make the room suitable for showing video works.
Electrical light, current light equipment	
Maximum flexibility.	The phase L1, L2 and L3 in the 3-track system should be controllable individually. Two phases need to have a dimmer function that works with LED light. One phase can be used as cleaning light.
Electrical light, new light equipment	
Museum quality lighting	Fixtures with a > 90 CRI must be found, with individual dimming option, preferably with > 100 lumen/watt energy efficiency of the LED chip.

Daylight quality of the electrical light	4000 K solution will be considered, but while the existing solution is a round 3000 K an on- site test with the client should be carried out.
Lighting up the vertical surfaces	Wall washers will be used to increase the general light level and make the room appear brighter. Wall washers can also be used for big art pieces.
Light grid supports the architectural shapes of the room.	A light grid that runs along the ceiling beams and is perpendicular to the windows.
Partition walls	
Best possible use of daylight while still avoiding reflections from the windows	Partition walls must be placed perpendicular to the windows and not block the view.
Symmetry of the room should be respected	Partition walls must be placed in a regular pattern. Windows used for daylight intake must underline the rooms geometry.

5. Design solutions

In this chapter, the design solution based on the specifications in the previous chapter will be presented. The design solutions inside the SF room and at glass bridge will be described.

5.1 The six elements of the design solution

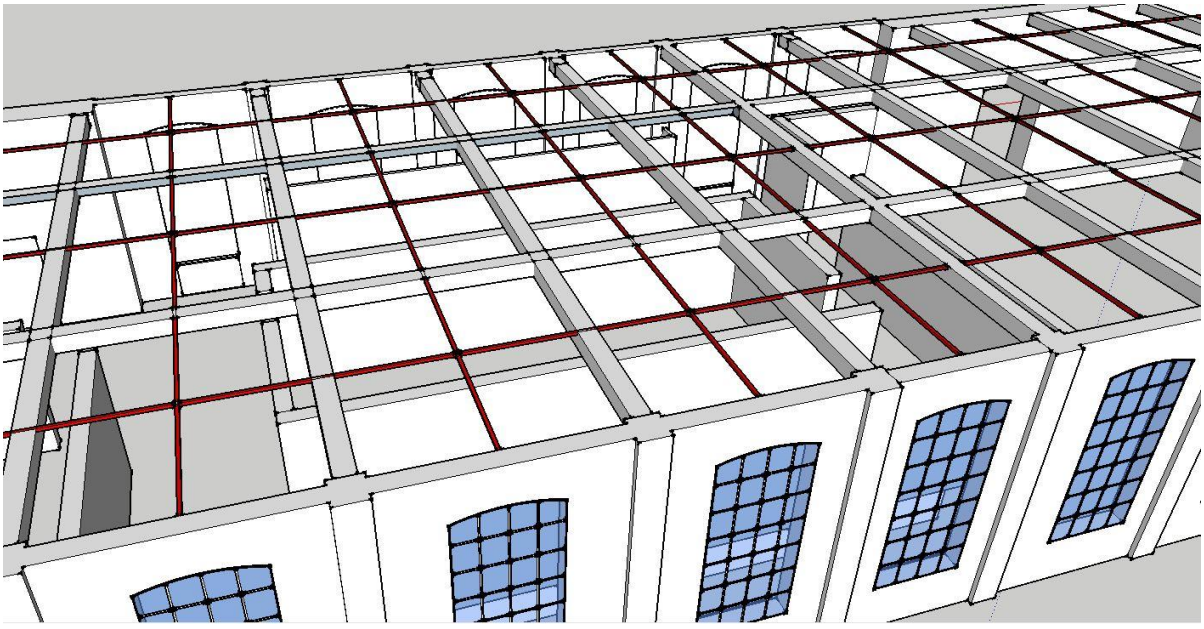
The design solutions consisted of six elements inside the SF room:

A. The light grid
B. Light fixtures
C. Light reducing filters on windowpanes
D. Blinds mounted in the interior of the building
E. Venetian blinds at the glass bridge
F. Placement of partition wall

A. The light grid

The light tracks from a manufacturer like Erco or similar will be used to make a light grid that must be mounted directly onto the ceiling. The tracks are placed in the middle between the ceiling beams. The reasons for this are:

- Fixture will be partly hidden behind the ceiling beams that are 30 cm high.
- To get benefit from the daylight, partition walls must be placed perpendicular to the windows underneath the beams. When the tracks are placed in the middle between the beams, fixtures can illuminate partition walls both on the left and the right side.
- The increased density of the grid will give maximum flexibility.



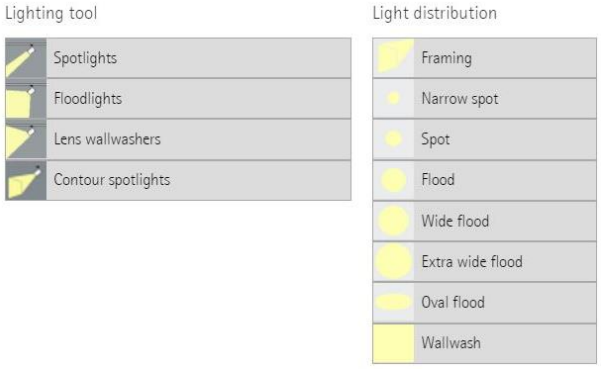
For dimming of the lights that are used today, a trailing edge dimmer from the manufacturer ABB or similar can be used. Trailing edge dimmer are specially designed to dim LED lights. The use of an external dimmer is a cheap way to get more benefit from the lamps that are now owned by Brandts.

The same type of dimmer can also be used with new light fixture. Even if those lamps have an internal dimmer it can be very useful to be able to adjust all lights at once, in case of special occasions when higher or lower light levels are needed.

Another important issue is also the variable character of the daylight. With an external dimmer, it is possible to adjust the light level of the electric light in the evening or in the winter. More advance solution could be made based on light sensors or computer programmable scenarios. It goes beyond the scope of this thesis to find and develop those scenarios.

B. Light fixture

Good quality light from Erco or a similar manufacturer are chosen. These fixtures are individual dimmable. As there is a wish for maximum flexibility the Optec series from Erco is chosen because it is possible to change lenses.



While there are 50 fixtures in use today the same amount has to be bought. Whether the fixture should be 4000K (closer to daylight) depends on the level of flexibility wanted. But the wish was expressed to have maximum flexibility. That is why 3000K is preferable as this colour temperature match best the other lights at Brandts.

C. Light reducing filters on window panes.

The filter chosen is the DN 50 from the manufacturer Johnson Window Films. The film is distributed by a local supplier that is used by Brandts for other foils that are used in the exhibition space. A filter with similar specifications from another producer such as 3M could also be used.

According to the supplier, DN 50 does not change the spectrum of the visual light.
The filter has a transmission of 49% of the visual light and a 99% UV reduction. This filter has an IR reduction of 39% to avoid heat gain. Filters with a high IR reduction tend to give a mirror-like appearance and this is not wanted. This filter can only be mounted on the inside.
The best practice is to mount filters with IR reduction on the outside because then there is least heat gain inside the building. This is most important when it is applied on double or triple layered glass. At Brandts the window panes consist of single layered glass and this is less important. Mounting an exterior filter would also involve a lift or scaffolding.
Before the final decision is made the filter should be tested, in order to confirm that there is no change in the visual light spectrum.

DaylightNatural.
NEUTRAL, NON-FADING SPUTTERED FILMS

SPECIFICATIONS

FILM TYPE	APPEARANCE	VISIBLE LIGHT TRANSMISSION	SOLAR ENERGY REJECTION	VISIBLE LIGHT REFLECTANCE	GLARE REDUCTION
Clear Glass	clear	89%	14%	8%	0%
DN 60	neutral	62%	30%	11%	29%
DN 50	neutral	49%	39%	14%	45%
DN 35	neutral	37%	45%	18%	58%
DN 20	neutral	22%	60%	26%	75%
DN 15	neutral	18%	62%	19%	80%
DN 35 EXT	neutral	37%	49%	16%	58%
DN 20 EXT	neutral	22%	63%	26%	75%

D. Blinds mounted on the inside of the building

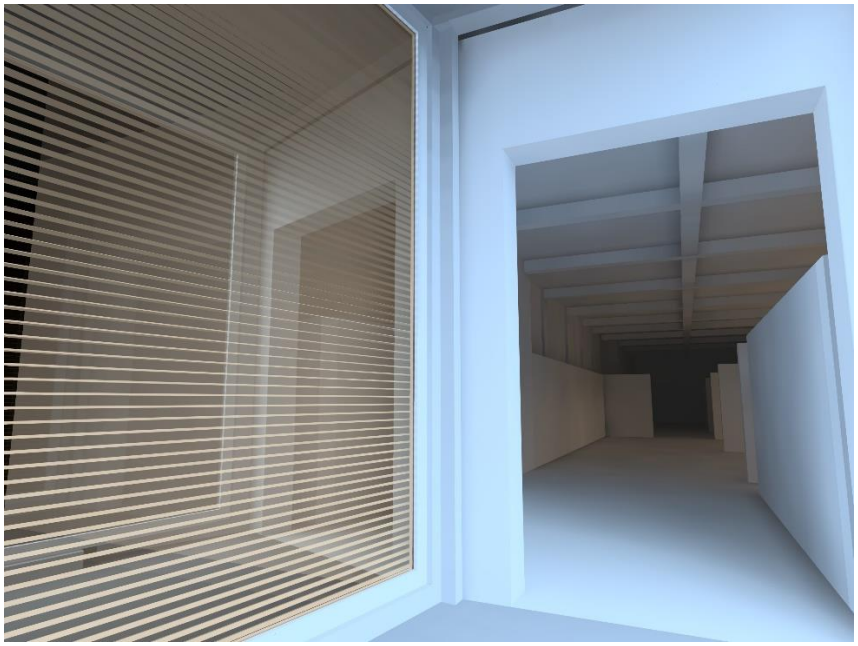
To reduce the overall daylight, quality blinds must be used on all 19 windows in the room. To avoid light leaks around the edges, a system with guiding tracks for the blinds must be used. A system from the manufacturer Faber or similar can be used. To make the blinds match the colour of the room, white guiding tracks and white blinds (not shown in the picture) are preferred but the costumer should be involved in the final decision.

The adjustable blinds make it possible adjust the geometry of the window aperture and regulate the daylight intake at any desired level. This gives maximum flexibility, and direct sunlight can be blocked. When the blinds are lowered approximately 60%, they are at the same height as the frame of the removable windows. In this position, an adult can look outside the windows.

Photomontage showing the blinds down at approximately 60%. Photograph by the author.

E. Venetian blinds at the glass bridge

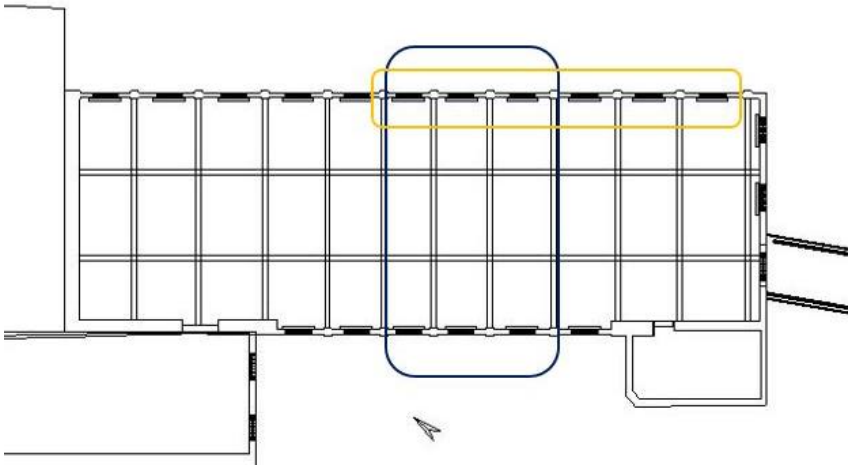
The light reduction at the glass bridge is done with venetian blinds. Blinds from Faber or similar can be used. The blinds are mounted on the inside.



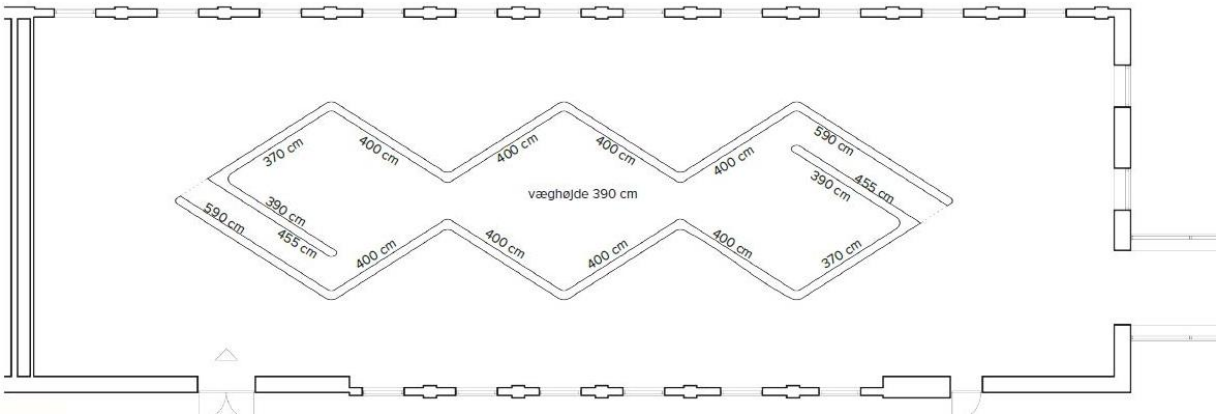
In the design solution presented at 5.2 and 5.3 the venetian blinds are down and 50% open (horizontal) on the southeast side of the glass bridge. In solution 5.4, the venetian blinds are down and 50 % open, on both sides of the glass bridge.

F. Placement of partition walls

Based on the specifications, six windows on the northeast side and three windows on the southeast side are selected to realize the daylight improvements in this the case study. The three windows on the southeast side can be used, but only indirect light from these windows is suitable for use; direct sunlight must be avoided. With this in mind three possible room designs are created with the use of partition walls. The blinds are used as describe at above in section C. The three designs represent different solutions to exhibit light sensitive artworks inside the SF room based on the specifications.



While all three of the designs demonstrate how daylight can be used. The designs are hypothetical concerning the dimensions of the artworks and the amount of wall space needed to show them. The assumption is that the space required is equal or more to the space available in the current exhibition at the SF room. Currently there is 70 meters available for paintings, and at the inner space created by the partition walls there is 45 meters available for paper works.

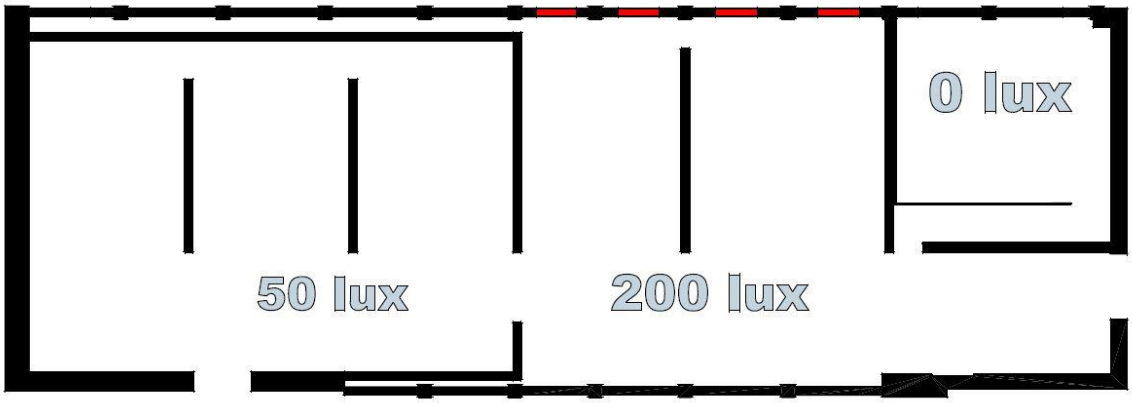


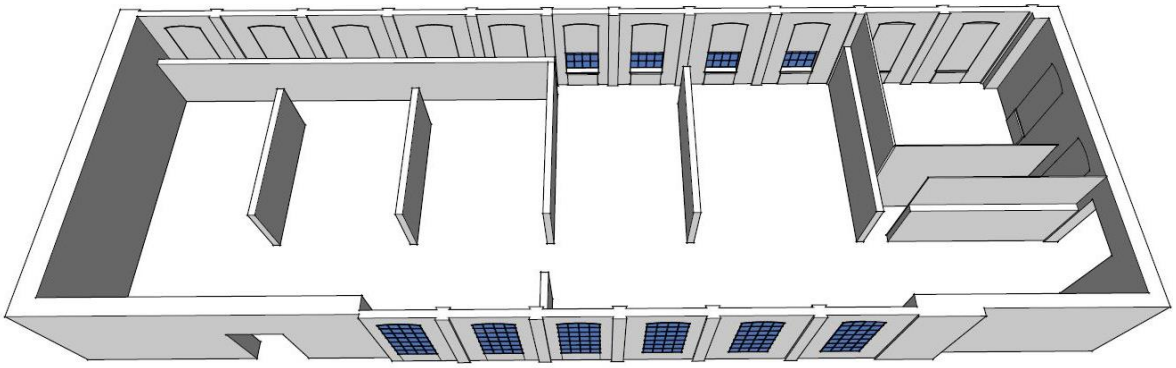
In all three designs, a partition wall is installed as an extension of the glass bridge. This wall serves to prevent sunlight from entering the corner of the room on the east side.

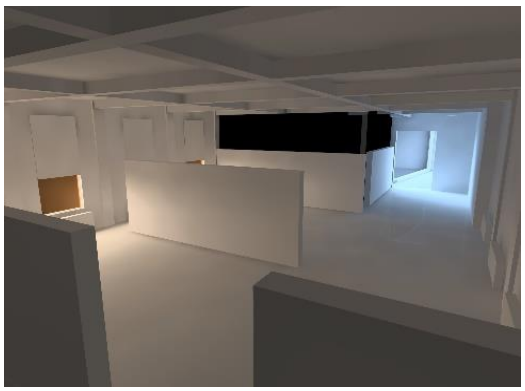
In all three solutions, the window blinds at the SF room are lowered. Only the windows marked with red are partly open as illustrated in the photograph at D.

5.2 Design A

This design provides the means to choose from three different levels of daylight (including no daylight).

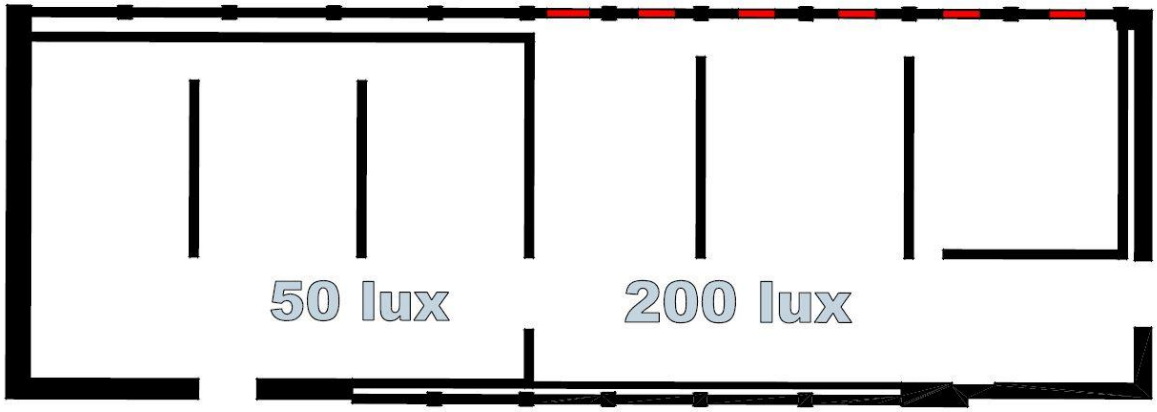


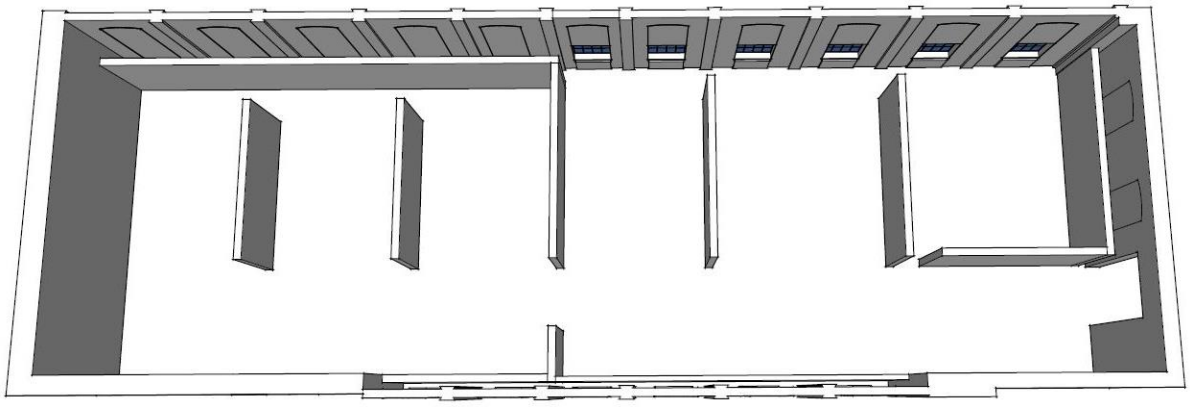


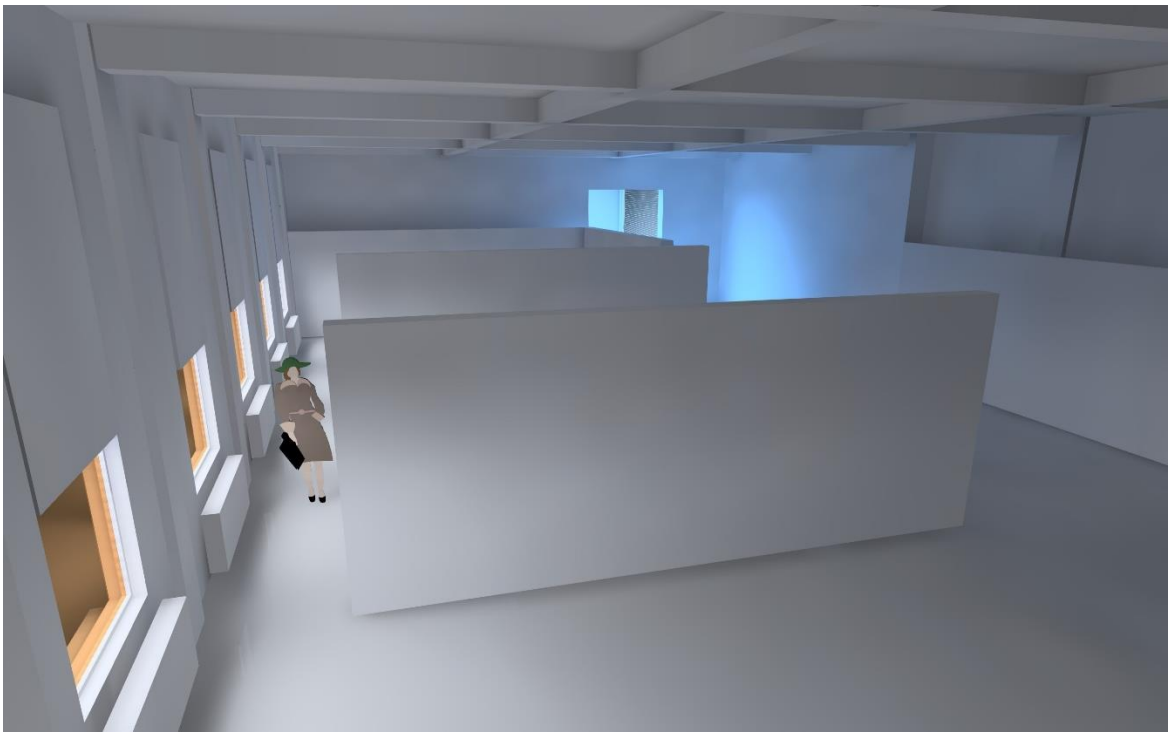


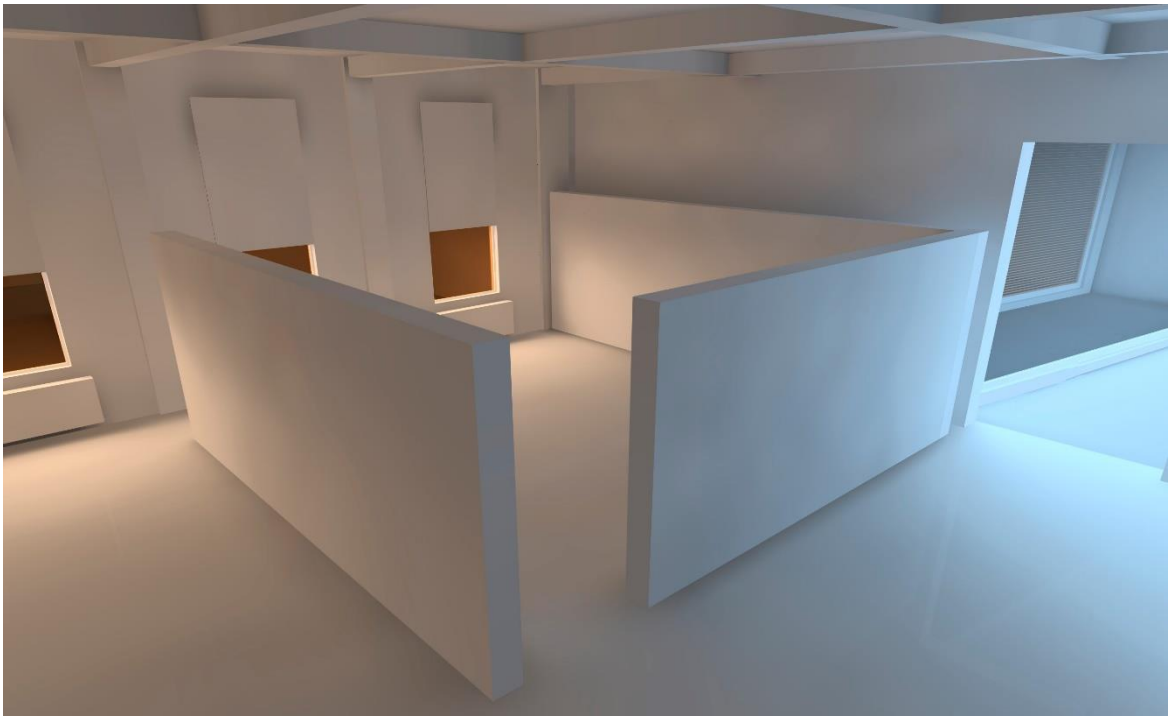
5.3 Design B.

Design B offers the greatest daylight intake and a sightline outside through six windows.



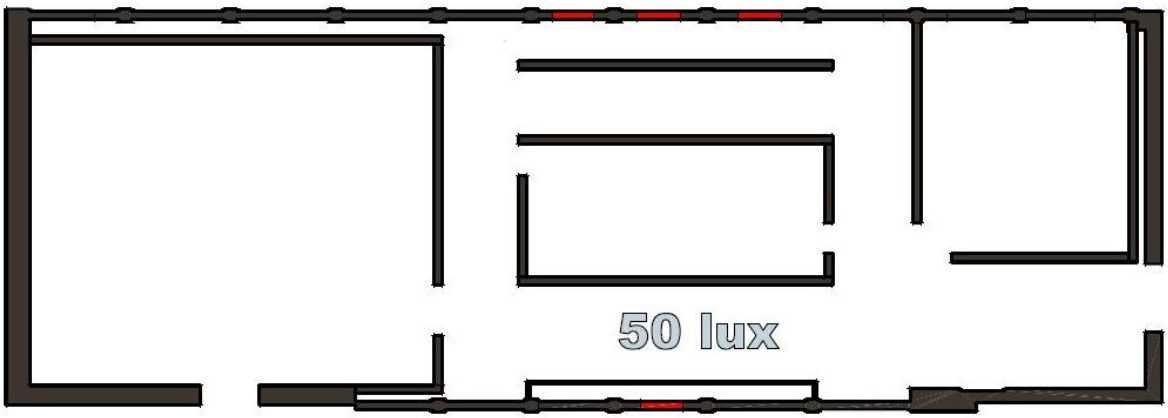


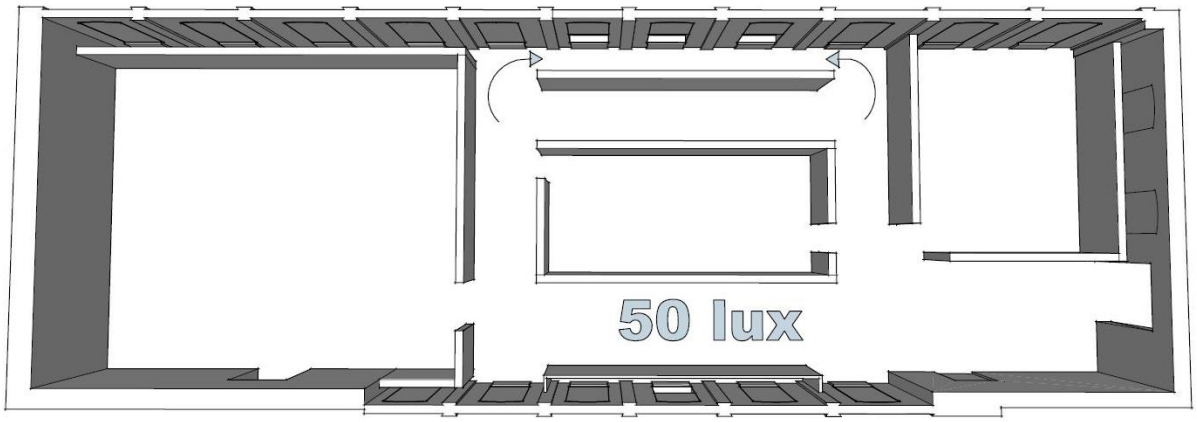


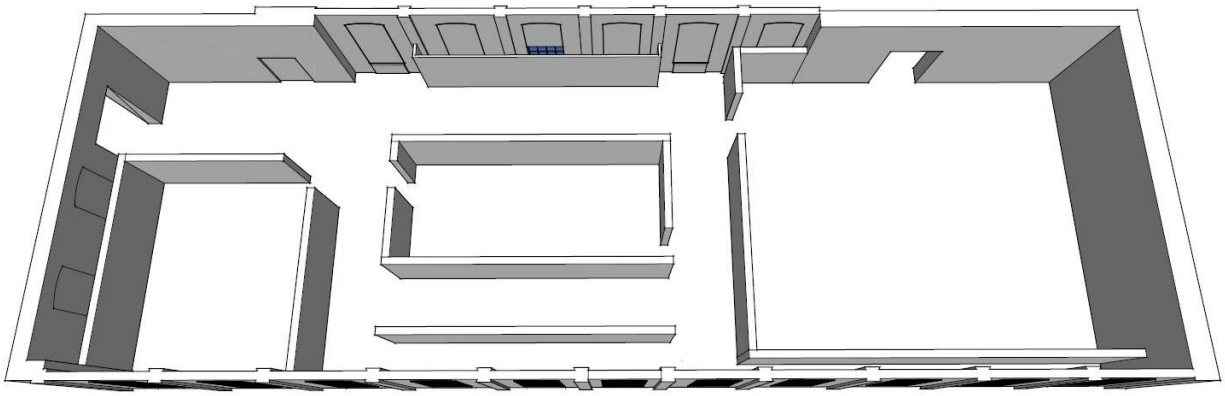


5.4 Design C.

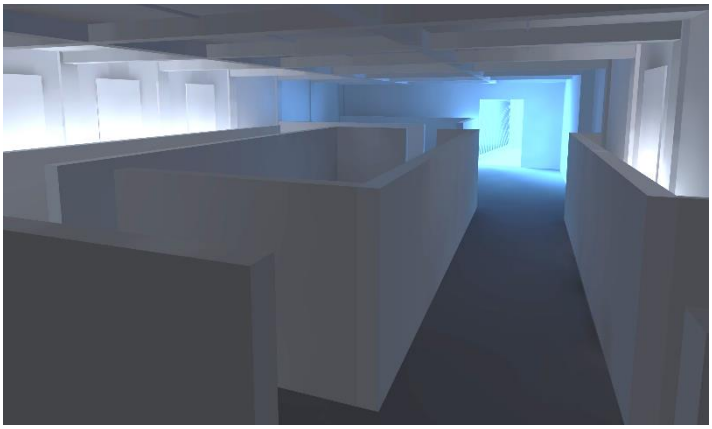
Design C allows for the use of indirect daylight within an exhibition space where photographs or other paper works can be shown. Both from the southeast side and the northwest side, indirect daylight is used. On the southeast side a partition wall is placed in front of one window and the sides of the partition wall are closed. Indirect light bounces from the inner side of the partition wall, onto the white blinds and is reflects onto the ceiling and distributed further into the room. On the opposite side, a slightly wider partition wall is placed in front of the windows. This set up makes it possible to go behind the partition wall and look outside.







(View from the opposite side)



6. Discussion

How is it possible to optimize the use of daylight and integrate electric lighting, in a side lit historical building, while still fulfilling museum standards for protecting light sensitive works?

That was the research question and the final design solutions shows that it is possible to do so.

The advantages of using daylight seem obvious, but out of concern for protecting light sensitive artwork, the use of daylight at low light levels at a museum took some persuasion. During the interviews, several staff member expressed that they liked daylight and recognize its range of qualities. By the end of the project when it was confirmed that Brandts would overtake the third and the fourth floors of the main building in the future, a staff member commented: "We can just block the daylight on the second floor (= SF room) and we'll use the fourth floor for a view outside."

This brings us back at the starting point of the thesis, which is that daylight has more positive qualities than just providing a view outside. Even if a view is not considered to be attractive, there are additional reasons for the use of daylight. Although fully blocking the daylight and the subsequent loss of orientation and contact with the outside world can be part of an artistic concept.

One of the conclusions from Augustesen (2009) was that making successful daylight solutions at museums required close communication with museum staff. In this case study at Brandts, there have been some challenges for the staff members to find time for meetings due to the high level of activities and the ongoing process of opening new exhibitions.

It is my hope that the solutions presented in this thesis will be implemented at Brandts at some point in the future. The method developed in this thesis can be used at any side lit historical building in which museum standards for protecting light sensitive works must be fulfilled. Applying these findings may help to create more museum interiors in which visitors can enjoy the entire museum experience and still remain aware of the time of day, the season and the surroundings outside the building. With these lighting solutions, conservators are satisfied with the controlled light levels that do not exceed the recommended light levels, and curators have more flexible solutions, a livelier atmosphere in the exhibition spaces, and the ability to create surroundings in which the artworks are represented in the best possible way.

As a lighting designer, it is my intention to use daylight solutions as an integrated part of my practice in any kind of project. I would like to come up with permanent solutions at museums and temporary exhibitions, because daylight is the best light.

References:

Augustesen, C. (2009). *Daylight at art galleries, Expectations versus reality, Does the use of daylight meet expectations?* (Unpublished doctoral dissertation). UCL, London

Boyce, P. (2014*). Human factors in lighting*. Boca Raton: CRC Press.

Bolving, G. (1995). *Brandts Klædefabrik*. Odense: Forlaget Brandts Klædefabrik

Boubekri, M. (. (2014). *Daylighting design: planning strategies and best practice solutions.* Basel: Birkhäuser.

Brandston, H. M. (2008). *Learning to see: a matter of light*. New York, NY: Illuminating Engineering Society of North America.

Burkard, L., & Søndergaard, T. (2012). *Kunsthallen Brandts: 25 år*. Odense: Kunsthallen Brandts

Clegg, P., (2014), *Lighting for the build environment*. LG10 Daylighting- a guide for designers, London, CIBSE

Conn, D. (2012), *Protection from light damage*. retrieved 15. May 2015 https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.4-protection-from-light-damage

Figueiro, M.G., Bullough, J.D., Parson, R.H. and Rea, M.S. (2004) Preliminary evidence for spectral opponency in the suppression of melatonin by light in humans, *Neuroreport*, 15, 313-316

Fontoynont, M. (1999). *Daylight Performance of Buildings*. London: James & James

Hauser, K. (2016), *Evaluating light source color rendition using IES TM-30-15*. Retrieved 8. May 2017 http://www.personal.psu.edu/kwh101/IESChicago2017/IESChicago_EvaluatingColorRenditionWithTM30_Houser_20170126.pdf

Hefferan, S. (2008) "*Working with light in the museum environment*" WAAC newsletter vol. 30 number 1 Retrieved 8. May 2017 http://cool.conservation-us.org/waac/wn/wn30/wn30-1/wn30-107.pdf

Henningsen, P. (1974). *Om lys*. København: Rhodos

Jensen,R. (1993). *Brandts Klædefabrik: Erindringer fra arbejdslivet på fabrik i hjertet af Odense*. Odense: Forlaget Brandts Klædefabrik

Küller, R., & Lindsten, C. (1992). *Health and behavior of children in classrooms with and without windows*. Journal of Environmental Psychology, 12(4), 305-317. doi:10.1016/s0272-4944(05)80079-9

Krogh, A. (2016). *Flux luminous*. Copenhagen: Strandberg Publishing

Küller, R. (1996). "*The Subterranean Work Environment: The impact on wellbeing and health*" Environment International 22 (1) 33-52 Retrieved 8. May 2017 https://doi.org/10.1016/0160-4120(95)00101-8

Küller, R., & Lindsten, C. (1992). *Health and behavior of children in classrooms with and without windows. Journal of Environmental Psychology*, 12(4), 305-317. Retrieved 8. May 2017 https://doi:10.1016/s0272-4944(05)80079-9

Livingston, J. (2014). *Designing with light: the art, science and practice of architectural lighting design*. Hoboken (N.J.): Wiley

Marsh, R., Larsen,V., (2006), *Arkitektur og energi*, Hørsholm, SBI,

Meek, C., & Wymelenberg, K. V. (2015). *Daylighting and Integrated Lighting Design*. London: Routledge

Norman, D. A. (1986). *User centered system design: new perspectives on human-computer interaction*. Hillsdale, NJ: Erlbaum

Plummer, H. (2012). *The architecture of natural light.* London: Thames & Hudson.

Ruys, T. (1970) *Windowless offices*, MA thesis, Seattle WA: University of Washington

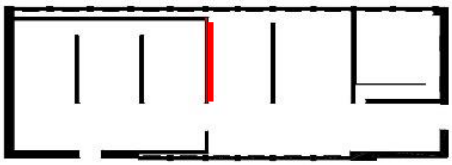
Shaw, K. (2015*). Lighting for the build environment*, LG8 Lighting for museums and art galleries, London, CIBSE,

Svendsen, S. P., Hammer, C., Steffensen, L. .., & Raun, H. .. (2010). *Window words*. , Denmark: VKR.

Thomson, G. (1986). *The Museum Environment,* London, Butterworth & co

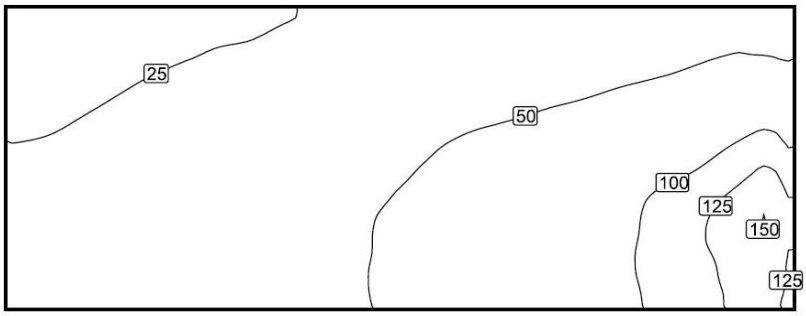
Appendix

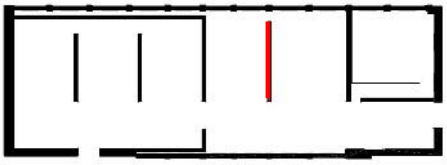
Design A. Light calculations



Average: 51.8 lx, Min: 21.4 lx, Max: 150 lx, Min/average: 0.41, Min/max: 0.14

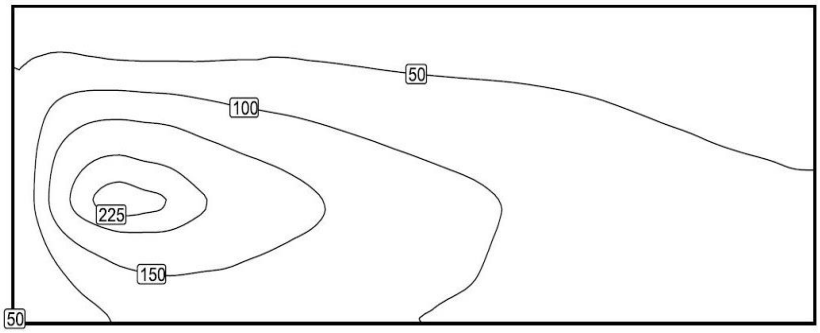
Isolines [lx]





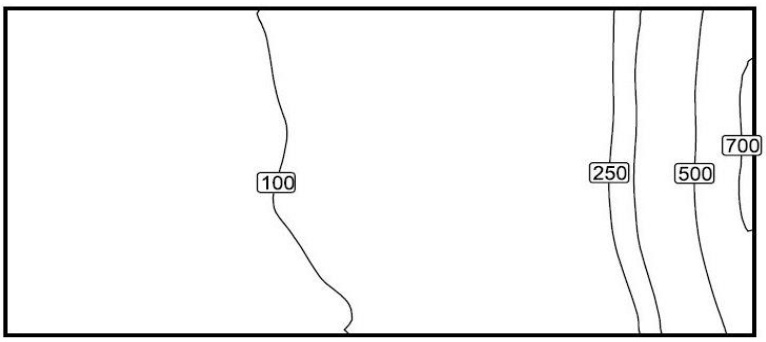
Average: 87.5 lx, Min: 29.3 lx, Max: 236 lx, Min/average: 0.33, Min/max: 0.12

Isolines [lx]

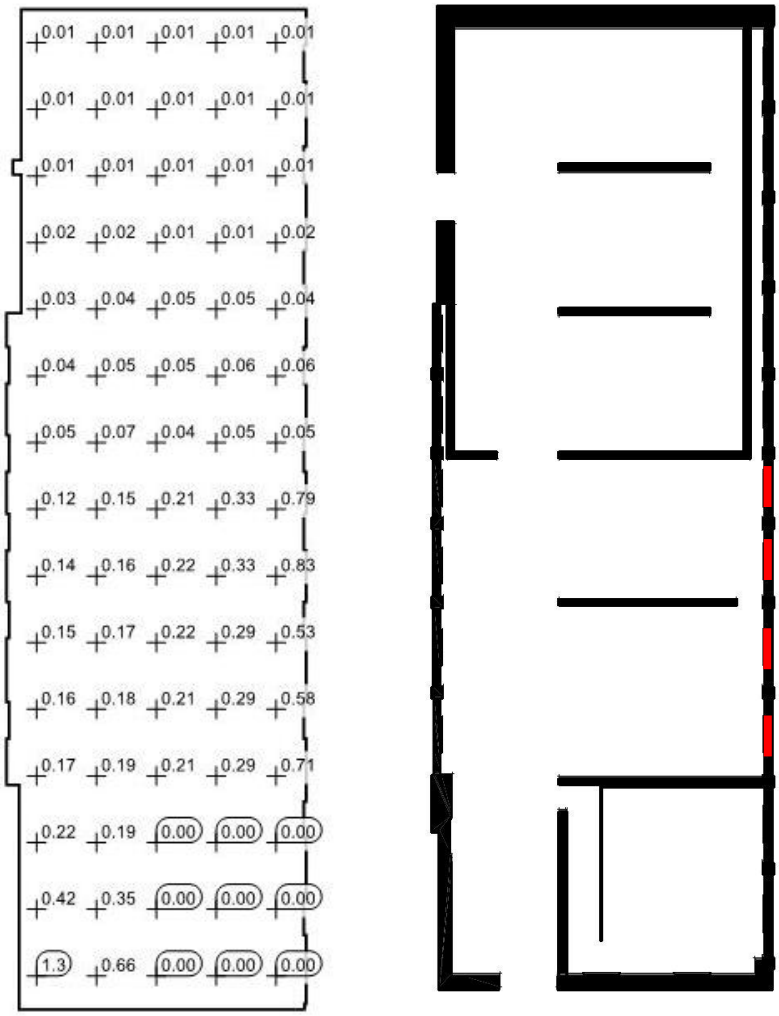


Average: 176 lx, Min: 61.7 lx, Max: 721 lx, Min/average: 0.35, Min/max: 0.09

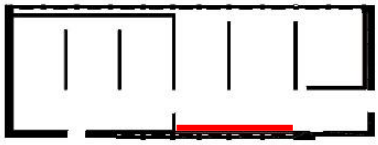
Isolines [lx]



Daylight factor

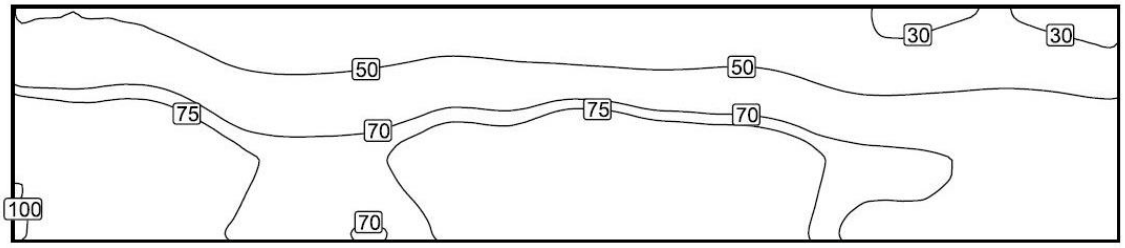


Design B. Light calculations



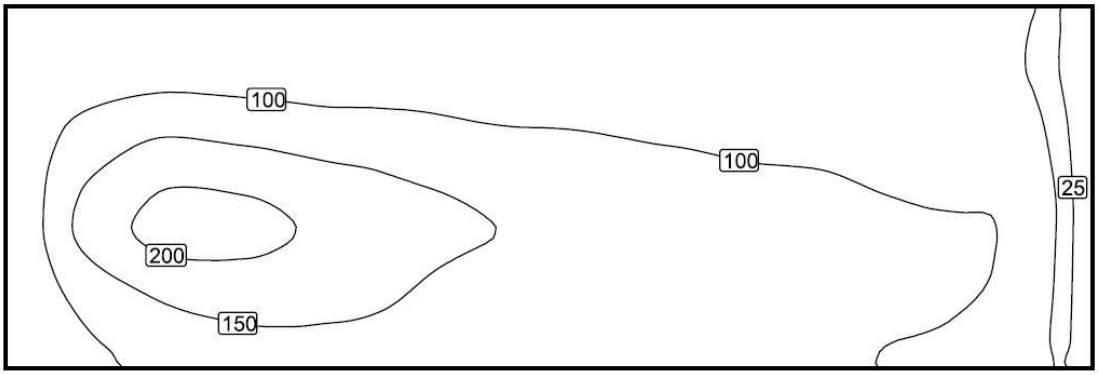
Average: 64.4 lx, Min: 28.2 lx, Max: 101 lx, Min/average: 0.44, Min/max: 0.28

Isolines [lx]

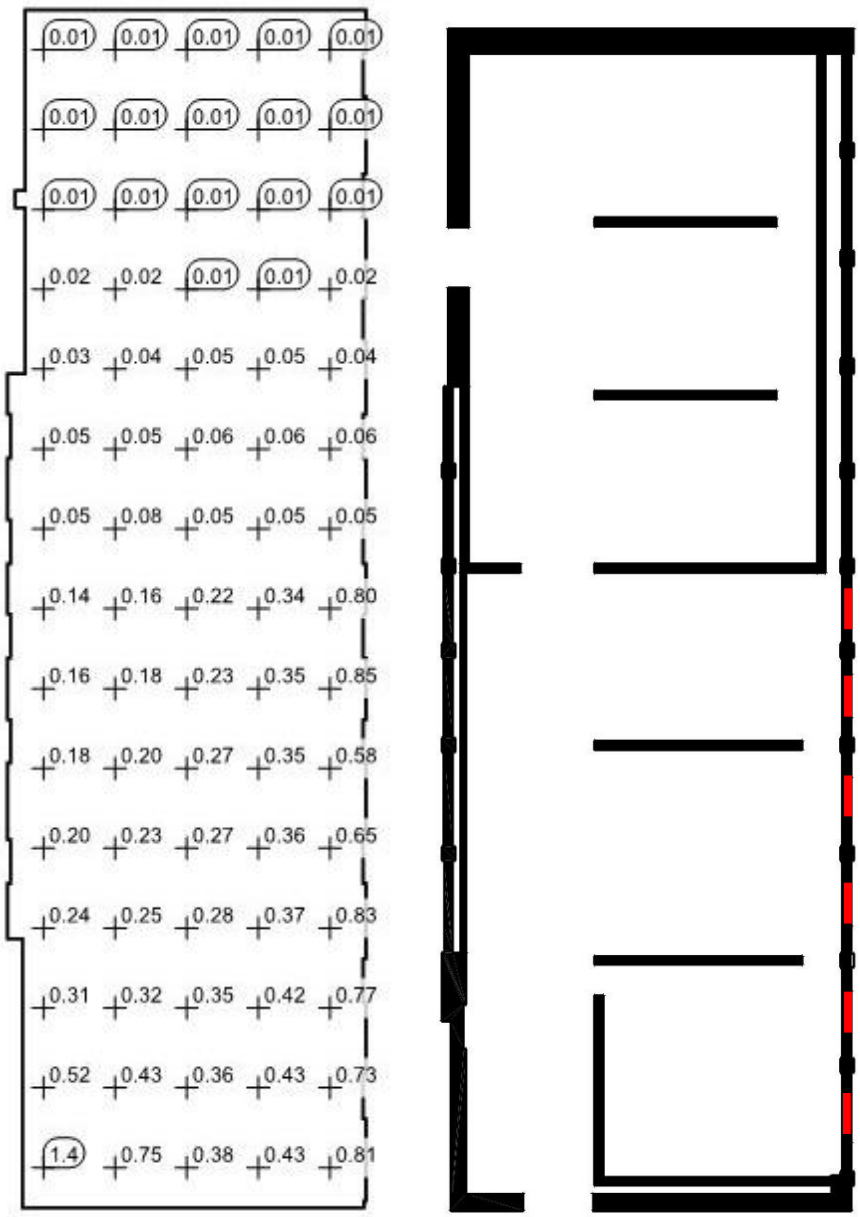


Average: 106 lx, Min: 4.50 lx, Max: 220 lx, Min/average: 0.04, Min/max: 0.02

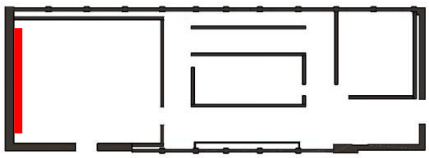
Isolines [lx]



Daylight factor

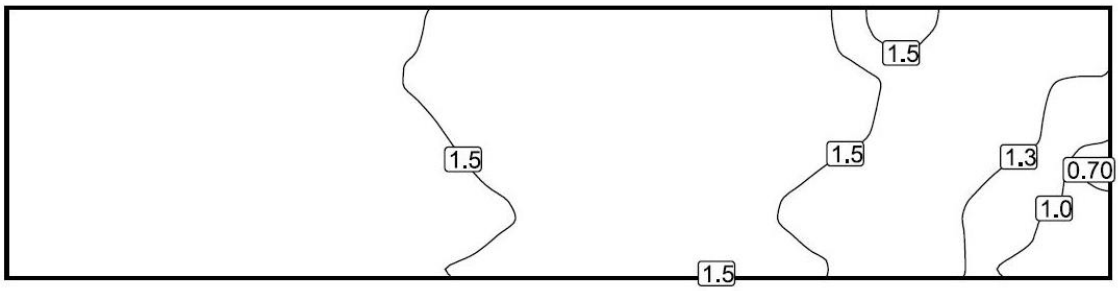


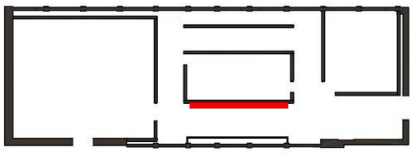
Design C. Light calculations



Average: 1.42 lx, Min: 0.61 lx, Max: 1.67 lx, Min/average: 0.43, Min/max: 0.37

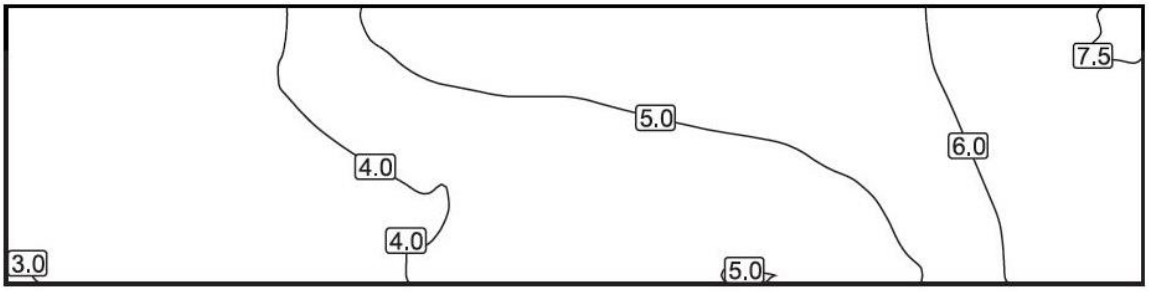
Isolines [lx]





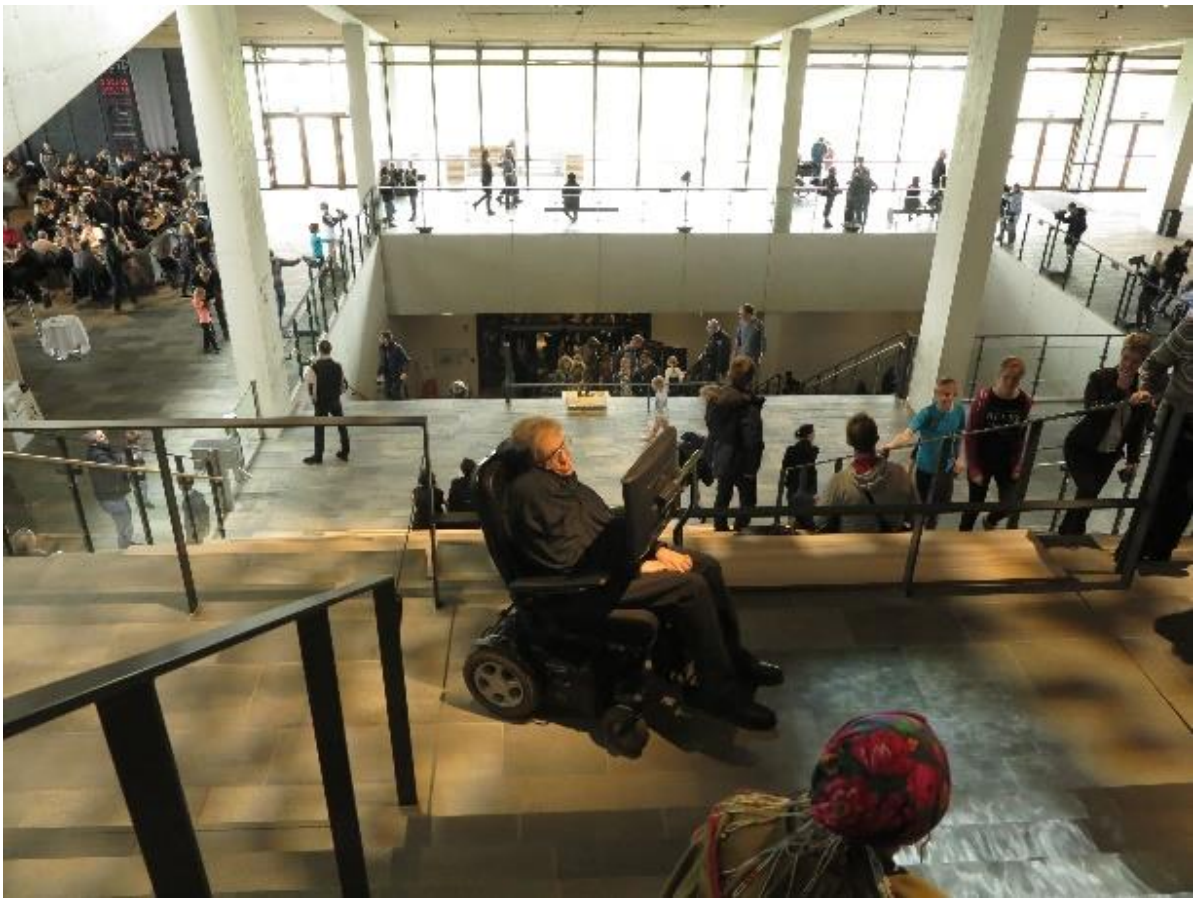
Average: 4.78 lx, Min: 2.60 lx, Max: 7.53 lx, Min/average: 0.54, Min/max: 0.35

Isolines [lx]



Inspiration

Moesgaard Museum



Exhibition areas are located below and above ground level. At this transition area, the big staircase itself, lux levels are 30-40 lux and the room still is perceived as being very bright.

The first floor an area was created where visitors can take a break from the exhibition and enjoy the view outside and the natural light.

The David Collection

The David Collection has a few rooms with daylight, which are supported with electrical lighting. It is done with such expertise that it is hardly noticeable.

Lighting control is done in part with the venetian blinds. Certain security guards are responsibility for adjusting the blinds throughout the day. Specific instructions are written down for reference listing the times of the day or the circumstances under which the blinds have to be adjusted.

The light levels are low but the room still appears to be relatively bright, because of the soft diffuse lighting in the entire room and the light colours on the walls. Measured light levels are between 40-100 lux.

Typical for The David Collection is that lighting solutions are designed specifically for the individual room. In the photo below, there is a curtain that reduces much of the daylight but allows some of daylight to be visible. This solution works well for the paintings by Vihelm Hammershøj. The light on the paintings is only 100 lux, and that is sufficient for viewing the paintings.