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Lehrstuhl für Raumkunst und Lichtgestaltung

Concept of Lighting Design in Egyptian Museums' Spaces

(Case Study: The West Wing in the Egyptian Museum in Cairo)

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Concept of Lighting Design in Egyptian Museums' Spaces

(Case Study: The West Wing in the Egyptian Museum in Cairo)

A dissertation by

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*"To my beloved parents,
without whom none of my successes would be possible"*

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Introduction

Museum lighting

The mission of a museum is to collect and exhibit the artifacts and objects of interest for public education and enjoyment; as well to protect the collection from damage. Therefore, the museum lighting is widely connected to these goals.

Fundamentally, museum lighting should give a good visual condition that is free from distraction and pleasant, to help the visitors focus their attention on the exhibits and enjoy the display. On the other hand, to insure not to cause any harm to the exhibits by fully applies the recommendations of conservation.

Aesthetically, the lighting should be designed to emphasize the characteristic of the objects in display and underline its original intention of creation. As well, the lighting configuration should be part of the design of the display and the exhibit space. How the artifact and space are perceived depends on the interaction of the light with their physical characteristics.

Technically, the lighting quality depends mainly on the light source and how to utilize its potential. Perhaps artificial light is more controllable and fits more with the conservation aspects of museum lighting. On the other hand, daylight is more powerful to revile the aesthetic attributes of the artifacts and the architecture; and it is essential for human well-being. The strategy of utilizing these sources is crucial in determining the quality of lighting in the museum. In museum applications often difficulties arise from reconciling between preservation standards and the aesthetics aspects of the artifacts.

Accordingly, the museum lighting is an integrative process with various design aspects and requirements. A distinguished concept of a museum lighting emerges from finding the right strategy that harmonizes all these aspects together and fulfils the museum lighting requirements.

Problem of the research

Most Egyptian museums are old and do not meet the requirements of the contemporary standards of lighting design in museums. On the other hand, the architecture and interior design fields in Egypt needs more research in the field of lighting design in museums.

Although the Egyptian artifacts are displayed in a lot of museums around the world; these museums, from a lighting point of view, do not share a common perspective of how should the artifacts be illuminated.

Since the lighting design in a museum revolve mainly around the artifacts, the research questions are:

- How should we light the Egyptian artifacts?
- How can the museum lighting reveals the characteristics and attributes of the Egyptian artifacts?

- How to reach a high quality of lighting in Egyptian museums' spaces?
- How to benefit from the daylight condition of Egypt?
- Is lighting design for Egyptian artifact in the Egyptian climate and daylight condition will lead to special concept?

Aim of the research

The study aims to formulate a set of guiding principles and a general lighting concept to improve and insure the quality of lighting design in Egyptian's museum spaces.

The guiding principles depend on understanding the contemporary standards of museum lighting and studying its applicability in museum practice.

The general lighting concept depends on revealing the characteristic and aesthetic of the artifacts and benefit from the Egyptian climate condition by utilizing the abundant direct sunlight in Egypt as a constant element in the lighting scheme of Egyptian museums.

Importance of the research

A better understanding of lighting design in Egyptian museums' spaces will help to improve the environment of many old museums and guide designers to further design new spaces with high lighting-design quality. This will make museums more interesting and enjoyable for the visitors and insure the safety of the artifacts.

Hypothesis of the research

With the change of the climate the characteristics of light change; its colors, rhythms, softness, harshness, patterns of shadows, etc. all change; thus the atmosphere of the space change, the visual characteristics of objects change, and how people react to light change. Therefore light is the spirit of a place, the formgiver of an object, and a part of people's culture.

The ancient Egyptian artifacts (sculpture, reliefs, and architectural elements which are the main exhibits in Egyptian museums) had been created in the past under the harsh daylight of Egypt with the consideration in which place, position and direction in the temple they will be presented and that was part of their characteristics. Further, the styles of Egyptian art changed remarkably little over more than three thousand years. These facts lead to the idea that understanding the visual characteristics of the Egyptian art and how they are created under the strong daylight of Egypt, will lead to a new lighting concept that reveals more of the artifacts' aesthetics. As well, understanding the artifacts cultural background will make the display and lighting underline the artifacts' original intention of creation. Accordingly, this hypothesis supports the idea of utilizing the daylight as a constant element in the light scheme of Egyptian museums.

Methodology

The methodology of the research varies between the analytical and experimental studies. The research contains a wide field study about museums in general and Egyptian museums in particular, and several lighting experiments with physical models.

Case Study

The case study is The West-Wing in the Egyptian Museum in Cairo. The museum is founded in the 19th century by the French Egyptologist Auguste Mariette (1821-1881) and it is housing the world's most valuable collection of its kind. The museum is an ideal case study that consistent with the nature of our study because it is originally designed to be a daylight museum. However, a redesign process can be more changeable and have a lot of limitations.

Structure of the research

The research is constructed from five chapters:

Ch1: Lighting Design Aspects in Museum

The aspects were classified to: the human visual performance in museums, the lighting strategies in the museum (daylight and artificial light), and the exhibits lighting quality and techniques. The chapter depends on collecting the up-to-date knowledge about lighting design in museums to serve as a background knowledge for the research.

Ch2: Lighting and Displaying the Egyptian Artifacts

The chapter tries to answer the main research question: How should we light the Egyptian artifacts? The chapter discusses the visual quality and characteristics of the ancient Egyptian arts from a lighting design point of view, and presents some examples of lighting and exhibiting of Egyptian artifacts in museums around the world.

Ch3: Exhibits Conservation Aspects in Museum Lighting

In this chapter we deeply studied the conservation aspect in museum lighting. As well, we conducted a spectrum power distribution analysis for several museum light sources to show the potential of damage that can occur from visible light. The results of this analysis can be used as a reference in selecting light sources for sensitive-to-light material in museum applications.

Ch4: Visual Perception Experiments for Lighting Levels in Museum

In this chapter we question the applicability of applying norms of illumination levels in the museum practice. The chapter is an experimental study where we conducted several visual perception experiments in a scale-model and a mock-up to define the proper illumination levels and lighting compositions for museum practice.

Ch5: Case Study: The West Wing in the Egyptian Museum in Cairo

In this chapter, we apply the knowledge and results of the previous chapters in a real case study. The case study is the West Wing in the Egyptian Museum in Cairo.

The proposed lighting design for the case study includes the daylighting and artificial lighting design in three phases: Pre-design, Schematic Design, and Design Development. Additionally, since the museum is old and do not have an appropriate display to be illuminated, we proposed a new concept for the interior design in the area of interest.

The chapter is a large and important part of the research because it includes a vast knowledge about the daylighting design process. The process depends on both the physical model and daylight simulation analysis tools, and it includes the development of a new daylighting system, as well the use of existing daylighting systems in the market to reach the goals of the design.

The research gives a vast and profound knowledge about museum lighting and it focuses on the aesthetics of lighting the Egyptian artifacts. The case study adds more depth to the research and connects the theoretical finding to the real practice.

Keywords

lighting design, lighting concept, museum lighting, Egyptian museum, daylighting, daylight analysis, daylight system, daylight simulation, lighting strategy, artificial lighting, exhibits lighting, Egyptian artifacts, conservation lighting, spectral analysis, light damage, visual perception, visual perception experiments

Lighting Design Aspects in Museum

Ch. 1

Chapter 1. Lighting design aspects in museum

The mission of a museum is to collect and preserve art and artifacts, as well to display them for the study, education, and enjoyment of the public. Accordingly, the exhibits are the main focus of museum design, and, by extension, the lighting design.

Lighting design is the media that connects together the vision, the built environment and the exhibits in harmonized way for the sake of exhibits' better vision, enjoyment and safety.

The lighting design, as an integrated part in the museum architecture and the exhibit design process, aims to:

- Insure a comfortable and clear vision of the exhibits.
- Enhancing the exhibits' display and surrounding.
- Revealing the aesthetic of the exhibits.
- Insure not to harm that exhibits' colour and materials.

In this chapter we will discuss the main aspects of lighting design in museum. The aspects were classified to: human visual performance in museum, lighting strategies in museum (daylight and artificial light), and exhibits lighting quality and techniques.

It is important to point out that these aspects encompass a lot of lighting parameters that are interrelated, affect each other, and have to be coordinated together to reach a good quality of light in museum. As a matter of fact, the balance between the aesthetics and conservation aspects are mainly what make the museum lighting very sensitive and need to be highly controlled.

1.1 Human visual performance in museum

Vision depends on light and lighting should provide visual conditions in which people can function effectively, efficiently, and comfortably.[(1)] Visual performance mainly depends on the amount light, distribution of light in the visual field, the contrast of the visual task with the surrounding, and light spectrum quality. The visual performance can be judged by measuring the ability to resolve detail, to detect luminance and colour differences, and to see temporal changes in luminance.[(2)] Knowing the visual requirements in museum helps light designer to enhance visual performance and comfort.

1.1.1 Illuminance levels

Museum standards mainly written in illuminance (symbol: E). It indicates the amount of luminous flux falls on a surface and it is measured in (Lux). The illuminance value for a museum object is not only measured from the direct light source but also from the indirect light

1. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000. p88.
2. Previous reference, p107.

of the surrounding. Illuminance is measured on horizontal and vertical surfaces, and its uniform distribution facilitates the visual task.

The level of illuminance in museum is often determined by: First and foremost by the sensitivity of the exhibits. The second criterion is the design intention. And in third place is the question of how much light is needed to enable the visual task to be performed. Applying all three criteria produces a consensus on the illuminance level required, although it needs to be realised that the level must not be too low.(1)

The CIE(2) museum lighting norms depend on classifying artefacts to groups according to its material responsivity to visible light that is free of IR and UV radiation, and assigning illuminance and time of exposure according to these groups.

- High responsivity: 50 lux - Limiting exposure 15.000 (lx h/y).
- Medium responsivity: 50 lux - Limiting exposure 150.000 (lx h/y).
- Low responsivity: 200 lux - Limiting exposure 600.000 (lx h/y).
- Irresponsive: no limit.

These recommendations are widely used, however, for dark colour objects it may not be possible to achieve a satisfactory appearance at 50 lux. Generally, it is suggested that a ratio of 3:1 for object to background illuminance be used to enhance object's visibility.(3)

The IESNA(4) norms give more guideline for illuminance of circulation and general background in galleries based on artefacts' lighting, reflectance, and intended degree of visual attraction in display.

For bright artefacts with light reflectance ≥ 0.5:

- Dramatic display, Avg $E_{surrounding} : E_{object}$ (1:10).
- Moderate display, Avg $E_{surrounding} : E_{object}$ (1:5).
- Subdued display, Avg $E_{surrounding} : E_{object}$ (1:2).

For dark artefacts with light reflectance < 0.5:

- Dramatic display, Avg $E_{surrounding} : E_{object}$ (1:20).
- Moderate display, Avg $E_{surrounding} : E_{object}$ (1:10).
- Subdued display, Avg $E_{surrounding} : E_{object}$ (1:5).

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1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p26.
2. CIE: Commission internationale de l'éclairage (French), The International Commission on Illumination, is the international authority on light, illumination, colour, and colour spaces. It was established in 1913 as a successor to the Commission Internationale de Photométrie and is today based in Vienna, Austria. < https://en.wikipedia.org/wiki/International_Commission_on_Illumination> (07.02.16).
3. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p25, 26.
4. IESNA or IES: Illuminating Engineering Society of North America is a non-profit learned society that was founded in New York City on January 10, 1906. < https://en.wikipedia.org/wiki/Illuminating_Engineering_Society_of_North_America> (07.02.16).

For the previous recommendation, room surfaces light reflectance values (LRVs) are assumed to be 90 ceiling, 60 walls, and 20 floor. Mentioned ratio between illuminance are either horizontally at floor level or vertically at 150 cm from floor level. Illuminance uniformity over covered area are (2:1) Avg : Min and (4:1) Max : Min.(1)

In any event, for purposes of comfortable and convenient circulation throughout exhibits and galleries, horizontal illuminance on floor should be no less than 10 lx.(2)

Generally, The size of the details and its colour is also crucial in determining the illuminance, since the more the object is smaller or darker the more illuminance is needed.

(More details about exhibits illuminance and luminance levels are addressed in Ch.4: Visual perception experiments for museum lighting).

1.1.2 Luminance distribution

The apparent brightness (subjective brightness) of surface depends partly on the adaptation state of the eye, an partly on the quantity of light reaching the eye from a surface. The term Luminance (objective brightness) is used to define the physical quantity. The magnitude of luminance depends on the intensity of light from the surface in direction of the viewer, and the projected area of surface emitting or reflecting this light. Luminance (symbol: L) is measured in candelas per unit area (cd/m^2).(3)

Luminance distribution in the visual field has a crucial bearing on visual performance because it defines the state of adaptation of the eye. The higher the luminance, the better the visual acuity, contrast sensitivity and performance of ocular functions.(4)

There are luminance roles to arrange the luminance in the visual field for people in the working place, these roles are adopted by a lot of lighting designers to arrange the light environment of museum space. I quote: "For visual tasks at a desk, concentration is promoted by brighter areas in the centre of the visual field. In the context of an exhibition, this means that exhibits should always have a higher luminance than their surroundings. One way to achieve this is with graduated brightness levels".(5) (i.e. graduated luminance levels).

Well known luminance roles in office practice are:

- A luminance ratio of 3:1 and 10:1 between the task and nearby surroundings, and the task and more distant surroundings is desirable for visual comfort (Osterhaus, 2002).

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1. IESNA The Lighting handbook, Application - Light for art,10th Ed. 2011, p(21.4).
2. Previous reference, p(21.12)
3. Peter Tregenza and David Loe, The design of Lighting, E&FN Spon, London, UK, 1998, P4.
4. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p26.
5. Previous Reference, p26.

- The maximum luminance in the field of view should not exceed 1500 cd/m^2 (Osterhaus, 2002). This is approximately 12 to 15 times brighter than an average CRT or LCD computer screen.[(1)]

The attraction and satisfaction to high luminance objects can be experienced in museum spaces, and whenever the exhibits present more luminance than the surrounding it drags visitors attention and become more comfortable to be watched. (Figure 1.1)

Otherwise, if the surrounding has more luminance, for example a white-walls illuminated uniformly with the exhibits, the exhibits will look dark against the bright background and observer has to come very close to the exhibit to reduce and overcome the effect of the bright background, or maybe an accent spotlights has to be directed on the exhibits to make it look better. However, in a museum a dark painting or statue will never have more luminance than the background ! (Figure 1.2)

Figure 1.1 *The eye is dragged to the highest luminance in the space. In a surrounding with moderate colour and illumination, the well lit bright-coloured statues, stones and show-cases drag eye attention. (Romano-Germanic Museum, Cologne, Germany).*

(a) **(b)**

Figure 1.2 *Background and exhibit luminance ratio: (a) A bright background affect the appearance of the exhibits and make it looks darker (b) Raising the illuminance of the painting with spotlight will enhance its appearance. In both cases, the background has more luminance! (Museum Ludwig, Cologne, Germany).*

The luminance ratios that are used in working environment has limitations in museum lighting; for example, it cannot define luminance for a dark objects against a bright background. A luminance of a black object cannot in any case exceed the luminance of a bright background, and if this happened the object will appear odd and unnatural. There is a substantial difference between the visual task of seeing text in an office and the object-background visual relationship in a museum. We conducted a series of experiments in a scale model and a mock-up for a museum lighting situation to experiment and define light levels, as well to investigate the object-background brightness relationship. *(For more details see Ch. 4 : Visual perception experiments for museum lighting).*

1. Impact on Users' Discomfort Glare Perception and Productivity in Daylit Offices, Master of Building Science, Victoria University of Wellington,2008, P3.

For conservation aspects it is very important to measure the light falling on the object (illuminance), however for the visual performance, the light received by the eye (luminance) is more crucial. To balance between museum conservation needs and visual needs is a dilemma in museum lighting, especially for high sensitive-to-light dark materials. Lighting designer can overcome such a situation by:

- Insure that the object has a contrast with the background (a dark object will appear better on bright background and vise versa).
- Concentrate the light only on the object and its near surrounding.
- Insure that illuminance has a good uniformity on the object.
- Lowering the general illuminance of the room to lower the state of adaptation and to rise the luminance sensitivity.

(For more details see Ch.4, EXP 4)

1.1.3 Simultaneous contrast

Simultaneous contrast is the change in the appearance of a surface caused by the presence of an adjacent surface that is much brighter or darker. In (Figure 1.3) it shows that the brightness of a surface is a function of its background, and not only the light it receives. Simultaneous contrast is often encountered in exhibition design. Sometimes it is used intentionally and effectively to dramatize a part of the display, and in other situations it is extreme and not appropriate, and it is better to be entirely avoid.[1]

Figure 1.3 *Simultaneous contrast alters the subjective brightness (apparent luminance) of an object although object objective brightness (luminance) stay the same.*

Simultaneous contrast is a tool to adjust the luminous ratio between the object and its direct background. However, changing the whole colour of museum walls the effect takes another level and it affects the eye state of adaptation.

In simultaneous colour contrast the appearance of colours moves away from that of the surrounding colour in all three dimensions of surface colour: hue, saturation and lightness. In (Figure 1.4) (a) Simultaneous contrast of hue: a purplish-red colour looks more purple against red and more red against purple (b) Simultaneous contrast of saturation: the same purplish-red looks lower in chroma against bright purple-red and progressively higher in chroma against dull red-purple (c) Simultaneous contrast of lightness: The same purple-red looks darker against a lighter colour and lighter against a darker colour of similar hue and chroma. However, the visual system exhibit a colour constancy.[2]

1. Lou Michel, Light: The Shape of Space, Design with space and light, John Wiley and Sons, INC.1st ed.1996. p13-14
2. David Briggs, The dimensions of colour, <http://www.huevaluechroma.com/035.php>(10.10.14)

Figure 1.4 *Simultaneous colour contrast (a) Simultaneous contrast of hue (b) Simultaneous contrast of saturation (c) Simultaneous contrast of lightness. (Modified after David Briggs, The dimensions of colour).*

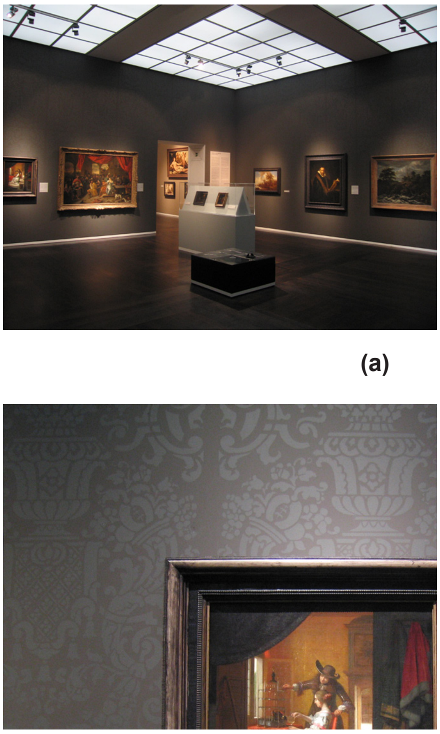
The last examples used a close colours in hue to show how sensitive the appearance of colours can be to the simultaneous colour contrast. In any case, the same types of simultaneous colour contrast can occur between different colours in hue. It is famous between designers to use a complementary colours or warm and cold colour to raise the effect of the simultaneous colour contrast. However, in museum spaces monochromatic colour is preferred as a background to avoid the change in colour appearance.

In (Figure 1.5) a picture gallery in Museum Wallraf, Cologne, Germany, the mid-tone neutral gray walls help not to alter the brightness or the colour of the paintings. The diffuse luminance ceiling give a soft general illumination with high uniformity and the spotlights accentuate the painting and drag visitors attention. In such arrangement a 200 lux standard illuminance on the painting can be firmly sufficient.

Figure 1.5 *The mid-tone neutral gray walls helps not to alter the brightness or the colour of the paintings. (Wallraf Museum, Cologne, Germany).*

Some exhibition designers use surface textures and patterns on wall surfaces. The contrast between the bright and dark parts of the texture or the pattern helps to raise walls subjective brightness. The walls will look more bright in comparison to a plain wall with the same average luminance.[(1)] Generally, a texture or a pattern on the walls will make the wall more attractive and it is important that this effect do not interfere with the exhibits. (Figure 1.6 and Figure 1.7)

1. A visual study of wall texture effect was conducted during the preparation of the visual perception experiments in Ch. 4, the study and the results are not published.



(a)

(b)

Figure 1.6 *(left) A picture gallery with dark walls. (a) the dark walls were decorated with a slight bright pattern, the contrast of the pattern with the background makes the walls look brighter, in the same time maintains the general dark atmosphere of the place. (b) a close up photo of the pattern. (Wallraf Museum, Cologne, Germany).*

Figure 1.7 *(right) A picture gallery with daylight luminance ceiling. The mid-tone natural-gray walls with dry brush texture create a quiet large surface, that articulate the colour of the landscape painting and maintain a quiet atmosphere. (Neue Pinakothek, Munich, Germany).*

1.1.4 Adaptation

Adaptation: is the process by which the retina becomes accustomed to more or less light than it was exposed to during an immediately preceding period. It results in a change in the sensitivity to light.(1) And when the visual system is not completely adapted to the prevailing retinal illumination, its capabilities are limited. This state of changing adaptation is called transient adaptation.(2)

Different facts in adaptation can be important in planning museum spaces. Mainly, how object brightness is affected with the state of adaptation, and the time needed for the eye to be completely adapted to light situation.

The subjective visual appearance (subjective brightness) will depend upon adaptation. The eye can adapt to a wide range of lighting conditions. However, the eye cannot adapt to the whole of this range at one time. In dark adaptation a small intensity of light can be helpful to read a text and; in contrast, in daylight adaptation the same amount of light can be hardly noticeable. At night the headlights of an oncoming car will dazzle a dark-adapted viewer, whereas on a sunny day these lights will be barely noticeable.(3) This shows how low object illumination can be sufficient in a dim lit gallery. As well, how planning dim lit

1. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p971.
2. Previous reference, p99.
3. Society of light and lighting, Code for lighting, Butterworth-Heinemann, UK, 2002, p11.

spaces is very sensitive, since a dark adapted eyes are prepared to notice any slight luminance change and the range between the luminance of the brightest and darkest area are very narrow. In a dim lit gallery a direct small view to adjacent bright space can grab visitors attention and reduce the brightness of objects in the gallery. On the other hand, a gallery with a bright well lit walls and/or low-height luminance ceiling will raise the visual adaptation of the eye and exhibits will appear dark. In such situation, exhibits will need much more directed light on it to enhance its appearance. In contrast, where walls are moderate in colour and illumination are more directed onto the painting, low illuminance is sufficient to rise the painting brightness. (Figure 1.5, Figure 1.8, and Figure 1.9).

Figure 1.8 *A picture gallery with a large diffuse luminance ceiling that lies in the visual field, thus it grabs the eyes attention, and alters the adaptation state; which makes the colour of the painting look desaturated and darker. (Brandhorst museum, Munich, Germany).*

Figure 1.9 *A picture gallery with north oriented skylight, that do not cover the whole ceiling, thus more light is directed to the middle of the wall than the upper part. Although, the bright ceiling raises the adaptation state; the black background create a strong contrast with the painting and maintain good visibility. (Lenbachhaus Museum, Munich, Germany).*

Figure 1.10 *Changing between light situations in museum, creates interesting spaces that enriches the visiting journey and relieves the eye stress.(Ludwig Museum, Cologne, Germany).*

During the movement of people through museum spaces their eyes goes through involuntary process of responding to different brightness values of successive spaces. Actually people did not feel small changes of light level in the indoor or outdoor situation, On the contrary, small change is important because it comfort the human's eye.(1) In figure (Figure 1.10) the change of light situations between a transition zone with a small window that connect the visitor to outside, to a bright daylight gallery, then to a dark passage where sensitive-to-light drawings art exhibited; creates interesting spaces that enriches the visiting journey and reliefs the eye stress.

In fact Adaptation can be a problem in museum only when the magnitude of the change is quite large and quickly occurs; on the other hand it depends also on the direction of the change. Adapting from dark to light situations occurs relatively rapidly, whereas adapting from light to darkness requires a considerably longer time.(2) A gradual change of illumination or a transition zone can be very useful to connect dark conservation gallery to adjacent spaces.

Actually, adaptation can be more critical in the entrance zone, when museum visitors step out of bright daylight into a darker building or out of night-time darkness into a brightly lit interior. To enable their eyes to adjust to the change in brightness level, adaptation zones are recommended. During the day, the immediate entrance area needs to be particularly brightly lit; at night, the illuminance inside the building should decrease towards the exit.(3)

1.1.5 Glare

Glare is the sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility.(4)

Glare has many types and levels in which it can effect our vision:

Disability glare (direct glare): is the effect of stray light in the eye whereby visibility and visual performance are reduced.(5) This is commonly occur in museum when the sun and sky are seen through windows, strong sun patches fall on the interior surfaces in the immediate field of view, and artificial light sources seen directly. Generally, direct sunlight has to be eliminated not only for avoiding glare but also for artifacts conservation aspects and human thermal comfort. This can

1. Lou Michel, Light: The Shape of Space, Design with space and light, John Wiley and Sons, INC.1st ed.1996, p18.
2. Previous reference, p18.
3. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications published by Fördergemeinschaft Gutes Licht, p12.
4. Illuminating Engineering Society of North America, The IESNA LIGHTING-HANDBOOK, 9 ed 2000. p996.
5. Previous reference, p988.

be achieved, for example, by the use of external louvres, dark glass, or internal screens. Where direct glare from artificial light sources can be managed by choosing the right beam angle and direction according to the light task. (Figure 1.11).

Discomfort glare: is glare that produces discomfort. It does not necessarily interfere with visual performance or visibility.[1] The discomfort can be experienced when some elements of an interior have a much higher luminance than others. It can occurs immediately or sometimes only becomes evident after prolonged exposure. The degree of discomfort will depend on the luminance and size of the glare source, the luminance of the background against which it is seen, and the position of the glare source relative to the line of sight. A high source luminance, large source area, low background luminance and a position close to the line of sight all increase discomfort glare. In any proposed lighting installation, the likelihood of discomfort glare being experienced can be estimated by calculating the unified glare rating (UGR).[2] This is commonly occur in museum from bright-colour walls when strongly illuminated, from low-height luminance ceilings and bright windows. Discomfort glare are generally managed by arranging the luminance intensity and distribution in the visual field.

Veiling reflection (Reflected glare): is a high-luminance reflections that overlay the detail of the task. Task performance will be affected because veiling reflections usually reduce the contrast of a task, making task details difficult to see, and may give rise to discomfort.[3] In museum spaces windows and bright white surfaces have a high potential of cousin reflected glare. In such situation it is advisable not to use showcases or present artifacts covered with glass. Generally, veiling reflection cannot be totally eliminated but it can be significantly reduced by the use of matt materials in the space, anti reflective glass, and arranging the geometry of the viewing situation so the reflected luminance do not lay within the angle of sight or cover the visual task. (Figure 1.12).

Figure 1.11 *Direct glare from direct connection to outside through unshielded small entrance in a sunny day. Transition zone are needed to avoid this situation. (Luxor Museum, Luxor, Egypt).*

1. Previous reference, p988.
2. Society of light and lighting, Code for lighting, Butterworth-Heinemann, UK, 2002, p14.
3. Previous reference, p14.

(a) (b)

Figure 1.12 *Reflected glare (a) The high-luminance from windows' white screen are reflected on the showcases glass obscures viewing the artifacts. (b) A view for the whole gallery. Windows and bright surfaces have high potential of causing reflected glare. (Egyptian Museum, Turin, Italy)*

1.1.6 Vision of colours

The process of adaptation from total dark to good light situation takes the visual system through three distinct states. These states are mainly defined by the characteristics of the eye receptors the rods and cones.(1)

- Scotopic vision (Night vision): when the luminances less than approximately 0.001 cd/m^2 only road cells react thus we see no colour and we only see grades of grey.
- Mesopic vision (Dusk vision): As the luminance increase cones gradually start to function and we start to see some degree of colours and details. Most of night-time outdoor and traffic lighting scenarios are in the mesopic range.(2)
- Photopic vision (Day vision): when luminances is higher than approximately 3 cd/m^2. Retinal response is dominated by the cone photoreceptors. This means that colour is perceived and fine detail can be resolved in the fovea.

Accordingly, to insure seeing details and good colour vision in museum light levels has to be more than 3 cd/m^2.

In museum practice, for photopic vision, an existence of 10 lm/m^2 is required (10 lux vertically on the eye). If a person having normal visual ability is adapted to this level of light from objects in the field of view , then that person should be able to discriminate moderately fine detail in the objects, and if the colour rendering of the incident light is satisfactory, they should also be able to discriminate fairly small colour differences.(3)

1. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p 99.
2. CIE Publication No. 41. Light as a true visual quantity: principles of measurement. 1978. < https://en.wikipedia.org/wiki/Mesopic_vision> (10.02.16)
3. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p237.

1.1.7 Correlated Colour Temperature CCT

Correlated colour temperature (CCT) of a light source: is the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source. CCT measurement unit is kelvin (symbol K).[(1)]

The CCT of a light source will determine whether the display takes on a cool or a warm appearance. Generally, the customary names in practice are ww = warm white CCT < 3300 K, nw = neutral white CCT 3300 to 5300 K, cw = cold white > 5300 K.[(2)] (Figure 1.13)

Figure 1.13 *A set of statues comparatively representing the different CCT of LED light sources from 2700K to 6500K. (Citizen electronics co. ltd. Japan, Euro Lucci 2009)*

Note: Although the photos illustrate the CTT differences, photos generally can not represent real vision.

Experiments have suggested that using lamps with high CCT values at low illuminances will make a space appear cold and dim. Conversely, using lamps with low CCT values at high illuminances will make a space appear artificial and overly colourful. The Kruithof Curve (Figure 1.14) describes a region where the correlation between illuminance levels and colour temperatures are comfortable or preferred. Where high illuminance levels are preferred with high CCT and low illuminance levels are preferred with low CCT. Although these findings have been broadly replicated, other investigators have found that when people spent sufficient time in the room for colour adaptation to occur, the perceptions of rooms illuminated with two different CCT will not be noticeable. However, Where comparisons can be made or colour adaptation does not occur, CCT is more likely to be important.[(3)]

Accordingly, in museum practice where different lamp types are used in the same space, lamps CCT must be closely matched. As well, where artificial light is seen with daylight or boosted the reduction of daylight, the CTT of artificial light has to match that of daylight.

1. lluminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p985.
2. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p34.
3. Previous reference, p145.

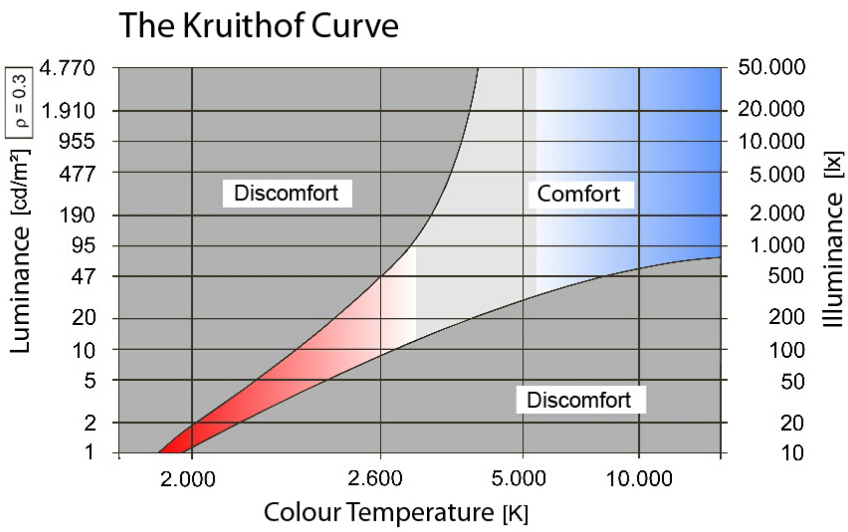


Figure 1.14 *The Kruithof Curve describes regions of illuminance levels and colour temperatures that are often viewed as comfort or discomfort. (Bartenbach Academy, Innsbruck, Austria)*

Figure 1.15 *(lift) The warm white CCT of the spotlights are recognizable against cold white CCT of the daylight. (Ludwig Museum, Cologne, Germany).*

Figure 1.16 *(right) The spotlights warm white CCT is recognizable on the dark statue because the statue has a glossy surface and the warm appearance contrast with the cold white CCT of the daylight general illumination. (The State Museum of Egyptian Art, Munich, Germany).*

The change in CCT appears as yellowish or bluish cast on exhibits and walls surfaces. Slight CCT differences can be acceptable, however big difference can change exhibit appearance and become unacceptable. (Figure 1.15 andFigure 1.16)

1.1.8 Colour Rendering

The quality of colour we see depends on light source spectrum power distribution (SPD). The ability of spectrum to render a colour can be assessed by the colour rendering index of a light source (CRI): is a measure of the degree of colour shift objects undergo when illuminated by the light source as compared with those same objects when illuminated by a reference source of comparable colour temperature.[1]

1. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p982.

The most common used colour render index is the **CIE Test-Colour Method.**[(1)] [(2)] In this method a reference source is a blackbody (standard tungsten lamp) at the temperature equal to the CCT of the test source, and if the CCT is 5000 K or more, the reference source becomes a standard daylight spectral power distribution. A set of different colour samples are compared under the test source and noted a ratio from 1 to 100 in comparison to a similar set of sample under the reference source by calculating their chromaticity values. The test-colour samples consists of a general index $R_{a,}$ a set of eight colour samples with moderate lightness and equally spaced in hue. The *Ra* is supplemented later with special indices *Ri* contain six special colour samples include four saturated colour, an one each representative of Caucasian skin and moderate green foliage. Of a particular interest among the 14 test-colour, is R9 the saturated red. Light sources with low value for R9 are less likely to be accepted for general illumination. Since CRI is an average value of all 14 samples, a lamp exhibiting a weak R9 may still exhibit a high CRI, a mock-up are recommended.

Because the reference illuminated for CRI change with CCT, it is only valid to compare the CRI of different lamps if their CCT is similar. For example, a 6500 K daylight fluorescent lamp with a CRI of 84 should be expected to render objects differently than a 3000K rti-phosphor fluorescent lamp with the same CRI of 84. The number has different meaning for each different CCT lamp. Despite this restrictions, mostly the higher CRI of a lamp the better it making objects appear as expected.

Despite of the widespread use of CIE CRI in the light community, it has limitation due to the representation of the CRI in a single number that cannot fully characterize multidimensional experience of colour. As well, CIE CRI cannot correctly rank sources by colour rendering when LEDs are included. Mock-ups remain the recommended method of assessing lamps colour rendering properties, particularly in critical application.

It should be noted that, the IES published in 2015 a new colour rendering method (IES TM-30-15) that cover shortages of old methods.[(3)] However, all lamps in the market still evaluated with CIE CRI.

For museum practice, lamps with CIE CRI values of 80 or greater should be used, but it is important to visually inspect the artifact under the proposed light source.[(4)] For LED lamps the CIE CRI has limitation. Mostly, the LEDs spectrums has a weak ability to render the saturated red R9. An effective way to approve the colour rendering ability of LED or any other light source is to use two identical standard colour checker (e.g. Macbeth Color Checker) to compare the light source (e.g. LED light source) with a standard lamp (e.g. MR16 Halogen lamps with CRI 95-100) at the same CCT.

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1. Previous reference p173.
2. IESNA The Lighting handbook, Framework - Colour, 10th Ed. 2011, p(6.19 - 6.22).
3. Evaluating Color Rendition Using IES TM-30-15. <http://energy.gov/sites/prod/files/2015/12/f27/tm-30_fact-sheet.pdf> (17.02.16).
4. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p542.

1.2 Lighting strategies in museum

Lighting the exhibits is the main task of museum lighting, and it cannot be separated from the background or surround lighting. The exhibit lighting (task lighting) is more about performing a good vision of the exhibits, rendering its aesthetics, and insure its protection from any light damage. The room lighting (ambient light / general illumination) is more about the appearance and feeling of the space. It is important to perceive the geometry of the space and give it a sense of spaciousness. As well, to give the visitors a welcoming feeling, supports them to move freely and safety, communicate effectively, and stay comfortably longer in the space. In addition, it supports the exhibit lighting as a background light. Beside these two main lighting elements, The accent light can be used to highlight parts of the interior for visual relief, visual attraction and way finding. However, precaution has to be taken that this kind of light do not interfere with the exhibit light.

Lighting in museum spaces is essentially made up of diffuse and direct light [(1)]; and its success depends on the relative amounts, resulting mix, and distribution of these two lighting types on the surfaces of the room and exhibits to create a comfortable and intersecting luminance environment.

In the practice of museum lighting, room lighting, either natural daylight or artificial, is meant to light the whole room. It comes from a diffuse light source or reflected by room surfaces to generate diffuse light. Room lighting alone is rarely enough to meet all exhibitions needs. Exhibit lighting uses hard-edged directional light to accentuate individual items on display. As a general rule, it needs to be supplemented by softer room lighting. Exhibit lighting based on spots alone is advisable only where a particularly dramatic effect is required. Exhibit lighting does not provide bright enough room lighting except in a few mostly small and bright interiors.[(2)]

Accordingly, the key elements of lighting strategy in museum are the balance between: bright and dark areas (luminance distribution), diffuse and direct light, and room and exhibit lighting.

Museum lighting strategies can be classified to daylighting- and artificial light strategies, since the architecture and the interior of a museum change dramatically according to which type are the main lighting source.

1.2.1 Daylighting strategies

Daylighting involves the delivery and distribution of light from the sun and the sky into a building interior to provide ambient and/or task lighting to meet the visual and biological needs of the occupants. This requires a comprehensive understanding of the source of daylight and the role that architectural design, space planning, material selection, and system integration play in daylight system performance.[(3)]

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1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p2.

2. Previous Reference, p2.

3.. IESNA, The Lighting handbook, Designing Daylight,10th Ed. 2011, p14.1.

1.2.1.1 Historical influences

The development of museum building in the 18th and 19th centuries optimized the use of daylight. The strategy mainly was to reduce windows to use the walls for presentation and to depend on different types of skylights to direct and distribute light in the space. In the middle of the 20th century the development of artifacts conservation changed museum lighting criteria by restricting the UV radiation and high level of illumination, that can damage the organic composition of the artifact. As a result, museum lighting strategy replaced daylight with electric light and reduce the use of daylight. During the last decades, energy conservation requirements and improved daylight control systems have revived the use of daylight in museums. These advances have fostered creative strategies to the problems of good illumination, human comfort, and artifact preservation.(1) An a lot of new daylight systems and strategies were implemented in museum buildings.

1.2.1.2 Daylight advantages

In general, daylight is a crucial factor in architecture for the sake of human well being. It provide a wide range of benefits, including: enhancement of the visual environment, improving occupant satisfaction and worker productivity, enhancement of circadian rhythm, energy savings through a reduction of the electric lighting load,(2) and connecting people to the outside world to provide them with information about the change in time, weather, and seasons.(3) Additionally, in museum daylighting has incomparable ability of renderings colours. Objects often described as naturally seen, when they are seen in daylight.

1.2.1.3 Daylighting criteria in museum

Beside the general museum lighting recommendation daylight has to fulfil the following criteria:(4)

- Daylighting should only be considered where objects are not sensitive to UV and visible radiation or where automated and fail-safe control of the light is employed.
- Direct sun can be most destructive causing damage in a very short time, and it is a strong source of glare, thus it has to be eliminated.
- Shades, louvres and other mechanical devices should be able automated to limit the light to the maximum allowed for a given object to the series of objects.
- Specifications for glazing inter-layer and films can reduce UV, must cover the range below 400 nm.
- Finishes consisting of titanium dioxide can be used to further reduce UV for sensitive object.

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1. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA, p31.
2. IESNA, The Lighting handbook, Designing Daylight,10th Ed. 2011, p14.1.
3. Derek Phillips, Daylight: Natural Light in Architecture, Elsevier, UK, 2004, p10-37
4. IESNA The Lighting handbook, Application - Light for art,10th Ed. 2011, p(21.13).

1.2.1.4 Daylighting factors in architecture

Mainly, six factors affect the final luminance produce by architectural surfaces and daylight:[1]

- The area of operative glazing in relation to floor area.
- The room dimensions, especially the ceiling height and room depth.
- The placing and spacing of available glazing.
- Site location in term of longitudinal, latitude and direction.
- External and internal obstructions.
- The reflecting characteristics of interior surfaces.

1.2.1.5 Daylighting typologies in museum

Daylighting strategy in museum building depends on how daylight admit the space. This is very important since it defines how the architecture, the space and the artifacts will appear. Daylighting strategies in museums can be presented by the following museum daylighting typologies: Side-lit rooms, Monitor skylights, Central skylight picture galleries, Overall daylight-diffusing ceilings, Restricted daylight-diffusing ceilings, Polar-oriented skylights, Wall-lighting picture galleries.[2]

1.2.1.5.1 Side-lit rooms

Lateral lighting via openings in the external walls are commonly used in building, since they give a good view to the outside, suitable for multi-storey building, easy to control, and easier to be planned than skylights. However, it has limitations as far as light deep goes in the room. One rule of thumb is: Room depth to be lighted naturally = window height x 2,5.[3]

In museum spaces, side-openings and windows are very problematic and not commonly used, since they have high potential to cause uncomfortable glare; veiling reflection on showcases' glass and artifacts shiny surfaces; uncomfortable high luminance contrast between the view through windows, room surfaces, and objects; and low windows will cast shadow from visitors on the exhibits. Further, light level and light distribution from side-openings change dramatically according to orientation and time of the day, which make daylight control to maintain stable illuminance level very difficult. Otherwise, rooms with side-openings lose wall areas that can be used in the display.

In the contrary of previous disadvantage aspects, windows is important for the vital contact and view to the outside. To balance between this important feature and the lighting disadvantages of side-opening, windows for direct view can be located outside the exhibit rooms in areas like the staircases, corridor, and lobby; or it can be as a small opening in the corner of the space. (Figure 1.10 and Figure 1.35)

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1. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA, p30
2. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p54
3. Paul von Naredi-Rainer, Museum Building, A design Manual, Birkhäuser - Publisher for Architecture 2004 p55.

Despite all its disadvantages in picture gallery, side-lit rooms can work well in galleries for sculpture when side-openings are large in dimension or high in position; oriented north or fitted with god sun protection; and sculpture stand facing the opening. An example of a side-let sculpture gallery, we can see in the old photo of **The Egyptian department in Louvre Museum,** France. (Figure 1.17) As well, in modern time, in the two large sculpture halls in The State Museum of Egyptian Art, Munich, Germany. (Figure 2.18)

Before the exist of public museum buildings and the use of skylight, galleries were mostly side-lit and large windows were construct to enhance the lighting, and in some occasions windows were faced with mirrors on the opposite wall. A famous example of this is **The Hall of Mirrors**, the central gallery of the Palace of Versailles in France, (1678–1684), where seventeen mirror reflect the seventeen arcade windows to enhance the spaciousness and the light distribution in the space.[1] Generally, in the 17th and 18th centuries the galleries were part of the architecture program of the palaces. The galleries served as a exhibition for sculptures, paintings, antiques and whose ceiling frescoes that glorified the owner.[2] (Figure 1.18).

Figure 1.17 *Sculptures facing windows is a good arrangement for side-lit exhibit rooms. A historical photos for the Egyptian collections in Louvre Museum, France. (http://www.archaeology.land/forums/viewtopic.php?t=25735).*

Figure 1.18 *Facing windows with mirror to enhance the spaciousness and the light distribution of the place. The Hall of Mirrors, Versailles, France. (https://en.wikipedia.org/wiki/Hall_of_Mirrors).*

1. Hall of Mirrors, Wikipedia, <https://en.wikipedia.org/wiki/Hall_of_Mirrors>, (14.01.16).
2. Paul von Naredi-Rainer, Museum Building, A design Manual, Birkhäuser - Publisher for Architecture 2004, p19

1.2.1.5.2 Skylight

The even illumination of rooms and objects with daylight is significantly easier to be achieved by means of skylights than by side windows. However, direct sunlight should be avoided, and so the diffuse light of the sky is essential. A skylight reveals a larger section of the sky than a side window, and correspondingly, the light incidence in the room is higher, and up to five times more.(1)

Skylights are classic daylighting elements for picture galleries. They provide uniform, diffuse lighting. Because the light is admitted over a large area, the shadows produced are soft. The incident daylight that passes through a skylight reaches nearly every part of the room. Because no windows are present, more wall space is available for paintings. There is also no problem with reflections on exhibition walls due to incident daylight from the side.(2)

With large skylights, unwelcome interference may occur and needs to be tackled by positioning the skylights appropriately and providing for precise optical control. There is a risk, for example, of light being unevenly distributed over the walls. In rooms with dark furnishings, in particular, the vertical illuminance at eye level is often too low. The contrast between wall and ceiling brightness can cause glare. And even with light incidence from above, reflections can sometimes occur on pictures on the wall.(3)

Generally, the problem with the monitor skylight is that, to avoid direct sunlight on to the pictures, the glazing has to be diffusing or fitted with diffusing blinds. That means that the windows' diffuse panel, as a light source of illumination, will spread the light uniformly; accordingly, the result is a suffusion of diffused light in the region of the skylight, and declining light levels towards the lower regions of the walls where the pictures hang.(4)

A very early example of galleries that used monitor-skylight is **The Dulwich Art Gallery**, Dulwich, UK, 1814. (Designed by Sir John Soane). The monitor-skylight was modified when it was rebuilt after an extensively damaged in the Second World War. An early reports indicate that visitors complained about the lack of light. Thus a part of the top section of the lantern skylight is opened, that not only increased the admission of daylight into the gallery, but also changed the daylight distribution. Light onto the walls would be increased, but by a lesser proportion than light onto the floor. The overall effect of this change would be more towards the impression of a well-lit space, than towards the appearance of well-lit pictures.(5) (Figure 1.19 and Figure 1.20).

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1. Previous reference, p55.
2. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht. p22
3. Previous reference, p22.
4. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p67.
5. Previous reference, p63-66

Figure 1.19 *(left) Dulwich Picture Gallery, London, UK. A photo from (1974) showing the modification occured to the skylight by glazing in the sloping roof elements.(http://www.dulwichpicturegallery.org.uk/about/our-architecture/).*

Figure 1.20 *(right) A night photo for the Dulwich Picture Gallery, London, UK. The artificial light has the same direction as the daylight and it functions as exhibit and room lighting. (https://artes-uk.org/category/xavier-bray/).*

1.2.1.5.3 Central skylight picture galleries

Central skylight is a very famous type of illumination for picture gallery. It is basically a glazed intermediate roof space between the gallery and the sky. This space have a diffuse or translucent glass roof that admit daylight directly into it; and a diffuse glass floor, that works as a luminous ceilings (laylight) for the gallery, which delivers and distributes the light directly into the gallery. This space was developed with time to contain mechanical louvres to control the fluctuation of daylight, and artificial light sources to boost the shortfall of daylight.

While central skylights come in a variety of forms, the problem with them is all about proportions. If the ratio of height to width is too low, veiling reflections become apparent in the upper parts of the pictures. If the ratio is made higher, then the best-lit surfaces in the gallery are the upper walls and the floor, and the poorest-lit surfaces are the lower walls where the pictures hang. The gallery proportions that are necessary to avoid veiling reflections in upper parts of the pictures for overall and central skylights is illustrated in (Figure 1.21).[1]

A masterly example of a space proportion for central skylight gallery is, still the first built type, **The Alt Pinakotek**[2], Munich, Germany, 1836 (Architect: Leo von Klenze). The museum built to accommodate large painting, thus Klenze designed a large spaces to give a sense of the painting being properly accommodated, as well to allow viewers to stand further back to properly observe the extent of large picture. While by making the spaces tall and opting for near-square plans, he ensured that the skylights would be above the veiling reflection zone for viewing all four walls. And to avoid the strong illumination on the

1. Previous reference, p67.
2. Pinakothek (german word) alternative pinacotheca (noun) pinacothecas (plural) an art gallery (especially a picture gallery). <http://www.yourdictionary.com/pinakothek>, (17.01.16).

upper parts of the walls he created a vault connecting the ceiling with the walls, as a transition zone that distribute the light evenly.[1] An old photo shows that the volt was decorated, which helps soften the light. The museum was severely damaged by bombing in World War II and it was rebuilt with the same proportion, but the details of the skylight was changed and the volt was built plain without decoration.[2] (Figure 1.22 and Figure 1.23). See as well (Figure 1.54 to Figure 1.56).

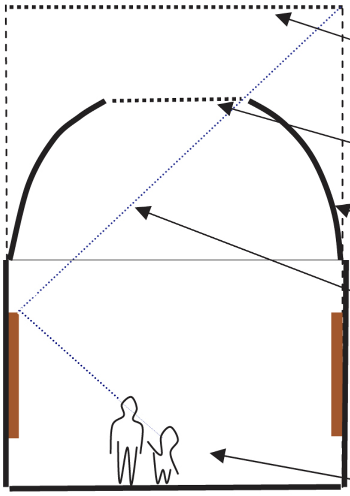


Figure 1.21 *Comparison between the proportions of a picture gallery with an overall daylight diffusing ceiling and other with a central skylight.. (Christopher Cuttle, Light for Art's Sake p68).*

Figure 1.22 *(left) A historical photo 1926 for the Rubens Hall, one of the galleries in the Alte Pinakothek, Munich, Germany. It shows the laylight and the decorative volt between the ceiling and the walls. (http://www.pinakothek.de)*

Figure 1.23 *(right) A contemporary photo for gallery IX in the Alt Pinakothek, Munich, Germany. It shows the changes occurred to the laylight and the volt. (https://en.wikipedia.org/wiki/Alte_Pinakothek)*

The **Neue Staatsgalerie**, Stuttgart, Germany, 1984, is a modern central skylight picture galleries with a sophisticated daylight control system. (Architect: James Stirling; Daylighting design: Dr.-Ing. Hanns Freymuth). The museum has 15 galleries daylit from the ceiling. Typical gallery dimensions are 10.6 m x 14.6 m and the ceiling height

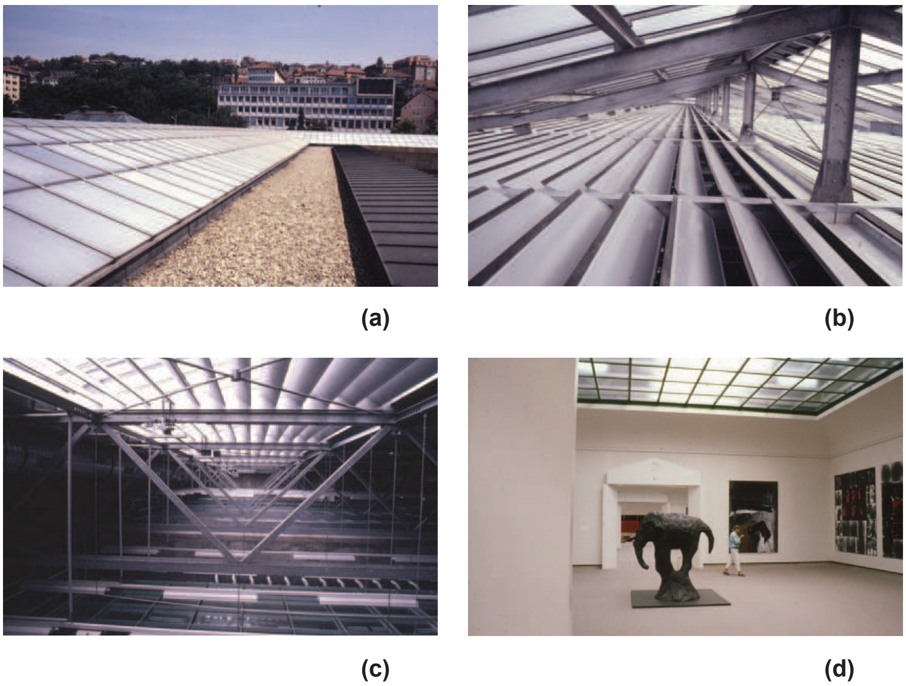
1. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p67-69

2. Alt Pinakothek official site, Kalender, < http://www.pinakothek.de/kalender/2011-07-28/10608/die-alte-pinakothek-historischen-fotografien>, (17.01.16).

varies from 4 to 6 m. From the interior, the appearance of the ceiling is a large rectangle of semi-transparent glass, where visitors can recognize various elements of the central skylight structure through it.[1]

The skylights constructed from the exterior glass roof to the interior luminance ceiling (laylights) as follow:[2]

- First is the glass roof, an outer weather protection layer consists of single pane diffusing therm olux glazing. (Figure 1.24 - a).
- Under the glass roof exist a sophisticated system aims to control daylight and prevents direct sunlight penetration: it consists of horizontal aluminium blinds, mounted on horizontal bearing rods which can be tilted in an angular range from 0° to 135° to the horizontal plane. Attached rubber seals enable almost total blocking of daylight. The blinds are controlled by electric motors. (Figure 1.24 - b).
- Below the daylight control system and close to the interior luminance ceiling lay a set of luminaires equipped with fluorescent lamps (CCT: daylight white, and CRI: $80 < Ra < 90$). These lamps are located in the path of the incoming daylight to offer similar lighting pattern as daylight and to boost the daylight, when it is insufficient. (Figure 1.24 - c).
- Finally, the inner layer is made of semi-translucent triple glazing: 4 mm float glazing, 4 mm special glazing (without green additives), and a 9 mm security compound glazing. This glazing offers thermal insulation to the space which is heated and ventilated but not cooled. It also contains a UV absorbing film. (Figure 1.24 - d).



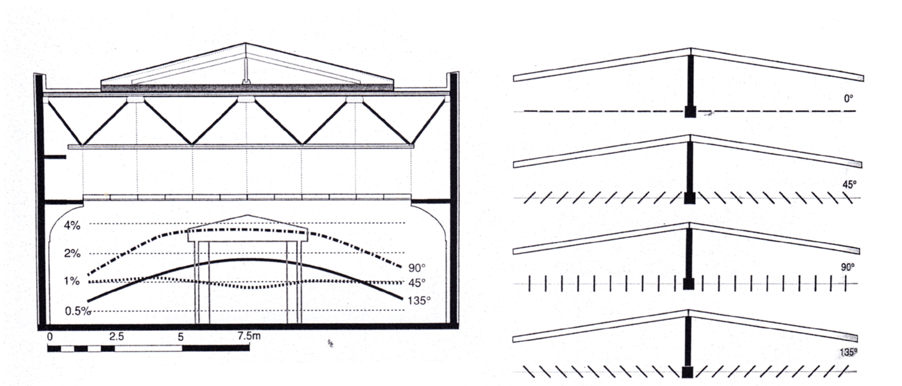
(a) (b) (c) (d)

Figure 1.24 *Construction of the central skylight in Staatsgalerie, Stuttgart, Germany (a) Roof glazing (b) Space between the roof glazing and the motorized daylight control louvres (c) Space between the louvres and the gallery glass ceiling (d) The glass ceiling from one of the gallery spaces. (Christopher Cuttle, Light for Art's Sake p75-76).*

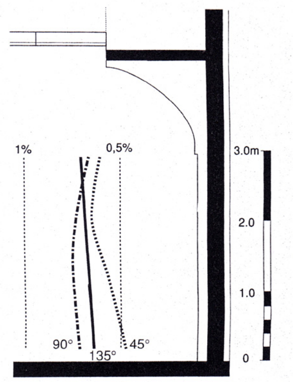
1. Marco Fontoynont, Daylight Performance of building, Published by james & James for the European Commission 1999, p73.
2. Previous reference, p74.

The central skylight performance can be summarized in the following points:[(1)]

- Daylight factor (DF)[(2)] is a function of blinds position.
- The DF varies significantly and reach its maximum at centre of the room and it decries toward the walls.
- Due to the low reflectance of the floor (20 %), little light is scattered from the floor area onto the walls. The resulting DF on walls do not vary much as a function of the blind position.
- DF distribution on the walls is rather uniform, with a decrease toward the corners no less than 0.25%
- The systems does not provide a possibility for high attenuation levels, which would be required to adapt to skies of different luminances (overcast skies of 2000 to 10000 cd/m^2 for instance).
- The position of the blind is then regulated as a function of the horizontal illuminance and position of the sun.
- The artificial lighting system are not linked to the daylight control unit. Two artificial lighting levels can be switched manually (two luminaire groups in each room).



(a) (b)



(c)

Figure 1.25 *The performance of central skylight in the Staatsgalerie, Stuttgart, Germany. (a) Daylight factors measured on horizontal plane 0.8 m above the floor level for different blinds position. (b) blinds position. (c) Daylight factors measured on the walls for different blinds position. (Marco Fontoynont, Daylight Performance of building,p74, 75).*

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1. Marco Fontoynont, Daylight Performance of building, Published by james & James for the European Commission 1999, p73.
2. The daylight factor is used to estimate the lighting in the room under cloudy sky. Daylight factor, DF = (Ei / Edh) . 100 , where Ei is the illuminance of a point in the room, and Edh is the simultaneous illuminance from the whole sky (the illuminance on an unobstructed horizontal surface outside). (Peter Tregenza and David Loe, The design of Lighting, E&FN Spon, London, UK, 1998, P37)

General recommendation: luminous ceilings that imitating natural daylight need to deliver a high level of luminance: 500 to 1000 cd/m^2, ranging up to 2000 cd/m^2 for very high-ceilinged rooms. Luminous ceilings are especially suitable for interiors with 6 metre ceilings or higher. Where room heights are lower, their light can dazzle because they occupy a large part of the field of vision. Where the lighting is dimmed for conservation reasons or to reduce glare, the luminous ceiling loses its daylight quality and looks grey and oppressive.(1)

1.2.1.5.4 Overall daylight-diffuser ceilings

Enlarging the skylight to cover the whole space and to create an over all daylight-diffuser ceiling will bringing more light and an even distribution to the gallery, however it result in more lighting difficulties. Mainly, visitors entering the space adapt to the brightness of the ceiling and upper walls, and also to that of the floor unless it is dark in colour. If the light level is raised to achieve an overall satisfactory sense of brightness, the illuminance on the pictures is likely to be far in excess of recommended levels. Lowering the light level to comply with conservation limits is likely to produce an overall appearance that would be judged dull or even gloomy. Pictures have to be restricted to the lower parts of the walls to avoid unacceptable veiling reflections, and so are noticeably in the poorest lit zones of the gallery.(2) Sculpture shadow and shades will be very soft and details will lose its sharpness. (Figure 1.8)

Essentially, to overcome lighting problems when planning overall daylight ceiling is to avoid using diffuse glass ceiling in the interior space and to insure that the ceiling do not interfere with the visitors' visual field. This can be managed with systems like: daylight prism system, louvres system, and interior lamella.

A high tech overall daylight-diffuser ceilings is in **Haus der Geschichte** (House of History Museum), Bonn, Germany, 1996. (Architect: Rüdiger Hartmut and Ingeborg; Lighting designer: Christian Bartenbach and Martin Klinger.) The three large exhibition spaces in the museum are the dominating feature of this complex building. Each of them has a barrel-shaped glass roof, allowing daylight to penetrate the space and to create an extremely positive reaction. (Figure 1.26).

The glass roofs are constructed of several compressed optical layers of glass. Its unique function is mainly due to the solar protection prism that transmitting 37-51 % of the sky light and directing back 85% of direct sunlight; and the property of light control is when the sunlight incident at right angles, it is reflected back by the oblique prism edges and the more the sun ray is inclined the more it penetrate the prism. Additionally, on edge of the prism has an aluminium layer to block direct sun from the south.(3) (Figure 1.28 and Figure 1.29).

1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications Fördergemeinschaft Gutes Licht. p22

2. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p87

3. Haus der Geschichte Boon, In Licht der Gegenwart, Prof. Ch. Bartenbach Private Collection of Articles, with permission, Bartenbach, Innsbruck, Austria.

The glass structure gives the ability of covering the whole space, having abundance of light, allowing translucent connection between interior and exterior that creates a dynamic feeling, blocking the direct sun rays, and insure protection from UV radiation. The Artificial lighting has the task of supplementing daylight at dusk and replacing it in night. The small shining lamps produce a sparkling ceiling effect. The lamps are metal halide lamps with 4300 K. The planned illuminance on average horizontal 600 lx vertical 200 lx with even distribution.[1] (Figure 1.27)

Figure 1.26 *External view of the glass roof. House of History Museum, Bonn, Germany.(http://www.architektenruediger.de/).*

Figure 1.27 *Interior view of the glass roof. The photo was taken during the afternoon time and the sky was totally covered with clouds and the artificial light was turned on. The translucent connection to the bluish light of the sky outside adds a natural feeling to the space. (House of History Museum, Bonn, Germany).*

Figure 1.28 *The glass roof construction:*
(1) 10 mm single panel safety glass
(2) 6 mm cavity
(3)12 mm solar protection prismatic plates
(4) 2 mm air
(5) 12 mm light-directing prismatic plates
(6) 2 mm air
(7) 8 mm float glass with low-e coating
(8) 10 mm cavity with special gas filling
(9) 8 mm composite safety glass with UV foil and REFLOW coating.
House of History Museum, Bonn, Germany. (In the light of the Present, Bartenbach Article Private Collection).

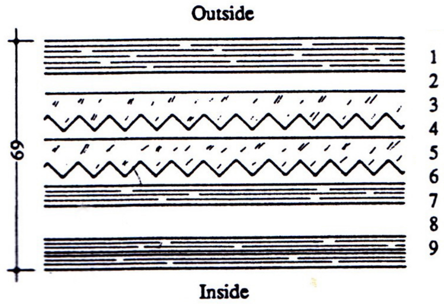
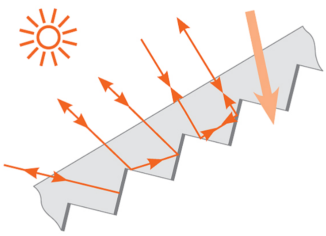


Figure 1.29 *Prism system for solar protection and light control. The flat plate side is oriented to the outside sunlight internet on right angle is reflected back by the oblique praise edges. The aluminium layer in one prism edge also reflect light rays from flat angles. (Daylight systems brochure, SITECO, www.siteco.com).*



1. Previous reference.

The Menil Collection Galleries, Houston, USA, 1982, (Architect: Renzo Piano, Lighting engineering: Ove Arup & Partners), represents an innovative solution for overall daylight-diffuser ceilings. To fulfil the museum curator Dominique de Menil's requirement that *"works should be viewed under daylight, with all its shifting moods through the day and season"*. The result was a clear glass ceiling with a UV filter and; underneath it a curved structural element made of 25 mm thick ferro-cement in dimension of 130 x 90 cm, known as 'leaf '. The 291 leaves became the inner layer of the roof. It works as a louvres to diffuse and disturb light into the gallery. Each leaf is held in place on a steel grid and fixed in a rotation system allowing closing or opening the leaves according to conservation aspects of the art work in display.(1) (Figure 1.30 and Figure 1.31)

In this daylight solution the layers of glass and number of reflections are reduced to maintain the daylight change qualities. The control system 'the leaf' become a visible part of the interior. Although the structure height is about seven meters, it has a strong existence in the space. Artificial light is spotlight tracks attached in the long lower edge of the 'leaf'.

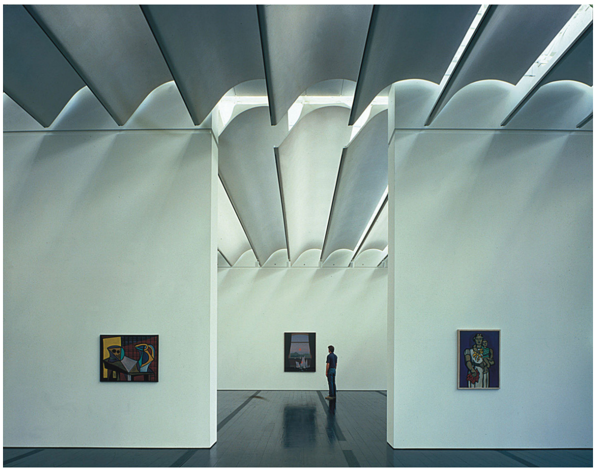


Figure 1.30 *Interior view from the Menil Collection galleries, Houston, USA. (http://www.rpbw.com/project/25/the-menil-collection/#).*

Figure 1.31 *External view from the Menil Collection galleries, Houston, USA. A part of the roof and ceiling construction was used externally as shading device. We can see carefully from this photo the construction of the glass roof and the ceiling 'leafs'. (http://www.rpbw.com/project/25/the-menil-collection/#).*

1. The Menil Collection, Renzo Piano Building Workshop, <http://www.rpbw.com/project/25/the-menil-collection/#>, (03.02.16).

1.2.1.5.5 Restricted daylight-diffuser ceilings

Reducing the luminance area in the ceiling help to reduce the glare and having more control on light distribution in the space, thus having the possibility to integrate the luminance ceiling in a low-ceiling gallery. There are plenty of examples of galleries making use of restricted areas of skylights to achieve quite different effects.

At **The Simon Norton Museum**, Pasadena, California, the central zone of the gallery space is lit by daylight, and the peripheral zone by electric lighting. The daylight was used to illuminate the statues and to connect the gallery with outside. While the controlled level of artificial light is used to illuminate the painting and reach the conservation goals.[1] (Figure 1.32)

At **The North Wing of The National Gallery of London**. A perimeter daylight-diffuser ceiling is effectively reduces downward light to the central floor area and concentrate the light on the walls. However, it can be seen that there is a significant gradation of illumination down the walls, and that the pictures mounted above eye level have been noticeably tilted to avoid veiling reflections.[2] (Figure 1.33)

Figure 1.32 *Simon Norton Museum, Pasadena, California, the central zone of the gallery space is lit by daylight, and the peripheral zone by electric lighting. (Christopher Cuttle, Light for Art's Sake, p91).*

Figure 1.33 *A perimeter luminance ceiling in the North Wing of the National Gallery, London. (Christopher Cuttle, Light for Art's Sake, p89).*

1. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p92.
2. Previous reference, p89.

1.2.1.5.6 Polar-oriented skylights

Polar-oriented skylights use orientation (to the north in the northern hemisphere) and external shading elements to prevent direct sunlight reaching the glazing, so that the source of light is diffused daylight from the sky. This has several advantages. The source of light is much less variable throughout the day than when direct sunlight is included. Because solar heat gains are minimal, larger glazing areas can be used without incurring summer overheating problems, and this enables satisfactory daylight levels to be maintained for greater proportions of normal daylight hours, even during overcast weather. Because the incoming light is diffused, clear glazing may be used, enabling occupants to see clouds passing overhead, and even stars at night. It must not be overlooked that, larger glazing areas will incur the increase of winter heat losses and multiple glazing would be expected in this case, however this is not necessary in mildest climates.(1) (Figure 1.9)

Ludwig Museum of Modern Art , Cologne, Germany,1986. (Architect: Peter Busmann and Godfrid Haberer. Daylighting design: Dr.-Ing. Hanns Freymuth. Artificial Lighting: Hans Theo von Malotki). The museum has a great example of polar-oriented skylights. Fifty-three roof monitors, oriented to the north, with a total length of 1100 m filtered light to the upper-floor galleries. (Figure 1.34 and Figure 1.35)

The glass position is inclined at 53° to the horizontal plane. The daylight is filtered through a triple-layer security glazing. External motorized blinds block sun penetration and internal motorized textile blinds adjust the variation of daylight to regulate illumination levels inside the galleries. To shield rooms from direct sunlight which might penetrate the room at low sun angle, fixed external sheet metal blinds have been mounted on the glazing frames of the roof monitors. For the protection of exhibits, a UV-absorbing foil is embedded in the triple-layered security glazing. The overall luminous transmittance of the glazing is 58%. The textile blind has a transmittance of 35% allowing attenuation by a factor of 3 when fully lowered. Fluorescent tubes are located below the inclined frame elements of the glazed shed areas. They distribute light in approximately the same way as daylight. The artificial lighting boost daylighting when it is insufficient during dark overcast days, or at the beginning and end of the day. (Figure 1.36)

A gallery is covered with one or more of the skylight. The skylights are painted white (reflectance: 77 %). The skylight curved form allows a smooth variation of luminance on the top part of the walls, and redirects light toward the south-facing walls to compensate for the fact that daylight comes mainly from the north side. As a consequence, daylight factors (DF) on south-facing walls are 45% lower than they are on north-facing walls. DF on horizontal levels (1.5 m above the floor) is approximately double the amount on the walls. DF offer good compromise between protection of exhibits and pleasure of the visitors.(2) (Figure 1.37)

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1. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p99.
2. Marco Fontoynont, Daylight Performance of building, Published by james & James for the European Commission 1999. p77-80

Figure 1.34 *The Polar-oriented skylights on the top of Ludwig museum characterize the building. (Ludwig Museum, Cologne, Germany).*

Figure 1.35 *View of one of the galleries during a winter cloudy day. The textile blinds are closed perhaps to reduce the bluish light of the gloomy day and the fluorescent lamps are turned on to boost the daylight. A small window located in the corner to connect people to the outside. (Ludwig Museum, Cologne, Germany).*

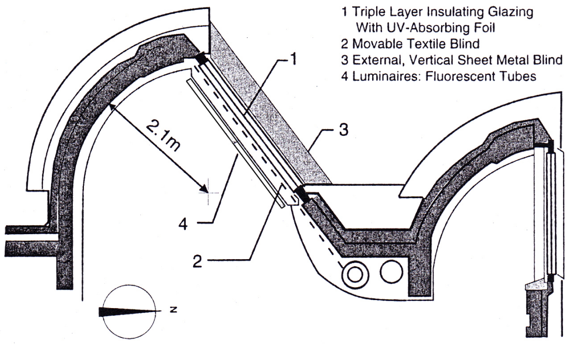

Figure 1.36 *Detail drawings for skylights.*

(1) Triple layer glazing with UV-absorbing foil.
(2) Movable textile blend.
(3) External vertical sheet metal blend.
(4) Fluorescent tubes.

Ludwig Museum, Cologne, Germany. (Marco Fontoynont, Daylight Performance of building,p79).

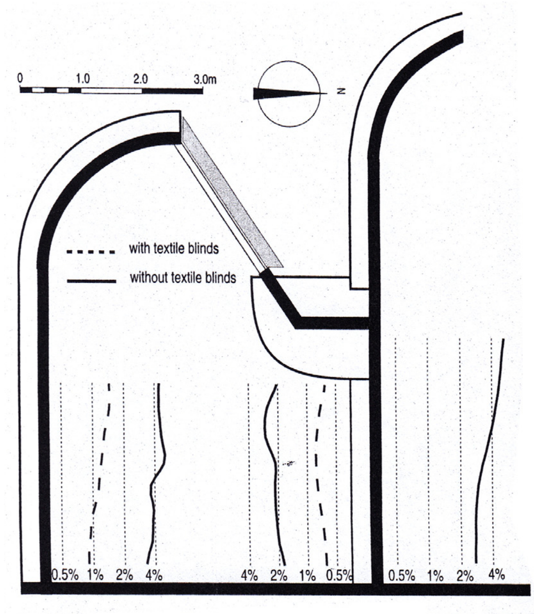

Figure 1.37 *Daylight factor distribution on the north and south facing walls, with and without blinds. Ludwig Museum, Cologne, Germany. (Marco Fontoynont, Daylight Performance of building,p78).*

The High Museum of Art, Atlanta, Georgia, USA, 1999-2005. (Architect: Renzo Piano and Lord, Aeck & Sargent Inc.). The daylight concept depends on north orientation, and the daylight inter the galleries via a grid of 1000 circular light scoops atop of each building. The north facing skylights fill the gallery spaces with the required amount of light.[1] While the shading element block the direct sun orbiting south, the circular opening is directed to the north and zenith of the sky to collect the diffuse light. Such an orientation helps to maintain constant level of illumination as much as possible. (Figure 1.38)

The vault and curvy configuration of the ceiling distribute daylight evenly in the gallery and reduce contrast between the opening and the ceiling surface. A spotlight tracks are aligned along the construction of the ceiling giving a flexibility of positioning spotlights for night illumination. (Figure 1.39)

Figure 1.38 *The light scoops atop of High Museum of Art, Atlanta (Georgia), USA. (http://www.hillyerphoto.com/Selected-Projects/High-Museum-of-Art/3/).*

Figure 1.39 *View of one of the daylit galleries. Museum of Art, Atlanta (Georgia), USA. (http://www.rpbw.com/project/54/high-museum-expansion/)*

The Main Hall of Art Museum Wolfsburg, Wolfsburg, Germany, 1994. (Architect: Schweger & Partners; and Lighting designer: Christian Bartenbach) The main hall is covered with an over all daylight ceiling system that technically depends on north and zenith sky light.

The hall is used mainly for changing exhibitions and other multi-function purposes. The hall roof is a square roof with dimension of 60 x 60 m constructed from 49 pyramids with a raster of 8.1 m. The glass pyramids are constructed with a micro sun shielding louvres in laminated glass panels that reflect direct sun light back while allow

1. High Museum of Art Expansion, Renzo Piano Building Workshop, <http://www.rpbw.com/project/54/high-museum-expansion/#>, (03.02.16).

zenith and diffuse light to enter the space. A rigid cantilever with sun protection lamella encircle the roof to reduce the glare in the area of the facade. (Figure 1.40 and Figure 1.41) A ceiling off daylight grid louvres below the glass roof reduce the luminance of the glass roof and redirect the light in the space. (Figure 1.42)

The daylight is boosted for its shortages in overcast days with secondary reflector luminaires contain alternately Dulux 55W and HQI-TS 70W lamps. The luminaries are fixed above the daylight ceiling support structure and it radiate its light up to an arched secondary reflector that reflect the light further downward throw the daylight grid-louvres into the interior. Between the daylight grid-louvres hanging suspended double-focus lights with 75 W halogen. The luminaires with its warm colour supplementing the evening atmosphere of the setting sun and use for the night illumination.[1] (Figure 1.43).

Figure 1.40 *Art Museum Wolfsburg external view, Wolfsburg, Germany. (http://www.monopol-magazin.de/)*

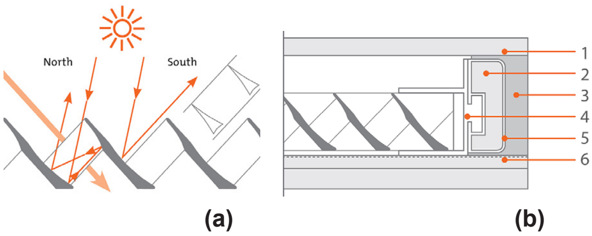

Figure 1.41 *The roof micro sun shielding louvres. (a) The function principle. (b) The construction:*
(1) Toughened safety glass
(2) Molecular sieve
(3) Edge composite
(4) U-section
(5) Aluminium spacer
(6) Laminated safety glass
(Daylight systems brochure, SITECO, www.siteco.com).

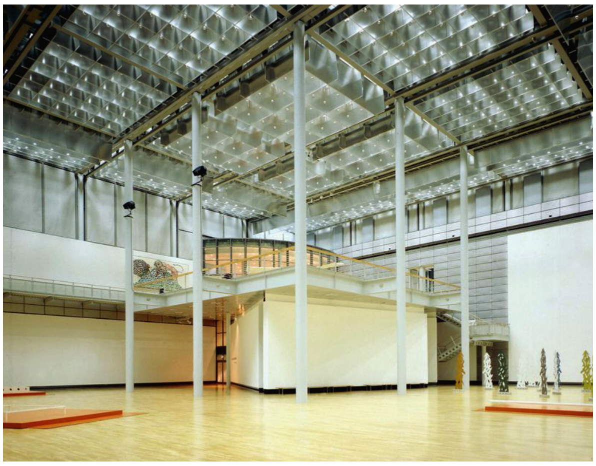

Figure 1.42 *The daylight grid louvres ceiling directs the luminance of the glass roof inside the main hall. Art Museum Wolfsburg, Germany. (with permission of Bartenbach GmbH).*

1. Kunstmuseum Wolfsburg, Prof. Ch. Bartenbach Private Collection of Articles, with permission from Bartenbach GmbH, Innsbruck, Austria.

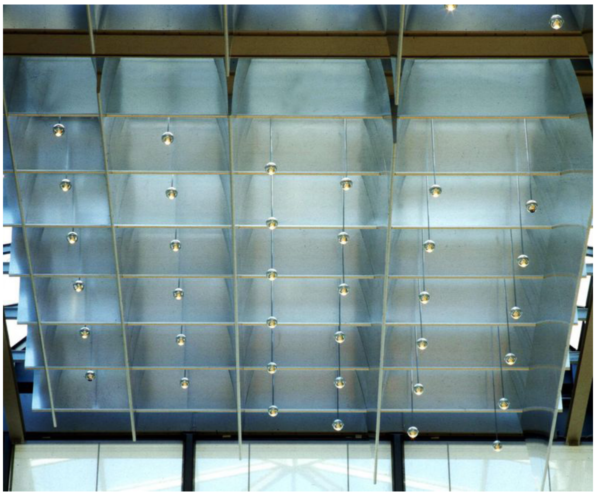

Figure 1.43 *Close up photos for the daylight grid louvre ceiling. Art Museum Wolfsburg, Germany. (with permission of Bartenbach GmbH).*

1.2.1.5.7 Wall-lighting picture galleries

The main concept for wall-lighting picture galleries is to direct more light on the walls and reduce light level in the middle of the gallery. This will make the walls look more attractive and acceptable with a low conservative illumination level.

This idea appeared first in a paper published by Samuel Hurst Seager, a New Zealand architect, in the Journal of the Royal Institute of British Architects in 1912. In this paper he presented the "Top Side Lighting Method" for picture galleries; and demonstrated that, the light incident from the diffuse skylight glass will be proportional to the projected area of the skylight in that direction, thus maximum intensity is directed to the bottom of the display wall. (Figure 1.44) However, this is not the zone of maximum illuminance because the upper wall is closer to the skylight, and this arrangement produces an illuminance distribution with peak value around the mid-height of the picture hanging wall. What makes the idea attractive is the arrangement of the spaces where, viewers adapt first to the relatively low light level in the corridor, and then as they turn into one of the lofty bays, they are faced by a wall washed with daylight. Seager recommended that just the first 1.5 m of the side walls may be used for small pictures, but otherwise these walls should be left blank. **The Sarjeant Gallery**, Wanganui, New Zealand, 1917, epitomized this concept.[1] (Figure 1.45)

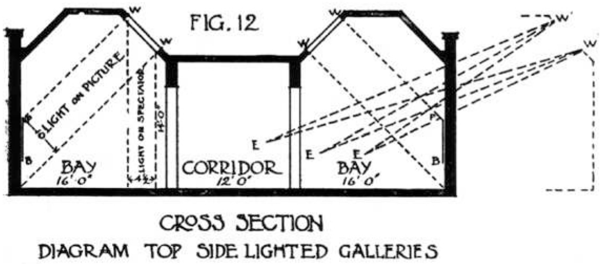

Figure 1.44 *Seager's proposal for Top Side Lighting Method. (Christopher Cuttle, Light for Art's Sake, p100)*

1.Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p99-102.

An alternative approach to direct more light to the wall is to construct a ceiling of baffles. In the extension of **The Tate Gallery London**, opened in 1979, the exhibition space is divided to 9 x 9 m module, where each is lit via a pyramid skylight. (Figure 1.46) In every skylight there is a two-level motorized louvre, and beneath which is a deep baffle structure. The baffles are unpainted, and the grey tone of the concrete is partially effective in achieving wall-directed lighting. The square enclosure at the centre of the baffles shields daylight from the middle of the space and houses fluorescent lamps to provide ambient illumination, when daylight is insufficient. Lighting track around the perimeter of the enclosure carries spotlights which may be used to supplement wall illumination during daylight hours.[1] Although the large baffles system function well, it is an exaggerated solution and the ceiling form visually dominates the space.

Figure 1.45 *The Top Side Lighting Method in The Sarjeant Gallery, Whanganui, New Zealand, 1917. (Christopher Cuttle, Light for Art's Sake, p101.)*

Figure 1.46 *A baffles system that direct light more to the walls. The extension of The Tate Gallery, London, 1979. (Christopher Cuttle, Light for Art's Sake, p109).*

A more developed example of wall-lighting picture gallery is the daylighting system in **The New Extension of Bern Museum of Fine Arts**, Bern, Switzerland. (Architect: Atelier 5, Lighting designer: Christian Bartenbach, 1976–1983) To allow daylight to enter the galleries in a multi-storey museum the concept is to recess the facade back for every ascendant floor allowing the light to enter the gallery from the ceiling edge. On the other hand, the galleries in the three floors are arranged around a central hall (atrium) that is lit by daylight from the roof. And for the last floor daylight is entering every gallery from a peripheral skylight. (Figure 1.47 to Figure 1.50).

1. Previous reference, p108-110.

The lighting system is developed with the aim to provide 3% daylight factor on the walls with even distribution, to have a high efficiency sun protection, and to be visually glare-free from the inside. (Figure 1.53).

The daylight enter the skylight into the space through: first, a weather protection clear glass with UV filter; then through a sun shielding louvres with IR filter to allow only diffuse light from the sky to pass and to reflect back direct sun light; then through a clear glass with UV filter; and finally, an aluminium reflector redirect light onto the wall. The reflector has a parabolic mirror lamella to regulate the distribution of light in the longitudinal direction.[1] (Figure 1.51 to Figure 1.53)

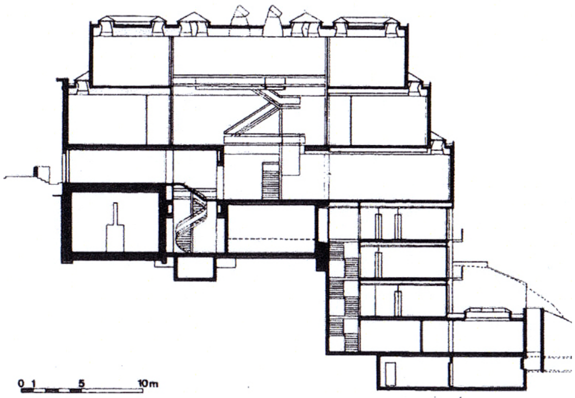

Figure 1.47 *(left) A bird-eye view of Bern Museum of Fine Arts and its extension, Switzerland. (http://www.bernerzeitung.ch/)*

Figure 1.48 *(right) Section in the extension building of Bern Museum of Fine Arts, Switzerland. (Für Das Kunstwerk, p139).*

Figure 1.49 *(left) A gallery in the upper floor in the extension building of Bern Museum of Fine Arts, Switzerland. (with permission of Bartenbach GmbH).*

Figure 1.50 *(right) The-central hall in the extension building of Bern Museum of Fine Arts, Switzerland. (with permission of Bartenbach GmbH).*

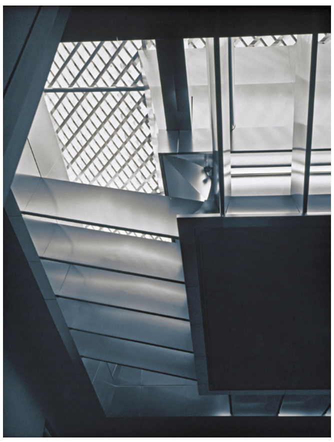

Figure 1.51 *(left) Daylighting system from inside the gallery. Extension building of Bern Museum of Fine Arts, Switzerland. (with permission of Bartenbach GmbH).*

Figure 1.52 *(right) Daylighting system from the roof. Extension building of Bern Museum of Fine Arts, Switzerland. (with permission of Bartenbach GmbH).*

1. Hans Christoph von Tavel, Christian Bartenbach, and Balthasar Burkhard; Atelier 5, FÜR DAS KUNSTWERK, Ammann Verlag, Zürich 1983, p89-100.

The daylight reflector profile is designed in a way that it accommodate and concealed the artificial light, which is a fluorescent lamp. The parabolic mirror lamella operates for both daylight and the artificial light. The artificial light has almost the same daylight distribution. It is used to boost daylight when it fails or at night times. Rooms lit from one side with daylight are lit with artificial light in the other three wall sides and the artificial light is a custom-made luminaire with fluorescent lamp and mirror louver integrated in HVAC system.(1)

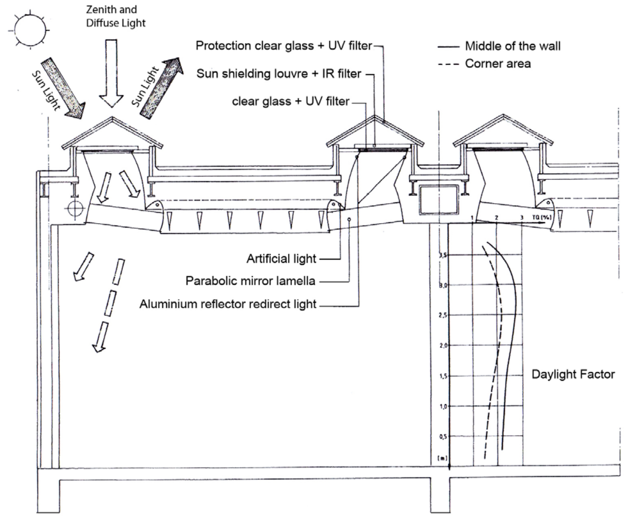

Figure 1.53 *Section in the last floor galleries shows the daylight system and the Daylight Factor on the walls. Extension building of Bern Museum of Fine Arts, Switzerland. (with permission of Bartenbach GmbH).*

1.2.1.6 Daylight and artificial light integration

Mainly if daylight and artificial light are mixed, their rays should be fully blended before they fall on an exhibit. If not, the appearance of exhibits will be unnatural or may be distorted. The artificial light has to have almost the same CCT and the spatial distribution of daylight.(2)

The coordination of CCT is commonly achieved by using natural white lamps around 4000K; by mixing two types of warm and cold lamps CCT that can give different acceptable CCT scenarios; or by automated dynamic lighting systems that change its CCT with change of daylight during the day. *(See: "1.1.7 Correlated Colour Temperature CCT").*

To coordinate the distribution of artificial light with daylight. The artificial light has to be mounted close to the daylight opening or integrated within the daylight system to fall in same direction on the exhibits as the daylight do. Alternative solution is to use the daylight as room lighting and the artificial light as exhibit lighting. So if the daylight fluctuate, what mainly change is lighting ratio between the exhibit and the background. The highest and lowest change of daylight in the room during the day has to be estimated to insure that the degree of change in display visual attraction are acceptable. (For examples: return back to daylighting topologies) and (Figure 2.19).

1. Previous reference, p99-100.
2. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p23.

If good blending is not manageable, lighting segregation is required. This means keeping the daylit zone and the zone illuminated by artificial light far enough apart to ensure that the two types of light do not interfere with one another. Unless the twilight is deliberately used to create a particular atmosphere in the room.[1]

The following examples (Figure 1.54, Figure 1.55, and Figure 1.55) are three central skylight picture galleries in **The National Museum of Fine Arts**, Stockholm, Sweden, built 1866. The three museum space are identical in form and different in finishing colours. They are illuminated from a central skylight and spotlights on tracks. The skylight

Figure 1.54 *A classic central skylight picture gallery with a light-rose colour walls during daytime. (The National Museum of Fine Arts, Stockholm, Sweden).*

Figure 1.55 *A classic central skylight picture gallery with a dark-gray colour walls during daytime. (The National Museum of Fine Arts, Stockholm, Sweden).*

Figure 1.56 *A classic central skylight picture gallery with a light-blue colour walls during night time, where the skylight general illumination is turned off. (The National Museum of Fine Arts, Stockholm, Sweden).*

1. Previous reference, p23.

provide a diffuse illumination for room- and exhibit-lighting, where the spotlight highlight the painting and statues in display. (Figure 1.54 and Figure 1.55) show the effect of different colour, light-rose and dark-gray, on the illumination and the general atmosphere of the museum during daytime. (Figure 1.56) shows another gallery with a light-blue colour at night when the general illumination is totally turned off. We can realise that the exhibit illuminance is sufficient to light the gallery in the absence of the skylight illumination. Due to the camera adjustment we can see the difference in CCT between daylight and spotlight. However, it is less noticeable in reality due to eye adaptation.

1.2.2 Artificial lighting strategies

In daylighting strategies there is no clear separation between exhibit- and room-lighting; since in most cases there both are generated together from the same daylight system. The best scenario, that daylighting entering the room can be more directed to the exhibits than the room. In artificial lighting strategies, the full control of artificial light give the opportunity to totally separate the exhibit lighting from the room lighting if needed; and to use the artificial light in more specific tasks and special effects in the interior.

1.2.2.1 Artificial lighting Advantages

While the outstanding feature for daylight is its dynamic change and ability to connect us with the environment; in the contrary, the artificial light outstanding feature are precision and constancy. The full control of artificial light is highly important for artifact conservation in museum. Aesthetically, highlight and shadow patterns can be defined with high levels of sharpness that cannot be matched by sunlight, and contrasts of brightness and colour can be presented in away that either do not occur, or occur only sporadically, under daylight.[1]

1.2.2.2 Artificial lighting factors in architecture

It is very important that luminaries do not become intrusive to the eye of the visitors. It have to be fit or integrated with the architecture of the room; interior elements; or other building systems, e.g. HVAC systems. (Figure 3.5 and Figure 3.6).

1.2.2.3 Artificial lighting typologies in museum

Artificial light strategies are countless, however, the lighting systems types used in museum can be quantified. Therefore, we will present different artificial lighting strategies via the discussion of the main principles and application of artificial lighting systems in museum. We will not discuss technical details of hardware, lamps, and management systems, since technology is rapidly developed. Such technical information can be obtained from manufacturers and suppliers.

1. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p143.

The most important lighting systems used in exhibition rooms are: luminous ceilings, louvre ceiling, cove lighting, indirect lighting, wall-washers, spotlights. Artificial lighting strategies mostly use a combination of these systems and less frequent when it used one of them separately.

1.2.2.3.1 Luminous ceilings

The idea of luminous ceilings stems from a desire to imitate daylight. Luminous ceilings deliver light which is particularly suitable for picture galleries and wall presentation. Light is mostly diffuse with an opal enclosure, or partly directional with enclosures of translucent glass or textured glass. The light sources of choice are tubular fluorescent lamps arranged according to the structural grid of the luminous ceiling. For good uniformity, the fluorescent lamps should be spaced no further apart than the distance to the ceiling enclosure. The size of the luminous ceiling, its subdivision, and the transitions between ceiling and walls need to suit the proportions of the room and the nature of the objects displayed.[1] (Figure 1.5 and Figure 1.6)

Over all luminance ceiling follow the same principles for overall daylight ceiling.[2] Luminance ceiling provide more uniformity of light on horizontal plan than on the vertical plan. The colour of the floor determine how much light is reflected back onto the walls. However, a relatively dark floors is preferred since it helps to control glare in the visual field. Spaces that are covered with luminance ceiling have to be at least six meter high. It may be suitable to be reduced in size in small and low ceiling spaces to have more control over glare and light distributions. Luminance ceilings have a high potential to cause veiling reflection on glass and shiny surfaces. Alternatively, an array of diffuse rectangular luminaire can be more efficient than overall diffuse ceiling. Luminance ceiling can be the only lighting source in a gallery, or to work as a dim room lighting and be combined with other systems like spotlight. (Figure 1.57, Figure 1.58, and Figure 1.59).

Figure 1.57 *Overall luminous ceilings. (Architekturmuseum der TU München – Home in Pinakothek der Moderne, Munich, Germany)*

1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p4.
2. For more information about daylight luminance ceiling: "1.2.1.5.3 Central skylight picture galleries" , "1.2.1.5.4 Overall daylight-diffuser ceilings", and "1.2.1.5.5 Restricted daylight-diffuser ceilings".

Figure 1.58 *Reducing the size of the luminance ceiling in small galleries give more control on glare and light distributions. (New modern wing of the Lenbachhaus, Munich, Germany).*

Figure 1.59 *An array of diffuse rectangular luminaire can be more efficient than overall diffuse ceiling. (MoMA, Museum of Modern Art, Vienna, Austria).*

1.2.2.3.2 Louvre ceiling

The main purpose of louvre ceiling is to maintain a high degree of anti-glare protection with the use of linear fluorescent lamps, and do not lose a lot of sources' light output; which result in efficient lighting, high energy-saving, and overcoming all luminance ceiling visual problems. However, it may not be so attractive as the luminous ceilings. Artificial light louvre ceiling can be used as main source of lighting in picture gallery or only for general illumination. (Figure 1.60 and Figure 1.61).

1.2.2.3.3 Cove lighting

The cove or (coving) is an indirect lighting solution, where light sources (generally tubular fluorescent lamps) installed in a curved transition between wall and ceiling to illuminate the ceiling, which in turn reflect and diffuse the light in the room. The cove luminaires most frequently used in modern museum buildings are models with housings which themselves form the coving. The light is largely shadow-free. Excessive luminance at the ceiling and on the upper part of walls can causes glare and interferes with spatial experience, if no steps are taken to provide optical control.[1] (Figure 1.62)

1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p5.

1.2.2.3.4 Indirect lighting

The indirect lighting system principle is to direct the light on the ceiling, which in return reflects the light back into the room. The indirect luminaires system has an effect similar to that of ceiling cove lighting. Generally, This system is rarely used in museum. In most cases it is used when the ceiling has to stay free from equipment or when the ceiling itself is a display object, as painted ceiling in historic buildings. Indirect luminaires system can be in a form of stand luminaires, wall mounted luminaires, or suspended power track luminaires. (Figure 1.63)

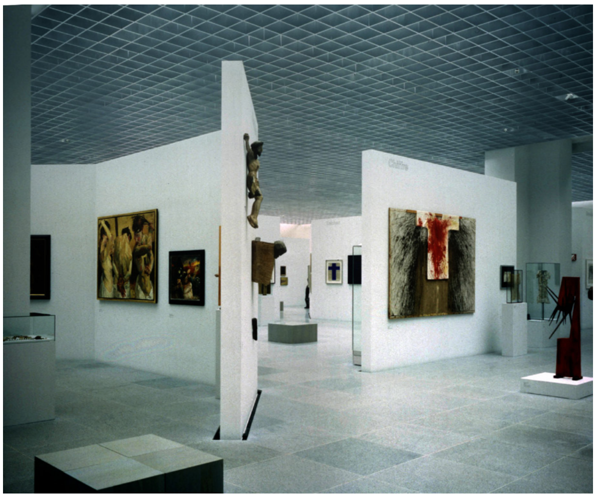

Figure 1.60 *An artificial lighting louvre ceiling. (Diözesanmuseum St. Kilianhaus, Würzburg, Germany).*

Figure 1.61 *An artificial lighting louvre ceiling as general illumination and spotlight on tracks to softly highlight the exhibits. The ceiling is fitted as well with wall-washer in case the walls need to be brightly illuminated. The illumination level is lowered for the sake of the painting conservation. (Ludwig Museum, Cologne, Germany).*

Figure 1.62 *Cove lighting in a small picture gallery. (The Lenbachhaus, Munich, Germany).*

Figure 1.63 *A track lighting system fitted from above with indirect lighting that illuminate the vaulted ceiling to create a soft room lighting and from below with spotlights as exhibit lighting. (Rijksmuseum, Amsterdam, Netherlands).*

1.2.2.3.5 Wall-washers

The main application of a wall-washer luminaires is to provide a uniform intensity over a large flat surface; mainly walls to illuminate paintings and flat surface objects. Wall-washers are used as individual luminaires or in continuous rows. They can be installed flush with the ceiling, mounted close to the ceiling, or fixed in a track lighting. The wall-washer uniform illumination is performed by reflectors with asymmetrical optics. It is important to ensure good shielding in the direction of the observer.(1) (Figure 1.64)

The wall-washer lighting draws attention to the walls and the arts displayed on it. However, a strong wall lighting raise the viewer's adaptation state. Inevitably, this will have the effect of causing the artworks to appear darker and less colourful.(2) Additionally, wall-washer will produces relatively deep shadows for paintings with large frames and wall installations with strong figuration.

1.2.2.3.6 Spotlights

Spotlights are the most effective lighting systems in museum lighting. Spotlights have different beam angles, various qualities of light range from directional-sharp to totally-diffuse, highly controlled, and flexible in use. Spotlights come in different sizes and forms. It can be fully or partially integrated into a ceiling, walls and interior elements; surface-mounted; or track mounted. A lot of accessories can be used with spot light to control the light beam or to add an effect such: diffusing filters, coloured filters, spreader lenses, louvres, snoots, barn-door, and beam-shaping attachments.(3)

Spotlights effectively used to reveal form, texture and detail with high levels of clarity. It is important for painting to revile fine brush strokes, and it is the main lighting for sculpture and three dimensional

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1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p5.
2. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p149.
3. Previous reference, p189, 199.

objects that create defined shadows and highlights. On the other hand, spotlights can be strong source of glare, thus its beam angles and direction have to be carefully determined.

In lighting strategies, spotlights are used to draw attention and its effect depends on surrounding and room lighting level. Commonly, Spotlights used as combination with daylight or diffuse light sources to highlight objects. As well, in small and bright interiors spotlights are enough to meet both exhibit and room lighting criteria by directing the light onto the exhibits and adjacent wall surfaces, exhibit will be accentuated and the reflected light will generate enough diffuse room light. Further, in dark spaces spotlights can be a strong tool to create dramatic lighting effects. (Figure 1.65 to Figure 1.68)

Figure 1.64 *A wall-washer system illuminate the walls and painting, while down spotlights illuminate the room. Notes that the right wall is painted light-gray colour to reduce its brightness. (Museum of Modern Art, Bonn, Germany).*

Figure 1.65 *A picture gallery lit by track-spotlights and track-projectors. The reflected light from the exhibits and walls are sufficient for room lighting. The distribution of the light creates bright zones for the exhibits and dim zone where a projected film is running. (Schirn Kunsthalle, Frankfurt, Germany).*

Figure 1.66 *Ancient Greece statues gallery is illuminated only with track-spotlights. (The Antikensammlung Berlin, Germany).*

Figure 1.67 *A medieval statues gallery. The general lighting is a dim luminance ceiling and the statues are highlighted with spotlights on tracks. (Liebieghaus, Frankfurt, Germany).*

Figure 1.68 *A collection of religious clothes and old paintings illuminated with ceiling mounted spotlights in a dramatic way. Notes: the spots of light on the floor lead to the dark door in the corner of the gallery. (Kolumba Museum, Cologne, Germany.).*

Figure 1.69 *Classical Greece statues illuminated with projectors mounted over the wall cornice. The room lighting is the daylight from the windows' diffuser panel. (Museum of Art History, Vienna, Austria).*

1.2.2.3.7 Projectors

A projector is type of luminaires with lenses that narrow the beam spread. Projectors are mostly used in museum when small object is illuminated from high ceilings and no spill light around the object is needed. It is more appropriate for illuminating three dimensional objects then flat objects. Paintings that illuminated with projectors in a dark surrounding have a strange appearance, it looks self-luminance. It is necessary to have general lighting in the space to avoid this effect and/or to spread the beam of light to cover the painting and a part of the wall. (Figure 1.65 and Figure 1.69)

1.2.2.4 Special lighting tasks

There are several other lighting tasks in exhibit space rather than exhibit and room lighting, which need to be fulfilled:

- **Exhibit labels:** Exhibits' labels should have enough light to be read, as well as any text in the exhibit space. Mostly the labels is lit by the object's lighting or its spill-light. If the label is separated from the exhibit, it has to have its own lighting or to be back-lit.
- **Way finding lighting:** In large or low illuminated exhibit spaces visitors need to have some orientation to find the visiting round or an exist, this can be visually managed by lighting. It is important that the light used to guide the visitors do not interfering with exhibit lighting. (Figure 1.68)
- **Circulation lighting:** corridors and lobbies connect museum spaces together has to be illuminated according to the level of general illumination in the galleries with minimum of 100 lux. Additionally, panels or back-lit signs for route guidance system have to have a bright light to be easy noticeable and readable.(1)
- **Safe light:** Where a difference in floor levels or stairs is exist, illuminance should be at least 150 lux. The lighting should ensure that steps are clearly discernible.(2)
- **Emergency light:** For most rooms in museums, mains-independent emergency lighting is required by law to enable visitors and staff to vacate the building safely in the event of a power failure. To permit this, security lighting is needed for escape routes and escape route signs. Rules governing the installation, operation and maintenance of emergency lighting are set out in DIN EN 1838 and DIN 4844 (lighting requirements) and in DIN VDE 0108 (electrical requirements).(3)
- **Security light:** it is required to enable security cameras to operate and security staff to move through the building as required. Level of illumination need to be sufficient for camera technology in use.(4)
- **Cleaning light:** cleaning, mainly the floor and showcases glass, need to be done after visiting hour. The room lighting can be used for this purpose after dimming or partially lit. Alternatively, cleaning light can be provided by an unobtrusive installation of luminaires that directs its light output onto the floor and avoids direct illumination of exhibits.(5)

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1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p12.
2. Previous reference, p12.
3. Previous reference, p33.
4. IESNA The Lighting handbook, Application - Light for art,10th Ed. 2011, p(21.12).
5. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p264.

1.3 Exhibits lighting quality and techniques

The lighting strategies that are previously presented are general solutions of light in museum spaces. Understanding how the light interact with object and how to insure the best visual quality for an object in display improves the application of these strategies.

1.3.1 Characteristics of light and shadow

Identifying the light and shadow characteristics, will help to understand how light reveals the form. When we view an object there are two main zones: **Light and shadow**:[1] (Figure 1.70)

In the **Light Zone** there are two main types of light on an object:

- **Full-light:** where the form points directly at the light.
- **Highlight:** is a specular reflection of the light source on the object.

  Full light depends on the position of the object to the light source; where highlight depends on the angle between the observer and the light source (the angle of incidence is equals to the angle of reflection) thus highlights move when the observer moves.

  The point that is facing directly the light known as **central-light**, and as the surface get away from the light it start to be darken and immediately before the terminator is the **half-light**.

- **Terminator:** is the edge where the form transitions from light to shadow. It is located at the tangent between the light source and the form. In other words, just before the planes start to face away from the light. With directional light the transition between light and shadow is very harsh; and the more the light is diffuse the transition become softer.

In the **Shadow Zone** there are two main types of shadows:

- **Form-shadow:** is a shadow caused by the planes turning away from the light source.
- **Cast-shadow:** is caused by one form blocking the light from hitting another form.

  Light bounces off objects in the surrounding and it is reflected back into the shadows and softened it. When form shadow is attenuated, its dark area near the terminator known as **core-shadow**. If we don't see a distinct core shadow that means a lot of light is reflected from the surrounding and eliminating the form shadow. Where the object is closer to the surface on which it stands the shadow become darker, often known as the **occlusion / crevice shadow**.

  For relatively large light source the cast shadow will have a soft outer area known as **Penumbra**. Generally, the wider the light source, the more blurred the shadow becomes.

1. David Briggs, The Dimensions of Colour, Basics of light and shade. <http://www.huevaluechroma.com/021.php> (01.03.2016).

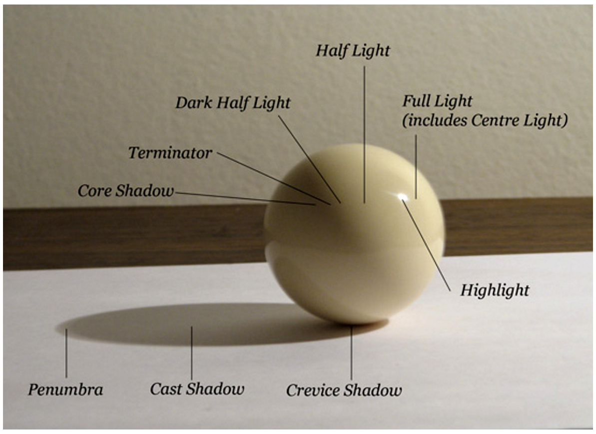

Figure 1.70 *Glossy sphere under a single direct light source, showing terminology of light and shadow. Photograph by David Briggs. (http://www.huevaluechroma.com/022.php).*

1.3.2 The visual quality of exhibits in museum lighting

The coupling between light and object properties is what determine the exhibits appearance. Lighting designer need to understand the attributes of the surfaces and form, and what kind of light is needed to be applied to reveal these attributes. As well, where in the range, from harsh or dramatic to soft or subtle, modelling the design should be set.

We thought to cover this subject by discussing the importance of light and shadow characteristics and the impact of diffuse and direct light on it. Further, demonstrating some important examples of exhibits museum lighting qualities.

1.3.2.1 Significance of light and shadow characteristics

The pattern of full-light and form-shadow is what mainly reveal the form. It is a result of light orientation. It become stronger when directional light sources are used and its direction is obvious to the observer.

Shadow is a good indicator of surface forms and textures, provided it is not so strong as to conceal relevant detail.(1) The number and nature of shadows produced by lighting installations depend on the size and number of light sources and the extent to which light is interreflected. The strongest shadows are produced from a single point source in a black room. Weak shadows are produced when the light sources are large in area and the degree of interreflection is high.(2)

Highlights give a good visual clue about surfaces spicularity. Lighting of specular objects is all about producing highlights to reveal the specular nature of the surface. A small points of high luminance can enhance visual interest,(3) but care must be used so that highlights don't become dazzling or annoying repetitive pattern.(4)

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1. Society of Light and Lighting, Code for Lighting, Butterworth-Heinemann, London, 2002, p 2.
2. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p132.
3. Previous reference, p133,455.
4. Society of Light and Lighting, Code for Lighting, Butterworth-Heinemann, London, 2002, p27.

1.3.2.2 Impact of diffuse and direct light

Diffuse light is generated by relatively large light source that emit light evenly in all direction. A space or an object is described as diffusely illuminated, when light fall on its surface evenly and the direction from where light comes cannot be clearly determined.[1] Diffuse light minimizes and soften shadows. It provides relaxing and less visually compelling atmosphere. When diffuse light is used alone, no object in the visual scene is given prominence. Diffuse light that is void of highlights and shadows, is similar to the light of an overcast day.[2]

Directional lighting is generated by relatively small light sources that emit light in definite direction. An area within a space or an object is described as directly illuminated, when light falls directly onto it, striking it, or parts of it, at an angle defined by the geometry of the lighting arrangement.[3] Directional light draw attention to a part of the field of view. Directional light provide highlights and shadows that emphasize texture and form. Brilliance or sparkle can be achieved with small unshielded sources. The glitter of crystal and polished brass, and the sheen of surface materials can be heightened by directional lighting to create a sense of warmth and festivity.[4]

In many application, light cannot be clearly defined as wholly diffuse or directional; a combination and a degree between both lights are always exist according to design intention. In museum, designers mostly use directional lighting as exhibit lighting and diffuse light as a room lighting and for overall effect.

1.3.2.3 Examples of exhibits lighting qualities

The following examples demonstrate some of the important exhibits lighting qualities in museum. The examples is more concern about statues and three-dimensional objects since its lighting qualities varies more than the flat exhibits.

1.3.2.3.1 Lighting for painting

A picture gallery with a luminance ceiling is an ideal setting for paintings. In such galleries the diffuse atmosphere is dominating insuring an even illumination on the surface of the paintings. The quality of the light depends on the glass type, and the geometry of both the ceilings and the room. A structure of relatively small an high diffuse ceiling; a mid-tone walls, and a dark floor will make the diffuse light fall more directional from above and avoid glare. The diffuse-directional light

1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p2.
2. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p653.
3. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht, p2.
4. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p653.

emphasize the fine textures of the brush strokes and show the glossiness of oil painting by creating a tiny delicate patterns of highlights and shadows. (Figure 1.23 and Figure 1.71) When the luminance ceiling has low luminance an additional spot light (directional light) is needed. (Figure 1.5, Figure 1.54, and Figure 1.56). As well, artificial light has to have a diffuse light with some degree of direction, or combination of diffuse and directional light. (Figure 1.61 and Figure 1.63).

(b)

(a) (c)

Figure 1.71 *The Rembrandt painting "The Night Watch, 1642". (a) A general view of the painting in a central skylight picture gallery. The painting is tilted little bit toward the visitors to avoid glare. The diffuse light on the painting is even and more directed from the ceiling as a result of the low reflections from the dark room finishing. (b) A close-up photo (c) Detail photo showing the fine brush strokes. (Rijksmuseum, Amsterdam, Netherlands).*

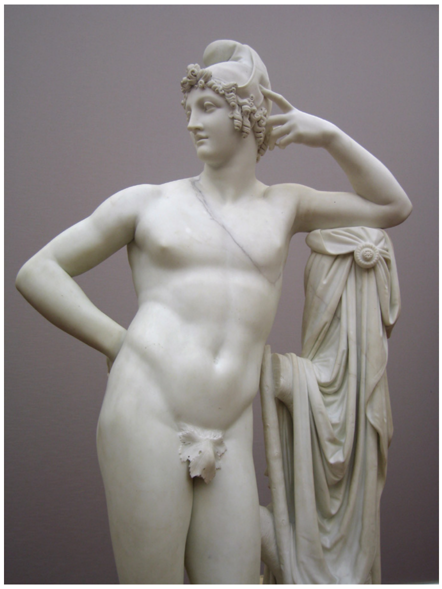
1.3.2.3.2 Classic white sculpture lighting

Classical sculpture and relief [1] are widely spread and presented in many museums around the world. Studying the lighting of these works will give us the opportunity to demonstrate several lighting qualities.

In (Figure 1.72), a classic white marble statue stands in a central skylight picture gallery. The diffuse atmosphere is dominating the gallery. The dark floor help to reduce the light reflected upward, and the mid-tone walls relatively reduce the vertical illumination; this allow the light coming from the luminance ceiling to create a soft form-shadow facing downward. The pattern of full-light and form-shadow is very soft. There is no highlights and no cast-shadows. The white marble appears soft and homogeneous. Notes the statue is positioned away from the centre and closer to the wall. This position helps to give a oblique direction to the light falling on the statue, which formulates shadows that better show depth and detail in the object.

1. Classical sculpture and relief: is sculpture and relief work from Ancient Greece and Rome time, as well as late works that follow the canon of classical forms. Reference: Classical sculpture, Wikipedia, <https://en.wikipedia.org/wiki/Classical_sculpture#cite_ref-1>, (03.03.2016).

(a)



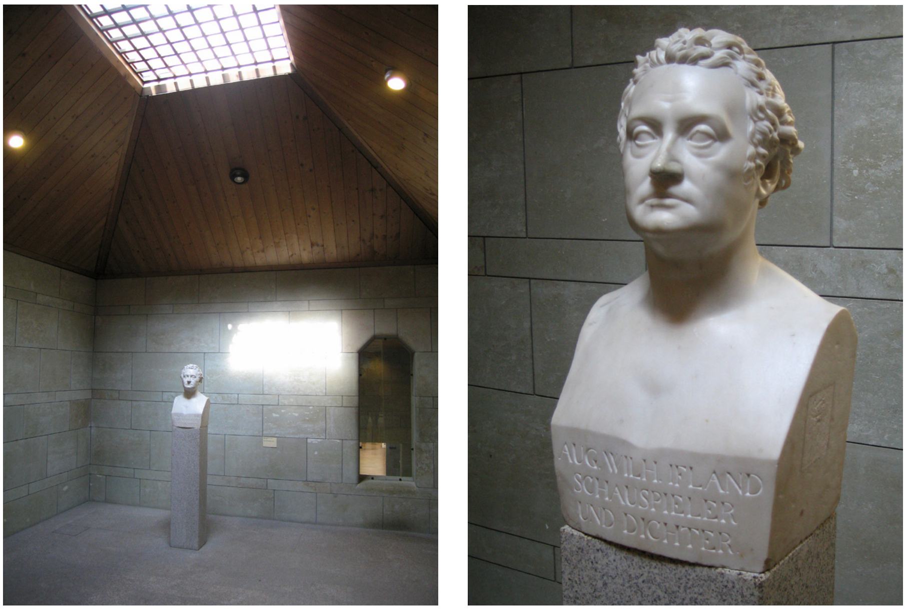
(b)

(c)

Figure 1.72 *The lighting quality of a classic white marble statue stands in a central skylight picture gallery. (a) The position of the statue in the gallery. (b) Close-up view of the statues body. (c) Close-up view of statues head. (The Neue Pinakothek, an art museum, Munich, Germany).*

In (Figure 1.73), a white marble bust is based in a small chamber. The bust is lit from a small opening in the centre of pyramid-shaped roof. The direct sky light falling in an oblique angle on the statues creating moderate form-shadow and soft highlights, that emphasize the surface forms, details, textures, and show the hardness of the material. The sun beam falling on the back wall is reflected back to add a rim light on the back of the statue's head, which highlight the outline and separated the statue from the background. There is a fuzzy cast shadow. The artificial downlights add a slight undisturbed light to the bust. The downlights are for the night illumination and most probably they are forgotten to be turned off. Compare the quality of light in (Figure 1.72 and Figure 1.73).

In (Figure 1.74), a comparison between the lighting quality of two classic white reliefs is demonstrated. The first relief (a) is displayed on a wall in a lighting sittings similar to the bust in (Figure 1.73) and it has a moderate form-shadow and soft highlights. The second relief (b) has a sittings similar to statue in (Figure 1.72) and it has a very soft shadows. The details and form in (a) is more visible than in (b). The reliefs need more directional light to show off details and protrude its form.



(a) (b)

Figure 1.73 *The lighting quality of white marble bust that is lit by daylight from a small opening in a small chamber. (The Neue Pinakothek, an art museum, Munich, Germany).*

(a) (b)

Figure 1.74 *A comparison between the lighting quality of two classic white relief. (a) The relief has a similar sittings like the bust in Figure 1.73 (b) The relief has a similar sittings like the statue in Figure 1.72 (The Neue Pinakothek, an art museum, Munich, Germany).*

(a) (b)

Figure 1.75 *The lighting quality of a white marble statue that is side lit with diffuse daylight from a large window. (The Neue Pinakothek, an art museum, Munich, Germany).*

In (Figure 1.75), a white statue is displayed in a small room and it is side lit with diffuse daylight coming from a large window. The light from the right side suits the composition of the statue, that turn its face toward the light. The bright colour of the room reflect the light back on the statue, which soften the form-shadows in the left side of the statue that is not facing the window. The pattern of full-light and form-shadow is very soft. There is no specular highlights and there is a fuzzy edge cast-shadows.

(a) (b)

Figure 1.76 *The lighting quality of white marble statues lit with Artificial light. (a) A statue lit with two spotlights and has a moderate atmosphere. (The Antikensammlung Berlin, Germany). (b) A statue lit with for spotlights and has a dramatic atmosphere. (German Historical Museum, Berlin, Germany).*

The previous examples showed that, where daylight is the source of lighting in museum, spaces are bright and exhibit is flooded with light coming from big light source. The control of exhibits' lighting depends on exhibits position to the daylight source and the selection of room surface reflectance. The patterns of light and shadow mostly range between soft to moderate. Some museum like to exhibit its sculpture in the outdoor, courtyard or atrium to benefit from directional sunlight to create strong and dramatic patterns.

Modelling a sculpture with artificial light gives more control on the patterns of light and shadow, and the opportunity to create variety of visual artistic effects. This control depends mainly on the numbers, orientation, beam angle, and intensity of luminaires, and much less on light reflected from the surrounding. Artificial light is mostly used to create a strong highlights and deep shadows. In (Figure 1.76 - a) the statue is lit with two track spotlight different in intensity and they are positioned relatively close to each other. The light fall from about 30° angle and cover the whole statue. The light reflected from the surrounding illuminate the back of the statue and slightly attenuate the strong shadows. The luminance contrast between the statue and the surrounding helps the statue to stand out and become an interesting visual point. In (Figure 1.76 - b) The statue is lit with four ceiling-mounted spotlights similar in intensity and they are positioned two from the front and two from the back. The light beams are focused on statue face and chest, while the legs and wings have less light. The deliberate use of a non-uniform luminance pattern provides greater visual impact without losing structural coherence. The statue is positioned in the centre of the hall directly in front of the main entrance and statue's illumination catch visitors' attention. Compare the pattern of light and shadows created with artificial light in these examples (Figure 1.76) with that created with daylight light in (Figure 1.72 to Figure 1.75).

1.3.2.3.3 Coloured sculpture lighting

Basically, highlights appear clearer on glossy and dark objects, than on bright and matt objects.(1) The specular reflected pattern will have sharp edges on glossy surface, and the more the surface is mutt the more the highlight is fuzzy, till it disappear on total diffuse-bright surfaces. On the other hand, form-shadow appear clearer on bright objects and subdued on dark objects. The form-shadow pattern will not be evident on high gloss or transparent surfaces.

Colours of objects appear to change according to the surface finish. A matte finishes surface reflect diffuse light and give an object a more consistent colour appearance, while glossy surfaces can lose their colour when viewed in a direction near the spicular angle. Finishes such as velvet and deep-pile carpeting appear darker than smooth surface materials such as vinyl or plastic laminate of the same colour under the same lighting.(2)

The comparison between the lighting quality of a wight and black bust in (Figure 1.77) shows how the light and shadow patterns change between bright- and dark-coloured statues in extreme situation. The lighting strategy depends on spotlights in a dim surrounding. The white bust is illuminated with two track spotlights. The left spotlight has more intensity and it creates strong shadows, while the right spotlight has less intensity and it attenuates the darkness of the shadows. The patterns of lights and shadows reveal face features, hair details, and three dimensional form. Note that the white diffuse material do not show highlights. In the opposite side, the black bust is illuminated with two track spotlights with the same intensity. The glossy black surface exhibits almost no form-shadow. The lighting technique depends on creating specular patterns that contrast with the black colour of the bust. Note that the specular patterns obscure the colour of the statue. The the sharpness and softness of the pattern can be controlled by using different types of diffuse filters with the light source. The pattern were created strong and large so it will not change its intensity and place so much when observer change his view position.

In (Figure 1.78), the two statues are similar in material (dry clay) and in colour. The first (a) is displayed in a picture gallery with central skylight in a diffuse illumination like the situation in (Figure 1.72). The statue form-shadows and highlights are weak; and they are barely visible against the colour of the material. Cast-shadows only occur in

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1. Materials that are opaque even on a microscopic scale have no perfect diffuse reflection they exhibit a degree of specular reflection. The amount of specular reflection generally appears to be greater on dark objects than on white objects of similar composition, but this is an illusion caused by swamping of the specular reflection by the greater diffuse reflection from the latter. Reference: David Briggs, The Dimensions of Colour, Basics of light and shade. <http://www.huevaluechroma.com/021.php> (01.03.2016).

2. Illuminating Engineering Society of North America, The IESNA LIGHTING HANDBOOK, 9 ed 2000, p798

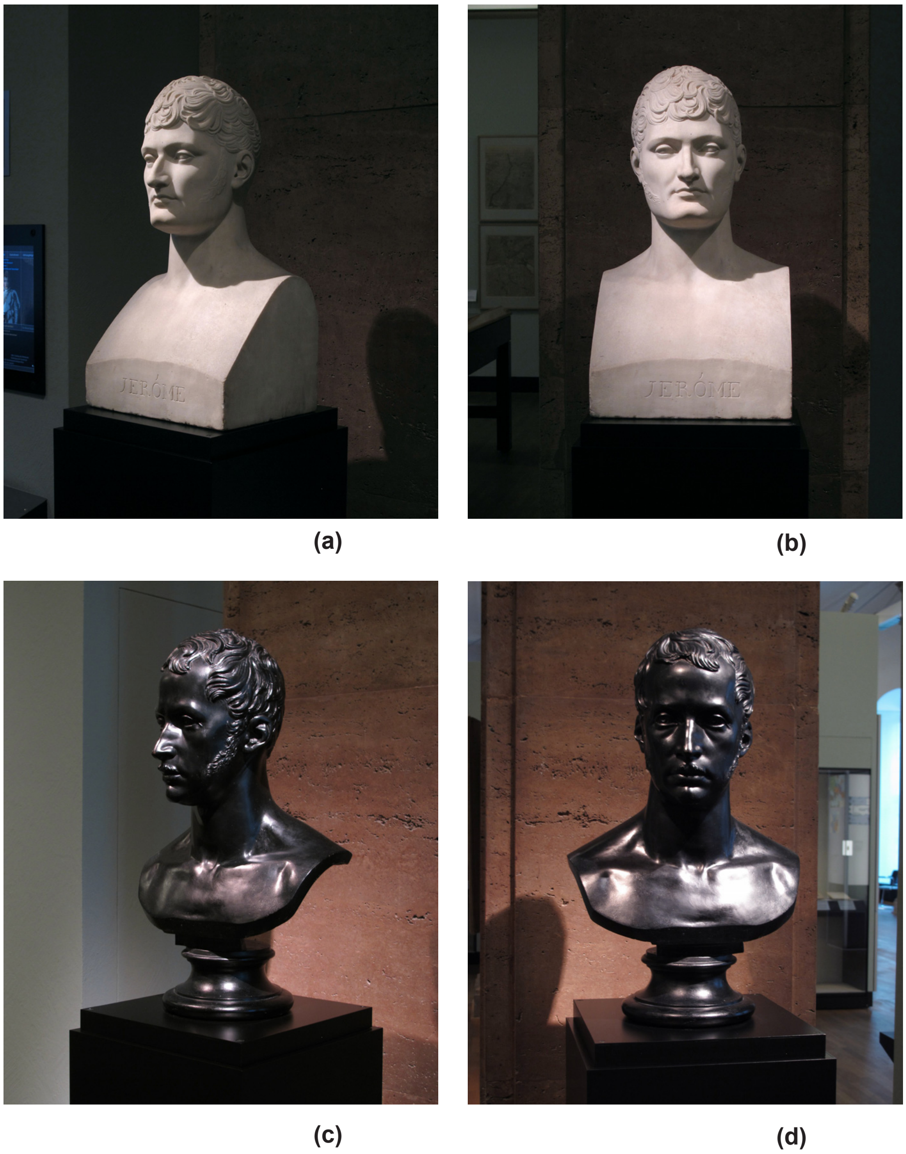
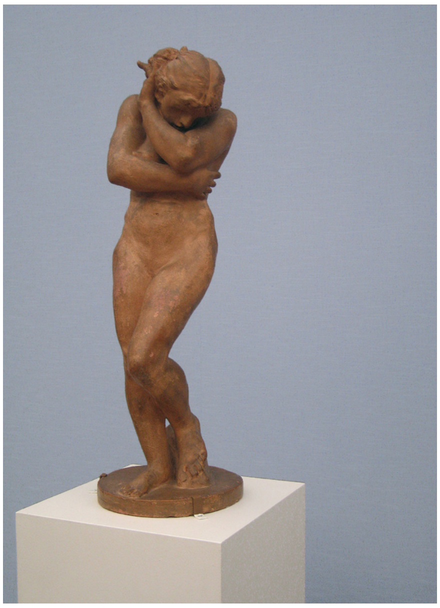


Figure 1.77 *The light and shadow patterns for white and black busts. (a) , (b) The lighting technique for the white bust depends on shadow patterns. (b) , (c) The lighting technique for the black bust depends on creating specular patterns that contrast with the black colour of the bust. (German Historical Museum, Berlin, Germany).*

the deep folds of the form and are vanished from the surrounding. The statue gain its form mainly from the toning in the colour of the material. The second statue (b) is displayed as well in a picture gallery with central skylight, but the lighting designer installed several big strong spotlights behind the glass ceiling directed toward the areas where the statues are. Thus, the diffuse light of the ceiling in some areas has a directional light falling on the exhibits. This helps to create highlights on the surface of the statue and to show for some degree the form-shadows. The highlights show the hardness and specularity nature of the surface and enhance the visual interest.

In (Figure 1.79), a clay statue is displayed in a showcase and illuminated with track spotlights, where the gallery is illuminated with indirect lighting from the same track system. (Similar situation in Figure 1.63). The statue is lit with two spotlights one from the front and the other from the back. The spotlights have a steep angle about 30°. The beam of light cover the whole state and create a strong shadows and a moderate highlights on the upper part of the statue. The surrounding light contribute in the illumination and it does



(a)

(b)

Figure 1.78 *The lighting quality of two statues similar in material (a sort of dry clay) and almost in colour. (a) The statue is displayed under a diffuse luminance ceiling. (The Neue Pinakothek, an art museum, Munich, Germany) (b) The statue is displayed under a diffuse ceiling with additional spotlights behind the ceiling. (The National Museum of Fine Arts, Stockholm, Sweden).*

Figure 1.79 *(left) A clay statue displayed in a showcase and illuminated with track spotlights in a dim surrounding. (Rijksmuseum, Amsterdam, Netherlands).*

Figure 1.80 *(right) The lighting quality depends on strong highlights and overlapped cast-shadows. (Liebieghaus, Frankfurt, Germany).*

not attenuate the shadows to much. The strong pattern of light and shadow enhance the statue's appearance and make it clearly visible in the dim surrounding.

In (Figure 1.80), a wood statue with shiny coloured painting is displayed in a corner of a gallery. The statue is illuminated with six small spotlights mounted on a track system; and the soft dim general illumination comes from two windows covered with a textile screen, and from the reflected light from the exhibit. The six spotlight has the same intensity and three of them come from the front of the statue and the other three from the statue's left hand side. The small strong spotlights help to create a shiny highlights, that show the beauty of the shiny coloured painting; and create a multiple overlapped cast-shadows pattern, that suit the subject and form of the statue.

1.3.2.3.4 Metal exhibits lighting

Metal surface gain its nature from the strong shiny highlights. The coloured metals like copper and gold, the specular reflection retains the colour temperature of the light source. Highly polished objects may show not only the conspicuous image of the main light source, but also recognizable reflections of the entire environment.[1] Such surfaces can not be illuminated directly, but lighting designer has to light and organize the surrounding that will be reflected in the object.

In (Figure 1.81), a small bronze statue is displayed in a central skylight picture gallery under a diffuse luminance ceiling. The lighting situation is similar to the lighting situation in (Figure 1.72 and Figure 1.78 - a). The luminance diffuse ceiling is reflected on the statue's shiny surface and it creates a soft large pattern of highlights. The statue gain its visual quality mainly from the contrast of the soft highlight with the dark bronze colour; as well, from the dark form-shadows.

Figure 1.81 *(left) The lighting quality of a small bronze statues displayed under a diffuse luminance ceiling. (The Neue Pinakothek, an art museum, Munich, Germany)*

Figure 1.82 *(right) The lighting quality of a dark bronze bust illuminated by spotlights. (The National Museum of Fine Arts, Stockholm, Sweden).*

Figure 1.83 *(left) A high polished sculpture shows reflections of the entire surrounding. (The Lenbachhaus, Munich, Germany).*

Figure 1.84 *(right) Pot of silver displayed in a showcase and illuminated with fiber-optics. (The National Museum of Fine Arts, Stockholm, Sweden).*

1. David Briggs, The Dimensions of Colour, Basics of light and shade. <http://www.huevaluechroma.com/021.php> (01.03.2016).

Notes the differences in light and shadow pattern between the white marble statue, the clay statue, and the bronze statues in the same lighting situation. (Figure 1.81, Figure 1.72, and Figure 1.78 - a).

In (Figure 1.82), a dark bronze bust is illuminated by only one relatively big spotlights. The spotlight is directed from the front of the statue with an angle about 15°. The beam of light cover the whole bust and create a strong form-shadows and strong shiny highlights.

In (Figure 1.83), a high polished sculpture stands in front of a dark wall and the rest of the room surfaces are white. The room is illuminated by a window opened to a garden and a cove lighting in a similar situation to the room in (figure 62). There is no source of light directed toward the sculpture. The sculpture gain it visual quality from reflecting the surrounding. By organizing and illuminating the surrounding we can control the brightness of the reflected image on the high specular surface of the statue.

In (Figure 1.84), the silver pot is displayed in a showcase and illuminated with fiber-optics, that are integrated in the showcase frames. The use of many small fiber-optic spotlights help to create many small shiny highlights that revel the quality of the shiny silver work. The showcase stands in low illuminated surrounding to reduce the reflection of the surrounding into the shiny surfaces of the silver pot.

1.3.2.3.5 Glass exhibits lighting

Two attributes decide how to light a glass or a transparent material. The high reflectivity of the surface and transparency of the material. A glass surface will reflect the surrounding, which makes the control of the colours and luminance of surrounding very important. Properly placed, reflections can do a lot to help define the shape of the object. The ability to see through the glass makes the colours and lighting of the background crucial. Simply, lighting a glass is a combination of lighting what is behind the glass and what is seen reflected in the glass. Glass structure that contain clear cuts or coloured particles can be revealed with transmission of light through it, e.g. by emitting light from a small hole in the base of display table through the glass structure; or by strong narrow beam spotlight directed directly on it.[1] (Figure 1.85)

Figure 1.85 *The display of a clear cuts crystal glass in a showcase. The glass is illuminated with the gallery luminance ceiling and a strong narrow-beam spotlights from a track light. (Rijksmuseum, Amsterdam, Netherlands).*

1. Lowel EDU, Lighting Glass, < http://lowel.tiffen.com/edu/lesson_lighting_glass.html>, (10.03.2016).

1.3.3 Lighting techniques for exhibits in display

Patterns of light and shadow that define the visual quality of an object in display are countless, and the examples that we discussed previously are a general over view. In this part of the research we will summarize the guidelines of the lighting techniques that are common in museum practice, to insure a good lighting free of visual distractions.

Most of museum displays can be categorized into one of four groups: flat displays on vertical surface, three dimensional objects, display cases, and realistic environment.(1) Through out these four categories we will discuss the display lighting techniques.

The exhibits conservation aspects has a strong impact on lighting in display. This subject is very important and technically complicated, thus it will be deeply cover in separate chapter. *(See Chapter 3: Exhibits' Conservative Aspects in Museum Lighting).*

1.3.3.1 Flat displays

Illuminating large vertical exhibits uniformly present a difficult lighting situation in museum. This situation is mostly solved in picture gallery by luminesce ceiling lighting. Large painting in picture gallery has to be tilted slightly toward the observer to avoid veiling reflection in the upper part. As well, wall-washer is a good choice for achieving uniform intensity over a large flat surface. Spotlight is more suitable for small- and medium-size flat surface exhibits. When applying the spotlights, it is practical to allow some spill light onto the surrounding area for a softening effect.(2) Generally, the lighting should provide uniform intensity over the entire surface and spotlights have to be positioned so that the beam centre axis is 30° from the vertical, this will produce minimal shadow and glare free viewing, while allowing the visitor to approach the artifacts closely without casting his own shadow on the artifacts.(3)

To define the optimal position of a luminaire for a flat display on a wall the following points has to be considered: (Figure 1.86)

- The museum standard observer's eye level is at 150 cm above floor level. In most cases for regular size painting the horizontal centre of the painting is adjusted at 150 cm.
- It is claimed that people will naturally tend to adjust their viewing distance from an image so that its width or height, whichever is the greater, subtends an angle of approximately 40° at the eye. This makes the viewing distance from the wall approximately 1,4 times the biggest side of a painting.(4)

1.Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA, p22.

2. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA, p22.

3. Previous Reference p22.

4. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p166,167.

- Directing the spotlight onto the centre of the picture would give a noticeably uneven illuminance distribution, and it would be better to direct the beam centre-line to a point two-thirds of the way down the picture.(1)
- The luminaire has to have a angle of 30° from the vertical, this will make the beam centre-line formulate an angle of 60° to the horizon of the painting.(2)
- The luminaire distance from the wall (*X*) can be calculated as follow:

  $X = Y \,.\, \tan 30°$

  Where: *Y* is the distant between the target point and the luminaire mounting height.
- The simple approach to calculate the spotlight beam angle is to calculate the both required horizontal and vertical angle, and then to allow a bit for the corners. Keeping in mind that the spotlight will cover more from the wall area below the painting, since the inclination of a symmetric light beam will lead to create an ellipse-shape lit area on the wall; To reduce the lit area and to cover only the painting asymmetric spotlight, prism, or shutters has to be used.
- The luminous intensity required can be calculated as follow:(3)

  $I = E \,.\, d^2$

  Where: *I* is the intensity of the spotlight (average in covered area), *E* illuminance needed, *d* distant between the spotlight and the painting.

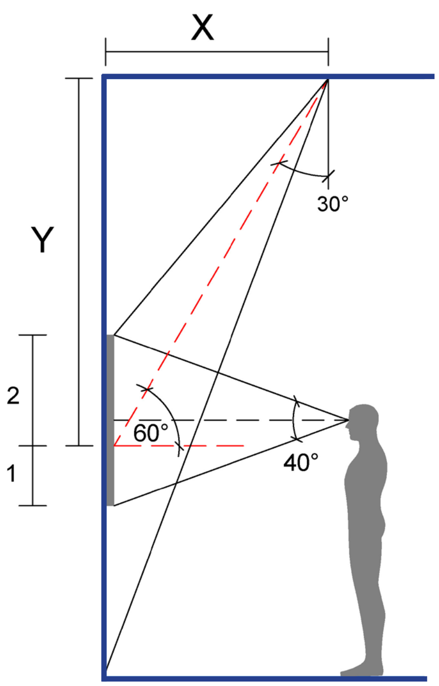


Figure 1.86 *Guidelines for luminaires mounting position for a flat displays on a vertical surface.*

1. Previous reference, p202.
2. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA. p23.
3. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p203.

1.3.3.2 Three-Dimensional Objects

Irrespective of size, a three-dimensional artifact must have some variation of illumination from several different directions to provide the essential highlights and shadows that reveal the object's visual qualities. For relatively low and small objects, the light fixtures may be steeply angled limiting the risk of glare for the observer on the opposite side. When an object is tall, some light may go past the display and cause glare for viewers on the far side looking upward at the artifact.[(1)]

The following points are general tips for lighting three-dimensional objects in museums:[(2)]

- The centre beam axis of the luminaire should be around 30° from the vertical.
- It is important to choose carefully the material of the interior, since the reflected light in the interior will affect the shading patterns of the objects. e.g. Light reflected back from the pedestal or the floor can attenuate the shading pattern of an object.
- A bright pedestal can pose a problem when it reflect back the light of strong spotlight causing glare.
- It is advisable to insure that the light beam entirely cover the whole objects. However, in some cases for large objects focusing the beam on the important parts of the object will be enough.
- Using overall soft lighting in the display space helps to soften the shadows and to see details in the shaded areas.
- In some cases lighting the object from behind (back light) is needed to highlight object's outline and separate it from the background.
- Objects can be illuminated from below as long as appearances are not distorted.
- Objects have to have more light than the surrounding.

1.3.3.3 Showcase

Museum showcases usually contain a large variety of vulnerable, delicate, precious, and/or small exhibits, which in most need a conservation attention. Showcases give the visitors the advantage of approaching the exhibits closely to improve visibility, while ensuring exhibits' safety and protection. Showcases vary in sizes, shapes and design dramatically according to the exhibits' nature and display concept. Correspondingly, showcase lighting has to consider the conservation aspects, good visibility, the close approach of visitors, nature of the exhibits and concept of display.

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1. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA, p27.
2. Previous reference, p27.

1.3.3.3.1 Conservation aspect in showcases lighting

The showcases may have external or internal lighting, which may vary between all kinds of lamps that fulfil museum task illumination, the important aspect is to avoid heat gain and ultraviolet radiation.

Lamps or equipment that radiate heat has to be positioned outside the showcase and either a transparent or translucent barrier should always be put between the luminaires and the exhibit.(1) The light chambers attached to showcases require ventilation to prevent heat build-up, and should have air vents for convection cooling. In extreme situation, theses chambers may require conditioned air or electric fans. All chambers opening should be filtered to reduce dirt deposit on the fixtures and glazing.(2)

Glassing or lense for luminaires should have UV filtering, or the showcase should be constructed from UV filtering glass to prevent UV radiation from either artificial light source or daylight opening from penetrating the showcase.

It is recommended to use the LEDs luminaires, since it deliver a beam that is free of UV or IR radiation, and fibre-optic lighting systems, which have a very low UV/IR content. As well, because of their size, both of these solutions can be easily integrated in showcases and be suitable for illuminating very small display cabinets.(3) Some reference refer to fibre-optics have no UV and IR. In all cases the light source spectrum has to be checked out before use.

Visible light free from UV and IR radiation can as well damage sensitive artifacts, therefore the annual exposure hours have to be controlled. Showcases can be designed to have a automation and/or lighting management system that control light exposure time.

(For more info about conservation lighting in museum see Ch. 3).

1.3.3.3.2 Minimizing reflection in showcases

Showcases glazing has a high potential of causing veiling reflection (reflected glare) and disturbing seeing the artifacts. Avoiding reflection totally is very difficult. Mostly, some reflections have to occur, however if it is not bright, it is generally acceptable. To minimize reflection and insure good visibility, the gallery and the showcases have to be carefully designed. Of things that help minimizing veiling reflection are:(4) (5)

- Showcase has to have more light than the surrounding. IES recommended lighting ratio (10:1) between the interior and the exterior of the showcase.

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1. Previous Reference p23.
2. Previous reference p25.
3. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications, Fördergemeinschaft Gutes Licht. p8-9
4. Previous reference p9.
5. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA. p23-24

- How visible reflections are depends on its degree of contrast with the surroundings. Accordingly, a showcase with well lit and bright-coloured interior will have low potential of causing veiling reflection. On the other hand, a showcase with dark-coloured interior or low lit will have high potential of causing veiling reflection.
- Minimizing the outward light spill from the showcases helps that the visitors image will not be reflected back on the glass.
- Reflections on horizontal glass surfaces occur less frequently if the glass is tilted towards the observer. Vertical glass, as well, can be angled toward the viewer. This angle direct the reflections from the gallery toward the floor, which must kept dark.
- Non-reflective glass is very effective protection against reflected glare, however it is very expensive.
- Daylight openings especially windows have a great potential to case reflection on showcases' glass. Therefor, direct sun has to be avoid, opening luminance has to be reduced e.g. with a screen, and showcases has to be arranged in appropriate position to the daylight source.
- Luminous ceilings has a high potential in causing veiling reflection on showcases. In the contrary, spotlight track lighting gives a high control on avoiding veiling reflection and glare on showcases.
- Showcase integrated lighting helps to reduce veiling reflection and glare.

1.3.3.3.3 Showcases lighting concepts

Showcase lighting is mostly designed according to the nature of the exhibits, concept of displayed, and the general gallery atmosphere. Showcase lighting is achieved by external lighting, showcase integrated lighting, or a mix between both.

Showcase lighted from external source, the light should be above and front of the case and focused straight down through the top of the showcase. Other luminaires position will produce shadows within the case from case edges and corners, even if there are no opaque supporting structures.[1] A relative large showcase gives more room around the exhibit, which free the artifact from the sense of captivity inside the glass box and give more options for the luminaire positions. (Figure 1.87 and Figure 1.88).

In some cases using a diffusion material such as milk white diffusing acrylic placed across the top of the case reduce harsh shadows and produces a self-lighted affect. The diffusion material will cause a reflection from the case top onto the ceiling.[2]

1. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA. p23
2. Previous reference p23.

Figure 1.87 *(left) Showcase illuminated by external spotlight. The showcase contain Pottery and pieces of dry clay. (Egyptian Museum, Turin, Italy)*

Figure 1.88 *(right) Showcase illuminated by external spotlight. The showcase contain gold-plated pots. (Rijksmuseum, Amsterdam, Netherlands).*

Internal showcase lighting gives the opportunity to conceal light source and customize the lighting to fit the content. Mostly lighting is concealed in a chamber above the showcase. This chamber can contain different types of light fixtures according to the design requirement. Spots are mostly directed through small aperture in opaque material or in a lover. Parabolic wedge louvres are preferred choice with fluorescent lamps. For the top-lit showcases supplementary lighting from the side, bottom, or/and surrounding is practical and can enhance the display. Further, it is important to keep in mind that, the glass will reflect some of the integrated light back into the lower area of the showcase. The reflected light helps to enhance the light gradients and the fill light on the exhibits.[1]

Using diffuse-light-box (mostly, diffuse acrylic glass with fluorescent lamps) as general showcase lighting will create a harsh veiling reflection. In some cases diffuse-light-box is used as background or a base in the showcases, which lead to see the Exhibit as a silhouette; and to overcome the silhouette appearance the diffuse-light-box has to be dimmed and the exhibit has to be highly illuminated with a spotlight.

The LEDs fixture size gives the opportunity of easily integrating the lighting in the showcases, and focusing it exactly on the exhibits. LEDs can be integrated in display shelves, showcase structure, or a special installed arms and poles. Integrating the light in showcase bases is not desirable since it creates unnatural shades on the exhibits. LEDs are frequently used in small and shallow showcases. (Figure 1.89)

Fiber-optics are a practical and efficient light source for showcase. Low-level of light can piped directly into a showcase and focused at a specific object while the case remain sealed. Fiber-optics cables have approximately 10 - 20 m long and end with small lenses. The light injector can be remotely located outside the display thus mitigating heat build up.[2] (Figure 1.84)

1. Previous reference p25.

2. Previous reference p27.

Generally, showcase integrated lighting helps to reduce veiling reflection and glare. General room lighting is essential to enhance the showcase display and it should be below the level of the showcase lighting. Some design intention eliminates the general lighting and depends on the stray light from showcases as an orientation lighting; in this case showcase lighting should not be too low.(1) (Figure 1.90)

Figure 1.89 *Showcase illuminated by internal LEDs spotlight. (The Antikensammlung Berlin, Germany).*

Figure 1.90 *Showcase with white interior and it is internally illuminated with LEDs and a small diffuser-ceiling. The gallery interior is black and the general illumination depends on the stray light from showcases. (The German Film Museum, Frankfurt, Germany).*

1.3.3.4 Realistic environments

Museums sometimes desire environments, where the space itself becomes the message. Examples include period rooms, outdoor scenes, or historical houses. Lighting in character with the original purpose of the space is desirable, within reason.(2)

Lighting in realistic exhibit spaces has to be concealed and/or original flame source lighting (e.g. candles, mantels, gas jets), if exist, has to be replaced with modern light that imitates its appearance. The display lighting should complement in both colour and style the realistic lighting and do not contradict with the nature of the space.(3)

1. Good Lighting for Museums, Galleries and Exhibitions, Booklet 18 in the series Information on Lighting Applications published by Fördergemeinschaft Gutes Licht. p8.
2. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA. p27.
3. Previous reference p30.

An example of realistic exhibit spaces is the display of the Temple of Dendur in the Metropolitan Museum of Art, New York, USA. In 1965, the Egyptian Government gave the Temple of Dendur to the American people as a mark of thanks for their contribution to the rescue effort of a number of ancient Nubian monuments. The monuments were rescued from sinking in a formed huge artificial lake behind the High Dam of Aswan that was constructed in 1960.

The temple is displayed in a great space. As visitors enter the space, they find themselves confronted by a moat, the edge of which represents the Nile bank, and set back at the correct distance from the bank stands the gateway to the temple. Daylight floods into the space from a huge glass wall that opens onto Central Park, and after crossing the moat, visitors gain a sense of the scale of the temple due to the spaciousness of the enclosed space and the strong visual contact with the outdoors. It may be noted that the strong flow of light from the glass wall has been softened by light of the luminance ceiling. The interior of the temple is illuminated with artificial lighting, but the overall effect is an open, airy space in which daylight flows across the monumental stonework, playing on its forms and revealing the bas-relief carvings.(1)

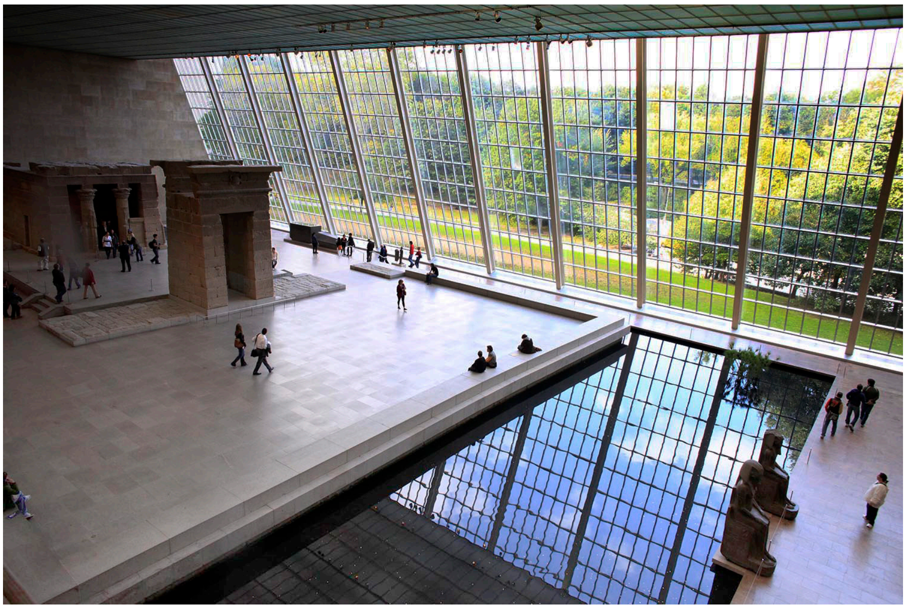

Figure 1.91 *Creating a realistic exhibit space for the Temple of Dendur in the Metropolitan Museum of Art, New York, USA. (http://www.today.com/id/33902191/).*

1. Christopher Cuttle, Light for Art's Sake, Elsevier, UK 2007, p246.

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Lighting and Displaying the Egyptian Artifacts

Ch. 2

Chapter 2. Lighting and Displaying the Egyptian Artifacts

The Egyptian exhibits are more than historical artifacts that need to be conserved and presented for public knowledge and academic studies; they are the manifestation of a great civilization that have to be displayed to demonstrate their aesthetics, cultural values, and historical background for public enjoyment and appreciation.

How should we light and display the Egyptian artifacts? There is no ultimate answer for that! However, the essence of the answer lays in what the Ancient Egyptians wanted their viewers to experience, when they created their artifacts; how these artifacts are related to the old Egyptian culture; and how to convey these insights to the viewers.

In this chapter, among the Egyptian artifacts, we will focus more on the Egyptian arts: architecture, sculpture, and painting. We will discuss the visual quality and characteristics of the ancient Egyptian arts from a lighting design point of view, and will present some examples of lighting and exhibiting of Egyptian artifacts in museums.

2.1 Approaching meaningful light for the Egyptian arts

Understanding how light interact with the form of the Egyptian arts and the important characteristics that have to be emphasized, will help to reveal the aesthetics of Egyptian arts and to add meaning to the display, which in return will improve the quality of lighting in museum.

2.1.1 Light and the visual quality of ancient Egyptian arts

Light reflects itself on life and culture, and effects the appearance of architecture and art we create. In ancient Egypt, light has a great impact on culture and what man-made. The sun was the god "*Ra*" that has a big role on the faith and religion of the ancient Egypt; as well, it is the rays that penetrate dark chambers to light the statues of the god.

2.1.1.1 Daylight conditions and the built environment

The change of location and climate is a major factor that influence people way of living and thinking. The change of location and climate, is accompanied with the change of light’s characteristics and its rhythms throughout the year. How people response to these variations, and use their intelligence to meet their needs in different conditions formulate part of their culture. Which makes responding and handling light deeply inherent in the cultures.

This can be obvious in how architecture is responding directly to daylight conditions. In north cold climate regions, where overcast sky is dominating, buildings have been developed with a large tall windows to admit more light in the depth of the rooms. In the Mediterranean region the sky become clearer and the sun shines more during the year, thus windows get smaller with wooden shatters to block the harsh light and temperature of the sun and allow aeration. In hot climate, where the sky is clear and the harsh sun shines most of the years, windows are very small. A small windows will help to control the heat and the sun;

(a)

(b)

Figure 2.1 *Response of windows as a lighting feature to the change in climate. (a) Large tall windows in cloudy climate. Amsterdam, Netherlands. (b) Small windows with wooden shutters in the sunny Mediterranean region. Cinque Terre, Italy (c) The Mashrabiya, a large wood screen insure good lighting distribution and allow more air to the room in hot climate region. Bayt Al-suhaymi, Cairo, Egypt.*

(C)

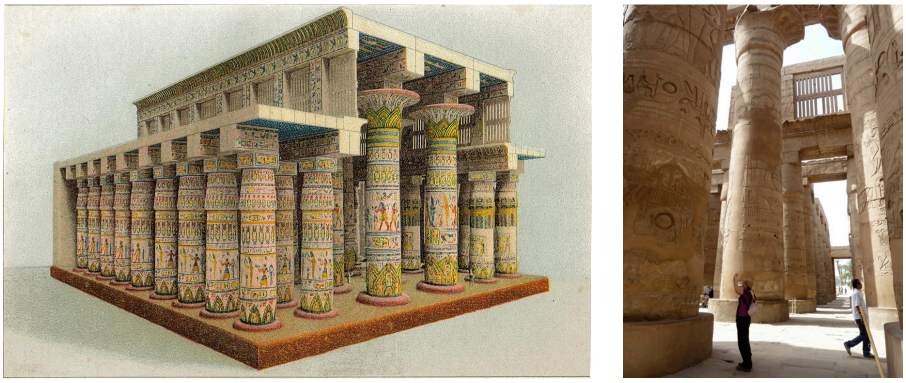
however, it will reduce aeration and will have a poor lighting distribution. As a solution, in some hot Arabic climate cites, building have a large opening with large wood screen (Mashrabiya), to allow more air in the room and have a good lighting distribution. (Figure 2.1)

2.1.1.2 Light in the ancient Egyptian architecture

Many examples show the skill and competence of the old Egyptian architect in creating lighting solution in buildings. A great lighting solution in the Egyptian Temples is the use of Clerestory Windows to illuminate the Hypostyle Hall. A perfect example is the Hypostyle Hall in Karnak temple.[1] The hall was illuminated by raising middle section of the roof higher than the neighbouring sections, then closing the vertical

1. A hypostyle hall is a flat-roofed room supported by a series of columns or pillars. The Great Hypostyle Hall of Karnak was begun during the reign of King Seti I (c.1290-1279 B.C.E.) and was completed by his son, Ramesses II (c.1279-1213 B.C.E.). Reference: LaChiusa, C. (2009). Architecture around the World. Available at <http://buffaloah.com/a/virtual/egypt/karnak/hall/index.html> (28/12/2015).

raised opening from both sides with windows. This design allows light to enter along the sides of the elevated roof section.[1] (Figure 2.2) The sky light and the reflected light from the lower roof level enter the hall from the high positioned windows (24 m above floor) and highlight the top of the large columns in the centre, thus creating an aura of light that illuminate the central nave and gradually fade as we move away to the side of the hall. While the widows' grille structure create light beams from the direct sun, which hit some of the columns and traversing others to pass deep in the space. The hall monumental scale and the lighting effect give the majesty and sacredness quality to the space. To emphasize the visual and psychological impact of this lighting effect, the ancient Egyptian architect created the 12 central columns that rise high in light with an open papyrus capital and the 122 side columns that line in the darkened sides with closed papyrus-bud capitals. Further, to complete the original image of the hall, the columns were carved in sunk relief and painted with strong colour. (Figure 2.2 and Figure 2.3).



(a) (b)

Figure 2.2 *The Hypostyle Hall in Karnak temple. (a) A restored model from the metropolitan Museum of Art, New York, USA. The model shows the clere-story windows that exist between the two levels of the roof. (https://commons.wikimedia.org/wiki/File:NIEdot361.jpg) (b) The curent situation. (https://ancientegyptheritage.wordpress.com)*

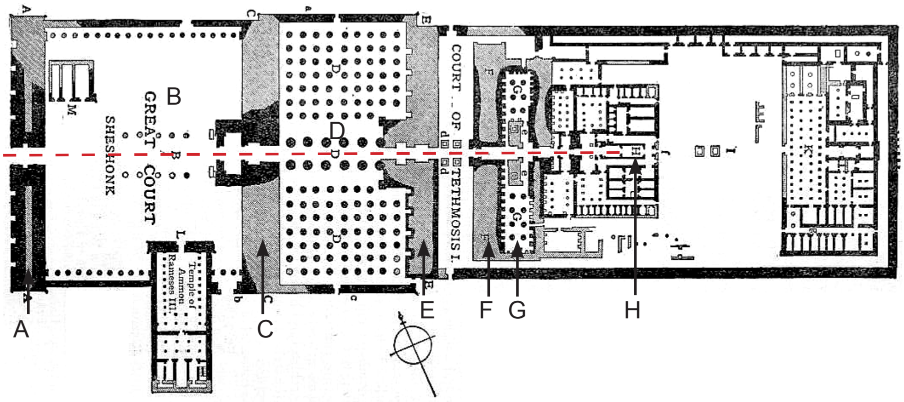
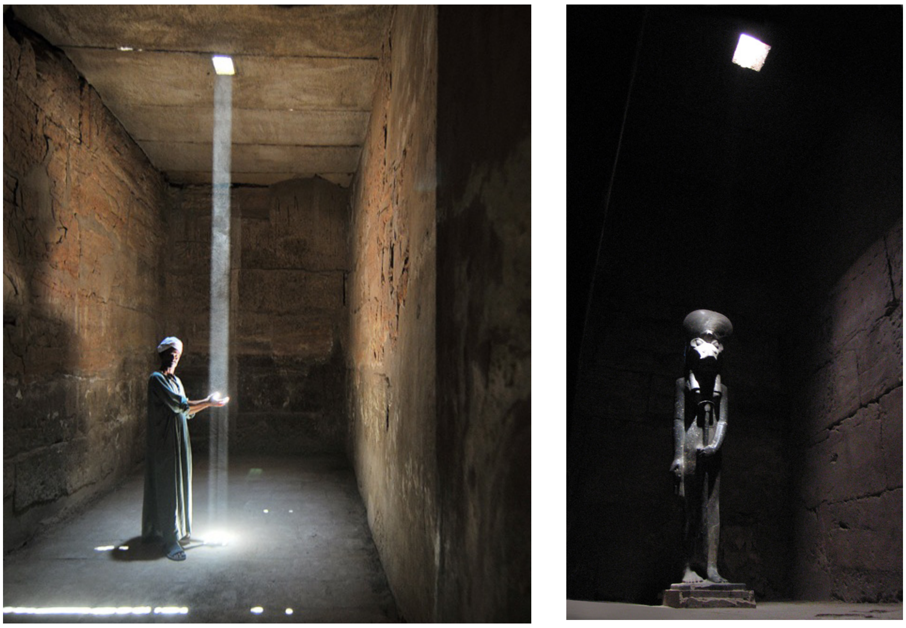


Figure 2.3 *Plan of Karnak temple.*
(A) First Pylon,
(B) Great Court,
(C) Second Pylon,
(D) Hypostyle Hall,
(E) Third Pylon,
(F) Fourth pylon,
(G) Hall with Osiris figures,
(H) Granite Sanctuary.
Red dashed line: direction of pilgrims movement (https://en.wikisource.org/wiki/1911_Encyclop%C3%A6dia_Britannica/Architecture).

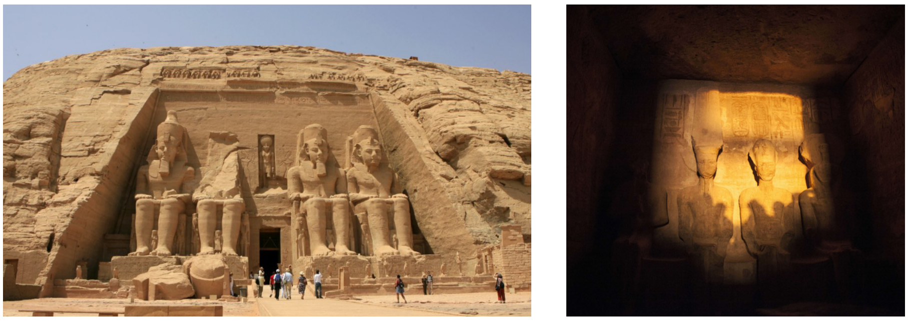
A common lighting effect in the temples is to deliberately make the Pilgrims' vision slowly adapted from the bright exterior to the darker interior, when they move successively from dark to darker places, along the axis of the temple. They move from the open courtyard, to the Hypostyle hall, to smaller rooms, till they the reach the sanctum, where they will be faced with the statue of the idol highlighted with a strong beam of light in a totally dark space. (Figure 2.3)

1. Sullivan, Elaine, 2008, Architectural Features. On Digital Karnak, Los Angeles. PDF <http://dlib. etc.ucla.edu/projects/Karnak> (28/12/2015).



(a) (b)

Figure 2.4 *Daylight penetrating the roof of small chambers in Karnak temple, Luxor, Egypt. (a) A beam of strong sun light can illuminate the whole chamber. (http://www.trekearth.com/gallery/Africa/Egypt/Inland/Luxor/Karnak/photo1305290.htm) (b) A daylight falling on a statue of Sekhmet (warrior and healing goddess) in a small chamber in temple of karnak. (The photo was taken one hour before the summer sun set).*



(a) (b)

Figure 2.5 *The solar phenomenon at the temple of Abu Simbel, Egypt. (a) The main entrance is located in the middle of the facade. (http://www.sued-deutsche.de) (b) The rays of the sun illuminate the statues in the inner sanctum of Abu Simbel temple. (http://www.dailynews-egypt.com/2014/02/26/abu-simbels-sun-festival/)*

Cutting angled slits and square holes into a temple's roof slabs, allowing daylight to enter through these small gaps are common lighting and ventilation solutions in ancient Egyptian architecture.[1] A beam of sunlight entering a small chamber can light the whole place and creates a dramatic effect. (Figure 2.4)

Moreover, the solar phenomenon at the temple of Abu Simbel witnesses the understanding of the ancient Egyptian architect to the sun movement and the accuracy of utilizing it in sacred Egyptian buildings. The temple main axis was carefully directed, that twice a year, at the dawn of Oct 21 and Feb 21 (traditionally the king Ramses II birthday and coronation day), the sun light penetrates the embossed facade and the successive narrow hallways of the temple to illuminate only three statues out of four that are shrouded the whole year in darkness inside the sanctum at the end of the temple. The sun illuminate the statues of sun god Ra-Horakhty and Amon-Re, as well as the statue of king Ramses II, while the statue of Ptah (the god of darkness) remains in shadow.[2] (Figure 2.5)

1. LaChiusa, C. (2009). Architecture around the World. Available at <http://buffaloah.com/a/virtual/egypt/karnak/hall/index.html> (28/12/2015).
2. Lisa Krause, Sun to Illuminate Inner Sanctuary of Pharaoh's Temple, National Geographic News, February 21, 2001. <http://news.nationalgeographic.com/news/2001/02/0221_abusimbel.html> (28/12/2015).

2.1.1.3 Light and the ancient Egyptian sculpture

Architecture is the cover that protects us from climate agents and help us to control them. Therefore daylight has a direct and evident impact in shaping the architecture. Strengthens this impact that light and heat go hand in hand in daylight. **The question that arises now is: whether light affects the production of plastic art or not?** A comparison between the sculpture art of ancient Egypt and, Classical sculpture will help to answer and explain this question.

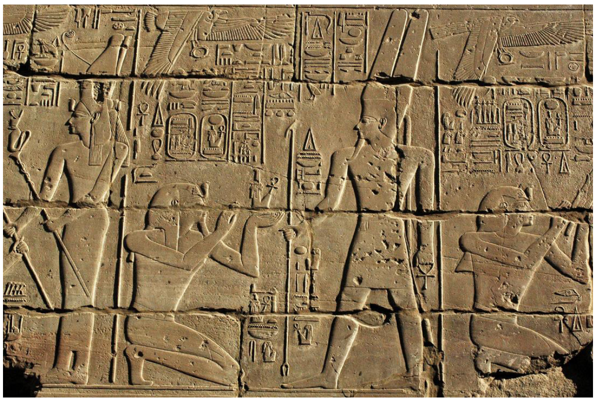
In general, the fundamental differences in form between the sculptures and reliefs of Ancient Egypt (created in the lower Nile Valley from about 3000 BC to 100 AD)(1) and, Classical work (created in Ancient Greece and Rome, as well late works that follow the canon of classical forms)(2) is that, Egyptian sculptures and reliefs are highly stylized and symbolized(3), while the classical work are more naturalistic and literal.(4) Nevertheless, there is more to understand and reveal by questioning these arts to the condition of light where they were created.

2.1.1.3.1 Light and Egyptian relief

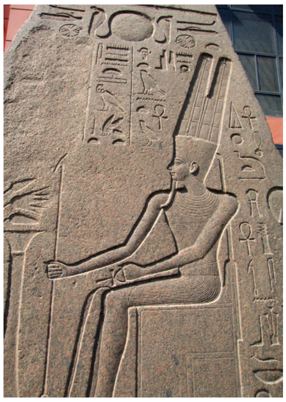
The Egyptians used a two distinctive technique of relief carving: bas-relief and sunk-relief.(5) (Figure 2.6) The bas-relief is a low relief in which the figures are flat and raised from the background, the whole space around the figures is lowered. This makes the relief very sensitive to direct sun light that give a strong highlight and dark shadow to its edges. In sunk-relief, the small forms are linear in nature, like hieroglyphs; while the figures are in low relief, but set within a sunken area shaped around the image, so that the relief never rises beyond the original flat surface; and no attempt is made to soften the edge of the sunk area, leaving a face at a right-angle to the surface all around it; which with the strong sunlight creates a dark shadow emphasizing the outlines of the figure. The sunk-relief method minimizes the work of removing the background, while allowing normal relief modelling. The sunk-relief is largely restricted to the art of Ancient Egypt, and become very common and the dominant type used after the Amarna period of Akhenaten.(6)

The classical sculpture used the high-relief technique, where in general more than half the mass of the sculpted figure projects from the background. In High-relief elements fully free of the background and

1. Art of ancient Egypt,Wikipedia, <https://en.wikipedia.org/wiki/Art_of_ancient_Egypt>,(28/12/2015).
2. Classical sculpture, Wikipedia, <https://en.wikipedia.org/wiki/Classical_sculpture#cite_ref-1>,(28/12/2015).
3. Art of ancient Egypt,Wikipedia, < https://en.wikipedia.org/wiki/Art_of_ancient_Egypt>,(28/12/2015).
4. Ancient Greek sculpture, Wikipedia, < https://en.wikipedia.org/wiki/Ancient_Greek_sculpture>,(28/12/2015).
5. The Art Of Ancient Egypt, A Resource For Educators The Metropolitan Museum Of Art, PDF, p45.
6. Relief, Wikipedia, <https://en.wikipedia.org/wiki/Relief>, (28/12/2015).



(a)



(b)

Figure 2.6 *The direct sun light creates strong highlights and shadows that emphasize the outlines of the ancient Egyptian Relief. (a) A bas-relief from the Hypostyle Hall in Karnak, Luxor, Egypt. (http://www.memphis.edu) (b) A sunk-relief on a small granite pyramid (open air exhibition at Egyptian Museum in Cairo).*

(a)

(b)

Figure 2.7 *The Classical high-relief figures appear pleasant in diffuse illumination. (a) A classic relief from the Pergamon Altar illuminated with diffuse light from a luminance ceiling. (b) An general view of the Pergamon Altar in the Pergamon Museum in Berlin, Germany. (https://en.wikipedia.org/wiki/Pergamon_Altar).*

parts of the figures are crossing over each other to indicate and emphasize the depth.[1] (Figure 2.7) Under the climate condition of Europe, where sky is mostly cloudy and light is soft, the high-relief figures and its overlapping will have soft shadows and pleasant appearance. While under the direct harsh sun it will have a strong dark shadows that will obscure details and parts of the relief. In contrast, the Egyptian relief under the diffuse light of the overcast sky will appear washed-out. It needs a direct sun light to create strong highlights and shadows that emphasize its outlines. Both reliefs, the Egyptian and classic, fit with the daylight condition where they are originally created and presented.

2.1.1.3.2 Light and Egyptian statues

Most of larger sculptures survive from Egyptian temples or tombs; their were built to represent gods and pharaohs and their queens, usually for open areas inside or outside temples.[2] Large sculptures were usually carved from sandstone or hard granite.[3] Egyptian stone sculpture, even when carved from the hardest materials, often possesses highly polished surfaces that contrast with finely incised details and patterns, whose surfaces are more rough.[4]

1. Previous reference.
2. Art of ancient Egypt, Wikipedia, < https://en.wikipedia.org/wiki/Art_of_ancient_Egypt >, (28/12/2015).
3. Ancient Egyptian Sculpture, The Sphinx And Obelisks <http://factsanddetails.com/world/cat56/sub365/item1935.html>, (28/12/2015).
4. The Art Of Ancient Egypt, A Resource For Educators The Metropolitan Museum Of Art, PDF, p45.

Egyptian sculptors seldom completely freed figures from the stone block. With few exceptions, no space was carved out between the arms and torso or between the legs of standing figures. The lower part of seated figures is adapted to a large degree to the rectangular shape of the block like seat. The backs of many standing figures remain attached to an upright slab or a back pillar. Such elements contribute to the centred and poised character of Egyptian stone statues and reinforce their frontality and axiality.(1)

The states' and dark materials are appropriate for high level of illumination and direct sun light of Egypt. Consistent with that, the statues' abstract geometry with its flat surfaces, smooth curves, less detail, and polished finishing. The form is revealed and obtained its visual quality from the large specular highlight and smooth lit areas that faces directly the sun, as well from the reflection of the surrounding in shadow of polished surfaces. The shallow incised lines and patterns (as in the fabric of the form-fitting kilt and folded striped headdress) creates sharp lines of highlights and shadows under the direct sun light, that easily characterize the surface and make it apparent when it contrast with the flat polished body. Additionally, the solid abstract form with no-gaps is made to give a robust, stability and durability to the statue. As well, for the sake of visual comfort, it helps to see the statue without seeing disturbing patches of bright background through the mass and/or avoid seeing the statue limbs in high unpleasant contrast with the bright surrounding. (Figure 2.8)

On the other side, the classical sculptures are mostly made of white marble showing the bare surface of the material, and were created in a realistic manner that reproduce the naturalistic structure anatomy of the human body as ideals of beauty and physical perfection. People real faces are depict; and figures stand free, move naturally in a variety of poses, or interact together to create an epic scene.(2) These classical sculpture with its white material, realistic appearance, fully modelled details and overlapping elements can be comfortably seen and enjoyed visually only under northern types of cloudy skies, (i.e. a mix of diffuse and direct light and moderate level of illumination). Since the white marble will be dazzling under strong direct sun light and details cannot be fully perceived. As well, shadows will be very strong and, it will obscure details and parts where it fell. (Figure 2.8)

Additionally, in the architecture context, a common technique is to place the classical statues in niches or recess in the walls. Visually this will help to darken the background of the statue, thus raise its contrast with the background, which will emphasize the statue's outline and raise its visibility; as well, eliminates any interference from the surrounding with the form. This technique is more successful with northern types of cloudy skies, where in hot climate regions the harsh

1. Previous reference, p38.
2. Classical sculpture, Wikipedia, <https://en.wikipedia.org/wiki/Classical_sculpture>, (28/12/2015).

sun light will create a strong shadows inside the niche that will obscure the details of the statue standing inside. As well, this technique in not needful for dark or a solid mass statue. (Figure 2.8)

Another example of art response to the weather condition is that, the shiny and golden materials are more used externally in the architecture and sculpture of cloudy climates. Under the diffuse light of overcast skies the high-reflective surfaces of golden materials will capture the light and appear brighter than any other element in the dim surrounding; this will drag attention of the eye and the worm colour of the gold materials will be pleasant in the winter atmosphere.

The creation of visual art involves various subjective and objective dimensions, that lead to create a form that reflect these dimensions. The interaction of light and material is substantially in the creation of form, thus the creation of art. The continuous attempt to optimise the intended form according to the dominant daylight condition ingrain the available quality of light in the nature of the form. This can be obviously observed in the analysis of outdoor statues in Ancient Egypt and Classical Europe.

(a) (b) (c)

Figure 2.8 *The visual quality of ancient Egyptian and classical statues in different light situation. (a) Egyptian dark granite statue under direct harsh sun light in the open air exhibition at Luxor Museum, Egypt. (b) Egyptian granite statue in diffuse daylight inside the Egyptian museum, Cairo, Egypt. (c) The classical statue of Apollo Belvedere standing in diffuse light in the Vatican Museums, Italy. (https://en.wikipedia.org/wiki/Apollo_Belvedere)*

2.1.2 Characteristics of the Egyptian art

Ancient Egypt left us a vast collection of artifacts that reflect the life and culture of almost three thousand years. Certainly, the dominating weather condition has an influence on the creation of Egyptian art and artifacts, however, the major and main impact comes from the way of life around the Nile and the beliefs of the ancient Egyptian. Exploring the general characteristic of the Egyptian art and artifacts will help definitely in displaying and lighting these artifacts in museums.

2.1.2.1 Art for ancient Egyptian beliefs

Ancient Egyptian art was created using media ranging from drawings on papyrus to sculpt and painting stones. Much of the surviving art comes from tombs and monuments and thus there is an emphasis on life after death and the preservation of knowledge of the past. Ancient Egyptian art displays an extraordinarily vivid representation of the Ancient Egyptian's socioeconomic status and belief systems. Egyptian styles changed remarkably little over more than three thousand years.(1)

2.1.2.2 Order and clarity

The significant feature of Egyptian arts are the clear outlines, the simplified shapes, and the flat surfaces, that create order and clarity. The structural elements of Egyptian art are the cube and horizontal and vertical axes. When preparing to carve a statue or decorate a wall, Egyptian artists first drew horizontal and vertical guidelines on the surface so the proportions of the figures would be consistent with the established canon. The result of such measured proportions and relationships was an art of remarkable order and uniformity that maintains the same balance whether in a colossal statue or a figure in hieroglyphic script.(2)

2.1.2.3 Stylized

Forms are developed in an ideal and standard way to express desired meanings. Figures and scenes were arranged in horizontal rows (called registers). The major figure of a composition, was usually larger than the more subsidiary ones, and its poses (standing, walking, sitting, or kneeling) were the most stylized. Even for subsidiary figures a limited number of arm and hand gestures were used to explain what the figure was doing.(3) Figures are drawn to show a profile view and a side view of the animal or person at the same time to make drawings more vivid.(4)

Sculpture art merges the abstract forms with naturalism, and focus more on geometric aspects. When Ken Johnson (5) describe the 4,000 years old and 10 feet tall statue of "Amenemhat II", when it was presented in the Metropolitan Museum of Art (Figure 2.9), he said: (6)

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1. Art of ancient Egypt,Wikipedia, < https://en.wikipedia.org/wiki/Art_of_ancient_Egypt>,(28/12/2015).
2. The Art of Ancient Egypt, A resource for educators, The Metropolitan Museum of Art, PDF, p38.
3. Previous reference, p37, 38.
4. Bill Manley, Historical Atlas of Ancient Egypt, Penguin Group, USA, 1996 p. 83
5. Ken Johnson (born 1953 in Montclair, New Jersey) is an American art critic who lives in New York. Johnson is a writer for the arts pages of The New York Times, where he covers gallery and museum exhibits.< https://en.wikipedia.org/wiki/Ken_Johnson_(art_critic)>, (27.03.2016).
6. The statue belong to Berlin's Egyptian Museum and Papyrus Collection since 1837. But now the courtyard in Germany where he usually presides is under reconstruction, so he will be a guest of honor in New York for the next 10 years. Ken Johnson, A Pharaoh Lords Over A Museum, The new York Times, AUG. 22, 2011. <http://www.nytimes.com/2011/08/23/arts/design/amenemhat-ii-at-metropolitan-museum-review.html?_r=1>, (27.03.2016).

"Amenemhat II feels at once deeply familiar and otherworldly. Its tension between geometric abstraction and organic naturalism, its ambition to transform inert material into something that seems to live and breathe, anticipates the basic aesthetic terms that would define Western art from the Greeks to the start of Modernism. Despite its rigid stillness, the statue has an uncanny animated feeling, as if it were inhabited by some eternal consciousness. That, at least, is what the Egyptians wanted their viewers to experience. For them the pharaoh was truly a divine being."

In the previous description Ken Johnson tries to explain the merge between abstract and naturalism in the statues as the tension between: familiar vs otherworldly, geometric vs organic, inert vs live, rigid stillness vs animated feeling, and human being vs divine being.

(a) (b)

Figure 2.9 *The colossal statue of Amenemhat II (ca. 1919-1885 B.C.) (a) The statue as it presented in the Great Hall of the Metropolitan Museum of Art, New York, USA. (www.nytimes.com) (b) A photograph of the statue from the Egyptian Museum of Berlin, Germany. (www.observer.com).*

2.1.2.4 Symbolic

Symbolism has a major role in the Egyptian art and culture. There are clear symbols that is used in Hieroglyphics (ancient Egyptian writing), painting, and sculpture to represent gods, religious thoughts,...etc. On the other hand there are indirect symbols can be interpreted from the scene. For example, figure size in drawing and relief indicate relative importance or authority. Images of the king are often much larger than life to symbolize the ruler's superhuman powers. In wall reliefs and paintings servants and entertainers, animals, trees, and architectural details are usually shown in smaller scale than the figures of the king, high official, or tomb owner.[1]

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1. The Art Of Ancient Egypt, A Resource For Educators The Metropolitan Museum Of Art, PDF, p44.

Colours were more expressive rather than natural: red skin implied hard working tanned youth, whereas yellow skin was used for women or middle-aged men who worked indoors; blue or gold indicated divinity because of its unnatural appearance and association with precious materials; the use of black for royal figures expressed the fertility of the Nile from which Egypt was born. Stereotypes were employed to indicate the geographical origins of foreigners.[1] (Figure 2.10)

Various materials held very symbolic significance for the ancient Egyptians. Gold was regarded as divine on account of its colour and brightness (symbolic of the sun and eternal life). Silver also had divine associations. The bones of the gods were said to be made of silver, and it was used extensively as a symbol of the moon in mirrors and in figures of lunar gods such as Khonsu and Thoth. Among stones, for example, the black coloration of basalt gave it a natural association with the underworld, while lapis lazuli was symbolic of the heavens because of its blue ground colour and star-like golden specks. Water, for example, functioned as a symbol of purification and acceptance.[2]

Accordingly, using colours in the display of ancient Egyptian Arts bears more than the technical art rules. It is a very sensitive subject that has to be addressed carefully with the museum curator and specialist, since it can adds or subtracts a meaning to the artifacts.

Figure 2.10 *Skin colour as a symbol in ancient Egyptian painting. Red skin for men, yellow for women, blue frog gods. The Tomb of Horemheb, Valley of the Kings, Luxor, Egypt. (https://en.wikipedia.org/wiki/Horemheb)*

Figure 2.11 *Statues of Ramses II (in the pause Osiris) are created as part of the pillars and associated with the architecture. Karnak Temple, Luxor, Egypt. (http://www.livescience.com/25184-karnak-temple.html)*

1. Bill Manley, Historical Atlas of Ancient Egypt, Penguin Group, USA, 1996 p. 83
2. John Watson, Ancient Egyptian Symbolism, The Forms and Functions, < http://www.touregypt.net/featurestories/symbolism2.htm>,(28.03.2016).

2.1.2.5 Association with architecture

Ancient Egyptian are is closely associated with Egyptian architecture. In most cases, reliefs are employed as parts of the walls and architectural elements and sculptures are employed for wall-reliefs, the capitals of columns, colossal figures guarding the pylons, and for long avenues of sphinxes.(1) This association makes the relief and sculpture follow the architectural order and concept. (Figure 2.11)

2.1.3 Revealing the attributes of Egyptian arts

As we discussed visual quality and characteristic of the Egyptian arts, we like to discuss some ideas about how museum lighting can evoke and connect the visitors to the aesthetics of the ancient Egyptian arts.

2.1.3.1 The quality of daylight pattern

The reliefs and statues of the ancient Egypt has a better visual quality under direct sun light. Of course it is better to present the statues and relief in same lighting condition as they were presented in the past, for example in an open air exhibition; however for conservation and safety reasons it have to be presented inside the museum. The pattern of clear sky with sun can be thought as bright diffuse atmosphere with one strong directional light. The pattern can be realized by means of daylighting or/and artificial lighting inside the museum.

For a relief more than one spotlight from different direction will create a multiple shades that will confuse seeing the details. A one main direct spot light has to be applied. We conducted a visual study to see the effect of changing the angles of spotlight on a relief replica size 23 x 23 cm, made of painted polyester.(2) (Figure 2.11) We made the vertical angle fixed at V 30° and changed the horizontal angle in steps of H 15°, there was no general light in the scene. We found that the details of the relief are seen clearly under all angles except H 90°. However, the best angles are between H 30° to H 60°. Angles are >H 60° create a long undesirable cast-shadow on the wall and deep form-shadows that can alter the appearance of some details. Note that our source of light in this study was relatively a large source to the exhibits (a set of LEDs with a very narrow beam lenses fixed on a ~ 80 cm dish).(3) For a relatively small and close light source the angle will be more between H 30° to H 45°. Of course the precise beam angles and direction of light will be decided according to the size and composition of the relief and the display concept. For example, if the relief contains figures, it is better that light will fall on the face or movement of the main figure.

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1. Egyptian Sculpture, History & Characteristics of Statues, Reliefs of Ancient Egypt, < http://www.visual-arts-cork.com/ancient-art/egyptian-sculpture.htm#subjects >, (28/12/2015).
2. The Pharaonic replica was purchased from the Egyptian Antiquities Authority 3 Al-adel Abou-Bakr Street, Zamalek, Cairo, Egypt.
3. See Chapter 4, Experiment 5, as well Appendix 2 for more details of the replicas, condition and more visual study.

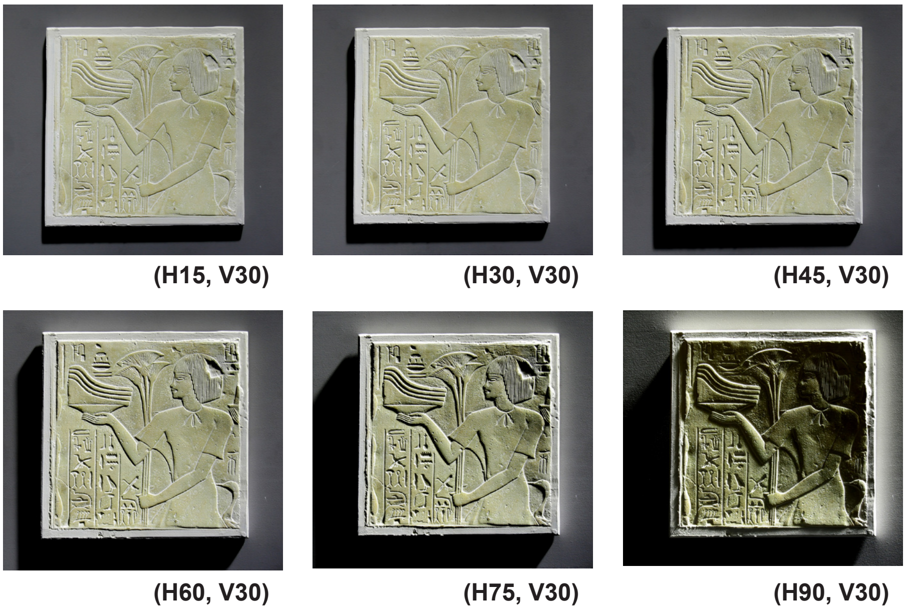

Figure 2.12 *A visual study of the effect of different light angles on a relief replica. The vertical angle is fixed at 30° and the horizontal angle is changed in steps of 15°*

For statuses that are displayed inside the museum daylighting will be the best condition of illumination. For example, statues that are arranged facing windows will have a good visual quality. (Figure 1.17 and Figure 1.75). For statues that are illuminated with artificial light, creating a pattern that is close to daylight can be achieved by ensuring that key/main spotlight has a predominantly direction, relatively large reflector, narrow beam angle and strong intensity. The relatively large reflector will insure creating a large strong highlights pattern and a narrow beam angle will insure that form-shadows have almost the same direction. A narrow beam spotlight can cover large area of the statue and have an even distribution, if it is mounted in a high position. If it is necessary to use more than one spotlight as a key light, they have to be in close direction and do not create an overlapped shadows. A secondary-reflector spotlight with narrow beam angle can achieve a good results. A bright surrounding will not help seeing the highlights evident on the statues. A moderate surrounding will be more suitable. The secondary/fill spotlight has to be in a cross direction to the key light to brighten the form-shadows and allow us to see the details in the shadow, without effecting the main pattern that is created with the key/main source. In addition, a soft spotlight can be used to illuminate the back of the statues.

The examples in (Figure 2.13) show the statue of Sekhmet (warrior and healing goddess) in different lighting situations. (a) The statue is illuminated with daylight coming from a side opening. We can realise the daylight pattern in the strong large highlights and strong forms-shadow. The directionality of light reveal the abstract cubic structure of Egyptian art via the contrast between the full-light area including the highlights and the form-shadow area. (Egyptian Museum, Cairo, Egypt). (b) A similar statue illuminated with a strong warm-white spotlights in a dark atmosphere. The statue is illuminated from different direction. The form is revealed with the strong highlights, however it lacks a clear form-shadow and its abstract cubic structure. (Egyptian Museum, Turin, Italy) (c) Two similar statue illuminated with a strong cold-white spotlights in a dark atmosphere. The spotlights has different

Figure 2.13 *Differentlighting situation for the statue of Sekhmet (warrior and healing goddess) (a) Daylighting from a side opening. (Egyptian Museum, Cairo, Egypt) (b) A strong warm-white spotlights in a dark atmosphere. (Egyptian Museum, Turin, Italy) (c) Strong cold-white spotlights in a dark atmosphere. (Museum of Art History, Vienna, Austria). (d) The gallery were the statue is displayed in previous figure .*

direction and a steep angle. The highlights is soft, as well the contrast between the full-light and the form shadow. (Museum of Art History, Vienna, Austria) (d) show the gallery were the statue is displayed in previous figure. See as well (Figure 2.4, Figure 2.8 , and Figure 2.9).

2.1.3.2 The majesty and sacredness of light

The Egyptian art is made to link the people of ancient Egypt to their beliefs and faith in life after death, thus it has a holiness and majesty in their souls. The lighting effects that are created in ancient Egyptian building were intended to add more sacredness to the places. The strong daylight beam that penetrates the darkness to highlights the statues of the deity is a vehicle to evoke a symbolic meaning and to create a spiritual experience in a religious spaces, it helps the visitors to focus their attention away from the external material world towards their inner spiritual feeling.

Therefor, the sensual experience of intense contrast between daylight and darkness can be the key to create a sacredness atmosphere.

According to Paul Goldberger [1] sacred space is not limited to purely spiritual, religious space. What gives a space the potential to become sacred can be explained in two main points: The first, it is about the timeless feeling. What is meant here is how space connects us to the rest of life. Like old historical places, areas that witnessed important events, or where people congregate together in positive fellowship can become holy. The second, is about the idea of the space not the structure. Space is intuitively less rational, and it is obviously less material. Space become sacred when the use of material forms evoke feelings that go beyond the material, and which cannot be measured. To conclude, we need only a look about us; and to feel with a new intensity the space and light, the solid and void, the sound and quiet; and listen to the presence of the past and from there look into ourselves. And then we will find the transcendent. Further, he explained that, in the modern life, we have in our culture conflated the aesthetic and the sacred. We have made the art museum the most intense arena of architectural expression today. We now use art museums as emblems of our aspirations. Perhaps, in part because the connections between art and religion, between art and the soul, are far deeper and more interdependent. However, it is not clear-cut that we elevate the aesthetic over the spiritual and made the aesthetic sacred.[2]

The explanation of Paul Goldberger about sacred spaces confirm that; sacredness can be in any space. In a museum connecting the visitors to the aura of the building, to the essence of exhibits in display, and/or to the visiting event where people gather to journey through time, will evoke the majesty and sacredness of the space. As well as, the formation of light and shadow and the idea of resembling the lighting effects that were used in ancient Egyptian architecture in a museum will add majesty and sacredness feeling to the space. A museum buildings have a strong potential to be timeless and connect people with the past.

2.1.3.3 Maintaining a visual identity of lighting

Ancient Egyptian art reached a high level in painting and sculpture, and was both highly stylized and symbolic. The Egyptian styles changed remarkably little over more than three thousand years.[3]

1. Paul Goldberger (December 4, 1950) is an American architectural critic and educator. The Huffington Post has said that he is "arguably the leading figure in architecture criticism". Paul Goldberger, <https://en.wikipedia.org/wiki/Paul_Goldberger>, (03.04.2016).
2. Paul Goldberger, Architecture, Sacred Space and the Challenge of the Modern, Chautauqua Institution, August 12th, 2010. <http://www.paulgoldberger.com/lectures/architecture-sacred-space-and-the-challenge-of-the-modern/>, (03.04.2016).
3. Art of ancient Egypt,Wikipedia, <https://en.wikipedia.org/wiki/Art_of_ancient_Egypt>,(28/12/2015).

The strong stylized and symbolic style that last without a major change for long time leads to the idea of maintaining a sense of constant lighting and display concept through out the museum space to help visitors receive a visual identity. A visual identity that represent the characteristic of Egyptian arts and artifacts.

The idea is already used in corporations. Building history reveals that companies make use of architectural design and symbols to communicate their brand identity. Consistent design concepts for retail outlets of a brand help a company to form a uniform image to the consumer for a clear brand identity. Recently, researches show that light can be an effective part in visual identity for brands in shops. Results show lighting can influence the decision to buy and have a greater emotional than functional aspect.[1]

In the first place, this shows that visual identity is an important aspect in communication between the exhibits and the observer. Revealing the aesthetics of the Egyptian arts in a constant visual image will help to connect it to the recipient. Second, it proves that lighting can be an effective part of the visual identity. The visual identity can be applicable on the statues quality of light and the impression of light in the space. (Figure 2.13 and Figure 2.14) show how different lighting qualities produce different appearances.

The quality of daylight pattern, the sacred lighting atmosphere, and the visual identity of lighting are direct aspects of lighting that can evoke and connect the visitors to the aesthetics of the ancient Egyptian arts in a museum space. On the other hand, the Egyptian art characteristics like order, clarity, and the association with architecture are more related to the display and the architecture of the museum. The concept of the display and the architecture can add much to the feeling of the space and the artifacts. Architecture elements and its order and size, and how the artifacts are organized in the space can directly evoke the since of majesty and sacredness and connect the visitor the display. In any way whatsoever, the architecture and display cannot be separated from the lighting.

(a) (b) (c)

Figure 2.14 *A statue of Akhenaten in three different lighting. Note the differences in shadows pattern and light CCT on the statue's stone-colour.*
(a) Diffuse daylight. (Egyptian Museum, Cairo, Egypt - https://en.wikipedia.org/wiki/Akhenaten)
(b) Artificial light with soft shadow patterns. (King Tut exhibit at the Seattle Center, Seattle, USA - http://arabiczeal.com/king-tut-seattle/)
(c) Artificial light with strong shadow patterns. (Egyptian Museum, Cairo, Egypt).

1. T. Schielke & M. Leudesdorff, Impact of lighting design on brand image for fashion retail stores, Lighting Research and Technology, 2014.

2.2 Lighting and exhibition in Egyptian museums

Discussing the artifacts lighting cannot be completed without discussing the design of exhibition. Exhibition design is, above all, about the planning of interpretive spaces. Rather than additive process, exhibition design is a simultaneously networked, dialectical process, one which develops in a dialogue between verbal-conceptual and visual-representational rhetorical techniques.(1) Lighting is a key factor in Exhibition design since it affects the perception of the exhibits, the intuitive guidance of visitors, and the quality of atmospheres in the space.(2) Exhibition design can be part of the architecture program, as well, it can be independent. Exhibition design overlaps a wide range of design subjects in order to communicate clearly.(3)

There are a big number of museums around the world presenting the Egyptian artifacts.(4) We selected some examples that help to demonstrate different lighting and exhibiting concepts of Egyptian artifacts.

2.2.1 Museum of Art History in Vienna

Ancient Egyptian Collection in Kunsthistorisches Museum (The Museum of Art History), Vienna, Austria, 1891; is one of the oldest Egyptian collection that was presented to the public. The rooms where the collection presented are decorated in an Egyptianesque design (resembling of a Egyptian style), and this was part of the original plan of the architects, Gottfried Semper and Carl von Hasenauer. Unique is the reuse of three original Egyptian monolithic columns more than six metres in height, instead of the marble pillars, to support the ceilings of the main halls. The columns, which had been excavated in Alexandria, were a gift to Emperor Francis Joseph I in 1869. Also worthy of note are the murals on paper, which lend the large halls a special character. They are copies of mural paintings from the tomb of Prince Chnumhetep at Beni Hassan in Middle Egypt and were made by Ernst Weidenbach for the Vienna International Exhibition of 1873.(5) Decoration that resemble the presented styles was often used in historic museum of the 19th century. We can find a similar Egyptianesque design in the Neues Museum in Berlin, Germany. It is an attempt to create an atmosphere that gives the feeling that you see the artifacts in its original atmosphere. (Figure 2.15)

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1. Hartmut John, Ulrich Schwarz, and Philipp Teufel; Museographie und Ausstellungsgestaltung, Ludwigsburg, 2001, p57.
2. Bertron Schwarz, designing exhibitions, A Compendium for Architects, Designers and Museum Professionals, Birkhäuser, Switzerland, 2006, p90.
3. Pam Locker, Basics of Interior Design 2, Exhibition Design, AVA Academia, Switzerland, p7.
4. List of museums of Egyptian antiquities can be found in the following link, <https://en.wikipedia.org/wiki/List_of_museums_of_Egyptian_antiquities>, (05,04,2016).
5. Egyptian and Near Eastern Collection, History of the collection,< http://www.khm.at/en/visit/collections/egyptian-and-near-eastern-collection/history-of-the-collection/>, (05,04,2016).

The illumination of the current situation depend on: covering the large windows in the main halls with screens to reduce their illumination and generate a general diffuse room-lighting, and to use tracks of spotlights on the sides of the beam in the middle of the ceiling as exhibits lighting. Showcases are internally illuminated. Objects is very clearly seen and the room has a general quite atmosphere. (Figure 2.15)

Some other rooms where Ancient Egyptian Collections are presented have another settings of decoration and lighting. (Figure 2.13 c - d)

Figure 2.15 *The large first hall where the ancient Egyptian collection presented are decorated in a Egyptianesque design, as attempt to create the feeling of seeing the artifact in their original atmosphere. (Ancient Egyptian Collection in the Museum of Art History, Vienna, Austria).*

2.2.2 The State Museum of Egyptian Art in Munich

One of the newest museum built specifically to contain the Ancient Egyptian artifacts is The State Museum of Egyptian Art, Munich, Germany, 2013. The museum is part of The University of Television and Film Munich building and it was designed by the architect Peter Böhm.[1] The project was inspired by an ancient Egyptian burial chamber and built under the ground level.[2] Via a separate forecourt in the shape of a flat, gently sloping ramp with steps, visitors can access the lowered entrance to the museum that is marked by a large, shear wall.[3] The wall resemble a pavilion of an Egyptian temple and serves as a landmark for the museum in the surrounding urban. (Figure 2.16)

Since the visitors are going to enter a series of low illuminated galleries, the visual adaptation was considered carefully in the visiting round. The spaces were organized that the visiting tour starts in a two daylit large halls, then a series of galleries illuminated with low level of artificial light, then the tour ends passing the two daylit halls to the entrance lobby. And there is no direct visual contact between the daylit halls and the low illuminated galleries. (Figure 2.17)

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1. Staatliche Sammlung für Ägyptische Kunst, (State Museum of Egyptian Art), <https://en.wikipedia.org/wiki/Staatliche_Sammlung_f%C3%BCr_%C3%84gyptische_Kunst>, (05,04,2016).
2. Previous reference.
3. University Of Television And Film By Peter Böhm Architekten, < http://111-architecture.blogspot.co.at/2015/03/university-of-television-and-film-by.html>, , (05,04,2016).

Figure 2.16 *The main facade of University of Television and Film, in Munich, Germany; Where The State Museum of Egyptian Art is accommodated. Note the entrance of the museum is at the large shear wall that resemble a pavilion of an Egyptian temple. (http://111-architecture.blogspot.co.at/).*

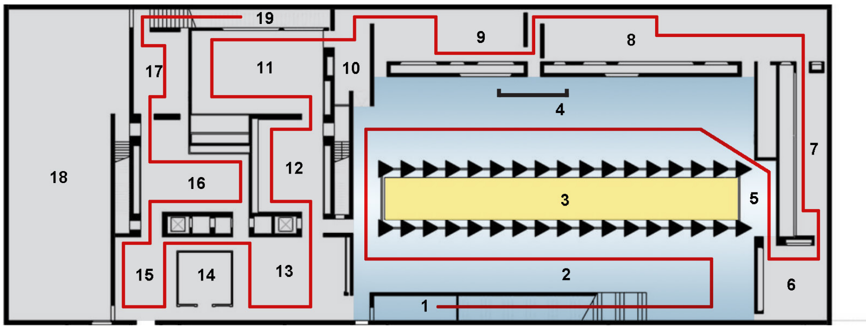


Figure 2.17 *The State Museum of Egyptian Art , Munich, Germany. A plan for the exhibition area on the underground level.*

(1) Large steps descending from the lobby to the underground level .
(2) Art and form (first hall)
(3) Daylit courtyard
(4) Art and form (second hall)
(5) Obelisk
(6) Pharaoh
(7) Five thousand year
(8) Beyond believe
(9) Religion
(10) Egypt in Rome
(11) After the pharaohs
(12) Writing and text
(13) Crafts
(14) Media room
(15) Grasping Egypt
(16) Nubia and Sudan
(17) Old Orient
(18) Temporary exhibition
(19) Large steps ascending to the lobby.

Colour symbols: Yellow: daylit courtyard, Blue: galleries lit by daylight, Gray: galleries lit by artificial, and Red line from 1-to-19: visiting direction. (According to: official Museum brochure, and http://111-architecture.blogspot.co.at/).

The exhibit spaces are built under ground level. The visitor descend from the entrance lobby on a large shallow steps to enter the first large hall. The first hall is connected to the second hall via a small corridor. The two large halls are for displaying statues and reliefs; and they are arranged parallel to a daylit courtyard, which allow the daylight to enter the halls. Each hall is opened from one of its long sides to the courtyard. The daylight enter the halls through tall glass windows about seven meters high. The windows are arranged between a large concrete columns has triangle section in plan. The view in the long depth of the hall reveal how daylight enter the hall with a very good light distribution. In sunny days windows are covered with a motorized screens to block the direct sun from entering the gallery. However, when the sun falls directly on the screens, the screen become very bright and seeing the statues standing in front of the windows become uncomfortable, and this as will create a veiling reflection on showcases glass especially for those with dark interior. (Figure 2.18)

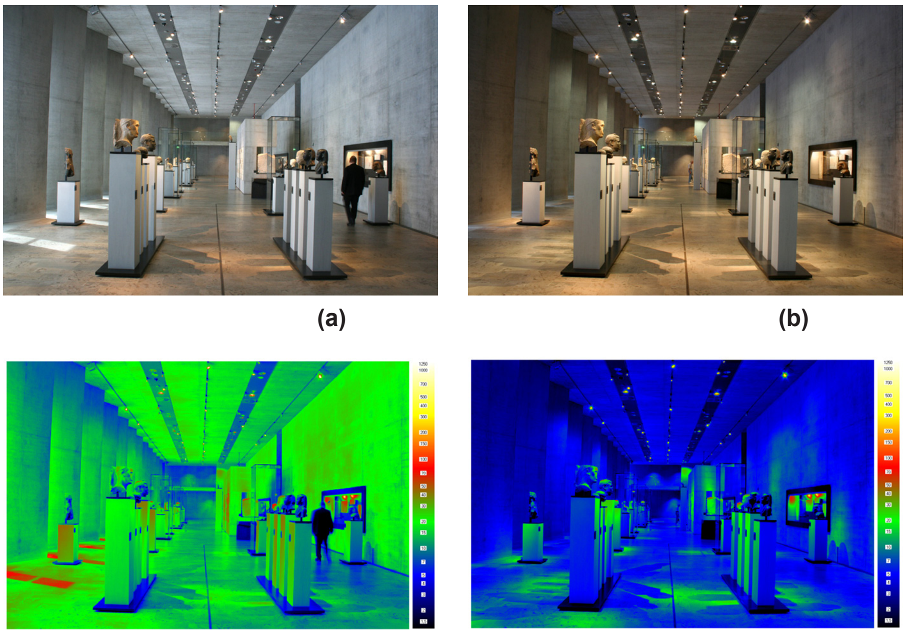
The artificial light in the two halls, as well in the all galleries, are track mounted LED spotlights that are integrated in the ceiling giving a flexibility in positioning and locating the spotlights. The spotlights have a warm CCT that do not fully match with daylight. Parallel to the lighting tracks there are built in ceiling channel contain cleaning light, loudspeakers, security cameras, and air conditioner grills. (Figure 2.18)

The minimal exhibition design by Die Werft in collaboration with M. Kammermeier insure that the whole focus of attention is on the extraordinary objects of the collection. The materials used to showcase the exhibits are limited to blackened steel, exposed concrete and nonreflective glass. The combined effect of the ultra-modern, linear ambience and dramatic architecture serves as a contemporary stage for these masterpieces from ancient Egypt.[1]

1. Die Werft, State Museum of Egyptian Art, <http://www.diewerft.com/en/projects/state-museum-of-egyptian-art.html>, (12.04.2016).

During several visit to the museum, I realized that even if it is a daylight gallery the artificial lights are always turned on. Thus, daylight is serving as general illumination, in spite of its wonderful distribution in the space. In summer 2015, I managed to photograph and analysis two different light situation in the second halls with a luminance camera. (Figure 2.19, with a permission from the museum authority) In that day, the sky condition was a sunny clear sky except of few white clouds. Museum windows were covered with internal screen. The first photo was taken when the sun was falling on the screens and the level of daylight illumination were high. The hall has a bright daylight atmosphere with cold-whit light. The second photo was taken when the clouds blocked the sun and only the sky diffuse light was falling on the screen. Once the daylight abate the artificial light atmosphere emerge strongly to the eye. The artificial light now is more dominating and the daylight

Figure 2.18 *The first hall. The large shallow steps descend from the entrance lobby. The hall is illuminated with daylight and artificial light; and it is for displaying statues and relief. (Gallery 2 in Figure 2.17) (The State Museum of Egyptian Art, Munich, Germany).*



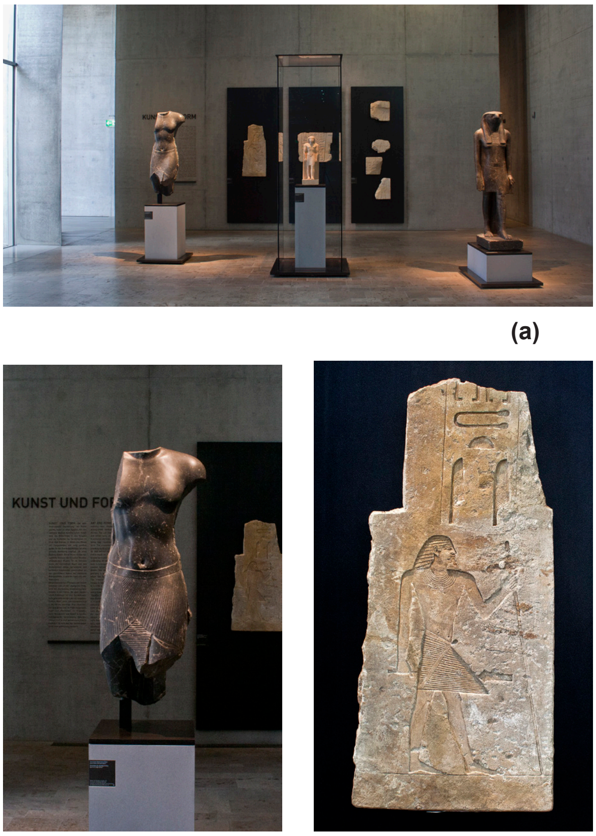
(a) (b)

(c) (d)

Figure 2.19 *Two different light situation for the second hall. (Gallery 4 in Figure 2.17) The hall is illuminated with daylight and artificial light. (a) The level of daylight illumination is high. The hall has a bright daylight atmosphere with cold-whit light. (b) The level of daylight illumination is decreased. The the warm colour of the artificial light become dominant. (c) Surrounding average luminance for the first situation is ~ 16.8 cd/ m². (d) Surrounding average luminance for the second situation is ~ 5,7 cd/m². The luminance scale values are in cd/m2: Approx. white 1250, yellow 350, orange 200, red 80, green 20, and blue 4. (The State Museum of Egyptian Art, Munich, Germany).*

is only the general illumination. The artificial light do not really follow the direction and distribution of the daylight. The beauty of daylight will be more emphasized, if the statue faced the daylight and the artificial light have the same direction and CCT of the daylight. From the luminance photo we can realize that the distribution of daylight did not change and daylight intensity is only reduced. In the first, the bright situation, the average luminance for the surrounding is ~16.8 cd/m^2, for the white stone statue is ~15.82 cd/m^2, and for the black polished stone statue is ~5.32 cd/m^2. In the second, the dim situation, the average luminance for the surrounding is ~5,76 cd/m^2, for the white stone statue is ~7.11 cd/m^2, and for the black polished stone statue is ~2.72 cd/m^2. In both situations the relationship between the statues brightness and the background brightness was comfortable and very acceptable.

The two halls contain free stand statues, relief displayed on the walls, and long frame-less showcases with anti reflective glass. Additionally, in the second hall there are two wall integrated show cases. The day light large opening and the strong LED spotlights create a large strong highlights pattern on the statues emphasizes the material and the details of the black statutes. The differences between the correlated colour temperature (CCT) of the daylight and the artificial light on the statues are noticeable. Reliefs are displayed on a black metal boards to have strong contrast, and it is illuminated with the diffuse daylight and a direct strong LED spotlight that helps to create strong shadows that emphasis the relief lines. Showcases have about 3 m height and are wide compared to statues displayed. This gives more space around the exhibits which



(a) (b) (c)

Figure 2.20 *The first set of exhibits that face the visitors descending to the first hall. (a) A general view. (b) A close photo for the black statues. (b) A close photo for one of the displayed relief on the wall. (Gallery 2 in Figure 2.17) (The State Museum of Egyptian Art, Munich, Germany).*

helps to view it, avoiding the sense that it is locked up, and allows to direct the light on the exhibit through the top of the showcases to avoid creating glare and villain reflection. (Figure 2.20 and Figure 1.16).

Follow the two large daylit halls a series of dim galleries lit with artificial light. (Figure 2.17) The galleries contain sensitive-to-light artifacts like: coloured relief, painted wood furniture and coffins, fabrics, papyrus; as well, small statues and tools from different materials. The exhibits are organized and displayed in a free stand showcase, integrated show cases in the walls, or presented on the wall behind a glass protection. The artifacts are illuminated by LEDs track spotlights and showcase are illuminated from a concealed spotlights in a chamber that is integrated above the showcases. The reflected light from the artifacts and the showcases light the space, there are no general illumination. The spotlights and showcases light in the dim atmosphere accentuate the exhibits and create many visual interest points in the space. The concrete colour and texture of the walls with the low illumination gives a tranquil atmosphere. The exhibits' direct dark background have a strong contrast with the exhibits and make it more visible in low illumination. (Figure 2.21 to Figure 2.24, and Figure 3.41 to 3.44).

In (Figure 2.21) is the first dim lit gallery (Beyond believe). The average luminance for the surrounding is ~3 cd/m^2. According to the concrete mid toon light reflectance value of 30%, the walls have average illuminance of ~32 lux. The average luminance for the reliefs is ~6.6 cd/m^2 and the golden mask is ~18.7 cd/m^2.

Figure 2.21 *The first dim lit gallery Beyond believe (Gallery 8 in Figure 2.17). (The State Museum of Egyptian Art, Munich, Germany).*

Figure 2.22 *The second dim lit gallery Religion (Gallery 9 in Figure 2.17). (The State Museum of Egyptian Art, Munich, Germany).*

Figure 2.23 *The dim lit gallery Nubia and Sudan. (Gallery 16 in Figure 2.17)(The State Museum of Egyptian Art, Munich, Germany).*

Figure 2.24 *A close photo fore one of the showcases in the gallery After the pharaohs. (Gallery 11 in Figure 2.17) (The State Museum of Egyptian Art, Munich, Germany).*

2.2.3 The Neues Museum in Berlin

The Neues Museum (New Museum) is located to the north of the Altes Museum (Old Museum) on Museum Island in Berlin, Germany. It was built between 1843 and 1855 according to plans by Friedrich August Stüler, a student of Karl Friedrich Schinkel. The museum was closed at the beginning of World War II in 1939 and was heavily damaged during the bombing of Berlin. The rebuilding was overseen by the English architect David Chipperfield. The museum officially reopened in October 2009. Exhibits include the Egyptian and Prehistory and Early History collections, as it did before the war.(1)

The original museum design concept aimed to link the exhibits and exhibition spaces in a symbiotic relationship. For that, the galleries interior were built and decorated in a resembling style to the exhibits' style. However, for the rebuilding and restoration of the building this concept had not only lost its appeal for the contemporary visitor but in many cases could simply no longer be recreated since much of the original material, both artefacts and rooms, no longer existed.(2) In (Figure 2.25), the red drawing indicates the areas that were damaged and newly rebuilt.

1. Neues Museum, Wikipedia, <https://en.wikipedia.org/wiki/Neues_Museum>, (10.04.2016).
2. David Chipperfield Architects, Neues Museum, <http://www.davidchipperfield.co.uk/downloads/projects/11/neuesmuseum_dca.pdf>, (10.04.2016).

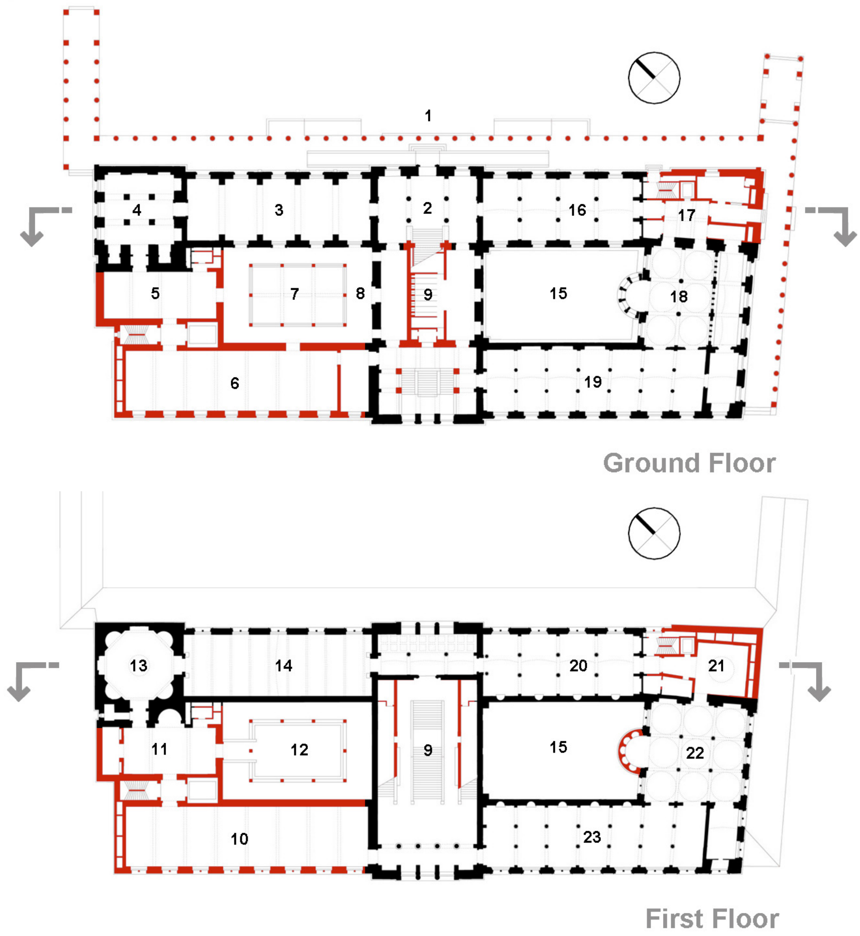


Figure 2.25 *The ground floor and first floor of The Neues Museum, Berlin, Germany.*

(1) Main entrance
(2) Vestibule (Lobby)
(3) Egyptology gallery
(4) Pharaoh gallery
(5) The human form gallery
(6) Temple reliefs gallery
(7) Courtyard balcony
(8) Egyptian courtyard
(9) Staircase
(10) Sculptural types gallery
(11) Amarna period gallery
(12) Platform gallery.
(13) North cupola gallery.
(14) Ancient Library.
(15) Greek courtyard
(16) Patriotic gallery
(17) South entrance
(18) Flat dome gallery
(19) Ethnographic gallery
(20) Roman gallery
(21) South cupola gallery
(22) Middle Ages gallery
(23) Modern gallery

Note: The red colour is the reconstructed parts. According to: (www.davidchipperfield.co.uk/), (https://en.wikipedia.org/wiki/Neues_Museum), (www. proyectos4etsa.wordpress.com), and (http://www.egyptian-museum-berlin.com/c43.php)

Figure 2.26 *Longitudinal section in the main entrance and the north-west wing. The Neues Museum, Berlin, Germany. (https://processionalcity.wordpress.com/tag/chipperfield/)*

The new concept considers that, the ruin should not be interpreted as a backdrop for a completely new architecture; as well, the exact reconstruction of what had been irreversibly lost in the war should not be seen as an option. A single continuous structure that incorporates nearly all of the available damaged fabric while allowing a series of contemporary elements to be added became the preferred path. The process can be described as a multidisciplinary interaction between repairing, conserving, restoring and recreating all of its components.[1]

1. Previous reference.

(a) (b)

Figure 2.27 *The Egyptian Courtyard in The Neues Museum, Berlin, Germany. (a) The original form with its Egyptian style and collection. (Space 7 in Figure 2.25) (http://www.egyptian-museum-berlin.com/c01.php). (b) The new constructed courtyard after restoration.*

(a) (b)

Figure 2.28 *The grand staircase in The Neues Museum, Berlin, Germany. (a) The original staircase before the world war two. (b) The new constructed staircase after restoration. (Space 9 in Figure 2.25) (https://proyectos4etsa.wordpress.com/tag/david-chipperfield/)*

The survived structure was restored. The gaps in the existing structure are complemented and filled in without competing with the original structure. The new constructed parts, the new exhibition rooms, the new main stair case, and a big part of the north-west wing, are built of large-format prefabricated concrete elements consisting of white cement mixed with Saxonian marble chips. The white neutral colour and the modern minimalist style of the new built parts emphasize spatial context and materiality of the original structure. The concept is that the contemporary reflects the lost but without imitating it.[1] (Figure 2.25 to Figure 2.28)

The Neues Museum was the first three-storey museum ever built and was executed according to a simple ground plan that enclose two courtyards and a central stair hall that rose through all floors and occupied the full width of the building.[2] (Figure 2.25) According to my visit to the museum in 2014, The Egyptian artifacts are exhibited in the ground and first floor in the north-west wing, as well in the basement.

The museum originally was open only during the day and relied heavily on daylight via large windows and courtyards with glass roofs. The architect and lighting designer (Kardorff Ingenieure Lichtplanung)[3] collaborated to create a sequence of harmonious and fluid spaces. The light is meant to be seen and the architects wanted the visitor to be aware of the changing light conditions inside and outside.

1. Previous reference.
2. Previous reference.
3. Kardorff Ingenieure Lichtplanung, Neues Museum, < http://www.kardorff.de/en/project/neues-museum>,(12.04.2016).

Figure 2.29 *(left) The Greek courtyard in The Neues Museum, Berlin, Germany. (Space 15 in Figure 2.25)*

Figure 2.30 *(right) The uppermost gallery on the free-standing platform in the Egyptian courtyard in The Neues Museum, Berlin, Germany. (Space 12 in Figure 2.25)*

The daylighting studies led the lighting design team to develop a series of sun-shading and glare-control strategies for use in all of the galleries windows, a dark gray coloured shades with a perforation pattern protect the interiors from glare and direct sunlight. The resulting effect corresponds to the needs for a reduced daylight factor, while at the same time retaining the excellent view. The artificial lighting scheme complement the daylight entering the museum as well as enhance the readability of the art work. While still responding to the specific needs of each space and of the artifacts on display. The artificial lighting scheme complement the daylight entering the museum as well as enhance the readability of the art work. While still responding to the specific needs of each space and of the artifacts on display.[1]

The daylight scheme for the two grand spaces, the Greek and Egyptian courtyards depends on daylight in different ways. In the Greek Courtyard, a clear glass roof encloses admitting direct sunlight into the space without any shading device. This approach is permissible since all the art on display are irresponsive to light; like sculptures, statues, bas-reliefs, and a cornice frieze depicting the destruction of Pompeii. To balance the natural light but also enhance the readability of sculptural details, the lighting team mounted projectors using 150 W metal halide lamps between the two layers of the glass roof. A shutter attached to the luminaires allows important features on the base reliefs to be highlighted without creating hard shadows and hot spots on the walls.[2] (Figure 2.29)

In the Egyptian Courtyard, which houses galleries on three different levels, the lighting design has a different lighting approach. The structure still consist of a double-layer glass system. However, it is constructed form diffuse glass with a light transmittance of 71% for the

1. Elizabeth Donoff, Classical Revival, Architectural Lighting Magazine, <http://www.archlighting.com/projects/classical-revival_o?o=0>,(12.04.2016).

2. Previous reference.

visible layer and a clear glass for the second, outer layer. The diffuse light illuminates the uppermost gallery on the freestanding platform whose new columns reach ceiling. (Figure 2.30) Custom-designed floodlights with 150 W halogen lamps positioned 16 inches from the glass add the necessary illumination balance. The floodlights are spaced on four tracks. The fixtures on the two outer tracks are positioned at a 15°angle to illuminate objects from the Egyptian collection and fragments of landscape frescoes that remain on the courtyard balcony walls of the level below.[1] The ground level of the courtyard contain heavy exhibits of sarcophagi and statues. The exhibits are illuminated with spotlights that accentuate the exhibits and create a strong effect. The spotlights are integrated in the ceiling in a custom made units. The general illumination generated from the reflected exhibits lighting and daylight entering this level from the courtyard balcony. The peripheral area under the courtyard balcony contain different artifacts. It contains sarcophagi, integrated showcase in the wall contains parts of wooden coffins, and collection of papyrus displayed on the walls. The artifacts in this area are illuminated with spotlights and the general light are fluorescent lamp luminaires. (Figure 2.27 - b)

The impressive grand staircase with its six meter-high windows on both end walls is intensively lit by natural light. The artificial lighting is added in stages as needed depending upon the time of day.[2] The artificial lighting is installed in the coffers of the oak ceiling, since the walls were meant to stay free of any kind of fittings. Only the display of several frieze reliefs is permitted. A uniformed homogeny lighting was required on the exposed brick walls and light-scalloping were avoided. Accordingly, a custom mad luminaire with two to four 35 W metal halide lamps are designed. The luminaire have bronze finish that matches the architecture material palette.(Figure 2.28 - b)

The vast differences between the spaces and the restrictions imposed by the conservation project made the development of more than a hundred individual customized luminaires necessary, which all needed to follow the overall lighting concept.[3]

In historical rooms restored elements cannot be touched by lighting installations, thus new ideas have to be developed for the lighting installation. In the first space in the Egyptian exhibition on the ground floor in the north-west wing, The Egyptology (or Egytomania) Gallery, was created to mimic the Egyptian style. (Figure 2.31). The room wall was painted with yellow ochre and bright blue colours resembling the desert and the sky. The ceiling and cornice were decorated with old Egyptian temple drawings. The doors are decorated with large frames with Egyptian gorge cornice (cavetto cornice). The exhibits are displayed in elegantly black metal showcases with anti-reflective glass. The exhibits

1. Previous reference.

2. Kardorff Ingenieure Lichtplanung, Neues Museum, < http://www.kardorff.de/en/project/neues-museum>, (12.04.2016).

3.Previous reference.

Figure 2.31 *The Egyptology Gallery is illuminated with daylight from the windows on both sides and with spotlights integrated in the beams between the pillars. (Gallery 2 in Figure 2.25) (The Neues Museum, Berlin, Germany).*

(a) (b)

Figure 2.32 *The Pharaoh Gallery. (a) The exhibits are illuminated with mounted track spotlights. (b) The uneven lighting of the coloured relief give it a dramatic appearance. (Gallery 3 in Figure 2.25) (The Neues Museum, Berlin, Germany).*

mostly are archaeological paper documents and different types of small artifacts. The daylight enters the room from large windows from both sides. Daylight is controlled with a dark gray coloured shades that cover the windows. The artificial light complement the daylight and helps to accentuate the exhibits. The whole ceiling is decorated, thus the designer created a new extension to the beams between the pillars to instal and conceal the artificial light fixtures. The room has a bright soft lighting atmosphere.

Along the axis of The Egyptology Gallery and through the exit door, we see a strong illuminated dark-gray statue that contrast with its black background dragging our attention to the next gallery, "The Pharaoh Gallery" (Figure 2.32). The gallery contain stone statues and coloured relief that are illuminated with mounted track spotlights in the ceiling. The windows in the gallery are closed and the general illumination in the room depends on the reflected light from the exhibit. The gallery has a dramatic atmosphere, that is gained from the appearance of the strong illuminated exhibit against the low illuminated surrounding.

The Pharaoh Gallery on the ground floor are followed by the Human Form Gallery and the Temple Reliefs Gallery. Above these two galleries in the first floor there are the Sculptural Types Gallery and the Amarna Period Gallery. All four galleries are part of the newly constructed sections in the north-west wing. All galleries have the same architecture features and the same lighting installation. Some of the galleries have windows and other not. (Figure 2.25 and Figure 2.35 to- Figure 2.37)

All finishing material in the new galleries have off-white colours. The walls and ceiling finishing is from white cement mixed with marble chips and the flooring material is off-white terrazzo. A custom made units contain spotlights, general lighting, and technical equipment, such as loudspeakers, are integrated into prefabricated ceiling elements. The exhibits, ranging from large sculptures to the smallest of gold objects, are illuminated with the spotlights.[1] Three types of light sources used in the galleries are: 35W and 50W tungsten halogen spotlights with 6° and 26° beam spreads; QR111 35W and 50W lamps with 4° and 8° beam spreads; and 50W to 65W IRC lamps with an 8° to 24° beam spread. For general lighting, fluorescent and metal halide sources are used.[2] The result is a generous and homogenous light atmosphere. Through optimal use of lamps, the power required is a maximum of 20 W/m^2. (The grand staircase and courtyards approximately 10 W/m^2).[3]

Figure 2.33 *(left) The Human Form Gallery. On of the new built gallery in the ground floor. The gallery display small statues in tall glass showcases. (Gallery 5 in Figure 2.25), (The Neues Museum, Berlin, Germany).*

Figure 2.34 *(right) The Berliner Green Head, Late Period, Dynasty 30, ca. 350 BC. One of the very famous displayed prices in the Human Form Gallery. (Gallery 5 in Figure 2.25), (The Neues Museum, Berlin, Germany).*

1. Kardorff Ingenieure Lichtplanung, Neues Museum, < http://www.kardorff.de/en/project/neues-museum>, (12.04.2016).
2. Elizabeth Donoff, Classical Revival, Architectural Lighting Magazine, <http://www.archlighting.com/projects/classical-revival_o?o=0>,(12.04.2016).
3. Kardorff Ingenieure Lichtplanung, Neues Museum, < http://www.kardorff.de/en/project/neues-museum>, (12.04.2016).

Exhibits are displayed in glass showcases, large statues stand freely on a off-white bases, and reliefs are displayed behind glass panels. The bright lit exhibits in the dim surrounding has a dramatic effect and the dim off-white surfaces of the gallery widen the space.

Follows the new constructed gallery on the first floor a restored gallery, the North Cupola Gallery, where the famous bust of Nefertiti is exhibited. The Nefertiti bust is a life-size, full coloured bust. It is placed in a octagonal space with a large dome. Daylight enters the doom from a circular opening to slightly illuminate the space revealing its old decoration and emphasis its form. The Nefertiti bust is the only piece of art in this very large space. It is displayed in a tall showcase in the centre of the space to be the focal point. It is placed slightly higher than eye level so observers look up at it. (Figure 2.38)

Figure 2.35 *Entrance to the offering chapel of Nefer-bau-Ptah. The controlled daylight and the uneven spotlights illumination on the entrance relief give a dramatic effect. Temple Reliefs Gallery,· (Gallery 6 in Figure 2.25), (The Neues Museum, Berlin, Germany).*

Figure 2.36 *The general lighting atmosphere at late afternoon in the Sculptural types Gallery. (Figure 2.25 - Gallery 10) (The Neues Museum, Berlin, Germany).*

Figure 2.37 *A block sitting statue at the Sculptural Types Gallery. The strong artificial light emphasise the geometry of the statue and overcome the silhouette effect that can occur as a result of the bright windows in the background. (Gallery 10 in Figure 2.25) (The Neues Museum, Berlin, Germany).*

The bust is illuminated with two sets of spotlights with very narrow beam. The first set consisting of 16 spotlight. The spotlights are mounted on a track system that is located in the existing cornice that rings the gallery. These spotlights are distributed evenly around the space, and they give the general illumination for the statue from all direction. The other set consisting of 5 spotlights that are mounted on a lower level, on a cornice between the arches. "The 5 spotlights have 50W halogen sources with a 4° beam spread. The spotlights are distributed two on the bust's backside, one on its right side, one on the front, and one directly on the pupil of her eye".(1) The second set of spotlights have more intensity then the first set. It is the main lighting that gives the statue its form shadows. (Figure 2.38 and Figure 2.39)

Follows the North Cupola Gallery the Ancient Library. It is an old restored gallery that contain large vertical showcases to display Egyptian papyrus. (See Ch.3 Figure 3.45 and Figure 3.46). By the Ancient Library the journey in the Egyptians collection in the first floor come to an end. The rest of the Egyptian collection are displayed in the basement on the same level of the Egyptian courtyard. Some of the galleries are newly built and have the same architecture and lighting features as other newly built galleries in the museum; others are restored. The old basement galleries have cross vaulted ceilings. The general illumination is indirect light created by spotlights that are directed to the cross vaulted ceiling. Exhibits are mostly displayed in showcases. Some of showcases are illuminated by spotlights from outside and other with "fiber optic lighting employing 150W 3000K lamps".(2) (Figure 2.40 and Figure 2.41)

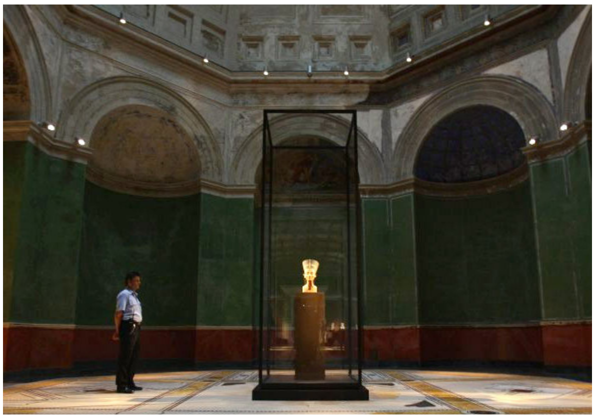


Figure 2.38 *(left) The North cupola gallery, where the famous bust of Nefertiti is exhibited in The Neues Museum, Berlin, Germany (Gallery 13 in Figure 2.25), (http://illicit-cultural-property.blogspot.co.at/).*

Figure 2.39 *(right) The bust of Nefertiti in The Neues Museum, Berlin, Germany. (https://en.wikipedia.org/wiki/Nefertiti).*

Figure 2.40 *(left) A group of showcase in the Journey to the underworld gallery, in the basement of The Neues Museum, Berlin, Germany.*

Figure 2.41 *(right) A showcase in the Nile valley habitat gallery, in the basement of The Neues Museum, Berlin, Germany.*

1. Elizabeth Donoff, Classical Revival, Architectural Lighting Magazine, <http://www.archlighting.com/projects/classical-revival_o?o=0>,(12.04.2016).
2. Previous reference.

2.2.4 The Kings Gallery in Museo Egizio

The Museo Egizio (Egyptian Museum in Turin, Italy) is the oldest of its kind with nearly 200 years and is considered the most important collection outside Cairo.(1) During my visit to the museum in 2009, I took some photos and collected information about the museum. One of the unique galleries in the museum, is the Kings Gallery. The gallery consist of two long rectangular spaces parallel to each other contain an extraordinary collection of large statues representing the gods and kings of ancient Egypt.

The display and lighting concept for the Kings Gallery are designed by Dante Ferretti(2), who focused his treatment of the subject on a sense of mysticism. He decided to encase the exhibits in a medium that would give the public the same perception of the sacred. The light that envelops the statues is carefully metered, and reflections have been created that cancel out the empty space surrounding them, and enhance the plasticity of the shapes. The gallery has dark red coloured skin and a dark mirrors covers the walls. Accent lighting provided by spot-lights mounted and concealed in a black lover ceiling hanging from the original ceiling of the gallery. The accent light enhance the exhibits by bringing them up out of the dark depths. The exhibition is completed by images projected onto the walls, new captions and an atmospheric sound accompaniment. The interplay of light and shadow augmented by mirrors, the particular illumination of the statues, the slow moving images and, not least, the sound track, all accompany the visitor on a truly fascinating visual journey.(3) (Figure 2.13 and Figure 2.42).

Figure 2.42 *One of the two identical species of the Kings Gallery. The statues is illuminated with strong spotlights and the reflected light illuminate the space. The parallel mirror at the end of the space enlarge the space. The whole setting give a theatrical atmosphere. (The Egyptian Museum in Turin, Italy.)*

1. Museo Egizio, Wikipedia, <https://de.wikipedia.org/wiki/Museo_Egizio>, (17.04.2016).
2. Dante Ferretti (born 26 February 1943) is an Italian production designer, art director and costume designer. Reference: Dante Ferretti, Wikipedia, <https://en.wikipedia.org/wiki/Dante_Ferretti>, (17.04.2016).
3. Iguzzini, Art Places and Cultural Spaces, Turin - Italy: Egyptian Museum, p33.

After five years of conversion work without interruption and opening of the city of Turin invested cost of 50 million euros, the museum was re-opened on schedule on April 1, 2015.(1) A big parts of museum display were changed; and all lighting fixtures were changed from conventional to LED lighting. However, the original display and lighting concept of the Kings Gallery did not changed.(2)

2.2.5 The New Statues Gallery in Luxor Museum

Luxor Museum in Luxor, Egypt, opened in 1975. The museum is housed in a small, purpose-built building. Among the most striking items on show are grave goods from the tomb of Tutankhamun and a collection of 26 well preserved New Kingdom statues that were found buried in a cache in nearby Luxor Temple in 1989. The royal mummies of two pharaohs - Ahmose I and Ramesses I - were also put on display in the Luxor Museum in March 2004, as part of the new extension to the museum, which includes a small visitor centre.(3) (Figure 3.49)

Who enter the New Statues Gallery descend few steps down narrow stair, resembling entering an ancient Egyptian tomb, to find himself in the main space of the New Statues Gallery. The small stairs lead to a nave that goes between two platforms, where six large statues stand facing each other, and at the end of the nave stands the statue of Amenhotep the third. A sloped wall on the right and the lift side of every statue, work as a partition that define a zone for every statue. The zones around the statues are large enough that visitors can go up the platform and move around the statues to see it from all direction. Every statue is illuminated with five ceiling recessed downlights. The downlights distributed as follows: two on every side of the statue and one from the front. The strong lights intensity create strong highlights on the dark statues and the sloped walls help to reflect the light back to fill in the form-shadows of the statues. The sloped walls create zones of light around every statue. The general illumination is generated from the reflected light from every zone. The yellow colour of the walls and the ceiling; and the bright page colour of the marble floor resemble the colour of the temples and the desert. The gallery's bright colour scheme helps to emphasize the dark statues and makes it apparent in the space. The end effect is well lit statues standing in island of light in moderate lit space. (Figure 2.43 and Figure 2.44)

2.2.6 The Mummification Museum in Luxor

The Mummification Museum, Luxor, Egypt, opened in 1997; is a museum dedicated to the art of Ancient Egyptian mummification. The museum have one exhibition space; where it display Coffins, animals and human mummies, tools and material used in mummification, and

1. Museo Egizio, Wikipedia, <https://de.wikipedia.org/wiki/Museo_Egizio>, (17.04.2016).
2. La importancia de la luz en los museos, Philips, <nhttp://www.tendenciasenilu-minacion.philips.es/la-importancia-de-la-luz-en-los-museos/>, (17.04.2016).
3. Luxor Museum, Wikipedia, < https://en.wikipedia.org/wiki/Luxor_Museum>, (17.04.2016).

Canopic jars (Used to save the guts of the Dead).[1] For conservation aspects all these artifacts need to be displayed in showcases and to be illuminated carefully with no more than 50 lux. The illumination concept depends on ceiling mounted spotlight tracks to illuminate the exhibits from the upper surfaces of the showcases and to generate general lighting from reflected light. To generate and control the reflected light in the space, the showcase interiors are white and the finishing material of the space is dark. As well, a great amount of light is reflected from the bright boards on the walls back into the space. The dark atmosphere helps to control the levels of illuminations for conservation aspects and to raise exhibits brightness with less amount of light. (Figure 2.45)

Figure 2.43 *Ageneralview of The New Statues Gallery. The partition between the states control the distribution of light and creates zones of light in a moderate lit space. The bright colour scheme of the space emphasizes the dark statues and make it apparent in the space. (Luxor Museum, Luxor, Egypt).*

(a) (b)

Figure 2.44 *The strong intensity of the lights creates strong highlights on the dark statues and the reflected light from the partitions fill in the statues form-shadows. (a) Statue of the king Horemheb 1338-1308 B.C. (b) Statue of the goddess Hathor period of Amenhotep III 1405-1367 B.C. (Luxor Museum, Luxor, Egypt).*

Figure 2.45 *The dark atmosphere helps to control the levels of illuminations and to raise exhibits brightness with less amount of light. (The Mummification Museum, Luxor, Egypt).*

1. Mummification Museum, Wikipedia, <https://en.wikipedia.org/wiki/Mummification_Museum>, (18.04.2016).

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Exhibits Conservation Aspects in Museum Lighting

Ch. 3

Chapter 3. Exhibits Conservation Aspects in Museum Lighting

Essentially museum lighting is planed to insure a good visual quality. However, lighting the sensitive-to-light artefacts in museum obligate lighting designer to limit the lighting levels for the sake of conservation, which always raise the dilemma of balancing museum lighting between visual perception and conservation aspects. To achieve a good results in this matter, lighting designer must work with conservators to define light for sensitive-to-light artefacts, in the same time bear in mind to provide a sufficient light for visitors to appreciate the artefact, and insure that the display and surrounding of the artefacts support its lighting and appearance.

Conservators are likely to approach lighting designers with some reserve, and the lighting designer will need to demonstrate understanding of conservation issues if cooperation is to be achieved.(1) Therefore, this chapter includes the important knowledge that assist the understanding of conservation aspects in museum lighting.

3.1 Light as part of museum environment

There are nine agents of deterioration that cause damage or loss to collections: direct physical forces, bad handling (thieves/vandals/displacers), fire, water, pests, radiation (IR, light and UV), incorrect temperature, incorrect relative humidity (RH) and contamination.(2)

The four agents, radiation, incorrect temperature, incorrect humidity, and pollutants have many features in common, each of which suggests paths for integration or as common they can be integrated into a single practical concept: “the museum environment.”(3)

What is common between this four agents: all four are “scientific” of deterioration, they can be measured precisely by instruments; all four are strongly associated with engineering and design of the building; all four except radiation move towards the artefact by air movement; and all four except incorrect temperature can be blocked by thin, low-cost, even delicate materials.(4)

Light interacts with other museum-environment agents. Uncontrolled daylight or electrical light can raise the temperature of the artefacts, thus affects the relative humidity. In the other way around, temperature, humidity and pollution can raise the effect of photochemical action, that is induced by light to the artefacts. Therefor, viewing the four museum-environment agents as a whole, well help to understand the conservation aspect in museum lighting and to achieve better lighting for museum.

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1. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA, p13.
2. Stefan Michalski, Running a Museum: A Practical Handbook, ICOM (International Council of Museums) Maison de l’UNESCO, France, 2004, p52.
3. Previous reference p83.
4. Previous reference p83.

3.1.1 Museum environment agents of deterioration

3.1.1.1 Light

Natural light and electrical light induced damage to museum objects in form of photochemical action and/or radiant heating effects. The strength of damage depends on the intensity of the incident radiation; and the composition of visible spectrum and its combined invisible radiation of both infrared and ultraviolet. (Will be explain in details later).

3.1.1.2 Incorrect temperature:

Since high and low temperature can be avoided inside the building by the usual building technic that insure comfort for occupants of the building, most of concern is directed toward the fluctuation of temperature and how suitable is human comfort temperature for some artefacts.

Temperature fluctuation is the temperature issue that has most interest in museum conservation together with fluctuations in relative humidity (RH), both request a precise climate control, both usually integrated together wen conservation strategies are planed, and both are the parameter the engineer and the mechanical systems are trying expensively to control.

Direct physical effect of temperature fluctuations on artefacts occur in two situations: when the components of a complex assembly have different coefficients of expansion, and when an object is subjected to a fluctuation more rapid than its ability to respond evenly. Mostly, any future pattern of fluctuations that is similar to the past pattern of fluctuations cannot be expected to cause significant fluctuation damage.(1)

Very important to know when dealing with incorrect temperature:(2)

- Generally, keep summer below 25° C; keep winter above 5° C. To improve preservation of chemically unstable materials such as newspapers, film, tapes, plastics, etc.
- Humans comfort are a very poor reference point. We like a temperature near 21° C, with no more than 2° C fluctuation if we are sitting. This set point is incorrect for most archival records and unstable modern plastics. (Figure 3.1)
- Most of incorrect RH levels in museum is more often cause of temperature when humid air reaching localized cold spots. In a closed and empty room or display case at 20° C and 50% RH, with no humidity-buffering materials, a fluctuation of 1° C causes ~3% RH fluctuation. A fluctuation of 5° C causes ~15% RH fluctuation. The most dangerous fluctuation, a temperature drop over 10° C will cause 100% RH and condensation. Fortunately, for most spaces in most historic house museums, these effects are greatly moderated by the moisture buffering of the room or case surfaces.

1. Stefan Michalski, Agent of Deterioration: Incorrect Temperature, Canadian Conservation Institute, http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap09-eng.aspx..
2. Previous reference.

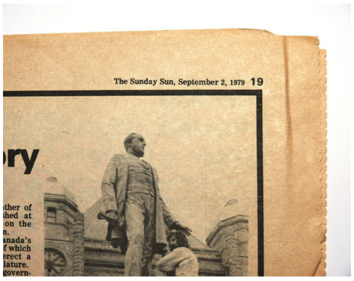
- Uneven temperatures from place-to-place in a building are generally a bigger problem than fluctuations over time, especially for museums in less than ideal buildings.

3.1.1.2.1 Light sources of incorrect temperature

The single most damaging source of incorrect temperature is direct sunlight. Surface temperatures of dark insulating materials oriented towards the sun, such as dark wood, textiles, and plastics, can quickly reach 40° C above ambient air temperature; therefore, on a warm summer day, surfaces can reach 75° C. If these surfaces are enclosed by glass, as in display cases and picture frames, even higher temperatures are possible. After direct sunlight, excessive incandescent lamps used in display cases are probably the most common cause of extreme temperature fluctuations in museums and the concurrent fluctuations in RH.[1]

3.1.1.2.2 Incorrect temperature accelerate photochemical action

Climate heat accelerate the photochemical action that is initiated by light.[2] Roughly, for every 10° C rise in temperature the rate of chemical reactions double. In edition, every watt of heat added to a space takes 3 to 4 watts of air conditioning to remove.[3]



(a)

(b)

Figure 3.1 *Examples of objects for which human comfort temperatures are "too high" for long-term preservation. When photographed, (a) the newspaper was 27 years old, and (b) the rubber doll about 30 years old. Only cold storage can keep such objects well preserved for much more than one human generation. (Canadian Conservation Institute, www.cci-icc.gc.ca)*

3.1.1.3 Incorrect relative humidity

Relative humidity, what does it mean:[4]

- Absolute humidity: is a measure of humidity in terms of the weight of water vapour per unit volume of air. At 20° C, the absolute humidity of 100% RH is 17.3 g/m^3.
- Relative humidity: is the ratio of the partial water vapour pressure to the saturation water vapour pressure at the same temperature.

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1. Previous Reference.
2. Robert L. Feller, Accelerated Aging Photochemical and Thermal Aspects, General Influence of Temperature in Photochemical Reactions, The Getty Conservation Institute , USA, 1994, p61.
3. Jack V. Miller and Ruth Ellen Miller, Museum lighting - pure and simple, Seaford, DE: NoUVIR Research, 2011, p6.
4. Stefan Michalski, Agent of Deterioration: Incorrect Relative Humidity, Canadian Conservation Institute, http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap10-eng.aspx

In other words, relative humidity is a measure of the thing we call "humidity" in everyday speech. It is that quality of the air that ranges between damp and dry. We do not actually perceive RH itself, we perceive the dampness or dryness of our bodies in reaction to ambient RH, or we perceive the effect on objects such as paper or cloth, which become damp or dry in response to the RH.(1)

The amount of moisture in organic collection materials and on the surface of inorganic materials can be predicted best by RH. We cannot avoid relative humidity (RH) but we can avoid "incorrect" relative humidity. Conservators search for the RH that causes the least amount of damage to the collection. For the majority of mixed museum collections this minimum damage rate is often very low, even zero, and the range of RH that yields this minimum damage is much wider than museums have assumed in the past.(2)

From a practical risk assessment perspective, incorrect RH in museum can be subdivided into four types:(3)

- Damp, over 75% RH: Damp causes several types of deterioration: mould, rapid corrosion, and extreme forms of mechanical damage. Mould causes disintegrates or discolours skin, leather, textiles, paper, basketry, and occasionally wood, paint, and glass. Generally, It is hard to control in historic buildings that so often house museums.
- RH above or below a critical value for that object: Some material have a critical HR levels that can not exceeded it, otherwise a series of special chemical reaction will be activated. For example, minerals, unstable glass, old metals. In generally for metal, the lower the RH the better, above 75% RH all corrosion speeds up. (Figure 3.2-a)
- RH above 0%: This definition is applied to all those archival materials such as acidic paper, magnetic tape, acetate and nitrate films, that decay chemically within a few decades – becoming weak, yellow, and brittle, or in some cases sticky.
- RH fluctuations: RH fluctuations concerns museums more than any other RH type. A change in RH causes the moisture content of organic materials such as wood, paper, leather, photographs, negatives, plastics, paints, glues, etc. to change, which in turn causes their size to change. If the material is free to expand and contract as RH goes up and down, then there is no problem, but if the material is constrained by other components of the object, or simply by its own inner bulk during a rapid fluctuation, then expanding parts will be crushed, and shrinking parts may fracture (as with the paint). Fluctuation in RH can occur seasonally, with day/night cycles, and in proximity to drafts, air vents, radiators, heating ducts, light sources, etc. (Figure 3.2-b)

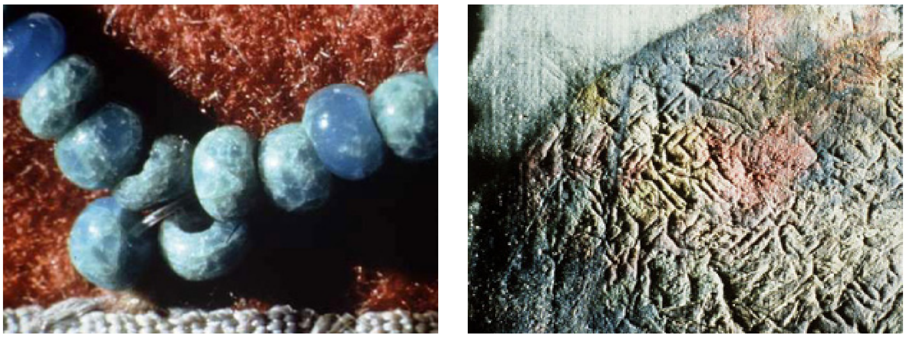
1. Previous reference.
2. Previous reference.
3. Previous reference.

3.1.1.3.1 The relation between RH and temperature

In general when warm air is cooled, the RH climbs. This leads to problems of damp when warm humid air finds cool spots in a building. Conversely, when cold air is heated, the RH falls. This leads to low indoor RH in winter, and drives the need for humidifiers.[1]

3.1.1.3.2 Interaction between humidity and light

It is generally agreed that degradation (photochemical action) will be speeded up by the presence of moisture. On the other hand, the elevated temperatures traditionally employed in thermal-aging and achieved in samples exposed to high-intensity light sources tend to reduce the moisture content of samples to levels far less than would be present under usual conditions of aging.[2]



(a) (b)

Figure 3.2 *Examples of objects damage due to incorrect RH in Museum (a) Crizzling of trade beads (unstable glass) due to frequent periods of RH above their critical RH. (b) A strong light directly across a surface of a painting shows the cracking and cupping of a painting due to a century of daily RH fluctuations. Note how the areas over the stretcher bars are not cracked, since the wood bars reduced daily fluctuations in the area of the painting above them by virtue of their moisture buffering capacity. (Canadian Conservation Institute, www.cci-icc.gc.ca)*

3.1.1.4 Pollutants

Pollutants can be gases, aerosols, liquids or solids of either anthropogenic or natural origin, that are known to have adverse effects or negative consequences on objects.[3]

In a museum, pollutants to reach objects and cause deterioration in three ways (or models):

- The pollutants are airborne, mostly associated with industrial and urban activities and maybe from construction products. Often cause acidification of papers, corrosion of metals, discoloration of colorants, efflorescence of calcium-based objects with RH (e.g. seashells), loss of strength for textiles. (Figure 3.3-a)
- The pollutants are transferred between two materials at points of contact, usually causing discoloration or staining e.g. unsealed woods, acidic paper or cardboard, flexible PVC, sulphur-based plastic, soft polyurethane foam, most adhesive tape. (Figure 3.3-b)

1.Previous condition.

2. Robert L. Feller, Accelerated Aging Photochemical and Thermal Aspects, General Influence of Temperature in Photochemical Reactions, The Getty Conservation Institute , USA, 1994, p55 and p115

3. Jean Tétreault , Agent of Deterioration: Pollutants, Canadian Conservation Institute, http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap07-eng.aspx

- The pollutant already exists, as part of the materials composing the object or is formed during chemical reactions on or within it. This type often called secondary pollutant and it causes acidification, discoloration or stain on objects and speed up other deterioration agents.

3.1.1.4.1 Pollutant and light in museum:

- Research has shown that high concentrations of atmospheric pollutants can increase the deleterious effects of ultraviolet light on synthetic polymers.[1]
- The Ozone (O3), a secondary vehicular pollutant generated by the reaction of nitrogen oxides and hydrocarbons with oxygen and light.[2] Which can be produced by sunlight reacting with pollutants in the upper atmosphere and indoors by electric or light equipment, such as photocopy machines, printers and some air filtering equipment,[3] which poses a hazard on the artefacts inside the museum.
- The elemental black carbon particles and soil-dust particles in museums are of particular interest because those species are light-absorbing and can produce visible soiling deposits on works of art. A result of an experiment conducted in five museum in California shows that, black elemental carbon particles and fine soil-dust particles are found in local museum environments at concentrations of about 20 to 50% of the outdoor levels at facilities with particle-filtration systems. For buildings that lack conventional particle filtration systems, both fine and coarse indoor elemental-carbon and soil-dust particle concentrations ranged from about 50 to 100% of the concentrations outdoors. This implies that museums should especially watch for indoor soiling problems caused by elemental carbon and soil-dust particles. Urban museums lacking environmental control systems can face indoor soiling hazards nearly as great as those found outdoors.[4]

(a) (b)

Figure 3.3 *Examples of objects damage due to pollution in Museum (a) Book covered with vegetable tanned leather shows significant deterioration known as red rot caused by sulphur dioxide. (b) Rubber tube staining a booklet after about 10 years of contact. (Canadian Conservation Institute, www.cci-icc.gc.ca)*

1. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000. p70
2. Cecily M. Grzywacz, Monitoring for Gaseous Pollutants in Museum Environments, The Getty Conservation Institute , USA, 2006, p90.
3. The National Park Service (NPS) Museum Handbook, Part I (1999), Chapter 4: Museum Collections Environment, p4.44
4. William W. Nazaroff and Others, Airborne Particles in Museums, The Getty Conservation Institute, USA, 1993, p36

3.1.2 Controlling museum environment

Difficulties of controlling Museum environment mostly arise from building type and condition; gallery and showcase volume; relationship between building spaces; movement of visitors throughout the building; concept of gallery display and varying needs of artefacts.

The museum environment is controlled at two levels: First, controlling the ambient climate in building spaces through designing the roof, the outer walls, the apertures, the daylight systems, the spaces' location and the mechanical systems. Second, defining and controlling microclimate areas, by specifying isolated zones that can be precisely defined both by measurements of the environment and by location.[(1)] Microclimate can be a showcase, a chamber or a storage area, that helps to keep the artefacts in their own individual ideal climates in order to minimize their deterioration.[(2)] Controlling museum environment on these two levels will help maintain a high control on the agents of deterioration. Nevertheless, according to some buildings or artefacts condition, it is sufficient to use only one of these levels to control the museum environment.

3.1.2.1 Museum active environmental control units

Relative humidity in small enclosers can be controlled easily by a passive controller, e.g. buffer hygroscopic materials. More effective is to use an active controller, a mechanical devices that able to control RH, temperature, and pollution in both small and large enclosers precisely.[(3)]

An HVAC system (heating, ventilation, and air conditioning) is designed to control both temperature and humidity in building spaces. A number of attempts were made to utilise HVAC building systems to supply conditioned air to display cases. In most applications it did not prove to be an appropriate solution. HVAC systems were too big to control and dangerous to sensitive artefacts.[(4)] A wide variety of microclimate control units, which can be integrated in or connected to a one display case or more, have been built over the years, usually as unique systems. For example: the Micro Climate Generator (MCG), Artefact Preservation System (APS) and Constant Volume Generator (CVG).[(5)]

Planning the controlled cases and its piping layouts has to take into account the varying needs of the objects, the volumes of the display enclosure, the power of the control systems in relation to the distance that the air must travel, and the leakage rate of the cases.[(6)] (Figure 3.4)

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1. Jerry Shiner, Trends in microclimate control of museum display cases, Museum-Microclimates, The National Museum of Denmark, 2007, p267.
2. MUSECC (Museum Climate Control), Canada. http://www.musecc.com/why-do-we-use-micro-climate
3. Previous Reference.
4. Jerry Shiner, Trends in microclimate control of museum display cases, Museum-Microclimates, The National Museum of Denmark, 2007, p270-271
5. Previos reference, p271-273
6. Helen Coxon, The good, the bad and the frustrating: designing and implementing a climate control system at the Royal Ontario Museum, Museum Microclimates, The National Museum of Denmark, 2007, p277.

(a)

(b)

Figure 3.4 *The active microclimate control units (MCG) for the Japan Gallery in the Royal Ontario Museum, Toronto, Canada. (a) Large display case in the Japan Gallery. (Free-standing Display Cases, GLASBAU HAHN Catalogue) (b) Two MCG 40s serving the Japan Gallery. (Helen Coxon, Museum Microclimates, p279)*

3.1.2.2 Interaction between lighting systems and environmental control units

The improper interaction between electrical lighting and HVAC systems will yield a luminaires deficiency and a fluctuations in museum environment control. The implication arise from: First, each luminaire type has a particular limited range of operating temperatures. Second, the furnishings in the space absorb slightly the radiant energy from the lighting system, and when it cannot heat up much it start to transfer the heat to the room air by convection. An effective procedures to raise the efficiency of the HVAC and lighting system are to insure that the optimum lamp temperature can be achieved, and to store the heat from the lighting system in the ceiling cavity as possible. As well to choose carefully the material of the space and to reduce unwanted objects such as desks, chairs and cabinets.(1) (Figure 3.5, Figure 3.6 and Figure 3.7).

Most of shortage or drop in museum environment control system occur during the change of season climate, when temperature changes rabidly between day and night as in continental climate area, and at the end of the day when the electrical lights are switched off. Therefore, it is important to insure that the heat leaking to the gallery from architectural apertures, daylight systems and electrical light systems during the course of the day and year are taken into account with other factors when designing the HVAC system.

At the level of microclimate, showcase lighting is usually caused a variations in temperature within the display volume, resulted in unstable RH levels. As well sunlight falling on a display case will cause a rise in temperature and correspondingly fall in RH.(2)

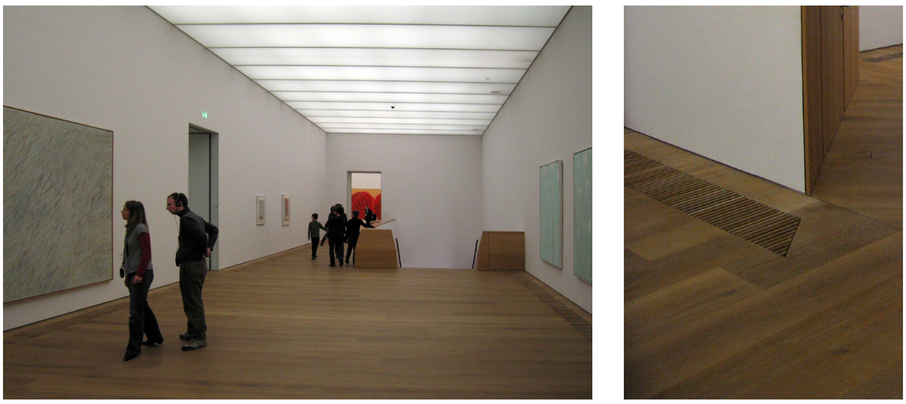
1. Stephen J. Treado and John W. Bean, The Interaction of Lighting, Heating and Cooling Systems in Buildings, Building and Fire Research Laboratory National Institute of Standards and Technology Gaithersburg, MD 20899, March 1992.
2. Helen Coxon, The good, the bad and the frustrating: designing and implementing a climate control system at the Royal Ontario Museum, Museum Microclimates, The National Museum of Denmark, 2007, p279 and p282.

(a) (b)

Figure 3.5 *Integration of HVAC system with the Lighting System. The HVAC exit (grill) is in between the wall-washer and the spots-track. The wall-washer is fitted with halogen and fluorescent lamps to achieve a good CCT and CRI. Spot lights are used as an accent light for the statue in the corner. (a) A wide photo for the gallery (b) Close up photo for the integrated lighting system with the HVAC system. Museum Ludwig, Cologne, Germany.*

(a) (b)

Figure 3.6 *Integration of HVAC system with the lighting system. The spots-track is integrated withe HVAC grill. The vaulted units of the ceiling are fitted with fluorescent lamps as general illuminance and the spots are used to highlight the artefacts. (a) A wide photo for the gallery (b) Close up photo for the ceiling. Museum Ludwig, Cologne, Germany.*



(a) (b)

Figure 3.7 *The HVAC system is separated from the lighting-system and integrated in the floor parallel to the walls. The lit membrane ceiling is covering the whole area of the gallery and lit with daylight and fluorescent lamp from above. (a) A wide photo for the gallery (b) Close up photo for the HVAC grill in the wooden floor. Museum Brandhorst, Munich, Germany.*

3.2 Effects of light, UV and IR on museum artefacts

Light is radiant energy, and exposure to light gradually causes permanent damage to many museum artefacts. When radiant energy is incident on the surface of a material, whether opaque or transparent, some portion of that energy is absorbed. This can promote two distinctly different processes that can cause degradation of museum objects: radiant heating effect and photochemical action.[1]

3.2.1 Spectrum composition and its related effects

Radiant energy can be envisioned as a stream of photons, all travelling at the same speed. The irradiance (i.e. watts per square meter of incident energy) characterizes the density of photons incident on a surface, and this is the source of radiant heating effect (absorbed portion). The spectral power distribution characterizes the mix of energy levels of the individual photons. The shorter the wavelength, the higher the photon energy level. At the long wavelength end of the visible spectrum (i.e., red) photon energy levels are relatively low, but increase with reducing wavelength through shortwave visible (i.e., blue) and into the UV spectrum. Photon energy level largely determines the potential of a photon to cause photochemical action.[2]

The different types of damage typical of UV, light, and IR result from their different photon energies. The photochemistry that underlies much of the disintegration of materials and production of yellow by-products typical of UV exposure requires energies greater than about 3 eV, whereas the photochemistry typical of colourant fading, as well as the operation of our retina, occurs in a range between about 2 eV and 3 eV. We see in the same band as that which causes sensitive colourants to fade, given the related photochemical phenomena. Infrared photons are not energetic enough to initiate any of the forms of photochemistry driven by UV or light, so their effect is simply a heating of the surfaces that absorb them.[3] (Figure 3.8)

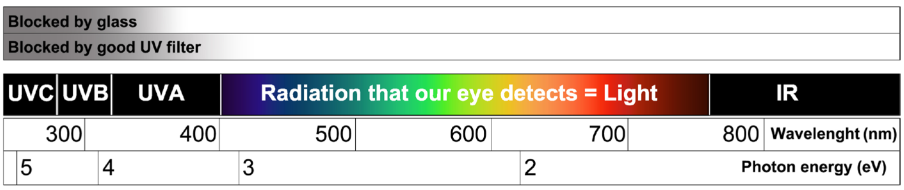


Figure 3.8 *Scale of light intensities with the conventional scale of wavelength (in nanometers – nm) and the reciprocal scale for photon energy (in electron Volts – eV). (Canadian Conservation Institute, www.cci-icc.gc.ca)*

1. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA, p12.
2. Jack V. Miller and Ruth Ellen Miller, Museum lighting - pure and simple, Seaford, DE: NoUVIR Research, 2011, p14.
3. Stefan Michalski, Agent of Deterioration: Light, Ultraviolet and Infrared, Canadian Conservation Institute, http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap08-eng.aspx

3.2.2 Radiant heating effect

3.2.2.1 Definition of radiant heating

Radiant heating effect is the raising of surface temperature above ambient temperature due to absorption of incident radiant flux. The maximum attainable temperature of an irradiated object is given by:[(1)]

$$T_{max} = T_a + (\,kAE_e / h_c) \tag{3.1}$$

Where: T_a is ambient (air) temperature (C), k is a proportionality constant, A is absorbance of the object, E_e is irradiance (W/m^2), h_c is coefficient of convection heat loss.

In general, unlike UV energy, IR energy is not evaluated on a wavelength bases but rather in terms of all such energy incident on a surface. In this expression, (A) is assumed to be averaged over the spectrum, but some situations may require spectral variations to be taken into account.

(Equation3.1) shows that the elevation of the object surface temperature ab, over ambient temperature is proportional to irradiance, and is independent of the object thermal capacity, density or thickness. When radiant flux is directed onto an object, some proportion is absorbed, depending on the spectral power distribution of the incident flux and the spectral absorptance of the object. Some small proportion of the absorbed radiation may promote photochemical action, but regardless of whether the object is light-responsive, its surface temperature will rise toward the maximum attainable temperature T$_{max.}$[(2)]

3.2.2.2 Effect of radiant heating on museum objects

Light source produces radiant heating energy that rises the temperature of material surface that is exposed to it. Even if the air conditioning is maintaining the ambient temperature the area within close limits to the light source and the object that has a spotlight focussed onto will be several degrees higher. Raising the temperature speeds all chemical actions including oxidation. Additionally, it has a physical deleterious effects. The surface will expand relative to the body of the object, and moisture will be driven from the surface material. At night the spotlight is switched off, and the surface cools to ambient temperature. The effects of this cycle can be devastating, particularly in materials that are hygroscopic, or that have differential expansion coefficients (e.g. wood), or where surfaces are composed of different materials, such as pigment and/or varnish over a substrate. The symptoms are surface cracking, lifting of surface layers, and loss of colour.[(3)] Unlike the molecular change that takes place in photochemical processes, which can come to a halt, the thermal load on an object during irradiation is always harmful.[(4)]

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1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p7.
2. Previous Reference, p8.
3. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA, , p13.
4. Good Lighting for Museums Galleries and Exhibitions, Booklet 18, published by Fördergemeinschaft Gutes Licht (FGL), Frankfurt am Main p32

3.2.2.3 Measuring the heating potential of IR from a light source

Total elimination of IR is not practical, and direct measurement is difficult. It is possible to obtain a measure of relative radiant heating effect by placing small black and white metal plates at the display location for a short time and measuring their temperatures with an infrared thermometer. The temperature of the white metal plate will be close to the ambient air temperature T_a, and the extent to which the temperature of the black plate exceeds this value gives an indication of the extent to which T_{max} could exceed T_a for a material of high absorptance (Equation 3.1).[(1)]

In some museum practice the bulb of an ordinary outdoor glass thermometer is painted with a matte black paint and placed in the light beam near the object for several minutes. If the temperature did not raise up there is no heat coming from the light source, if it rose up, the measured temperate has to be checked if it is correct for the object or incorrect. As a common-sense alternative estimate, place your hand in the light beam, at the point it might strike artefacts, and use a piece of cardboard to alternately illuminate and shade your palm. If you feel a noticeable warming due to the light, then sensitive artefacts to temperature will be at risk.[(2)]

3.2.3 Photochemical action

3.2.3.1 Definition of photochemical action

Photochemical action is the process by which a molecule undergoes a chemical change, with the activation energy for the change being derived from the absorption of a photon. While the initial event of the photon absorption is independent of the surrounding environment, subsequent chemical actions may be strongly affected by environmental factors such as temperature and humidity. The photon absorption may be the initial stage in a complex series of chemical changes, but whether or not the process is complex, the change is irreversible.[(3)]

All forms of chemical action affecting museum objects constitute damage. Materials differ substantially in their responsivity to light exposure. Unless an object is totally irresponsive to light exposure, for every incident photon there is a finite probability of permanent damage. There is no safe level of exposure for a light-responsive object.[(4)]

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1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p24.
2. Stefan Michalski, Agent of Deterioration: Light, Ultraviolet and Infrared, Canadian Conservation Institute, http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap08-eng.aspx
3. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p3.
4. Previous Reference p3.

3.2.3.2 Photochemical action effect

Photochemical action induces colour changes like: fading, darken, changes of hue, and yellowing. As well, it causes loss of strength, which may be evident as fraying of fibres on fabrics, or embrittlement and surface cracking of artefacts. These effects may be difficult to distinguish from effects of radiant heating.(1)

Generally, The visible radiation (light) is responsible about fades (or bleaches) of colours. Those colours that fade can disappear within as little as a few hours of direct sunshine, or just a few years at low museum lighting. UV causes yellowing, chalking, weakening, and/or disintegration of materials. Chalking of paint media is often mistaken for pigment fading. However, there is some overlap in the forms of deterioration caused by light and UV. Light (especially violet) can cause some of the disintegration and yellowing listed under UV, but only in a few materials, and only very slowly in comparison to UV. In turn, UV does contribute to the fading of colours. None of these overlaps reduces the practical reliability of these generalizations.(2)

For colours that are sensitive to light (the crux of the museum lighting dilemma) UV usually contributes less than half of the fading and often only one tenth. Why bother, then, with UV control? Because for many artefacts, such as paintings with permanent pigments or monochromatic prints and drawings, the yellowing and disintegration of the media induced by UV is the major form of deterioration suffered during uncontrolled museum lighting.(3)

The following figures are examples of light and UV damage. The photos were taken from controlled fading experiments, using a light source simulating daylight through glass, i.e. high in UV content. All samples are taken from early 20th century sample books for artists. (Figure 3.9) shows two different effects that can occur to oil paints; (a) The vermilion is darkened (b) The carmine lake glaze on white is faded. (Figure 3.10) shows the effect on a drawing inks on paper where all samples are faded. Note that, the letters on the samples indicate the exposure as following: 0 = unexposed; A = 0.17 Mlx h; B = 1.7 Mlx h; C = 6.2 Mlx h; D = 17 Mlx h; E = 67 Mlx h. Equivalent exposures range from A = 1 day of sunlight or 1 year at 50 lux to D = 8 months sunlight or 400 years at 50 lux. All areas are protected by a UV filter except areas marked with an asterisk (*). Note that, the differences between the presence or absence of a UV filter (B vs. B*, C vs. C*, D vs. D*), while sometimes noticeable, are much less significant than differences between different exposures (A vs. B vs. C vs. D).(4)

1. Previous Reference p4.
2. Stefan Michalski, Agent of Deterioration: Light, Ultraviolet and Infrared, Canadian Conservation Institute, http://www.cci-icc.gc.ca/caringfor-prendresoindes/articles/10agents/chap08-eng.aspx.
3. Previous Reference.
4. Previous Reference.

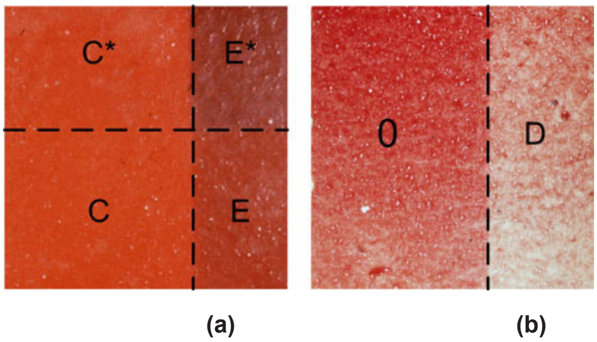


Figure 3.9 *Oil paints effected by daylight through glass. (a) The vermilion is darkened (b) The carmine lake glaze on white is faded. (Canadian Conservation Institute, www.cci-icc.gc.ca).*

Figure 3.10 *Drawing inks on paper faded by daylight through glass. (Canadian Conservation Institute, www.cci-icc.gc.ca).*

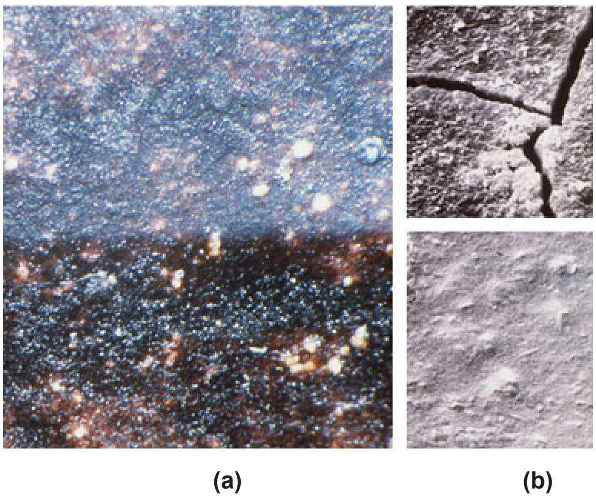
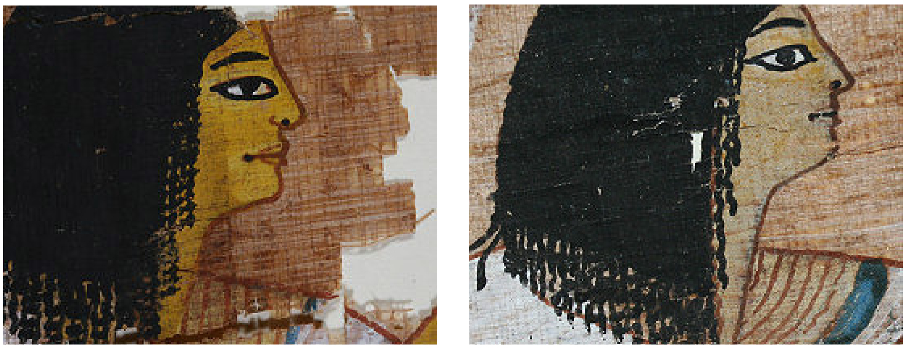


Figure 3.11 *Examples of UV damage. Tests burnt umber oil paint. (a) Is an optical microscope view. The bottom half was protected by a good UV filter. (b) black-and-white images from a scanning electron micrographs. The lower image undamaged by UV and the upper image shows the eroded and cracked surface damaged by UV. (Canadian Conservation Institute, www.cci-icc.gc.ca).*

(Figure 3.11) is an examples of UV damage. Tests on an early 20th century burnt umber oil paint. The images are all for an area exposed to 67 Mlx h of a light source similar to daylight through a window. Equivalent exposures is about 8 months full daylight, or 400 years of display at 50 lux. On the left (a) is an optical microscope view. The bottom half was protected by a good UV filter. The black-and-white images to the right (b) is a scanning electron micrographs of the previous top and bottom areas. The lower image shows the smooth oil medium surface undamaged by UV and the upper image shows the eroded and cracked surface damaged by UV. The brown (mineral) pigment is not affected by either light or UV.[1]

Colour changes as an indicator of alterations, such as natural ageing due to environmental influences, effects and performance of treatments over time need to be supported with a instrumental methods to help recognize, record and assessment the colour changes. For these matters, conservator depend on a colour appearance systems that has a perceptual coordinate or scale and uniform or equal visual spacing. For example: Munsell colour system, National Colour System (NCS) , etc. In many application the CIELAB and CIELUV colour space are used as approximation for colour appearance systems as will to calculate the colour difference in appearance.[2] However, Some colour or material changes cannot perceived with the naked eye and they need a laboratory instruments to record them. Such changes are mostly indicator for dramatic change that occur in a long period or under a hard condition. (Figure 3.12 and Figure 3.13).



(a) (b)

Figure 3.12 *(above) A noticeable colour change to the naked eye due to the dramatic effect of light damage. (a) The arsenic sulphide pigment on the face shows its original bright yellow (b) A fragment that was on display for several years from the 1960s on. All the colour has been lost from the face. From the papyrus Book of the Dead of Ramose (E.2.1922) in the Fitzwilliam Museum, UK.(http://camunivmuseums.wordpress.com/2013/07/15/lighting-calculator/)*

(a) (b)

Figure 3.13 *(down) Unnoticeable colour change to the naked eye. (a) The Egyptian blue pigment on this papyrus have darkened over time and look almost black to the naked eye. (b) When it was viewed under magnification blue particles are visible, indicative of what these pigments originally looked liked. From the Book of the Dead of the Goldworker Amun, Sobekmose. 1479-1400 B.C.E. Brooklyn Museum, USA. (http://www.brooklynmuseum.org/community/blogosphere/2010/09/22/pigments-and-inks-typically-used-on-papyrus/)*

1. Previous Reference.
2. Andrea Urland, Colour Specification and measurements, ARC laborratory hand book, Volum 5, ICCROM1999, p9.

3.2.3.3 Measuring the potential of photochemical damage from a light source

There are different ways to measure the change of colour or deterioration that occur to museum material from illumination, to know the duration of exposure that is needed to cause a noticeable or unwanted change to artefact, or to know the potential of light to induce a photochemical action that end to harm the artefact. The concepts and methods of measurements changed rapidly with the development of technology. Thus, the available data describing damage to museum artefacts are presented in different ways and the conservation policy in museums are varying. The following are most common and up-to-date methods of measuring the potential of photochemical damage from light.

3.2.3.3.1 Measuring ultra violet radiation

Most of museum staff are interested in measuring the UV in light sources since it is responsible of rapid damage to the artefacts and it does not contribute to vision.

Museum conservators treat all wavelengths shorter than 400 nm as ultraviolet light as the damage potential is high below this threshold and the visual effect is very small. Thus most of recommendation will therefore use 400 nm as the lower point of visible light. Wavelengths below this threshold can be easily filtered without affecting the appearance of the exhibition.[1] Additionally, since the sensitivity of the normal eye to radiation of different energies are valid only for visible light that between 400 and 700 nm (photopic curve) conservators take account of visible light only in this area when filtering light source or conducting calculation and research for conservation.[2]

The information provided about the UV radiation in light sources is mostly provided in two ways: First, as a single percentage number for the entire near-ultraviolet wavelength range (300 to 400 nm) to the flat weighted emission between 300 and 700 (UV plus visible). Second, as relative amount of the UV energy to the illuminance in microwatts per lumen (μW/lm).[3] This mixed units of microwatts per lumen indicate the rate at which ultraviolet energy is emitted per unit of perceived visible light.[4] (See Appendix 1.1 & 1.2 for typical values). However, data written in these ways did not take account of the wavelength distribution of the UV radiation and so do not provide a reliable indication of relative damage potential.[5] For a

1. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p9.
2. See researches and calculation included in Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000.
3. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p9.
4. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000, p10.
5. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p5.

reliable calculation of the amount of UV in a light source the entire irradiance flux of the lamp must be known with the spectrum distribution curve that describe the energy in every wave length.

Generally, getting information on energy outside the visible spectrum is sometimes difficult. It's even harder when you understand that most UV meters only read UV above 300 nm. UV emissions below 300 nm are found in many sources.(1) But this well not be a problem in museum practice since all ultraviolet radiation can be filtered out of the illumination. Thus, the ideal would be 0 μW/lm of UV radiation for the illumination of artefacts.(2) Nevertheless, the conservators' rule of thumb is to have less than 75 μW of ultraviolet light energy per lumen of visible light for a light source used as gallery illumination.(3)

3.2.3.3.2 Blue Wool standards

The Blue Wool Scale measures and calibrates the permanence of colouring dyes. Traditionally this test was developed for the textiles industry but it has now been adopted by the printing industry as a measure of lightfastness of ink colourants and also within the polymer industry for measurement of pigment & colour lightfastness. (Lightfastness is the chemical stability of the pigment or dye under long exposure to light). These scales are used for paint lightfastness testing under international standard ISO 105-B, and are also used by gallery curators to measure the accumulated amount of light received by museum displays of paintings, textiles or photographic prints.(4)

This scale consists of eight different blue dyes on wool fabric, each dye being roughly one-half to one-third as sensitive as the previous one to fading by light. The lightfastness of materials is stated on the basis of the visible-light exposure, usually quoted in lux hours, that causes the material to fade to the same extent as a particular Blue Wool standard.(5)

To demonstrate the degree of fading caused by the intensity of light in a particular location, cover half of the card with a light-blocking material to protect it completely from light damage, or cut the card up into strips one is placed in the dark as the control. (As well the exposed card can be compare with the standard gray scale, that is mostly provided with the Blue Wool standards card). Note the date and set out the Blue Wools in the desired location. Check periodically (every couple of weeks) to determine how long it takes the various samples to fade. (Figure 3.14) Since the sensitivity of the first few

1. Jack V. Miller and Ruth Ellen Miller, Museum lighting - pure and simple, Seaford, DE: NoUVIR Research, 2011, p7.
2. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p9.
3. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000, p14.
4. The Blue Wool Scale, Materials Technology Ltd , Hampshire, UK. http://www.drb-mattech.co.uk/uv%20blue%20wool.html.
5. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000, p31.

samples on the card corresponds to light sensitive materials such as water colours and textiles, the results will give you a general idea of the amount of damage you might expect if materials were exhibited for the same period of time at the current light level in that location. In most cases, a general correlation between the sensitivity of the artefact and the Blue Wool standard's scale will be sufficient to allow informed decision-making.(1)

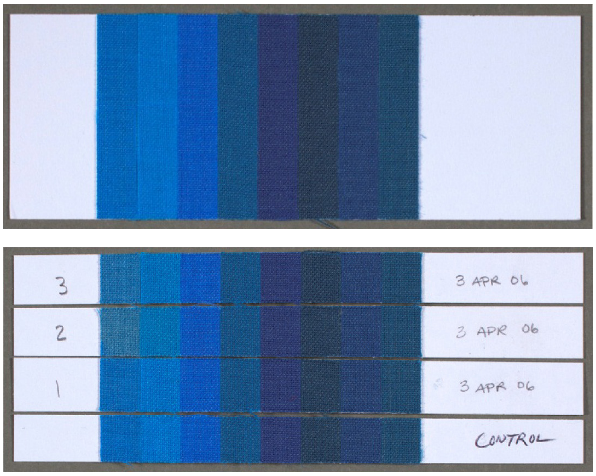


Figure 3.14 *Standard Blue wool Card for measuring the lightfastness of materials. (above) Unused card, (down) the card was divided for several strips. One strip was kept in the dark for control, the other strips were checked after different period of exposure to check the sample's lightfastness and how much it takes the sample to fade. Realize the change of blue wool no.1 in the strip no. 2 and 3. (*http://www.nedcc.org/*)*

The total light exposure that is generally recognized to cause a just-perceptible fade in Blue Wool no. 1, the most sensitive standard on the scale, is 4 x 10^5 lux hours of visible light. Therefore, this would be the total display lifetime of an object with a lightfastness equivalent to Blue Wool no. 1. This limit is reached after twenty display periods of forty days, 10-hour a day, at a light level of only 50 lux. If the materials in the object obey the reciprocity principle, more frequent or longer exhibits could be mounted at lower light levels.(2) The conversion of a Blue Wool rating into an estimate of the light exposure that will cause just noticeable fading is provided in (Table 3.3).

Although Blue Wool standards are rated in terms of sensitivity to visible light, they were originally designed for use in daylight, which includes ultraviolet light. Collections care staff regularly use the standards to monitor radiation of various spectral compositions. Apparently, the response of the standards is often assumed to be the same whether or not near-ultraviolet wavelengths are included. Some authors report results suggesting that this assumption is not appropriate. Bullock and Saunders (1999), while undertaking a detailed evaluation of the Blue Wool standards for use as light dosimeters, showed that Blue Wool nos. 1, 2, and 3 faded less when ultraviolet light was removed from the light source by filters. They also obtained data that suggest that Blue Wool no. 3 is relatively more sensitive to UV-A radiation than are Blue Wool nos. 1 and 2.(3)

1. Donia Conn, Preservation Leaflet, Protection from Light Damage, the Northeast Document Conservation Center, http://www.nedcc.org/, p2.
2. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000, p31.
3. Previous Reference p32-33.

3.2.3.3.3 Defining photochemical factors and Berlin Model

Four factors determine the level of photochemical action: irradiance, duration of exposure, spectral power distribution of incident radiation and action spectrum of receiving material.(1) By defining these factors and knowing how they work together conservators can determine the potential of light to cause damage to museum artefacts more precisely and the stage of damage that is occurred.

3.2.3.3.3.1 Irradiance and duration of exposure

The reciprocity principle / law: the exposure of a surface to irradiance (H) is the integration of irradiance and time:

$$H = \int_t E_e \, dt \qquad \text{Wh/m}^2 \qquad (3.2)$$

Where: E_e is irradiance incident on the surface (W/m^2), t is time in hours (h).

When E_e is constant, as with electric lighting, the equation takes the simple form:

$$H = E_e \,.\, t$$

According to this principle, a total exposure of 10 Wh/m^2 for 10 hours is equivalent to 20 Wh/m^2 for 5 hours or 5 Wh/m^2 for 20 hours if the spectrum power distribution is the same. It should be noted that the principle is defined in terms of irradiance, which is a measure of the density of incident radiant power (radiant flux).(2)

3.2.3.3.3.2 Spectral power distribution of incident radiation

The photons are the "bullets" that trigger photochemical reaction, and if absorbed, their energy levels indicate their potential to cause damage. Photons differ widely in energy level, although they all travel at the same velocity in vacuum. Photon energy level E (Joules) is directly proportional to frequency, and is given by the expression:(3)

$$E = \mathrm{h}\, v \qquad \mathrm{J} \qquad (3.3)$$

Where: h is Planck's constant (6,626 x 10^{-34} J s), a number that relates the units of frequency to energy; ν is frequency (Hz).

As shown in (Equation 3.3), photon energy is proportional to frequency. However, frequency is inversely proportional to wavelength λ , so that (Equation 3.3) can be rewritten:(4)

$$E = \mathrm{h}\, c\, /\, \lambda \qquad \mathrm{J} \qquad (3.4)$$

Where: c is the velocity of light in vacuum.

1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p3.
2. Previous Reference p4.
3. Previous Reference p4.
4. Previous Reference p5.

This shows that photon energy is proportional to the reciprocal of wavelength $1/\lambda$, so The potential of damage of a wavelength is increased as we go from long wavelength (i.e, red light) toward the short wavelength (i.e. blue light) in the spectrum, and UV has the highest photon energies and highest potential of damage.(1)

3.2.3.3.3.3 The material relative spectral responsivity

The near ultraviolet has more energy per photon than visible light but, conversely, fewer photons for a particular total energy. From the other side of visible light, infrared has less energy per photon than visible light and more photons for a given total energy.(2)

When the photon is absorbed, the molecule is said to be in an excited electronic state. In this condition, several different things can happen and only if a bond between atoms in the excited molecule is broken a chemical change in the molecule occur.(3)

Materials' molecules have different photon energy responsivity. A molecule that is highly responsive to light exposure will have a low photon energy threshold, so that a low level of photon energy is sufficient to trigger a chemical change and vise versa.(4)

Accordingly, expressing the relative spectral responsivity has to include the energy that has been absorbed; the photon energy level which is proportional to the reciprocal of wavelength; and a function of wavelength that is determined by the inherent properties of material. Which can formulated as following:(5)

$$s(\lambda)_{dm,rel} = \alpha(\lambda) .\ 1/\lambda\ .\ f(\lambda) \qquad (3.5)$$

Where: $s(\lambda)_{dm,rel}$ is relative spectral responsivity, $\alpha(\lambda)$ is spectral absorbents and $f(\lambda)$ is a function of wavelength determined by the receiving material. The suffix dm,rel indicate that damage is relative to wavelength. It may be noted that at a given wavelength, $\alpha(\lambda) = 1-[\rho(\lambda) + \tau(\lambda)]$, where $\rho(\lambda)$ and $\tau(\lambda)$ are spectral reflectance and transmittance, respectively.

3.2.3.3.3.4 Recording changes of surface colour

Not all materials demonstrate on-line fading under exposure. Some materials show yellowing, some darken, and some change hue. Researchers need to be able to record changes of surface colour over time, and for this they need a precise system of colour measurement. Currently, the most widely used system for exposure research is CIELAB. This system defines a three-dimensional colour space within which the colour characteristics of a sample material are specified in

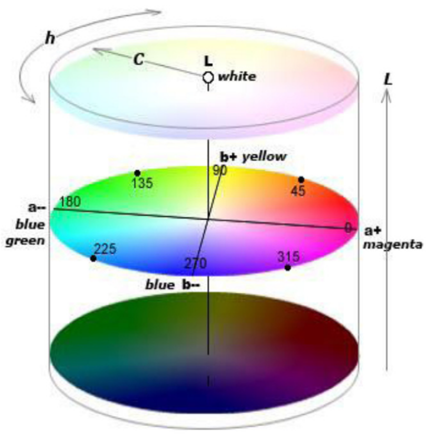
1. Previous Reference p5.
2. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000. p6.
3. Previous Reference p6.
4. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p4.
5. Previous Reference p7.

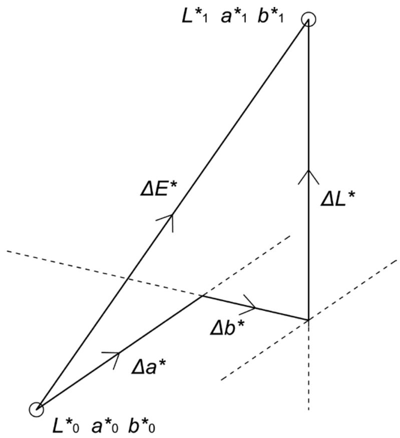
terms of a lightness dimension L^*, and two chromatic dimensions, a^* and b^*. The L^* dimension ranges from black to white. Positive values of a^* indicate redness, and negative values greenness. Positive values of b^* indicate yellowness, and negative values blueness. (as well the shift in CIELAB space can be calulated as L = lightnes, C = vividness (chroma), h = hue angle anti-clockwise from red (0)). The value of this system as a research tool is that it enables extents of colour difference to be measured and compared.(1) (Figure 3.15)

The magnitude of any colour difference can be represented by a vector, which is indicated by the symbol ΔE^*_{ab}, and takes account of the changes on all three dimensions in a colour space. (Figure 3.16) The scales of the three dimensions have been so chosen that when the colour difference is just discernible in a side-by-side comparison, ΔE^*_{ab} has a value of one. In this condition the human eye is a very responsive discriminator, and it requires quite elaborate equipment to reliably measure colour differences as small as one unit of ΔE^*_{ab}.(2)

Figure 3.15 *(left) In the CIELAB colour space. L* a* b* and L C h are different ways of describing the same shift in CIELAB space L* = Lightness a* = red-green axis b* = yellow-blue axis C = vividness (chroma) h = hue angle anticlockwise from red (0). (Micro-fading report, The National Museum of Australia)*

Figure 3.16 *(right) The distance between two points ΔE*ab in CIELAB CIE76 colour space. (CIE Technical report 157:2004)*





Using the subscript 0 for the standard and 1 for the sample, the distant ΔE^*_{ab} between $L^*_0\, a^*_0\, b^*_0$ and $L^*_1\, a^*_1\, b^*_1$ in rectangular coordinates:(3)

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (3.6)$$

Where: $\Delta L^* = (L^*_1 - L^*_0)$, $\Delta a^* = (a^*_1 - a^*_0)$, $\Delta b^* = (b^*_1 - b^*_0)$

In the above equation the ΔE^*ab represent JND (just noticeable difference) in the CIE76 colour space. However, ΔE^*ab values may be calculated using the more recent CIE equations (CIEDE 1996 & 2000) based on improved perceptual models, or other specialised but potentially relevant non-CIE models.(4)

1. Previous Reference p9.
2. Previous Reference p9.
3. Previous Reference p9.
4. Bruce Ford, Non-destructive microfade testing at the National Museum of Australia, AICCM Bulletin Volume 32, 2011, p59.

Microfading Test shows that perceptible colour change for the ISO Blue Wools has been revised downwards by about a factor of two (1BW step) for the same light exposure in the CIEDE2000 perceptual model, a range of other colours appear to respond twice as fast in comparison.[1] As well other researches showed that, a value of around $\Delta E^*ab = 2.3$ in the CIE76 corresponds to a JND.[2] (Figure 3.21 and Figure 3.21)

Other researchers in museum conservation field have the opinion that, the CIE76 is convenient, because most accelerated fading data exists in this form, and it is not possible to retrospectively convert from one model to the other without the original L*a*b* values. Although there can be quite marked differences between the older and newer ΔEab calculations, we have found this does not affect the sorting of objects into our quite broad relative lightfastness categories often enough to outweigh the advantages of reporting CIE76[3]. However, it is advisable to use the CIEDE2000 colour difference formula in calculating the change of museum objects's colour since it is the most up to date method and widely used in the colour industry. Further, the difference between CIE76 nad CIEDE2000 position for some colours are big enough that can lead to a wrong calculation and more exposure in the museum policy thus more damage.

The ClEDE2000 colour difference, ΔE_{00} between two samples shall be calculated by:[4]

$$\Delta E_{00} = [(\Delta L'/k_L S_L)^2 + (\Delta C'/k_C S_C)^2 + (\Delta H'/k_H S_H) + R_T (\Delta C'/k_C S_C)(\Delta H'/k_H S_H)]^{1/2} \qquad (3.7)$$

Where: $\Delta L'$ lightness difference, $\Delta C'$ chroma difference, ΔH hue-angle difference; K_L, K_C, K_H lightness-, chroma-, hue- parametric factors (Under the reference conditions =1); S_L, S_C, S_H lightness, chroma, hue weighting function, R_T rotation function. (For more details see Appendix 1.4)

3.2.3.3.3.5 Threshold effective radiant exposure (The Berlin Model)

In the Berlin model (J. Krochmann) the damage suffered by an exposed object DM is a function of the effective radiant exposure H_{dm}:[5]

$$DM = f(H_{dm}) \qquad (3.8)$$

The effective irradiance that cause the damage takes account of the spectrum of incident radiation and the relative response of the receiving material:[6]

1. Microfading report, National Museum of Australia, http://www.microfading.com/uploads/1/1/7/3/11737845/coulter_panorama_23-2-12.pdf
2. Gaurav Sharma, Digital Color Imaging Handbook, CRC Press LLC, (2003). p31.
3. Bruce Ford, Non-destructive microfade testing at the National Museum of Australia, AICCM Bulletin Volume 32, 2011, p60..
4. Colorimetry-Part6:CIEDE2000Colour-DifferenceFormula,CIES014-6/E:2013;P5.
5. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p10.
6. Previous Reference p10.

$$E_{dm} = \int_{\lambda} E_{e,\lambda} \cdot s(\lambda)_{dm,rel} \cdot d\lambda \qquad \text{Wh/m}^2 \qquad (3.9)$$

Where: $E_{e,\lambda}$ is spectral irradiane (Wh/m^2); $s(\lambda)_{dm,rel}$ is relative spectral responsivity normalised at 300 nm, so that $s(\lambda)_{dm,rel}$ =1,0 for λ = 300 nm; λ is wavelength (nm). The suffix $_{dm}$ indicate that effective irradiance is evaluated according to the spectral responsivity of the receiving material.

The effective radiant exposure is the effective irradiance over time:(1)

$$H_{dm} = \int_{t} E_{dm} \cdot dt \qquad \text{Wh/m}^2 \qquad (3.10)$$

Where: t is time (h).

The threshold effective radiant exposure is the measure of the absolute sensitivity of an object. Change starts to occur in light-sensitive materials on first exposure to radiation - at first invisibly, then with visible signs. The threshold at which visible damage starts to be done is the yardstick used for assessing light sensitivity.(2)

Mathematically, The Threshold Effective Radiant Exposure $H_{s,dm}$ is the value of H_{dm}, that will cause a just noticeable colour change, that is to say, for which $\Delta E^*_{ab} = 1$.(3)

$$H_{s,dm} = E_{dm} \cdot t_s \qquad \text{W h/m}^2 \qquad (3.11)$$

Where: t_s is the critical duration of exposure in (h).

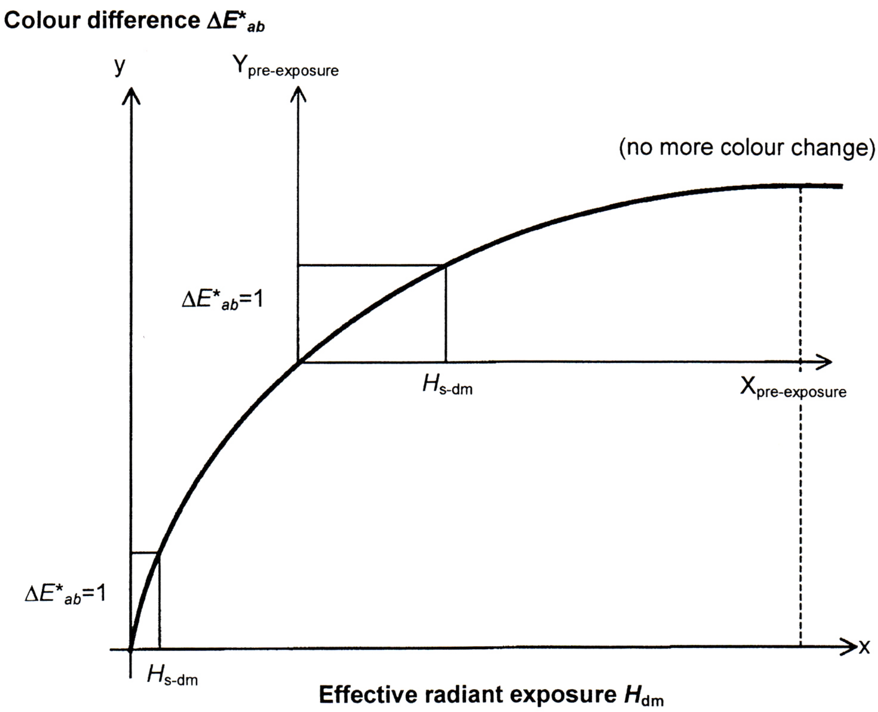


Figure 3.17 *The cause of damage (effective radiant exposure, H_{dm}) and the effect (colour change, ΔE^*_{ab}) according to the Berlin model. The threshold effective radiant exposure $H_{s,dm}$ is the exposure that causes one unit of ΔE^*_{ab} for the material concerned, and this increases as damage progresses. (CIE Technical report 157:2004)*

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1. Previous Reference p11.
2. Good Lighting for Museums Galleries and Exhibitions, Booklet 18, published by Fördergemeinschaft Gutes Licht (FGL), Frankfurt am Main, p30
3. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p11.

The illustration in (Figure 3.17) shows that, When the material is first exposed the curve is steep and the effect rapid, so that it requires only a relatively small level of $H_{s,dm}$, to cause one unit of ΔE^*_{ab} to occur, but as damage continues the density of susceptible molecules reduces, so that greater exposure is required to produce the same visible effect. Eventually the material stabilises, and no more colour change occurs because all of the colorant has faded.(1)

The responsivity of an object is defined by its threshold effective radiant exposure $H_{s,dm}$ and its relative spectral responsivity $s\,(\lambda)_{dm,rel}$. The general form of the $s\,(\lambda)_{dm,rel}$ function is given in (Equation 3.5). The Berlin researchers have exposed samples representing various categories of museum materials to a xenon source, with portions of each sample being shielded from selected spectral bands by a series of sharp cut-off filters. Data from periodic colorimetric measurements have indicated that $s\,(\lambda)_{dm,rel}$ may be represented by an exponential function of the form:(2)

$$s\,(\lambda)_{dm,rel} = \exp\,[-b\,(\lambda\text{-}300)] \qquad (3.12)$$

The $s\,(\lambda)_{dm,rel}$ function defines the action spectrum for each category of materials, and is normalised at 300 nm so that (Equation 3.12) returns a value of one for = 300 nm. The sample materials have been classified into five categories, and values of $H_{s,dm}$ and b are given in (Table 3.1). For incident monochromatic radiation of 300 nm wavelength, the values of $H_{s,dm}$ in (Table 3.1) indicate the exposures required to cause the samples to undergo a just discernible colour change. It should be noted, therefore, that reducing values of $H_{s,dm}$ indicate increasing responsivity. For other wavelengths, the required exposures correspond to the value of $H_{s,dm} / s\,(\lambda)_{dm,rel}$.(3)

The relative spectral responsivity s (λ)dm,rel is calculated after (Equation 3.12) and (Table 3.1) and the results is presented in (Figure 3.18). It is apparent that the curves are similar for materials b through e, while category a is distinctly different.

3.2.3.3.3.6 Damage potential of a light situation

With knowledge of the values of $H_{s,dm}$ and b for a material that is to be put on display, the museum stuff will be able to make decisions on display lighting with knowledge of the consequences of exposure.(4) As well, to define the damage potential for a lighting situation in a museum display. Damage potential: is the damaging irradiance and the illuminance at the exhibit stand in a fixed ratio to one another. That ratio indicates the damage potential. It is the crucial quantity

1. Previous Reference p11.
2. Previous Reference p12.
3. Previous Reference p12.
4. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p13.

used to describe the damage that can be done in a lighting situation where particular light sources and filters are trained on particular exhibits and materials.[1] And when this is done museum staff can plane their lighting conservation policy.

Table 3.1 *Threshold effective radiant exposure $H_{s,dm}$ and b values for the relative spectral responsivity function (Equation 3.12) for five categories of museum materials. (CIE Technical report 157:2004)*

Group	Samples	$H_{s,dm}$ (W h/m^2)	*b*
a	Low-grad paper	5	0,038
b	Rag paper	1200	0,0125
c	Oil paints on canvas	850	0,0115
d	Textiles	290	0,0100
e	Water colour on rag papers	175	0,0115

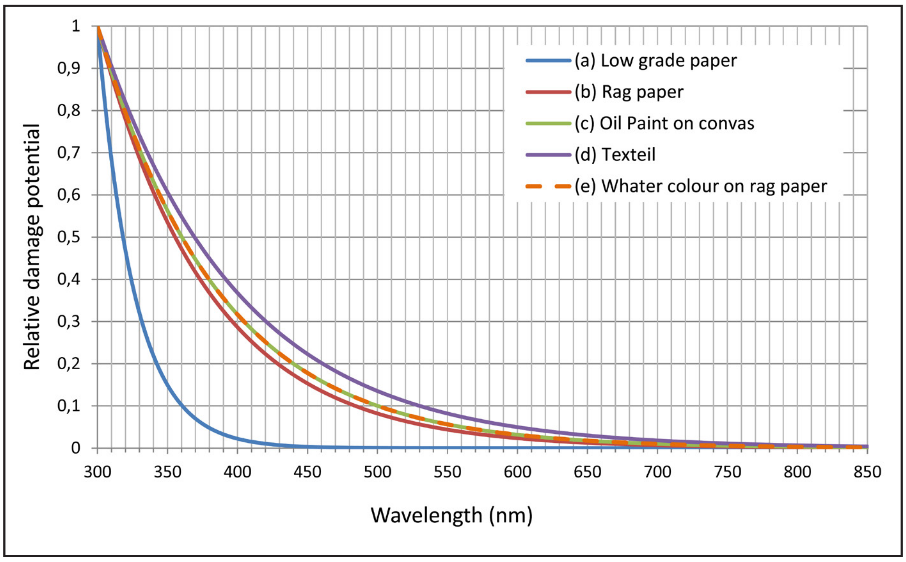

Figure 3.18 *The relative spectral responsivity function $s(\lambda)_{dm,rel}$ for different materials according to Equation 3.12 and Table 3.1 (CIE Technical report 157:2004)*

3.2.3.3.4 Microfading Test to collect fading data (Colour difference / time of exposure)

Microfading Test is an accelerated method for assessing the vulnerability of individual museum objects to light-fading, including those for which the identity of the colourant is unknown.[2]

Ideally, exposures data would be based on monitoring the colour change of individual objects under museum lighting conditions, however it is extremely time consuming and difficult or impossible in many cases for technical reasons. Accepting that accelerated techniques are necessary, microfade tester appeared to be the most practical way of bridging the information gap because it offered routine, rapid, and nondestructive access to object specific fading rate data.[3]

1. Good Lighting for Museums Galleries and Exhibitions, Booklet 18, published by Fördergemeinschaft Gutes Licht (FGL), Frankfurt am Main, P30- p31.
2. Microfading FAQ, http://www.microfading.com/microfading-faq.html
3. Bruce Ford and Nicola Smith, Protecting the most important, most exhibited and most fugitive museum objects from light-fading, textile speciality group post prints volume 20, 2010, p159.

3.2.3.3.4.1 Microfading Test instrument

Generally, the instrument is very simple in principle, a very high intensity light is directed from an optic fibre and lens assembly onto a tiny area of object's surface. A second lens assembly collects reflected light at 45° to the source from where it is directed to a photodiode array spectrophotometer via optic fibre. Some other instrument models additionally have a video cameras or borescopes which allow precise location and a magnified view of the surface being tested.[1] (Figure 3.19)

The light source is a 75W stabilized xenon source filtered to 400 -700 nm; The spectral distribution, similar to UV filtered daylight, has a higher colour temperature than the usual museum mid-range lighting, which will tend to systematically overestimate fading rates. The source intensity is equivalent to approximately 10 Mlx over the area of the 300 μm spot diameter; sufficient to fade ISO Blue Wool Number 1 (BW1) to more than 10 ΔE^*_{ab} within 15 minutes. Assuming reciprocity holds, this is equivalent to 15 -20 years on continuous display at 50 lux (UV filtered).[2]

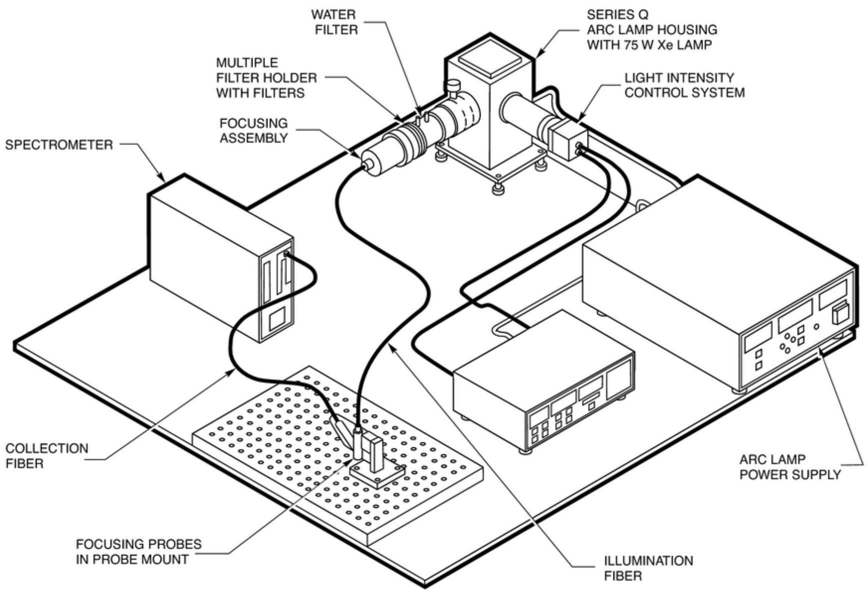

Figure 3.19 *The Oriel 80190 Fading Test System. The system is the result of scientists at Carnegie Mellon University developing a method for testing light - induced fading of museum artefacts, with an Oriel Light Source and Components from Newport company. This testing method was then replicated by other Conservationists. (http://search.newport.com/?x1=sku&q1=80190)*

3.2.3.3.4.2 Interpretation of data

The software provided with the spectrophotometer converts spectral into CIELAB L* a* b* and CIE76 (ΔE*ab 76 values). Fading rates report relative to the fading of the ISO Blue Wool swatches, however they can be expressed as ΔE*ab/Mlx hr.[3] or as CIEDE 2000 (ΔE_{00} 2000). (Figure 3.21 and Figure 3.22).

1. Bruce Ford, Non-destructive microfade testing at the National Museum of Australia, AICCM Bulletin Volume 32, 2011, p54.
2. Previous Reference, p54.
3. Previous Reference, p56.

While fading rates are important, the spectral and derived L* a* b* data contain a great deal of other information because they describe the trajectory of the colourant within the colour solid rendered by the particular perceptual model. One can tell, for example, whether a colourant darkens or lightens (L*) or becomes more or less yellow-blue (b*) or red-green (a*).[1] (Figure 3.20)

3.2.3.3.4.3 Reliability of Microfading Test data

With some caution there are several reasons to regard with some doubt the direct translation of microfading cumulative exposures into exhibition exposures:[2]

- The Microfading Test data tell us nothing about colour changes that occur in the absence of light, including reactions initiated by light but which continue in dark storage. [3]
- The Microfading Test data did not include the effect of other museum deterioration agents on the process of photochemical reaction that may occur to the material in a particular instance on display.[4]
- The Spectral Power distribution of the source in the instrument are different than that are used in display.
- The collected data from the test show that some colorant record a reciprocity failure.[5]

Whether Microfading Test or more conventional studies of surrogate materials in test chambers, is accelerated and suffers from the same kind of uncertainties. In spite of the inevitable uncertainties micro-fading tells us with much more confidence than the rather limited data in the literature whether a dye or pigment is likely to be at serious risk of unacceptable fading through time.[6]

Further, as advantage for the Microfading Test over the ISO Blue Wool Standard test, since each step in the ISO Blue Wool Standard differs from the next by about a factor of three (roughly one-half to one-third), a colourant equivalent to BW3 could be left on display 10 times longer than BW1 for the same degree of damage. The ability to make distinctions within this problem range for museums is micro-fading's great strength.[7] As well, the museum’s lighting guidelines depending on ISO Blue Wool Standard resulted in well-intentioned, but unnecessary over-protection of about half of all objects in long-term displays, and over-exposure of a vulnerable minority that are not easy to

1.Bruce Ford, Non-destructive microfade testing at the National Museum of Australia, AICCM Bulletin Volume 32, 2011, p61.

2. Previous Reference, p55.

3. Microfading FAQ, http://www.microfading.com/microfading-faq.html

4. Previous Reference.

5. Previous Reference.

6. Previous Reference.

7. Previous Reference.

predict.[1] With the Microfading Test the museum's lighting guidelines will be more precise allowing more display time for a lot of museum objects and the right exposure for vulnerable that are not easy to predict.

3.2.3.3.4.4 Microfading Test example[2]

The National Museum of Australia (NMA) conducted a Microfading Test for two identical printed paper representing a cycloramic view, the prints go back to 1911. One of the print was seriously affected to the extent that the magenta ink has faded out altogether; cyan has been quite badly affected, and the yellow ink is visually largely intact and the other was relatively unfaded. The other (pristine) was less faded. The fading results were calculated based on colour change ΔE^*_{ab} in the CIE76 colour space for a particular reason, however the ΔE_{00} in the CIEDE2000 results are also given. (Figure 3.20 to Figure 3.22).

Assuming reciprocity holds the microfading results for the CIE76 colour space indicate that for the magenta ink (BW2), 4 years of UV free exposure 8 hours a day at 80 lux would be sufficient to cause 1 Just Noticeable Fade (JNF) and it would take approximately 120 years 30 JNFs to destroy it completely; the cyan (mid BW2-BW3) 7 years for a JNF and 210 years to destroy completely; and yellow (mid BW3-BW4) 23 years for a JNF and over 600 years to fade out completely. The paper bleaching observed under UV-free accelerated light fading conditions has occurred in reality. The paper of the previously exposed cyclorama is noticeably whiter than the pristine unexposed example, and the former bleached much more slowly than the latter.

The significance of microfading results for (undyed) papers over the long term is unclear because of the complexity of the reactions involved in their ageing, both as a result of light exposure and as a result of other mechanisms. Microfading usually reflects only the photo-bleaching of paper under UV-free conditions however concurrent thermal reactions lead to yellowing as well as reactions initiated by light but which continue during subsequent dark storage (post-actinic processes).

The museum assumptions are based on those of the Victoria and Albert Museum, London: that is works should last for at least 500 years in a coloured form; a Just Noticeable Fade (JNF) = 1.6 ΔE and 10 JNFs signal the effective end of coloured life for an object. The NMA further makes a judgement based on a significance test as to whether the object/collection is likely to be in strong demand for exhibition and adjusts recommended exposures accordingly. If the pristine cyclorama were displayed according to this lighting guidelines, it would be considered suitable for display for 12-18 months/decade at 50 lux on the basis of the assessed lightfastness of the magenta ink.

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1. Bruce Ford and Nicola Smith, Protecting the most important, most exhibited and most fugitive museum objects from light-fading, textile speciality group post prints volume 20, 2010, p164.
2. Micro-fading report, The National Museum of Australia, http://www.microfading.com/uploads/1/1/7/3/11737845/coulter_panorama_23-2-12.pdf

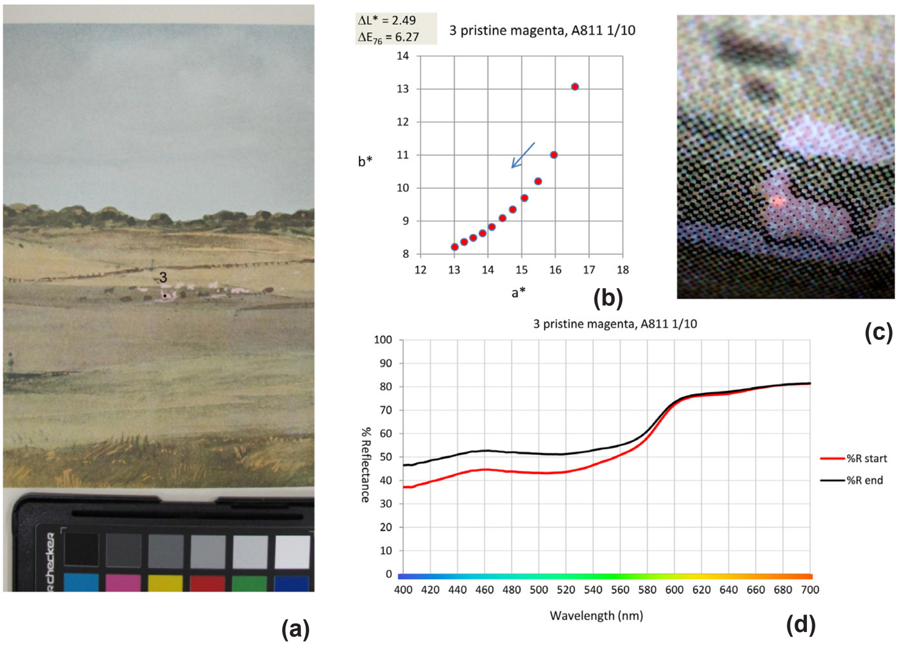

Figure 3.20 *Microfading Test. (a) A photo shows a part of the less faded printed paper (unexposed pristine cyclorama). Position 3 marks the test point for the magenta ink. (b) The trajectory of the faded magenta ink on the a*b* section in the CIE76 colour space. (c) A magnified view of the surface being tested at position 3 (d) The reflected spectrum power distribution of magenta ink at the start and the end of the test.(Micro-fading report, The National Museum of Australia)*

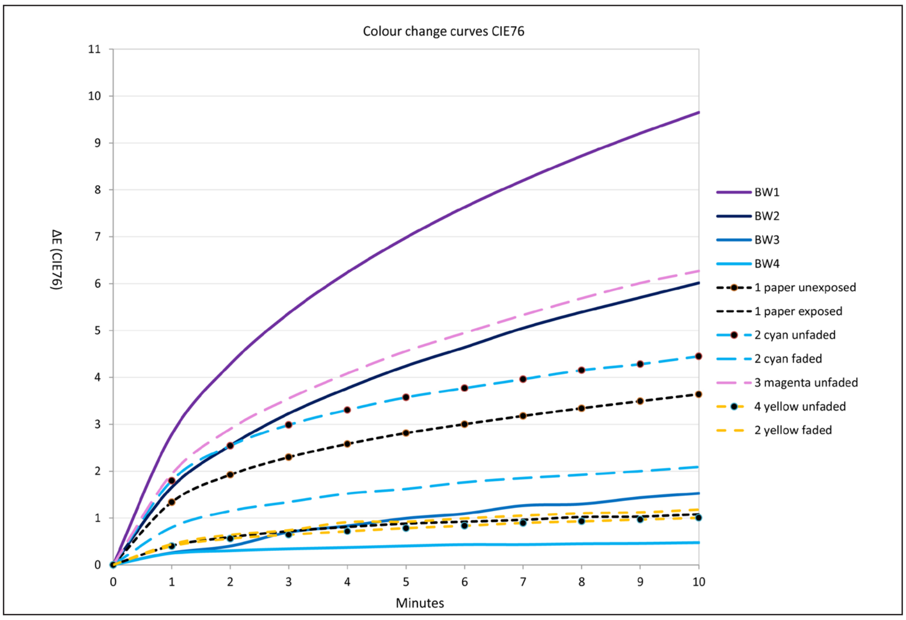

Figure 3.21 *Colourchange curves CIE76 for two identical printed paper. The graph is a result of a Microfading Test. It shows the comparison between the unexposed paper (dashed line with dot), the exposed paper (dashed line) , and the Blue Wool Standard BW1, BW2, BW3, BW4 (continuous line). (Micro-fading report, The National Museum of Australia)*

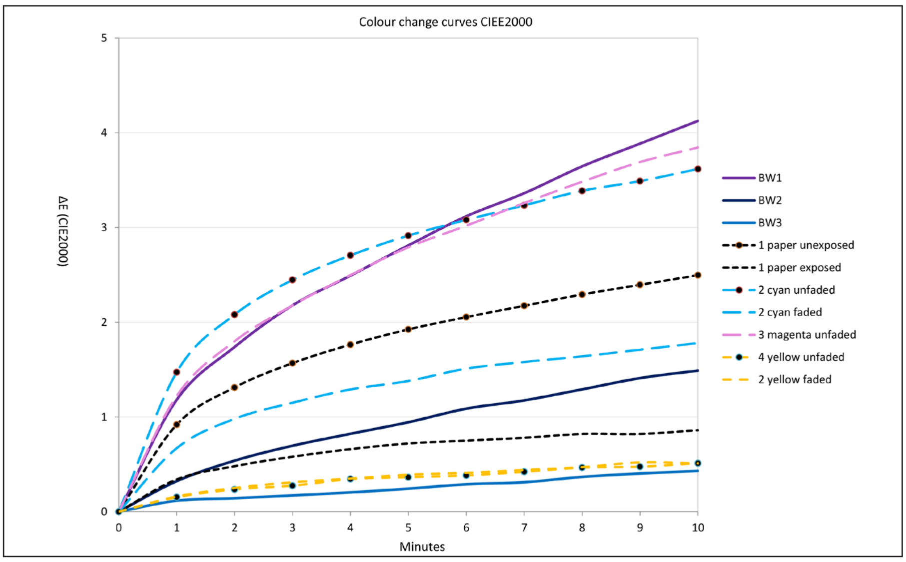

Figure 3.22 *Colourchange curves CIEE2000 for two identical printed paper. The graph is a result of a Microfading Test. It shows the comparison between the unexposed paper (dashed line with dot), the exposed paper (dashed line) , and the Blue Wool Standard BW1, BW2, BW3, BW4 (continuous line). (Micro-fading report, The National Museum of Australia).*

3.2.3.3.5 Difficulties in handling the photochemical actions

- The threshold effective radiant exposure $H_{s,dm}$ is not constant, but increases as exposure causes the material to become less responsive.(1) Accordingly, it takes much higher doses of light to cause the same damage to older material which has pre-exposed and already undergone change, than to new material which has less or never been exhibited. In these cases, it is possible to take account of the pre-exposure time and reduce the light protection measures accordingly. Pre-exposure to light is best established if all irradiation times and types are documented or by comparison measurements where parts of the object must be unexposed.(2) However, both methods unfortunately are difficult to managed with historic material. Museum conservators have to depend on and trust technology like Microfading Test to do such procedure.
- Other museum agents of deterioration: ambient and object temperature; moisture content of the object and its surroundings; and pollutants or dust deposited on the object all play a role in photochemical processes.(3) These influences are not considered in the calculation of the Berlin Model and can not be included in Microfading Test.
- Spectral sensitivities of the pigments vary according to its spectral absorptance values. Accordingly, it is clear that "typical" spectral responsivity functions, such as the Berlin Function, cannot be expected to accurately represent the spectral sensitivities of different colours of the same material. For example, if there is one highly responsive pigment in a low responsivity multi-coloured art work, then to assess the effective irradiance on the basis of a typical spectral responsivity function could be seriously misleading.(4)
- Relying only on CIELAB measurements for measures of the effects of radiation exposure assumes that the effects are entirely visible. At least as important as fading is the loss of strength caused by light exposure, as evidenced by the embrittlement of paper and the fraying of textiles. Although it will often happen that noticeable fading will precede significant weakening of the material, it is not safe to assume that there is correspondence between the two effects. For example, a material that incorporates a light-fast colorant may show little visible effect of light exposure while its physical structure is undergoing serious damage. Although progress is being made towards limiting rates of exposure based on the visible effect, more work is needed before this approach can provide reliable guidance for practice in museums.(5)

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1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p13.
2. Good Lighting for Museums Galleries and Exhibitions, Booklet 18, published by Fördergemeinschaft Gutes Licht (FGL), Frankfurt am Main, p31
3. Good Lighting for Museums Galleries and Exhibitions, Booklet 18, published by Fördergemeinschaft Gutes Licht (FGL), Frankfurt am Main, P30
4. Previous Reference p14.
5. Previous Reference p15.

3.3 Exhibits sensitivity-to-light classification

3.3.1 Classification of materials

To achieve a good lighting for conservation the items of a museum collection must be precisely classified according to their sensitivity to exposure. Generally, inorganic materials are less responsive to light than organic materials. Commonly, the recommended classification uses three or four categories. The IES use three categories: High-, low- and no-sensitivity-to-light materials, and they respectively assign 50 lx, 200 lx and up to 1000 lx to be used with every group.(1) The CIE, use four categories: High-, Medium-, low-responsivity, and Irresposive- to-light materials.(2) For examples of materials in every category see (Table 3.2).

The classification in (Table 3.2) are mostly natural materials and traditional pigments. Pigment and synthetic materials are generally more difficult to identify than natural materials. Synthetic materials add another level of complication. Polymeric substances form the basis of modern plastics, textiles, rubber, paints, varnishes, adhesives, pigments and dyes. In their pure form the polymers are generally colourless and quite stable at room temperatures, but invariably they are combined with other substances to give them particular properties. Some plastics and synthetic rubbers appear to "sweat" when placed on display, and this is because added plasticiser is leaching out of the material. Added pigments may fade while the base material is relatively unaffected. Some synthetic materials become "chalky" when exposed, and this is separation of filler that has been added to the material. It might actually be chalk.(3)

3.3.2 Classification of pigments

Pigments are a special concern for conservators because it often happens that the first visible sign of damage due to exposure is the deterioration of pigments, and pigments vary widely in responsivity to exposure. Identification of pigments requires the skills of a professional conservator or museum scientist.(4) The ISO Blue Wool rating scale are used from many researchers to classify the sensitivities of artistic pigment and based on these studies the for responsivity classifications may be related to ISO Blue Wool as shown in (Table 3.2). Michalski (1987, 1997) developed a recommendation for relating pigments to ISO ratings and estimates of probable fading. The study is shown in (Table 3.3).(5) (For more info see appendix 1.3).

It is important to point out that the light-fastness of a pigment may be substantially affected by how it is applied by the artist. Indigo on wool is a low responsivity material (lSO 7), and there are many examples in museums of woollen tapestries where indigo is the only pigment that is

1. IESNA The Lighting handbook, Application - Light for art,10th Ed. 2011, p(21.12).
2. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p18.
3. Previous Reference p18.
4. Previous Reference p19.
5. Previous Reference p19.

not seriously faded. However, on paper, cotton or silk, indigo becomes a high responsivity material (lSO 3) and must be treated with great care if its rich blue hue has not already been faded.(1)

3.3.3 Precaution for classifying

The following Precautions are important when classifying and working with preservation-worthy objects:(2)

- Preservation-worthy objects must be defined and placed to classified zones within the museum according to their sensitivity to light in order to develop appropriate lighting solutions.
- Where any doubt exists to classify an object between two sensitivity to light categories, it is recommended to assign it to the higher category.
- Objects or artworks consisting of a variety of the exemplified materials should be categorized in the most sensitive category, some objects, such as ceramics or metal, may exhibit fugitive finishes and should be assigned to the high-sensitivity to light category.
- Consult with conservator to establish light sensitivity categories for given objects.
- If an object is displayed the designer must evaluate all luminance falling on the objects from all of the lighting producing media, including daylight in the space to determine that this does not exceed the recommended maximum illuminance.

	Category	ISO Raiting Blue Wool Categories for pigments	Limiting illuminance (lx)	Limiting exposure (lx h/y)	Description
1	Irresponsive	----	no limit	no limit	The object is composed entirely of materials that are permanent, in that they have no light responsivity. Examples: most metals, stone, most glass, genuine ceramic, enamel, most minerals.
2	Low responsivity	7 & 8	200	600000	The object includes durable materials that are slightly light responsive. Examples: oil and tempera painting, fresco, undyed leather and wood, horn, bone, ivory, lacquer, some plastics.
3	Medium responsivity	4, 5 & 6	50	150000	The object includes fugitive materials that are moderately light responsive. Examples: costumes, watercolours, pastels, tapestries, prints and drawings, manuscripts, miniatures, paintings in distemper media, wallpaper, gouache, dyed leather and most natural history objects, including botanical specimens, fur and feathers.
4	High responsivity	1, 2 & 3	50	15000	The object includes highly light responsive materials. Examples: silk, colorants known to be highly fugitive, newspaper.

Table 3.2 *Four category classification of materials according to responsivity to visible light and its relationship to the blue wool categories. (CIE Technical report 157:2004)*

1. Previous Reference p19.
2. IESNA The Lighting handbook, Perception and Performance,10th Ed. 2011, p 21.1 and p21.12

Table 3.3 *The light responsivity of pigments and substrates. (CIE Technical report 157:2004))*

Broad category of responsivity to light	High responsivity			Medium responsivity			Low responsivity			Irresponsive (f)
Generalisations	Most plant extracts, hence most historic bright dyes and lake pigments in all media:(g) yellows, oranges, greens, purples, many reds, blues. Insect extract, such as lac (yellow), cochineal (carmine) in all media.(g) Most early synthetic colours such as the anilines, all media.(g) Many cheap synthetic colorants in all media.(g) Most felt tip pens including blacks. Most dyes used for tinting paper before 20th century. Most colour photographic prints with "colour" in the name.			A few historic plant extracts, particularly alizarin (madder red) as a dye on wool or as a lake pigment in all media.(g) The colour of most furs and feathers. Most colour photographic prints with "chrome" in the name.			Artists' palettes classified as "permanent" (a mix of truly permanent and low light responsivity paints, e.g. ASTM D4303 Category I; Winsor and Newton AA.) Structural colours in insects (if UV blocked). A few historic plant extracts,especially indigo on wool. Silver/gelatin black and white prints, not RC paper, and only if all UV blocked. Many high quality modem pigments developed for exterior use, automobiles.			Most but not all mineral pigments. The "true fresco" palette, a coincidence with the need for stability in alkali. The colours of true glass enamels, ceramics (not to be confused with enamel paints). Many monochrome images on paper, but the tint of the paper and added tint to the carbon ink are often high responsivity, and paper itself must be cautiously considered low responsivity. Many high quality modern pigments developed for exterior use, automobiles.
Blue Wool categories	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Over 8**	**-**
Mlx h (a) for noticeable fade (b) UV rich (c)	**0,22**	**0,6**	**1,5**	**3,5**	**8**	**20**	**50**	**120**	**-**	
Probable Mlx h (a) for noticeable fade (d) if no UV (c)	**0,3**	**1**	**3**	**10**	**30**	**100**	**300**	**1100**	**-**	
Selected specific examples (e)	Turmeric. Saffron. Sulphonated ndigo. Many modem dyes for paper, e.g. methyl violet, victoria blue, eosine (pink), bismarck brown.	Carmine lake. Gamboge. Quercltron lake. Madder on cotton. Old fustic. Coomassie violet on paper. Rhodamine on paper. Average photo. Colour print.	Madder on silk. Cochineal on wool and cotton. Weld, alum mordant on wool. Indigo on paper, cotton and silk.	Lac dye on wool. Seaweed on wool. Ling heather tips on wool. Weld, tin mordant on wool. Vegetable tanned leather.	Alizarin (madder) lake tint. Alizarin (madder) on wool. Colour photo print if silver-dye bleach processed, e.g. Cibachrome.	Cochineal on silk. Foxglove on wool. Chrome tanned leather	Alizarin (madder) lake. Madder on wool. Vermilion-Chrome yellow. Indigo on wool. Water lily roots (black) on wool.	Cadmium red, orange, yellow (may belong in No responsivity but insufficient data). Some dyes, such as indigo and cochineal on cotton, silk, and wool, move several steps up, to 8 or better, when one tests the remnant of a partially faded sample. This is NOT true of all colours, and especially not true of those that start in the range Blue Wool 1,2. These fade uniformly fast.		Carbon, hence: true pencil, charcoal, India Ink. (Not iron gall ink, not the yellow in Sepia). Ochre. Umber. Sienna. Indian red (iron oxide). Black oxide of iron. Ultramarine. Cobalt blue. Silver point. All the white pigments.

Note to (Table 3.3):

a. Mlx h is the exposure unit megalux hours =1000 kilolux hours.

b. A noticeable fade is defined here as Grey Scale 4 (GS4), the step used in most lightfastness tests as noticeable. It is approximately equal to a colour difference of 1,6 CIELAB units. There are approximately thirty such steps in the transition from a bright colour to white.

c. UV rich refers to a spectrum similar to daylight through glass. This is the spectrum generally used for the lightfastness data used to derive this table. The exposures here are the best fit to data that varies about ± one Blue Wool step.

d. Exposures estimated for UV blocked light source are derived from a study on 400 dyes and the blue wool standards themselves. As such, it is only probable, and probably only for organic colorants. These estimates show minor benefit of UV filtration for high responsivity colorants, but large improvements for low responsivity colorants. For conservative estimates, use the UV rich scale.

e. The specific examples are near optimum tint strength unless noted otherwise ("standard depth" for dyes, peak chroma for pigments). Heavier concentrations of colorant can be less responsive by up to two Blue Wool steps. The examples are also for unfaded samples. Partly faded samples may or may not show lower responsivity. Fading prediction is an imprecise science, so the broad categories of this table are most practical. Accurate predictions can only be made directly on the artefact in question, or on samples known to be identical. Several researchers are developing microspot tests in Canada, the UK, and the USA.

f. "Irresponsive" to light does not mean guaranteed colour life. Many colorants in this group are responsive to pollution. Many organic media will chalk or yellow or both if any UV is present.

g. The particular paint medium makes only small differences to fading rate, it is the colorant that matters in fading, not whether it is oil, or tempera, or watercolour, or acrylic. Media does, however, make large differences to rate of discolouration from pollutants such as ozone and hydrogen sulphide.

Note to (Table 3.3). (CIE Technical report 157:2004).

3.4 Management of lighting damage

To obtain benefits from the previous knowledge for the purpose of minimising damage that may occur to museum's worthy-objects in display, light designers have to comprehend techniques and strategy that implement these knowledge in practice of museum lighting. In the following points we will try to demonstrate techniques and strategies that help to achieve the best conservation aspects in practice of museum lighting.

3.4.1 Controlling non-visible radiation in electrical light sources

Studying the spectral power distribution (SPD) of a light source helps to know its effect on the artefacts, determine the right method of spectrum treatment and its appropriate application. Some light sources, notably incandescent (e.g. halogen), emit more IR energy than light and UV. (Figure 3.23) For this type of source, the radiant heating effect will be relatively high for a given illuminance unless corrective measures are taken. Most other light sources, including fluorescent lamps, mercury, metal halide discharge lamps, and daylight, emit significant quantities of ultraviolet energy. (See Appendix 1.1 & 1.2 for typical values). Although the UV energy is usually small compared with the energy in the visible portion of the spectrum, its high photon energies makes it a particularly potent source of photochemical action.[1]

1. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p9. p14.

3.4.1.1 Dimming the light source do not reduce damage

Conservators establish limits for measured levels of illumination to limit damage. Lighting designers over-light exhibits to provide a margin for future changes. Conservators then dim the lights to the specified light level using a "color-corrected" light meter. Everything is "correct" but the collections continue to fade. No one considers the fact that dimming just moves the light energy (spectrum) towards the red and infrared wavelengths, where a light meter is nearly blind. A light meter is filtered to the sensitivity of the human eye with the CIE photopic curve. Thus, it see none of the energy outside the visible spectrum. Most of the spectrum is still there and the damage continues.(1)

The graph (Figure 3.23) shows the complete spectral output of a quartz halogen track light at 3000 K. Most of the energy 95% is outside the visible spectrum. About 1% is ultraviolet, below 380 nm. Roughly 94% is infrared, above 770 nm. None of that energy is visible to you or your museum light meter and lighting manufacturers almost never give you full spectrum data. The actual result for dimming is a shifting in the peak of the curve toward the infrared, lowering the total energy hitting the exhibit by just 10%. Your light meter shows half the light, but your artefacts still experience 90% of the damage. This is why dimming incandescent track lighting is not an effective preservation tool. Further The orange-yellow colour of dimmed lighting also makes it harder to see, especially for older patrons.(2)

To solve this problem in practice, instead of dimming the light source it is much wiser to use lower wattage lamps or fewer lamps at full voltage(3) or to use layers of metal window screen to reduce light output without changing the colour temperature(4). At any case, as additional procedure, it is advisably to cutoff UV and IR with a filter if it exist or to use a LED source of light.

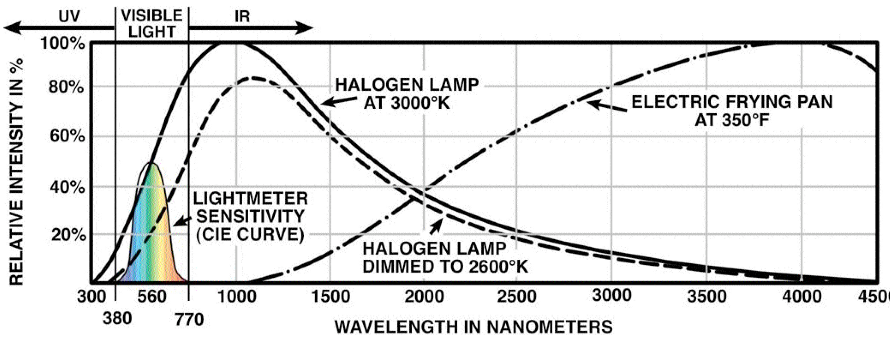

Figure 3.23 *A full SPD of a halogen lamp at 3000°K and when it dimmed at 2600°K. The light (visible spectrum 380–780 nm) and the adjacent non-visible IR and UV. The diagram also includes a SPD for the heat radiation of a electric frying pan at 350° F for comparison. (Museum lighting - pure and simple,p3)*

1. Jack V. Miller and Ruth Ellen Miller, Museum lighting - pure and simple, Seaford, DE: NoUVIR Research, 2011, p2.
2. Previous Reference p3.
3. Previous Reference p3.
4. NJ Miller and JR Druzik, Demonstration of LED Retrofit Lamps at an Exhibit of 19th Century Photography at the Getty Museum, March 2012, p2.

3.4.1.2 Controlling IR radiation in electric light sources

The radiant heating is less serious in causing damage to museum objects than photochemical action, that what makes museum stuff give more attention to photochemical action. However, the radiant heating can be a serious source of damage. Since it is associated with incandescent lamp, the favourite source of light to museum stuff, and its effect can not be distinguished from photochemical action.[1]

What makes the incandescent lamps favourite for museum staff, that it has a low content of UV and high colour rendering index. However, it contain a high content of IR. The developers try to reduce the heating effect of incandescent lamps to reduce the thermal load in the interior space and to rase lamp efficiency. Examples of the advanced incandescent lamps is the MR series and the parabolic aluminized reflector (PAR) lamp. (Figure 3.24)

(a) **(b)**

Figure 3.24 *Examples of incandescent halogen lamps that are modified to reduce the IR radiation in their spectrum (a) 50 Watt MR16 Bi-Pin 12V Wide Covered Glass Flood Halogen Light bulb (b) Feit Electric 75PAR30/QFL/MP/2 75-Watt Par 30 Halogen Reflector Flood Light, Clear (Examples from http://www.amazon.com/)*

The MR series of lamps is the combination of a compact, low voltage, high temperature filament in a quartz envelope, accurately located with regard to a precision-tooled multi-faceted reflector. However, the incandescent filament emits more energy in the IR portion of the spectrum than in the visible portion. By applying a dichroic coating to the reflector, reflection becomes wavelength specific. Long wave (IR) energy passes through to emerge behind the lamp, and only the short wave energy (light and UV) is directed into the beam. For a given illuminance, the irradiance, and hence the radiant heating effect, is reduced. However, practical experience with these lamps has not always been good. The dichroic coatings have tended to deteriorate during the life of the lamp, causing noticeable changes in the colour and shape of the beam. Some lamp manufacturers have responded by reverting to aluminium reflectors, but this puts the IR back into the beam. Improved dichroic coatings are now available that maintain performance over the life of the lamp.[2] (Figure 3.24-a)

1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p8.
2. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p17-18.

Another development has been the IR-halogen parabolic aluminized reflector (PAR) lamp, for which the spherical quartz envelope surrounding the filament has an IR reflective coating. This reflects IR energy back onto the filament, heating it, and reducing the electrical energy needed to maintain the filament temperature. This has been introduced as an energy conserving measure, but it also means that there is less IR in the beam. Unfortunately, there is a lack of data to enable the lighting designers to compare lamp types according to the amount of IR that accompanies the beam lumens.[1] (Figure 3.24-b)

There are no standards giving acceptable IR irradiance levels, nor are there meters for checking such levels. Protection depends on the vigilance of the museum staff. The only way to be sure that a spotlight is not causing needless radiant heating is to apply an infrared filter. The old type heat-absorbing glass filters have been largely replaced by dichroic glass filters, which are the opposite of the dichroic lamp filters: they reflect IR and transmit visible and UV. They seem to be less affected by ageing than dichroic lamp filters, possibly because they are mounted in front of the lamp and thus are less heat stressed.[2]

3.4.1.3 Controlling UV radiation in electric light sources

The significance of the UV radiation depends on: lamp wattage, centre beam candlepower, beam spread, distance between lamp and preservation-worthy material, and exposure duration.[3] The UV data of a light source has to be reviewed and a check up measurement has to be conducted.

A special UV meters have been developed for museum applications that give readings in microwatts per lumen, and these are useful for checking whether filter media have lost their effectiveness and whether filters have been replaced after lamp changes. The UV meters produced for scientific applications generally measure irradiance in specific bands within the UV range, and such measurements may be less useful indicators of potential damage to museum objects.[4]

For museum conservation, UV radiation is that which is $\leq$ 400 nm. A maximum recommended value of UV radiation is 75 μW/lm. If lamps exceed this value, then UV reduction filters should be applied to limit UV.[5] However, it is recommended that unless all artefacts in a display area are totally insensitive to exposure, UV has to be eliminated. As every source of "white" light emit some degree of UV, every light source must have a filter.[6]

1. Previous Reference p18.
2. Previous Reference p18-19.
3. IESNA The Lighting handbook, Application: Light for Art,10th Ed. 2011, p(21.13).
4. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p20.
5. IESNA The Lighting handbook, Application: Light for Art,10th Ed. 2011, p(21.13).
6. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p18.

Filters come in a variety of forms to suit the available light sources. Fluorescent lamps may be fitted with covers of UV absorbing acrylic, or may be located in a light chamber above a sheet of UV absorbing acrylic. Incandescent sources may require glass filters to withstand the heat, and these may be either a UV absorbing glass or a dichroic glass filter that selectively blocks UV. It should be noted that while dimming incandescent sources substantially reduces UV, the proportion of IR did not change[1]. (Figure 3.23)

Since incandescent sources emit only low levels of UV, some authorities claim that added protection is not necessary. The fact is that unfiltered incandescent sources expose artefacts to unnecessary damage, and for this reason it is recommended that even incandescent lamps are filtered to block wavelengths shorter than 400 nm. Lighting designers should be particularly wary of halogen lamps without cover glasses, such as open MR lamps. The quartz envelope of the halogen source transmits short wavelength UV (i.e., less than 320 nm), and while the energy at these wavelengths is small, it is very potent.[2]

3.4.1.4 Types of filters used with electric light sources

The transmission characteristics of filters used with light sources can be distinguished by categorizing them as band-pass or cutoff filters. Physically, these may consist of films of material adhered to glass or plastic, glass material incorporating absorbing dyes, or thin metallic layers vacuum deposited on quartz or glass to exacting thicknesses (dichroic filters).[3] It is very important to point out that some acrylic sheet and flexible polyester films change its transmission characteristics after aging, which require periodic control to insure efficiency.[4] (Figure 3.25)

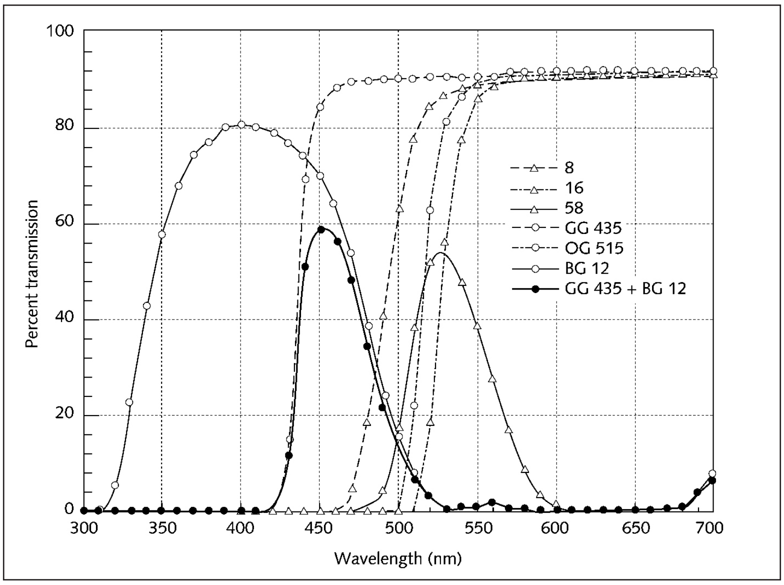

Figure 3.25 *Transmission spectra of several glass cutoff filters (dashed lines) or band-pass filters solid lines), manufactured by Schott (circles) or Kodak (triangles). A narrower band of light can be selected by the combination of a sharp cutoff filter and a broad band-pass filter, as indicated by the thicker solid curve. (Terry T. Schaeffer, Effects of Light on Materials in Collections, p26)*

1. Previous Reference p18.
2. Previous Reference p20.
3. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000. p26.
4. Previous Reference p28.

One of the state-of-the-art filter utilized in museum is the "Mark 2" filter. A filter designed for use with halogen lamps during earlier research carried out principally by Professor Carl Dirk (University of Texas at El Paso) and Jim Druzik (Getty Conservation Institute). The coated glass filter is intended to optimise energy, colour rendering, and lumens/optical watt, while minimizing risks for artwork. The filter is made to be used with a variety of tungsten halogen lamp types, these filters have been successfully installed at the Georgia O'Keeffe Museum in Santa Fe, New Mexico. They limit energy radiated to the surface of artworks even more than LEDs do, but it is striking how close the SPD of the most successful (i.e., those producing the least damage) warm-color LEDs are to these filters when each were developed independently.[1] (Figure 3.26 and Figure 3.27).

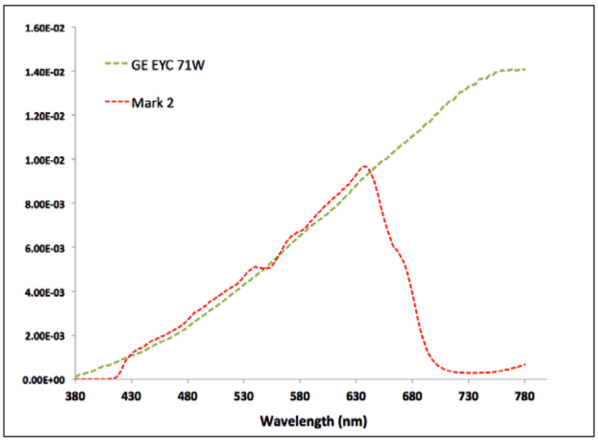

Figure 3.26 *Comparing SPD of :(dashed red line) a halogen lamp with special filter "Mark 2" to minimize UV and short-wavelength blue (<410 nm) as well as long-wavelength red (>700 nm) to (dashed green line) a halogen lamp (GE MR16 EYC 71W). (N. J. Miller and J. R. Druzik, Demonstration of LED Retrofit Lamps at Getty Museum, p8)*

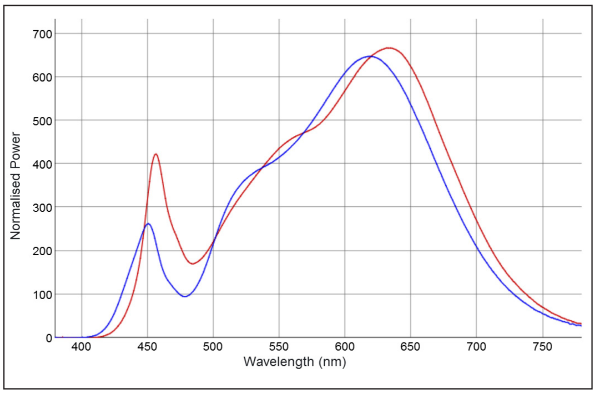

Figure 3.27 *Comparing SPD of : (blue) MR16 LED retrofit lamp manufactured by CRS Electronics to (red) a custom-designed source made by Xicato. The two white LEDs have 3000K. (N. J. Miller and J. R. Druzik, Demonstration of LED Retrofit Lamps at Getty Museum, p8)*

3.4.1.5 Working with LEDs

Tungsten halogen is still the dominant light source in museums and galleries around the world. However, there are a lot of studies and attempts to utilize LEDs in museum lighting since it has a lot of benefits as: long life, high energy efficiency, ecologically friendly, design flexibility, etc. From conservation point of view our concern will be about the potential of LEDs to cause damage to sensitive-to-light materials and this can be concluded by examine the LEDs spectrum power distribution (SPD) or be testing it direct on a material.

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1. N. J. Miller and J. R. Druzik, Demonstration of LED Retrofit Lamps at an Exhibit of 19th Century Photography at the Getty Museum, March 2012, p7.

3.4.1.5.1 Examining the LEDs spectrum

LEDs do not emit energy in the UV (unless designed to) or in the IR region of the electromagnetic spectrum and the have a full/continues spectrum in the visible region. Most of LEDs types have a peak in the blue region of the spectrum. This peak becomes bigger whenever the CCT of a LED increase (from worm-to-cold light). The blue peak indicates a high potential of damage, which often exceed the potential of damage for the conventional tungsten halogen lamp. However, some LEDs types with little blue peak is partially compensated for by the fact that the LED cuts off at about 420 nm when the halogen lamp continues to about 385 nm.[(1)] However, this possibility depends on the SPD of the LEDs. (Figure 3.28)

Some high quality LEDs perfectly suitable for museums have small or almost no peak in the blue region and the short wavelengths is generally no greater than an incandescent light source.[(2)] Compare the LEDs SPD with the Halogen lampe SPD in (Figure 3.29) and the filtered halogen lamp spectrum in (Figure 3.26).

It is important to point out that LEDs with different SPD can have the same CCT. Thus, the SPD for LEDs have to be reviewed carefully regardless of its CCT and potential of damage has to be determined accordingly to the energy distribution throughout the spectrum. (Figure 3.29 and Figure 3.30).

LEDs generally do not change colour when they are dimmed. However, it has been reported that some white LEDs may appear bluer when dimmed (U.S. Department of Energy 2011).[(3)]

Generally, LEDs with CCT range between 2700-3000 K is suitable for museum applications and LEDs with high colour temperatures has to be avoid for light sensitive materials.

3.4.1.5.2 ISO Blue wool and dyes test for LEDs

In the Getty Conservation Institute laboratories, LA California, J. R. Druzik (2012) has compared fading rates of 16 natural dyes and ISO Blue Wools Standards No. 1–3 exposed to 880,000 lux-hours (at 11,000 lux) from two MR16 LED replacement lamps, (MR16 LED retrofit lamp manufactured by CRS Electronics and a custom-designed source made by Xicato. Both LED light sources were approximately 3000K) to equivalent lux-hours of halogen MR16 lamps with Mark 2 filter.[(4)] (Figure 3.26 and Figure 3.27).

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1. James R. Druzik and Stefan W. Michalski, Guidelines for Selecting Solid State Lighting for Museums, Canadian Conservation Institute & The Getty Conservation Institute, September 2011, p6.
2. James R. Druzik and Stefan W. Michalski, Guidelines for Selecting Solid State Lighting for Museums, Canadian Conservation Institute & The Getty Conservation Institute, September 2011, p6-5.
3. Previous Reference p11.
4. N. J. Miller and J. R. Druzik, Demonstration of LED Retrofit Lamps at an Exhibit of 19th Century Photography at the Getty Museum, March 2012, p12-13.

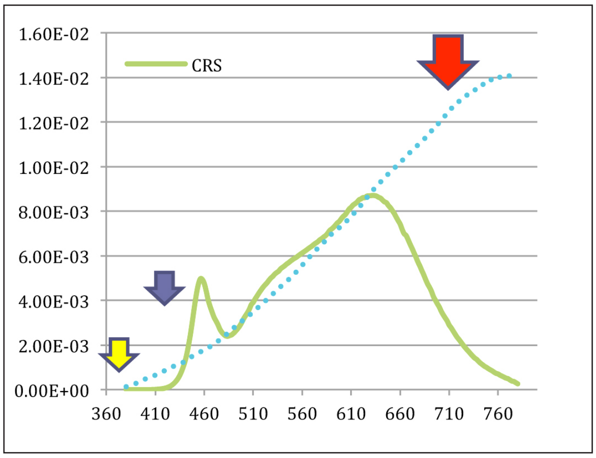

Figure 3.28 *The energy in the peak of the LED spectrum in the shortwave region (blue arrow) have the possibility to be equivalent to the energy in the extended end of tungsten halogen spectrum in the same region (yellow arrow). (James R. Druzik and Stefan W. Michalski, Guidelines for Selecting Solid State Lighting for Museums, p7).*

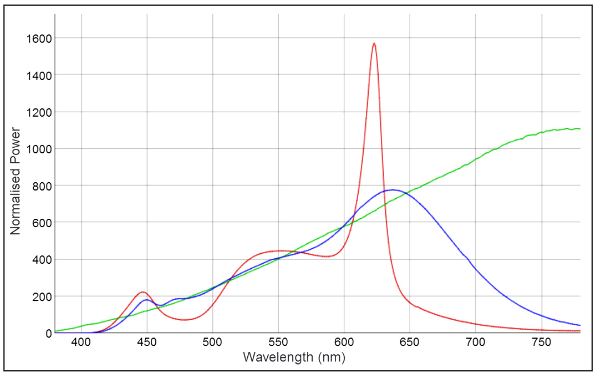

Figure 3.29 *Comparing different SPD: (red) CREE LRP-38 LED - 2700K - 93 CRI, (blue) LSI LumeLEX 2040-C2M2-6S: LED - 2700K - 96.00 CRI and (green) GE EYC 71W MR16: TH - 2709K - 99 CRI. Notes that all SPD has the same CCT. (SPD Curves, The National Gallery of London, Website).*

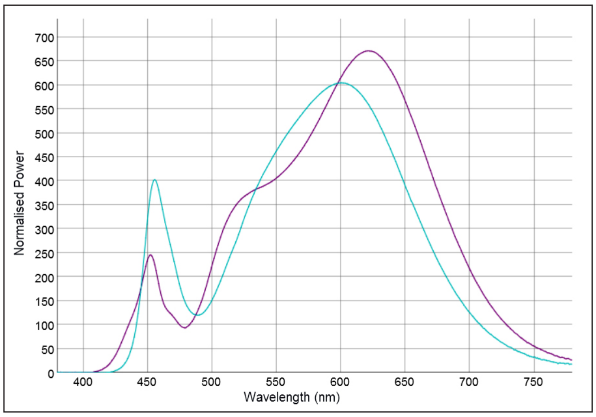

Figure 3.30 *Comparing different SPD: (Purple) Concord Beacon Muse 2052867 (Wide Beam): LED - 3000K - 90 CRI and (blue) Erco Light Board V01 72808 LED - 3000K - 89 CRI. Notes that all SPD has the same CCT. (SPD Curves, The National Gallery of London, Website).*

Druzik has found that most of the dyes fade at the same rate, regardless of which light source is being assessed, no doubt due to the similarity in the SPD of the sources. However, the first three Blue Wool swatches and 6 of 16 dyes known to have been available and used by artists in the past actually faded somewhat more slowly under LEDs than under halogens. Exceptionally was the crystal violet, which may also be an anomalous result because the increased fade rate with LED does not occur until the dye is almost destroyed by the light sources.[1]

In other experiment, Ishii et al (2008) and Druzik (2011) fond that some light sensitive blue dyes have been shown to fade less rapidly

1. Previous Reference p12-13.

under white LEDs than tungsten or tungsten halogen lighting, and this may due to the fact that LEDs miss much of light in the region near infrared, since the energy of photons in this area is capable of instigating photochemical reactions.[1] See area pointed out by the red arrow in (Figure 3.28).

It would be fallacious to say the LEDs reduce damage enough to allow an increase in the lux-hours of exposure on an object without inflicting greater damage. Rather, carefully selected LED light sources can be one tool that helps align damage to objects of art with their existing Preservation Targets.[2]

3.4.2 Controlling daylight for aspects of conservation

Designing an architectural daylight aperture has not only to concern about the direction and amount of light entering the building but also about the quality of light, thermal performance, and the amount of IR and UV radiation passing through. Solar energy has a wide spectrum (290 - 2500 nm), which are 47% visible light, 51% infra-red and 2% ultra-violet.[3] The optimum design for a museum daylight aperture is to admit the right amount of visible light according to material sensitivity-to-light in exhibition; eliminate UV radiation; and control IR radiation and thermal energy correspondingly to climate condition and conservation needs.

3.4.2.1 Mitigate the amount of daylight

Direct sun can be most destructive, causing damage in a very short time, as well it is a strong source of glare and discomfort. Accordingly, it is recommended to avoid direct sun light in museum galleries. However, sunlight can be redirected, disperse and mitigate to be used in museum spaces. Daylight (light from the sky) is more easy to control and mitigate to be a source of general illumination or main source of lighting as in north skylight galleries. Generally, it is recommended not to used natural light where high sensitivity-to-light materials are displayed[4].

Where daylight is under consideration in collection areas the magnitude of daylight must be well controlled as a responsive to available daylight. This can be achieved by shades, louvres, and other mechanical devices that should be automated to limit daylight to the maximum allowed for a given object or series of objects, as well systems controlling daylight has to have the ability to block all daylight.[5]

1. James R. Druzik and Stefan W. Michalski, Guidelines for Selecting Solid State Lighting for Museums, Canadian Conservation Institute & The Getty Conservation Institute, September 2011, p6.
2. N. J. Miller and J. R. Druzik, Demonstration of LED Retrofit Lamps at an Exhibit of 19th Century Photography at the Getty Museum, March 2012, p13.
3. G.James Glass co., Glass Handbook, first edition, Australia. p17.
4. IESNA The Lighting handbook, Application: Light for Art,10th Ed. 2011, p(21.5).
5. Previous Reference, p(21.13).

3.4.2.2 Controlling IR radiation and thermal energy in daylight

Heat energy can enter a building directly as IR radiation through architecture aperture or indirectly as thermal energy that associated with our surroundings and enter the building carried by air or via the inward emissivity of thermal loads that building envelop gains.

Managing infrared radiation with coated and laminated glass configurations leads to much more comfortable spaces. As for the amount of thermal energy a glazing system conducts, it depends on the temperature difference between indoors and outdoors, and the type of glazing system. Thermal energy is conducted, convected and radiated through a glazing system in the direction of the lower temperature. Thermal radiation transfer occurs in the far infrared region from 2,500-50,000 nm (outside the solar spectrum). Uncoated glass absorbs and emits 84% of far infrared radiation; therefore the emissivity of standard clear glass is 0.84. Much lower emissivity values are achievable with spectrally selective low-E coatings. It is in this range that low-E glass delivers significant improvement in comfort and energy savings. By combining the right low-E coating with a laminated glass package, it is possible to enhance comfort, safety, security, and energy efficiency, while prolonging the life of interior furnishings,[1] and as well, museum artefacts.

3.4.2.3 Controlling UV radiation in daylight

The UV component in daylight can be controlled by laminated glass for which the absorbers are in the inter-layer (adhesive plastic often acetate films applied to the inside glass surface), secondary windows of acrylic or polycarbonate sheet. As well it can be controlled by roller blinds of transparent (UV blocking plastic). Ordinary window glass blocks wavelengths less than 320 nm, but admits UV between 320 and 400 nm. Untreated glass is not an acceptable form of UV control.[2] For an extra procedure skylight wells, light tubes and walls, where daylight is reflected, can be finished with titanium dioxide to further reduce UV.[3]

The magnitudes experienced with daylight are so significant, that review of the remaining UV component must be made to assure the residual levels are acceptable. Regardless of UV mitigation, visible radiation from daylight may also be damaging given its potential magnitude.[4]

Beside using glass as a protection from non-visible radiation in daylight aperture and lamp housing it can be used as well for constructing showcases and in framing archival materials. In some cases, when the museum contains a small number of sensitivity-to-light artefacts, UV glass protection can be only used for showcases, where these artefacts are contained.

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1. Guardian ClimaGuard, Using Laminated Glass for Solar Control and Energy Management in Residential Applications, http://www.climaguardglass.com/cs/groups/climaguard/documents/web_content/dev_005421.pdf, p2.
2. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA p18.
3. IESNA The Lighting handbook, Application: Light for Art,10th Ed. 2011, p(21.13).
4. Previous Reference p(21.14).

3.4.2.4 Choosing the right glass for conservation

Light passing through a glass will be reflected (R), absorbed (A), transmitted (T) and reemitted from the glass (E). The important values when selecting a glass for a museum application are:

- U-value: a measure of the insulating characteristics of the glass or how much heat gain or loss occurs through the glass due to the difference between indoor and outdoor temperatures. The lower the number, the better the insulating performance. This number is the reciprocal of the R-value (a measure of resistance to heat gain or loss).[1]
- Visible Light Transmittance (VLT): the percentage of the visible spectrum of sunlight that is passing through a piece of glass. It is expressed as a figure between 0 and 100, a glass with a VLT of 0 would transmit no sunlight whatsoever, while a glass with a VLT of 100 would transmit all of the sun's light.[2]
- Solar Heat Gain Coefficient (SHGC) : measures how well a window blocks (or shades) the heat from sunlight. SHGC is the fraction of solar radiation transmitted through a window or skylight, as well as the amount that is absorbed by the glass and reradiated to the interior. SHGC is expressed as a number between 0 and 1. The lower a window's SHGC, the less solar heat it transmits and the greater its shading ability.[3]
- Light-to-Solar Gain Ratio (LSG): the ratio of visible light to solar heat gain. LSG = VLT ÷ SHGC. Glass with higher LSG numbers are typically desired by architects because they offer superior solar control, with relatively high visible light transmittance.[4]
- UV Light Transmittance (T-uv): there is not a single industry standard for calculating UV transmittance (T-uv). However, some reporting T-uv as UV energies ranging from 300 to 380 nm others reporting as UV energies ranging from 300 to 400 nm, which result in very different values for the same glazing, making comparisons impossible.[5]
- Damage-Weighted Transmittance factor (Tdw-ISO): is a calculation assigns a specific damage weighted factor to each wavelength of UV and visible light, based on its contribution to fading, (shorter wavelengths cause more fading damage than longer wavelengths). The sum total of these wavelength specific factors yields the Damage Weighted Transmittance for a specific glass product.[6]

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1. PPG Glass Education Center, Glossary. http://educationcenter.ppg.com/glossary.aspx
2. Previous Reference.
3. Previous Reference.
4. Previous Reference.
5. Pilkington NSG Group Flat Glass Business, Glazing Choice Can Affect Fading of Home Furnishings, Technical information, ATS-141, 2005-07-18
6. Reducing Fading and Material Degradation of Interior Furnishing Caused by solar Radiation Exposure, PPG, Glass Technical Document TD-148, p2.

By comparing the Damage Weighted Transmittance of various glass types, we can more effectively determine the ability to protect interior components from fading. Because Tdw-ISO represents damage caused by both UV and visible wavelengths, it is a more accurate tool for assessing potential fade resistance than the total UV transmittance measure that is traditionally used by many manufacturers.[1] (For some typical value see appendix 1.5).

The Damage Weighted Transmittance function recommended by CIE for the solar spectrum between 300 nm to 700 nm[2] can be calculated by the following equation:[3]

$$s(\lambda)_{dm,rel} = \exp^{3.6\text{-}12.0\,\lambda} \qquad \lambda \text{ in } \mu m \tag{3.13}$$

Applying the CIE Damage Factor directly to the Normalized Global Solar Spectral Irradiance from ISO 9050, 2003, will result into the Solar Weighted Damage Response Curve. Which show the potential damage of a Global Solar Irradiance between 300 nm to 700 nm.[4] (Figure 3.31 and Figure 3.32).

The material relative spectral responsivity in Berlin Model (Table 3.1 and Figure 3.18) can be more accurate to assess and select glass for a specific type of material, however, for a gallery window and showcase that contain different types of material a CIE Damage-Weighted Transmittance factor well be more practical.

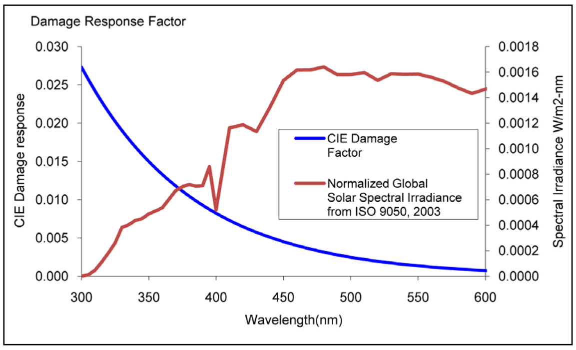

Figure 3.31 *Assigning the (blue) CIE Damage Factor to the (red) Normalized Global Solar Spectral Irradiance from ISO 9050, 2003 will result into the Solar Weighted Damage Response by wavelength (figure 2.32). (PPG, Glass Technical Document TD-148, p2).*

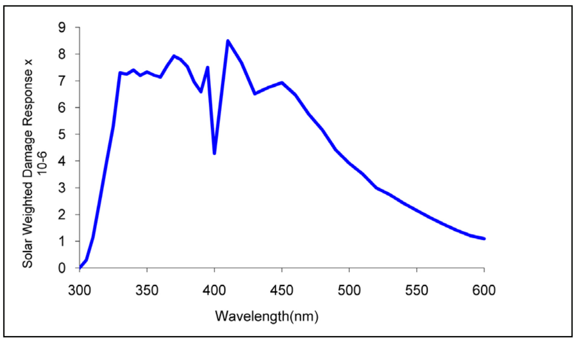

Figure 3.32 *(blue) the Solar Weighted Damage Response Curve.(PPG, Glass Technical Document TD-148, p3).*

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1. Previous Reference.
2. Per Werthwein, Shedding New Light on UV and Fading, AFG Glass, Sep. 2005.
3. UV Transmittance and Fading, Florida Solar Energy Center, http://www.fsec.ucf.edu/en/consumer/buildings/basics/windows/fading.htm
4. Reducing Fading and Material Degradation of Interior Furnishing Caused by solar Radiation Exposure, PPG, Glass Technical Document TD-148, p2-3.

3.4.3 Working with Visible Light

As we explained previously, not only IR and UV radiation cause damage to museum exhibits, but as well visible radiation (light). Understanding how the aspects of the visible radiation are related to the potential of damage; how to limit illuminance; and how to control of exposure duration will reduce damage that can be accrued to museum exhibits.

3.4.3.1 Comparing damage potential of various light sources

The spectra of visible light vary in type, quality and potential of damage according to the distribution and amount of energy in every wavelength between 380-780 nm. In museum lighting, the correlated colour temperature (CCT), the colour rendering index (CRI) and spectrum type are important for aesthetic aspects. On the other hand, the potential of damage is important for conservation aspects. How these aspects are related to potential of damage is very important issue when planing light for museums.

To investigate how the CCT, CRI and spectrum type are related to the potential of damage we conducted a comparison between a set of 27 spectrum power distribution (SPD) of different museum light sources, which were elected from a vast group of high quality CRI lamp spectrums that are often used in museum lighting. The data was obtained from The National Gallery of London online scientific page[(1)] and Bartenbach GmbH data bank with permission. It is important to point out that our selection can not cover all SPD possibilities, however, it is sufficient for our investigation and a good guideline for future comparison in practice.

3.4.3.1.1 Approach and method for comparison and investigation

3.4.3.1.1.1 Classifying and selecting SPD

We classified the 27 elected SPD to five groups according to its CCT and to additional three groups contain especial and standards SPD that are important in museum lighting. We ensured that every group contain three different types of spectrum: tungsten halogen (TH), light emitting diodes (LED), and fluorescent lamp (FL).

The groups are as follow:

a. Croup 2700K: (1) TH GE EYC 71W MR16 CRI-99 2708K, (2) TH Philips 50W MR16 CRI-98 2729K (3) LED LSI LumeLEX 2040-C2M2-6S (with Xicato XSM LED module) CRI-97 2710K (4) FL 827 LUMILUX Warm white CRI-70 2707K. (Figure 3.33)

   Note: Fluorescent laps have low CRI in low CCT. The SPD (4) FL has CRI Ra 80 and after recalculating with CRI-14TCS it has 70 with TCS09 9.93 and this may not be acceptable for museum lighting. However, this is the highest FL in our data for this category.

1. The National Gallery of London, online scientific page, http://research.ng-london.org.uk/scientific/spd/?page=home.

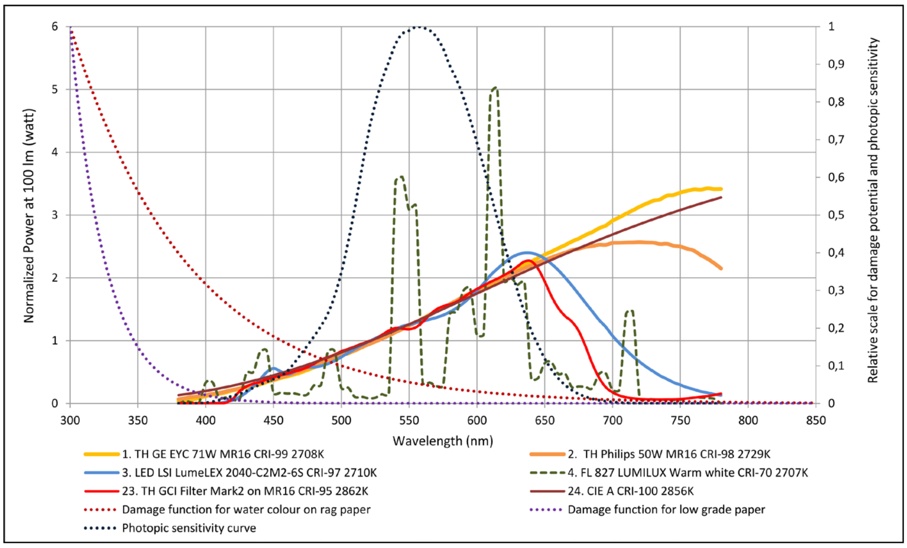

Figure 3.33 *The diagram represent group 2700K: the investigated SPD (1-to-4) at about CCT 2700K. As well, it represent the TH GCI Filter Mark2 on MR16 (23), the standard spectrum CIE A (24), the damage function of water colour on rag paper, damage function of low grade paper and the photopic sensitivity curve.*

b. Croup 3000K: (5) TH Sylvania Concord 2627632 MK41 CRI-99 2934K, (6) TH Osram 12V Diachroic CRI-99 2963K, (7) LED LSI LumeLEX 2040 C3M2-6S (with Xicato XSM LED module) CRI-95 2965K, (8) LED Sylvania Concord 2048794 CRI-97 3008K, (9) LED CRS SP12 WW MR16 LED CRI-94 3048K, (10) FL 930 LUMILUX DE LUXE Warm white HH31 CRI-89 2953K. (Figure 3.34)

Note: The SPD (10) FL has CRI Ra 91 and after recalculating with CRI-TCS14 it has 88,58 with TCS09 66 and this may not be acceptable for museum lighting. However, this is the highest FL in our data for this category.

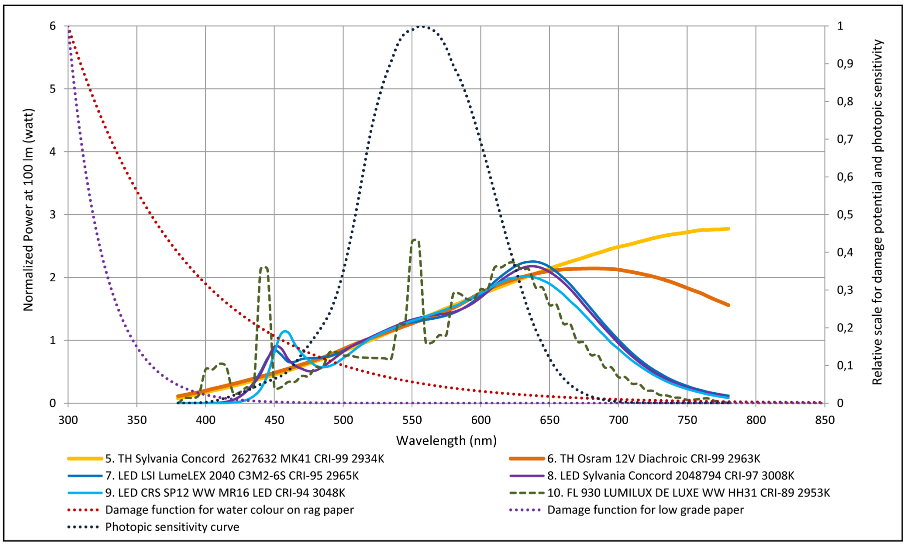

Figure 3.34 *The diagram represent group 3000K: the investigated SPD (5-to-10) at about CCT 3000K. As well, it represent the damage function of water colour on rag paper, damage function of low grade paper and the photopic sensitivity curve.*

c. Croup 4000K (3700-4300K): (11) TH Erco Eclipse Blue Lens CRI-94 4056K, (12) LED Osram Oslon CRI-92 3763K, (13) LED Oslon ColorChamp 70lm CRI-89 4001K, (14) LED LSI LumeLEX 2040 C4M2 6S (with Xicato XSM LED module) CRI-97 4113K, (15) FL 940 LUMILUX DE LUXE Cool white HH31 CRI-96 3769K, (16) FL Philips TLD 36W 95 CRI-96 4304K. (Figure 3.35)

Note: The spectra in group 4000K, 5000K and 6000K are not very close in the CCT value like the first two groups. It was not possible to have all SPD close to a single value and we have to considered this in our evaluation. Other Note: The (11) TH Erco Eclipse Blue Lens is most probably a modified spectrum (no information available from the producer).

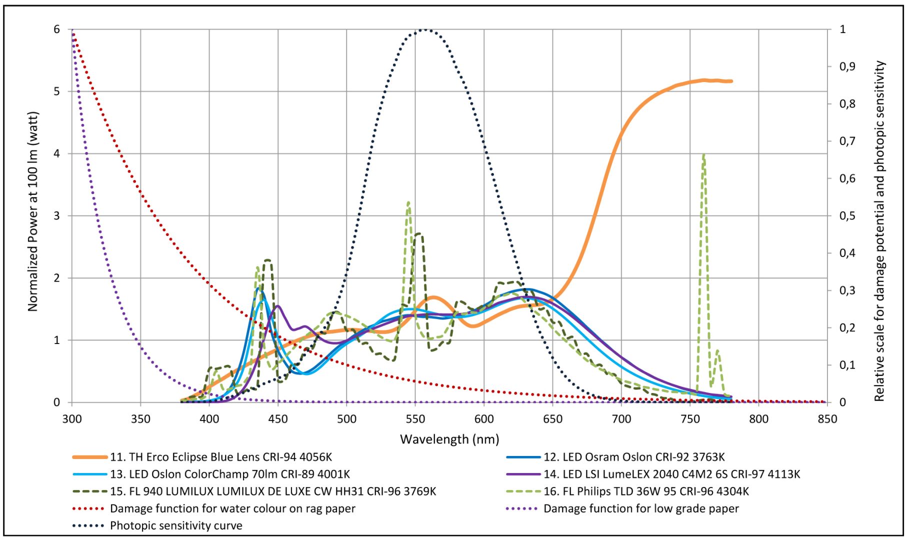

Figure 3.35 *The diagram represent the group 4000K: investigated SPD (11-to-16) between CCT (3700-4300K). As well, it represent the damage function of water colour on rag paper, damage function of low grade paper and the photopic sensitivity curve.*

d. Group 5000K (4400-5300K): (17) TH Solux 12V Diachroic CRI-97 4483K, (18) LED FEM CRI-91 5054K, (19) FL Osram Photon Beard Dulux L 954 CRI-87 5311K. (Figure 3.36)

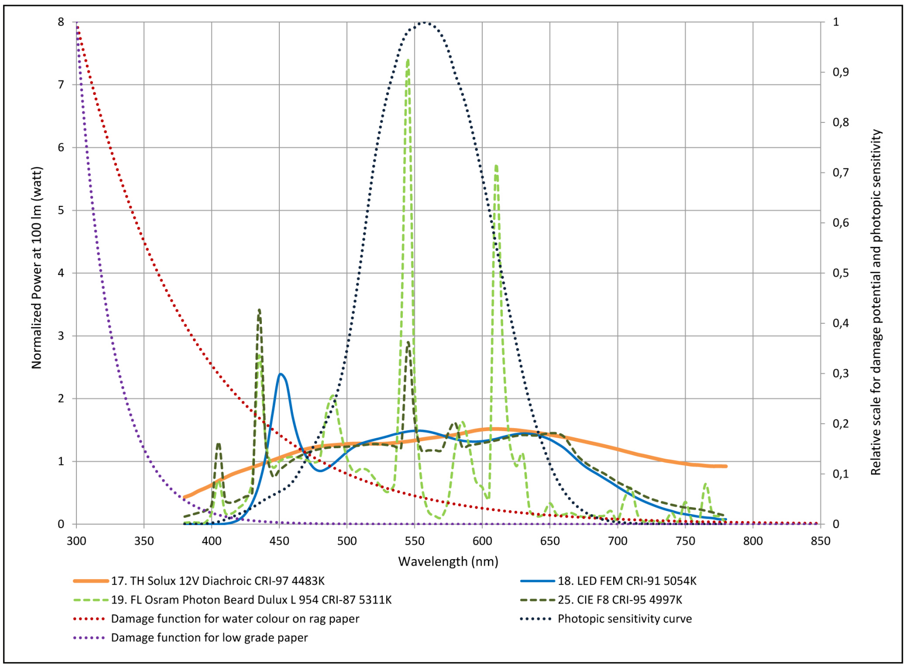

Figure 3.36 *The diagram represent the group 5000K: investigated SPD (17-to-19) between CCT (4400-5300K). As well, it represent the standard spectrum CIE F8 (25), the damage function of water colour on rag paper, damage function of low grade paper and the photopic sensitivity curve.*

e. Group 6000K (5600-6900K): (20) LED Z5 hCRI cold white 80 lm CRI-89 6899K, (21) FL GE F40W AD CRI-91 5669K, (22) FL 965er CRI-91 6496K.

Note: In this group there is no TH SPD since there in no electrical TH source have this CCT.

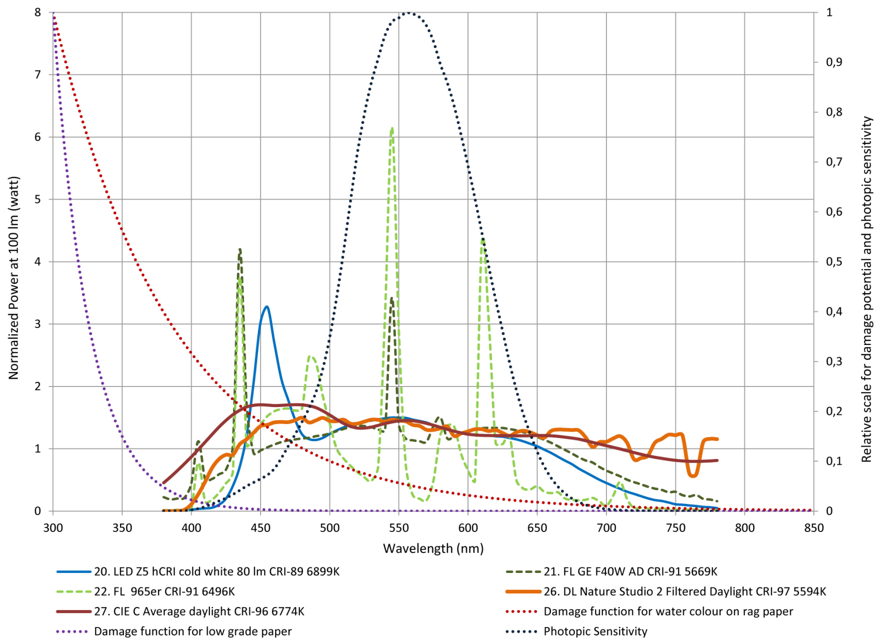

Figure 3.37 *The diagram represent the group 6000K: investigated SPD (20-to-22) between CCT (5600-6900K). As well, it represent DL Nature Studio 2 Filtered Daylight (26), CIE C Average daylight (27), the damage function of water colour on rag paper, damage function of low grade paper and the photopic sensitivity curve.*

f. Group Special filtered SPD: (23) TH GCI Filter Mark2 on MR16 CRI-95 2862K. (Figure 3.33)

Note: We included this especial filter TH SPD since it is one of the state-of-the-art light source used in museum lighting.

g. Standard Electrical Illuminant: (24) CIE A CRI-100 2856K (25) CIE F8 CRI-95 4997K. (Figure 3.33) and (Figure 3.36)

Note: CIE standard illuminant A is intended to represent typical, domestic, tungsten-filament lighting. Its relative SPD is that of a Planckian radiator at ~ 2856K.[(1)]. F8 is a CIE standard fluorescent lamps with multiple phosphors, "broadband" with higher CRI.[(2)]

h. Standard DL: (26) DL Nature Studio 2 Filtered Daylight CRI-97 5594K, (27) CIE C Average daylight CRI-96 6774K. (Figure 3.37).

Note: DL Nature Studio 2 Filtered Daylight is used to represent filtered daylight in museums.[(3)] The CIE C was introduced in 1931, with the intention of representing average daylight.[(4)]

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1. This joint ISO/CIE Standard specifies two illuminants for use in colorimetry. http://www.cie.co.at/publ/abst/s005.html.
2. Colorimetry, CIE Technical Report 15:2004, 3rd Ed. CIE Central Bureau, Vienna. ISBN 3-901-906-33-9.
3. The National Gallery of London, online scientific page, http://research.ng-london.org.uk/scientific/spd/?page=home.
4. Colorimetry , CIE Technical Report 15:2004 , 3rd ed., CIE Central Bureau, Vienna.

3.4.3.1.1.2 Calculating CCT and CRI

For all tested SPD we calculated the CCT after the CIE standards to ensure correction and accuracy of information. As well, we calculated the CRI for all tested SPD after the 14 TCS (14 test colour samples). The 14 samples include: the eight low saturated colours of the Munsell Atlas (TCS01-to-TCS08) which are used to calculate the general colour rendering index Ra; four saturated colour (TCS09 Red, TCS10 Yellow, TCS11 Green, and TCS12 Blue); and two representatives of well-known objects (TCS13 light yellowish pink and TCS14 leaf moderate olive green). The CRI-14TCS gives more precise information about the render quality of light source than the most used Ra in the light industry.[1] In addition, we calculated the standard deviation between the 14 TCS value to show the variability and dispersion of the data. (See calculation figures in appendix 1.6)

3.4.3.1.1.3 Normalizing the SPD at 100 lm

Since the target of museum lighting is to adjust the amount of illuminance on the exhibits. We normalize the radiant flux Φ_e of tested SPD at luminous flux Φ_V of 100 lm. Accordingly, we can compare the power in watt and the potential of damage of every SPD at the same illuminance level. As well, we can calculate and compare the luminous efficacy of radiation (K).

3.4.3.1.1.4 Calculating the potential of damage

Damage potential: is the damaging irradiance and the illuminance at the exhibit stand in a fixed ratio to one another.[2]

To calculate the damaging irradiance we used the material relative spectral responsivity function $s(\lambda)_{dm,rel}$ in Berlin Model, which is represented by (Equation 3.12). We used two value of this function: First, the (e) value for the water colour on rag paper, which is equal to oil paint on canvas (c) and can be close to the average value between (b to e). Second, the (a) value since it distinctly different and depart from other values. See (Table 3.1) and (Figure 3.18). We calculate and compare the potential of damage for the selected SPDs at the full visible spectrum range A (380-780 nm) and at the conservation recommended range B (400-700 nm). (See calculation figures in appendix 1.6)

3.4.3.1.2 Investigation of damage potential and results

3.4.3.1.2.1 The luminous efficacy of radiation (K)

The luminous efficacy of radiation (K), is quotient of the luminous flux Φv, by the corresponding radiant flux Φe. Unit: lm/W [3], it is a measure of how well a spectrum of a light source produces visible light.

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1. Previous Reference.
2. Good Lighting for Museums Galleries and Exhibitions, Booklet 18, published by Fördergemeinschaft Gutes Licht (FGL), Frankfurt am Main, P30.
3. Definition of luminous efficacy (of radiation) in CIE online, http://eilv.cie.co.at/term/730

The results for all tested SPD in the full range A (380-780 nm) normalized at luminous flux Φ_V of 100 lm show that, the FLs have the highest luminous efficacy of radiation, followed with LED, DL and TH respectively.

The TH have the least luminous efficacy of radiation since most of spectrum lay outside of the photopic luminosity function of the eye in the short wavelength area. On the other hand, it have high consistency with CCT, the higher the CCT the higher the luminous efficacy of radiation, and this is due to a relatively consistence SPD form. See (Figure 3.33 to Figure 3.37).

Note: the (11) TH Erco Eclipse Blue Lens is most probably a modified spectrum (no information available from the producer). The (23) TH GCI Filter Mark 2 on MR16 and (26) DL Nature Studio 2 Filtered Daylight are filtered SPD data and they do not represent the luminous efficacy of radiation.

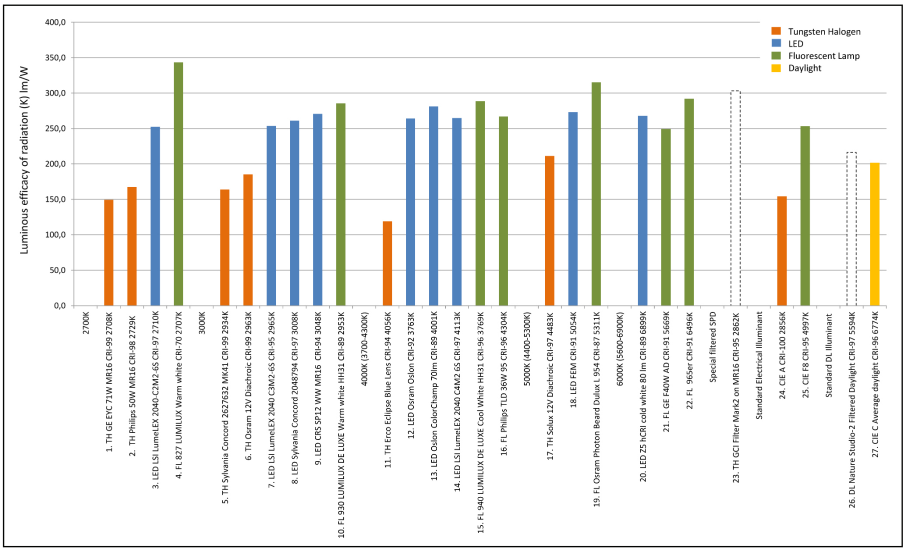

Figure 3.38 *Luminous efficacy of radiation (K) lm/W for tested SPD range A (380-780 nm) at Φe 100 lm*

3.4.3.1.2.2 Damage potential

a. Damage potential on water colour on rag paper

- According to the relative spectral responsivity function of water colour on rag paper for the full range of visible spectrum A (380-780 nm), generally, the LEDs show less potential of damage in every group followed with the FL then TH. Exceptionally, in group 2700K the (4) FL 827 LUMILUX Warm white shows the least potential of damage, however this lamp has a relatively low CRI. In group 3000K the (10) FL 930 LUMILUX DE LUXE Warm white HH31 shows the highest potential of damage. (Figure 3.39)
- For the recommended conservation range B (400-700 nm) there was a reduction in the damage potential value and it was more in the TH types than LED and FL. Generally, the results did not change and it is similar to A (380-780nm). (Figure 3.39)

- In both groups A and B, the (4) FL 827 LUMILUX Warm white CRI-70 2707K shows the least potential of damage, followed respectively with the (23) TH GCI Filter Mark2 on MR16 CRI-95 2862K, (3) LED LSI LumeLEX 2040-C2M2-6S CRI-97 2710K and (9) LED CRS SP12 WW MR16 LED CRI-94 3048K.

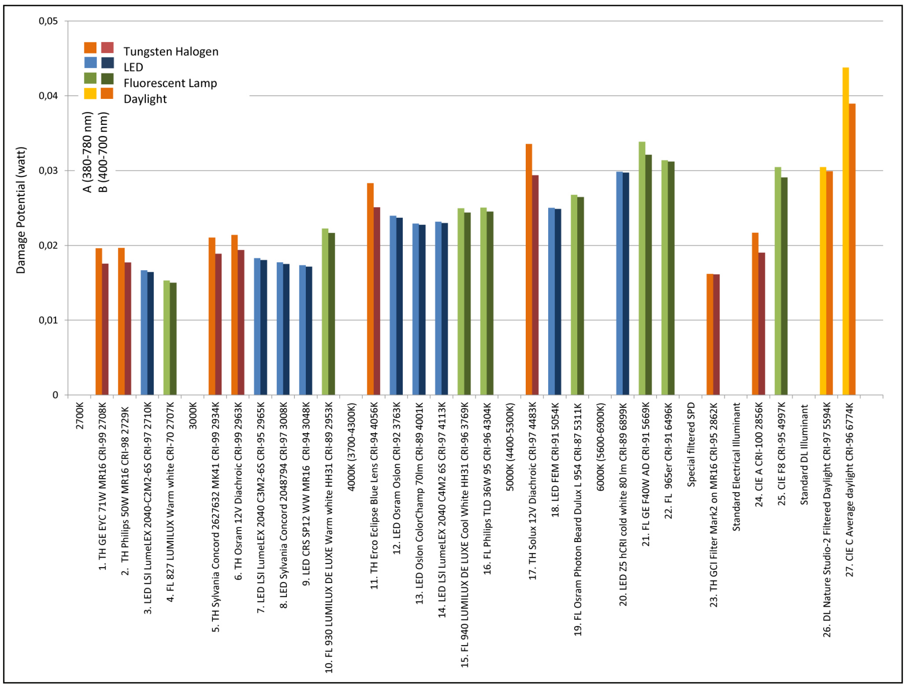

Figure 3.39 *Damage potential according to the relative spectral responsivity function of water colour on rag paper (e) in Berlin Model, CIE 15:2004. (Bright colour) Damage potential in full visible range A (380-780 nm). (Dark colour) conservative recommendation range B (400-700 nm).*

b. Damage potential on low grade paper

- According to the relative spectral responsivity function of low grade paper, generally, the results show less potential damage values and different results than that of water colour on rag paper function. This is due to the fact that the low grade paper function do not stretch into the middle area of the visible spectrum like other functions, so the results are only affected with the differences of energy distribution in the long wavelength area (blue). (Figure 3.33 to Figure 3.37)
- For the full range of visible spectrum A (380-780 nm), the LED show less potential of damage in all groups without exception. The FL then TH show different ranking according to the group. In groups 2700K and 3000K the TH show less potential damage value then FL. In groups 4000K and 5000K the FL show less potential damage than TH. (Figure 3.40)
- For the recommended conservation range B (400-700 nm), Overall, the order of potential damage value between the different tested SPD did not change than the previous result with A (380-780 nm). However, there was a reduction in the damage potential values and it was more in the TH and DL types then FL. In the TH and DL types the value of reduction increase when the CCT increase. As for the LED types, the potential of damage values did not show a noticeable change than the values in A (380-780 nm). (Figure 3.40)

In both groups A and B, the (3) LED LSI LumeLEX 2040-C2M2-6S CRI-97 2710K shows the least potential of damage, followed respectively with the (23) TH GCI Filter Mark2 on MR16 CRI-95 2862K, (8) LED Sylvania Concord 2048794 CRI-97 3008K, (7) LED LSI LumeLEX 2040 C3M2-6S CRI-95 2965K and (9) LED CRS SP12 WW MR16 LED CRI-94 3048K.

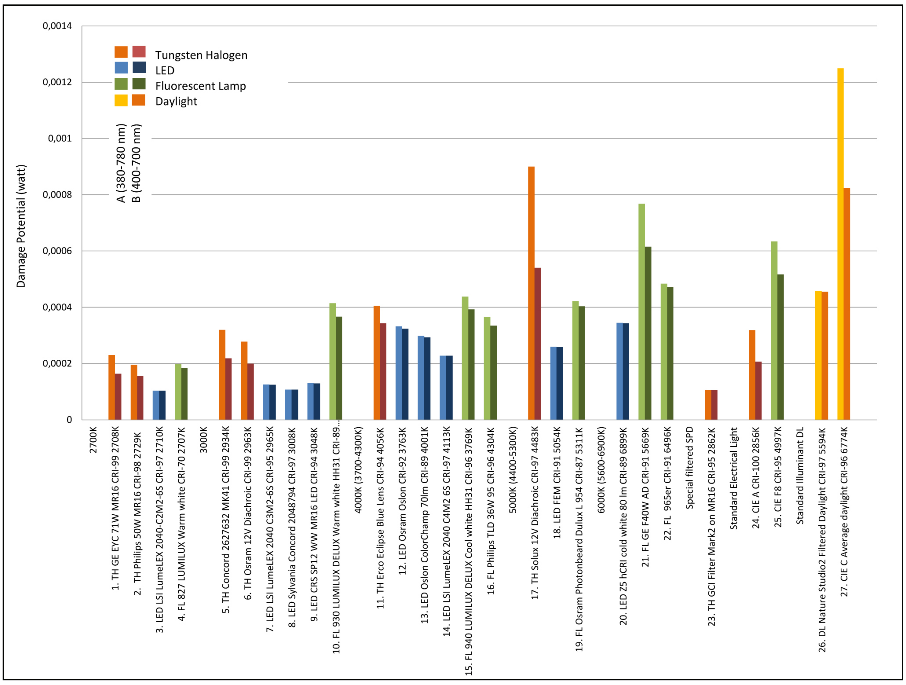

Figure 3.40 *Damage potential according to the relative spectral responsivity function of low grade paper (a) in Berlin Model, CIE 15:2004. (Bright colour) Damage potential in full visible range A (380-780 nm). (Dark colour) conservative recommendation range B (400-700 nm)*

3.4.3.1.2.3 Relationship between damage potential, luminous flux Φ_V and radiant flux Φ_e

By comparing the damage potential with luminous flux Φ_V, radiant flux Φ_e, luminous efficacy of radiation (K) of tested SPD we found that, there is no one-to-one correlation between these values. In other words, if all tested spectra have the same luminous flux Φ_V, the same radiant flux Φ_e or the same luminous efficacy of radiation (K) they will not have the same potential of damage. It depends on the shape of the spectrum power distribution and how it interact with the relative spectral responsivity function of the material.

3.4.3.1.2.4 Comparing damage potential and the CCT

It has been shown that there is a general effect for the relative damage potential to increase as colour temperature increases (Cuttle, 1988)[1] This statement can be relatively valid for spectra that have the same type of power distribution. Our study shows that the relation between the potential of damage and the CCT vary according to spectrum types and sensitivity of the material (damage function).

a. Between the same type of spectra

- With the damage function of water colour on rag paper the results

1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p15.

show generally that the higher the CCT, the higher the potential of damage. This is obviously clear with TH. While LED and FL show slight differences in some cases. For instance, the (9) LED CRS SP12 WW MR16 CRI-94 3048K has less potential of damage than the (7) LED LSI LumeLEX 2040 C3M2-6S CRI-95 2965K (about 5% for 83K differences in the CCT) and (22) FL 965er CRI-91 6496K has less potential of damage than the (21) FL GE F40W AD CRI-91 5669K (about 7% for 827K differences in the CCT).

- With the damage function of low grade paper the results show that, only TH spectra can follow the rule; the higher the CCT, the higher the damage. While LED and FL show different results with bigger differences than the previous damage function. For instance, the (18) LED FEM CRI-91 5054K has less potential of damage than the (12) LED Osram Oslon CRI-92 3763K (about 22% for 1291K differences in the CCT). The (14) LED LSI LumeLEX 2040 C4M2 6S CRI-97 4113K has less potential of damage than the (12) LED Osram Oslon CRI-92 3763K (about 31% for 350K differences in the CCT). The (16) FL Philips TLD 36W 95 CRI-96 4304K has less potential of damage than the (10) FL 930 LUMILUX DELUX Warm white HH31 CRI-89 2953K (about 11% for 1351K difference in the CCT).

b. Between different type of spectra

- There is no order or correlation according to CCT between spectra with different types. In high CCT a FL can have less damage potential than a halogen lamp, e.g. (19) FL Osram Photon Beard Dulux L 954 CRI-87 5311K have less damage potential then (17) TH Solux 12V Diachroic CRI-97 4483K. Although the (17) TH is less 828K then the (19) FL.
- The CCT can not be a precise indicator for the potential of damage between spectra with different types or between spectra with irregular power distribution form like LED and fluorescent.

Using lower colour temperature light source to avoid high potential of damage will led to avoid the wight appearance of higher colour temperature and the appearance of natural daylight. A lower colour temperature can be very effective in some types of display like old books and old manuscripts, where yellowness of appearance is not objectionable. On the other hand, a higher colour temperature is more favourable where white colour appearance are required. It is recommended that decisions on the colour temperature of lighting should be made with concern for the visible characteristics of the objects on display and the setting in which they will be seen. Where the viewing conditions call for moderate or high colour temperature lighting, conservation concerns should not override design objectives for the display. If necessary, the duration of exposure should be restricted rather than the visual qualities of the display be compromised.[1]

1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p25.

3.4.3.1.2.5 Comparing damage potential and the CRI

Generally CIE Colour Rendering Group 1A (Ra 90-100) will be specified for museum lighting (ClE, 1995), but if Group 1B (Ra 80-89) is specified for some locations, this does not affect the exposure rate.[1]

The CRI is a very important criteria in museum lighting however in some cases where colour rendering is not important using a low CRI lamp with less damage potential will be more practical. For instance, our investigation shows that (4) FL 827 LUMILUX Warm white CRI Ra 80 and CRI 14-TCS 70 at 2707K has the least damage potential on water colour on rag paper between all tested SPD.

3.4.3.1.2.6 Damage potential and SPD type

Both (23) TH GCI Filter Mark2 on MR16 CRI-95 2862K and (3) LED LSI LumeLEX 2040-C2M2-6S CRI-97 2710K show almost the same results value and Both have the least potential of damage.

Generally, throughout all groups LED spectra types show better results than TH and FL.

3.4.3.1.2.7 The effect of changing material colour on potential of damage

Changing the colour of material will alter material absorption to radiation, e.g. a dark colour will absorb more radiation than a bright one and a red colour will absorb more radiation from the short wavelength (blue) than from the long wavelength (red). For that reason the potential of damage will be altered according to the change in colour.

This motivate the museum light designers to use warm light with low CCT to light old printed documents, where the paper has yellowed and discrimination depends upon the luminance contrast formed by ink. The yellow colour of the substrate material indicates that it is preferentially reflecting long wave light and absorbing short wave light (associated with blue). Thus, to illuminate it with a source that is deficient in short wave light, such as dimmed incandescent, will do little to detract from its appearance, but could significantly reduce photochemical action.[2]

It is clear that "typical" spectral responsivity functions, such as the Berlin function, cannot be expected to accurately represent the spectral sensitivities of individual pigments, it might be supposed that they could represent the overall responsivity of a palette of pigments. According to this supposition, if there is one highly responsive pigment in a low responsivity multicoloured artwork, then to assess the effective irradiance on the basis of a typical spectral responsivity function could be seriously misleading.[3]

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1. Previous Reference, p25.
2. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA, p21.
3. Previous Reference, p14.

What we mentioned previously, will not change our results but it show the entanglement of determinants that are involved in calculating the damage potential of light to museum material and susceptibility of results to change when materials' colour change.

3.4.3.2 Controlling of Exposure

3.4.3.2.1 Controlling non-display lighting

Display light is not the only light in a museum gallery, there are working light, cleaning light, security lighting, daylight that enter the museum space after or before exhibit hours and there is even a flash-light from the visitors' or researchers' cameras.

During periods of exhibit installation and exhibit dismantling, sufficient light should be available to assist in the basic tasks involved. This lighting scheme is also appropriate for cleaning.(1)

Security lighting should illuminate the circulation routes while providing guards with just sufficient light on the exhibits to enable them to see that all is well. In many cases, the security lighting and the emergency lighting can be provided by the same system.(2)

Summer evening and early morning daylight streaming into the galleries could substantially add to exposure thus daylight must be switched of like electric lighting.(3)

Most of museums prohibit visitors to use camera flashlight as a protection for collection and to prevent visual disturbing that is caused by flashlight, however flashlight is frequently used by researchers and museum conservators themselves to study and document the artefacts. Accordingly, it is important to consume some of the calculated illuminance for the display lifetime of a museum object to other purpose like research, photographing and conservation services.

Non-display lighting needs to be taken into account for assessing annual exposure.

3.4.3.2.2 Calculating and controlling annual hours of exposure

Calculating annual hours of exposure are an end procedure of planning museum lighting. After fulfilling all of visual, aesthetic and conservative aspects. An annual exposure hours are determined by measuring exposure rate (lux/hours per year) for an objects in display and assessing its damage potential to this object. It is necessary to have a pre-calculation or an estimation of annual hour of exposures in the design phase, as well to plan the methods and strategy of controlling annual exposure.

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1. IESNA The Lighting hand book, Applications, Lighting for Art, 10th Ed. 2011, p(21.15).
2. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA, p21.
3. Previous Reference.

3.4.3.2.2.1 Estimating annual hours of exposure

The annual hours of exposure cannot be estimated without knowing the total display lifetime, which is in must museum policy marked by a Just Noticeable Fade (JNF) or acceptable change. The object's physical and appearance condition, exposure history, and preciousness determine the tolerance extent in determining the total display lifetime for an object in a museum policy. (See p23-24 and p31)

The total display lifetime for a sensitive-to-light object: is the total light energy exposure that the materials can tolerate before their appearance or integrity is changed to an unacceptable degree.[(1)]

The total display lifetime or a Just Noticeable Fade, (JNF = approximately equal to a colour difference of ΔE 1,6 CIELAB units), can be determined with accelerated techniques like the Microfading Test instrument. (see p31)

For example, if a JNF will occur for the most vulnerable part of an exhibit after 1,0 Mlx h (1 megalux hours = 1 000 000 lux per hour), assuming reciprocity holds, this will be for a material with high responsivity equal to (50lx x 20 000 hour). If a museum intends to display the objects for 8 hour every day in 6 day a week in a permanent display 52 week in the year this will be 2496 hour per year. For the exhibit with high responsive material this will be 20 000/2496 = 8,0128 years of display. However, the policy for such an exhibits can be at least 100 year of display till a JNF occur. Which mean the museum has to put the exhibit in a temporary exhibition 200 hour/year (25 days every year). If a museum wants to put the exhibit in a permanent exhibition, it has to tolerate its policy to have more than JNF or to limit display time, e.g. by putting the object in a drawer which will be opened only for a quick peek.

In some cases, for a very precious exhibit, museum policy will be 500 year of display till a JNF occur. Which mean the museum can only display the object for 40 hour/year (5 days every year), which is practically not possible. In this case museum has to restrict object's exhibition by putting it in a archive where it will be only displayed for study and documentation. In this case it important to write down the exposure history of this exhibit to calculate the cumulative exposure time.

Unfortunately the accelerated techniques are not widely spread in museum practice since it is relatively new technology. A museum conservative light planning will mostly depend on exhibits' record data or norms to determine the annual exposure.

The CIE gives a limiting annual exposure (lux hour per year) for the four category classification of materials according to responsivity to visible light: High responsivity materials illuminated with 50 lx are limited exposure 15 000 (lx h/y), Medium responsivity materials illuminated with 50 lx are limited exposure 150 000 (lx h/y), Low respon-

1. Terry T. Schaeffer, Effects of Light on Materials in Collections, Data on Photoflash and Related Sources, The Getty Conservation Institute , USA, 2000. p2

sivity materials illuminated with 200 lx are limited exposure 600000 (lx h/y) and irresponsive material are not limited. [1] (Table 3.2)

Further, The CIE related the illuminance to the light-fastness of the most susceptible pigment present is indicated by the " Mlx h for noticeable fade" data given in (Table 3.3). Consider the case of a medium responsivity material with an ISO rating of 5 on permanent display (3 000 hours per year), where the display illuminance is 50 lux and UV is eliminated. The annual exposure is 3 000 hours x 50 lux = 150 kilolux hours/year. The Table indicates that noticeable fading is probable after 30 megalux hours of exposure, and this will occur after 30000/150 = 200 years of display. Suppose now that a highly responsive material with an ISO 2 rating is placed in the same display situation. Probable fading will occur after 1 megalux hour of exposure, and this will occur in 1000/150 = 6,7 years. It is for this reason that the "highly responsive" category has been included in (Table 3.2), and it is recommended that materials in this category are not placed on permanent display.[2]

Norms are practical in planning and roughly estimating the annual hours of exposure. However, it can not be use to expect the time frame for colour fading or damage of a material. Thus, for a precise data and planing, especially for high responsivity materials, accelerating methods has to be used and a Just Noticeable Fade (JNF) has to be defined.

It is advisable during calculation to consume some of the estimated annual hours of exposure to purpose like research and conservation services. As well, to keep a record of all unexpected events that can happen during display time and alter the exposure time.

3.4.3.2.2.2 Strategy of controlling annual exposure

If the estimated annual hours of exposure is exceeded, then the display hours has to be restricted. When annual our is limited a lot of strategies may be employed to regulate the display time to keep the object in display:

- An occupancy sensor could be used to switch on the display lighting only when viewers are present.
- The artefact could be protected by a motorized screen that reveals the artefact for a few minutes each hour, or by a curtain that is lifted by the viewer and falls back into place when released.
- The artefacts can be displayed in a drawer which will be opened only for a quick peek.
- The artefact can be removed from display for some months each year. During this period some museum display a replica instead of the original piece.

The following figures represent examples of displaying sensitive Egyptian artefacts and its environment. (Figure 3.41 to Figure 3.456).

1. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p26.
2. previos Referenc p19.

Figure 3.41 *A drawer system integrated in the wall to organize the time of seeing the sensitive-to-light exhibits and control time of exposure. (a) A display of old textile in a drawers which will be opened only for a quick view. (b) A general view of the gallery where the drawer system is in display. A dark gallery atmosphere. The ambient light is generated by the reflected light from objects and showcases. The drawer display existed along the right wall and the area in front of the drawers is illuminated from the ceiling by a spotlights track. So the artefacts will be only illuminated when the drawer is opened. (After The Pharaohs Gallery, The State Museum of Egyptian Art, Munich, Germany).*

(a)

(b)

Figure 3.42 *An innovative system to display Papyrus. (a) A long roll of Egyptian papyrus displayed under a glass surface and lit with warm white LED light. The LED strip is integrated in the upper and lower edge of the showcase. The showcase is fixed on the wall at eye level and provided with monitor that can be dragged along the showcase. The monitor shows a bright image of the papyrus at the same size with an interactive graphic and text to explain the papyrus. The bright image give the opportunity to see the detail of the papyrus and to concentrate only on a small part. (b) A general view of the gallery. The papyrus showcase is not illuminated from the out side to maintain a stable level of low illuminance on the papyrus and to help the observer to see the papyrus at law illuminance level. (The Religion Gallery, The State Museum of Egyptian Art, Munich, Germany)*

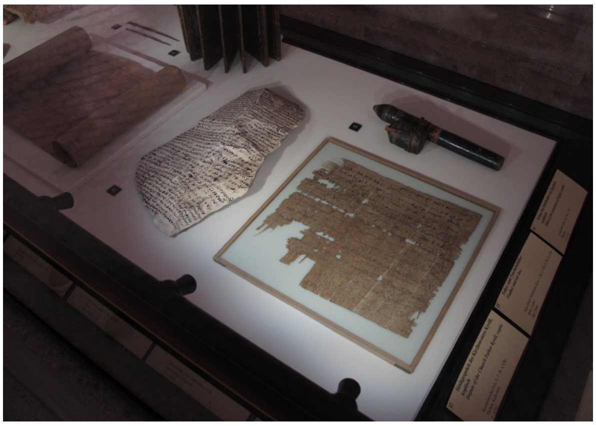
(a)

(b)

(a)

(b)

Figure 3.43 *An innovative showcase to display papyrus. (a) A horizontal showcase provided with a motorized drawer to display Egyptian papyrus. The show case is illuminated from outside with a wall mounted spotlight. The drawers can only be opened when the visitor push its own button. (b) A general view of the gallery where the papyrus showcase is in display. It is a part of old building that still existed with its old style. The gallery windows are covered with screens to reduce the ambient light. And horizontal showcases are illuminated with a wall mounted spotlights. (The Ancient Library Gallery, The Egyptian Museum of Berlin, Germany)*



(a)

(b)

Figure 3.44 *A horizontal showcase to display Egyptian papyrus. (a) The cracked papyrus is preserved between two plate of glass. The showcase is lit from inside with a small LED spotlights. The small LED give the opportunity to direct the light precisely on the papyrus. (b) A general view of the gallery where the papyrus showcase is in display. It is a basement in the lowest level of the museum, a brick barrel vaulted rooms. The vaults are illuminated with for spotlights mounted in the corners. The reflected light from volts' ceiling creates the abient light. Showcases are illuminated from inside. (The Egyptian Museum of Berlin, Germany).*

(a)

(b)

Figure 3.45 *A small dark chamber to display an Egyptian mummy. The mummy is illuminated by a ceiling track spotlights and to maintain a fixed low illuminance level the mummy is isolated in a small dark chamber from the rest of the gallery. Where wall, ceiling and floor have a dark colours; and there is no ambient light. The dark surrounding as well helps to see the mummy in a low illuminance level. (a) A view inside the mummy chamber. (b) Another view from different angle shows the entrance and the ceiling track spotlight. (Luxor museum, Luxor, Egypt).*

(a)

(b)

Figure 3.46 *The two mummy galleries in the Egyptian Museum in Cairo. (a) the first displays eleven royal mummies from the Empire Age (17th to 19th Dynasty). (b) The second display mummies belong to royal individuals of the 20th Dynasty. The design of the galleries, the showcases, and the lighting are very simple. The rooms has dark floors and beige marble walls. The first room has a dark blue ceiling and the second has a vaulted ceiling. Showcases have a light beige colour. The lighting concept depends on integrated spotlights in the ceiling and to maintain 50 Lux on the showcases. The walls are illuminated and there is sufficient light to move and to see the mummies. The relatively bright atmosphere help to stay longer time in the room. (Cairo museum, Cairo, Egypt).*

3.4.4 Special treatment

Conservation researches showed that protection of museum objects from environmental deterioration can be enhanced by reducing their exposure to oxygen. This can be done by displaying the objects in a free-oxygen showcases.[(1)]

Not only the deleterious effects of oxygen-dependent organisms such as insects, fungi, and aerobic bacteria on organic cultural objects would be eliminated if the objects could be maintained in a nitrogen or other oxygen-free atmosphere, but also many colorants found in oil paintings and watercolours would fade less when exposed to light in vacuo. Kuhn (1968) demonstrated that improved protection for some light-sensitive artists' materials (dyes and pigments) could be attained by replacing air with nitrogen. In addition, there have been applications for parchment (collagen); paper (cellulose); and metals that benefit from an anoxic environment.[(2)]

It is very important to mention that the technique of free-oxygen environment are used in the Royal Mummy Collection showcases at the Egyptian Museum in Cairo. The design and construction of a hermetically sealed, inert-gas-filled display and storage case was carried out at the Getty Conservation Institute,California, USA.[(3)]

3.4.5 General guideline for control of museum lighting in practice

The CIE recommended a few steps that help to check the procedure of lighting control when setting up lighting for a new display. The steps cover all previous important aspect of controlling light in museum and put them in order. :[(4)]

- Classify all exhibits according to the four-category scale given in Table 3.1.
- Install UV filters on all light sources, including windows and skylights, and check each source with a UV meter to ensure that UV is below the detection threshold (UV <10 μWlm).
- Focus the lighting, and visually assess the effect of reducing display illumination with the aim of ensuring that illuminances are no greater than is necessary to satisfy display objectives. Check illuminance values. The limiting illuminance is the maximum illuminance at any point on the exhibit's surface.
- Check the radiant heating effect for each object, particularly where incandescent filament spotlighting is in use. If radiant heating

1. Shin Maekawa, Oxygen-Free Museum Cases, The Getty Conservation Institute, USA, 1998, p1-4.
2. Previous reference, p7.
3. Previous reference, pxi.
4. Control of damage to museum objects by optical radiation, CIE Technical report 157:2004, p27.

effect seems to be significant, consider use of dichroic reflector lamps or IR filters.

- Check controls and procedures for restricting the duration of display lighting. Estimate annual hours of exposure.
- Measure and record illuminances for each object or group of objects. Calculate annual exposures and plan for the duration of display to be restricted as necessary, both for the exhibition and for individual objects at risk.

During the life of the display:

- Periodically check the lighting with a UV meter, and replace filters where necessary.
- Periodically check radiant heating effect and reduce IR if necessary.
- Periodically check illuminances, and adjust if necessary.
- Check that procedures for restricting the duration of display are operating satisfactorily, both for the exhibition and for individual objects at risk.

Visual Perception Experiments for Lighting Levels in Museum

Ch. 4

Chapter 4. Visual Perception Experiments for Lighting Levels in Museum

Norms and standards used for practice are general guidelines that cannot cover all lighting situations. Understanding the factors that govern the lighting situation will help the lighting designer to adjust and apply the lighting gauges correctly in practice. A common technique to study lighting situation is to mimic the situation in a physical scale-model or a mock-up to define the proper lighting composition and levels.

We conduct a series of experiments in a physical scale-model and a mock-up to study the favourable light levels for exhibits in museum's spaces; to analyse the factors that govern the brightness relationship between an exhibits and its background in museum lighting; and to use the collected measurement as guideline in the practice of museum lighting.

In the following chapter we will present:

- General introduction includes an overview of the difficulties that can be countered in applying standards of museum lighting in practice, and a general perception knowledge that will help to study and analysis the experiments data.
- Research methodology and tools.
- Five experiment.
- General results.

4.1 General introduction

4.1.1 Difficulties in applying standards of museum lighting

Norms and standards for lighting are a general guidelines that can not cover all cases of museum display. To demonstrate this we can imagine a dark gray statue (15 % reflectance) against a mid-tone gray wall (50 % reflectance) displayed in picture gallery museum, where the walls and paintings are illuminated with 200 lux according to CIE norms for low responsivity to light artefacts. The question here is, how much light (illuminance or luminance) is needed for the statue? (Figure 4.1)

In this case we have the following suggestions:

a. Illuminating the statue with the same illuminance 200 lux and depending on the reflectance differences between the statue and the wall to have luminance contrast about 9.6 : 32 cd/m^2. However, the resulted luminance ratio did not match with the common object-to-surrounding luminance ratio for visual comfort, do not match with museum recommendation and there is no reference supporting this ratio to say if it is sufficient or favourable.

b. If we use the common luminance ratio for task-to-nearby surroundings, which is range between 3:1 to 10:1.[1] We will have between 96 to 320 cd/m^2 on the object, that is equal to 2000 to 6700 lux. Which is extremely too much illumination.

1. Andrew Scott Linney, Maximum Luminances and Luminance Ratios and their Impact on Users' Discomfort Glare Perception and Productivity in Daylit Offices, Master of Building Science, Victoria University of Wellington,2008, P3.

c. If we follow the IES recommendation,[1] background of a dark object has to vary between 0.05, 0.1 or 0.2 times the object illuminance according to intended degree of visual attraction in display. Which means object has to have 4000, 2000 or 1000 lux, that is equal to 190, 95.5 or 47.5 cd/m^2. Which is relatively to much illumination and do not follow the common luminance ratio.

d. From a practice experience, a light designer will estimate that the 200 lux for the statue are insufficient and statue illuminance must be around 500 lux, that is equal to 24 cd/m^2.

This simple example shows that, norms and recommendations give various results, as well extreme in some cases. (A black statue against a white wall can be more extreme than our example). However, the example raises different questions about lighting statues and its surrounding walls in museum such as:

- What is the sufficient amount of illuminance?
- What is the comfortable luminance ratio?
- Is it better to express object-background lighting ratio with luminance or illuminance value?
- What is the role of reflectance (colour value) of both objects and its background in defining the preferred luminance/illuminance ratio in museum lighting?

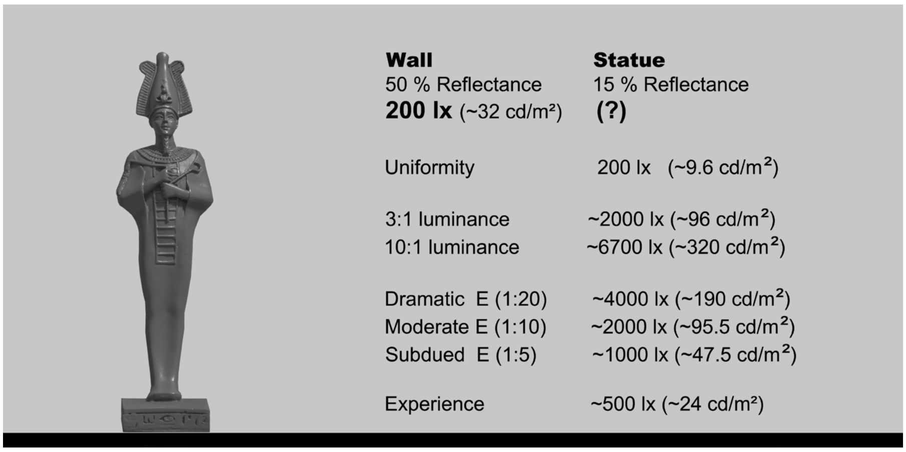


Figure 4.1 *What is the correct light level for the statue? The figure presents different lighting levels that can be suggested according to norms and experience..*

Additionally, a common lighting design procedure is to enhance objects visibility and visual comfort by alerting luminance ratio between objects and its background. This is commonly done by changing background reflectance (colour value) or by altering the illuminance failing on either the objects or its background. This procedure raise an important questions: Is dimming the background light perceptually equal to reducing background light reflectance value? Simple answer is no, dark is not black and bright is not white. However, this is the procedure is widely use in practice.

1. IESNA, The Lighting handbook, Perception and Performance,10th Ed. 2011, p4.6.

We all visually experienced that a bright or white statue will be more visible against dark or black background; and it will need to have more illuminance against a brighter or whiter background. This raise the question: To which extend the difference in luminance or reflectance between an object and its background will affected the comfort object-background luminance/illuminance ratio?

The answers depend on the understanding of how we visually perceive the illuminance incident on a surface, the luminance reflected from a surface and surface reflectance (colour value). Moreover, how these perceptual dimensions interact with each other and when it can be described as comfortable or favourable? Accordingly, we presented the following visual perception introduction.

4.1.2 Understanding Brightness and lightness

The aim of this visual perceptual approach is to demonstrate the important perception knowledge of brightness and the mapping of luminance (a physical dimension) with brightness (a perceptual dimension). Being aware of this fundamental information helps analysing the visual perception experiments and to know for which extend it is applicable in real museum practice.

4.1.2.1 Visual perception and photometry definition

Brightness: is the subjective attribute of any light sensation giving rise to the perception of luminous magnitude, including the whole scale of qualities of being bright, light, brilliant, dim, or dark.(1) Some reference may use surface brightness or light source brightens to refer to the source of brightness.

Luminance: is the measure of the light emitting power of a surface, in a particular direction, per unit apparent area. Luminance is one of the direct stimuli to vision and many measure of performance and perception have been shown to depend on luminance.(2)

Lightness: is the perceptual attribute related to the physical quantity of reflectance. In most lighting situations, it is possible to distinguish between the illuminance on a surface and its reflectance, that is, to perceive the difference between a low-reflectance surface receiving a high illuminance and a high-reflectance surface receiving a low illuminance, even when both surfaces have the same luminance. It is this ability to perceptually separate the luminance of the retinal image into its components of illuminance and reflectance that ensures that a piece of coal placed near a window is always seen as black while a piece of paper far from the window is always seen as white, even when the luminance of the coal is higher than the luminance of the paper.(3)

Reflectance: it the ratio of reflected to incident luminous flux.(4) Some reference may refer to reflectance as Light Reflectance Value (LRV).

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1. The IESNA lighting hand book, 9th, 2000, p1029.
2. IESNA, The Lighting handbook, Concept and language of light,10th Ed. 2011, p5.14.
3. The IESNA lighting hand book, 9th, 2000, p135.
4. IESNA, The Lighting handbook, Concept and language of light,10th Ed. 2011, p5.15.

4.1.2.2 Ambiguity of visual stimuli

Any element of any visual stimulus could have arisen from many combinations of physical parameters in the world. The reason is that the illumination of the relevant objects, their surface reflectance properties, the transmittance of the intervening medium, and a host of other factors that determine the quantity and quality of light are intertwined in any visual stimulus. How the visual system recovers useful information in the face of this inherent uncertainty is called the inverse optics problem.(1)

The appearance of any element in a scene can be changed, sometimes quite dramatically, by the context in which it is presented.(2) (Figure 4.2)

Accordingly in the practice:

- The relationship between an objects and its surrounding can alters the object appearance, which can be perceived as a change in surface brightness, lightness, colour and/or shape.
- A measurement of a physical stimuli do not have one-to-one relationship with its perceived effect.

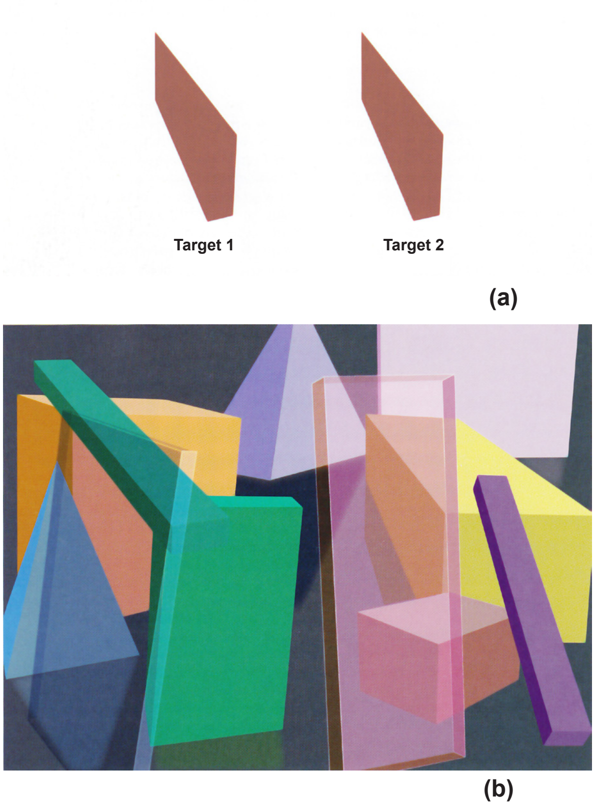

Figure 4.2 *Objects can alter its appearance when it is seen in a different surrounding. (a) The two patches shown here are physically identical. (b) the same target appear quite different when presented in a more natural scene. The two identical patches now appear to have different surface reflectance values, to be under different illuminance, and to be seen through different transmitting media. Moreover, the two objects now seem to have different shapes, to be in different orientations, and to be at different distance. (Dale Purves & R. Beau Lotto, Why we see what we do redux. p7)*

1. Dale Purves & R. Beau Lotto, Why we see what we do redux, A wholly empirical theory of vision, Sinauer Associates, Inc. USA 2011, p5.
2. Previous reference, p5-6.

4.1.2.3 Lightness and surface-brightness dimensions

Luminance is bifurcated into two perceptual dimensions lightness (apparent reflectance) and surface-brightness (apparent luminances). Particularly, any luminance edge produces a lightness edge and a surface-brightness edge, which are coupled in space. Surface-brightness is a perceptual dimension of an object rather than a characteristic of either the ambient or direct illumination. Of course, when the physical illumination of an object is altered, surface-brightness is what mainly changes.(1)

These terms may be better understood by (Figure 4.3). The block is made of a set of four cubes, each coloured either light or dark gray. We call this the checker-block. Illumination comes from an oblique angle, lighting different faces differently. The luminance image can be considered to be the product of two other images: the reflectance image and the illuminance image, shown below. Patches p and q have the same reflectance, but different luminances. Patches q and r have different reflectances and different luminances; they share the same illuminance. Patches p and r happen to have the same luminance, because the lower reflectance of p is counterbalanced by its higher illuminance. Faces p and q appear to be painted with the same gray, and thus they have the same lightness. However, it is clear that p has more luminance than q in the image, and so the patches differ in brightness. Patches p and r differ in both lightness and brightness.(2)

According to this explanation, surface-brightness and lightness dimensions are defined with respect to fixed, or absolute, bright/dark and white/black poles, respectively.(3)

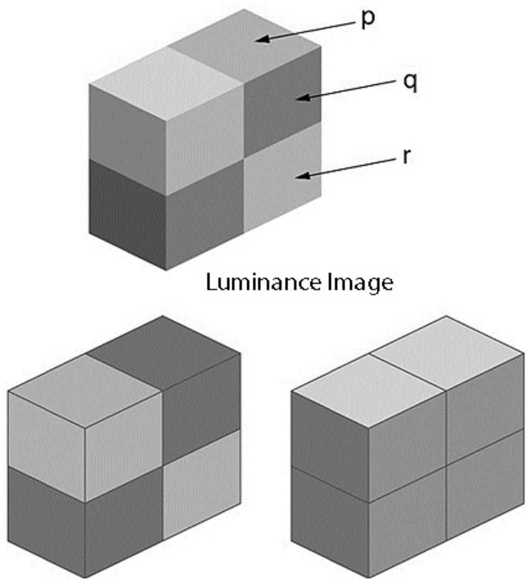

Figure 4.3 *The Checker-block and its analysis into two intrinsic images. The luminance image can be considered to be the product of two other images: the reflectance image and the illuminance image (Edward H. Adelson, Lightness Perception and Lightness Illusion p342)*

1. Alexander D. Logvinenko, Does luminance contrast determine lightness?, VSP (Virtual Sensory Perception) 2005, Spatial Vision, Vol. 18, No. 3, p341.
2. Edward H. Adelson, Lightness Perception and Lightness Illusions. In The New Cognitive Neurosciences, 2nd ed., M. Gazzaniga, ed. Cambridge, MA: MIT Press, pp. 339-351, (2000), p342.
3. Tony Vladusich, Gamut relativity: A new computational approach to brightness and lightness perception, Journal of Vision (2013) , p1.

Like all other percepts, lightness and surface-brightness are not subject to direct measurement; they can only be evaluated by asking observes to report their threshold for light detection, the just noticeable difference between two stimuli, or, more commonly, the appearance of one surface or light source relative to the appearance of another.[1]

4.1.2.4 Lightness and surface-brightness constancy

Objects are visible because they reflect light. Different objects often have different reflectances. Objects reflecting almost all of the incident light (across the visible part of the spectrum) appear white. Those reflecting only little or none of the light appear black. The perceptual continuum of various shades of grey (from white to black) is called lightness. Yet when ambient illumination changes, white objects seem to remain white, and blacks remain looking black. This remarkable feature of human vision called lightness constancy poses a problem for visual science since the reflected light (the only direct source of visual information available) depends on both incident light and the object's reflectivity.[2]

When a dimly illuminated strips white paper presented against a highly lit black background, it appears white even when it have the same luminance value with the background. This simultaneous lightness constancy demonstration indicate that:

- A target may dramatically differ in lightness from its background even when the target and the background have the same luminance.[3]
- Lightness constancy can be observed without any change in gain control (an adaptive gain control in receptors and possibly other visual neurons).[4]
- Lightness cannot be reduced to relative brightness as is widely believed.[5]

A general explanation is that, our judgment of the lightness of a surface involves an assessment of its surroundings and a judgment of the illumination condition. Lightness constancy is part of the perceptual process of extracting meaning from what we see.[6]

As well the visual perception perform brightness constancy. Objects of various reflectance under uniform illuminance will each assume a brightness. If the uniform illumination is increase or decreased, the relative brightness among objects remain relatively unchanged, though there is some increase in the maximum brightness as luminance

1. Dale Purves & R. Beau Lotto, Why we see what we do redux, A wholly empirical theory of vision, Sinauer Associates, Inc. USA 2011, P17.
2. Alexander D. Logvinenko, Does luminance contrast determine lightness?, VSP (Virtual Sensory Perception) 2005, Spatial Vision, Vol. 18, No. 3, p337.
3. Previous reference, p338.
4. Previous reference, p338.
5. Previous reference, p337.
6. IESNA, The Lighting handbook, Perception and Performance,10th Ed. 2011, p4.9.

is increased. This is a results of the over all sensitivity of the visual system changing to provide the necessary adaptation and a perceptual mechanism that attempt to centre the range of luminance within the field of view between very bright and dim.(1)

As a comparison, lightness and brightness have different topological structure. The lightness continuum has two endpoints (black and white), whereas the brightness continuum has only one (complete darkness). Hence, lightness cannot be reduced to relative brightness since relative brightness remains to be open at one end while the lightness continuum is topologically similar to an interval.(2)

Accordingly, in practice:

- Two equal luminance values measured from two surfaces with different reflectance value cannot represent the same brightness.
- The effect of changing reflectance of a surface are perceptually more stable than changing its illuminance; where the first depend perceptually on an assessment with the surrounding without any change in receptors gain control, while the second depend on amount of change in illuminance according to visual adaptation.

4.1.2.5 Lightness and surface-brightness interrelation in local luminance contrast.

Luminance contrast has an important role in lightness perception as it determines the relationship between the lightness and surface-brightness. While luminance contrast does not determine the specific value of either lightness or surface-brightness per se, it dictates their relative proportions; in this way lightness and surface-brightness are interrelated. Indeed, there is a reciprocal relationship between lightness and surface-brightness (referred to as lightness/surface-brightness invariance). Note that the lightness/surface-brightness invariance implies that when surface-brightness in a scene is constant the lightness ratio (contrast) should be equal to the luminance ratio (contrast). If a scene is partitioned into several areas where each region of surface-brightness is kept constant, the lightness ratio will equal the luminance ratio when derived from within a single area, but not from different ones. Therefore, the ratio rule can be valid only within areas of equal surface-brightness.(3) (Figure 4.4)

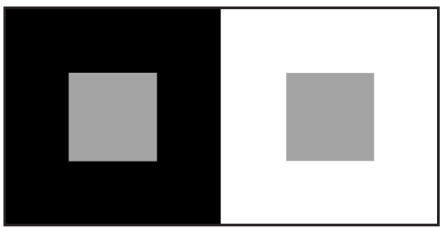

Figure 4.4 *Standard demonstration of simultaneous brightness contrast.*

1. IESNA, The Lighting handbook, Perception and Performance,10th Ed. 2011, p4.9.
2. Alexander D. Logvinenko, Does luminance contrast determine lightness?, VSP (Virtual Sensory Perception) 2005, Spatial Vision, Vol. 18, No. 3, , p343.
3. Previous reference p342.

Accordingly, in practice:

- Relative luminance ratio (luminance contrast) represent the relative brightness ratio (surface-brightness/lightness contrast) only in a uniform illuminated area in a scene. Accordingly, the use of the common mathematical contrast ratios, e.g. Weber–Fechner's law ($C = L_{target} - L_{background} / L_{background}$) which is mostly used where background is brighter than the target and Michelson contrast law ($C = L_{max} - L_{min} / L_{max} + L_{min}$) which is applies to periodic pattern[1], are applicable only across surfaces that uniformly illuminated.

4.1.2.6 Lightness and surface-brightness in natural scene

A key task of the visual system is to determine whether two image regions with different luminance values have the same reflectance under different illuminants, or different reflectances under the same illuminant, or some linear combination of these two extremes.[2]

Insofar as the visual system can successfully discount the illuminant to estimate surface reflectance, observers are said to exhibit lightness constancy. Insofar as the visual system can successfully estimate the intensity of light reflected to the eyes, observers are said to exhibit brightness sensitivity; that is, to exhibit some measure of sensitivity to illumination intensity.[3]

A very important theory explaining the perception of lightness and brightness in a scene is the anchored theory, which asserts that the highest luminance plays a privileged role in establishing absolute lightness values within and across regions that are presumed to share common illumination.[4] Reinforce that, what established recently, the human visual system uses some cues to distinguish illumination borders from material (reflectance) ones, and thus to establish areas of equal illumination.[5]

In natural scene anchoring occurs in tow levels global anchoring and local anchoring. Global anchoring means that the region of highest luminance in the entire scene anchors the lightness values of all other regions, and local anchoring means that the highest luminance value within each illumination level anchors all the lightness values in that level. Global anchoring is thus favoured when a scene is uniformly illuminated, and local anchoring is favoured when different regions of a scene are variably illuminated.[6]

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1. The Lighting handbook, perception and performance, IES 10th Edition, p4.6.
2. Tony Vladusich, Gamut relativity: A new computational approach to brightness and lightness perception, Journal of Vision (2013), p2.
3. Previous reference, p1.
4. Barton L. Anderson, Byung-Geun Khang and Juno Kim, Using color to understand perceived lightness, Journal of Vision (2011) 11(13):19, p1.
5. Alexander D. Logvinenko, Does luminance contrast determine lightness?, VSP (Virtual Sensory Perception) 2005, Spatial Vision, Vol. 18, No. 3, p342.
6. Tony Vladusich, Gamut relativity: A new computational approach to brightness and lightness perception, Journal of Vision (2013), p2.

Under the assumption of an identical spatial arrangement of surfaces viewed under different illuminants, local anchoring ensures that surfaces with the same reflectance values all have the same lightness values. Local anchoring thereby effectively discounts the illuminant, giving rise to achromatic colour constancy, or, as it is conventionally termed, lightness constancy.(1)

4.1.2.7 Lightness and surface-brightness in the Staircase Gelb Effect

The term Staircase Gelb Effect refers to a phenomenon occurs in dark rooms for achromatic colours (natural-gray tones from black-to-white). The phenomenon, to a large extent, illustrates the distinction and correlation between lightness and brightness. The effect is typically observed using physical papers and a hidden spotlight: A piece of paper that appears black in ‘‘room illumination’’ appears white when illuminated by a hidden spotlight of high intensity in an otherwise darkened room. When a paper that appears a shade of gray in room illumination is now placed in the spotlight (adjacent to the paper appearing white), the newly introduced paper looks white, but is said to look brighter than the white of the original ‘‘black’’ paper—an effect that may be termed brightness escalation. Each new paper that previously appeared white now appears a shade of gray upon the addition of a paper of higher reflectance to the display. The process is repeated with additional papers of progressively higher reflectance up to a paper that appears white in room illumination. Each new paper appears progressively brighter along the putative brightness dimension, and all papers that previously appeared white appear to blacken along the putative lightness dimension.(2)

During testing this phenomenon in the laboratory we found that the background has an influence on the appearance of the achromatic patches. When we repeated the previous steps against a gray background, only patches with higher reflection than the background exhibits the phenomenon and appears white under the spotlight. In addition, the phenomena was eliminated against a white background and all patches have the same appearance as in room illumination.

The phenomenon shows how the visual system, in a very simple context consists only of one reflected luminance intensity in dark surrounding, assigns the lightness dimension (black-to-white) to the surface, accordingly the surface appears white. Successively, with every new entrance of reflected luminance intensity the visual system adds one more interval step in the scale of lightness according to a comparison between the existing intensity. The visual system relates the surface-brightness dimension (dark-to-bright) gradually to all steps of the lightness dimension (black-to-white) to obtain differences between the surfaces and overall impression of the light situation.

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1. Previous reference p2.
2. Tony Vladusich, Gamut relativity: A new computational approach to brightness and lightness perception, Journal of Vision (2013), p2.

Even if this phenomenon do not occur in normal light situation or with the three dimensional objects. It gives an idea about how the brain processes the perception of lightness and brightness. Tony Vladusich 2013 proposed computational theory, termed gamut relativity, that explains a new approach to compute brightness and lightness perception based mainly on this phenomena.(1)

4.1.2.8 Mapping luminance with Lightness/ brightness

The approach Stanley Stevens (1906-73) and other neuroscientist took to study the relationship between the physical characteristics of a class of stimuli and the overall "shape" of the relevant perceptual, was to present a full range of stimuli in the same simple context (e.g., a light source whose intensity could be varied or pieces of paper ranging in reflectance from dark to light) and ask subjects to rate their perceptions on a subjective scale. Stanley and others found many peculiarities in scaling tests as in responses to stimuli: (2) see (Figure 4.5)

- Doubling the intensity of light coming from a source or reflected from a surface does not simply double perceived brightness.
- The lightness/brightness seen is greater than expected for relatively small increases in the target luminance above the background luminance and less than expected as target luminance values increase under the background.
- Another peculiarity is that the relationship varies according to the circumstances of testing. For instance, when the light sources of different intensities are presented in a dark background, the exponent of the Stevens Law function (relationship between luminance and lightness/brightness measured under standard conditions) is approximately 0.5 ; and if, however, the target intensities arise from the reflectance values of a range of gray papers, then the exponent of the psychophysical function approaches 1 (one).
- Other anomalies are that the slope of the relationship is more or less opposite for increments and decrement, that the relationship varies as a function of the background luminance, and that the slope is greatest when the luminance of the test target is similar to the luminance of the background. There is no generally accepted explanation of this phenomenology, although various models have been proposed.

Studies additionally showed that, a cognitive variable, such as figure-ground relationship, can affect the amount of perceived brightness contrast. Area perceived as figure shows a greater amount of brightness contrast than when that same area is perceived as ground.(3)

1. Previous reference.
2. Dale Purves & R. Beau Lotto, Why we see what we do redux, A wholly empirical theory of vision, Sinauer Associates, Inc. USA 2011, p40-41.
3. Stanley Coren, Brightness contrast as a function of figure-ground relations, Journal of Experimental Psychology, Vol 80 (3, Pt.1), Jun 1969, p517-524.

Outside the laboratory standard condition, usually five factors govern the transformation or mapping of luminance as stimulus to brightness as response: object luminance, surrounding luminance, state of adaptation, gradient, and spectral content.(1)

- **Object Luminance:** in simple settings, the brightness of an object is proportional to a fractional power of its luminance. That is, the relationship between luminance and brightness is compressive and is approximated by a power law with an exponent of luminance being approximately 1/3.(2)
- **Surround Luminance:** the luminance around an object affects the object's brightens; a low luminance surround increases the brightness of an object, while a high luminance surround decreases the brightness of an object.(3)
- **Adaptation:** the state of adaptation and the highest luminance in the visual field affects the brightness of objects in a complex field. At high adaptation luminances, small changes in object luminance produce small changes in brightness and so there are many brightness steps or shades of gray. At low adaptation luminances small changes in object luminance produce large changes in brightness and so there are few brightness steps or shades of gray.(4)
- **Gradient:** is the rate of change of luminance with visual angle. High gradients are produced by surface edges, abrupt changes in illumination, or changes in reflectance. High luminance gradient are usually necessary to produce noticeable brightness step. Low luminance gradient usually suppress brightness change and give the perception of brightness uniformity.(5)

Despite the apparent validity of several descriptions for simple target-surround stimuli, the relationship between luminance and the perceptions it elicits in different circumstances remains unexplained. Because in many instances the activity of visual neurons is correlated with perceptual qualities rather than the physical properties of the stimulus, the response properties of neurons in the early stages of the visual pathway are unlikely to explain in any direct way the scaling relationship of luminance and brightness.(6)

Accordingly, in practice, the mapping of luminance to brightness is not linear and it changes according to the luminance relationship between object and background in a peculiar way. This indicate that the preferences of comfortable brightness of an objects against a background may have similar peculiar behaviour according to object and background brightness/lightness relationship.

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1. IESNA, The Lighting handbook, Perception and Performance,10th Ed. 2011, p4.9.
2. Previous reference p2. p4.9.
3. Previous reference p2. p4.9.
4. Previous reference p2. p4.10.
5. Previous reference p2. p4.11.
6. Surajit Nundy & Dale Purves, A probabilistic explanation of brightness scaling, PNAS journal, 29 October 2002, vol. 99, no. 22, p14486–14487.

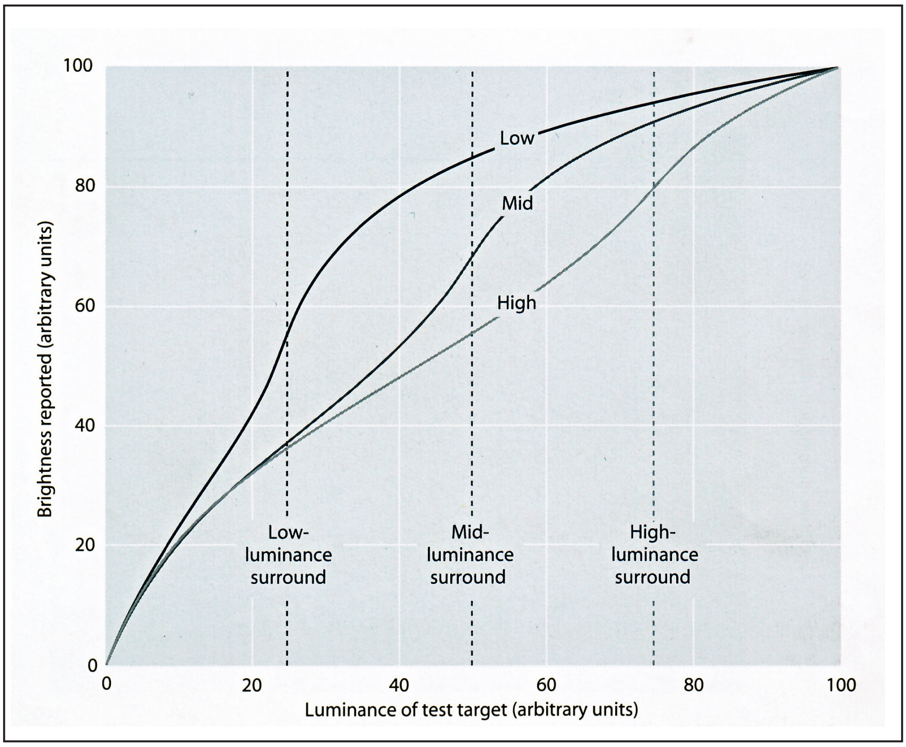


Figure 4.5 *The major features of lightness/brightness scaling. The graph shows scaling tests at three levels of background luminance; the three vertical dashed lines indicate the point at which the luminance of the target is the same as the background. The features include: (1) The non-linearity of the relationship, (2) The different form of the function for increments and decrements, (3) The different shape of the relationship as a function of the background luminance, and (4) The steeper slope of the relationship when the luminance of the target is near that of the background. The units are arbitrary. (Dale Purves & R. Beau Lotto, Why we see what we do redux, p41)*

4.1.2.9 General discussion

The lightness and brightness are to different interrelated perceptual dimension. An essential key of the visual system to extract them from luminance (one stimulus) is to discount and estimate the illuminant in a region and compare it with all other regions in a hierarchy that comprises the whole scene.

In a natural scene, lightness is perceptually more stable than surface brightness since it can be perceived without any change in adaptive gain control. Oppositely, surface-brightness is sensitive to change in luminance intensity, material (lightness), and adaptation level.

Accordingly, the visual system sensation of brightness is an evaluation of illuminant (energy on a surface), that is related to both lightness and brightness. This implies that luminance (a physical measurement) cannot individually represent the brightness, and the mapping of surface brightness to luminance measurements has to include a weighting factor that represent the lightness of the object and surrounding.

Since most of psychophysical models depend on using the only luminance to map brightness we assume that adding a factor representing the lightness perception will help to build a more reliable models.

Note: Although the visual system perform brightness and lightness constancy with colours, we did not address the dimension of colour in the previous introduction. We focused on the black-to-white scale since it is more related to the perception of dark-to-bright and reducing the variable involved in the explanation make it easy to be understood.

4.2 Research methodology and tools

4.2.1 Problem of the research

Museum's standards and recommendations for lighting an object against a background is general guidelines cannot cover all situations. Additionally, psychophysical tests show that a brightness relationship between an object and its background is not easy to predict and scaling/mapping brightness to luminesce in an simple target-background relationship has a lot of peculiarities.

4.2.2 Aim of research

The experiments aim is to record the illumination levels of a set of artefacts and backgrounds with different colour values, when the observer choose the preferred brightness between the artefacts and the background, within a condition similar to a museum display. The data are meant to be used as a guideline in museum practice and to study the effect of object and background colour values on preferred illumination levels.

4.2.3 Importance of research

The importance of the research resides in linking the practice of lighting design with the psychophysics experiment and analysis, which helps to improve the practice of lighting design.

4.2.4 Hypothesis of research

Luminance is bifurcated into two interrelated perceptual dimensions lightness and brightness. Observer's judgment of surface-brightness involves lightness. As well, two surfaces equal in luminance measurement can be extremely different in reflectance. Thus, luminance measurement can only represent the perceived brightness of a surface when it is evaluated according to the perceived lightness (degree of perceived surface colour value). Accordingly, in museum objects are usually presented against a plain background and illuminated with more light than the surrounding. In such object-background relationship we assume that the observer's preferred brightness of and the objects and background will depend on the visual system degree of interpretation/estimation of the apparent luminances according to its apparent reflectance; surely without neglecting other factors.

4.2.5 Tools of the research

Tools were as follow:

c. Physical model: a simple wood box representing a simple museum's showcase or room. The box interior space dimensions is 50 x 50 cm and 35 cm height. The walls and floor colour able to be changed and the ceiling is fixed in black. (Figure 4.7)

d. Light fixtures: the model is equipped with three different light fixtures represent different types of illumination. All lamps colour temperature is ~ 4000 K. Every lamp is controlled individually with a dimmer. (Figure 4.7)

- Fiber optics (36 point in the ceiling as a general illumination).
- Fluorescent lamp (three compact fluorescent lamps with raster as a wall-washers).
- LEDs points (Six LEDs as spotlights for exhibits direct illumination).

e. The exhibits samples: see (Figure 4.9)

- Round statues, 5 pieces, height 20 cm, from polyester.
- Head statues replica, 5 pieces, height 15 cm, from limestone.
- Relief replica, 5 pieces size 23x23 cm, from polyester.

(See Appendix 2.1 for more details)

e. Selecting Natural-gray tones for the experiment.

The human eye does not see the total world in black, white or gray, but the gray scale provides a means of assessing and controlling the appearance of colour value in terms of brightness as seen on surfacing materials when subjected to illumination.[1] Accordingly, working with the natural-gray tones scale will help to reduce experimental variables without losing the connection with colours and surface materials.

In order to have a natural-gray tones with equal perceptional steps including the black, middle gray and white tones, we intended to choose an odd number of tones from the natural-gray scale of the Natural Colour System (NCS). To chose five steps from a scale of 18 steps we obliged to pass one step and to have the black tone on step darker. Nevertheless, after applying the tones to the five round statues and re-measure its light reflectance values (LRVs), we fond that there is a compression in spaces between the lightness steps. Most probably, this is regard to the simple method of measurement we use or/and the samples were not perfectly diffuse. However, the middle gray of the five samples has a 27.4 LRV which is very close to the NCS middle gray 26 LRV. Notice that; the equal perceptual lightness steps are not an equal physical reflectance values. (Figure 4.6) (See Appendix 2.2 for more details).

The tones were denoted and organized from black-to-white according to its LRV as following:

B1 (5.2), G3 (15.9), G5 (27.4), G7 (49.3),W9 (77.00).

For the model's wall tones (background) we chose three natural-gray tones black, gray, and white. The LRVs measurement for the panted plywood background were:

Black (4.0), Gray (26.3), White (85).

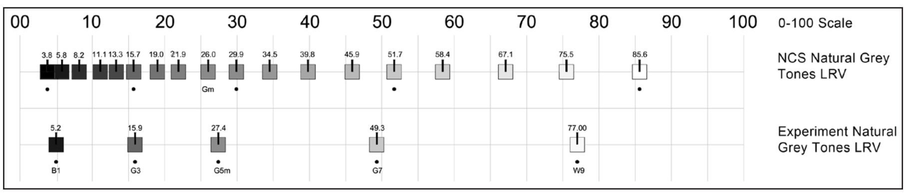


Figure 4.6 *Comparison between the natural-gray tones LRVs of standards NCS notation and experiment samples on a linear scale 0-to-100 .*

1. Lou Michel, Light: The Shape of Space, Design with space and light, John Wiley and Sons,INC.1st ed.1996, P69.

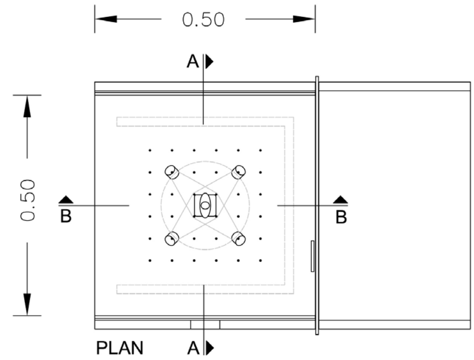
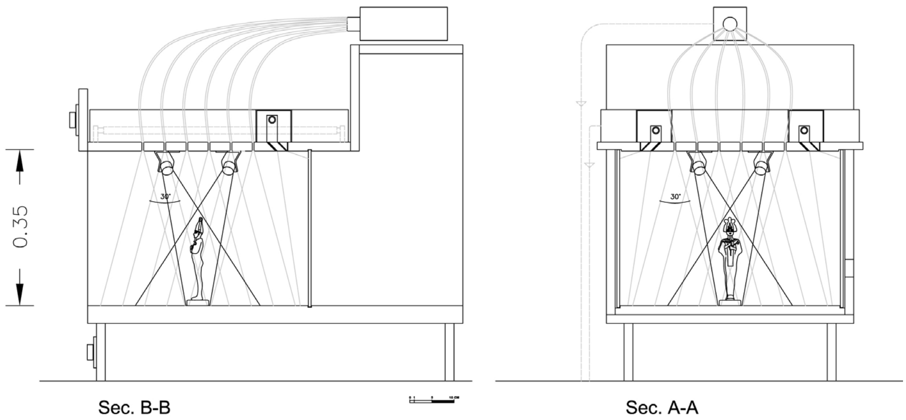


Figure 4.7 *The experimental physical models and the position of the light fixtures.*



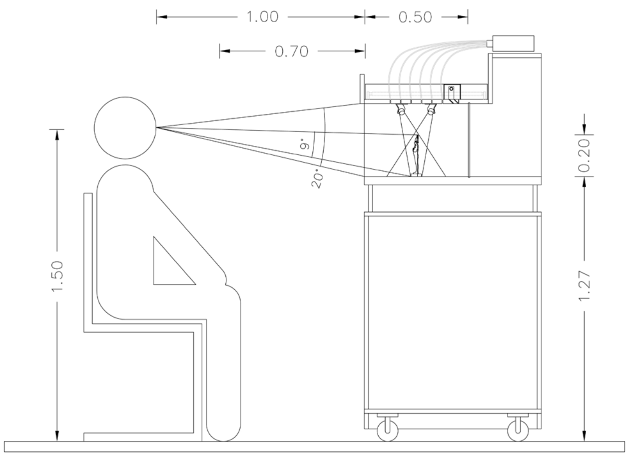


Figure 4.8 *Position of the observers from the model.*

(a) (b) (c)

Figure 4.9 *Experiment's samples: (a) Grayscale round statues (b) Head statues replica (c) Relief replica*

4.2.6 Procedure of the research

The experiments were conducted in a controlled environment, where the surrounding walls have the same colour and illumination. This will insure that the observers state of adaptation will not change. We conducted five experiment: four in the physical model to resemble a museum showcase in a dim surrounding and one in the artificial sky of Bratenbach light laboratory to resemble a museum gallery in daylight.

In every experiment one variable was tested to mange controlling the result. In the beginning of every experiments we have a preliminary phase; in which I, personally, repeated the experiment several times to record the first results and determine the right procedure for the experiments. The second phase is to conduct the experiment with three different observers. Their gender and age were: Male 26, Female 32, and Male 42 years old.

The observers sit on a chair far from the model 100-to-70 cm (according to head movement), which is 150-to-120 cm from the back wall of the model. (Figure 3.8) The observers were asked to chose the preferred brightness of the statue according to the brightness of the background or vice versa by controlling the level of illuminance.

Data were record with a luminance meter, luxmeter and luminance camera. (Appendix 2.3). The average value is used for the analysis and to present the final results. The results are described with the combine of charts.

4.3 EXP 1: The effect of background colour values at the same luminance on object luminance value.

4.3.1 Objective

The objective is to study the effect of different background colour value at the same luminance on the object preferred brightness (luminance value), when the observer chose the preferred brightness of the statue in accordance to the background brightness. As well to study how the visual system will perceive the same luminance from different background colour values.

4.3.2 Strategy

We illuminate the three different backgrounds at the same average luminance level (~ 4 cd/m^2) and we asked the observer to match the brightness of the statue with the brightness of the direct background.

4.3.3 Tools

Experiment tools are: The physical scale-model, The five small round polyester statues (Figure 4.9-a), and The three different background.

4.3.4 Procedure

- First step is to fix the model back-wall's luminance level at average of (~ 4 cd/m^2) by using the wall-washer in the back of the model and with the help of luminance-meter; then to place the statue without illumination in the middle of the model on front of the back-wall. Other walls in the model were black and without illumination.

- Second step is to ask the observer to raise the illumination of the statue using two LED points connected in parallel, one from the front-right and the other from the back-left, till the observer reach the preferred brightness relationship between the statue and the direct background. (Figure 4.10-a)
- The experiments was carried on from the use of dark-to-bright background and from the place of bright-to-dark statue.
- The experiment was conducted in a dark room, thus the observer was only adapted to experiment's light level and the reflected light from the model on the lab's white walls, which did not exceed 10 lux.

4.3.5 Collecting the data

When the observer adjust and chose the statue brightness we measured and collected the data in two steps: First, we took different luminance points on both the statue (on the chest and leg) and on the background (three points parallel to the statue), as in figure (Figure 4.10-b). We recorded, as well, the level of illumination on the light control panel. Second: Since we need to have a luminance capture of the final result. We calculated the average luminance of the three observers and we adjusted the luminance on statue and background to this average. Then, we took a capture with the luminance camera. The observer luminance were very close to each other and we did not find anomalous measurements.

The data were collected by using a luminance camera. The capture was taken on the same height as the observer eye-level. The luminance false colour image was processed and analysed by TechnoTeam Image Processing GmbH - Software. (Figure 4.10)

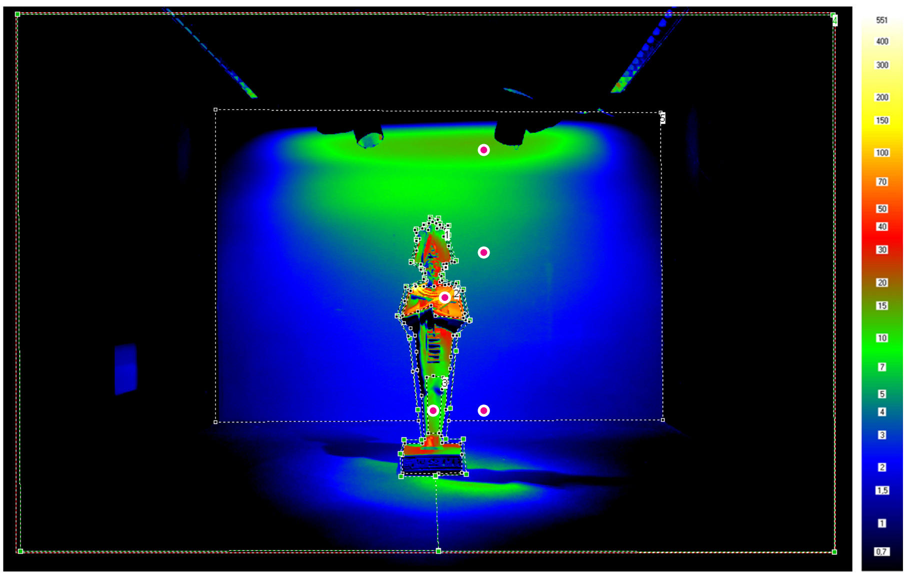
It was noticeable during the test, that the bright area on the statue's chest drags observer attention and always is compared in brightness with other part of the statue; which can be interpreted as the relationship between the heist and lowest area in luminance distribution on the statue's surface. Accordingly, Our interest was to record the following luminance level (cd/m^2) from the luminance image with the selection feature in the TechnoTeam Software:

- From the statue: maximum point, general average, chest average, and leg average. (Table 4.1)
- From the model: Model average (all walls, floor, and ceiling), direct wall average (model back wall), and model maximum point (mostly exist in model back wall). (Table 4.1)

4.3.6 Notes

- We use average luminance of the statue and direct background to describe the result. The statue average value will evenly cover all perceptual effect of surface properties, e.g. shading, shadows, highlights, etc and this will relate the variances in results more to the colour value, since all statues are identical. The average luminance value of the direct background is used in the analysis, since it is the point of interest in the model. Other lit parts is on the ground around the statue and it is almost similar in all scenes and did not change the result. We analysis the results with other values (e.g. highest luminance in the statue and the background) and it was relatively the same and did not contradict with the result from the average.
- People describe the black background with ~ 4 cd/m^2 as brighter than the gray and white background.

(a)



(b)

Figure 4.10 *Exp. 1: (a) Statue G5 against gray wall (b) A false colour image representing luminance distribution for the above image and a luminance scale is on the right.*

4.3.7 Analysis

- Against the same background and at the same luminance level, whether it is black, gray or white, the bright statues have higher average luminance value than dark statues and that was successively from white statue W9 till the black statue B1. (Figure 4.11 & Figure 4.12) On the contrary , the dark statues have more illuminance than the bright statues and that was successively from the black statue B1 till white statue W9.
- Exceptionally, the G7 statue was not consistent with the data and shows higher luminance level than the W9 statue. According to observers comments, this is probably because gray statue G7 is close to white statue W9 and observers raise the illumination to make sure it is bright gray not white. (Figure 4.11)
- When we compare the average luminance value of the same statue against different backgrounds that have the same luminance level, we found that the statue has more luminance with the black background, then less with white background, and at least with gray background. Additionally, the differences between the statue average luminance on the three backgrounds expand gradually whenever the statue become brighter. (Figure 4.11)

4.3.8 Results

In the process of choosing the preferred brightness of a statue in accordance to the brightness of the background, that vary in colour values at the same luminance level (average ~ 4 cd/m^2):

- Statue's colour value (reflectance) affects the amount of illuminance needed to illuminate a statue. Dark statues need more illuminance (lux) than bright statues, and this is respectively from Black-to-white. Otherwise, bright statues exhibits more luminance (cd/m^2) than dark statues, and this is respectively from white-to-black.
- The dark background will raise the statue's luminance level more than the brighter background.
- The change of statue average luminance value in accordance to the change of backgrounds colour value at the same luminance is larger for brighter statue than darker one.
- The colour of the statue are more influential in determining the statue luminance level than the colour value of the background.

4.3.9 Discussion

The observers demonstrate lightness constancy; since object form, shading, shadow, highlights, etc and the difference in colour value between the object and the background, all help the visual system to discount the surface illuminant to estimate surface reflectance. However, the inconsistency of statue G7 data with other statues data can be due to inability of the visual system to discount the illuminant

Nr.	Statue Tone	Direct Wall Tone	Statue luminance cd/m²				Model luminance cd/m²		
			Max Point	Statue Avg	Chest Avg	Leg Avg	Model Avg	Dirct wall Avg	Max Point
1	W9	B	611	58,90	199	27,90	1,69	3,38	159
2	W9	G	361	37,50	126	18,23	1,11	3,06	19,25
3	W9	W	488	45,80	153	21,09	1,24	3,55	18,72
4	G7	B	817	64,30	201	34,95	1,78	3,46	128,00
5	G7	G	560	48,84	149,70	27,86	1,55	4,24	30,58
6	G7	W	680	56,94	176,70	31,01	1,37	3,79	37,31
7	G5	B	931	36,60	119	19,84	2,14	4,24	44,33
8	G5	G	550	20,66	68,26	10,14	1,28	3,52	28,82
9	G5	W	616,30	22,95	76,24	11,16	1,27	3,61	32,74
10	G3	B	334	14,64	46,90	7,31	1,89	3,81	29,40
11	G3	G	306	12,64	40,82	6,17	1,52	4,24	27,20
12	G3	W	286	12,80	41,36	6,39	1,58	4,68	25,91
13	B1	B	218	3,83	17,56	0,5	1,84	3,83	27
14	B1	G	181	3,1	14,6	0,41	1,45	4,11	25,7
15	B1	W	175	3,23	15,13	0,409	1,42	4,25	20,93

Table 4.1 *Exp.1: Collected data, all values are in luminance (cd/m²).*

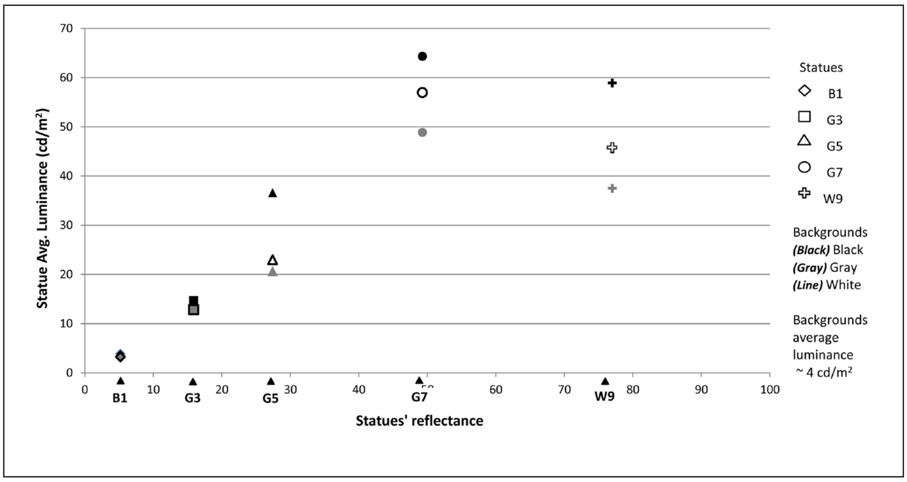


Figure 4.11 *Exp.1: The changes of the five statues' average luminance (preferred brightness) in accordance to black, gray and white backgrounds at ~4 cd/m² average luminance.*

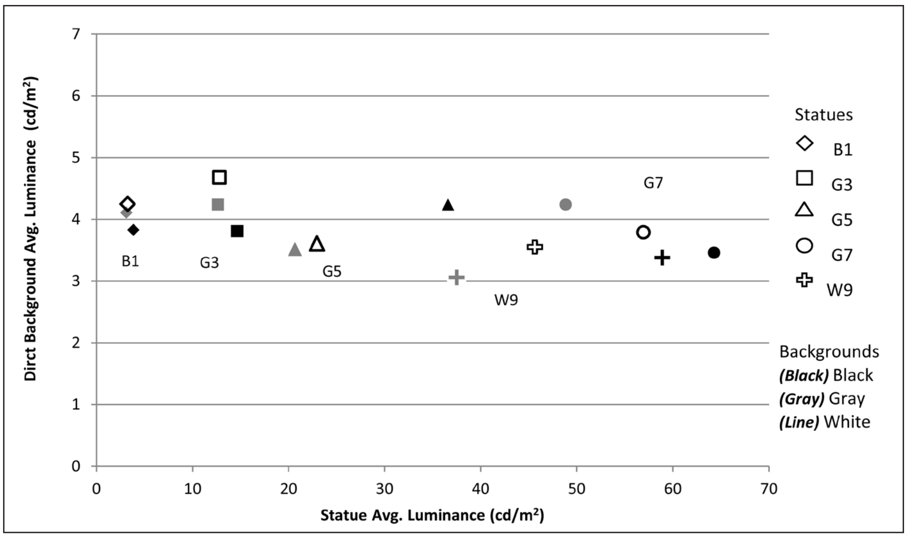


Figure 4.12 *Exp.1: The relationship between the statues' average luminance (cd/m²) and the black, gray and white backgrounds average luminance.*

to estimate surface reflectance, weather the statue is bright gray or white. As a result observer raise the illuminance level to eliminates this uncertainty.

When all backgrounds have the same luminance, the observers choose a higher luminance level for the statues against black, then white, then gray backgrounds. In addition, observers described the black background as brighter than other backgrounds. This indicates that observers' judgement of brightness depends on the assessment of light intensity (energy) incident on a surface, and this could be done perceptually by interpreting the luminance of a surface according to its apparent reflectance (colour value). The 4 cd/m2 reflected from a black surface have perceptually higher brightness evaluation than 4 cd/m2 reflected from a white surface. However, this cannot explain why the statues have higher luminance against the white background than the gray background.

The experiment data did not show any indication that simultaneous luminance contrast has an influence on statues preferred brightness. Normally under uniform illuminance white target will need more luminance against white background to enhance its visibility and less luminance against black background since its visibility is enhanced due to the strong simultaneous luminance contrast with the background; on the contrary, in our experiment white statue W9 has more luminance against black background and less against white background. And this promotes our assumption that observers' judgement of brightness depends on the assessment of light intensity (energy) incident on a surface.

In the experiment the statue and the background are differently illuminated (not uniformly) and they are at a distance from each other. These help the visual system to focus on the statue and reduce the effect of the background and surrounding. That may probably explains way the statue colour values have more influence on the observer preferred statue luminance than the background colour values; as well, why the simultaneous luminance contrast has no influence on the results.

It is important to point out that, black and dark statues depend on surface attribute like glossiness to exhibit highlight parts that create a strong contrast with its dark surface; while bright and white statues depend instead on the surface shades. Thus judgment of surface-brightness cannot be perfectly weighted with the mathematics average. However, it the best we can use for the analysis. This may explain, why the black statue B1 has almost the same average luminance with backgrounds, in particular the black background, and still visible.

4.4 EXP 2: The effect of background colour values at the same illuminance on object luminance value

4.4.1 Objective

The aim is to study the effect of different background colour value at the same illuminance on the object preferred brightness (luminance value), when the observer chose the preferred brightness of the statue in accordance to the background brightness. As well to study how the visual system will perceived the same illuminance from different background colour values.

4.4.2 Strategy

Lighting recommendation 50, 100, 200 lux for sensitivity-to-light material can be the surrounding illumination, the background walls, or the nearby object in a museum. Thus, we used these values to illuminate the model's walls and we asked the observer to raise statue illumination till he find his preferred statue brightness in accordance to the walls brightness.

4.4.3 Tools

The same like experiment 1.

4.4.4 Procedure

- First step is to illuminate the model's walls with the wall-washers and use the luxmeter to fix the illuminance level. The measurement points for the luxmeter are in the middle of every wall. In every step of the experiment walls are the same in colour value and vary in illuminance.
- Second step is to place the statue in the middle of the model and ask the observer to raise the illumination of the statue using two LED points connected in parallel, one from the front-right and the other from the back-left, till the observer reach the preferred brightness relationship between the statue and the background. (Figure 4.13-a).
- The experiment was conducted in three phase according to walls colour: black, gray, and white. In every phase walls are illuminated at 50,100 and 200 lux and statues are placed successively from white-to-black.
- The observer was only adapted to experiment's light level and the reflected light from the model on the lab's white surfaces did not exceed 10 lux.

4.4.5 Collecting the data

The same like experiment 1.

See (Figure 4.13, Table 4.2, Table 4.3 and Table 4.4)

4.4.6 Notes

- We used the statue average luminance and the model average luminance (all walls, floor, and ceiling) in analysis and diagrams.

- The luxmeter's value helps to have the same illuminance on the wall, however it does not indicate the wall average illuminance since the wall illuminance is not perfectly uniformed.
- The illuminant distribution on wall surface was relatively uniformed for the human eye. However, in some cases, particularly white walls, it reach its maximum luminance difference to ~1:5 (min : max) vertically across the walls and this is only noticeable in the luminance photo. (Figure 4.13)
- Generally, in all cases walls are similarly illuminated.

4.4.7 Analysis

- According to the change of background illuminance as a variable: statues luminance values did not have a noticeable change against black background at 50, 100, and 200 lux. On the contrary, statues luminance values altered gradually against gray and white background with the increase of background illuminance. (Figure 5.14 to Figure 4.17)
- According to the change of background colour value as a variable: statues luminance values did not change with the change of background colour value at 50 lux. On the contrary, statues luminance values change with the change of background colour value at 100 lux and 200 lux. (Figure 5.14 to Figure 4.17)
- At the same background illuminance value, the statues luminance values against gray and white background are close to each other and higher than the statues luminance values against black background. (Figure 5.14)

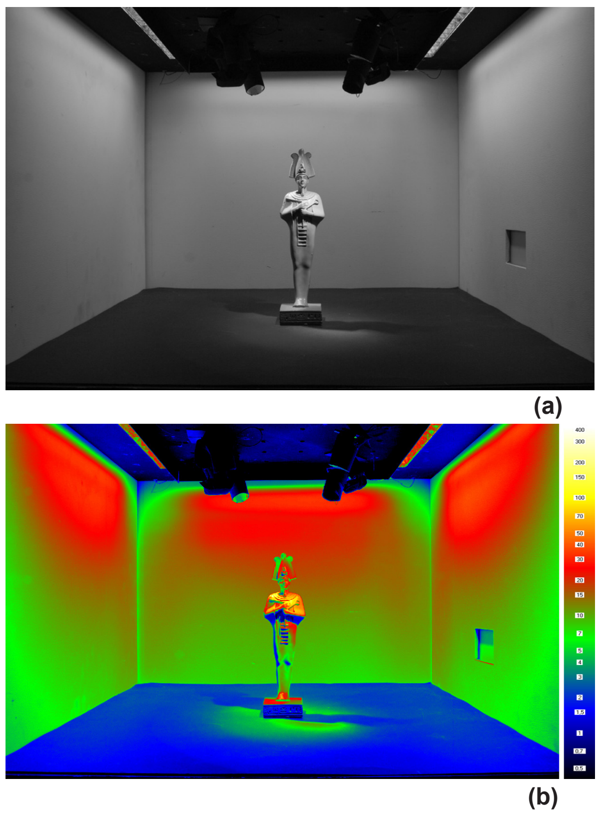


Figure 4.13 *Exp.2: (a) Statue G5 against white walls 100 lux (b) a false colour image representing luminance distribution for the above image, a luminance scale is on the right.*

4.4.8 Results

- The statues preferred average luminance values did not significantly influenced with the change of background colour value at 50 lux and with the change of illuminance between 50, 100, and 200 lux on black background.
- The increase of illuminance between 50, 100, and 200 lux on gray and white background increase the statues' preferred average luminance values.
- The statues preferred luminance values did not significantly influenced with the change in background colour value or luminance when the background average luminesce value is than ~3,5 cd\m^2 and it is influenced over this value. (Note: at 200 lux on black background recorded luminance value are : maximum model avg 3,45, direct wall avg 2,56 and max wall point 20,94 cd\m^2).
- The preferred luminance of dark tone statues are less affected with the change of background colour value and illuminance than the bright tone statues.

4.4.9 Discussion

Generally, the increase of background's illuminance or colour value influence the statues preferred luminance levels. The increase of illuminance has more influence on brighter background and the change of background colour value has more influence under higher illuminance. (Figure 5.14 and Figure 4.15)

The increase of illuminance on the black background and the change of background colour values under 50 lux did not have a significant influence statues preferred average luminance values. This may indicate that below ~3.5 cd\m^2 change in background colour value and increase in illuminance has no significant influences on object brightness.

In general, the experiment data are more consistent than data in Exp 1. First, Statue G7 did not exceed statue W9 in luminance level as in Exp 1. Second, the statues luminance values did not show a higher level against white back ground than gray background as in Exp 1. We do not have any explanation why these occurred. However, the only difference between the two experiments is that, in Exp 1 the side walls were black and not illuminated; while in Exp 2 the side walls changed in colour and were illuminated. This probably helps the observer to demonstrate better lightness constancy in Exp 2 than in Exp 1.

The gray background at 200 lux (~12,11 cd\m^2) and the white background at 100 lux (~10,66 cd\m^2) have very close luminance value, and statues against the gray background show higher luminance levels than against the white background. (Figure 5.14) This corresponds with results of Exp 1 and emphasizes that observers' judgment of brightness depends on the perceived luminance in correlation with the perceived reflectance of the same surface. This result can be simply explain with the common sense as white background under 100 lux (~10,66 cd\m2) is

Table 4.2 *Exp.2: Collected data from Phase 1, black background with 50, 100, 200 lux, all values are in luminance (cd/m²).*

Nr.	Statue Tone	Walls Tone & Lux	Statue luminance cd/m²				Model luminance cd/m²		
			Max Point	Statue Avg	Chest Avg	Leg Avg	Model Avg	Dirct wall Avg	Max Point
1	W9	B 50 lx	242,6	27,84	86,5	15,5	0,218	0,097	10,29
2	G7	B 50 lx	212,9	19,05	55,71	11,97	0,2	0,0819	11,61
3	G5	B 50 lx	187,6	12,09	42,1	6,004	0,198	0,077	13,2
4	G3	B 50 lx	117,2	7,38	23,61	3,88	0,2175	0,0829	14,4
5	B1	B 50 lx	96,69	3,04	15,6	0,328	0,236	0,08	19,84
6	W9	B 100 lx	289,2	27,7	92,85	11,98	1,057	0,6902	9,163
7	G7	B 100 lx	346,6	25,57	86,61	14,24	1,18	0,752	14,54
8	G5	B 100 lx	290	10,61	36,57	4,84	0,985	0,6283	11,71
9	G3	B 100 lx	164,2	6,687	20,89	3,67	1,013	0,642	13,27
10	B1	B 100 lx	162,9	3,026	13,23	0,366	1,174	0,733	19,31
11	W9	B 200 lx	280	27,7	88,82	14,13	3,211	2,49	13,85
12	G7	B 200 lx	288	20,51	63,96	12,15	3,09	2,411	13,51
13	G5	B 200 lx	275	18,38	64,21	8,413	3,368	2,567	19,26
14	G3	B 200 lx	263	11,64	37,76	5,72	3,451	2,63	20,87
15	B1	B 200 lx	200	3,396	15,28	0,42	3,09	2,361	20,94

Table 4.3 *Exp.2: Collected data from phase 2, gray background with 50, 100, 200 lux, all values are in luminance (cd/m²).*

Nr.	Statue Tone	Walls Tone & Lux	Statue luminance cd/m²				Model luminance cd/m²		
			Max Point	Statue Avg	Chest Avg	Leg Avg	Model Avg	Dirct wall Avg	Max Point
1	W9	G 50 lx	302	28,04	96,98	14,54	0,58	0,47	10,61
2	G7	G 50 lx	186	13,7	44,76	8,57	0,52	0,41	8,78
3	G5	G 50 lx	268,5	10,84	36,69	5,25	0,56	0,445	12,3
4	G3	G 50 lx	124	5,95	19,26	3,3	0,59	0,419	11,79
5	B1	G 50 lx	78,8	1,6	7,93	0,2	0,5	0,38	11,12
6	W9	G 100 lx	337	35,8	120	18,55	5,08	5,42	15,17
7	G7	G 100 lx	257	20,56	64,57	11,69	4,78	5,13	14,53
8	G5	G 100 lx	261,5	16,41	54,94	7,71	4,776	5,1	16,97
9	G3	G 100 lx	266	11,46	35,09	6,13	5,54	5,94	21,73
10	B1	G 100 lx	112,5	2,2	9,85	0,28	4,69	5,06	14,48
11	W9	G 200 lx	526	60,69	190,8	31,17	12,74	13,38	37,33
12	G7	G 200 lx	547	38,11	115,3	21,8	10,9	11,42	31,71
13	G5	G 200 lx	420	16,47	52,06	8	11,38	11,76	32,74
14	G3	G 200 lx	282,6	11,03	32,02	5,82	12,26	12,82	34,9
15	B1	G 200 lx	178,4	3,98	17,68	0,465	13,26	13,97	38,59

dimmed and gray background under 200 lux (~12,11 cd\m2) is bright in accordance to the dim condition of the experiment (observer adaptation).

In addition, under illuminance of 50, 100 and 200 lux the gray and white background show closer statues luminance value. Accordingly, the statues luminance values against white and gray backgrounds have closer results when the backgrounds have the same illuminance and

Nr.	Statue Tone	Walls Tone & Lux	Statue luminance cd/m²				Model luminance cd/m²		
			Max Point	Statue Avg	Chest Avg	Leg Avg	Model Avg	Dirct wall Avg	Max Point
1	W9	W 50 lx	250,8	26,52	84,14	15,32	1,88	2,1	10,22
2	G7	W 50 lx	242,5	17,51	54,37	10,09	2,06	2,27	10,09
3	G5	W 50 lx	396,9	15,48	55,67	6,94	2,1	2,339	16,65
4	G3	W 50 lx	167,3	8,49	26,15	4,5	1,91	2,07	15,49
5	B1	W 50 lx	161,5	2,8	13,35	0,37	2,13	2,32	17,7
6	W9	W 100 lx	270,9	31,78	96,11	18,07	10,34	14,41	34,33
7	G7	W 100 lx	310,5	22,21	64,09	13,23	10,28	14,3	34,35
8	G5	W 100 lx	339	17,63	58,02	8,38	10,46	14,53	34,74
9	G3	W 100 lx	248,5	10	35	5,2	11	15	34
10	B1	W 100 lx	158	3,36	12,82	0,483	11,23	15,65	37,96
11	W9	W 200 lx	500	59,48	190	29,53	32,12	43,14	99,05
12	G7	W 200 lx	562	45,3	128,9	28,01	35,25	47,72	109,9
13	G5	W 200 lx	616,5	26,16	93,91	16	35,37	47,56	110,6
14	G3	W 200 lx	471,25	12	46	8,7	34	46	107,85
15	B1	W 200 lx	326	6,83	24,36	1,054	33,38	44,96	105,1

Table 4.4 *Exp.2: Collected data from phase 3, white background with 50, 100, 200 lux, all values are in luminance (cd/m²).*

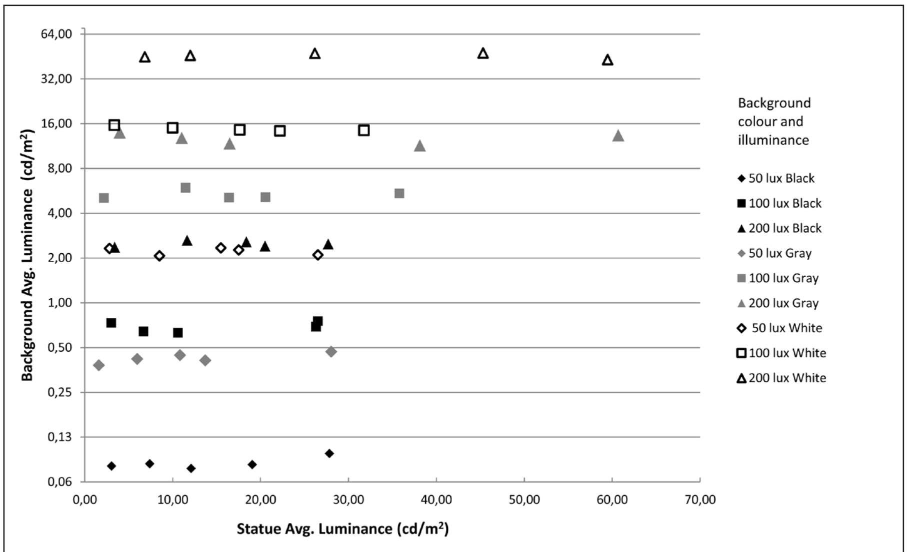


Figure 4.14 *Exp.2: The relationship between the average luminance values of the statues and the backgrounds in (cd/m²). The backgrounds are illuminated at 50, 100, 200 lux. Note: The axis of background luminance is in a logarithmic scale with base 2.*

they have different results when the backgrounds have the same luminance. Which indicate that, within the level of experiment's illumination, the illuminance values are closer to represent the visual system process of estimating the illuminant failing on background and sensing its surface-brightness more than the luminance.

Following a simple luminance ratio between the average luminance of the statue and the background shows that, the ratio is bigger for the dark and dim background than for bright and lit backgrounds. (Figure 5.14)

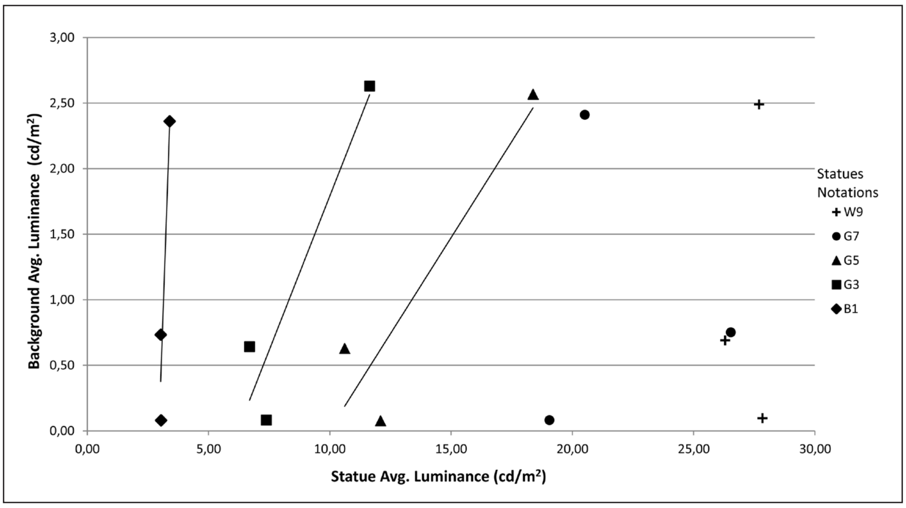


Figure 4.15 *Exp.2: Statues luminance values altered gradually against black background with the increase of background illuminance from 50 to 100, then to 200 lux.*

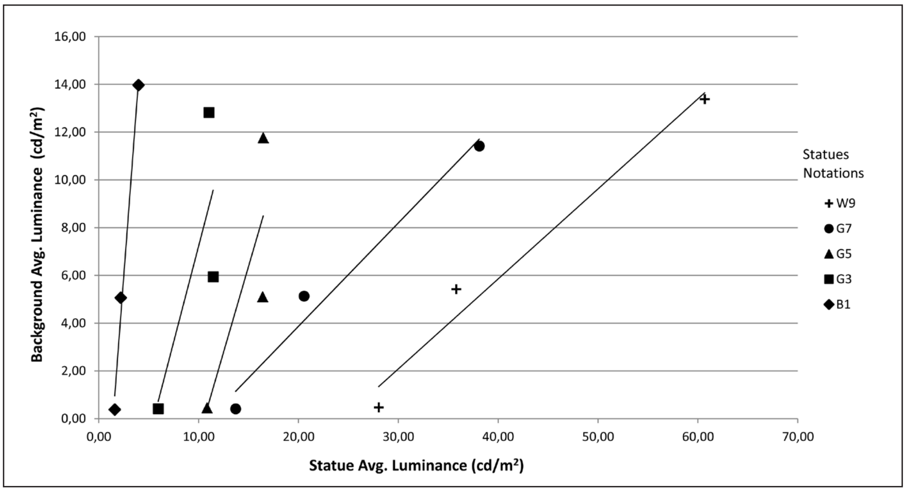


Figure 4.16 *Exp.2: Statues luminance values altered gradually against gray background with the increase of background illuminance from 50 to 100, then to 200 lux.*

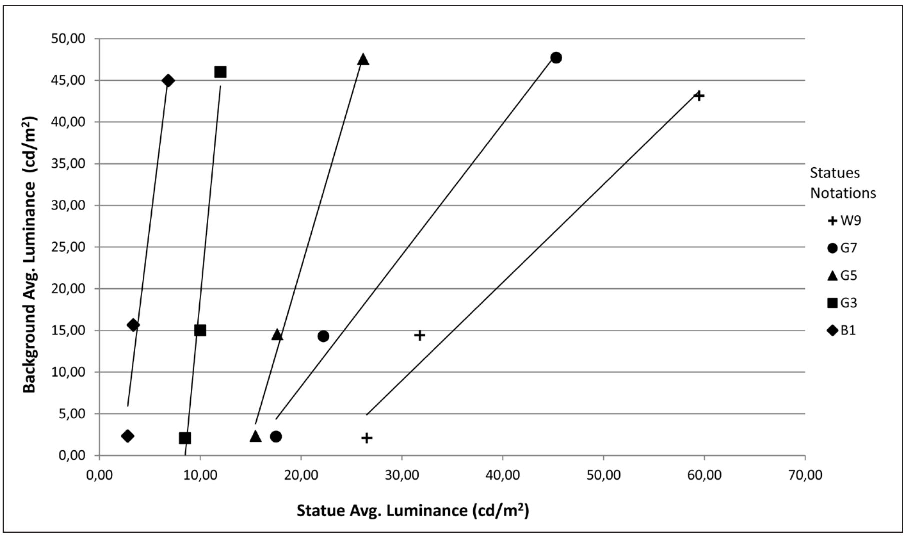


Figure 4.17 *Exp.2: Statues luminance values altered gradually against white background with the increase of background illuminance from 50 to 100, then to 200 lux.*

4.5 EXP 3: The effect of background colour values at the preferred luminance on object luminance value

4.5.1 Objective

During conducting experience 1 and 2 we realise that the observers described the black background as brighter in comparison with gray and white background, when all backgrounds have the same luminance level (~ $4cd/m^2$). As well, observers preferred less luminance from dark background and more luminance from bright backgrounds. Thus, the objective is to define the background luminance level according to observer's preferences; then to study its effect on the statue preferred brightness (luminance value).

4.5.2 Strategy

The strategy is to ask the observer to raise the walls illumination till he find his preferred walls brightness, then to ask him to define the statue brightness according to it.

4.5.3 Tools

The same like experiment 1.

4.5.4 Procedure

- First step is to let the observer illuminate the model's walls with the wall-washers till he reach a preferred backgrounds' luminance level.
- Second step is to place the statue in the middle of the model and ask the observer to raise the illumination of the statue using two LED points connected in parallel, one from the front-right and the other from the back-left, till the observer reach the preferred brightness relationship between the statue and the background. (Figure 5.18).
- The experiments was carried on from the use of dark-to-bright background and from the place of bright-to-dark statue.
- The observer was only adapted to experiment's light level and the reflected light from the model on the lab's white surfaces, did not exceed 10 lux.

4.5.5 Collecting the data

The same like experiment 1. (Figure 5.18)

4.5.6 Notes

- We used the statue average luminance and the model average luminance (all walls, floor, and ceiling) in analysis and diagram.
- The illuminant distribution on wall surface was relatively uniformed for the human eye. However, in some cases, particularly white walls, it reach its maximum luminance difference to ~1:5 (min : max) vertically across the walls and this is only noticeable in the luminance photo. (Figure 5.18)

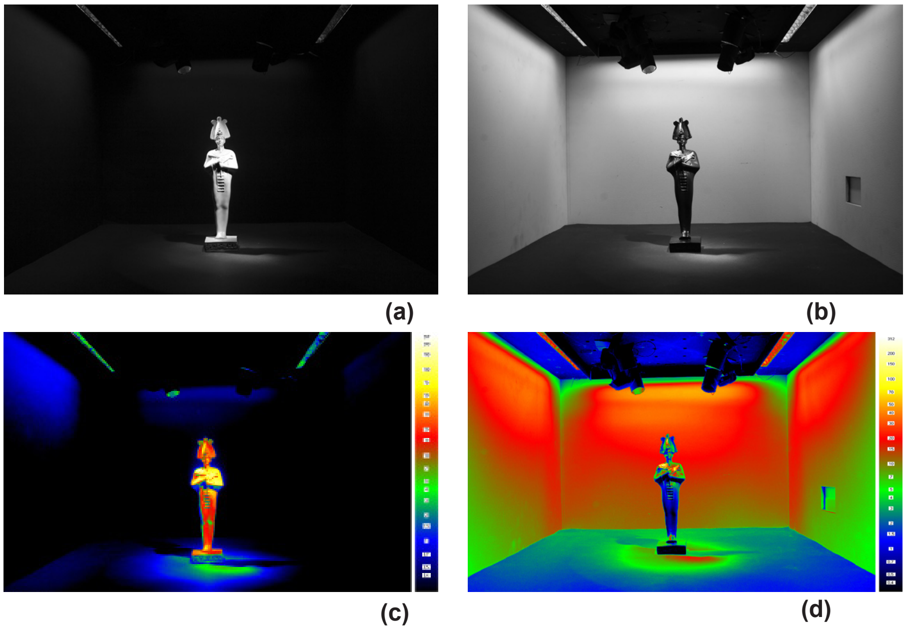


Figure 5.18 *Exp.3: (a) Statue W9 against black walls (b) Statue B1 against white walls (c) & (d) a false colour image representing luminance distribution for the above images, a luminance scale is on the right.*

4.5.7 Analysis

- The chosen illuminance level was less for dark backgrounds than bright backgrounds. The model average luminances were (black ~ 0.24 cd\m^2, gray ~ 4 cd\m^2, and white ~11.84 cd\m^2). If we calculate the average illuminance from these values we will have approximately (black ~18.84 lux, gray ~ 47.78 lux, and white ~ 43.76 lux). Additionally, Direct wall average luminances were (black ~ 0.13 cd\m^2, gray ~ 5.29 cd\m^2, and white ~19.12 cd\m^2). If we calculate the average illuminance from these values we will have approximately (black ~10.71 lux, gray ~ 63.19 lux, and white ~70.66 lux).[1]
- Generally, statues have the same result as in experience 1 and 2. Dark statues needs more illuminance than bright statues.

4.5.8 Results

- Dark statues is preferred with more illuminance than bright statues, while dark backgrounds in preferred with less illuminance then bright background.
- In a dark room or low illuminated room; as in a museum conservation gallery; walls, backgrounds, and showcases walls will be comfortable with average luminance of (~ 0.24 cd\m^2 on black, ~ 4 cd\m^2 on gray and ~11.84 cd\m^2 on white) and uniformity not less than 1:5 (min:max).
- The table and diagram (Table 4.5 and Figure 4.19) can be used to define statues and backgrounds luminance levels in conservation gallery. However, the statues illuminance values are higher than the recommended illuminance for museum's sensitivity-to-light materials, which indicate the limitation of standards and norms.

1. Note: We used the equation $E=(L \cdot \pi) / \rho$ to calculate average illuminance from the average luminance. The equation is only precise for perfect diffuse surface. However, it is applicable in practice with non-specular surfaces and it is helpful to imagine and to approximate the illuminance value in our case.

Nr.	Statue Tone	Walls Tone	Statue luminance cd/m²				Model luminance cd/m²		
			Max Point	Statue Avg	Chest Avg	Leg Avg	Model Avg	Dirct wall Avg	Max Point
1	W9	B	206,3	21,19	71,56	11,6	0,21	0,149	8,23
2	G7	B	303,75	23,92	76,92	13,86	0,25	0,152	14,29
3	G5	B	261,85	15,47	53,1	7,84	0,26	0,132	17,56
4	G3	B	143,3	8,18	27,03	4,52	0,255	0,121	16,42
5	B1	B	83,84	2,23	11,34	0,249	0,235	0,108	14,54
6	W9	G	429	45,38	150,5	25	4,4	5,81	18,08
7	G7	G	411	24,64	75,1	15,04	3,82	5,03	15,14
8	G5	G	555,4	18,64	65,05	8,42	3,84	5,06	19,59
9	G3	G	230,9	9,84	30,19	5,269	3,93	5,17	18,82
10	B1	G	195,3	3,83	18,94	0,44	4,11	5,4	22,91
11	W9	W	619,95	64,48	218,7	29,55	12,54	20,14	51,65
12	G7	W	504,8	36,8	111	21,19	11,73	18,89	49,07
13	G5	W	537,5	19,22	65,43	8,44	11,15	18,01	46,98
14	G3	W	317	13,86	43,32	6,59	12,26	19,83	51,89
15	B1	W	252,1	4,72	21,54	0,56	11,525	18,73	49,05

Table 4.5 *Exp.3: Collected data, all values are in luminance (cd/m²).*

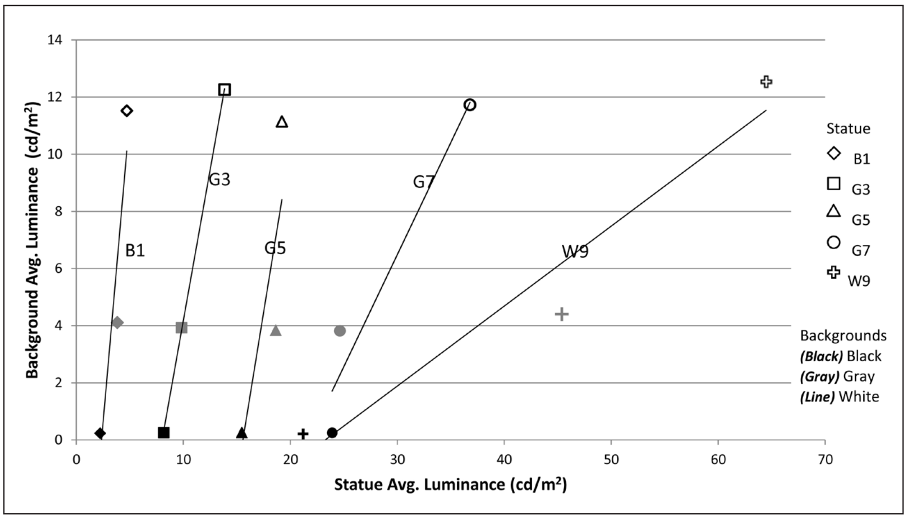


Figure 4.19 *Exp.3: The relationship between the average luminance (cd/m²) of the statues and the backgrounds. Note: the data represent the statues average luminance values against three different backgrounds and every background is illuminated with its preferred illuminance.*

4.5.9 Discussion

The observers choose more illuminance for the black statue than the white one and choose less illuminance for the black background then the bright one, this can be due to the difference between zones of the visual field. In our experiment the statue is detected with the precise, focussing, central, foveal vision/field (~1-to-2° solid angle); where optimal sharpness and colour vision is guaranteed.(1) Thus, more light is desirable. The model (background) is detected within (~20° solid angle) that surrounds the foveal field. The brightness of the field surrounding and accompanying the foveal field is determinative of the

1. Christian Bartenbach & Walter Witting, Handbuch für Lichtgestaltung, Lichttechnische und wahrnehmungspsychologische Grundlagen, Springer-Verlag/Wien 2009, p225.)

local adaptation of the eye; and it is responsible for the perception of contrast.[1] Thus, the background brightness have an influences on the statue brightness. Additional difference between the central and non-central vision is that, the more the object is viewed in the centre of the visual field, the more clearly it will be recognized, as well its colours. The further the object moves to the periphery of the visual field, and is thus further depicted at the edge of the retina, the more blurred and colourless it is perceived.[2] Thus, most probably, the statue is preferred with more light then the background.

4.6 EXP 4: Defining the lowest acceptable statue illuminance and its compatible direct surrounding

4.6.1 Objective

During conducting experience 3 we realise that, when the observers define the preferred statues luminance levels according to background colour values , the lowest statue average illuminance was about 100 lux. It was recorded for the white statue against a black background. This indicate that, values lowest than 100 lux cannot stabilize a comfortable visual perception within the experimental condition, which is similar to a museum showcase in dark or dim-light gallery. Our objective is to define the lowest sufficient illuminance for the experimental statues in dark or dim room with less than 10 lux. As well, to find the best surrounding configuration that can enhance this law illuminance level.

4.6.2 Strategy

The strategy is to start illuminating the statue with 50 lux in a dark and dim surrounding, change background configuration and luminance level to enhance the observer visual condition, and raise statue luminance level if needed till we reach the lowest acceptable level of statue illuminance. We start with 50 lux because it is the minimum illuminance value for sensitivity-to-light material in IESNA recommendation

4.6.3 Tools

The same like experiment 1.

4.6.4 Procedure

- First step is to place the statue in the middle of the model and illuminate it with 50 lux using the LED points connected in parallel, one from the front-right and the other from the back-left.
- Second step is to change the model configuration: walls colour value, floor colour value, background luminance, and source of light, till we reach the preferred condition according to observers.
- The experiments was carried on from the use of dark-to-bright background and from the place of bright-to-dark statue.

1. Previous refrence p225.
2. Previous refrence p101.

- The observer was only adapted to experiment's light level and the reflected light from the model on the lab's white surfaces, did not exceed 10 lux.

4.6.5 Collecting the data

The same like experiment 1.

4.6.6 Notes

- The illuminance values were measured horizontally at statue's shoulder level.
- Photos cannot express perception of light in the reality but they give an insight about real situation.
- The presented steps did not cover all possibilities. However, it is enough to reach experiment's gales.

4.6.7 Analysis

For every analysis step we recorded the luminance values in the table (Table 4.6) and a HDR photo in figure (Figure 4.20).

a. White statue and black surrounding: The experiment starts with the white statue W9 illuminated with 50 lux. The model's walls, floor and ceiling are black. The 50 lux was acceptable; however observers were not completely satisfied.

b. Changing floor colour value to white: The reflected light from the white floor enhanced the luminance of statue lower part (legs). The differences in colour value between the walls and the floor was clearly visible, this helps perceiving the dimension of the floor and space geometry in low illuminance level.

c. Changing walls' colour value to white: Model's white floor and walls alter the internal reflection between model surfaces, thus enhance the statue luminance and perception of model geometry. On the other hand, the white walls relatively decrease the simultaneous contrast between the statue and the surrounding and the internal reflection increase statue illuminance value to about ~70 lux.

d. Changing walls colour value to gray: Model's gray walls enhanced the simultaneous contrast between the statue and the walls. The statue average luminance did not have a noticeable change.

e. Changing floor colour value to gray: Model's gray walls and floor increase the simultaneous contrast between the statue and the surrounding. However, it decreases the internal reflection in the model and diminishes the perception of model geometry.

f. Changing light source: instead of the LED points we used the fiber optics as a general illumination. The fiber optics appears as a grid of spotlights in the model ceiling. They are directed only downward to the floor and the light did not hit the wall. Illuminance level is 50 lux as previous steps. Changing the light source enhance the previous situation configuration (step e). It creates differences between the floor and the walls luminance, thus helps perceiving the model geometry. On the other hand, it decrease statue luminance and changes the modelling of highlights, shade, and shadow of the statue.

g. Using a white floor with the previous configuration (step f): The luminance of the white floor is relatively high in comparison with the whole scene. Floor luminance catches eye attention and disturbs the vision of the statue. The luminance of statue lower part is increased and shades in this part are softened or erased. In general, statue average luminance is decreased in step (f) and (g).

In the seven previous steps (a-to-g) we tried to change the configuration of the surrounding and the source of light to get the most benefit of 50 lux illuminance to light and enhance the perception of white statue W9. Among these steps step (d) then step (f) was the most preferred from observers.

By repeating step (d) and step (f) with the rest of experimental statues we found that Statue G7 was acceptable with ~50 lux but preferred with ~100 lux, Statue G5 preferred with ~100 lux, and statue G3 and B1 was preferred with ~150 lux. These were the lowest preferred illuminance level.

h. A dark-gray statue G3 in a model with gray walls, white floor and general ceiling light. Configuration and illuminance are similar to previous step (g). The simultaneous contrast between the statue and the surrounding is relatively low.

i. A dark-gray statue G3 in a model with gray walls, gray floor and 150 lux illuminance from the four LED points and the general illumination. Using both spot light and general illumination is a common technique used in most museum galleries, it helps controlling the illumination. There is enough simultaneous contrast between the statue and the surrounding. Floor's luminance is higher than the walls' luminance which helps perceiving the geometry of the model. More LED points show better result with dark and black statue, because dark statue surface depends on highlights more than shades in rendering the topology and details of the surface.

j. Pervious situation (step i) with extra bright-gray base G7. The base add fill light to the statue shades, increase model internal reflection and create more variety of colour values in the scene.

k. Previous situation (step j) with a white statue W9. The white statue needed lowest Luminance level than the dark-gray statue G3. (Note: A faller in possessing Luminance image, thus luminance level for this step was not reported).

l. A black statue B1 with a white base and the same previous configuration (step j). The base added white shades on the statue lower parts. However, the high luminance of the base demoted the luminance of the statue. The statue has relatively low simultaneous contrast with the walls. (Compare figure Figure 4.20-l with figure Figure 5.18-b).

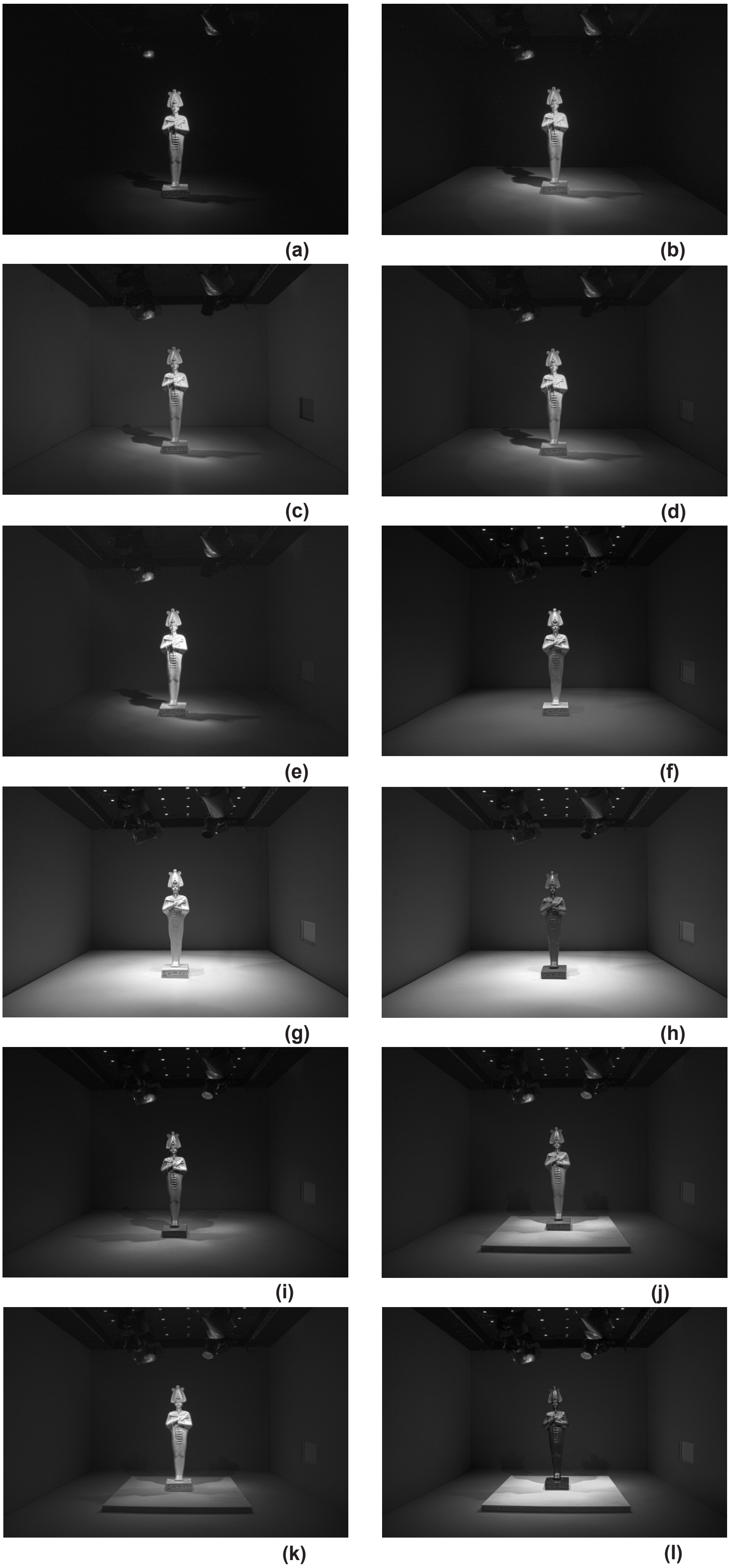


Figure 4.20 *Exp.4: Analysis steps' with HDR photos showing the visual perception improvement of the statue an surrounding under low illuminance by the change of surrounding configuration. Steps illuminance level: (a-h) 50 lux (i-l) 150 lux. Values were measured at statue's shoulder level.*

Nr.	Statue Tone	Walls, Floor, Base Tone	LED Point	G. Light	Statue luminance cd/m^2				Model luminance cd/m^2		
					Max Point	Statue Avg	Chest Avg	Leg Avg	Model Avg	Dirct wall Avg	Max Point
a	W9	B, B	2	-	20,02	3,7	12,67	1,37	0,014	0,016	8,85
b	W9	B, W	2	-	22,94	3,75	12,31	2,42	0,09	0,015	8,75
c	W9	W, W	2	-	28	4,11	13,38	2,6	0,24	0,19	8,28
d	W9	G, W	2	-	27,45	3,96	13,31	2,42	0,12	0,045	9,6
e	W9	G, G	2	-	23,11	3,52	12,05	2,02	0,05	0,026	8,56
f	W9	G, G	-	ON	8,9	1,55	3,64	0,95	0,16	0,04	18,04
g	W9	G, W	-	ON	8,6	1,9	3,37	1,4	0,53	0,13	21,77
h	G3	G, W	-	ON	0,02	0,4	0,64	0,24	0,5	0,12	14,82
i	G3	G, G	4	ON	26,19	2,37	7,31	1,16	0,34	0,11	20,37
j	G3	G, G, G7	4	ON	17,6	2,08	4,68	1,83	0,45	0,138	24,9
l	B1	G, G, W	4	ON	18,89	0,93	1,89	0,22	0,69	0,18	20,25

Table 4.6 *Exp.4: Collected data, all values are in luminance (cd/m^2).*

4.6.8 Results

- The darker the statue the more illuminance needed, and vice versa. In a dark surrounding with less than 10 lux, the lowest levels of illuminance needed to illuminate a set of statues ranged from white-to-black are gradually range from 50-to-150 lux.
- Configuration of the surrounding has a big role to support the visual system especially in lowest illuminance levels.

Within the experience diminution we find that:

- Middle-gray walls with a white or bright-gray floor give a good result in general. However, black and dark statues need bright walls.
- Black and dark statues need more spots than white and bright statue to enhance surface shades and details.
- Differences in colour value or in luminance value between the floor and the walls help perceiving the space geometry.
- A base with a different colour value can be helpful to enhance the luminance of the statue's lower part, raise the model internal reflection and give variety in scene's colour value.
- Angled spots were more preferred then general light. However mixing both give a better results.

4.6.9 Discussion

The experiment shows the possibility of enhance target's perceived information by changing the surrounding configuration and without any noticeable change in target luminance. The average luminance between the first five steps (a-to-e) are almost the same, however altering the surrounding configuration associated with small differences in surrounding's average luminance create great change in the perceived information, that enhance the perception of the target and the surrounding. It is more about the qualitative then the quantitative of the luminance image.

Differences in colour value and luminance value convey different information to the visual system and a combination of both enrich the visual information, thus stabilize visual perception.

The experiment is more applicable for showcases in dark or dim museum spaces and it gives a good insight about general spaces.

4.7 EXP 5: Defining Illuminance for exhibits in bright surrounding

4.7.1 Objective

The previous experiments were conducted in a dim room with less than 10 lux, thus statues luminances were limited. According to the IESNA recommendation no-sensitivity-to-light exhibits can reach up to 1000 lux for observer age of 25-to-65. Our objective is to define and study the illumination levels for no-sensitivity-to-light exhibits with different colour value in a bright surrounding similar to daylight museum gallery.

Additionally, daylight enter a museum space from a daylight system or an architecture aperture is mostly diffuse and a supplementary source of electric light well be helpful to enhance the exhibit appearance and details and to control the fluctuation in daylight levels during the course of the day and year. Our objective is to study the proportion of general diffuse light to the direct accent light.

4.7.2 Strategy

In a daylight museum gallery the strategy always is to find a general illumination for all set of exhibits and to support it with a supplementary electrical light source. As well, to find a main background colour value to create a sufficient simultaneous contrast with most of exhibits and to change it only when needed. Accordingly, we simulate the exhibits in a daylight gallery as follow: We installed a set of different sculpture types with different colour value and glossiness on a painted wood boards. The painted wood boards represent the direct wall colour value. We conducted the experiment in the artificial sky of Bartenbach Light Laboratory, so we can use different surrounding luminance levels and different direct light intensity and angel. The hemisphere form of the artificial sky represent a bright daylight gallery space. (Figure 4.21)

4.7.3 Tools

- Relief replica: 4 pieces size 23 x 23 cm from polyester. Samples colour and LRV values as follow: W9 (white 0.77), W7 (bright-gray 0.493), W3 (dark-gray 0.159) and B1 (black 0.052). All four pieces are fixed on 80 x 80 cm wood board painted with G5 (middle-gray 0.274). (Figure 4.22)
- Head statue replica: 4 pieces size 15 cm from limestone. Samples colour and LRV values as follow: Bm (black-matt ~ 0.052) , Wm (white-matt ~ 0.77), Bg (black-gloss) and (Wg white-gloss). Last two samples have the same white and black value but with glossiness. All four pieces are fixed on 60 x 60 cm wood board painted with G5 (middle-gray 0.274). (Figure 4.23)

- Artificial Sky: The Artificial Sky at Bartenbach GmbH[(1)] is a sky simulator has a half-dome space with about 6 meters diameter and it is raised at 1,10 m from the ground on metal supports. The half-dome inner surface is from a plastic membrane, that is back-lit with mini size fluorescent tube. The membrane brightness is adjusted to create different luminance distribution to simulate standard sky conditions. We adjusted the half-dome brightness to create different surrounding luminance levels, and we used the artificial sun (a set of LEDs with narrow beam lenses) to control the direct light intensity and angle. During the experiment we used the overcast-sky mode in the artificial sky, which means that the half-dome luminance distribution ratio is 3:1 zenith-to-horizon. As well, we sometimes close the lower part of the hemisphere to have more light from above, since most of museum galleries are lit from ceiling. The sun of the artificial sky (direct light) was adjusted in position 45° horizontal and 30° vertical. (Figure 4.21)

4.7.4 Procedure

Our experiment has two phases: one with the 4 relief replica and the other is the same steps repeated with the 4 head statues replica.

In the first phase:

- First step is to place the wood board with the 4 relief replica in the middle of the artificial sky and adjust the vertical illuminance level on the board to ~ 200 lux, to be 50% from the surrounding and 50% from the direct light. (Figure 4.22)
- Second step is to change the ratio between the surrounding light and the direct light till the ratio is preferred from the observer.
- The experiment first step started with ~200 lux and we raised the starting point for every subsequent step ~100 lux.
- The observer was adapted to artificial sky luminance level and freely focused on the experiment samples. Distance between the observer and the samples was about 2.25 m.

Second phase: is a repetition of last steps with the 4 head statues replica.

4.7.5 Collecting the data

The data were collected by using a luminance camera as in previous experiences. Our interest was to record the following average luminance level from the luminance image: The whole samples and board (Object avg and max L cd/m^2), The samples individually (Statues avg L cd/m^2) , Direct background (direct board), the direct lower part of the artificial sky (direct A. Sky wall) , the floor behind the scene from the appeared floor part on luminance photo (floor). In addition, we measured the vertical illuminance falling at a middle point between the samples (E_V Object), and we measured both the direct and the surrounding illuminance compound separately (E_V Object direct/diffuse). (Table 4.7)

1. Bartenbach GmbH, Innsbruck, Austria, with permission.

4.7.6 Notes

- Photos cannot express perception of light in the reality but they give an insight about real situation. Thus, we listed in the analysis observer 's opinion with every step.
- Among the collected data we presented only the important data: The start point, the preferred level and the maximum level.

4.7.7 Analysis

Phase 1: Relief replica.

a. First step started with 221 lux (43 lux direct light and 178 lux general diffuse light from the surrounding, ratio 1: 4.13). Statue W9 and G7 appearances were acceptable, while G3 and B1 needs more light.

b. At 385 lux (73 : 312 lux direct-to-diffuse, ratio 1: 4.27). Generally all relief replica looks better. The increased luminance of the surrounding enhance the dark and black statue G3 and B1.

c. At 612 lux (166 : 446 direct-to-diffuse lux, ratio 1: 2.68). The appearance of the reliefs replica were better than last steps. However, the luminance of the direct lower part of the artificial sky was annoying to some extent (direct A. Sky wall avg 70.5 cd/m^2). (Figure 4.24)

d. We decrease the luminance of the direct lower part average to 25.64 cd/m^2, this was at 548 lux (100 : 448 direct-to-diffuse, ratio 1: 4.48). It was much better. And it was the most acceptable among previous steps. However, the bright reflection from the lower surrounding on the black relief B1 was diminished.

e. We reached the last acceptable illuminance level at 909 lux (185 : 724 direct-to-diffuse, ratio 1: 3.91). However, the luminance of the direct lower part of the artificial sky need to be decreased.

Phase 2: Head statues replica.

Through the same steps in phase 1 we fond that: The formed 3D objects of the head statues appear better in less illuminance than the flat relief and its appearance was acceptable at 385 lux up to 800 lux. Illuminance at 909 lux was to much for the white matt and glance statues. (Figure 4.25)

We made an extra step to used a colour paper horizontally as floor in front of the wood board to show the effect of the coloured surrounding on the appearance of experiment samples. (Figure 4.26)

4.7.8 Results

In most cases, direct light is generated when light comes directly from light source that is relatively smaller than the illuminated object and / or its intensity is greater then any other source in the scene. Direct light is associated with strong shades and shadows. While diffuse light is generated when light comes evenly from different direction from light sources, from surrounding surfaces as a reflection, or from an even soft source far large in comparison with illuminated object. Diffuse light is

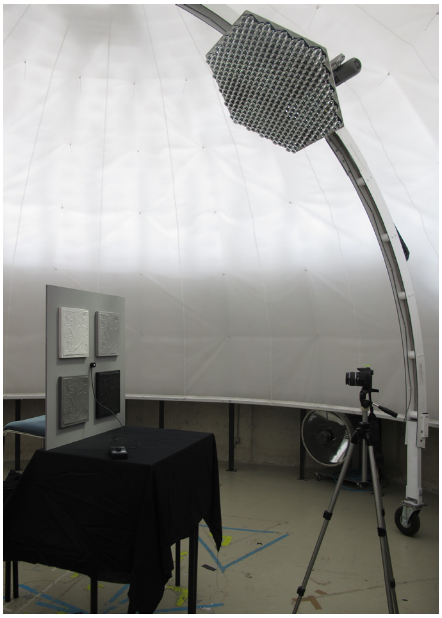


Figure 4.21 Left side .Exp.5: While conducting the experiment in the artificial sky in Bartenbach Light Laboratory.

Figure 4.22 *Right above. Exp.5: Relief replica: 4 pieces size 23 x 23 cm from polyester.*

Figure 4.23 *Right down. Exp.5: Head statue replica: 4 pieces size 15 cm from limestone.*

Table 4.7 *Exp.5: Collected data, values are in luminance, L (cd/m²) and illuminance, E (lux).*

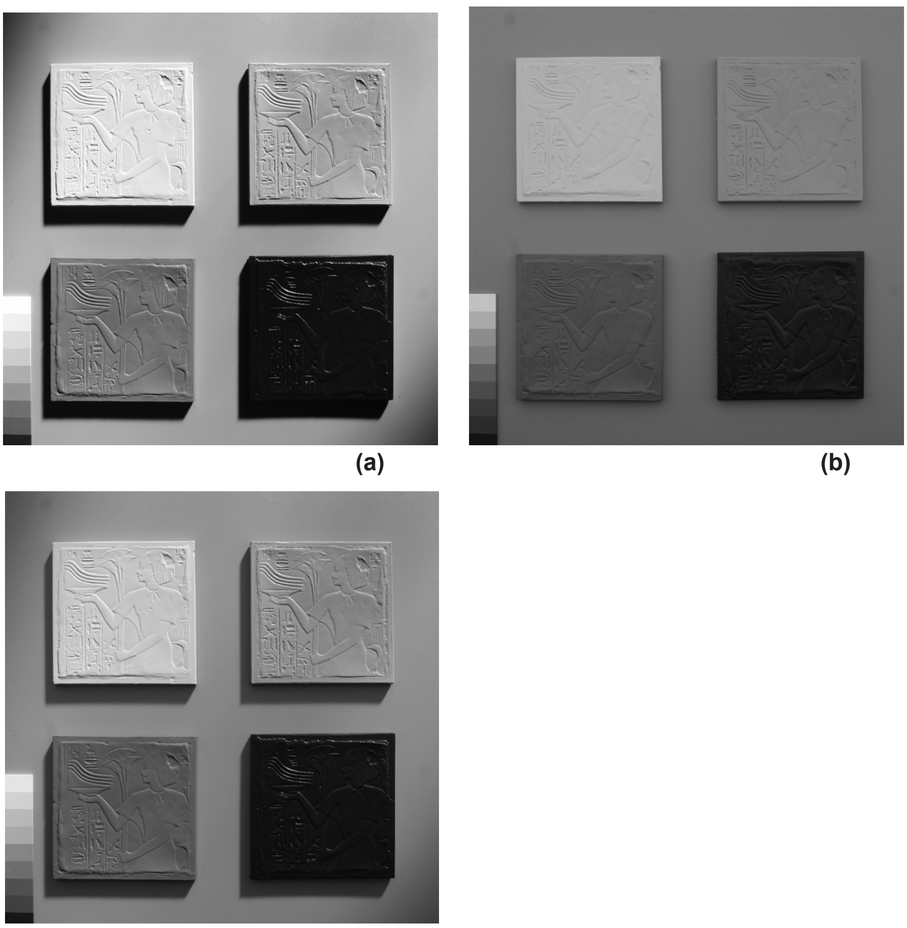
Nr.	E_v Object	E_v Object direct/ diffuse	Object avg L cd/m²		Statues avg L cd/m²				Back ground avg L cd/m²		
			avg	max	W9	G7	G3	B1	Dirct Board	Dirct A. Sky wall	Floor
	• **Phase 1: Relief replica**										
a	221	1 : 4,13	12,44	94,2	28,27	14,25	7,15	1,05	16,8	6,81	1,43
b	385	1 : 4,27	20,2	155,9	47,68	23,17	11,49	1,67	26,87	15,65	2,07
c	612	1 : 2,68	33,81	237,7	78,73	39,1	19,53	3,55	43	70,5	3,78
d	548	1 : 4,48	25,71	205,6	61,09	29,51	14,64	2,1	33,71	25,64	2,41
e	909	1 : 3,91	44,57	331,7	105,3	51,24	25,77	4,47	56,41	74,46	4,75
	• **Phase 2: Head statues replica**										
					Bm	Bg	Wm	Wg			
a	221	1 : 4,13	14,91	449	3,67	3,96	41,81	46,2	14,46	6,1	1,77
b	385	1 : 4,27	21,89	711	5,35	5,89	61,17	65,4	21,36	9,4	2,35
c	612	1 : 2,68	38	1421	9,13	10,59	107	112	37,3	61,06	4,73
d	548	1 : 4,48	35,55	1129	8,57	9,4	97,7	103	34,92	15,11	3,54
e	909	1 : 3,91	63,89	2259	15,23	17,33	178	185	62,83	87	7,45

associated with soft, hazy or unclear shades and shadows. Both Direct and diffuse light are important to render three dimensional forms. Direct light is responsible to create highlights, shades and shadow. While, diffuse light creates soft luminance gradation and it fills shades and shadow with light to show details in them.

According to experiment:

- Highlights and an reflection appear clearly on dark and glossy objects. On the contrary, shades and shadows appear clearly on bright and matt objects. Thus, a good use of bright surrounding or multiple sources of light enhance dark and glossy objects. While, light from clearly defined direction will create better shades and shadows for bright objects. (Figure 4.25)

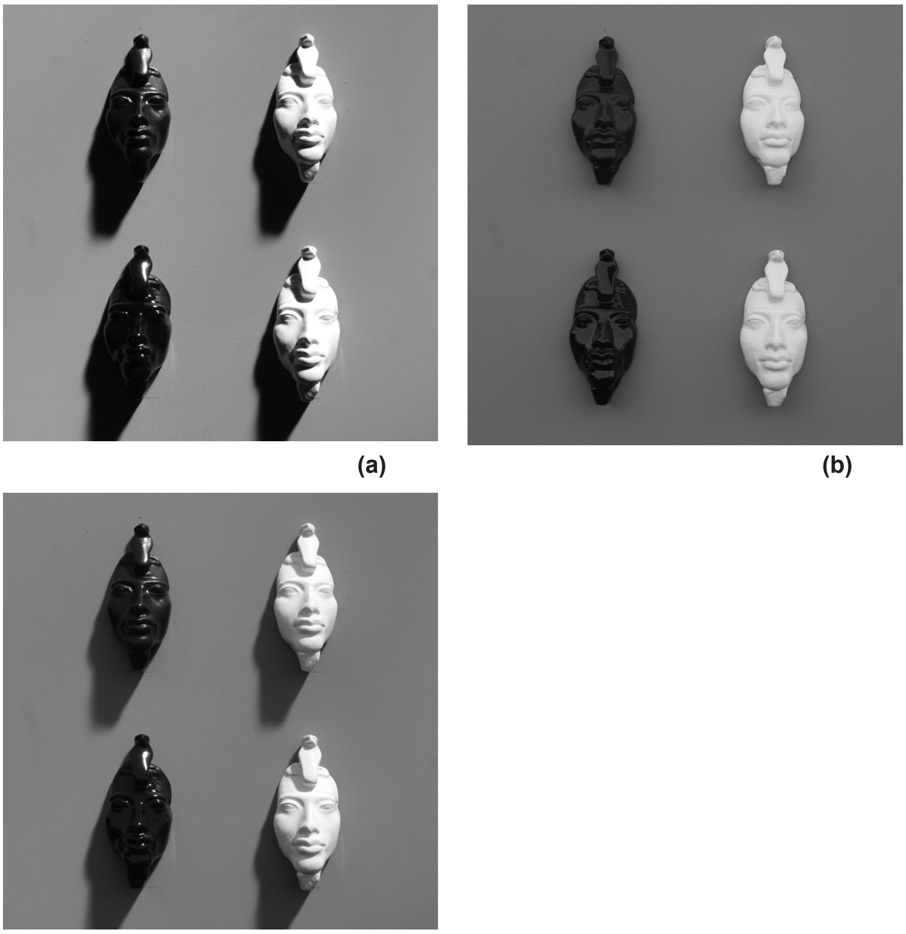
- Reflected light from coloured surrounding fill in shadows, fill in shades of bright objects more than dark objects, and appear in the reflection of dark objects according to angle of sight. (Figure 4.26)
- Generally, Dark sculpture relief or round needs more illuminance than bright one. In precise, relief sculpture tolerate more illuminance than round sculpture.
- Direct light is important for relief sculpture to render surface details, while round sculpture can be rendered in diffuse light with less direct component. (Figure 4.24-b and Figure 4.25 -b)
- Within experiment condition, a set of Relief sculptures with different colour value tolerate illuminance range from 548 to 909 lux and a set of black and white sculpture heads with matt and glossy surfaces tolerate illuminance range from 385 to 800 lux. Bearing in mind, to reach optimum enhancement dark statue needs to have more illuminance and different configuration than bright statues.
- It is difficult to unified illuminance level and surrounding configuration for a set of statues with a wide range of colour value or different surface glossiness. However, according to our experiment condition, an illuminance ranged between 550 to 800 lux, a middle-gray direct background with LRV 0.263, and a surrounding with not more than 35 cd/m2 luminance will be a good general recommendation for a bright museum gallery.



(a) (b) (c)

Figure 4.24 *Exp.5: Phase 1, Relief replica, step c. The difference in appearance between (a) Direct light (b) Diffuse light (c) Both direct and diffuse light.*

- According to experiment configuration preferred illuminance ratio between direct and diffuse light is about 1:4.20. In a daylight museum gallery it can present the illuminance ratio between daylight system and supplementary artificial light.



(a) (b) (c)

Figure 4.25 *Exp.5: Phase 2, Head statue replica, step c. The difference in appearance between (a) Direct light (b) Diffuse light (c) Both direct and diffuse light.*

(a) (b)

Figure 4.26 *Exp.5: Phase 2, Extra step. The effect of reflected light (direct with diffuse) from a horizontal surface on experiment samples (a) Pale yellow paper (b) red paper. Compare differences with figure 3.28-c.*

4.7.9 Discussion

The experience gives a good insight about illuminance and luminance levels in daylight museum space. In case of applying the result to reality, we have to keep in mind that the differences in space configuration between our experience and reality may require some adjustment.

4.8 Experiments general results.

In the previous experiments we studied and record the illumination levels of a set of artefact and backgrounds with different colour values, when the observer choose the preferred brightness between the artefacts and the background, within a condition similar to a museum display. The data are meant to be use as a guideline in museum practice and to study the effect of object and background colour values on preferred illumination levels.

4.8.1 Values for practice

We conducted five experiments. The first four experiments are conducted in a physical model that simulates a museum showcase or a gallery where sensitive-to-light material are displayed. The experiments are conducted in a dark room where maximum illuminance is ~10 lux on a white walls. The fifth experiment simulate a daylight museum where no-sensitive-to-light artefacts are exhibits. Experiments results and details can be used as a guideline for practice and it can be obtained from experiments tables and diagrams.

The experimental five natural gray tones were applied to statues samples are denoted and organized from black-to-white with its LRVs as following: B1 (5.2), G3 (15.9), G5 (27.4), G7 (49.3),W9 (0.77); and for background: Black (4.0), Gray (26.3), White (85).

The white, gray and black background at the same average luminance value have different influence on statues average luminance levels (preferred brightness). (Experiment 1, Figure 4.11).

The gradual increase of background illuminance level and the change in background colour value from black to white, gradually increase the statues luminance values (preferred brightness). However, backgrounds with average luminance equal or less than ~3,5 cd\m^2 have no significant effect. (Experiment 2, Figure 5.14)

In a dark room where maximum illuminance is ~10 lux on a white walls, the comfortable average luminances for show case backgrounds are (~0.24 cd\m^2 on black, ~4 cd\m^2 on gray and ~11.84 cd\m^2 on white) and luminance uniformity is not less than 1:5 (min:max). For the statues average luminance values according to this backgrounds see (experiment 3, Table 4.5 and Figure 4.19).

In a dark room where maximum illuminance is ~10 lux on a white walls, the lowest levels of illuminance needed to illuminate a set of statues ranged from white-to-black are gradually range from 50-to-150 lux, and this value has to be supported with a suitable surrounding configuration to raise artefacts visibility. (Experiment 4, Table 4.6 and Figure 4.20)

A good general recommendation for a bright museum gallery: is illuminance ranged between 550 to 800 lux, a middle-gray direct background with LRV 26.3, and a surrounding with not more than 35 cd/m^2 luminance. Bearing in mind, to reach optimum enhancement: dark statue needs to have more illuminance and different configuration than bright statues; both direct and diffuse light has to be in use and the preferred illuminance ratio is 1:4.2 (direct : diffuse). Additionally, illuminance uniformity over area of coverage according to IES has to be not less than 2:1 (avg:min) and 4:1 (max:min). (Experiment 5, Table 4.7 and Figure 4.21 ot Figure 4.26).

4.8.2 The effect of colour values on illumination levels.

Planning light for a museum involves not only the comfortable levels of illumination but as well it takes into account the preferred brightness of the exhibits with the background and surrounding. A necessary requirement to understand the exhibit preferred brightness is to know how colour value and surface attribute of exhibits, background and surrounding are interrelated to illumination levels.

According to the first four experiments condition:

- The colour value and its preferred brightness depend on the location of the perceived area, is it perceived as a target (statue in focus) or as a background, and the adaptation state (mainly the surrounding illumination condition). Generally, whatever the colour value of the statue and the background are the statue needs higher illuminance than the background; whereas the background may have more luminance than the statue this depends on the colour value of the statue and the background. Further, the dark statue needs higher illuminance than bright statue and it generate less luminance. On the contrary, the dark backgrounds are preferred with less illuminance, while the bright background is relatively preferred with more illuminance; thus the bright background preferred always with more luminance.
- For statue and direct background relationship: Generally, the more luminance on the background the more luminance we need on the statue. However, if dark and bright backgrounds (e.g. white and black) have the same luminance value the statue's preferred average luminance (brightness) will be more against the dark background.
- Target colour value is more effective: in the process of choosing the preferred brightness of the statue against the brightness of the background, the statue colour value is more influential in determining its luminance level (brightness). Further, the preferred luminance of dark tone statue are less affected with the change of direct background colour value or luminance than bright tone statue.
- The visual system adaptation state: which depend on the quantity and distribution of luminance in the visual field especially

the general surrounding luminance (unfocused peripheral vision), influence the luminance level of both the statue and its direct background (about ~30° in central visual field). The higher the state of adaptation the more luminance needed in central visual field to reach an efficient and comfort vision, and vice versa. This property can be understood via the luminance model[(1)].

- Surrounding configuration of colour value, shapes and forms; as well the light quality (diffuse and direct); and luminance distribution have a big role in enhancing the visibility and perception quality of a statue in lowest illuminance levels.
- Surface attribute: In general, highlights and reflection appear clearly on dark and glossy objects. On the contrary, shades and shadows appear clearly on bright and matt objects. Dark statues need to be illuminated from different direction to generate and enhance the highlights and reflection. On the other hand, bright statue to heed to be illuminated mainly from one direction to enhance the appearance of shades and shadows.

4.8.3 Relation of luminance to brightness

The experiments show that, if two surfaces have the same luminance value in a dim surrounding, the surface with dark colour value will increase the preferred brightness of an object seen against it more than the surface with the bright colour value. This observation may indicate that the light intensity physically registered by the eye from the background is interpreted differently according to the background colour value. On the other hand, this means that the illuminance incident on the dark surface is higher than the illuminance incident on bright surface, and the visual system estimates the illuminance incident on the surfaces; and accordingly the observer chooses the brightness of the statue. This explanation can be supported with the experiments data; since the statues preferred luminance values are closer to each other against different background with same illuminance than different background with the same luminance. Further, simply, in a dim surrounding, a middle gray surface at 10 cd/m2 = ~ 120 lux will look bright and a white surface at 10 cd/m2 = ~ 26 lux will look dimed, and this what observers expressed when they were ask..

Additionally the experiments show that, the dark statues and backgrounds are associated with low luminance value; and bright statues and backgrounds are associated with higher luminance.

As well, the experiment data show different behaviour for the colour value perceived from an object in the central vision (focus/primary-infield) and the direct background (secondary-infield). Where the dark object is preferred with more illuminance and the dark background is preferred with less illuminance. This can be due to the fact that a

1. Christian Bartenbach & Walter Witting, Handbuch für Lichtgestaltung, Lichttechnische und wahrnehmungspsychologische Grundlagen, Springer-Verlag/Wien 2009, p171)

details and surface attributes of dark objects need more illuminance to be generated than bright object, as well due to the difference between zones' characteristic of the visual field. (See discussions of experiments)

This indicates that mapping luminance to brightness has to take into account the perception of lightness, the location of the perceived area in the visual field, and the surface attribute.

4.8.4 Clarification

Our experience is a subjective experience, since brightness, like all other perception feature, not a subject for direct measurement. Subjective experience need to be repeated with a big number of observers to have a precise result. This will alter the experiment result within an acceptable range, but will not change it main finding.

As well, we have to keep in mind that conducting the experiments in other conditions; e.g. change in exhibits properties, surrounding configuration or adaptation state; will alter the results. However, in our experiment we use the same exhibits types and simple surrounding for our case study, the Egyptian museum in Cairo, as much as possible.

Case Study: The West Wing in the Egyptian Museum in Cairo

Ch. 5

Chapter 5. Case Study: The West Wing in the Egyptian Museum in Cairo

In the previous chapters we discussed the aspects of museum lighting, as well we studied deeply the lighting and display of the Egyptian artifacts, the exhibits conservation aspects, and the illumination levels of exhibits via visual perception experiments. This knowledge are a basic requirements of the lighting design process, and it work as a guidelines and parameters that increase the likelihood for technically adequate lighting solutions. However, it do not necessary lead to a successful lighting design for a particular museum case. A successful lighting design will emerge from a comprehensive design process that is a part of the building process, and aims to apply knowledge in practice to meet client prerequisites, budget constraints, and application limitations in a creative and sustainable way.

There is several strategy for practicing lighting design that depends on type and scale of the project, and the scope of lighting design involved. Regardless of the planning strategy employed and the project, a lighting design process that parallels and complements the building design process will make the most of lighting and the architectural resources involved. The IES outline six phases of lighting design in the building design process, that with a good knowledge can yield a successful lighting design in practice. The six phases can be identified as:[1]

- **Pre-design:** project information, scope of work, time schedules, involved teams and its responsibilities, and knowing the budget.
- **Schematic Design (SD):** first phase in designing that involves:
  1- Programming: collecting information and analysis.
  2- Taking inventory: client's prerequisite and sanders.
  3- Design goals: aspects need to be achieved.
  4- Design Strategy: daylight and artificial light strategy that can lead to achieve design goals.
  5- Lighting schemes: a preliminary lighting design that presents untested partial composition of strategies.
- **Design Development (DD):** A number of design steps aim to verify techniques and solutions that help to realize the schematic design. For instance: checking lighting effects, selecting luminaire and systems, rendering scenes, conducting calculations, building model, quantifying luminaires and preparing preliminary documentation.
- **Contract Documents (CDs):** the necessary documentation for the procurements, installation, and operation of the lighting systems.
- **Construction Administration (CA):** During the construction of the project lighting designer role can be answering contractors inquiries, reviewing work shop drawings, and installations.
- **Post occupancy:** a set of evaluations helps to establish a baseline of performance to be checked against design predictions.

1. IESNA, The Lighting handbook, Lightin design in the building design process,10th Ed. 2011, p11.1-to-p11.14.

In this chapter we will design the lighting for a real case study; The West Wing in the Egyptian Museum in Cairo. During our design we will try to apply the knowledge we studied in previous chapters to our design, and to experience how the lighting design process evolve. We will follow the IES design steps to organize our work and get the most benefit from it. However, since this design is part of scientific work not a real practice, not all steps will be addressed. Our work will partially address the three first phases: Pre-design, Schematic Design (SD), and Design Development (DD).

Precisely, since there are several spaces with different configuration in the museum there will be a General Schematic Design for west wing in the museum, followed with Space-by-space lighting design, which is schematic design and design development for every unique space in the west wing. It is important to mention that the lighting design will be oriented toward the daylighting, and the artificial lighting will be followed in the end. In addition, the current condition of the spaces in the museum lacks a good organized interior and display, thus there will be an interior design concept as an additional phase to the General Schematic Design.

(See Appendix 3 for more details about IES lighting design process)

5.1 Pre-design

5.1.1 Brief history

The Egyptian Museum, Arabic Al-Matḥaf Al-Miṣrī, museum of Egyptian antiquities in Cairo, founded in the 19th century by the French Egyptologist Auguste Mariette (1821-1881) and housing the world’s most valuable collection of its kind. The Egyptian Museum was founded in 1858 at Būlāq, moved to Al-Jīzah (Giza), and moved to its present site in 1897–1902. It is unique in its presentation of the whole history of Egyptian civilization, especially of antiquities of the Pharaonic and Greco-Roman periods.(1)

The current building in Tahrir Square is designed in Neoclassical style by the french architect Marcel Dourgnon (1858-1911), winner of an international design contest. The reinforced concrete dome, the ventilation system, and the special effects inside the museum created by the use of suffused lighting are judged to by very innovative at that time.(2)

1. Encyclopedia Britannica, http://www.britannica.com/EBchecked/topic/180750/Egyptian-Museum

2. The Redesign of the Egyptian Museum Midan Tahrir, 2009, Part 2, Ch.1, (pages 152-to-179). This is a study made by an Italian team and sponsored by Italian Authority (Ministero degli Affari Esteri Roma, Ministero degli Affari Esteri Cooperazione Italiana allo Sviluppo, Ministero per i reni e attività culturali, Museum Engineering SRL, and Laboratorio museo tecnico Goppion). The study was presented to the Egyptian Supreme Council of Antiquities as a future plan to redesign the Egyptian Museum. I was given the part (page 152-to-179) from Dr. Tarek El Awady, the director of the Egyptian museum 2011, as a guideline and support for my work.

5.1.2 Location and site plan

The Egyptian museum is located in the hart of Cairo in Tahrir square. The geographic coordinates of the museum is 30° 02' N and 31° 14' E elev 81 ft. (Google Earth program 2014).

Regarding the site plan (Figure 5.1), the buildings that surround the museum are:

- From the north there is a raised roadway (Six Oktober Road) and behind it the high building of Ramses Hilton hotel.
- From the east there are a number of residential buildings in Art Nouveau style, which are in a poor condition.
- From the south and directly in front of the museum's main entrance and garden there is an open air public area beneath it an underground parking.
- From the south west there is the Nile Hilton hotel. It is a large building and in front of the building to the east there is a public area and a garden belonging to the hotel .
- From the west there is a tall building that accommodates the National Democratic Party and the headquarter of the Women's Movements. This building occupies a large area that once belonged to the Egyptian Museum, an area that connects the museum directly to the Nile.(1) The building was burned while the Egyptian Revolution in 2011 and there is a lot of effort to demolish the building and restore the area back to museum. This will be very important since it will reconnect the museum to the Nile creating an unique entrance from the Nile as well add a more space to the museum that can be use for exhibition, storage, facilities, open air museum and/or a public spaces.
- From the west and between the museum and the National Democratic Party building there is an area belonging to the museum where the museum cafeteria and shop are located.
- Along the west side of the site the Nile river flows from the south to the north.

5.1.3 The building's architecture

The museum is designed in the Neoclassical style. The building is characterized with its large dome and the skylights that cover the roof. As well, with its height and Burnt Sienna colour (a sandy-brown-orange colour). The facades have a large windows in the ground floor and it have a few small narrow windows in the upper floor, which makes the building looks to some extent like a fort. (Figure 5.2, Figure 5.3, and Figure 5.4)

The museum consists of the ground floor (GF), the upper floor (UF), and the basement. The floor plan is symmetrical around the entrance axis, and the entrance is oriented directly to the south. The plan can be

1. The Redesign of the Egyptian Museum Midan Tahrir, 2009, Part 2, Ch.1, p153.

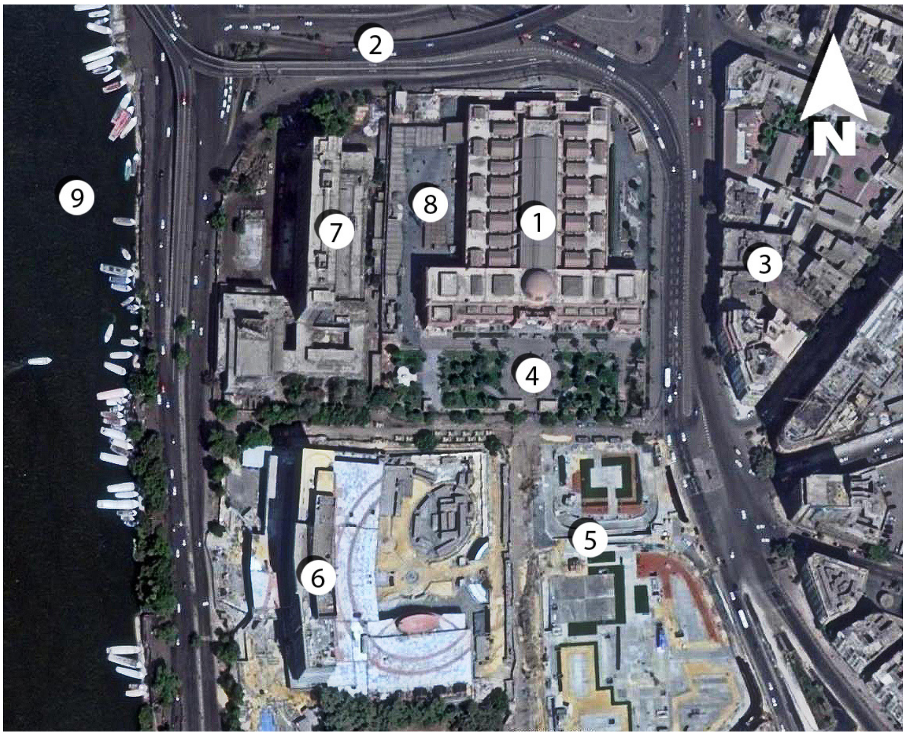


Figure 5.1 *Egyptian Museum site and surroundings. (1) The Egyptian Museum (2) A raised roadway (Six October Road) (3) Residential building (4) Museum main entrance (5) Open air public area and underground parking (6) The Nile Hilton hotel and its garden. (7) The National Democratic Party building (8) The museum coffee-shop and gift shops. (9) The river Nile. (Satellite site photo 2014, google earth program).*

divided to five main parts: the South Wing, the East Wing, the North Wing, the West Wing and the Central Atrium area. The plan is divided to 57 space or zone in every floor. The numbering of spaces starts from the North Wing and it is arranged in five columns throughout the building with addition to the two Grand Staircase in the South Wing. The cast balconies around the Central Atrium is not numbered and it is used for exhibiting artifact. The space in the museum are denoted with letter R for room before each number: R1, R2, R3, etc. (Figure 5.5 and Figure 5.6).

The South Wing contains the building main facade and the main entrance R54. The Entrance Lobby R48 is opened via a circular void to the upper floor and the space is covered with a massive dome. (Figure 5.7) From the north, the Entrance Lobby leads to hall R43, which leads further via stairs to **the Central Atrium** R38-to-R18. The atrium is characterized with its vast space, great height, and large glass ceiling. The atrium is the main hall of the museum (The Memorial hall), where the largest pieces in the museum are exhibited. The atrium floor levels is at about (-1,80 m) and it is lower than ground floor level which is at (+1,30 m). The atrium leads from the north to hall R13. (Figure 5.11 and Figure 5.12)

The Entrance Lobby R48 leads directly from the west and east to two Large Halls R47 and R49. The halls are symmetrical in form and they are opened to the upper floor via a large rectangular void. Both spaces are covered with a glass ceiling lit via a skylight. (Figure 5.9 and Figure 5.10) The South Wing leads from his two ends to a small distribution halls R46 and R50, where the two Grand Staircase are located R51 and R57; and the west and East Wing started. (Figure 5.8) Further, in the South Wing directly behind the facade there are a coffee shop R55, a museum library R52 and R53, and the administration offices R56; and in the upper floor two mummification galleries R52 and R56. (Figure 3.46).

Figure 5.2 *The Egyptian Museum's main facade. The facade is oriented directly to the south. The main entrance is in the middle of the south facade and a the massive dome is above the Entrance Lobby. The entrance in the east side of the facade leads to the administration offices and the entrance in the west side leads to the museum library. Beside the dome we can see the skylights that cover the South Wing halls, the distribution halls and the Grand Staircases. (en. wikipedia.org/wiki/Egyptian_Museum)*

Figure 5.3 *A bird-eye photos shows the North Wing facade, the West Wing facade, the skylights that cover museum's halls, and the huge skylight roof of the Central Atrium. As well, we can see Tahrir square in front of the museum and the surrounding buildings. (The photo is from Google Earth program 2014).*

Figure 5.4 *The Egyptian museum main facade, west facade and the surrounding buildings to the west. In the left side we can see the National Democratic Party building that separate the museum from the river Nile and far away we can see the Nile and the tall building of Ramses Hilton hotel. (The photo is from Google Earth program 2014).*

The west and the East Wing are a symmetrical mirrored plans in both the ground and upper floor. From the outer wall toward the Central Atrium they are consists of three parts: the Lateral Gallery, the side halls, and the cast balcony. **First part: The lateral galleries** (in the West Wing R41-to-R11and in the East Wing R45-to-R15) are the main path of the visit and they have the form of large corridor. The lateral galleries in the ground floor are illuminated through a large windows, while in the upper floor they are illuminated with skylights. The lateral galleries end to hall R6 and R10 where visitors are connected directly to the North Wing and the northern staircases R1 and R5. (Figure 5.13 and Figure 5.14) **Second part: The side halls**, in both east and the West Wing, consist of seven halls in every floor. The seven halls are consist of four Large Halls (West Wing R42, R32, R22 and R12; East Wing R44, R34, R24 and R14); located between them three small halls (West Wing R37, R27 and R17; East Wing R39, R29 and R19). Each large gallery is opened to the gallery in the upper floor via a large void and the entire space is illuminated bey sky light. (Figure 5.15) Each small gallery in the ground floor is connected to the surrounding galleries with big windows allowing light to inter the space. However, the illumination is not enough and the galleries are used as a storage area except gallery R37. In the upper floor the small galleries are illuminated by a skylight. (Figure 5.16) Generally, the side halls in the ground floor are opened from one side to the Lateral Gallery, while the side halls in the upper floor are opened from both sides to the Lateral Gallery and the cast balcony. **Third part: The cast balconies** are an interval space between the side halls and the Central Atrium. It allows visitors to wake around the Central Atrium and it takes its illumination from the cental atrium.

The North Wing in the ground floor consists of: the main gallery R6-to-R10 where the visiting path continue to unfold, the hall R3 which is dedicated to Akhenaten collection, and rooms R2 and R4 which are conservations laboratories. Additionally, as an extension of the North Wing hall R13 contain the artifacts of Amarna era. In the upper floor, the North Wing is consists of: the main gallery R6-to-R10, the hall R3 and hall R13 which are dedicated to Tutankhamun's treasure, and the two galleries R2 and R4 which are used to exhibit jewellery. (Figure 5.17 and Figure 5.18)

5.1.4 The building's interior

The main feature of the museum's interior are the great heights of the ceiling in both floors (~ 7,00 m); the large opening between the ground floor and the upper floor; the circular arches, and the great scale of architecture elements. On the other hand, the museum's interior gain its majestic impression from the large circular void opening and the massive dome that cover the entrance; the Central Atrium space with its great height and its large glass ceiling; the glass ceilings that cover the North Wing's halls; the two Grand Staircases with its glass ceilings; and the great heights of large galleries in the west and East Wings.

The interior colour changed several times throughout the museum's history. The original museum colour is lost during and maintenance work in the museum. Currently the general colour of the interior in some areas is light beige colour tends to yellow and in other areas light beige tends to pink. Exceptionally, some halls has special colours like Akhenaten's Hall R3 in the ground floor has Tacao Colour (Salmone Colour) and Tutankhamun's Hall R3 in the upper floor has a Dark Blue Colour. The museum in 2011 repaint a part of North Wing and the side halls of the East Wing with a light violet colour. However, it was not successful. (Figure 5.19 to Figure 5.22)

5.1.5 The exhibits and exhibition

According to the Egyptian Museum authority there are 107 space or zone used for exhibiting the artifacts in the museum. The museum houses approximately 160,000 objects plus 30,000 in storage, which are covering 5,000 years of Egypt's past dating from the prehistoric through the Roman periods, while the majority of the collection focused on the pharaonic era.

The visiting journey start from the lobby R48 and it goes lift through hall R47, than it continue in a counterclockwise direction in the ground floor. The ground floor takes the visitor on a chronological tour through the collections, while the objects on the upper floor are grouped according to tomb or category; exhibits here include for example, and not as a limitation, the treasures of Tutankhamun, wooden models of daily life, statuettes of divinities, a rare group of Fayum Portraits and many of the New Kingdom royal mummies.(1)

Ongoing addition of discovered artifacts to the collection over time made the exhibit overcrowded and caused visual disorder.(2) As well, it cause that the museum display become without any clear concept. Generally, heavy stone artefacts are exhibited in the first floor with few showcases for small pieces, while all exhibits in the upper floor are displayed in showcases. The museum showcases are very old. It is a simple wood and glass showcases without artificial light except for a few showcases that are illuminated with fluorescent lamps. The showcases and galleries lack modern means of conservations except the galleries and showcases for displaying the royal mummies R52 and R56. (Figure 5.22 to Figure 5.24) and (Figure 3.46).

5.1.6 The technical and architecture documents

The Museum was modified over time. A major and minor works have been done on all parts of the building at various times during the history of the museum. However, little or no technical documentation exists regarding this work. It is known that much was done to the roof: renovation of the skylight and the large dropped ceiling in the Central

1. The Egyptian Museum official website 2014. http://www.sca-egypt.org/eng/MUS_Egyptian_Museum.htm
2. The Redesign of the Egyptian Museum Midan Tahrir, 2009, Part 2, Ch.1, p153.

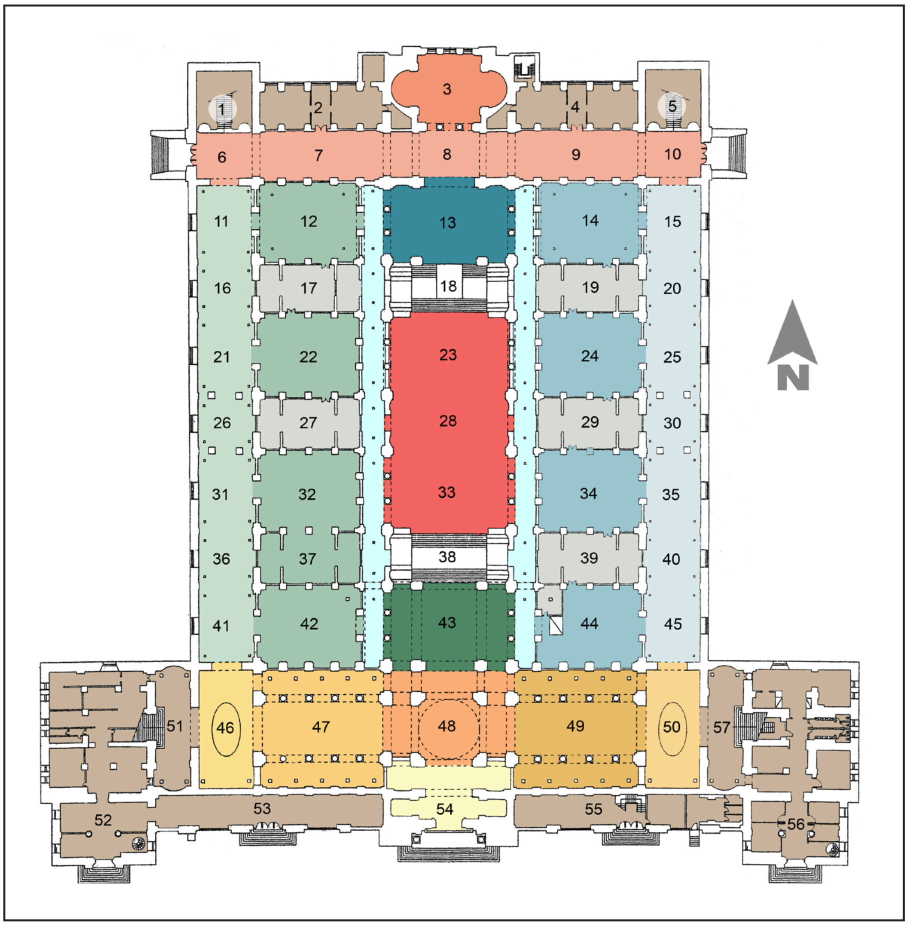


Figure 5.5 *The Egyptian Museum Ground Floor Plan.*

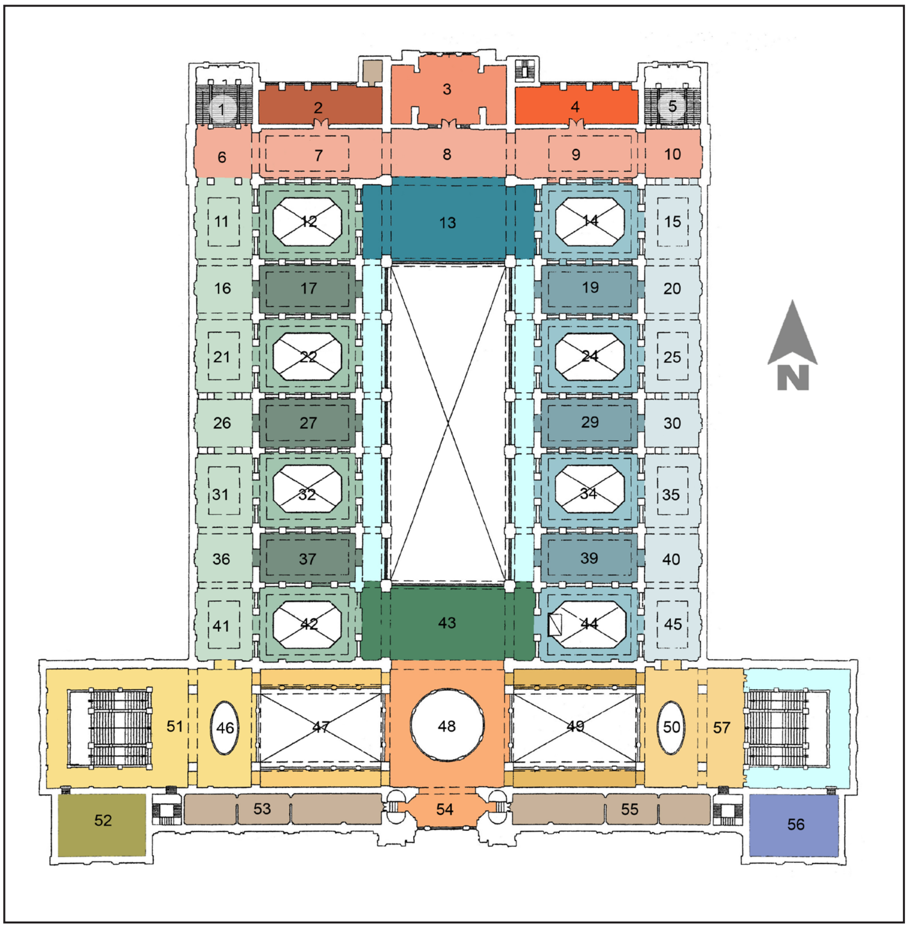


Figure 5.6 *The Egyptian Museum Upper Floor Plan.*

Figure 5.7 *(Left) Entrance Lobby R48. A fish-eye photo from the ground floor toward the Central Atrium and the dome.*

Figure 5.8 *(right) Grand Staircase R57.*

Figure 5.9 *(left) Large Hall R49 in the South Wing. Photo from the upper floor toward the entrance.*

Figure 5.10 *(right) Large Hall R49 in the South Wing. Photo from the ground floor toward the entrance.*

Atrium, reconstruction of the skylights above the grand stairways, modifications to all the skylights in the lateral wings, and adding a reinforced concrete roof structure that appear to be much more recent. As well, the museum interior was substantially modified: wall surfacing, partitions, raised platform, etc. A few photographs documents these modifications but no accompanying text.[1]

One of the difficulties we encountered is that, the only architectural drawings we found by the museum authority are old photocopies of two proposed renovations projects studies. One by The International Council of Museum in 1980 and the other by Shaker Consultancy

1. Previous document. p153.

Figure 5.11 *The Central Atrium R38-to-R18. The photo direction is toward the North Wing.*

Figure 5.12 *The Central Atrium R38-to-R18. The photo direction is toward the West Wing.*

Group in 1999. The drawings are only for the floor plans, the roof, and the facade. There are no sections and details drawings. Accordingly, we invested a long time digitizing the drawings, creating sections and details drawings, and most important checking and updating the drawings with real situations and measurements from the museum. (Figure 5.25 to Figure 5.33).

5.1.7 The involved team

The lighting design process must involve input from many individuals. Discussions with the curator and the museum educators will help determine how the objects should appear when exhibited, how to direct the visitor through the exhibition, and how to direct the visitor's eye in viewing individual objects. Discussions between the conservator

Figure 5.13 *(left) The East Lateral Gally R45-to-R15 in the ground floor, East Wing. The photo is from R40 toward the north.*

Figure 5.14 *(right) The East Lateral Gally R45-to-R15 in the upper floor, East Wing. The photo is from R40 toward the north.*

Figure 5.15 *(left) Large Side Hall R34. The photo is from the ground floor toward the west.*

Figure 5.16 *(right) Small Side Hall R39 in the upper floor. The photo is toward the west.*

Figure 5.17 *(left) The North Wing in the ground floor. The photo is from R7 toward the east.*

Figure 5.18 *(right) The North Wing R12 and hall R13 in the upper floor. The photo is from the roof.*

and the lighting designer should focus on the light sensitivity of the objects, the illumination limits for the objects, the exposure duration limits, and/or wavelengths. Close work with the exhibition designer will enhance the appearance of the exhibition.(1)

During our field research and visits to the Egyptian Museum on summer 2011, we met Dr. Tarek El Awady, the director of the Egyptian museum. Dr. El Awady support us with many valuable information and facilitate our field research in the museum. Concerning conservation data the museum lacks a lighting conservation information about its artifacts. For conservation aspects in lighting we will depend on our study in Chapter 3: Exhibits' Conservative Aspects in Museum

1. Frank A. Florentine, Museum and Art Gallery Lighting: A recommended Practice, Copyrights 1996 by IESNA, USA, p2.

Figure 5.19 *(left) Exceptionally, some halls has special colours like Akhenaten's Hall R3 in the ground floor. It has Tacao Colour (Salmone Colour). Dark Blue Colour.*

Figure 5.20 *(right) Exceptionally, some halls has special colours like Tutankhamun's Hall R3 in the upper floor has a Dark Blue Colour.*

Figure 5.21 *(left) Large Side Hall R14 in the East Wing. The gallery was repaint with a light violet colour in the year 2011 as a try to enhance its appearance, however, it was not successful. Compare with Figure 4.15.*

Figure 5.22 *(right) Large Side Hall R24 in the East Wing. A photo from the skylight. The gallery exhibit a sensitive papyrus and it is overexposed to daylight.*

Figure 5.23 *(lift) A showcase in Large Hall R47. A simple showcase made from wood and glass and it do not has artificial light or any means of conservations. Additionally, The exhibits lack to have a contrast with its background.*

Figure 5.24 *(right) A showcase in Large Side Hall R34. The showcase is lit with fluorescent lamp. The lamp do not illuminate all the artifacts. And the glass has spots of veiling reflections.*

Lighting. About the display, there is no professional exhibit designer in the museum and the display is in a bad condition. Accordingly, a new interior design concept has to be accompanied with the first phase of lighting design or to come previously. Additionally During your lighting design process we will take into account the design considerations for other building technical aspects, e.g. the HVAC equipment.

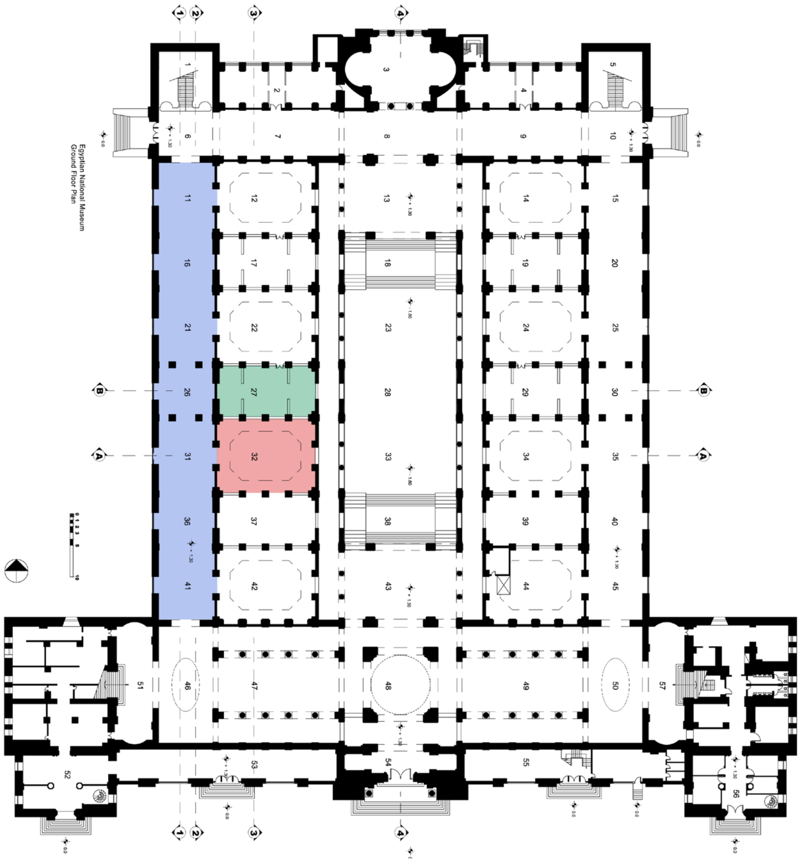


Figure 5.25 *The Egyptian Museum ground floor plan. Area of study: The Large Side Hall GF R32 (Red colour). The Small Side Hall GF R27 (Green colour). The Lateral Gallery GF R41-to-R11 (Blue colour).*

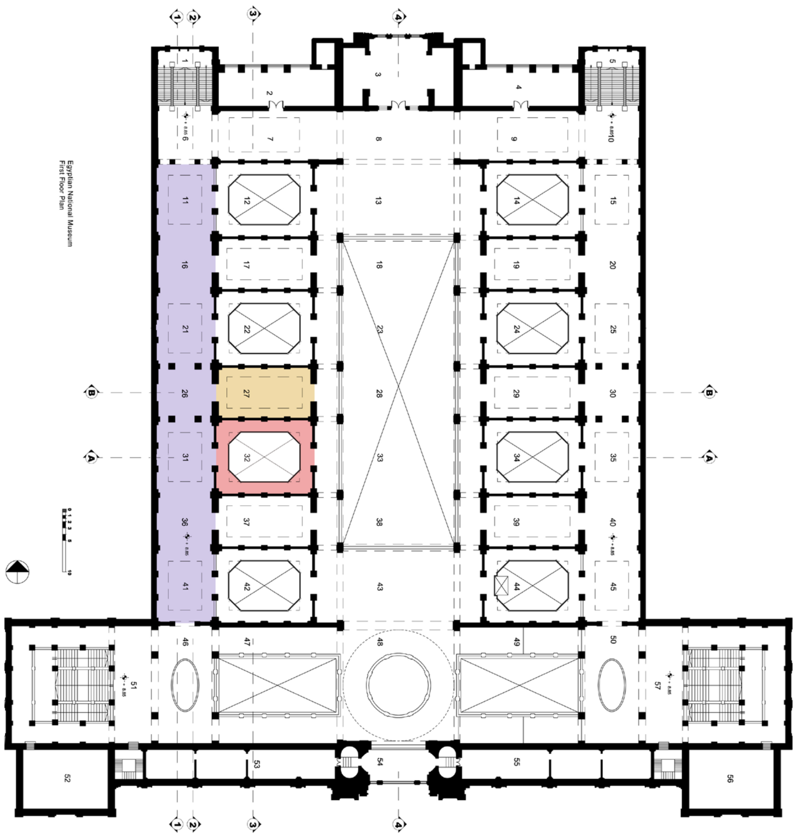


Figure 5.26 *The Egyptian Museum upper floor plan. Area of study: The Large Side Hall UF R32 (Red colour). The Lateral Gallery UF R41-to-R11. (Purple colour). The Small Side Hall UF R27 (Yeloow colour).*

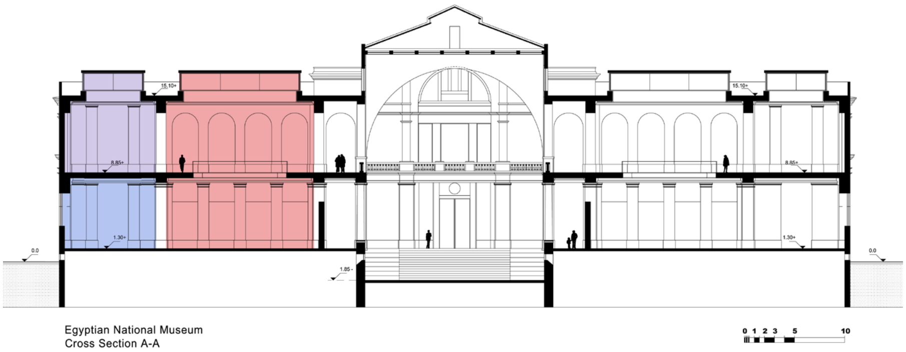


Figure 5.27 *Section A-A across the West Wing, the Central Atrium, and the East Wing. Area of study: The Large Side Hall GF R32, and UF R32 (Red colour). The Lateral Gallery GF R41-to-R11 (Blue colour). The Lateral Gallery UF R41-to-R11 (Purple colour).*

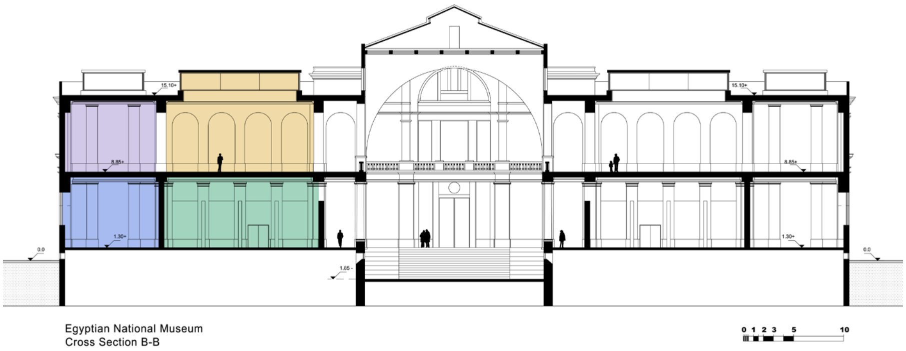


Figure 5.28 *Section B-B across the West Wing, the Central Atrium, and the East Wing. Area of study: The Small Side Hall GF R27 (Green color). The Small Side Hall UF R27 (Yeloow colour). The Lateral Gallery GF R41-to-R11 (Blue colour). The Lateral Gallery UF R41-to-R11 (Purple colour).*

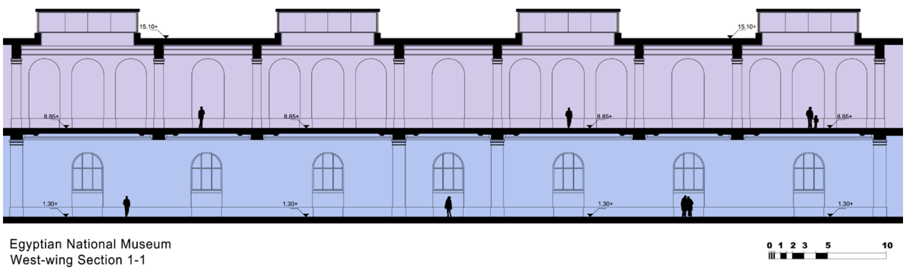


Figure 5.29 *Section 1-1 across the literal galleries in the West Wing. Area of study: The Lateral Gallery GF R41-to-R11 (Blue colour). The Lateral Gallery UF R41-to-R11 (Purple colour).*

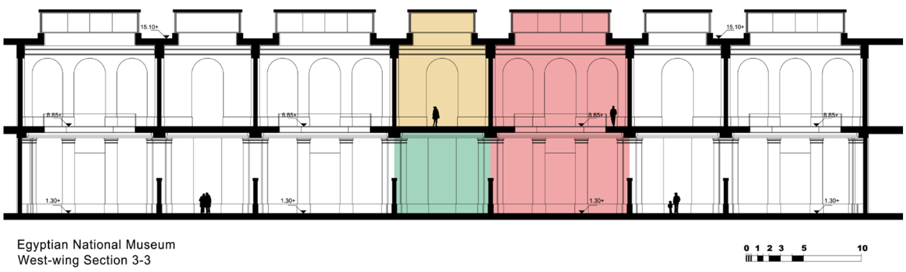


Figure 5.30 *Section 3-3 across the side galleries in the West Wing. Area of study: The Large Side Hall GF R32, and UP 32 (Red colour). The Small Side Hall GF R27 (Green color). The Small Side Hall UF R27 (Yeloow colour).*

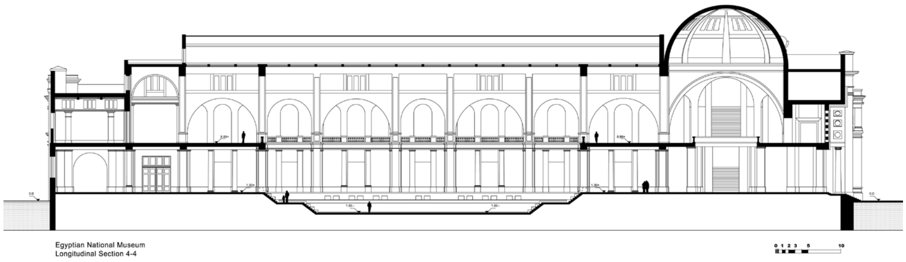


Figure 5.31 *Section 4-4 across the museum.*

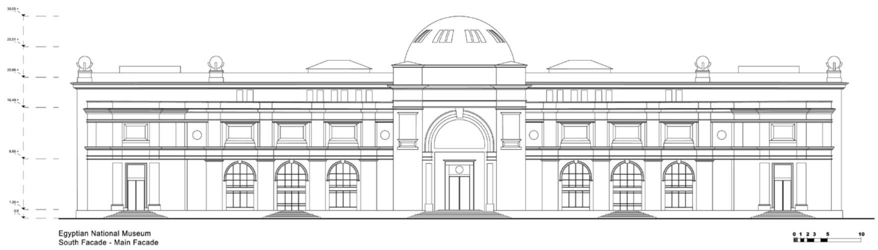


Figure 5.32 *Main Facade, The south facade, where the main entrance is located. (after modifying the drawings by Shaker Consultancy Group in 1999).*

Figure 5.33 *The west facade. Note: the existed concrete protection roof is added to this drawing and absent from the previous section drawings. (after modifying the drawings by Shaker Consultancy Group in 1999).*

5.1.8 Area of study

We had chosen the West Wing to be our area of study because it is similar to the East Wing and the geometry of spaces in the West Wing resemble many other spaces in the museum; therefore by carefully studying and designing the lighting for the West Wing, we are designing the lighting for most of the spaces in the museum. The West Wing in both the ground and the upper floor consist of: the Lateral Gallery, the side halls, and the cast balcony. (The cast balcony is more connected to the Central Atrium, accordingly it's lighting has to be designed with the Central Atrium). Our study will be focused on the following areas:

(1) The Lateral Gallery GF R41-to-R11. (Blue colour)

(2) The Lateral Gallery UF R41-to-R11. (Purple colour)

(3) The Large Side Hall GF & UP R32. (Red colour)

(4) The Small Side Hall GF R27. (Green color)

(5) The Small Side Hall UF R27. (Yellow colour)

More details and analysis about the selected gallery will come in the schematic design.

5.2 General Schematic Design for the west wing

5.2.1 Lighting analysis

The aim here is to collect the information and conduct analysis about the lighting in the existing building that help to formulate a decision about which design is to be undertaken.

5.2.1.1 Means of lighting

The building was originally planned to utilized only daylight since back in 1902 there was no means of artificial lighting.

- The Lateral Gallery in the ground floor GF R41-to-R11 is illuminated via large windows. (Figure 5.39 to Figure 5.41).
- The Lateral Gallery in the upper floor UF R41-to-R11 is illuminated via skylights. (Figure 5.42 and Figure 5.43).
- The Large Side Hall GF R32, and UP 32 are two connected spaces via a large void (a double-height space) which are illuminated from the roof via skylight. (Figure 5.44 to Figure 5.47).
- The Small Side Hall GF R27 is used as a storage area and it has no direct daylight illumination from the outside.
- The Small Side Hall UF R27 is lit via skylights. (Figure 5.48).

Each Lateral Gallery in the ground floor contains seven large windows. The windows are constructed from wood frames and clear glass; and it is covered with steel bars from the outside.

The skylights on the east and West Wing of the museum are originally simple parallelepipeds positioned between the brick buttresses with glass on all four sides. The skylight was modified by raising them and installing a simple peaked roof presumably prior to the world war two. Later they were protected with a higher external structure in reinforced concrete, which suggests a temporary, disharmonious solution that detracts from the building's architecture.[1]

All existing skylights over the West Wing and East Wing have the same construction. (Figure 5.34 to Figure 5.42) The skylights windows are constructed from a metal frames and wire reinforced glass. The skylights have a flat wood ceiling from the inside and peaked wood roof from the outside. The space between the ceiling and the roof is left empty and opened via perforated screen from both side to help mitigate thermal loads on the halls. All skylights are covered with external reinforced concrete roof to protect the skylights from damage during the war in the 1960s and 1970s. (Figure 5.3 and Figure 5.34 to Figure 5.36)

The existing skylights are in a very bad condition since the wood roof is crackled, windows are not airtight, and some windows are left opened. As well, there are no technical means of controlling daylight on the skylight's windows instead some windows are painted with opaque colour to reduce illumination and others are closed with wood panels to block direct daylight from penetrating the space. (Figure 5.35)

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1. The Redesign of the Egyptian Museum Midan Tahrir, 2009, Part 2, Ch.1, (p155).

The museum was utilized for a long time without artificial light, however, later around the middle of the twenties century the museum was supplied with electricity and a conventional luminaire with 120 cm fluorescent lamps all over the museum. The luminaires in the ground floors have a mirror raster and in the upper floor a translucent glass cover.

Although the skylights on the South Wing and the Central Atrium are not included in our area of study, we like to point out that they are different in construction than the skylights on the west and East Wing. The skylight on the South Wing has a translucent glass ceiling that is centred over the space beneath it (a restricted daylight-diffusing ceilings). The daylight entered the skylight from all direction via side windows, then it enter the space via the translucent glass ceiling. Their are a few large spotlight integrated directly in the ceiling. (Figure 5.9 and Figure 5.36)While the Central Atrium has a large skylight with an overall daylight ceilings; however the ceiling admit light only from the its centred part to the space. The ceiling is constructed from a metal frames and translucent glass. The skylight has a large peaked roof that admit light only from the centre. Their are a few large spotlight integrated directly in the ceiling. (Figure 5.11, Figure 5.12, and Figure 5.37).

5.2.1.2 Visual and photometric evaluation

The visual and photometric evaluation were carried out during summer time in 24 August 2011. *(Except Figure 5.39-b)* The photos and the measurements were taken between 11:00 am to 15:00 am and the sky condition was totally clear sky with sun. The unobstructed global horizontal illuminance (GHI) measured on the roof of the museum at 15:00 was about 80000 lux and for the diffuse horizontal illuminance (DHI) 18000 lux. The data are very close to the EnergyPlus Weather file (EGY_Cairo.623660_IWEC.epw)[1] that recorded the average GHI on this day and time at the Cairo Airport 79000 lux and for DHI 19400 lux. This gives us confidence to rely on the EnergyPlus Weather data in our evaluation.

The energyplus weather data shows the following average measurements at 24 August at Cairo Airport:

11:00 = GHI 97600 lx and DHI 33000

12:00 = GHI 103800 lx and DHI 17300

13:00 = GHI 103000 lx and DHI 16400

14:00 = GHI 94000 lx and DHI 17200

15:00 = GHI 79000 lx and DHI 19400

The measurements give a general idea about the condition outside during taking the photos. In this phase our aim are not to evaluating how the geometry of the building affect the amount of illuminance inside, but to evaluate the luminance distribution and daylight quality in the

1. Source of the data: <https://energyplus.net/weather-location/africa_wmo_region_1/EGY//EGY_Cairo.623660_IWEC>, (17.06.2016).

Figure 5.34 *(left) The skylights on the West Wing. All existing skylights over the West Wing and East Wing have the same construction.*

Figure 5.35 *(right) A close photo shows the bad condition of the skylights. The skylights over R24 on the East Wing.*

Figure 5.36 *The skylights over R15, R14 and R9 on the east and North Wing.*

(a) (b)

Figure 5.37 *The skylight on the South Wing over R47. (a) An external view for the skylight. (b) A view inside the skylight.*

Figure 5.38 *A photo inside the large skylight that cover the Central Atrium. R38-to-R18.*

museum spaces. It is important to note that conducting the evaluation in summer shows the highest possible levels of illuminance in the building.

The false colour image that represent the luminance distribution are made using the online tool (WebHDR Roll-Your-Own) on following internet address (www.jaloxa.eu). Notes: The results of the luminance photos have tolerance of ±5%; and the luminance photos do not share the same scale limits.

5.2.1.2.1 The Lateral Gallery GF R41-to-R11

The Lateral Gallery in the West Wing GF R41-to-R11 is part of the main visiting path that circle the museum in the ground floor. (Blue colour in the architecture documents page 226 and page 227) (Figure 5.39 to Figure 5.41) According to the visiting direction the side hall entrances are located on the right hand side of the Lateral Gallery facing the large arched windows that are located oppositely on the left hand side. The space dimension is ~ 8,5 x 72,5 m and hight ~7 m. The space is not divided with any partitions. In the middle of the space there are four squared columns. The aligned windows and entrances, as well the ceilings panels and beams, create a rhythm in the space. However, the unorganized display interfere and disturb this rhythm.

The gallery contains mainly heavy stone exhibits like architectural parts, sphinxes, statues, and reliefs. Most of the exhibits are displayed freely on simple bases or fixed directly on the walls. There is only a few showcases that mainly contain small pieces. The gallery is crowded with the exhibits and there is no clear concept for the display. A lot of the reliefs and statues have a close colour to the beige wall. The low contrast between the exhibits and the walls make the exhibits not clearly visible.

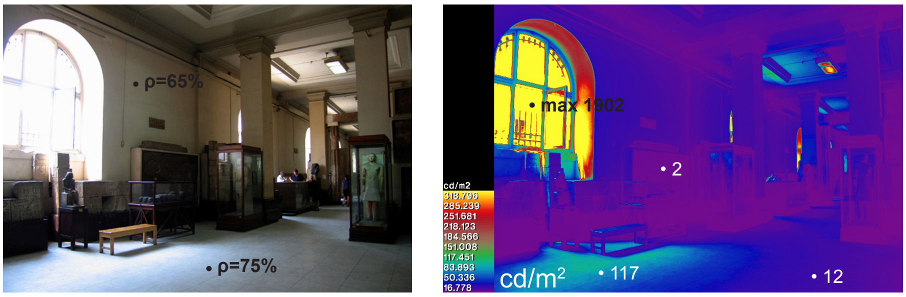
The Lateral Gallery in the West Wing is illuminated with the seven large windows. The windows have no means of controlling daylight and glare and it is a great source of glare and visual disturbance. The direct sun rays penetrate the space in the afternoon causing glare, reducing the visual performance, and altering room atmosphere. (Figure 5.39-b) The area in front of the windows and the wall opposite to the windows get the highest level of illuminance in the space, while the windows' wall has the least level of illuminance. Accordingly, the exhibits facing the windows have sufficient illuminance, while all the exhibits on the windows' wall have insufficient illuminance and look dark due to the contrast with the high level of windows luminance. During the day the fluorescent luminaires are always turned on, perhaps to enhance the exhibits visual condition little bet. However, the distribution of light on the exhibits are not sufficient and do not emphasize its aesthetic aspects. See false colour image for light levels and distributions. (Figure 5.39 to Figure 5.41).

5.2.1.2.2 The Lateral Gallery UF R41-to-R11

The Lateral Gallery in the West Wing UF R41-to-R11 is part of the main visiting path that circle the museum in the upper floor. (Purple colour in the architecture documents page 226 and page 227) (Figure 5.42 and Figure 5.43). According to the visiting direction in the upper floor all side halls' entrances are connected to the gallery on the right hand side. The wall on the left hand side is solid without any windows. The walls are characterized with integrated arches. The space dimension is similar to the Lateral Gallery in the ground floor ~ 8,5 x 72,5 m and hight ~7 m. The space is not divided with any partitions. In the middle of the space there are four squared columns. The four large skylight are a strong architectural feature that creates a rhythm and characterizes the space.

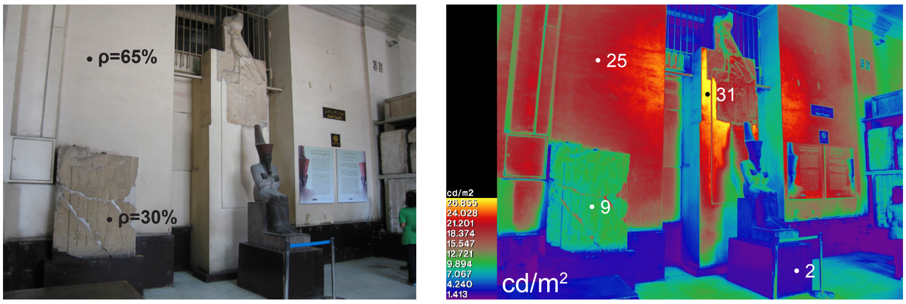
(a) (b)

Figure 5.39 *The Lateral Gallery GF (a) A view from the first zone R41. The photo was taken before noon. The diffuse light falling from the windows strongly highlight the area in front of the windows. (b) A view from zone R21. This photo was taken after noon in the winter. It shows the penetration of sun rays to the space.*



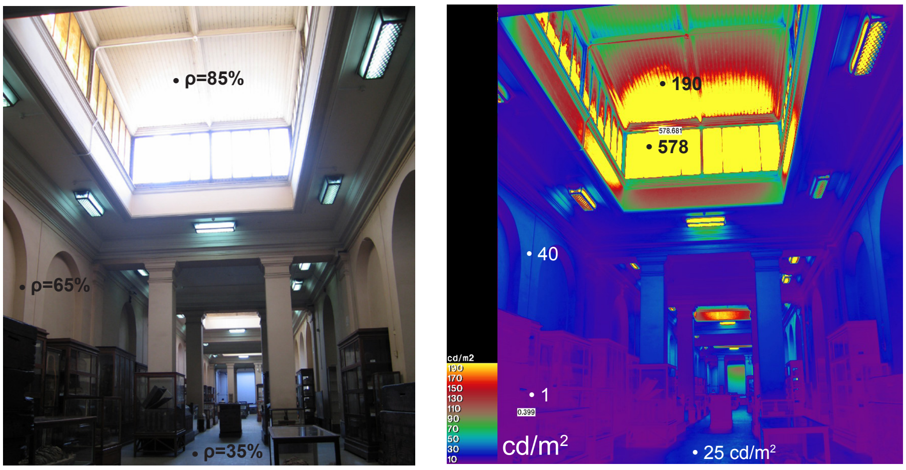
(a) (b)

Figure 5.40 *The Lateral Gallery GF (a) A view from zone R31. (b) A false colour image representing the luminance distribution of the previous image.*



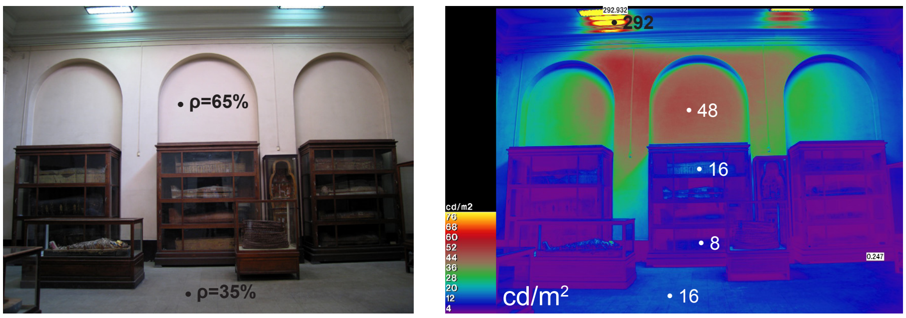
(a) (b)

Figure 5.41 *The Lateral Gallery GF (a) A view from zone R26. (b) A false colour image representing the luminance distribution for the previous image.*



(a) (b)

Figure 5.42 *The Lateral Gallery UF (a) A view from zone R31 shows the skylight and the area below it. (b) A false colour image representing the luminance distribution for the previous image.*



(a) (b)

Figure 5.43 *Lateral Gallery UF (a) A view for the showcases in zone R31. (b) A false colour image representing the luminance distribution for the previous image.*

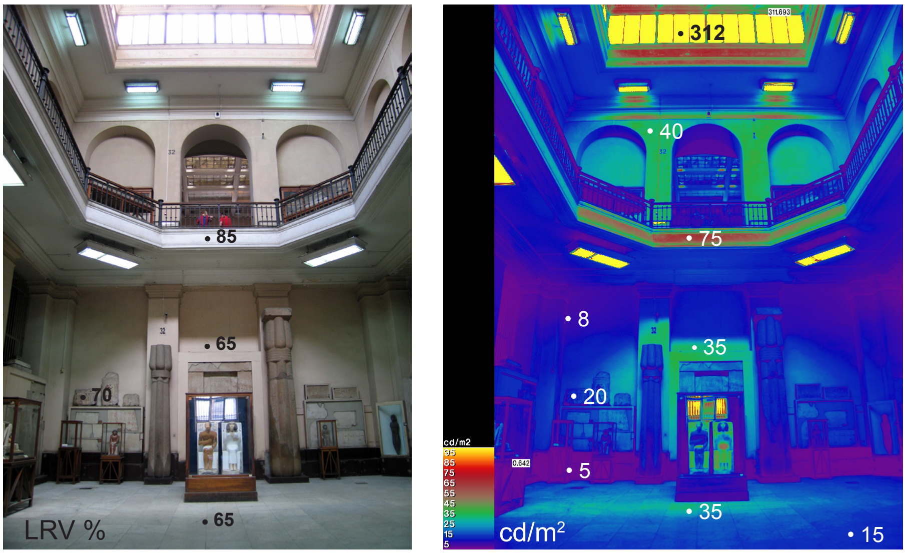
The space is dedicated to present the ancient Egyptian funeral exhibits like: wooden coffins, wrapped Mummies, wooden boxes, canopic jars, pots and tools used in mummification, etc. All exhibits are displayed in simple showcase made of wood and clear glass. The space is full of vertical showcases (cupboards) on the walls and top showcases in the middle of the space. The vertical showcases are crowded with the wooden coffins which makes seeing and lighting it very difficult. Some areas are crowded with the showcases and there is no enough space to move around the showcases. Most of exhibits are low-responsive-to-light and both the gallery and the showcases lack means of conservations.

The gallery is illuminated with the four large skylight and for night time by the conventional fluorescent luminaires mounted on the ceiling. The artificial light is always turned on during the day. The skylight translucent glass soften the light quality in the space. A big part of the skylights glass panels are painted to reduce the illumination and block the direct sun rays; however the skylights still a source of glare in some hours of the day. (Figure 5.42) The four skylights are positioned over the zones adjacent to the Large Side Hall, this makes the zones adjacent to the Large Side Halls (UF R41, R31, R21, and R11) brighter then the zones adjacent to the Small Side Halls (UF R36, R26, and R16). Generally, the luminance distribution is not even over the showcases. The vertical showcases that are crowded with the wooden coffins have insufficient illuminance. See false colour image for light levels and distributions. (Figure 5.42 and Figure 5.43)

5.2.1.2.3 The Large Side Hall GF & UF R32

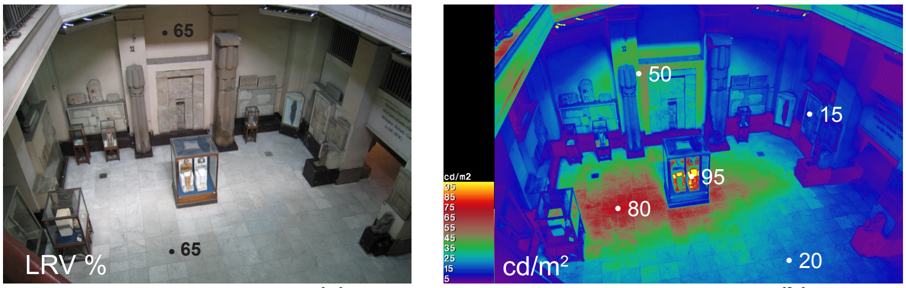
The Large Side Hall is a double-height space consists of the gallery GF R32 in the ground floor and the gallery UP R32 in the upper floor. The two galleries are connected via a large void. (Red colour in the architecture documents page 226 and page 227) (Figure 5.44 to Figure 5.47) The ground floor dimension is ~11,75 x 15,35 m and the height is ~ 14,60 m to the second floor ceiling and 17,47 m to the skylight ceiling. The plan of the upper floor gallery has a shape of a passage or a balcony that circle the void with width of a 2 m. The UP R32 gallery is connected from one side to the Lateral Gallery UF and from the other side to the cast balcony and the memorial hall (Central Atrium). In a comprehensive manner, opening the space up and changing its dimension connect the two floors visually together, change the rhythm of the successive side halls, relieve the eye during the visiting round, and give a majestic impression to the space. The large skylight and the integrated arches in the walls of the upper floor are a strong architectural features that characterizes the space.

The gallery GF R32 in the ground floor display heavy artifacts like architectural parts, statues, and reliefs. The display is part of the chronological visiting round on the ground floor. The statues are displayed freely on a simple bases or in showcases. Reliefs are fixed directly on the walls. The statue of "Rahotep and his wife" (4th dynasty 2613 to 2494 BC) is the master piece of the gallery. It is displayed in a showcase



(a) (b)

Figure 5.44 *The Large Side Hall GF R32, and UP R32. (a) A view from the ground floor. (b) A false colour image representing luminance distribution for the previous image.*

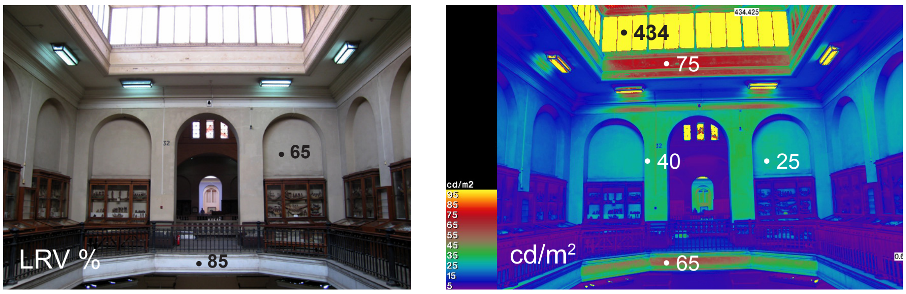


(a) (b)

Figure 5.45 *The Large Side Hall GF R32 (a) A view from the upper floor. (b) A false colour image representing the luminance distribution for the previous image. Notes that the sun penetrate the skylight and illuminate the half of the ground floor level.*

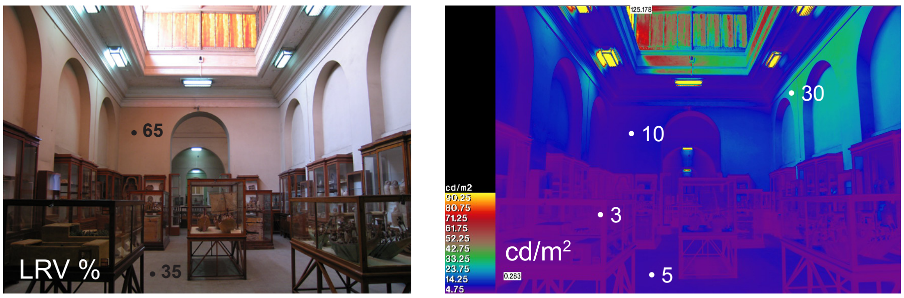
(a) (b)

Figure 5.46 *The Large Side Hall GF R32 (a) A view toward the Small Side Hall GF R27. (b) A view toward the Small Side Hall GF R37.*



(a) (b)

Figure 5.47 *The Large Side Hall UF R32 (a) A view shows the showcases and the skylight. (b) A false colour image representing the luminance distribution for the previous image.*



(a) (b)

Figure 5.48 *The Small Side Hall UF R27. (a) A view shows the showcases and the skylight. (b) A false colour image representing the luminance distribution for the previous image.*

in the middle of the gallery. Most of Large Side Halls display its important pieces in the primacy of the gallery. The walls are crowded with the reliefs and small statues, however, the middle part is relatively empty and contain few showcases. The gallery GF R32 are connected to the Small Side Hall GF R37, which is the only used Small Side Hall in the ground floor for display.

The gallery UP R32 in the upper floor like other side galleries in the upper floor is dedicated to one subject. It displays small wood models for boats that was used on the Nile in ancient Egypt. The exhibits are displayed in a vertical wood cabinets, where the upper parts have clear glass and the lower parts are closed for storage. The cabinets cover all walls and it is crowded with exhibits. The boots models exhibits are low-responsive-to-light and both the gallery and the showcases lack means of conservations.

The Large Side Hall's both galleries GF R32 and UF R32 are illuminated by a large skylight and for night time by the conventional fluorescent luminaires mounted on the narrow peripheral ceiling of both galleries. The artificial light is always turned on during the day. The skylight's translucent glass makes the light quality in the space semi diffuse. The southern part of the skylight's glasses are painted to block the direct sunlight from the south, however it is easy to see big bright area of light wander with the movement of the sun in the space. (Figure 5.45) Although, the exhibits in the upper floor are low-responsive-to-light and the exhibits in the ground floor are irresponsive-to-light, the level of illuminance in the upper floor is higher then the level of illuminance in the ground floor. This is due to the proximity of the upper floor to the skylight, as well as a result of blocking the narrow peripheral ceiling around the void a part of the light falling on the walls of the ground floor. The narrow peripheral ceiling as well cast a deep shadows on the upper part of the walls in the ground floor. (Figure 5.44). Generally, the illuminance in the ground floor is not even distributed, it changed dramatically during the day, and not sufficient for all the exhibits. The illuminance in the upper floor is sufficient for seeing the exhibits, however it is not even distributed; and it change dramatically during the course of the day and exceeds the illuminance limits of conservation. See false colour image for light levels and distributions. (Figure 5.44 to Figure 5.47).

Deuring our visit in summer time in 24 August 2011 we measured the luminace level in the Large Side Hall GF R32 in the middle of the room, away from the bright sun light area (Figure 5.46), at 14:00 (Accourding to energyplus weather data the average GHI 94000 lx and DHI 17200) and at hight of 2,2 m and it recorded 245 lux. This is a very low illuminance level for existing statues in the ground floor. Additionally, the expecting level of illuminance in winter will be too low, which will makes the room look dull and will not help visitor to clearly see the exhibits.

5.2.1.2.4 The Small Side Hall GF R27

The Small Side Hall GF R27 (Green colour in the architecture documents page 226 and page 227) is used as a storage area and it has no direct daylight illumination from the outside; instead it is illuminated by a large windows with steel bars that are opened to all the surrounding spaces. The space dimension is ~ 8 x 14,6 m and hight ~7 m. (Figure 5.46)

5.2.1.2.5 The Small Side Hall UF R27

The Small Side Hall GF R27 is one of three Small Side Halls in the upper floor. (Yellow colour in the architecture documents page 226 and page 227) (Figure 5.48) It is located between the Large Halls in the upper floor and it is connected from one side to the Lateral Gallery and from the other side to the cast balcony and the memorial hall (Central Atrium). The hall has a simple rectangular plan. The space dimension is ~ 8 x 14,6 m and hight ~7 m. The large skylight and the integrated arches in the walls are a strong architectural features that characterizes the space.

The gallery display different types of artifacts. It displays wooden models for boats, houses, and everyday life activities. As well as, canopic jars, pots, and wooden coffins. All exhibits are displayed in simple showcase made of wood and clear glass. The space is full of vertical showcases on the walls and top showcases in the middle of the space. The space is very crowded with the showcases. Most of exhibits are made of wood and contain paintings which make it low-responsive-to-light, however both the gallery and the showcases lack means of conservations.

The hall is illuminated by the large skylight and for night time by the conventional fluorescent luminaires mounted on the narrow peripheral ceiling of both galleries. The artificial light is always turned on during the day. The skylight's east, south, and west glass panels are painted to reduce the light and block the direct sunlight. The orange colour painting ads a warm-white light to the space and contrast with the fluorescent cold-white colour. The illumination in the space is sufficient for seeing the exhibits, however it is not even distributed; and it change dramatically during the course of the day and exceeds the illuminance limits of conservation. See false colour image for light levels and distributions. (Figure 5.48)

5.2.1.2.6 General evaluation

The translucent and the painted glass panels of the museum's architectural openings create a semi-diffuse illumination, that is characterized with a bit of directionality and soft shadows. As a result, the diffuse light is the general characteristic of the illumination in the museum. On the other hand, all architectural opening either windows or skylights have no means of controlling light or glare. The absence of real sun protection allow the sun rays to enter the space in some hours of the day causing glare, visual disruption, altering room atmosphere, raising level of illuminance over the lighting limits of conservation, creating uneven light distribution, and dramatically change the illuminance level during the course of the day and the year.

Within the time of the analysis (between 11:00 to 15:00, on 24 August 2011), illumination levels were sufficient in many areas regardless of its poor distribution. However, the recorded levels show that illumination will be totally insufficient in other time of the year especially winter time; as well in the early morning and the late afternoon.

In fact, studying the light levels in the museum and evaluating the daylight performance of the architectural opening are not feasible, since the opening's glass panels are not unified; and some are painted, left opened, or blocked. Additionally, all museum's conventional fluorescent luminaires were turned on during the day time. The artificial lights are confined only to conventional fluorescent luminaires, that are unspecialized for museum lighting, and barely generate a poor general lighting. As well, evaluating the exhibit illumination is not feasible, since the display is very crowded and has no clear concept; and the showcases are very old and obsolete. Accordingly, we will study the performance of daylight in the museum via a architectural scale model, and we will propose an interior design concept for the area of study.

5.2.1.3 Lighting conservation aspects evaluation

The main lighting conservation problems in area of study are:

- The galleries and showcases lack modern means of conservations.[1]
- The museum exhibits lack lighting conservation data.
- In the upper floor most of exhibits are low-responsive-to-light and in many areas the illuminance levels exceed the conservation limits.
- Sun penetrate the space and fall directly on the exhibits in some areas.
- The exhibits are not classified in zones according to its sensitivity to light. Classifying the exhibits will facilitate controlling light levels for conservation.

5.2.1.4 Daylighting analysis

To evaluate the daylight performance of the museum for both the existing situation and the proposed design we studied the daylight condition in Cairo and we built a physical scale model for the area of interest.

5.2.1.4.1 Daylight data for Cairo

Daylight is the main source of illumination in buildings. The dynamic changing of daylight condition make its study depends on predicting or collecting annual data for the sun and sky according to the geographic location of the building. As follows we will present the important daylight data for our case study.

1. See chapter 3: exhibits' conservative aspects in museum lighting, for more information about this subject.

5.2.1.4.1.1 Cairo standard skies

CIE (International Commission on Illumination) published the standard skies (a set of luminance distributions, that model the sky under a wide range of conditions) to be a universal basis for the classification of measured sky luminance distributions, and to give a method for calculating sky luminance in daylighting design procedures.(1)

The CIE Overcast Sky for Cairo has the following values:(2)

- The outdoor maximum horizontal illumination is ~20.000 lx. For daylight calculations in most cases the average horizontal illuminance 10.000 lx is used. (Figure 5.49)
- The overcast sky luminance ranges between 1.000 to 10.000 cd/m^2.
- The zenith luminance is three times the luminance of the horizon. When the horizontal illuminance is 20.000 lx the zenith luminance is 8.200 cd/m^2 and the horizon is 2.750 cd/m^2.
- The illuminance on west facade or any vertical surface, without ground reflected illuminance, is the half of the horizontal value, because the vertical measurement point faces half the sky. The maximum illuminance on west facade 10.000 lx. (Figure 5.51)

The CIE Clear Sky with Sun for Cairo has the following values:(3)

- The outdoor maximum horizontal illuminance of ~100.000 lx, consist of ~80.000 lx from the direct solar radiation and ~20.000 lx from the scattered light in the sky. (Figure 5.50)
- The luminance of the blue sky ranges from 1,000 to 10.000 cd/m^2, and the directed sunlight has 400 million cd/m^2.
- The illuminance on a vertical surface depends on its orientation to the sun and the time of the day. For the west facade, without ground reflected illuminance, the illuminance is around 10.000 lx before noun and it start to increase at noon to reach the maximum illuminance at ~14:30, which is ~70.000 lx in summer. (Figure 5.52)

Both CIE standard skies describe the two extreme sky conditions; the completely cloudy sky and the clear sky with no coverage. The frequency in which those two situations occur is very small. The real skies usually lie in between.(4) Therefore the CIE proposed other standard skies that represent the sky luminance in other conditions, as well more complex models are designed to simulate conditions based on weather data to describe a much wider range of sky conditions.(5)

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1. Spatial Distribution of Daylight - CIE Standard General Sky, <http://www.cie.co.at/index.php/index.php?i_ca_id=476>, (19.06.2016).
2. Data Bank, Research and Development department, Bartenbach GmbH, Innsbruck, Austria, with permission.
3. Previous reference.
4. Tsiopoulou Chamaidi, Calibrated Sky Luminance Maps for Daylight Simulation, MSc Building Science & Technology, TU Vienna, June 2006, p4.
5. IESNA, The Lighting handbook, Light Sources: Technical Characteristics,10th Ed. 2011, p7.2.

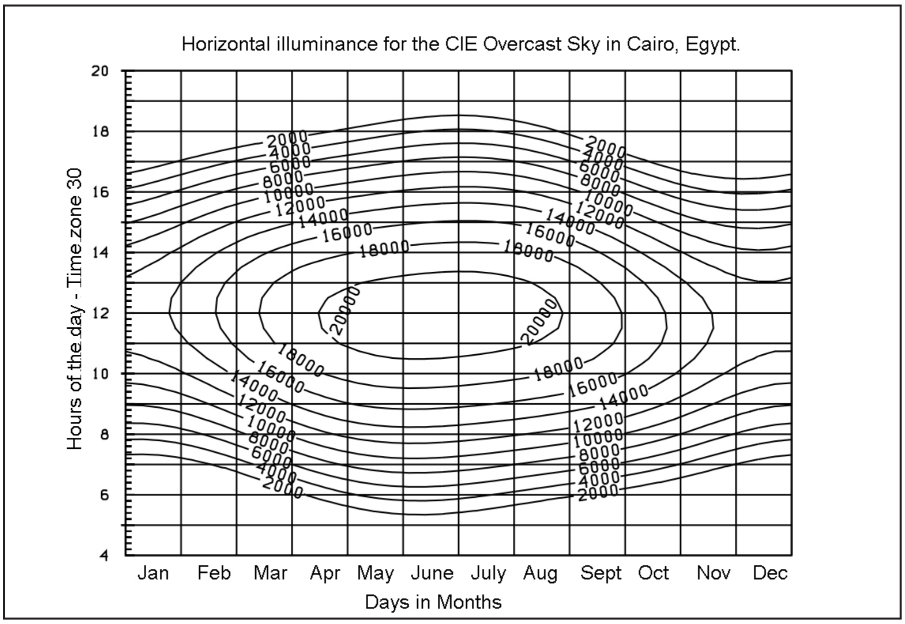


Figure 5.49 *Isolux curves represent the outdoor annual illuminance for the CIE overcast sky on a horizontal surface in Cairo, Egypt, coordinates : 30°1′ longitude, 31°4′ latitude. (with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).*

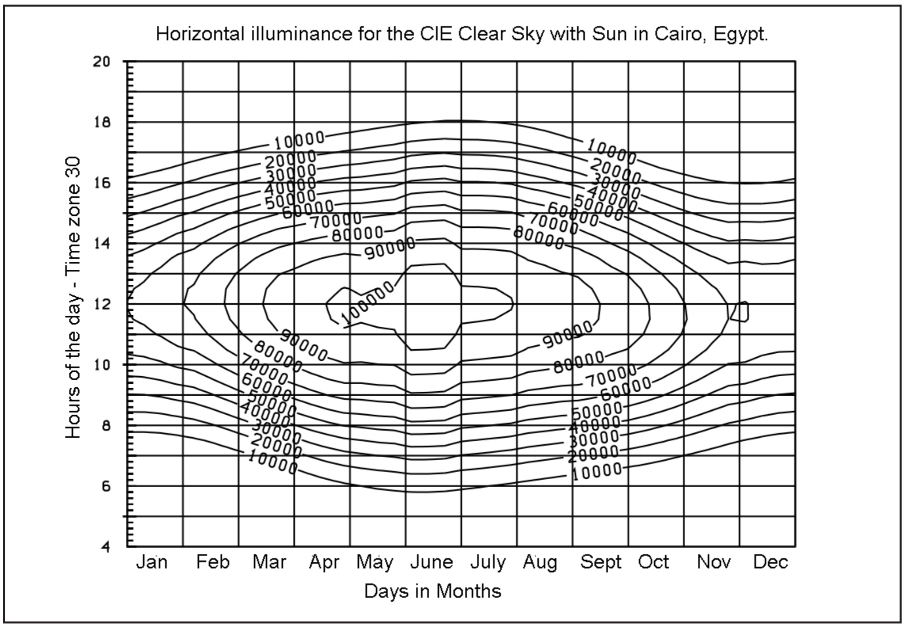


Figure 5.50 *Isolux curves represent the outdoor annual illuminance for the CIE clear sky with sun on a horizontal surface in Cairo, Egypt, coordinates : 30°1′ longitude, 31°4′ latitude. (with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).*

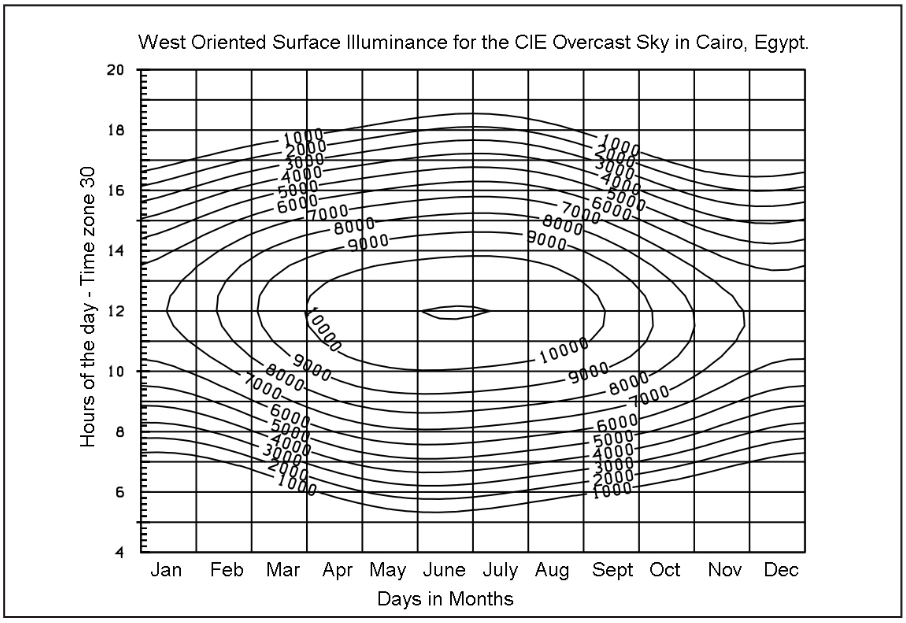


Figure 5.51 *Isolux curves represent the outdoor annual illuminance for the CIE overcast sky on a west oriented surface in Cairo, Egypt, coordinates : 30°1′ longitude, 31°4′ latitude. Note: without ground reflectance illuminance. (with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).*

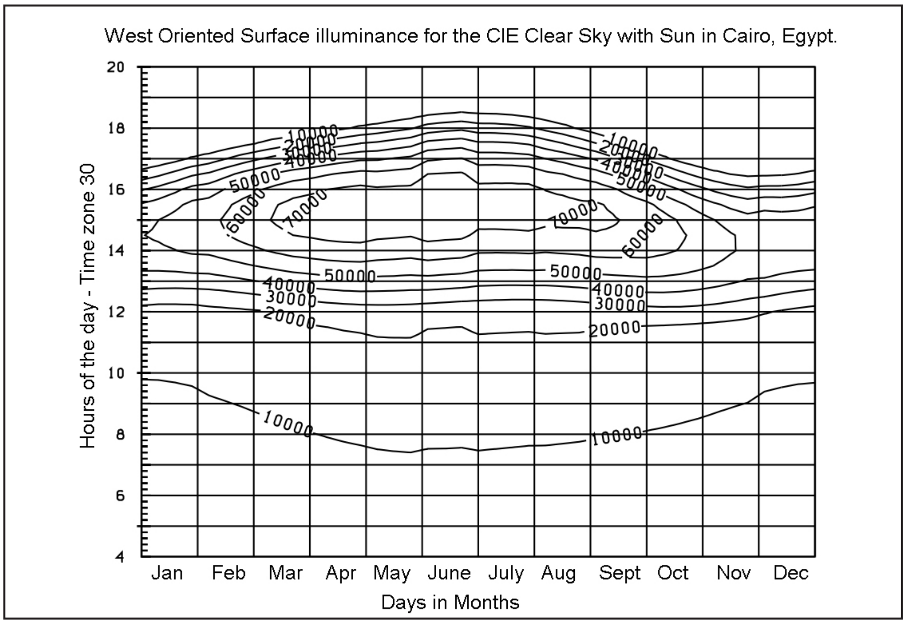


Figure 5.52 *Isolux curves represent the outdoor annual illuminance for the CIE clear sky with sun on a west oriented surface in Cairo, Egypt, coordinates : 30°1' longitude, 31°4' latitude. Note: without ground reflectance illuminance. (with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).*

5.2.1.4.1.2 Cairo climate based sky

The real amount of daylight available at a building site over the course of the year can be derived from the climate information provided from locally recorded weather data to preselected 'typical years' (1), e.g. the EnergyPlus Weather Format (EPW) file.

The EnergyPlus Weather Format (EPW) for Cairo, Egypt, is available in the file (EGY_Cairo.623660_IWEC.epw)(2) at EnergyPlus official site.(3) The file present a lot of meteorological elements among all what is interesting for our study are:

- Global Horizontal illuminance (GHI): Average total amount of direct and diffuse illuminance received on a horizontal surface during the 60-minute period ending at the timestamp.(4)

1. A Typical Meteorological Year (TMY) is a data set of hourly values of solar radiation and meteorological elements for a 1-year period. It consists of months selected from individual years and concatenated to form a complete year. The intended use is for computer simulations of solar energy conversion systems and building systems. A TMY provides a standard for hourly data for solar radiation and other meteorological elements that permit performance comparisons of system types and configurations for one or more locations. William Marion and Ken Urban, User's Manual for TMY2s, <http://rredc.nrel.gov/solar/pubs/tmy2/overview.html>, (17.06.2016).
2. The International Weather for Energy Calculations (IWEC) data files are ‘typical’ weather files suitable for use with building energy simulation programs for 227 locations outside the USA and Canada. The files are derived from up to 18 years of DATSAV3 hourly weather data originally archived at the U S National Climatic Data Center. The weather data is supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements, particularly cloud amount information. < http://bigladdersoftware.com/epx/docs/8-3/auxiliary-programs/source-weather-data-formats.html#international-weather-for-energy-calculations-iwec>, (17.06.2016).
3. Source of the data: <https://energyplus.net/weather-location/africa_wmo_region_1/EGY//EGY_Cairo.623660_IWEC>, (17.06.2016).
4. S. Wilcox and W. Marion, User's Manual for TMY3 Data Sets, National Renewable Energy Laboratory, USA, 2008, p5.

- Diffuse Horizontal illuminance (DHI): Average amount of illuminance received from the sky (excluding the solar disk) on a horizontal surface during the 60-minute period ending at the timestamp.[1]

Additionally, from this two data we can calculate the average amount of illuminance received from the solar disk (excluding the sky) on a horizontal surface. Simply: GHI - DHI = Solar Horizontal Illuminance. For abbreviation in our work we will use (SHI).

Following information can be constructed from the climate data[2]:

- The data show that the Climate Sky has higher illuminance levels than the standard CIE Skies.
- The Climate Sky has maximum horizontal illuminance GHI 112.900 lx, consists of SHI 92.200 lx from the direct solar radiation and HDI 20.700 lx from the scattered light in the sky.
- Heavy overcast sky is recorded only four times in the data. The least value for an overcast sky at noon is GHI 21.200 lx. Heavy overcast sky can determines from the sky cover data.
- The annual average horizontal illuminance between 8:00-17:00 are ~55.500 lx divided to DHI ~24.000 lx and SHI ~31.500 lx.
- For the west facade, without reflected illuminance from the ground, before noun the GHI range between ~10.000 to ~23.000 lx and in the after noon it increases till maximum ~80.000 lx in summer. It change dramatically during the course of the day and year.

More interesting value for the daylight in Cairo, Egypt, are presented in the table (Table 5.1) and see (Figure 5.53 and Figure 5.54).

Addition to the information that can be obtained from the data, based on annual climate file a calculation for the sky luminance distribution for direct and diffuse irradiance can be generated. This give the ability to model all sky conditions at building site over the course of the year and analyse annual building performance.

It is important to point out that, because the Typical Meteorological Year (TMY), represents climate data conditions judged to be typical over a long period of time; it can not describe extreme conditions and its components can not meet the worst-case conditions occurring at a location. Thus the data are not suited for designing daylight systems.[3] However, climate data is important to judge how the building is going to perform over the course of the year. Further, according to the information available for our case, the climate data shows more extreme

1. Previous reference, p5.
2. The climate data can be viewed with Weather Data Visualisation Program like DView software, which creates a lot of info diagrams that help to understand the daylight condition. As well, data can be converted to an Excel sheet contains all hourly recorded values. <https://beopt.nrel.gov/file/DView125.exe>, (18.06.2016).
3. William Marion and Ken Urban, User's Manual for TMY2s, <http://rredc.nrel.gov/solar/pubs/tmy2/overview.html>, (17.06.2016).

conditions, since it shows a higher illuminance for the GHI than the CIE Standard Clear Sky with Sun. Generally, a design has to benefit from the standard skies in facilitate designing daylight system under extreme or selected condition and from the climate sky in judging the applicability of the design in real condition.

5.2.1.4.1.3 Sunshine probability

After the norm 5034, part 2, the sunshine probability in Cairo, Egypt location is 79,8%, where monthly percentages are:

Jan. 73, Feb. 76, Mar. 75, Apr. 75, May 79 , June 84,

July 85, Aug. 85, Sept.87, Oct. 85, Nov. 82, Dec. 72.[1]

This gives the indication that the dominant sky conditions over Cairo is the clear sky and the intermediate sky with light cloud cover.

Interest Point	Date	GHI	DHI	SHI	Total Sky Cover	Opaque Sky Cover
Highest GHI	22.05.1988	112.900	20.700	92.200	0	0
Highest DHI	09.05.1988	79.000	77.600	1.400	5	2
Highest SHI	22.06.1988	109.400	15.200	94.200	4	0
Overcast Sky with least GHI	04.01.1988	21.200	21.200	0	10	6
Spring equinox	21.03.1994	80.600	44.100	36.500	3	3
Summer Solstice	21.06.1986	85.200	55.300	29.900	4	0
Autumn equinox	21.09.1993	94.800	17.500	77.300	0	0
Winter Solstice	21.12.1989	57600	24.500	33.100	2	2

Note: All information are from the data (EGY_Cairo.623660_IWEC.epw) from the (www.energyplus.net) site. All illuminance value are in Lux at 12:00 pm. The dates are from a Typical Meteorological Year (TMY): typical average months selected from 18 individual years and concatenated to form a compleat year.

Table 5.4 *Some interesting values for the Daylight in Cairo, Egypt. Data from the climate file (EGY_Cairo.623660_IWEC.epw).*

1. Data Bank, Research and Development department, Bartenbach GmbH, Innsbruck, Austria, with permission.

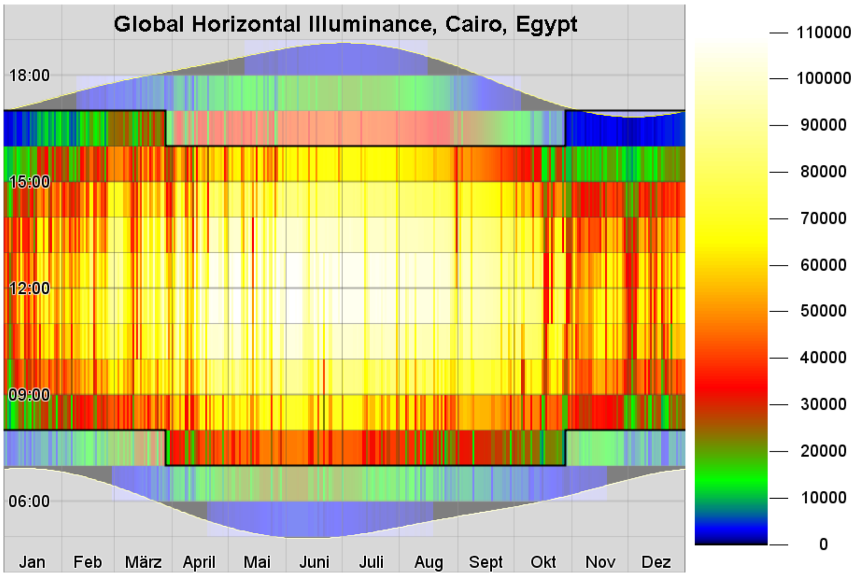


Figure 5.53 *A temporal maps for the Annual Global Horizontal Illuminance for Cairo, Egypt. Data from the climate file (EGY_Cairo.623660_IWEC.epw). (with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).*

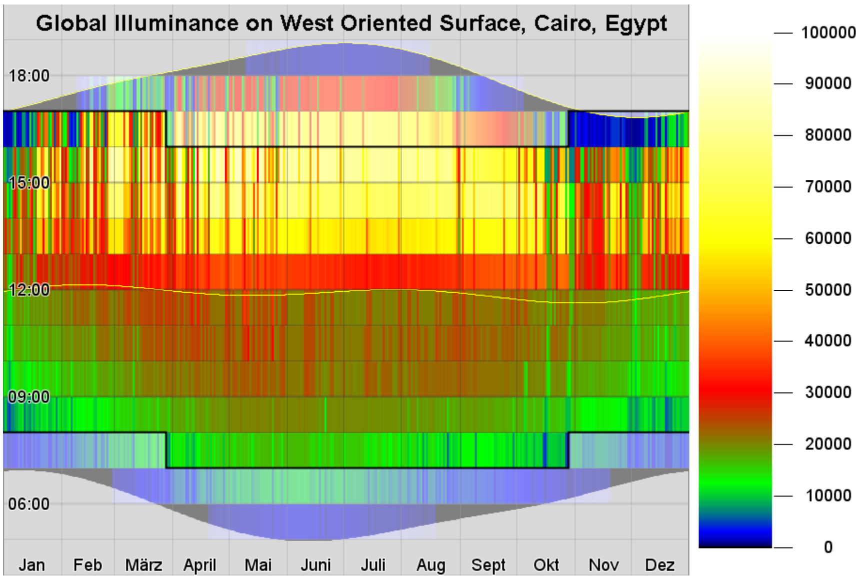


Figure 5.54 *A temporal maps for the Annual Global Illuminance on west oriented surface for Cairo, Egypt. Data from the climate file (EGY_Cairo.623660_IWEC.epw). Note: without ground reflectance illuminance. (with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).*

5.2.1.4.1.4 Stereographic Sun Path Diagrams

Sun path diagrams give information about how the sun will impact the site and building throughout the year. It can define sun position at any hour and date of the year.

For Cairo, Egypt, position very significant info:[1]

Spring equinox: 21/03 @12:00 azimuth 1,9°; altitude 59,58°

Summer Solstice: 21/06 @12:00 azimuth 185,12°; altitude 83,43°

Autumn equinox: 21/09 @12:00 azimuth -5,81°; altitude 59,67°

Winter Solstice: 21/12 @12:00 azimuth 181,54°; altitude 36,53°

1. A precise calculation for the angle can be done with softwares and online tools, e.g. <http://www.pveducation.org/pvcdrom/properties-of-sunlight/sun-position-calculator>, (20.06.1916).

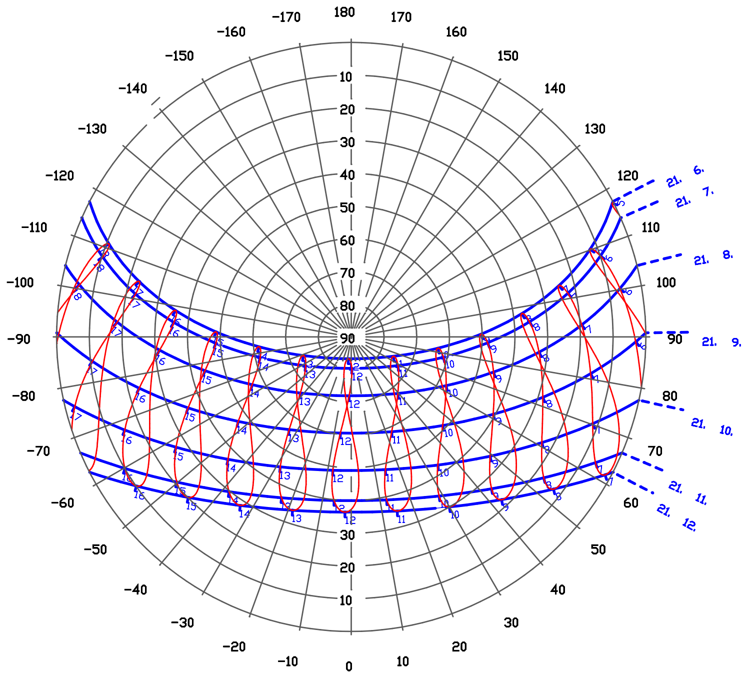


Figure 5.55 *Stereographic Sun Path Diagrams for Cairo, Egypt. Location 30.1 E, 31,4 N*
Azimuth angle: run around the edge of the diagram.
Altitude angle: concentric circular lines that run around the centre of the diagram out.
Date Lines: the path of the sun on one particular day. (Red Lines)
Hour Lines / Analemma: lines that intersect the date lines and represent the position of the sun at a specific hour of the day. (Blue Lines)
(with permission: Research and Development department, Bartenbach GmbH, Innsbruck, Austria).

5.2.1.4.1.5 The sky cover

The sky cover is an important indicator to understand the condition of the sky. In the weather data there are two factors to describe the sky cover. First, The Total Sky Cover: amount of sky dome covered by clouds or obscuring phenomena at the time indicated. Second, The Opaque Sky Cover: amount of sky dome covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the time indicated. Both factors are measured on a scale of one to ten, with 1 tenth resolution.[1]

The monthly statistic for the total sky cover show 4,8 annual daily high and 1,8 mean; and it show for the opaque sky cover 3,6 annual daily high and 1,3 mean. The sky over Cairo tend to be partly in the intermediate condition when it is cloudy and the totally overcast condition is seldom to occur. Anyway, the clear sky condition is dominating. (Figure 5.56)

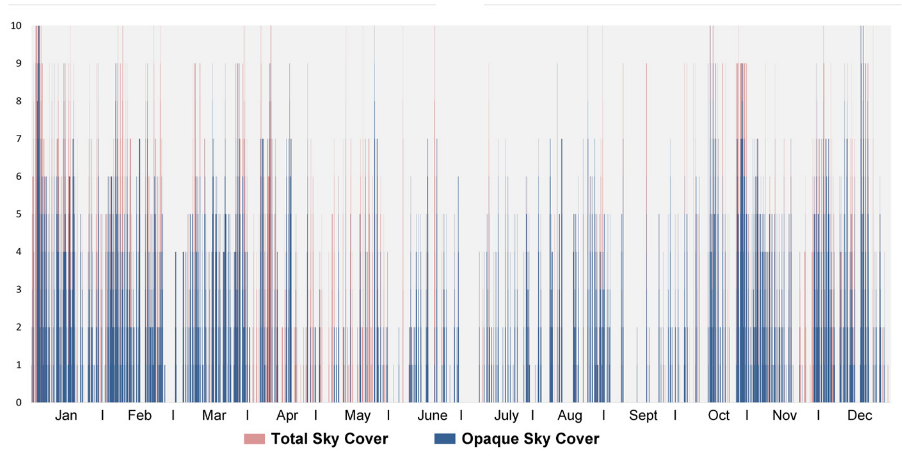


Figure 5.56 *Hourly recorded Total Sky Cover and The Opaque Sky Cover for Cairo, Egypt. Data from the climate file (EGY_Cairo.623660_IWEC.epw). Note: Shaded gray are is the time when the sky is clear.*

1. S. Wilcox and W. Marion, User's Manual for TMY3 Data Sets, National Renewable Energy Laboratory, USA, 2008, p5.

5.2.1.4.2 Physical scale model analysis

In this step we will use the physical model to evaluate the performance of the existing skylights and windows, and to estimate the physical amount of daylight available in area of study. Furthermore, in coming steps the model will be used as a design tool.

5.2.1.4.2.1 Model description

The model represent the area of study in scale of 1:20. This scale was chosen to help us integrate daylight components and systems that cannot be reduced in size and study their performance. (Figure 5.57 to Figure 5.60).

As a compromise to reduce model mass, the lateral galleries in both floors were reduced in length and two mirrors were installed parallel to each other in the ends of the galleries to compensate visually the loss of length and physically the loss of illuminance that would come from the windows that were not built in the model. As lighting technique, this method is acceptable in the GF, while is not for the UF. Since the position of the skylight is not symmetrical in the space. This makes the measurements in this area higher than normal. We handled this situation by blocking the ends of the Lateral Gallery UF during the measurement with a black boards.

The model is built with MDF wood according to the architecture of the building and the interior of the model was covered with paper. We had chosen the walls' colour little bit brighter than the original colour and the skylight glass transparent instead of the existing reinforced translucent glass, because the original colour and glass were nonhomogeneous and we wanted to test the maximum performance of the building. (Figure 5.59)

Materials Light Reflectance Value (LRV) and transparency (*t*) are:

- Walls: bright beige paper LRV ~85%
- Floors: printed gray marble texture on white paper LRV ~65%
- Ceilings: white paper LRV ~87%
- Plexiglas: *t* ~90%

External Model's dimension are: 1,08 x 1,26 m and height 0,92 m. The model is placed on a movable wheeled table with height 1,10 m

Additionally to the model , we built a shadow element that represent the parts of the museum building that can cast shadow and influence the amount of light falling on the architectural apertures. (Figure 5.58)

5.2.1.4.2.2 Measurements configurations

The measurements were conducted in the Artificial Sky at Bartenbach GmbH.[1] The Artificial Sky is a sky simulator has a half-dome space with about 6 meters diameter and it is raised at 1,10 m from

1. Bartenbach GmbH, Innsbruck, Austria, with permission.

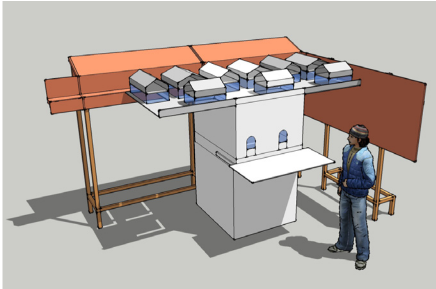


Figure 5.57 *(left) The location of study area in the Museum's West Wing.*

Figure 5.58 *(right) A perspective for the model and the shadow elements.*

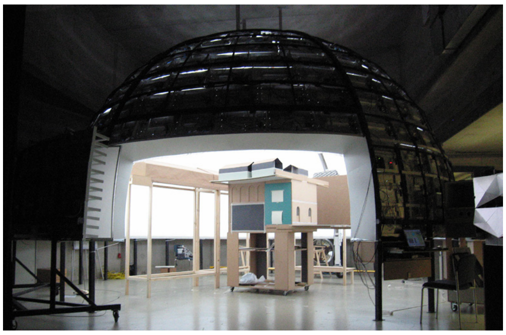


Figure 5.59 *(left) The physical scale model from inside.*

Figure 5.60 *(right) The model and the shadow elements inside the Artificial Sky at Bartenbach GmbH.*

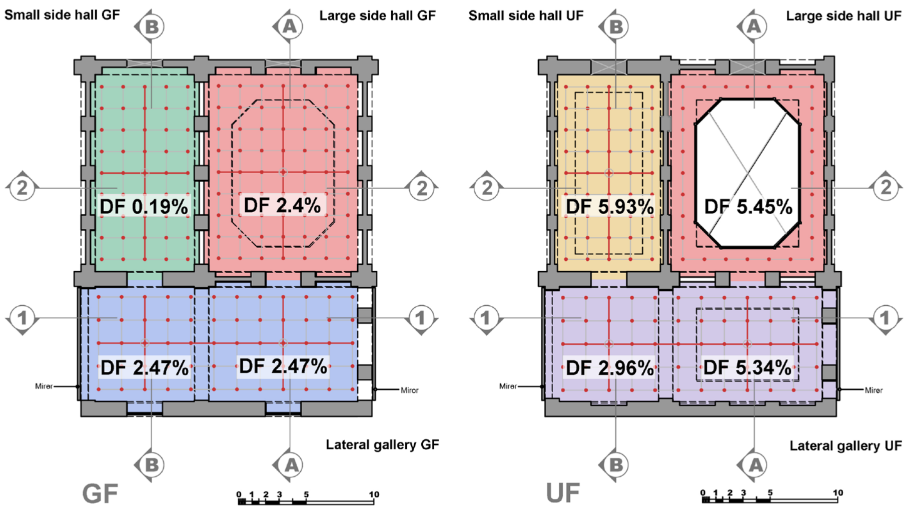


Figure 5.61 *The ground and upper floor plans for the area of study. The plans show the measurements raster and the average daylight factor.*

the ground on metal supports. The half-dome inner surface is from a plastic membrane, that is back-lit with mini size fluorescent tube. The membrane brightness is adjusted to create different luminance distribution to simulate standard sky conditions. Additionally, there is a set of LEDs with very narrow beam lenses fixed on a adjustable arm to simulate the sun position and its parallel rays. (Figure 5.60)

The measurement points in every space are organized in a raster as shown in figure (Figure 5.61). Distance between each two points in the model is 8 cm = 1,6 m in reality. Height of the measurement surface above the floor in the model is 4,2 cm = 0,85 m in reality.

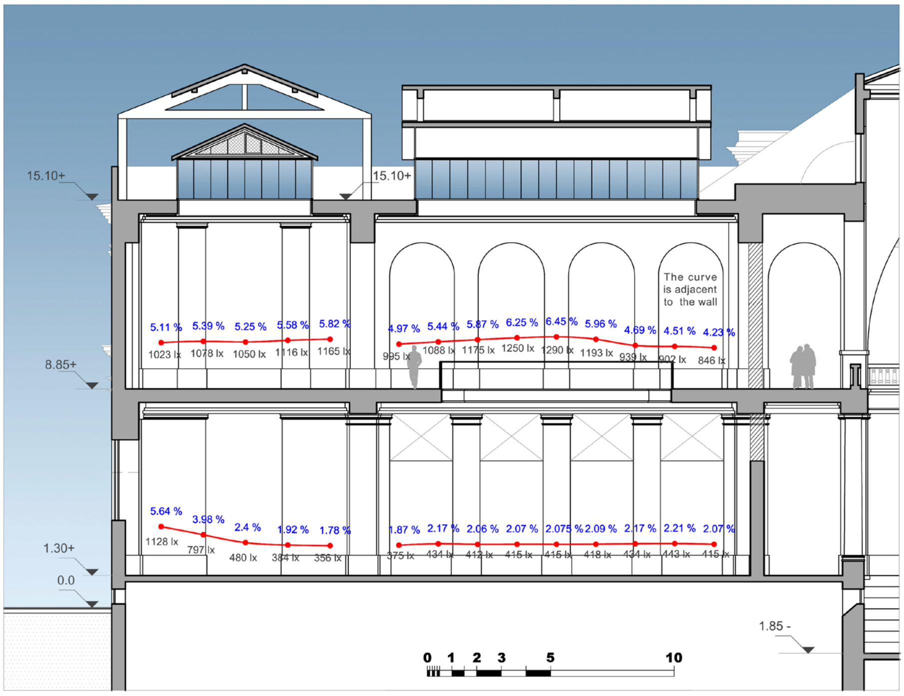


Figure 5.62 *Section A-A showing the daylight factor under overcast sky and the horizontal illumination value at working plane (0.85 m), when the sky has 20.000 lx. (See the plan in figure 5.61)*

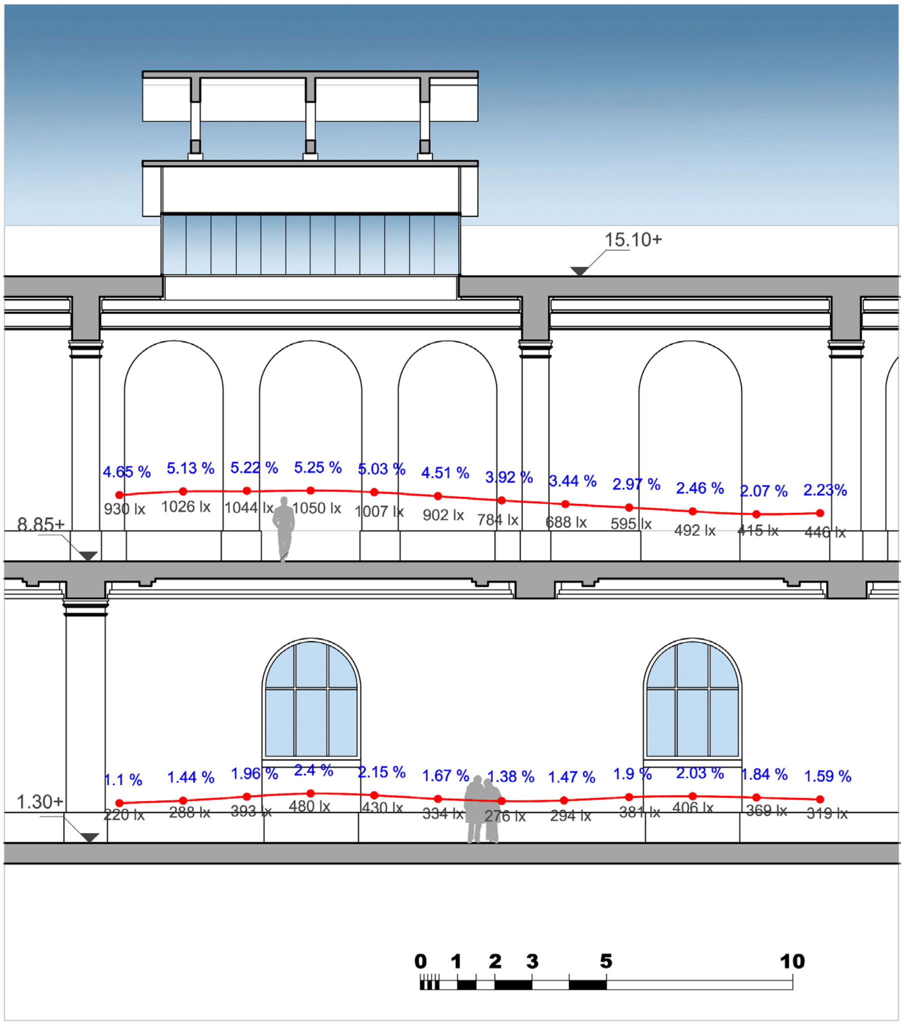


Figure 5.63 *Section 1-1 showing the daylight factor under overcast sky and the horizontal illumination value at working plane (0.85 m), when the sky has 20.000 lx. (See the plan in figure 5.61).*

Figure 5.64 *Section B-B showing the daylight factor under overcast sky and the horizontal illumination value at working plane (0.85 m), when the sky has 20.000 lx. (See the plan in figure 5.61)*

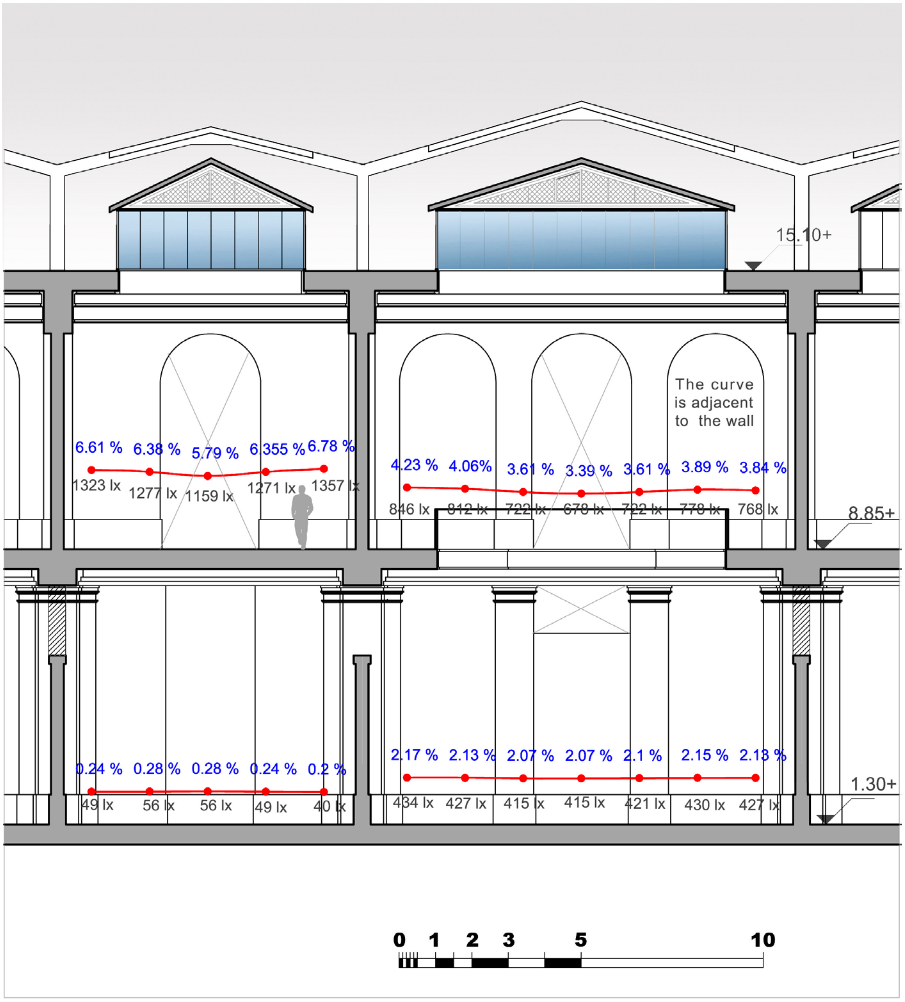


Figure 5.65 *Section 2-2 showing the daylight factor under overcast sky and the horizontal illumination value at working plane (0.85 m), when the sky has 20.000 lx. (See the plan in figure 5.61)*

5.2.1.4.2.3 Daylighting evaluation

The measurements were conducted in the artificial sky under the standard overcast sky adjustment, which means the half-dome luminance distribution ratio is 3:1 zenith-to-horizon. Accordingly, daylight factor is used as performance indicator and a measurement value.

The daylight factor (*DF)* is the ratio of the illuminance received at an interior point to the exterior horizontal illuminance produced by an overcast sky.[1]

$$DF = E_{int} / E_{kh,oc}$$

Where: E_{int} = interior illuminance at a point; $E_{kh,oc}$ = exterior horizontal illuminance from an overcast sky.

The IES recommendations for average daylight factor ($\overline{DF}$) ranges between 2 to 5% to provide adequate levels of daylight in an overcast climate. With a daylighting system that applies skylights in a location having predominantly clear skies, a daylighting factor closer to 1% is more appropriate.[2]

The average daylight factor ($\overline{DF}$) for every space at the working plan (0,85 m) was calculated from the model. See results in (Figure 5.61). According to IES recommendations, under overcast sky condition all spaces, except the Small Side Hall GF, have adequate daylight levels. However, the spaces in the upper floor have good daylight levels, and the space in the ground floor have slightly exceed the lower levels of recommendation. (Figure 5.61-to-Figure 5.65)

Additionally, under clear sky condition all spaces with skylight have sufficient levels of daylight. The IES did not determine any recommended $\overline{DF}$ for the side lit rooms under a clear sky. However, we can estimate that the Lateral Gallery GF in the west facade before noon will have sufficient illuminance from the sky. Since the value of DHI of clear sky is closer to that of overcast sky, and assuming that reflected sun rays from the surrounding and sky luminance distribution in this case is insignificant. A side lit room under clear sky with $\overline{DF}$ ranges between 2 to 5% will have adequate levels of daylight. In the after noon the sun rays will fall directly on the windows and penetrate the space, thus the illuminance level will increase. However, the sun rays will wander in the space continuously changing the light distribution; and harming the visual comfort. (Figure 5.66 d and f)

Generally, if a space under overcast sky condition have adequate daylight, it will for sure have adequate daylight under clear sky. The evaluation with $\overline{DF}$ insures that in overcast days or partly cloudy sky days the museum spaces will have adequate lights. However, if a daylight system is installed to block or reflect the sun rays; the $\overline{DF}$ will have no indication under clear sky, and another method of evaluation has to take place. More precise calculation will be carried out during the design steps.

1. IESNA, The Lighting handbook, Designing Daylighting,10th Ed. 2011, p14.46.
2. Previous reference, p14.46.

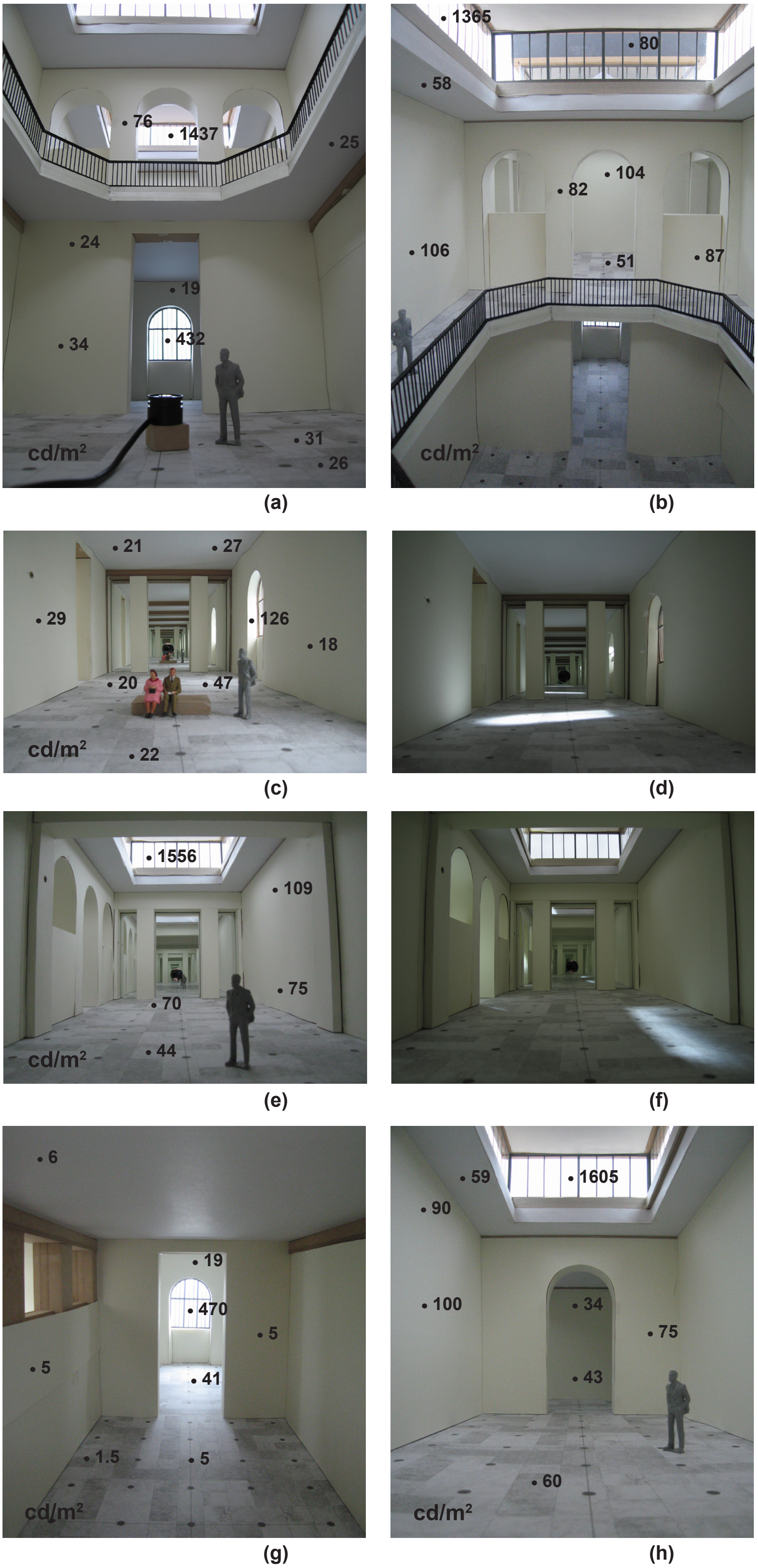


Figure 5.66 *Luminance distribution inside the model.*
(a) The Large Side Hall GF.
(b) The Large Side Hall UF.
(c) The lateral gallery GF.
(d) The lateral gallery GF.
(e) The lateral gallery UF.
(f) The lateral gallery UF.
(g) The Small Side Hall UF.
(h) The Small Side Hall GF.

(a), (b), (c), (e), (g), and (h) show the luminance distribution inside the model in cd/m² under overcast sky in the artificial sky at Bartenbach GmbH. Horizontal diffuse illuminance above the skylight 5960 lx.

(d) and (f) show the spaces under the same diffuse condition plus the sun. The sun alters the space atmosphere and the luminance distribution. The contrast of the strong sun spot light with the surrounding makes the spaces look darker.

Realize the comparison between: the lateral gallery GF (c) diffuse sky (d) diffuse sky plus after noon sun. As well, the lateral gallery UF (e) diffuse sky (f) diffuse sky plus before noon sun.

Note: Luminance measurements were taken from an luminance photos.

Average Daylight Factor on the working plan is widely used for spaces were reading and writing is the main visual tasks. For museum lighting design, knowing levels of illuminance and its distribution on the walls and floor are important. Accordingly, a set of luminance photos were captured during the measurement and the $\overline{DF}$ on the floor and walls were calculated. See (Figure 5.66) for luminance distribution and (Table 5.2) for $\overline{DF}$ values. Generally, the walls' $\overline{DF}$ results match with the previous results and emphasize it. Distribution of illuminance in spaces with skylight is better than side lit spaces. Walls in spaces with skylight has good $\overline{DF}$, which mean good daylight levels. Walls in the Large Side Hall GF have the minimum levels of recommendation. The Lateral Gallery GF has DF lower than recommended levels. The Small Side Hall GF is relatively dark.

5.2.1.4.3 Digital model analysis

A digital 3D model is built with SketchUp software for the museum and the surrounding to study the shadows and direct sunlight that fall on the skylights and windows. Furthermore, in coming steps the model will be used to calculate the illuminance falling on the architecture apertures and daylight systems. (Figure 5.67 and Figure 5.1)

5.2.1.4.3.1 Shadows study

With the help of SketchUp and Photoshop softwares a Shadow Profile (a pattern of overlapped shadows) is created to study the cast shadows on the building during the course of the day and year. (Figure 5.68) The study show the shadows before noon (8:00-12:00) and after noon (13:00 -17:00); during the working hours (8:00-17:00); in 21 June (summer solstice), 21 Sep (autumn equinox), and 12 Dec (winter solstice).

Before noon (8:00-12:00): In the West Wing, the seven windows of the Lateral Gallery GF receive only light from the sky. Concerning the skylights, all skylights are sunlit in 21 June; they become partly shaded in 21 Sep; and they become more shaded in 21 Dec. The shadows are generated from the central skylight roof and the South Wing roof. The first skylight over R42 and R41 are more affected by the shadows. Accordingly, The difference between skylights' illuminance between summer and winter are more than normally expected, and the skylight over R42 and R41 will have the least illuminance in winter time than other skylights.

In the after noon (12:00-17:00): The sun start to fall on the West Wing's facade. All windows are sunlit in 21 Jun. The first window receive shadows from the South Wing in 21 Sep and the shadow expand to cover the first three windows in 21 Dec. This makes the differences in illuminance between the windows in the beginning and end of the Lateral Gallery GF extremely large. Additionally, the first windows receive less illuminance not only because of the cast shadows but also because they view less from the sky. Concerning the skylights, all skylight are sunlit in 21 Jun. The shadow of the South Wing roof falls over R42 and R41

Interest Area	Wall	Floor	Ceiling
The Large Side Hall GF	2,03	2,26	1,4
The Large Side Hall UP	5,66	7,28	3,5
The lateral gallery GF	1,79 opposite to Windows 1,17 windows' wall	1,83	1,35
The lateral gallery UF	4,8 under the skylight 3,4 far from the skylight	5,53 3,8	3,45 ------
The Small Side Hall GF	0,3	0,57	0,41
The Small Side Hall UF	5,5	5,53	3,39
Note: The average daylight factor values are calculated form average luminance value taken from luminance photos during the measurement.			

Table 5.5 *The average daylight factor on walls, floor, and ceiling inside the model.*

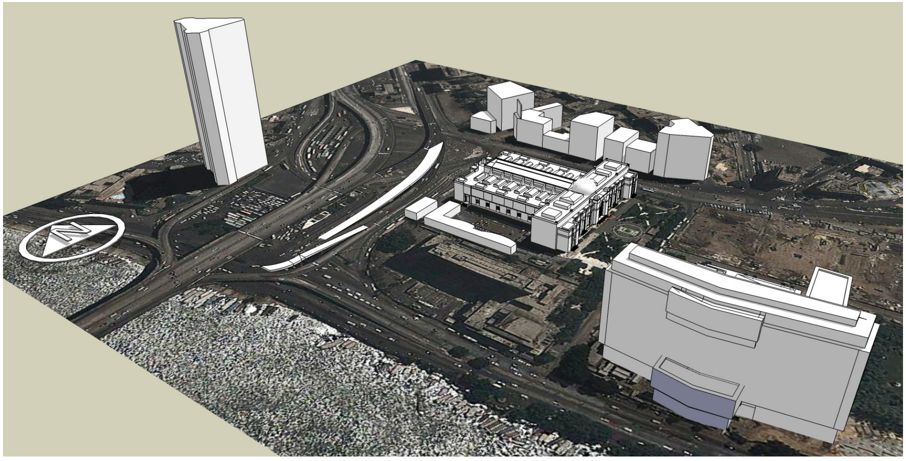
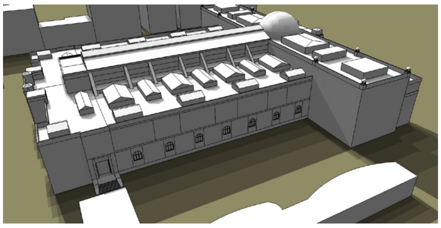
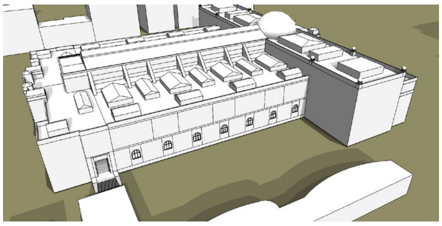


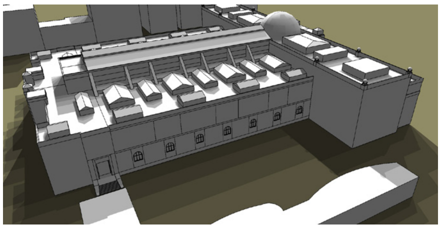
Figure 5.67 *A digital 3D model for the museum and the surrounding. The model is built using SketchUp software. The ground photo of the site is from Google Earth software.*



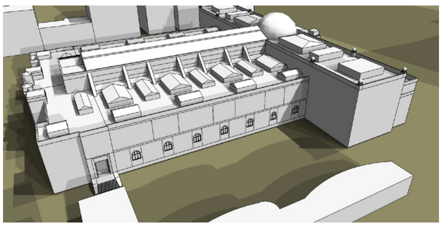
21 June 8:00 - 12:00



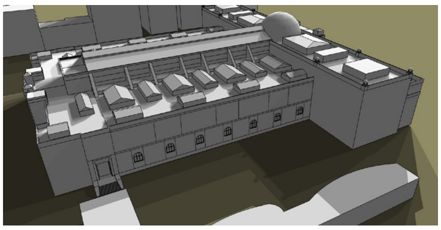
21 June 13:00 - 17:00



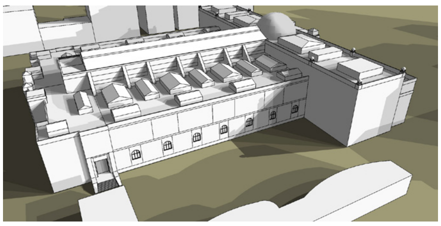
21 Sep 8:00 - 12:00



21 Sep 13:00 - 17:00



21 Dec 8:00 - 12:00



21 Dec 13:00 - 16:00

Figure 5.68 *A shadow study for the museum's West Wing. The study present the before noon (8:00-12:00) and after noon (13:00 -17:00) shadows during the working hours (8:00-17:00) in 21 June (summer solstice), 21 Sep (autumn equinox), and 12 Dec (winter solstice).*

in 21 Sep and start to expand in winter. The skylight over the Lateral Gallery UF are affected with the cast shadow from the roof fence especially when the sun is low. Accordingly, the Large Side Hall R42 and the first zone in the Lateral Galley UF will have less illuminance during the course of the year not only because the shadows they receive, but also because they view less area from the sky.

5.2.1.4.3.2 Sun path analysis for the windows

Studying the hours of direct sun and incident shadows annually can be done by superimpose a sun path diagram onto a fisheye/hemispherical rendering image. With the use of Relux[(1)] software we created a set of hemispherical rendering image toward the north from the centre of every window and we overlay a vertical sunbath diagram on the photo. (Figure 5.69) Note: The images were made before demolishing The National Democratic Party building. (Figure 5.1) We left the building in the image to give an impression about how much sun and sky the building will block, if it exist or any other building in this location.

The windows are numbered from 1 to 7 in the direction from south to north. The museum South Wing block part of the sky in the windows, as a result the more the window's position moves far from the South Wing, the more light from the sky the window receives. As well, the South Wing block part of the sun path especially low sun positions, as a result the north windows receive more direct sun light annually. From these facts we can conclude that, the amount of illuminance received by every window dramatically changes during the course of the day and the year. The illuminance in front of the first window is lower than other windows and it increases as the window's position moves toward the north. Moreover, there is a big difference in illuminance levels before and after 12:00 pm. More precise calculation for the illuminance incident on the windows will be carried out during the design steps.

5.2.1.4.4 Conclusion: guidelines for design.

- **In general,** the museum's spaces have sufficient daylight, except the Small Side Hall GF. Further, daylight levels in spaces with skylight are high and they are expected to be increased after eliminating the external reinforced concrete structure. Nevertheless, the main problem in the existing condition lays in the daylight distribution, and the lack of professional artificial light.
- **The Large Side Hall GF & UP** have adequate light levels, however it lacks a god distribution. According to the existing exhibits in display the illuminance is oppositely distributed. The high levels of illuminance exist in the upper floor where low-responsive-to-light exhibits are displayed in showcases, and the low levels of illuminance exist in the ground floor where the stone exhibits are displayed. A redistribution of illuminance levels is needed.

1. A light simulation tool, see following site for information (http://www.relux.biz/index.php?lang=en).

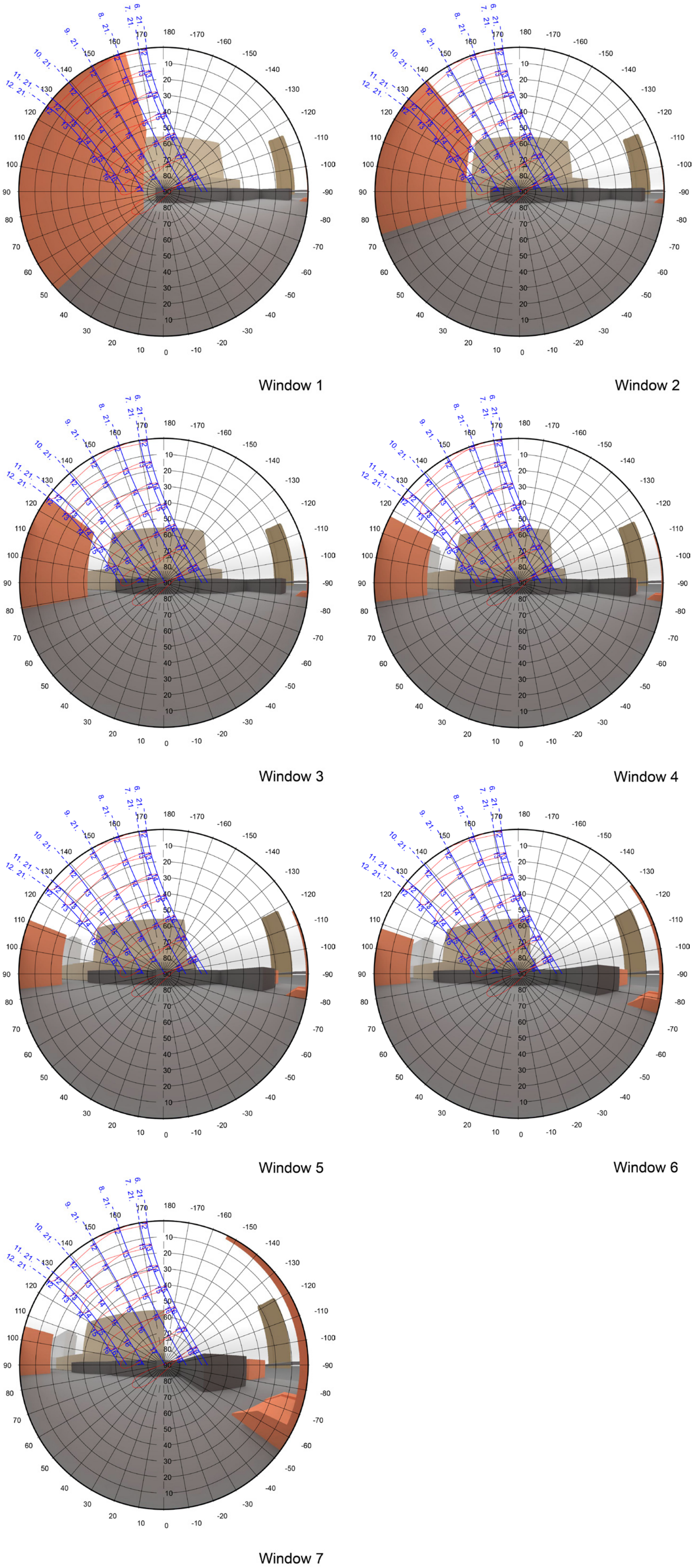


Figure 5.69 *A sun path diagram overlay a hemi-spherical rendering image, to study the hours of direct sun and incident shadows annually on the windows of the lateral gallery GF. The windows are numbered from 1 to 7 in the direction from south to north. Note: The National Demo-cratic Party building (the gray building in the meddle of the view) do not exist any more. (see fFigure 5.1)*

- **The Small Side Hall GF** is mainly attached to the Large Side Hall GF and it has insufficient daylight. The space has to be lit with artificial light.
- **The Small Side Hall UF** has a plenty of daylight. However, most of the exhibits are low-responsive-to-light, thus the illuminance levels and distribution have to be controlled to consistent with the exhibits' needs.
- **The Lateral Gallery UF** has uneven daylight distribution due to the location of the skylight. The zone in front of the Large Side Hall UF has almost double the daylight levels of the zone in front of the Small Side Hall UF. The illuminance levels have to be redistributed and controlled for the sac of the exhibits, or the exhibits in display have to take the existing light situation in consideration.
- **The Lateral Gallery GF** is a side-lit space, its windows are oriented west. There is a big difference between levels of illuminance before and after 12:00 pm, between windows located in the south and in the north, and between the walls opposite to the windows and windows' wall. These differences can be controlled and regulated with daylight systems.

Note: The order of spaces changes according to the subject of study.

5.2.2 Taking inventory (Museum authority prerequisites)

Taking inventory is to collect information, thoughts, and visions from the client, architect, users about the projects; as well reviewing available design documents, and requests and standards for qualifications.(1) Since we have already explained the museum standards in the first chapter and analysed the building in the previous part; we will focus here on the museum authority prerequisites that can affect the interior and lighting design. The museum authority prerequisites mainly derived from a renovation study made for the museum in 2009.(2)

The main goal of museum's authority renovation plan is to respect the original architecture by leaving the original walls, archways and passages, while eliminating the subsequent modifications that have altered the original design of the museum. As well, to insure that the adopted modern exhibition design does not contrast with or conceal the architecture, but rather enhances it by emphasizing its spatiality.

(See 2.2.3 The Neues Museum in Berlin for renovated museum example).

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1. IESNA, The Lighting handbook, Lightin design in the building design process,10th Ed. 2011, p11.7.
2. The Redesign of the Egyptian Museum Midan Tahrir, 2009, Part 2, Ch.1, (pages 152-to-179). This is a study made by an Italian team and sponsored by Italian Authority (Ministero degli Affari Esteri Roma, Ministero degli Affari Esteri Cooperazione Italiana allo Sviluppo, Ministero per i reni e attività culturali, Museum Engineering SRL, and Laboratorio museo tecnico Goppion). The study was presented to the Egyptian Supreme Council of Antiquities as a future plan to redesign the Egyptian Museum. I was given the part (page 152-to-179) from Dr. Tarek El Awady, the director of the Egyptian museum 2011, as a guideline and support for my work.

What mainly included in renovation plan and may alter the lighting concept are:

- Demolition of the reinforced concrete roofs over the skylights.
- Restoring the original lighter colour, similar to the stone decoration, to the facades.
- Integrated rooms R27, R17, R19, R29 and R39 that are used for the storage to be used as exhibition space in the newly renovated museum.
- Restoring the original interior settings. Accordingly, an investigation has to be carried out to determine the original colour of the rooms and the original nature of the their floors, which are currently hidden underneath non-homogeneous and incongruous flooring.
- Installing a HVAC system to ensure comfort of the visitors an the proper conservation of the artifacts. This will require redesign of the natural and artificial lighting systems that use the roof. *(See 3.1.2.2 Interaction between lighting systems and environmental).*
- Installing a micro climate control system for some of the showcases. *(See 3.1.2.1 Museum active environmental control units).*
- Installing a set of building electromechanical systems like: electrical system, plumbing system, fire protection system, telecommunications system, etc.

5.2.3 Lighting design goals

In general, lighting design goals can be classified to analytic and aesthetics aspects. Analytical aspects are categorized as physiological factors, task factors, and systems factors. While aesthetic aspects are about the spatial and the physiological factors, i.e. about the look and feel of the space.(1)

Analytical goals:

- Optimizing the use of daylight in museum without damaging museum objects and avoiding discomfort situations. This goal is necessary since Egypt is a land with abundance of daylight and there is a sufficient daylight in the museum's spaces. This will enhance the human well being, the appearance of the exhibits, the feeling of the space, and save energy. *(See 1.2.1.2 Daylight advantages and 1.2.1.3 Daylighting criteria in museum).*
- Optimizing lighting conservation aspects. *(See chapter 2).*
- Applying the illuminance and luminance levels according to the standards and the results of our visual perception experiment. *(See 1.1 Human visual performance in museum and chapter 4)*.

1. IESNA, The Lighting handbook, Lightin design in the building design process,10th Ed. 2011, p11.7.

Aesthetical goals:

- Enhancing the appearance of the Egyptian artifacts.

  This can be achieved by:

  - Understanding the exhibits lighting quality and applying the right techniques. *(See 1.3 Exhibits lighting quality and techniques).*

  - Respect the characteristic of the Egyptian art. *(See 2.1.2 Characteristics of the Egyptian art).*

  - Revealing the attributes of Egyptian arts by attain the quality of daylight pattern, the majesty and sacredness of light in the space, and maintaining a visual identity. *(See 2.1.3 Revealing the attributes of Egyptian arts).*

- Maintain the historical architecture aura of the building by respect the original architecture and insure that the new interior and display design do not contradict with or conceal the architecture. *(See 5.2.2 Taking inventory (Museum authority prerequisites))*.

5.2.4 Lighting design strategy

It is obvious from the analysis and the established goals, that a daylight strategy is to be undertaken. A daylight strategy is guaranteed to be successful, since the museum from the beginning is planed to be a daylight museum and its geometry are influenced with used daylight systems. In our case, the daylight strategy will concentrate on enhancing the existing systems to meet the modern museum requirements. Consequently, the artificial light strategy will follow the daylight strategy to boost the daylight when it abate or absent at night. In spaces where no daylight, as in the Small Side Hall GF, artificial light strategy will follow the exhibits and display needs. Selected methods and systems that can lead to achieve design goals well be addressed step-by-step in the design phase.

(See 1.2 Lighting strategies in museum, 1.2.1 Daylighting strategies, and 1.2.2 Artifi cial light strategies)

5.2.5 Interior design concept

Since the museum lack a good display and interior design, it is not correct to proceed in the lighting design process without a new interior design concept. The interior design concept presents a primary theme or element of consistency that is manifested in the project, and provide an idea about the appearance and ambience of the museum at the end of the project.

As a react to client prerequisites, the objective of the interior concept is to respect the original building aura by being simple as possible and response directly to exhibits and museum requirements. As well, to respect and emphasize the characteristic of the Egyptian art: a style of ancient Egyptian beliefs, order and clarity, stylized, symbolic, and associated with architecture. *(See 2.1.2 Characteristics of the Egyptian art).*

5.2.5.1 Key elements of interior concept

- **Reducing the density of exhibits in display:** The museum is very crowded with the exhibits. Thus, an important design priority is to create new areas for the display, e.g. by utilizing the Small Side Halls GF, dividing spaces with partition walls, using spacious showcases, etc. Additionally, it will be helpful if the museum authority store some pieces and change some of the exhibits between the seasons or years.
- **Organizing the exhibits:** We will adapt the existing order where the heavy stone pieces are in the ground floor, the reliefs are on the walls of the ground floor, and sensitive preserved objects mainly in showcases in the upper floor. Additionally, more precise classification will be done, according to exhibits types and conservation aspects. This will facilitate the display and interior design. This task is mainly the museum authority duty.
- **A clear visitor circulation:** One of the problems of the existing interior is the absence of good circulation and guiding text. A good circulation will determines what visitors will see, where they will focus their attention, and what they will experience. Circulation is part of the interior design, as well a part of the narrative story organized by the museum curator. Our new interior configuration will take this in confederation.
- **Background panels:** Reliefs are displayed directly on the walls, and most of them have a sandstone colour which lack a contrast with the original existing walls' colour. Adding dark background behind the relief will enhance its appearance. In addition, the panels will help in fixing the relief and organizing its display without harming the walls. Further, the panels can be a design element in the space. The panels can be constructed from wood, metal or fibres glass.
- **New showcases:** From a lighting design point of view, new showcases have to have enough volume around the exhibits, to be frame-less, and to be with glass roof to allow pointing the light on the exhibits from many directions. As well, an anti reflection coating on the glass is essential to optimise eliminating the veiling reflections. And foremost, showcases design should be as simple as possible to help showing the exhibits and do not contrast with the architecture. *(See good showcases examples in 2.2.2 The State Museum of Egyptian Art in Munich).*
- **New colour scheme:** The new colour scheme is inspired from the colour palette of ancient Egypt. After analysing several coloured wall paintings and reliefs, we chose a set of colours that help to work as a background for the exhibits and do not contradict with its appearance. Main colours are natural beige-gray, dark-gray-green and gray-stone-colour. (See colour palettes in Figure 5.70 and interiors in Figure 5.73 and Figure 5.79).

The colours are applied to the model as follow:

- The ceilings: have a beige-gray tone with LRV ~76%. The bright ceiling help to low the contrast with the skylight's windows and reflect more light in the space.

- The walls: have a beige-gray tone with LRV ~67%. In a daylit space bright wall colour give a since of spacious.

- The statues bases: have a beige-gray tone with LRV ~39%. The colour help to match the bases and showcases with the surrounding.

- The partition-walls and background panels: have a dark-gray-green tone with LRV ~14%. The dark-gray-green help to enhance the stone colour of the reliefs via simultaneous luminance contrast and to emphasize the warm faint colours that is used to draw human figures in the relief via colour contrast. Further, the colour help to connect the display together. The chosen colour can be uniform in the whole museum or replaced with other colour between wings and galleries. Different colour can be assigned to areas, subjects, or historical periods.

- The floors: have a matt marble with gray-stone-colour average LRV 24,5 %. A matt dark floor helps to reduce the reflected image of the skylight and track spot lights, which create a quiet atmosphere and help to concentrate visitor attention on the exhibits. The marble is applied in the model as printed texture on paper.

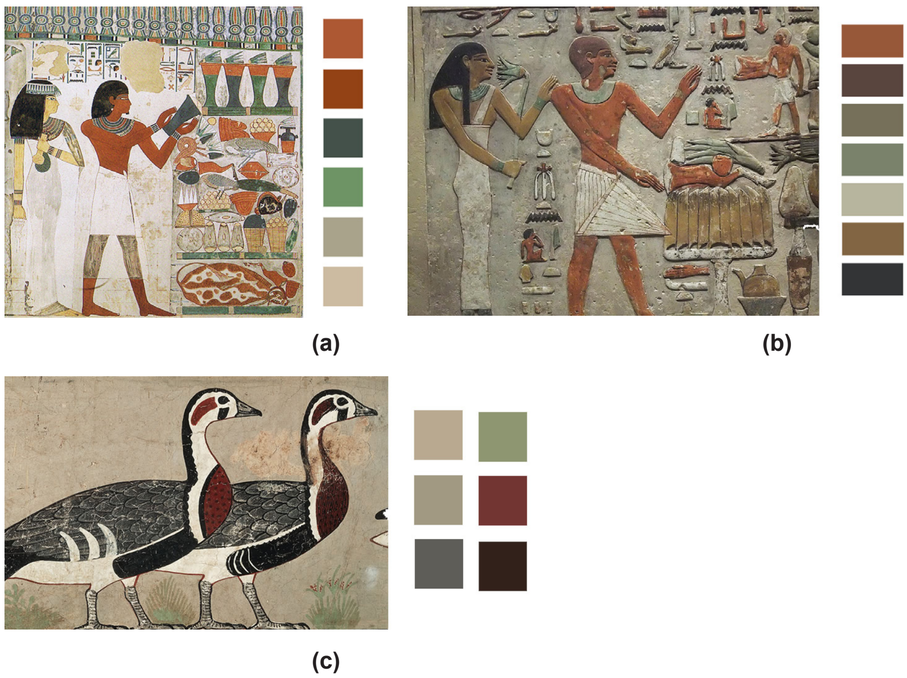

Figure 5.70 *The colour scheme of several ancient Egyptian wall paintings and reliefs. (a) Wall painting from tomb of Nakht (b) Relief fragment from the tomb of Amenemhet and His Wife Hemet (c) Fresco of "Meidum Geese" from Nefermaat's mastaba. Photos references: (https://en.wikipedia.org/wiki/TT52), (https://www.flickr.com/photos/mharrsch/44709039017), and (https://ferrebeekeeper.wordpress.com/tag/egypt/).*

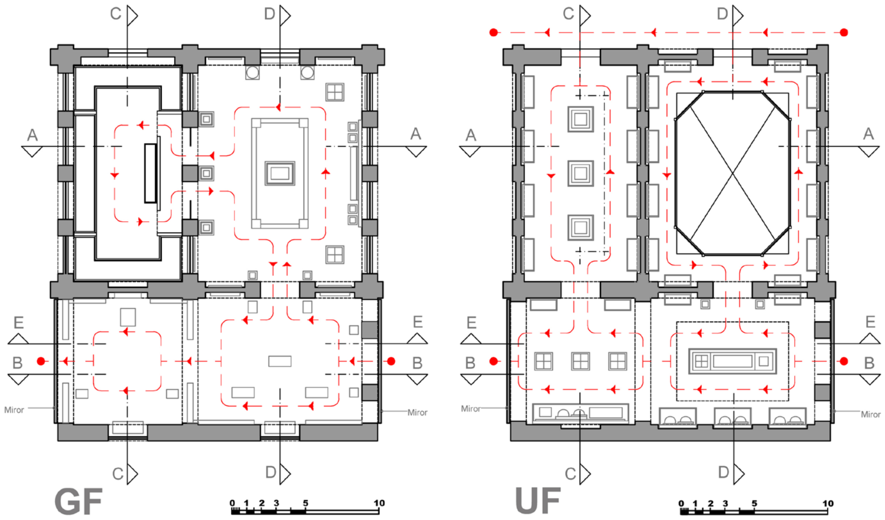

Figure 5.71 *The proposed interior design for the area of study. (left) Ground floor plan. (right) Upper floor plan. The red lines and arrows show the visitor circulation.*

Figure 5.72 *Large Side Hall GF new interior configuration. A 3D drawing with sketchUP software.*

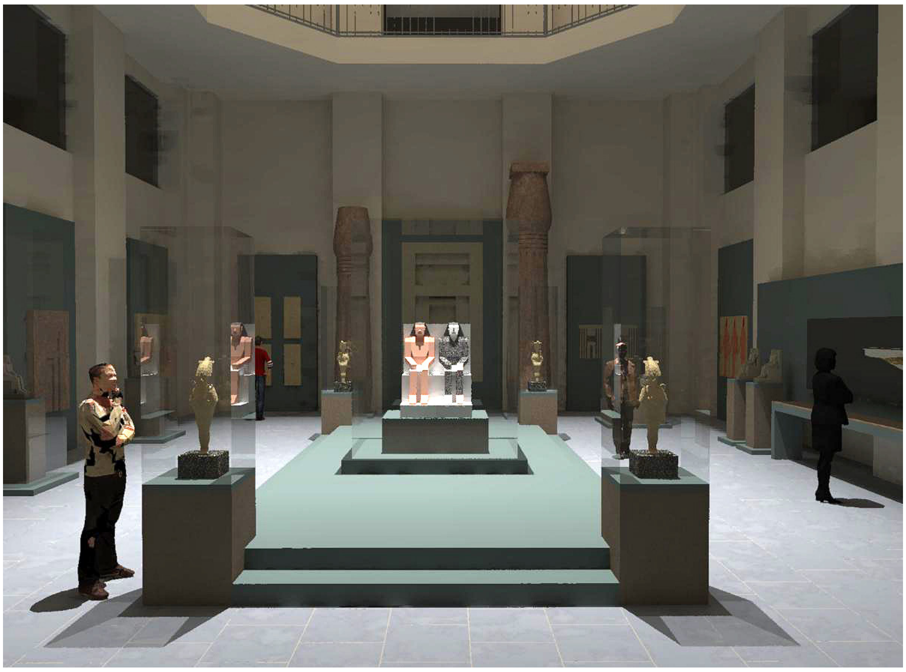

Figure 5.73 *Ray Tracing rendering for the Large Side Hall GF with the new interior and display concept. The lighting in the scene is an attempt to render the new proposed daylighting schemes.*

5.2.5.2 Interior configurations

5.2.5.2.1 The Large Side Hall GF

Based on the existing exhibits in hall R32 the display has the statue of "Rahotep and his wife" as a masterpiece in the middle of the gallery, there is a vast unused area around the masterpiece, most of exhibits are crowded near the walls, and the display is not coherent together. (Figure 5.44 to Figure 5.46) Accordingly, we designed a two steps platform in the middle of the gallery, where the masterpiece is positioned in the centre and four showcases in the corner. The platform helps to organize the visitor circulation, give order to the place, add a majesty to the masterpiece, and connect the display together. In addition, the alignment of the entrance with the platform, the large false door, and the two columns in the background on one axis gives order and a majestic impression for visitors entering the hall. (Figure 5.71 to Figure 5.73).

The Small Side Hall GF is connected to the Large Side Hall GF. We aligned three tall showcases to the large pillars in the entrance of the Small Side Hall to emphasize the entrance and gives it prestige appearance.

The famous fresco of "Meidum Geese" has a new settings with a dark background and large space around it to emphasize its beauty and grab eye attention to it. (Figure 5.46 and Figure 5.72) As well, all reliefs on the walls have a dark background to enhance its appearance. The height and form of the background panel fit with the architecture and add some colour to the walls.

Position of showcases, statues and new display settings respect the architecture and fit with its grid. The spread of the dark-gray-green tone in the background panels, the platform, bases of the statues, and showcases helps to connect the display together.

Note: Not all exist exhibits had been used in the new proposed interior design and some of the exhibits used in the 3D rendering are hypothetical forms to replace the original artifacts in display.

5.2.5.2.2 The Large Side Hall UF

The old cupboards and showcases are replaced with new showcase and there are no other changes in the interior. (Figure 5.47 and Figure 5.74) The new showcases have much space around the exhibits. The showcases' sides and roof are from glass this allow light falling from the skylight to flood the exhibits and allow visitors to have a good view. The dark background enhance the exhibits appearance, help to fix the shelves and needed equipment, and connect the display of the museum together. (Figure 5.74 and Figure 5.75).

5.2.5.2.3 The Small Side Hall GF

All three side hall in the West Wing are added to the display area and connected to the Large Side Halls. Since the side hall has no enough daylight, it is decided to be lit with artificial light and to be utilized

Figure 5.74 *Ray Tracing rendering for the Large Side Hall UF with the new interior and display concept. (The lighting in the scene is an attempt to render the new proposed daylight).*

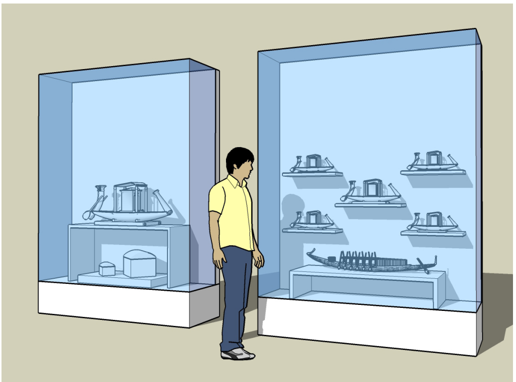

Figure 5.75 *(left) The design concept of the new showcase in the Large Side Hall UF. A 3D drawing with sketchUP software.*

Figure 5.76 *(right) Displaying coffins parts in different levels to help visitors seeing it. (The Egyptian Museum, University of Bonn, Germany.*

Figure 5.77 *(left) A display of wood coffin and its cover. (The Mummification-Museum, Luxor, Egypt).*

Figure 5.78 *(right)A display of wood coffins in wall-integrated showcase. (The State Museum of Egyptian Art, Munich, Germany).*

in displaying the low-responsive-to-light exhibits, that need a high control on illuminance levels. We designed a large showcase that goes around the walls of the hall and helps to have more spaces for the exhibits. The showcases and display can be changed according to the type of exhibits when it is defined, this is just a suggestion. Further, to control the illuminance falls from the surroundings spaces inside the hall an indirect entrance was designed and the height of the windows have been scaled down. As well, the iron bars had been removed and glass panels are installed to reduce noise between the room and to help controlling the HVAC. The hall's entrance and exit are separated to facilitate the movement of the visitors. (Figure 5.71)

5.2.5.2.4 The Small Side Hall UF

The Small Side Hall UF is organized to have the same type of showcases in the Large Side Hall UF on the walls, and three large glass showcases in the middle. The three large frameless glass showcases help to make the gallery more spacious and their central position help to organize the movement of the visitors. (Figure 5.71)

5.2.5.2.5 The Lateral Gallery UF

The Lateral Gallery UF has a similar interior concept to the Small Side Hall UF. (Figure 5.71) What can be different is that, the showcases' interior in this area have a special treatment and arrangement to display the coffins and other funeral artifacts. A good example of display a coffin is to display its part in different levels to help visitors to see it. (Figure 5.76 to Figure 5.78).

5.2.5.2.6 The Lateral Gallery GF

The Lateral Gallery GF in the West Wing is the most crowded gallery with heavy artifacts: statues, relief, architectural parts, etc. The display has no clear concept and there are no boundaries between the historical topics. (Figure 5.39 and Figure 5.40) Accordingly, our idea is to use partition walls to create different zones. The partitions will help to but the exhibits in order, to enlarge the display area, to instal the reliefs, to work as background for the exhibits, and to create a rhythm in the space. Statues, sphinxes, architectural parts will be based on a simple bases and distributed throw out the gallery. The existing few showcases will be removed to be displayed in other halls, since displaying show cases in side lit spaces have a high potential of causing veiling reflections. Additionally, some new seats will be placed under the windows for the comfort of the visitors. (Figure 5.79 and Figure 5.80)

5.2.6 General Lighting schemes

Responding to the previous analysis and the new interior concept the design scheme propose a set of illuminance targets and distribution that need to be achieved. The lighting schemes and its solution are designed for the area of study; however we take into account that they have to be flexible and can be adjusted to suit other similar galleries.

5.2.6.1 Lighting concept

The main objective is to utilize the daylight as much as possible. To achieve this correctly in museum spaces the daylighting will be used on three levels according to exhibits' sensitivity to light and way of display. First, in spaces where irresponsive-to-light exhibits are in display daylight will be used for both room lighting and exhibit lighting. Second, in spaces where low-responsive-to-light exhibits are in display daylight will be used only as a room lighting. Third, in spaces where high-responsive-to-light exhibits are in display daylight will be forbidden. This strategy will give a high control on light levels, time of exposure, and veiling reflection since most of responsive-to-light exhibits are displayed in show cases.

Figure 5.79 *Ray Tracing rendering for the lateral gallery GF with the new interior and display concept. (View toward the north).*

Figure 5.80 *Ray Tracing rendering for the lateral gallery GF with the new interior and display concept. (View toward the south).*

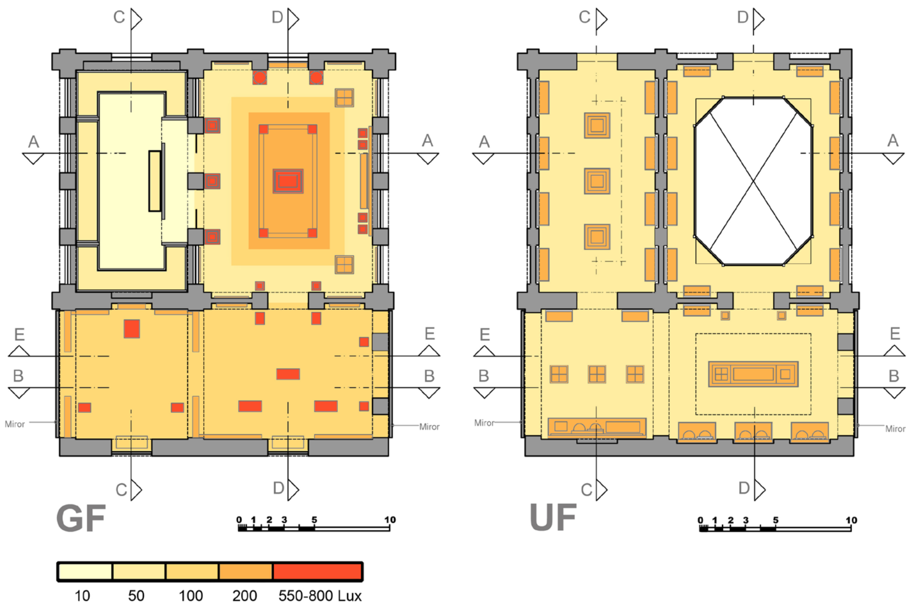

Figure 5.81 *General Lighting schemes for area of study.*

Concerning the artificial light, in spaces where daylight is used as exhibit lighting and/or as room lighting, artificial light will boost the shortage of daylight and replace it at night. In these cases, artificial light follows the daylight direction, level, and distribution. While, artificial light will be the exhibit lighting for low-responsive-to-light exhibits and the only lighting source for high-responsive-to-light exhibits. Simply, the more the exhibit is responsive to light, the more the artificial light will be used. This will give much control on levels and time of light exposure.

5.2.6.2 Illuminance values

All irresponsive-to-light exhibits like statues, reliefs, architectural elements, etc will be illuminated with illuminance level range between 550 - 800 lux in a surrounding with no more than 35 cd/m^2. Illuminance levels will be adjusted according to statues colours, material, composition, background, etc. According, for walls' with LRV 67%, illuminance levels on the walls have to be less than 164 lux. *(See "4.7.8 Results", of Illuminance levels for bright museum space).*

According to norms low-responsive-to-light exhibits as coloured statues and reliefs will be illuminated with 200 lx and high-responsive-to-light will be illuminated with 50 lx. Limitation of exposure will be adjusted according to museum authority recommendation. *(See "3.3 Exhibits sensitivity-to-light classification")*

Room lighting values will be assigned differently according to intended atmosphere. Room and exhibit illuminance values are defined at height of 150 cm horizontally above the floor or vertically on the wall from floor level.

5.2.6.3 Illuminance distribution

- **The Lateral Gallery GF:** The gallery is part of the main visiting path that circle the museum in the ground floor. The visiting path is connected directly to the main entrance and side entrances, thus how is entering the museum from outside will be in few minutes in the Lateral Gallery. The gallery is daylit with windows and there is a direct visual contact to the outside. The gallery in the new arrangement do not contain showcases and all exhibits are irresponsive-to-light. Accordingly, it is appropriate for this space to be mainly illuminated with daylight and to have a bright atmosphere. A value of 100 lx room lighting on the walls and floor will be very appropriate. This value with the bright wall colour will help to have a satisfying daylight space and to have a good contrast with coloured relief with 200 lx and statues with 550-800 lx. All exhibits as much as possible will be lit with daylight, however this will be a challenging task in a side-lit space. (Figure 5.81) Additionally, illuminances of main entrance and areas that lead to the gallery have to be controlled and do not exceed 500 lx, as well the entrances from the outside have to be shaded. *(See examples of daylight space Figure 1.35, Figure 5.124, and Figure 5.145)*
- **The Large Side Hall GF:** According to exhibits new display concept, the gallery's masterpiece "Rahotep and his wife" and the four small statues are arranged in the middle of the space on the platform, while other small statues and reliefs are displayed aside on the walls. Since the masterpiece and most of the statues are coloured (low-responsive-to-light), the room lighting have to be created with daylight and the exhibits lighting will be created with artificial light according to our light scheme concept. However,

exceptionally for this space, the illuminance distribution concept is to cover the entire platform in the middle with 200 lux daylight and to create a gradual distribution from the platform toward the walls. This will highlight the masterpiece and create a room atmosphere. Accordingly, the masterpiece and the statues on the platform will be illuminated with 200 lx daylight and the statues and reliefs on the walls will be locally illuminated with 200 lx artificial light. The wall will have general daylight illuminance from the reflected light in the room ~ 50 lx. The dim walls are a good background for the relief and will create a general dark surrounding around the centre of the space. The dim background, the large lit area in the middle, and the light gradation from the platform to the walls will highlight the centre of the space, give majesty to the space and the masterpiece, and draw visitors attention to the masterpiece and statues on the platform. So, the concept is to construct the bright and dark areas to raise the brightness of the artifact without exceeding the recommended conservative illuminance value.

In other Large Side Halls the main statues are irresponsive-to-light and located in the centre of the gallery. For that reason we can use the same light distribution and additionally we will raise the statues illuminance in the centre with artificial light to 550-800 lx. This will make the design applicable for other Large Side Halls. This values and ratio between the centre and sides can be increased or decreased according to the type of exhibits in middle of the display and the needed effect. (Figure 5.81 and Figure 5.73)

In all cases, reliefs on the wall regardless of being coloured or not will be illuminated with 200 lx, to have a uniform appearance for the reliefs and surrounding; while statues and architectural elements near the walls will be illuminated according to its sensitivity.

- **The Small Side Hall GF:** All exhibits in the showcases are highly-responsive-to-light, thus all exhibits will be illuminated with 50 lx artificial light. The room lighting will be generated by the spilled light from the showcases and form galleries large windows that connect the gallery to the two adjacent Large Side Halls. The room lighting is expected to be ~ 10 lx on the walls and floor.

  According to the lighting scheme of the previous three galleries, visitor who move from the Lateral Gallery, through the Large Side Hall, then to the Small Side Hall, will be gradually moving from brighter to darker surrounding. This will help visitors to be gradually adapted to low illuminance and to perform good vision when they enter the dark Small Side Hall GF.

- **The Large Side Hall UF:** The gallery is a part of the Large Side Hall GF. The room lighting will be 50 lx on the walls and floor provided from the skylight. This will help to connect the walls of the ground and upper floor together, which emphasizes the visual continuity of the space. The gallery display only showcase and most of exhibits are low-responsive-to-light, thus exhibit lighting will be 200 lx provided from artificial light sources that are mounted outside the showcases.

- **The Small Side Hall UF:** Similar to the previous gallery, the gallery contains showcases where low-responsive-to-light exhibits are displayed. The room lighting will be 50 lx provided from the skylight and exhibit lighting will be 200 lx provided from artificial light sources that are mounted outside the showcases.
- **The Lateral Gallery UF:** The gallery is characterized by displaying funeral exhibits, which are mixed between low and high responsive-to-light exhibits. Additionally, unlike other spaces in the upper floor, the skylights do not evenly centre the space beneath it. These situations raise different solutions according to the exhibits in display. Maybe the easiest way to manage this situation is to reduce the daylight and to illuminate all exhibits with artificial lights.

  Other solution is to reorganize the exhibits (if possible) in a way that the low-responsive-to-light exhibits will be displayed under the skylight to have 50 lx room lighting from the skylight and 200 lx artificial light from sources mounted outside the showcases. As for the area far from the skylight, it will contain high-responsive-to-light exhibits and will be illuminated only with artificial light, where exhibits will have 50 lx artificial light from sources mounted outside the showcases and room lighting will be ~ 10 lx generated from the showcases and skylight spilled light. This lighting distribution concept will creat islands of light in a long dark passage.

  Further possibilities may exist after arranging the exhibits in the museum and the area far from the skylight my contains low-responsive-to-light exhibits. In this case the room lighting will be 50 lx and the exhibit lighting will be 200 lx and both will be provided from artificial light sources.

  As a result of the above, our schematic design has to be flexible and to fulfil all possibilities. In our general schematic design we adopt the last solution, while ensuring the ability of dimming any part of the gallery and achieving other situations.

  (For adjusting the luminance of exhibits in showcases see 4.4 EXP 2 and 4.5 EXP 3)

5.3 Space-by-space lighting design

The previous general lighting scheme is a general lighting design for the area of interest. It helps to coherent the design and creates a harmony between the spaces. In the following parts we will address the schematic design and design development for every space separately. We will start with daylighting design followed with artificial lighting design. In fact, during working this design the process takes a back-and-forth path between defining, testing, developing, verifying and refining the solution. What is presented here is the main path to the final design.

We will focus our effort on the Large Side Hall GF & UF, as well on the Lateral side gallery GF. Since the concepts and solutions of these spaces can be applied to other spaces as we will explain.

5.3.1 Daylighting design for the Large Side Hall GF & UF

5.3.1.1 Schematic Design (SD)

5.3.1.1.1 Analysis of the problem

From the previous analysis we can summarize the main technical illumination problems in the space to:

- There is enough daylight, however its distribution do not match with the exhibits in display. There are tow spaces connected to each other via a void; and they are both illuminated with the skylight that topped them. This makes the illuminance levels high in the UF and lower in the GF. Which contradicts with the display of the low-responsive-to-light exhibit in the UF and the irresponsive-to-light exhibits in the GF.
- Unstable levels of illumination. The absence of daylight control system makes illumination level and distribution dramatically change during the course of the day and the year.
- The direct sun penetrate the space.
- Generally, there are no aspects of modern museum lighting for both the daylight and the artificial light.

5.3.1.1.2 Fundamental concept

The concept mainly depends on integrating two daylight system in the skylight to illuminate every space separately as follow:

- The first system is to illuminate the GF. The system needs to concentrate the daylight from the skylight's roof on the middle of he space through the void between the UF and GF. This light will be the exhibit lighting for the statues (between 200-800 lx (according to its response to light). Further, the illumination has to be graded to the periphery of the space, to ~ 50 lx if possible. The interreflection of light in the space will create the room lighting. The coloured relief on the walls will be artificially illuminated with 200 lx. Since the skylight is raised high from the GF (~ 17 m) and the illuminance level recommended is relatively high the system needs to redirect a big amount of daylight into relatively narrow beam to the ground floor. (Figure 5.82)

- The second system is to illuminate the UF. The system needs to control the daylight entering the skylight's windows to create a soft diffuse room lighting with 50 lx for the space around the showcases. While the exhibits in the showcases (low-responsive-to-light exhibit) will be illuminated with artificial light at 200 lx. To reach an even illumination on the four walls of the UF, all skylights windows have to pass the same luminous flux into the interior. This can be achieved be blocking the sunlight and allowing only diffuse skylight to inter the windows, or by making the windows exposed to the same amount of light from both sun and the sky. (Figure 5.82)

5.3.1.1.3 Proposed solutions for GF illumination.

- **The systems objective:** is to redirect a big amount of daylight in a narrow beam to the ground floor.
- **The system main concept:** is to diffuse sunlight into a CPC[1]. Parallel sunlight entering a CPC will be reflected non-parallel within the CPC cut-off-angel and will formulate irregular sun-spot in the interior that wander with the move of the sun. On the other hand, diffuse skylight entering from the whole sky will be reflected almost evenly within the cut-off-angle. Accordingly, using a diffuser to diffuse the sun light will help to have a big amount of luminance flux in the CPC and insure it will be distributed evenly within the cut-off-angle. In this way the system will benefit from both the skylight and the sunlight that is transmitted through the diffuse glass. Further, we added a daylight collecting chamber to help diffusing sunlight, collecting more light into the CPC, integrate the system in the roof, and adding a control device to the system. (Figure 5.83).

  (Note: Although, the concentration of diffuse daylight is not possible, the interreflection of the light in the chamber may add more light. This concept will be tested later in the design development.)

- **Technical Description:** The system consists mainly of two parts, a daylight collecting chamber and a CPC reflector. The whole system is integrated in the gable roof of the skylight. (Figure 5.84, Figure 5.86 and Figure 5.88)

1. Compound Parabolic Concentrator (CPC) is a non-imaging optical elements. Its function is to concentrate and control the distribution of light, so light enter the CPC is almost evenly spread over a specific areas and completely blocked from other areas. The CPC reflector distributes the light downward and avoid any back reflection. Note: for more information about using CPC in daylight systems see, Nancy Ruck and others, Daylight in buildings, A source book on daylighting systems and components, A report of IEA SHC Task 21/ ECBCS Annex 29, July 2000. p4-85 to p4-104.

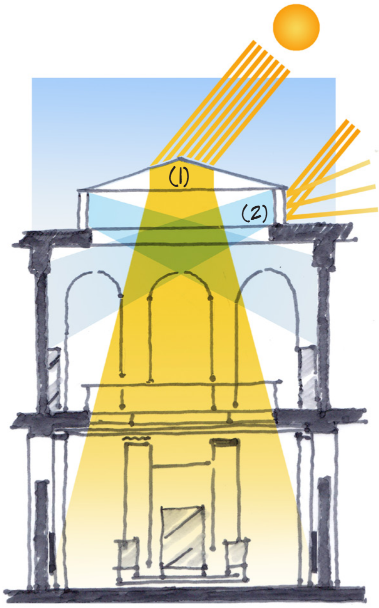

Figure 5.82 *Fundamental concept of the Large Side Hall GF & UF.*

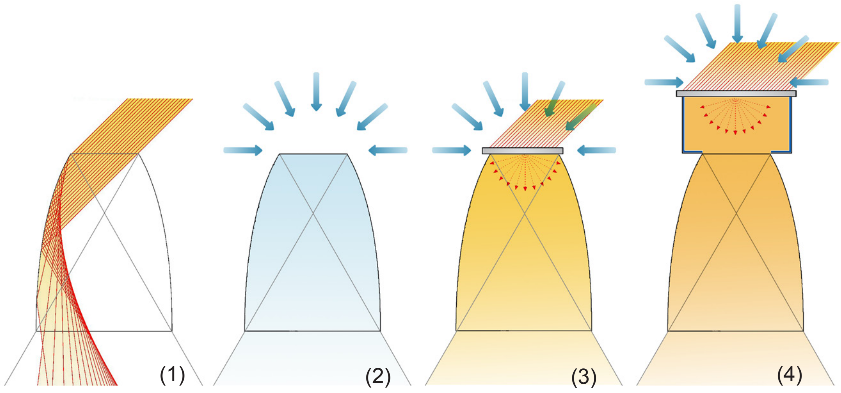

Figure 5.83 *The concept of GF daylight system depends of diffusing sunlight into a CPC. (1) direct sunlight in the cpc. (2) Diffuse skylight in the CPC. (3) Diffusing sunlight in the CPC. (4) adding a mirror-box (a daylight collecting chamber) to harvest daylight into the CPC.*

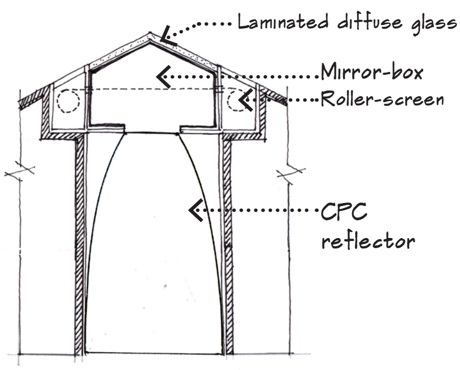

Figure 5.84 *(lift) A sketch shows the composition of the new proposed daylight system for the GF.*

Figure 5.85 *(right) A view inside a Mirror-Box Artificial Sky. (http://www.vashonbaker.co.uk/index.html)*

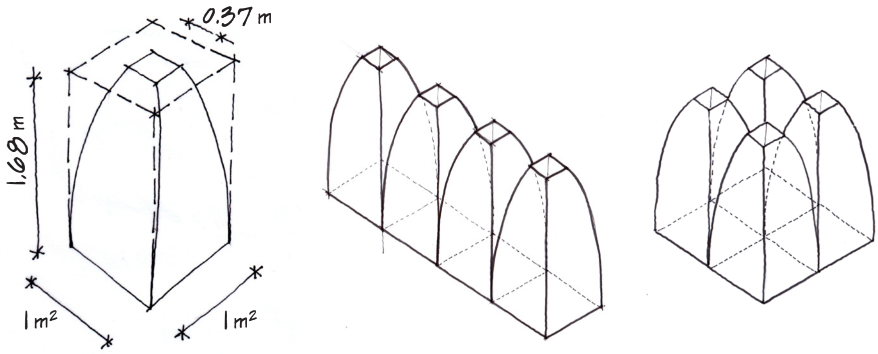

Figure 5.86 *(left) The dimension of the proposed crossed CPC. (middle and right) two different arrangement for the crossed CPCs show their flexibility in design.*

- **The daylight collecting chamber** is consisted out of: External laminated diffuse glass to diffuse direct sun light. Beneath the glass a roller-screen is installed. The roller-screen consists of different light transmitting materials connected in sequence to control the daylight or to block it if the system need to be closed. The screen and the glass top off a high reflective walls in a form of mirror-box. The walls are made of anodised aluminium with ~ 98% LRV. It enlarge the size of the light source that emits light, to insure that reflected light will enter the CPC. (Figure 5.84)

The chamber in this form has a similar concept to the Mirror-Box Artificial Sky, which has a brightness distribution that closely approximates to the CIE Standard Overcast Sky.[1] (Figure 5.85) In other words, the light from the sun and sky will hit the diffuse glass and create a bright patch of high luminance surface, which will be mirrored on the wall of the chamber to create a large diffuse horizontal surface with luminance distribution roughly similar to that of an overcast sky.

- **The CPC reflector** that we used in our design is a crossed CPC (a CPC with horizontal square section). The crossed CPC is easy to be built, attached to the collecting chamber, and arranged in the construction of the building. The CPC has a high specular surface made of anodised aluminium with ~ 98% LRV, thus the system does not introduce any optical dispersion, even with direct sunlight. According to the geometry of the void between the GF and UF, and the roof we succeeded to integrate five similar crossed CPC with cut-off-angle[2] of ~22,5° in the roof space. Where each CPC has, 1,686 m height, 0.3789 x 0.3789 m entrance opening, and 1 x1 m exit opening. The CPCs numbers and/or angles can be adjusted in the design after testing the system in the design development phase. (Figure 5.86, Figure 5.90, and Figure 5.91).

- **How it works:**

- On sunny days, the diffuse laminated glass will transformed sun light incident on it to a diffuse light and transmits it with the diffuse light from the sky into the mirror-box. Some of the transmitted light enter CPCs directly and other indirectly after it is reflected on the high mirrored walls of the mirror-box. The CPCs will direct the light downward in 45° angle in the room. The rolled-screen regulates the change in daylight amount, that enter the CPCs during the course of the day and year, to maintain a stable level of illumination in the room.

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1. Vashon Baker, Mirror-Box Artificial Sky, <http://www.vashonbaker.co.uk/index.html>,(16.10.2016).
2. A cut-off angle (of a luminaire or CPC) angle, measured up from nadir, between the vertical axis and the first line of sight at which the lamps and the surfaces of high luminance are not visible. IEC, Terminology, <http://www.electropedia.org/iev/iev.nsf/display?openform&ievref=845-10-30>,(26.10.20016).

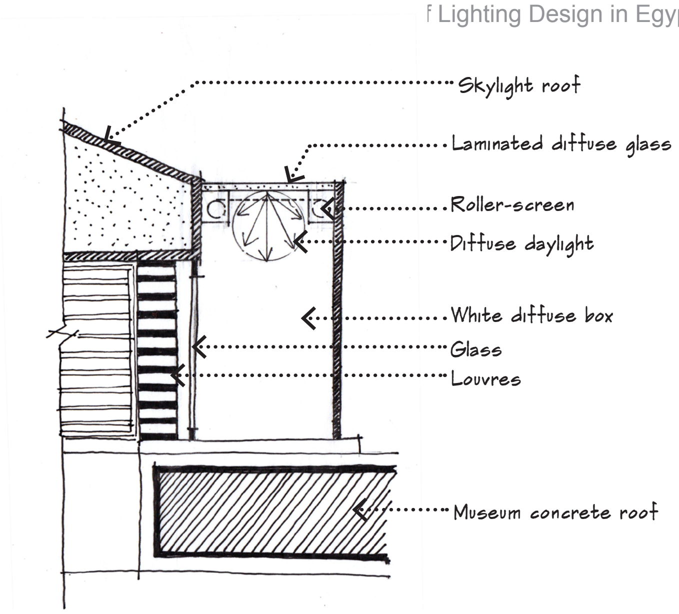


Figure 5.87 *A sketch shows the composition of the new proposed daylight system for the UF.*

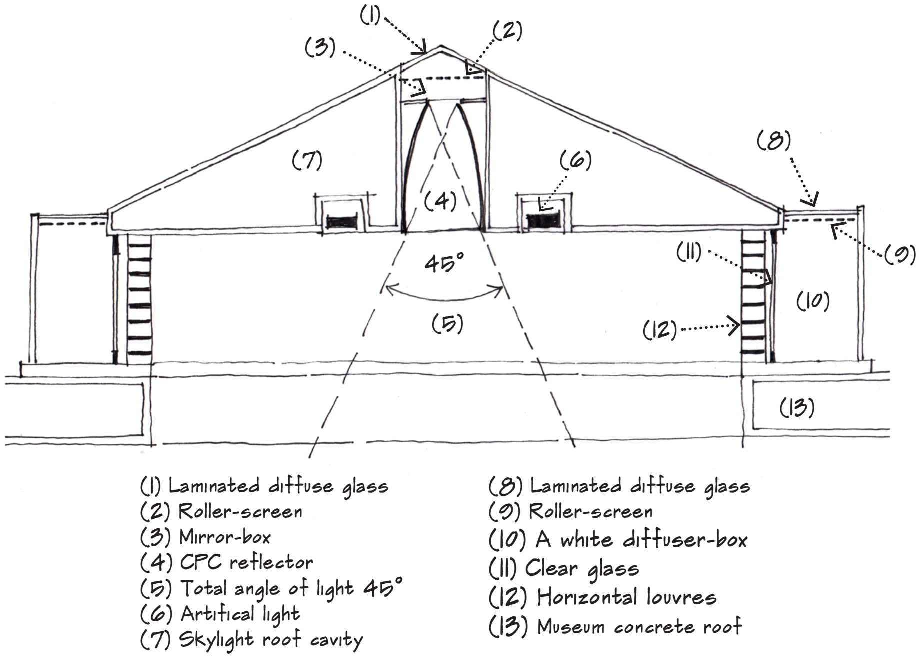


Figure 5.88 *A skylight cross section sketch shows the new proposed daylight systems for the UF and GF.*

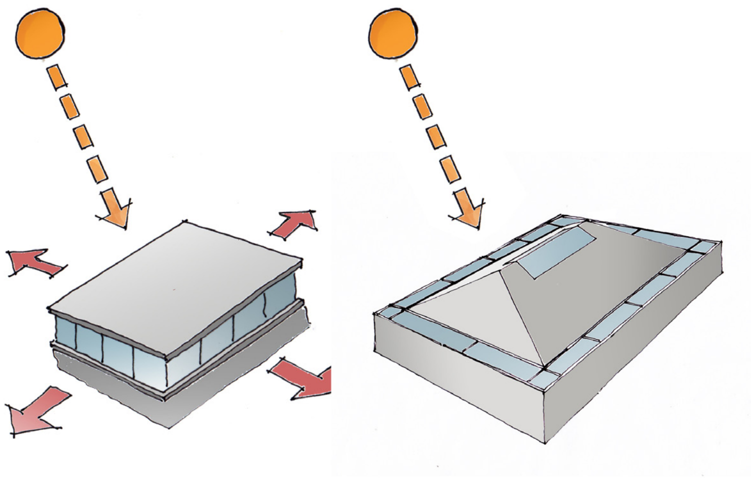


Figure 5.89 *Comparison: (left) In the old form of the skylight, the daylight falls unevenly on skylight's vertical windows. Daylight distribution inside the space is not uniform and it changes dramatically during the day. (right) In the new proposed design, daylight falls evenly on a horizontal serface of the new systems. Daylight distribution inside the space is uniform and roller-screen inside the system control the sloly change of daylight during the day.*

- On a cloudy day or at early and late time in the day, the system will collect light mainly from the sky, which may be insufficient to reach the target of illuminance needed in the space. In that case the artificial light will boost the daylight to reach the illuminance target.

- An alternative design idea is to make the laminated glass transparent to harvest more diffuse light directly from the overcast days, and to use the rolled-screen in sun condition to diffuse the direct sunlight. However, the angled diffuse glass has the benefit of catching the low-angled sun light in the early morning and late afternoon. Further, the 80% sunshine probability in Cairo supports the idea of using diffuse glass solution and makes it more appropriate.

- Artificial lighting design will follow after testing the daylight concept in the design development phase.

5.3.1.1.4 Proposed solution for UF illumination.

- **The systems objective:** is to control the daylight entering the skylight's windows to create a soft diffuse room lighting and have an even illumination on the four walls of the UF.
- **The system main concept:** The light falls unevenly on the skylights windows and it changes dramatically because of the movement of the sun. Furthermore, the adjacent skylights, the museum's south-wing, and the large skylight of the Central Atrium are blocking parts of the sky and casting shadows on skylight's windows. This makes controlling the light falling on the skylight's four sides to have an even light distribution with motorized solar shades and lovers a very complex and infeasible task. Accordingly, our idea is to surround the skylight with a diffuser-box that is opened from the top, so it receives light directly from the sun and sky, minimize the shadow falls on it from the surrounding, and brings an even light on the skylight windows, thus an even light distribution inside the space on the walls. (Figure 5.89)
- **Technical Description:** The system is consists mainly of two parts a diffuser-box and a window system with horizontal louvres.

  - **The diffuser-box** is a white diffuse box circling the skylight and opened with a laminated diffuse glass from the top. The horizontal glass will receives the same amount of light and avoids casted shadows from the surrounding. Thus the diffuse light failing on the windows' system will be even, as well as inside the space after it is distributed. Beneath every segment of the diffuse laminated glass a roller-screen is installed. The screen consists of different light-transmitting materials connected in sequence. The screen is rolled in and out by a motor to control the daylight.

  - **The windows system** is consists of two parts: A clear glass to close the diffuser-box and to protect it from dust, and a horizontal louvres toward the space to control the distribution of daylight. The louvres' slats are have a white diffuse colour on the upper surface

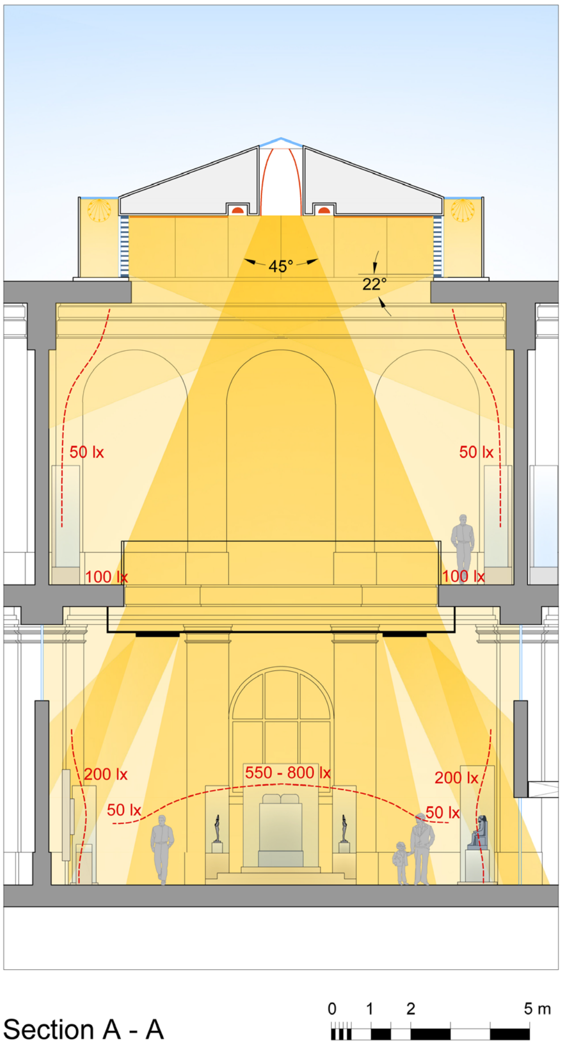


Figure 5.90 *Section A-A shows the daylight schematic design in the large side gallery GF & UF.*

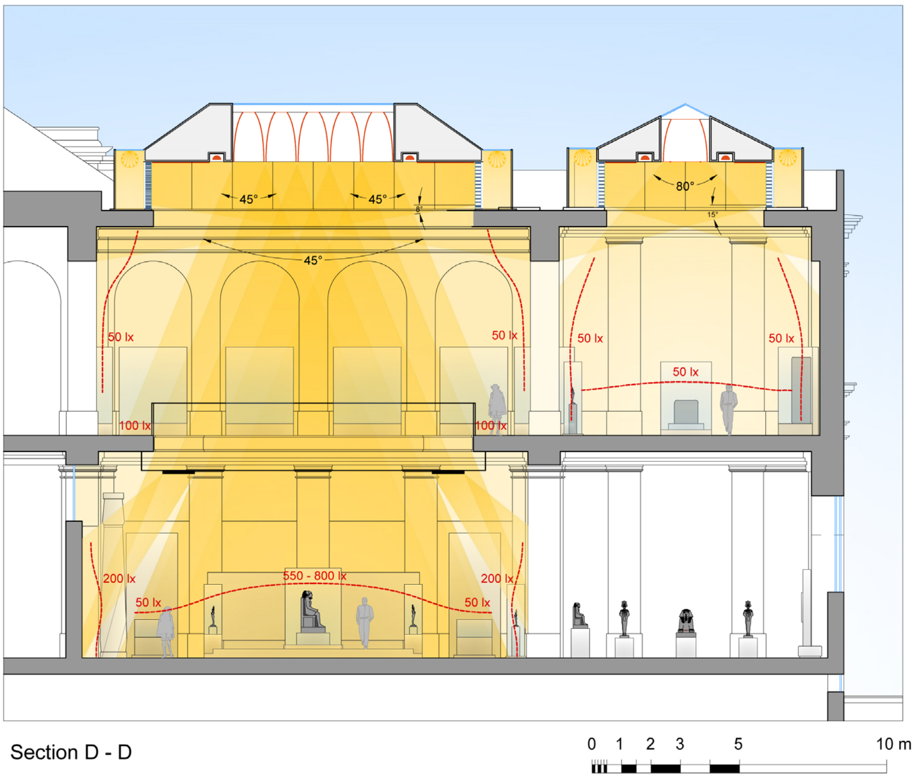


Figure 5.91 *Section D-D shows the daylight schematic design in the large side gallery GF & UF, and lateral gallery UF.*

and a mid-tone gray on the lower surface. The slats cut-off-angle[1] and colour will insure that the diffuse light is reflected more to the upper part of the walls in the UF avoiding any glare and veiling reflection on the showcases. (Figure 5.90 and Figure 5.91).

- **How it will work:**

  - On sunny days, the direct sunlight will be transformed to a diffuse light inside the diffuser-box. The light will be internally reflected inside the box and part of it will pass through the louvres. The louvres will distribute the light to the upper parts of the walls in the UF. The roller-screen will control the amount of daylight and maintain a stable level of illumination in the room.

  - On a cloudy day or at early and late time in the day, when the daylight is not sufficient, the artificial light will boost the daylight.

  - The system performance can be increased by constructing the diffuser-box and the louvres from a high specular surfaces. However, the light levels needed in the upper floor are achieved and it is not required to optimise the system and reach its maximum capacity.

  - Artificial lighting design will follow after testing the daylight concept in the design development phase.

5.3.1.1.5 Finalizing the schematic design

The schematic design phase is usually finalized with a check up calculation to verify the possibility of achieving the determined levels of illumination, and a set of visualization to show the expected appearance. However, since the system is an innovative system and we do not have a real data for the calculation, the calculation will be done after testing the system mock-up during the development phase.

Concerning the visualization, the longitudinal and cross section in (Figure 5.90 and Figure 5.91) are the final schematic design drawings. The sections correspond with the plan in (Figure 5.81). The sections contain the new proposed daylighting systems in scale and the illuminance targets for every zone. The deferent tones of the yellowish colours represents the level of illuminance. Besides, we suggested in this two sections to use the same daylight systems in the skylight of the Lateral Gallery UF. The only different is that the CPC cut-off-angle is 40° to fit with the geometry of the space. (Figure 5.91). As well, we suggested to reflect a part of the light coming from the GF daylight system to illuminate the walls in GF. (Figure 5.90).

Additionally, the rendering in (Figure 5.73 and Figure 5.74) are an attempt to render the visual effect of the new proposed daylighting scheme with ray tracing technique in Relux Software. In our rendering we used LDT files that have a similar distribution of a CPC and the diffuse light from the louvres.

1. Note: The slats cut-of-angle in the cross section is the angle formed between the diagonal line connect two opposite slats edges and a horizontal line.

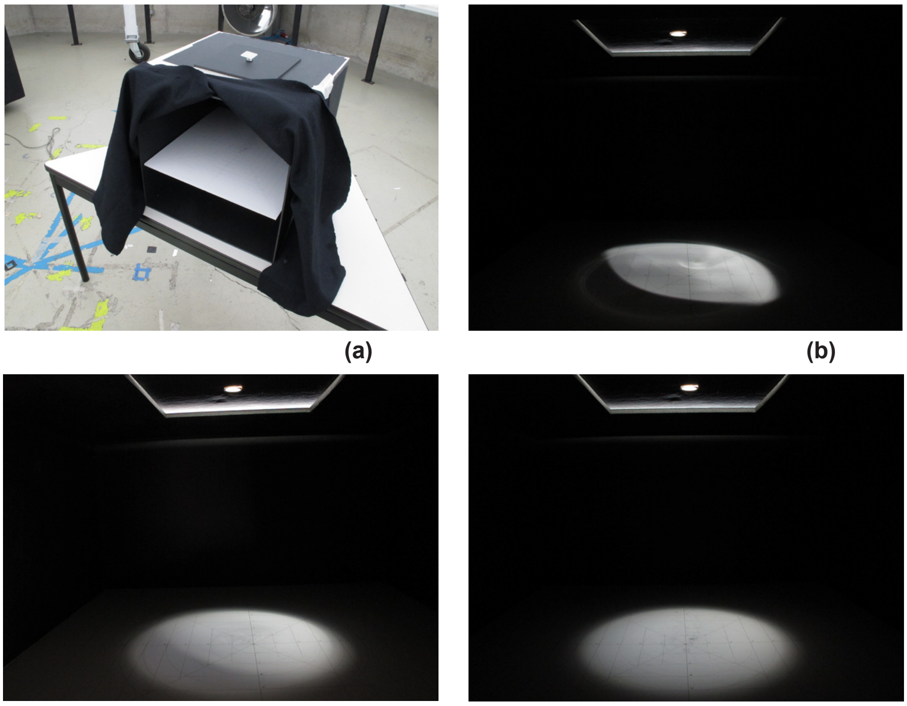
As a result of the visualizations we can realize that the cone of light falling from the ceiling to the GF through the void emphasize the geometry of the space. We anticipate that it will add a majesty and sacredness to the space. This is confirmed as will with the renderings in (Figure 5.73).

5.3.1.2 Design Development (DD)

The design development is a number of design steps aim to verify techniques and solutions that help to realize the schematic design. The DD steps occur simultaneously and do not follow a fixed order, it influence each other, and it depends on designer's perspective and priorities.[1]

5.3.1.2.1 Selecting the diffuse glass

It is very important for the proposed daylighting systems to have a diffuse glass with best possible light transmission and even distribution. Therefore we examined the light transmission and distribution of different diffuse glass that is available to us. To conduct the test we constructed a black carton box (0.5 x 0.5 x 0.5 m), where we installed on the top of it a small round CPC reflector from a luminaire. The box interior are black, and only the floor is white in colour. The box was placed in the artificial sky of Bartenbach Light Laboratory under the condition of sun (only direct light). The best result was for the poured acrylic glass: **White 4110 WH10, 010, 27018** translucent 68 % (3, 4, 5 mm), Wilkes GmbH, Germany. This glass will be used in all our daylighting systems in the following tests. (Figure 5.92)



(a) (b) (c) (d)

Figure 5.92 *Selecting the diffuse glass for the daylighting systems. (a) test box. (b) light reflected from the CPC without diffuse glass is distributed unevenly. (c) weak diffuser glass will have uneven distribution. (d) good diffuser will have an even distribution.(In all three images direct light is falling in an angle of 45°).*

1. IESNA, The Lighting handbook, Lightin design in the building design process,10th Ed. 2011, p11.1-to-p11.14.

5.3.1.2.2 Testing the system's lighting effect on exhibits

To check the lighting effect of the new solar collector system on the exhibits, we used the same box of previous test and we installed on the top of it a luminaire reflector with a close form to a CPC. We placed a middle gray tone statue (20 cm height) inside the box to test the lighting effect on it. We placed the box in the artificial sky of Bartenbach Light Laboratory under the condition of clear sky (diffuse sky with sun).

The test was conducted under two conditions: First, the reflector was uncovered; and second, the reflector was covered with a diffuse glass. (Figure 5.93) In the first condition: the light was uneven distributed in the box, highlights and shades on the statues are strong, and cast shadow on the ground has a sharp edge. In the second condition: the light was evenly distributed in the box, the highlights and shades on the statues are little bit softer then the first condition, and cast shadow on the ground has a blurry edge. We expected, in real condition, when the light will come from a larger source (five CPC reflectors) and fall on relatively small statues, the highlights will be wider and shadows will be softer. Large highlights help to render the form of the statues specially the dark statues and soft shades help not to disturb the form of the statues. As well, soft cast shadows on the surfaces of the interior will not cause a visual disturbance for the visitors. The results is acceptable and it will reveal the attributes of the Egyptian statues.

(See "2.1.1.3.2 Light and Egyptian statues", and Figure 1.9)

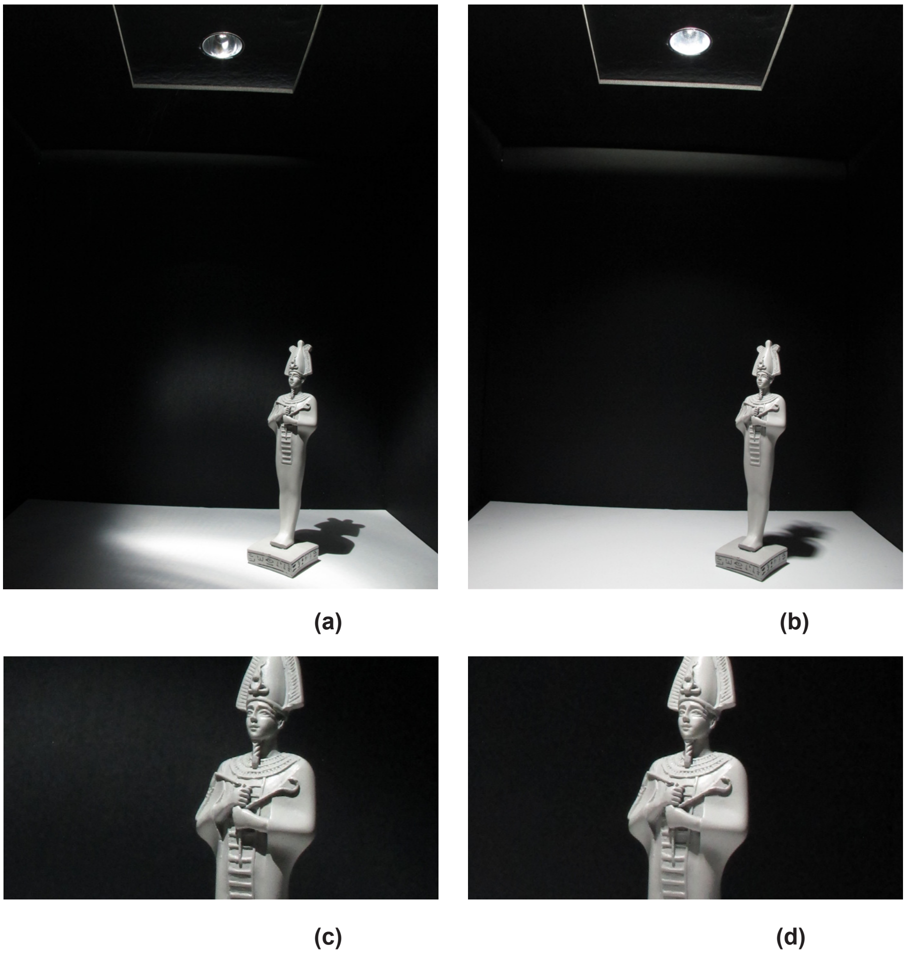

(a) (b) (c) (d)

Figure 5.93 *Testing the lighting effects of the solar collector system on a statue in a physical model. (a) The reflector is uncovered and it reflect both diffuse and direct light. (b) The reflector is covered with a diffuse glass and it reflect only diffuse light. (c) and (d) are a close photos showing shadows formed on the statues of (a) (b) respectively.*

5.3.1.2.3 Enhancing the daylight collecting chamber's performance

Very crucial for the daylight system of the GF is to have the maximum benefit from direct sun light and this depends on the design of the daylight collecting chamber. Since the chamber simply consists of the diffused laminated glass and the mirror-box we can think about how to enhance these two parts.

5.3.1.2.3.1 Choosing the suitable tilted angle

The tilt angle of the diffused laminated glass has a major impact on the solar radiation passing to the daylight system. Since the irradiance or illuminance falling on any surface varies as the cosine of the incident angle (γ).The reason behind this is that the perceived measurement area orthogonal to the incident flux is enlarge at oblique angles, causing light to spread out over a wider area than it would if perpendicular to the measurement plane. (Figure 5.94) This called the Lambert's Cosine Law and can be expressed as follows[1]:

$$E_n = E_s \cdot \cos \gamma$$

Where: E_n is illuminance normal to the surface, E_s is illuminance normal to the source/sun, (γ) is the angle between the two normals.

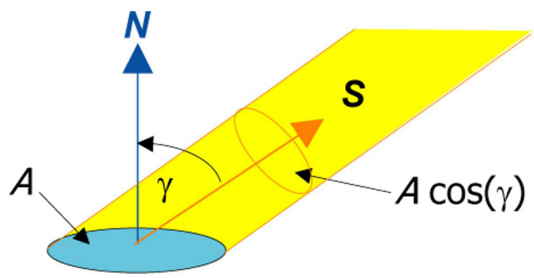


Figure 5.94 *The light striking a surface at an angle is spread out over a larger area. The reduction in intensity is the dot product of the unit vectors S and N. (http://www.pveducation.org/pvcdrom/arbitrary-orientation-and-tilt)*

This means the luminous flux will always be at its maximum when the surface is perpendicular to the incident sun rays. Since the system is fixed and not automated, according to photovoltaic engineering, we can adjust the glass to be facing south at a tilted angle equal to the latitude of the location to obtain the maximum luminous flux over the course of the year.[2] Or perhaps more suitable for our design is to make the tilted angle steeper to increase the luminous flux in winter (low sun angle) and balance the amount of luminous flux incident on the glass over the course of the year. This will reduce the variation range of incident luminance flux on the surface between the seasons, which will stabilize the amount of illuminance entering the space over the course of the year, and assist the performance of the roller-screen in controlling the daily changes of illuminance levels inside the space.

1. Alex Ryer, Light Measurement Handbook, International Light Inc., 1998, p27.
2. The Photovoltaic Education Network, Solar Radiation on a Tilted Surface, <http://www.pveducation.org/pvcdrom/properties-sunlight/solar-radiation-tilted-surface>, (1.11.2016).

The online tool for calculating the solar radiation incident on a tilted surface[1] helps us to check the previous concept for a tilted surface facing south on Cairo latitude 30° North. The results are represented in (Figure 5.95). The blue line represents the maximum incident power, which is the solar radiation perpendicular to the sun's rays and it is what would be received by a surface that perfectly tracks the sun. The red line represents the solar radiation incident on horizontal surface. The green lines represents the solar radiation incident on a tilted surface at 30°, 40°, 50°, and 60°. The surface at tilted angle 30°, which is equal to the latitude of Cairo, obtains the maximum solar radiation over the course of the year. By gradually increasing the tilted angle the amount of solar radiation incident on the surface start to drop-down in summer time and to raise in winter time. However, the increase in winter time is less than the decrease on summer time and the curve do not shows an perfect equilibrium of solar radiation throughout the year. According to these results, an angle between 40° and 50° can be suitable for our design, since it will help to boost the illuminance value in winter, stabilize the amount of luminance flux falling on the surface for a longest period (from April to September), and not losing a lot of the energy falling on the surface.

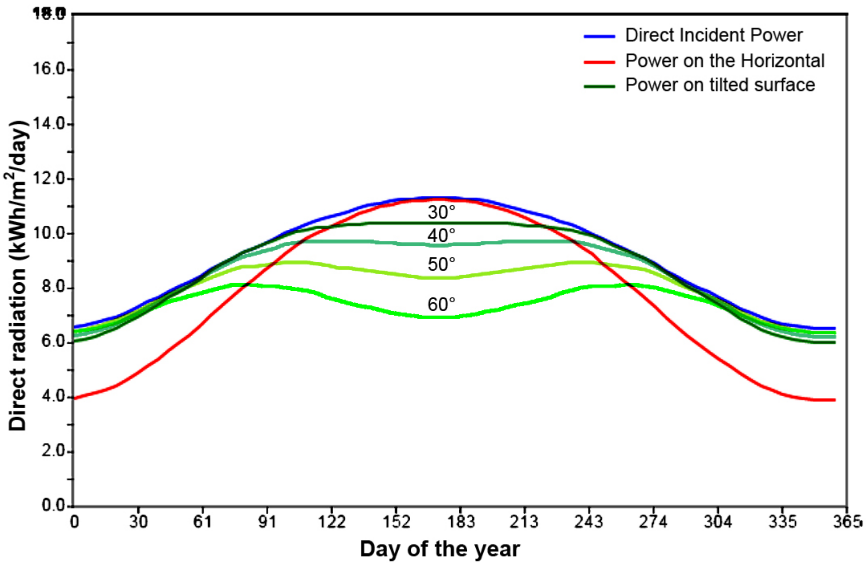


Figure 5.95 *The effect of latitude and module tilt on the solar radiation received through out the year in* $W.h.m^{-2}.day^{-1}$ *without cloud cover on Cairo latitude 30° North. (http://pveducation.org/pvcdrom/properties-sunlight/solar-radiation-tilted-surface)*

Before we precisely chose a specific angle for our system there are other aspects have to be taken in account: the calculation of sky component, the effect of weather conditions, the reflection losses of the glass surface, and the effect of the surrounding. Thus a calculation based on Cairo weather data with considering these factors to estimate the amount of illuminance passing through a tilted single glass panel can help to decide precisely which angle is suitable for our daylight system and how much luminance flux we can have inside the system.

1. Previous reference.

5.3.1.2.3.2 The available daylight through tilted glass

Daylight transmitted through a tilted glass panel can be obtained from Cairo weather data[1] via the sum of three illuminance components: the sun component, the sky component, and the reflected component.

$$E_t = E_{s,t} + E_{h,t} + E_{b,t}$$

Where: E_t is daylight illuminance transmitted through a tilted glass in lux.

1. The sun component:

$$E_{s,t} = DNI \cdot \cos\gamma \cdot \tau_i$$

Where: $E_{s,t}$ is sun illuminance transmitted through tilted glass panel in lux, *DNI*[2] is direct normal illumination in lux, γ is the angle of incident sun ray to the normal of the surface in degree[3], τ_i is glass light transmission factor according to the incident angle.

2. The sky component:[4]

$$E_{h,t} = DHI \cdot (180 - \alpha) / 180 \cdot \tau_h$$

Where: $E_{h,t}$ is sky illuminance transmitted through tilted glass panel in lux, *DHI* is diffuse horizontal illuminance in lux, α is surface tilted angle to the horizontal in degree, τ_h is glass light transmission factor for diffuse light.

3. Reflected component:[5]

$$E_{b,t} = GHI \cdot \rho/2\ (1- \cos\alpha) \cdot \tau_h$$

Where: $E_{b,t}$ is global horizontal illuminance reflected from the ground and transmitted through tilted glass panel in lux, *GHI* is global horizontal illuminance in lux , ρ is light reflectance value of the ground, α is surface tilted angle to the horizontal in degree, τ_h is glass light transmission factor for diffuse light.

For calculating the DNI, DHI, and GHI we used average values for every working hours per month. Which is hour between 8:00 to 17:00 in every month of the year (10 hour daily x 12 month = 120 values). All values were obtained from Cairo weather data.

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1. Source of the data: <https://energyplus.net/weather-location/africa_wmo_region_1/EGY//EGY_Cairo.623660_IWEC>, (17.06.2016).
2. Direct Normal Illumination (DNI) is the average amount of direct normal illuminance received within a 5.7° field of view centred on the sun during 60-minute period ending at the timestamp S. (Wilcox and W. Marion, User's Manual for TMY3 Data Sets, National Renewable Energy Laboratory, USA, 2008, p5).
3. The angel was calculated by MIDC SPA Calculator, that compute the solar position from universal time and location using NREL's Solar Position Algorithm (SPA). <http://www.nrel.gov/midc/solpos/spa.html>, (18.11.2016).
4. The Photovoltaic Education Network, Making Use of TMY Data, <http://www.pveducation.org/pvcdrom/properties-sunlight/solar-radiation-tilted-surface>, (1.11.2016).
5. Data Bank, Research and Development department, Bartenbach GmbH, Innsbruck, Austria, with permission.

For calculating the light transmission factor of the glass, we used value for a single 6 mm float glass panel.[1] (Table 5.3)

For calculating the Light Reflectance Value (LRV) of the building roof, we assumed to be a diffuse surface with LRV of 30 %.

Table 5.6 *Light transmission factor for a single 6 mm float glass panel. (Data Bank, Bartenbach GmbH).*

Light transmission factor for a single 6 mm float glass panel

Angle	0	10	20	30	40	50	60	70	80	90	Hemis
tau_v	0,888	0,888	0,887	0,884	0,876	0,857	0,809	0,693	0,431	0	0,81

We conducted the previous calculation for the following glass position: Horizontal, 30°, 35°, 40°, 45°, 50°, 55°, and 60°. The results shows that, daylight passing through a horizontal glass varies significantly between the monthly average illuminance values. See (Figure 5.96) At 12:00 pm the difference is ~47 klx between the highest months June and July with ~90 klx and the lowest months Jan and Dec with ~43 klx. As well, the difference are high at early morning and late after noon hours. At 8:00 am the maximum difference is ~32 klx between June with ~38 klx and Jan with ~5 Klx.

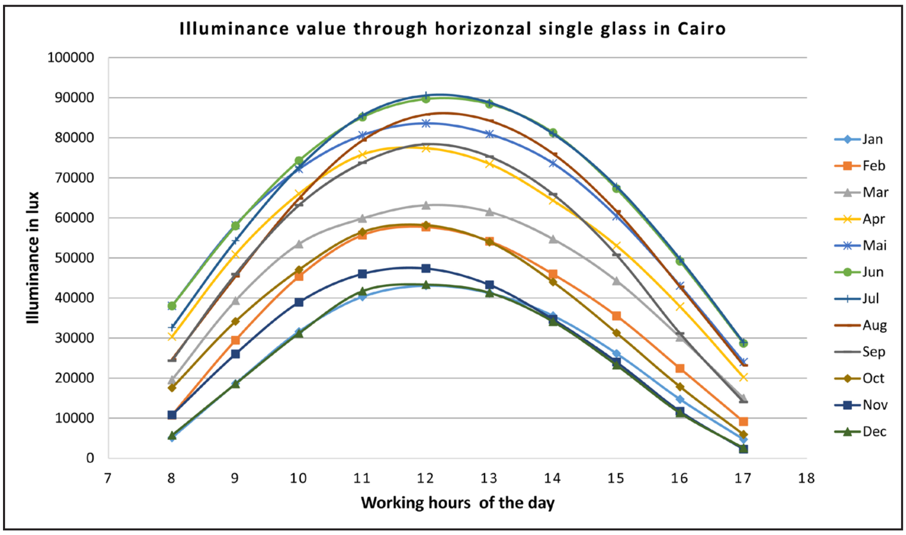


Figure 5.96 *Average illuminance for every working hours per month passing through 6 mm single float glass panel, lay horizontally in Cairo.*

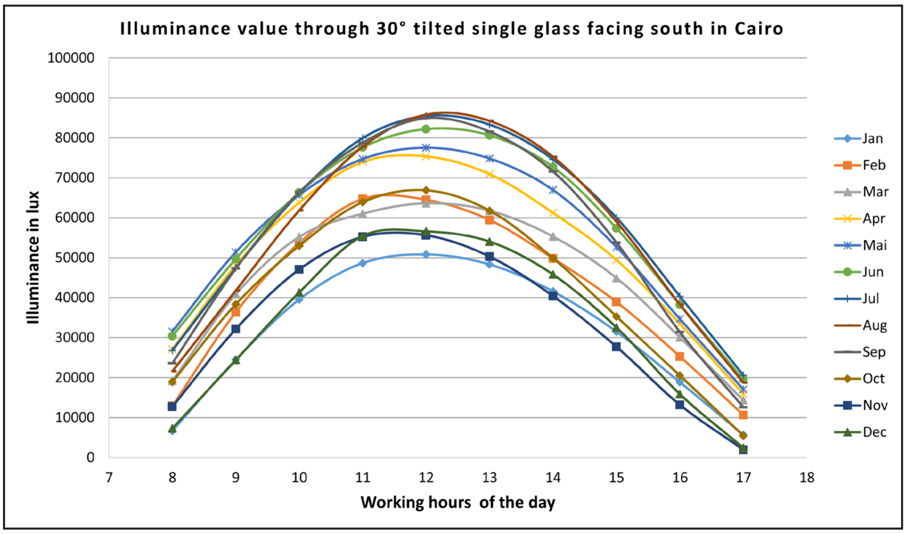


Figure 5.97 *Average illuminance for every working hours per month passing through 6 mm single float glass panel, tilted 30° and, facing south in Cairo.*

1. Previous reference.

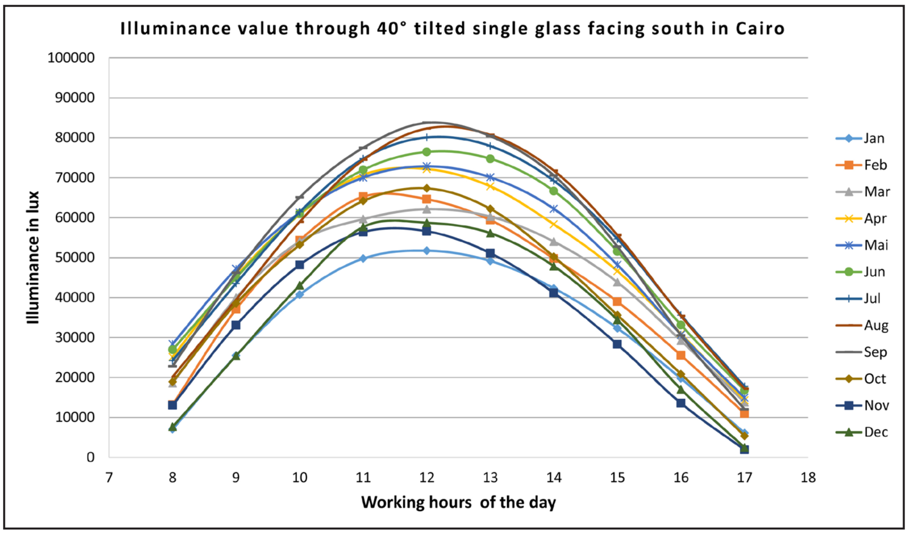


Figure 5.98 *Average illuminance for every working hours per month passing through 6 mm single float glass panel, tilted 40° and, facing south in Cairo.*

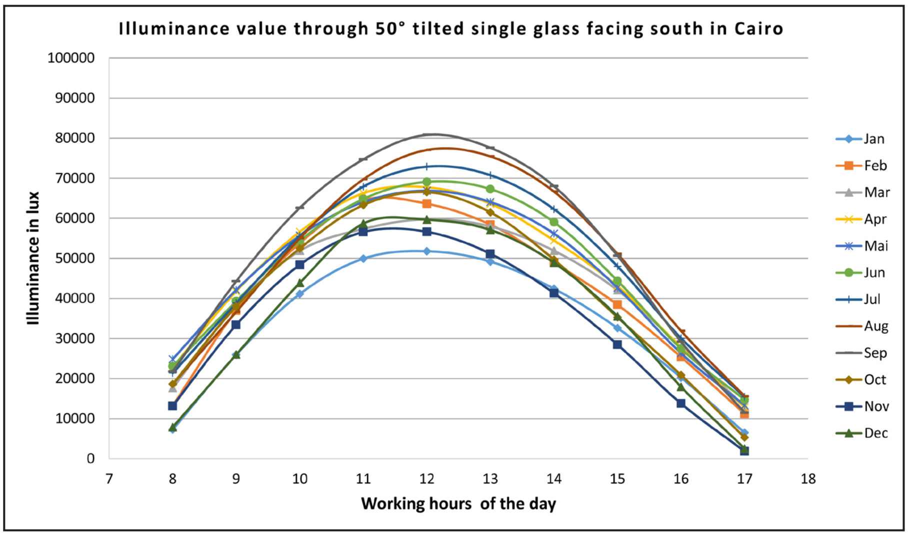


Figure 5.99 *Average illuminance for every working hours per month passing through 6 mm single float glass panel, tilted 50° and, facing south in Cairo.*

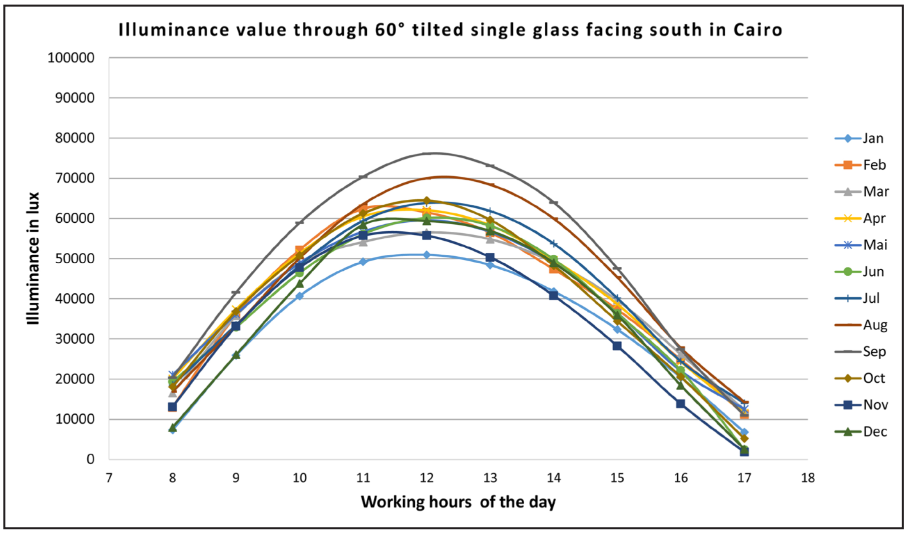


Figure 5.100 *Average illuminance for every working hours per month passing through 6 mm single float glass panel, tilted 60° and, facing south in Cairo.*

By tilting the glass panel at 30° we realize that monthly average illuminance values become closer to each other, where the values decrease in summer months and increased in winter months. (Figure 5.97) At 12:00 pm the difference is ~34 klx between the highest months July, Aug, and Sep with ~85 klx and the lowest month Jan with ~51 klx. At 8:00 am the maximum range is ~24 klx between Mai with ~31 klx and Jan with ~7 Klx.

By further tilting the glass panel to 40° we realize that the monthly average illuminance values become more closer to each other, as the values continue to decrease in summer months and increased in winter months. (Figure 5.98) At 12:00 pm the difference is ~31 klx between the highest month Sep with ~83 klx and the lowest month Jan with ~52 klx. Additionally, we realize that Dec increases dramatically to ~58.5 klx from ~43 klx at horizontal position. At 8:00 am the difference is ~21 klx between Mai with ~28 klx and Jan with ~7 Klx. In general, in winter the increase in values at midday are more than at the early morning or late after noon due to sun low angle in the sky and lateral position in the east or the west.

At tilting angle between 45° and 60° we realize that the monthly average illuminance values continue to be more closer to each other, however this is only because the decrease of values in summer time. Winter values did not show any increase at 50° except for a banal increase in Dec values, and at 60° all values start to increase. Additionally, Sep and Aug values start to move apart of other values. (Figure 5.99 and Figure 5.100)

According to this analysis, we decided to take the tilted angle 40° for our design, since it will help to boost the illuminance value in winter and not losing a lot of the energy falling on the surface. As well, a low tilted angle helps the glass to harvests more light from the sky, since it faces the sky more than high angle; which is important in cloudy days , early morning and late after noon in summer.

5.3.1.2.3.3 Required glass system

The required diffuse laminated glass in the proposed system consists of a transparent glass panel to the out side, diffuse glass panel to the inside, and an interlayer of EVA (ethylene-vinyl acetate) between the two glass layers. The EVA interlayer helps to keep the glass bonded even when broken, to increase the sound insulation rating, and to block up to 99.9% of the UV rays.[1] Furthermore, the glass system may required an additional clear glass layer (a triple glass system) for a thermal reason. However, in our previous calculations we used only a single clear glass. The reason for that, we do not have a photometric measurement at different angles for a single clear glass combined with an EVA interlayer and our selected diffuse glass. Using a single clear glass in the calculation will give the ability to take the light transmission factor at different

1. Laminated glass, Wikipedia, <https://en.wikipedia.org/wiki/Laminated_glass>, (05.12.2016).

angles into account and will give a flexibility of adding the light transmission factor of the diffuse glass and the interlayer later as required. A precise measurement can be conducted in the physical model, as we will do later, and in final phase with the system prototype.

For more details about selecting glass in the museum and typical class factors see: "3.4.2.4 Choosing the right glass for conservation", and "1.5 Appendix: Comparison between important values for selecting a glass for a museum application".

5.3.1.2.3.4 The new daylight collecting chamber form

Based on the glass new 40° tilted angle concept, the form of the daylight collecting chamber needs to be changed. We suggest a new form, where the glass is installed in one direction toward the south and tilted 40° from the horizontal. In addition, on the opposite side of the glass, the wall is curved to reflect the light into the CPC. The new chamber size is smaller in comparative to the previous suggested form in the schematic design. However, the glass area is larger.

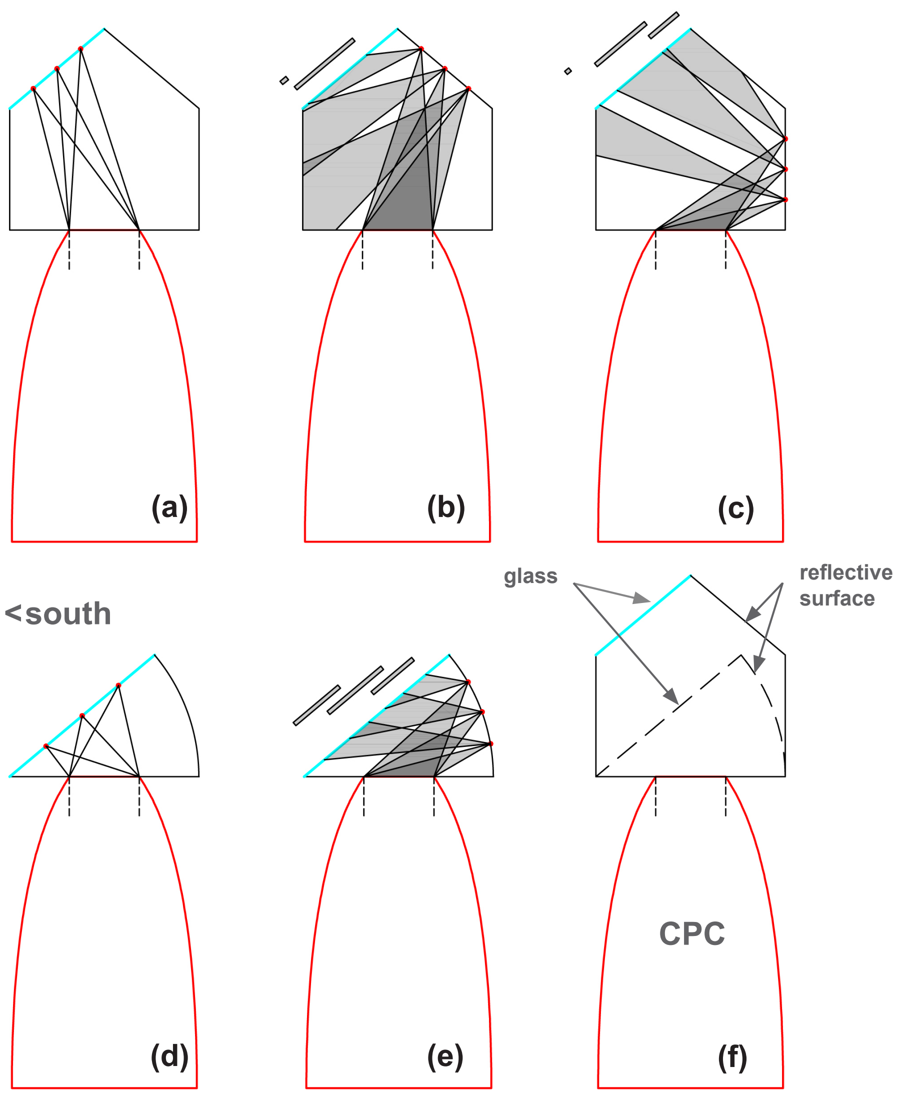


Figure 5.101 *Light paths analysis for the old and new form of the daylight collecting chamber. (a) & (d) show paths of direct light entering the CPC opening from three certain diffuse points. (b), (c) & (e) show reflection paths of the CPC opening backward to the glass at certain points. (f) shows the size of the collecting chambers and its glass areas. As a result of these analysis: the new form emit and reflect more light into the CPC opening.*

Figure 5.101 shows light paths analysis which support using the new form. From these analysis by comparing (a) & (d) we can find out that the amount of diffuse light received directly by CPC opening is more from the new form than that from the old one. This is due to the proximity of the new glass position from the CPC opening. This is examined by comparing the amount of diffuse light reach the CPC opening directly from three points with equal spacing on the glass of the two compared forms. From (b), (c) & (e) we realise that the amount of light received by CPC opening after the first reflection inside the chamber is more in the new form than the old one. This is tested by following the reflection of the CPC opening backward to the glass. All points on the curved surface in the new form reflect the CPC opening on the glass, while a large number of points on the flat surfaces in the old form do not reflect the CPC opening on the glass. From (f) we recognize that the new form is smaller in size, but it has a larger glass area than that of the old form. The small size will help integrating the system in the architecture. As a conclusion: the new form emit and reflect more light into the CPC opening.

5.3.1.2.4 Evaluating the daylight collecting chamber performance

In order to evaluate the performance of the proposed daylight system, we built a physical scale model where we can measure the system photometric data, compare it with other systems, and record needed data for planning.

5.3.1.2.4.1 Constructing evaluation tools

The evaluation tools are a scale model for the proposed system, and a measurement box. The system parts, the collecting chamber and the CPC, are constructed with aluminium sheets MIRO-SILVER 27/4270 AG from the company Alanod. The material is a top grade aluminium sheets with high reflective coating layers. The material has a total reflectivity of ≥98 %, low diffuseness <6 %, very low preferential direction, and optical mirror effect. The CPC top opening from inside is 3,7 x 3,7 cm, the bottom opening is 9,8 x 9,8 cm, and the height is 16,5 cm. The CPC has 44,5° beam angle. Whereas, the daylight collecting chamber base is 10 x 10 cm, the height is 6,3 cm, and the 40° tilted opening from inside is ~ 9,8 x 9,8 cm. The opening is covered with a 3 mm single diffuse glass panel. The glass 3 mm edge is cover with a black tape to block light that can penetrate the glass from its edge. The glass light transmission is 68 %. The chamber is connected to the CPC via a 3,7 x 3,7 cm opening in its base. (Figure 5.102 and Figure 5.103)

The measurement box is constructed from wood and covered from inside with a matt black ballistic sheets. The box's floor is covered with a black carton sheet, that contains a 75 x 75 cm raster with a 9 x 9 points raster. The raster area is covered with CPC beam and the calculation area is 84,375 x 84,375 cm. The box dimensions from inside are 80 cm width, 100 cm depth and 83 cm height. The CPC is fixed to an aperture in the box ceiling. The distant between the measurement surface (the lux meter cell) and the CPC opening is 80,6 cm. The box is opened from the back side and the opening is covered with thick cloth, to help working inside the box without allowing the spilled light to penetrate the box. (Figure 5.102 and Figure 5.106). The measurement was conducted in the artificial sky of Bartenbach Light Laboratory. A digital lux meter MINILUX was used in the measurement. (Appendix 2, "2.3.2 Illuminance-meter").

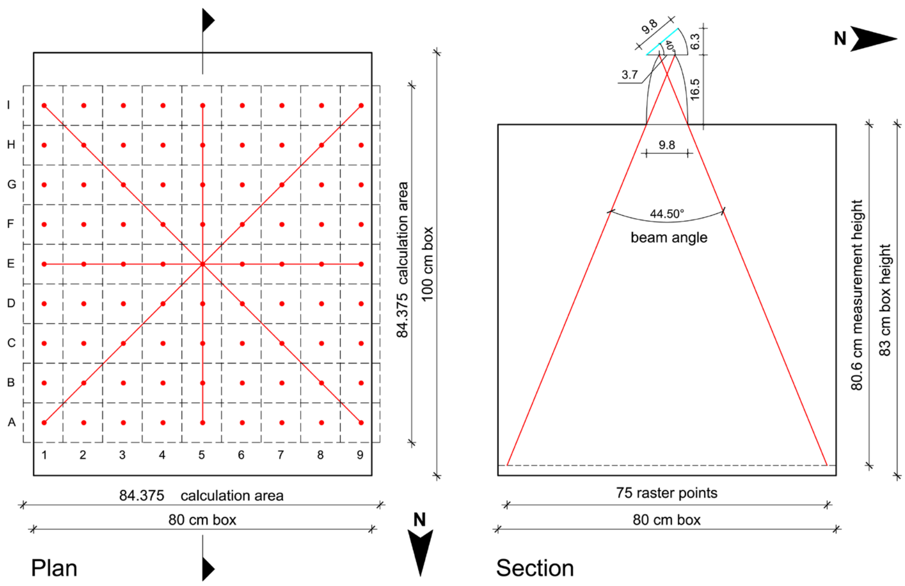
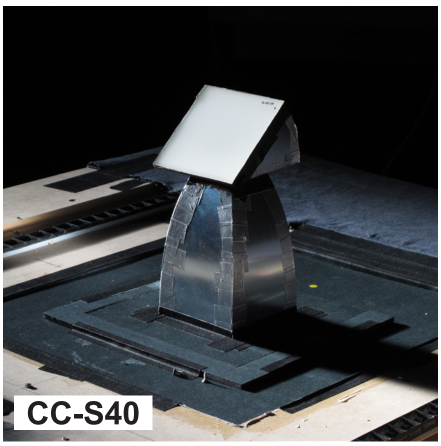


Figure 5.102 *The plan and the section drawing show the dimension of the daylight system model, the measurement box, the measurement raster, calculation area, and CPC beam angle.*



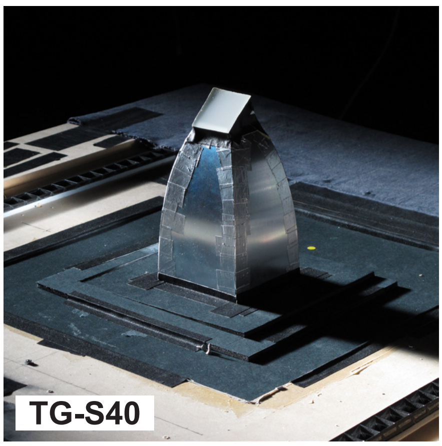


Figure 5.103 *(left) The proposed daylight system. The system consists of a collecting chamber with a 40° tilted diffuse glass connected to a CPC that distribute the light into the measurement box.*

Figure 5.104 *(right) First system in comparison: a diffuse glass panel the size of the CPC opening tilted 40° and connected to the CPC with a form similar to that of the collecting chamber.*

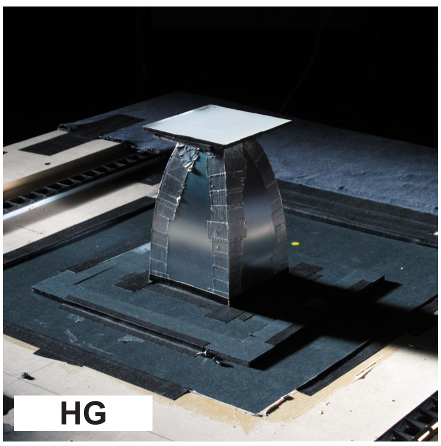


Figure 5.105 *(left) Second system in comparison: a horizontal diffuse glass panel closing the CPC opening.*

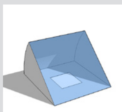
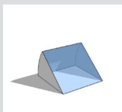
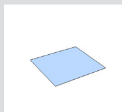
Figure 5.106 *(right) The daylight system model and the measurement box during conducting the experiment in the artificial sky.*

5.3.1.2.4.2 Checking system capacity

To evaluate the capacity of the new proposed daylight system (Figure 5.103), we compared it with two other systems. The first is a diffuse glass panel the size of the CPC opening tilted 40° and connected to the CPC with a form similar to that of the collecting chamber. (Figure 5.104) By comparing this form to the proposed one, we can infer the effect of the collecting chamber's form. The second is a simple horizontal diffuse glass panel closing the CPC top opening. (Figure 5.105) By comparing this form to the previous one, we can infer the effect of tilting the glass. We denote the daylight collecting chamber system CC-S40, the tilted diffused glass TG-S40, and the horizontal diffused glass HG.

The comparison and evaluation of the systems depends on measuring the luminous flux incident on the measurement area Φ_m to know how much daylight every system delivers. The calculation of Φ_m was done with the illuminance values at the central horizontal and vertical axis of the raster. In our case, this procedure is sufficient to evaluate the systems, and to provide a sense about the light distribution of every system. Additionally, we calculated the system's daylight transfer efficiency η_t which is the ratio between the luminous flux received by the system Φ_s and the luminous flux incident on the measurement area Φ_m. This is important to know how much the system is affected by the incident angle of the sun rays.

As the direction of the sun rays to the glass surface is crucial of determining how much light penetrates the glass and collected by the system, we conducted three measurements A, B, and C with three different sun angles 45H/45V, 0H/45V, and 0H/20V, respectively. Where south is 0, East is 90, West is -90, and North is 180. (Figure 5.55) During conducting the measurement, the system was always facing south, and the artificial sun (a set of LEDs with narrow beam angle lenses) has always the same intensity and changes only in position.

MEAS	Sun Position	CC-S40			TG-S40			HG		
		Φ_m	$\overline{E}$	η_t	Φ	$\overline{E}$	η_t	Φ_m	$\overline{E}$	η_t
A	**45H/45V**	**31,05**	43,6	12,3%	**22,3**	31,33	62,02%	**19,37**	27,21	65,51%
B	**0H/45V**	**37,48**	52,65	12,82%	**28,31**	39,77	67,96%	**17,41**	24,46	58,89%
C	**0H/20V**	**29,86**	41,95	10,8%	**22,17**	31,15	56,44%	**5,28**	7,4	36,93%

Where:
Φ_m is luminous flux incident on the measurement area.
$\overline{E}$ is average illuminance on the measurement area.
η_t is system daylight transfer efficiency, as $\eta_{dl} = \Phi_m / \Phi_{system} \cdot 100$

Illuminance incident on 40° tilted surface and at the horizontal for every measurement:
A - E40° = 26270 lx, Eh = 21600 lx
B - E40° = 30430 lx, Eh = 21600 lx
C - E40° = 28700 lx, Eh = 10447 lx

Table 5.7 *Measurement results of comparing three daylight systems at three different sun positions.*

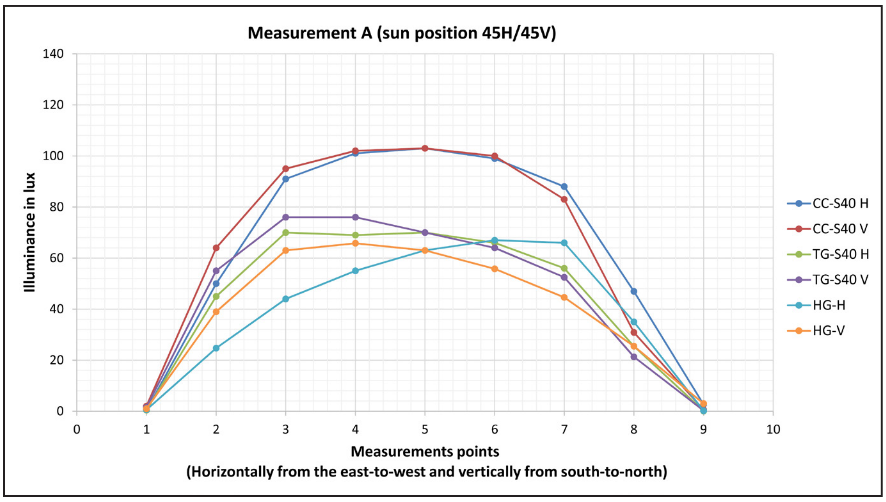


Figure 5.107 *Measurement A. The illuminance values measured on the horizontal and vertical axis of the measurement area for the systems CC-S40, TG-S40, and HG under 45H/45V sun position.*

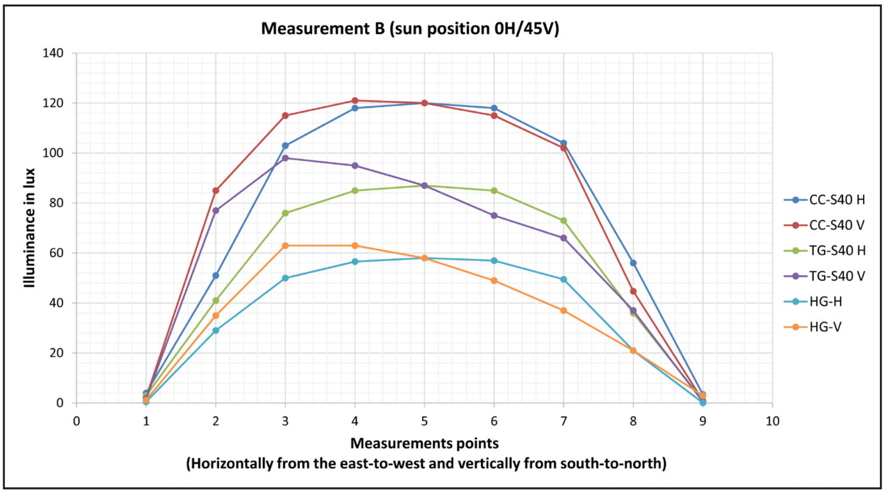


Figure 5.108 *Measurement B. The illuminance values measured on the horizontal and vertical axis of the measurement area for the systems CC-S40, TG-S40, and HG under 0H/45V sun position.*

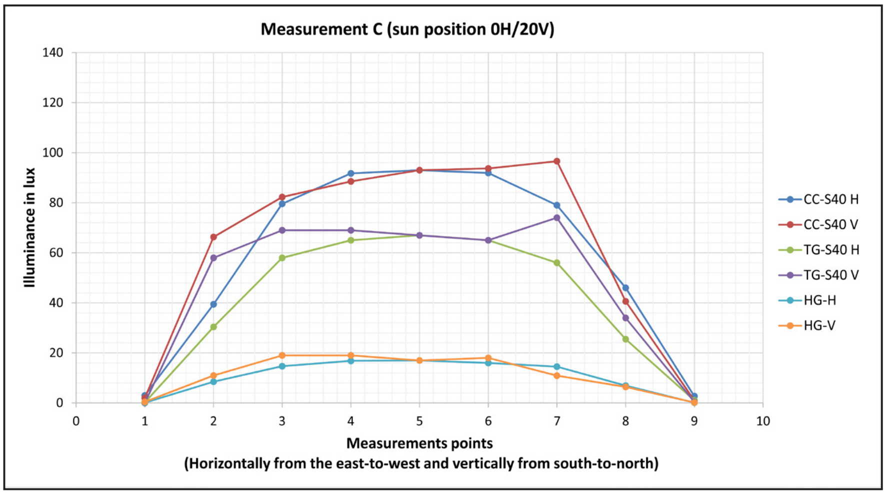
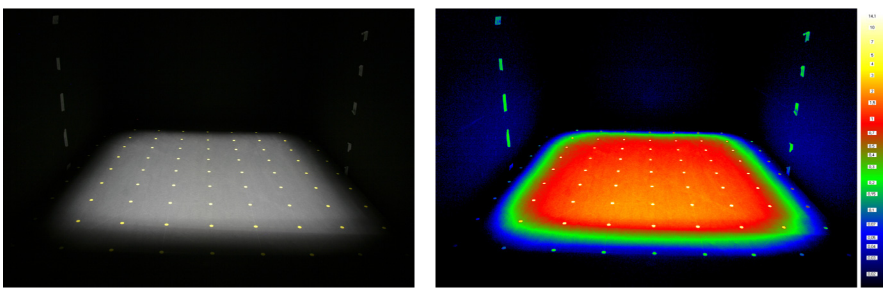


Figure 5.109 *Measurement C. The illuminance values measured on the horizontal and vertical axis of the measurement area for the systems CC-S40, TG-S40, and HG under 0H/20V*



(a) (b)

Figure 5.110 *(a) The light distribution of proposed daylight system CC-S40 under sun position A (45V/45H) (b) A false colour image shows the luminance distribution for the first image. (Values are in cd/m²: Approx. white 14, yello 4, orange 2, red 1, green 0.2, and blue 0.6)*

The results show that, luminance flux Φ_m for HG increased when the glass is tilted in TG-S40, and further increased by using the chamber's form in CC-S40. The increase between HG and TG-S40 dramatically varies and it is related to the sun position, while the increase between TG-S40 and CC-S40 does not varies much and ranges between 38,8% and 33,6%. This is because the glass orientation to the sun in both systems are the same, and the chamber increases the luminous flux entering the CPC by the internal reflections occurred inside it. (Table 5.4)

The system daylight transfer efficiency η_t shows that, tilting the glass helps to balance the amount of light entering the system between the three sun positions as we expected. (See previous part "5.3.1.2.3.1 Choosing the suitable tilted angle"). Additionally, it shows that the CC-S40 has a low daylight transfer efficiency η_t . This is because not all internally reflected light in the chamber is redirected into the CPC. However, the chamber collects more light and increases the luminous flux entering the CPC significantly.

The illuminance values measured at the central horizontal and vertical axes of the systems at different sun position show that the collecting chamber CC-S40 creates more even light distribution around the centre axis of the light beam than other systems the TG-S40 and HG. (Figure 5.107 to Figure 5.110) The slightly uneven distribution exist because the glass is not perfectly diffuse and thus the light incident angle has an effect on the light distribution. The internal reflection reduce this effect in collecting chamber. Using a perfect diffuse glass well insure a perfect light distribution, however it will lower significantly the amount of light that penetrates the system.

To sum up the results, the daylight collecting chamber CC-S40 increased the luminous flux, balance the luminous flux received by the system at different sun positions, and creates an even light distribution around the centre axis of the light beam.

5.3.1.2.4.3 Measuring system performance

We evaluate the CC-S40 daylight system at certain sun positions that can show the system performance during the course of the day and the year. Additionally, we used the evaluation measurement to create an Eulumdat files,[1] to help utilizing the photometric data of the proposed system digitally in the lighting design process.

Since the working hours extend from 8:00 to 17:00, we measured the system performance according to the change of sun position every two hours at 8:00, 10:00, 12:00; and also at 17:00. These four measurements are repeated on three days: 21 June (Summer Solstice), 21 Mar (Spring Equinox), 21 Dec (Winter Solstice). Additionally, we measured the system under diffuse sky. Note that, the system is facing south and sun position at 14:00 and 16:00 are a mirrored repetition for 10:00

1. Eulumdat is a data file format used for specification of photometric data especially intensity distributions from light sources such as lamps and luminaries. Eulumda, Wikipedia, <https://en.wikipedia.org/wiki/EULUMDAT>, (14.12.2016).

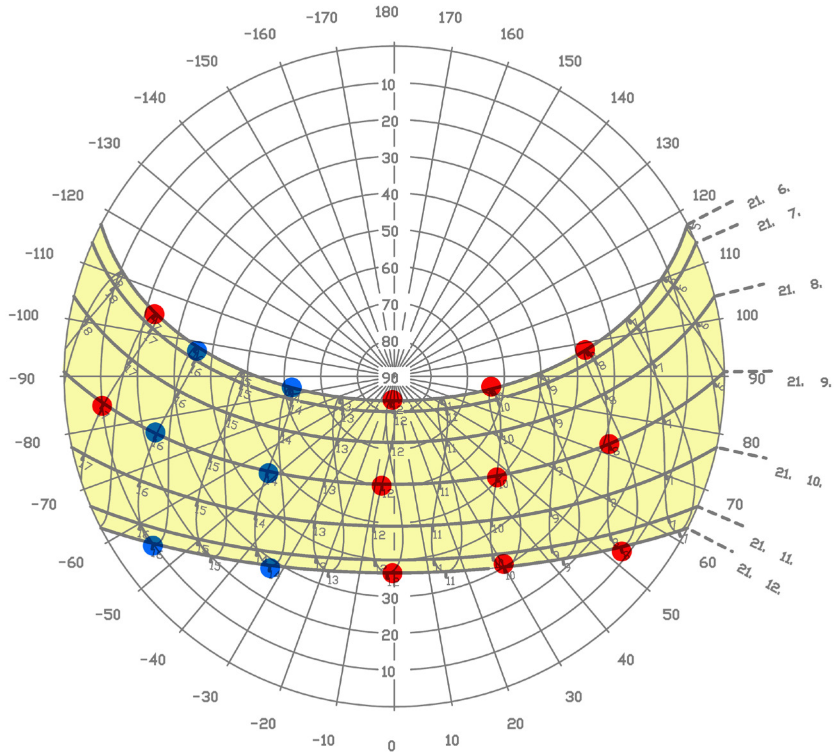


Figure 5.111 *The red dots on Cairo's stereographic sun path diagrams show sun positions, at which the measurements are done to test the daylight system performance. The sun position at the blue dots are excluded because it is a mirrored repetition for sun position at the red dots.*

MEAS	Date	Time	Sun Position	Φ_m	$\overline{E}$	$\overline{E}$ at 10 klx	η_t
1	**21 June**	**08:00**	98H/37,2V	11,21	15,7	11,2	**8,33%**
2	**21 June**	**10:00**	83,0H/63V	28,66	40,3	14,1	**10,47%**
3	**21 June**	**12:00**	-5,1H/83,4V	42,70	60	15,9	**11,76%**
4	**21 June**	**17:00**	-104,6H/23,3V	0,78	1,1	4,6	**3,40%**
5	**21 Mar**	**08:00**	73,8H/24,4V	14,94	21	12,6	**9,32%**
6	**21 Mar**	**10:00**	49,5H/47,3V	36,57	51,4	14,9	**11,04%**
7	**21 Mar**	**12:00**	2,0H/59,2V	47,27	66,4	15,8	**11,72%**
8	**21 Mar**	**17:00**	-81,1H/13,4V	5,51	7,7	8,4	**6,23%**
9	**21 Dec**	**08:00**	53,3H/12,4V	17,23	24,2	12,5	**9,30%**
10	**21 Dec**	**10:00**	30,5H/30V	37,33	52,4	14,8	**10,95%**
11	**21 Dec**	**12:00**	-1,5H/36,5V	44,52	62,5	15,4	**11,42%**
12	-	-	**Diffuse**	3,85	5,4	13,7	**10,15%**

Where:

Φ_m is luminous flux incident on the measurement area.
$\overline{E}$ is average illuminance on the measurement area.
$\overline{E}$ at 10 klx is value of $\overline{E}$ normalized at 10000 lx.
η_t is daylight system's transfer efficiency, as $\eta_{dl} = \Phi_m / \Phi_{system} \bullet 100$

Table 5.8 *Measurements results of studying the proposed daylight system CC-S40 at different sun positions that show the system performance during the course of the day and year.*

and 8:00; sun position at 21 Sep (Autumn Equinox) are similar to that in 21 Mar (Spring Equinox), and measurement at 17:00 on 21 dec discounted because the sun is already set at this time. Inclusively, we have 11 measurement that cover the change of the sun position during the day and the year, and one measurement under diffuse sky to cover the condition when the sun is obscured. (Figure 5.111 and Table 5.5)

We used in the measurements two plexiglas panels to resemble the required glass system for the collecting chamber in reality. The panels are a transparent plexiglas panel to the out side with about ~88% light transmission, and our selected diffused plexiglas panel to the inside with ~68% light transmission.

The evaluation depends on measuring the illuminance value incidents on the system and on the 81 points of the measurement raster. From the measurements we calculated the luminous flux incident on the measurement area Φ_m to know how much light is harvest by the system at every sun position. As well, we calculated the system daylight transfer efficiency η_t which is the ratio between the luminous flux received by the system Φ_s and the luminous flux incident on the measurement area Φ_m . This is important to know how much the collected light is effected by the incident angle of the sun rays.

The results in (Table 5.5) show that the η_t have a very close value at the same hour on 21 June, 21 Mar, and 21 Des; and it changes slightly between hours of the same day at 8:00, 10:00 and 12:00; and it drops down at 17:00. This means that the η_t value is more affected with the change of sun azimuth than sun altitude. However, when excluding the value at 17:00, the maximum range of change in η_t value is 12% between 8:00 and 12:00 on 21 Jun. (Figure 5.114) Of the above, the system balance the η_t value for a long time between different sun positions during the day from 8:00 to 16:00 all over the year.

For the purpose of evaluating and comparing the light distribution on the measurement area at every sun position; we normalised/re-scaled the 81 measured lux value to arrive at values equal to that when 10 klx is incident on the system, and from this normalization we constructed an isoline diagrams. The isoline diagrams give information on the distribution of light in plan, and they show that the light distribution is not perfectly symmetrical around the central axis of the beam. It is slightly shifted with the change of sun position. As well, the areas covered in the centre have a constant illuminance value and the value drop gradually till it fades shortly before reaching the border of the measurement area. Generally, the light distribution and its change in all diagrams can be distributed as similar. (Figure 5.113)

Additionally, from the 81 measured lux value we constructed a Eulumdat files by using a special software designed by the development department of Bartenbach Lighting Laboratory. The software depends on calculating the luminous intensity from the illuminance value at every measured point and linearly interpolate the intensity values between the points. The Licht Distribution Curve (LDC) generated in the Eulumdat illustrates the distribution of luminous intensity, in candelas, for the transverse (C0-C180) and axial (C90-C270) planes of the light beam. The results show that, the two planes are slight shift form each other. The slight shift changes with the change of the sun position. Which match with the results from isoline diagram. (Figure 5.112)

As a conclusion, the performance evaluation shows that the daylight system CC-S40 has a close value of (η_t) for a long period during the day around the year, and maintains a stable distribution.

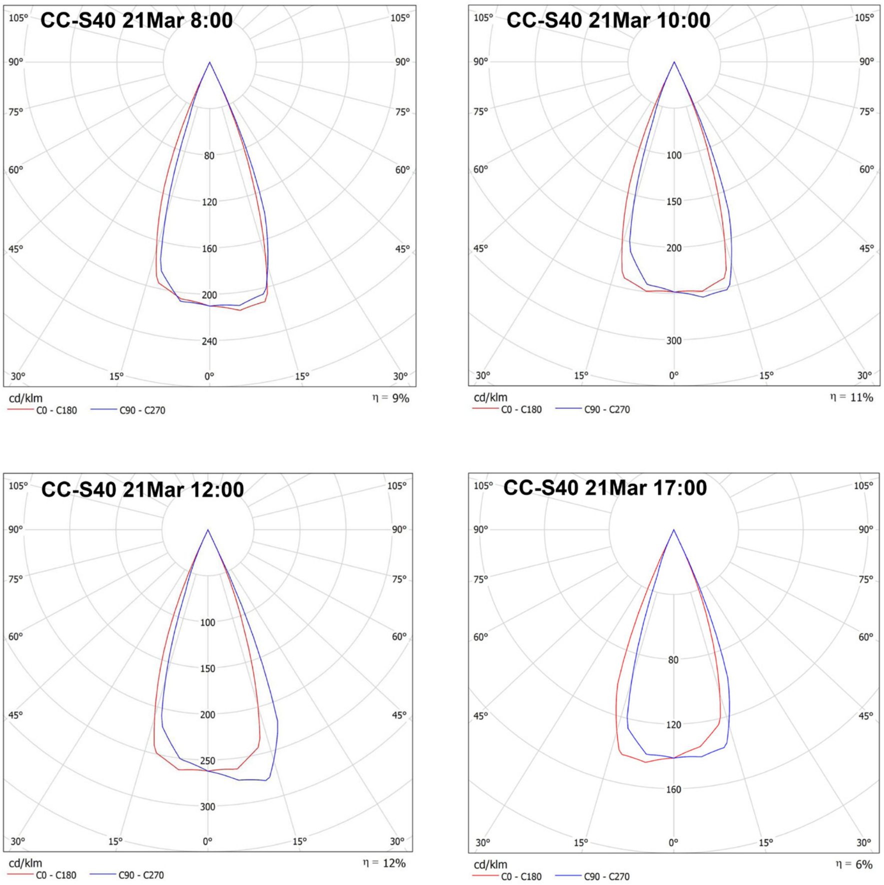


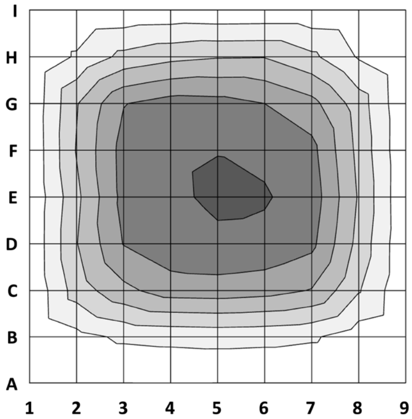
Figure 5.112 *The Light Distribution Curve (LDC) generated by the Eulumdat for the measurements at 8:00, 10:00, 12:00, and 17:00 on 21 Mar.*

5.3.1.2.4.4 System performance in practice

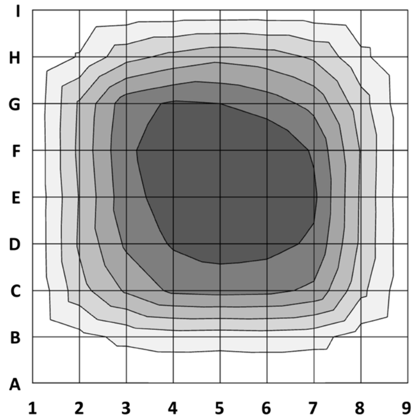
It is very important to know how the proposed daylight system CC-S40 functions in real application, thus we calculated the luminous flux Φ_m and the average illuminance $\overline{E}_m$ incident on the measurement area according to Cairo weather data. The calculation was conducted based on the results of the previous calculation of daylight transmitted through a tilted glass panel (See 5.3.1.2.3.1).(1) Thus, we used the system daylight transfer efficiency η_t for several sun position and for diffuse light, to calculate the luminous flux Φ_m as the sum of the three luminous flux collected from the sun, the sky, and the reflected light.

1. Using the data of the previous calculation means: a 88% daylight transmission value for a single clear glass is added to the luminance flux value Φ_m calculated from Cairo weather data. This can be considered as an extra glass panel added to the system or as a maintenance factor.

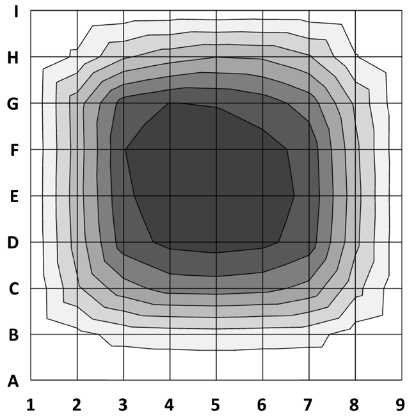
CC-S40 21Jun 8:00 98H/25,5V



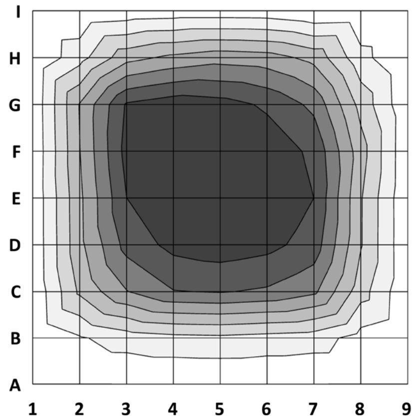
CC-S40 21Mar 8:00 74H/37,5V



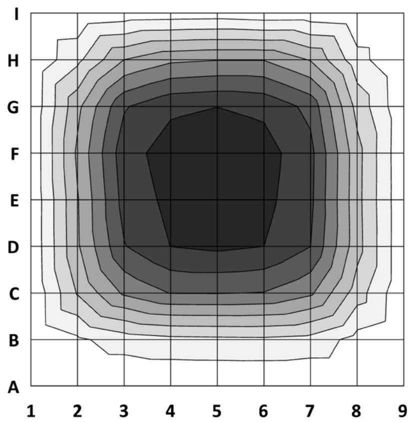
CC-S40 21Jun 10:00 83H/63V



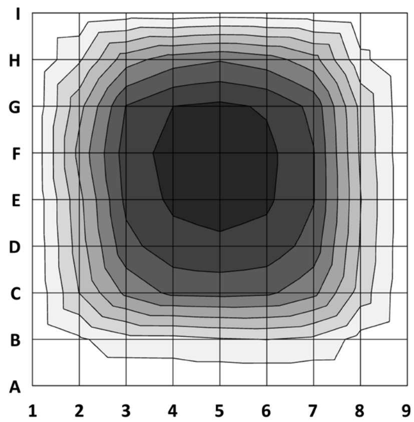
CC-S40 21Mar 10:00 50H/48V



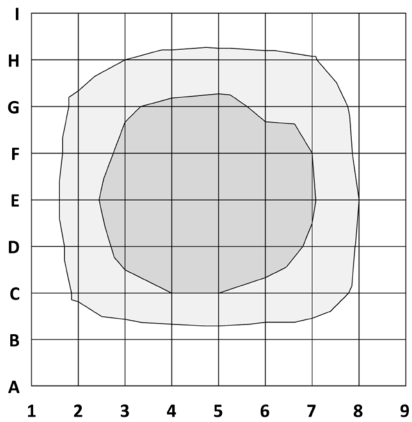
CC-S40 21Jun 12:00 -5H/83,4V



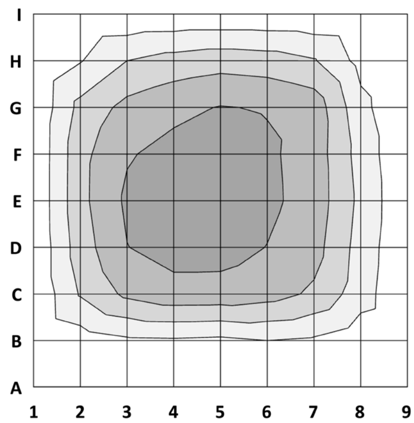
CC-S40 21Mar 12:00 2H/60V



CC-S40 21Jun 17:00 -104,5/23V



CC-S40 21Mar 17:00 -81,5H/23V



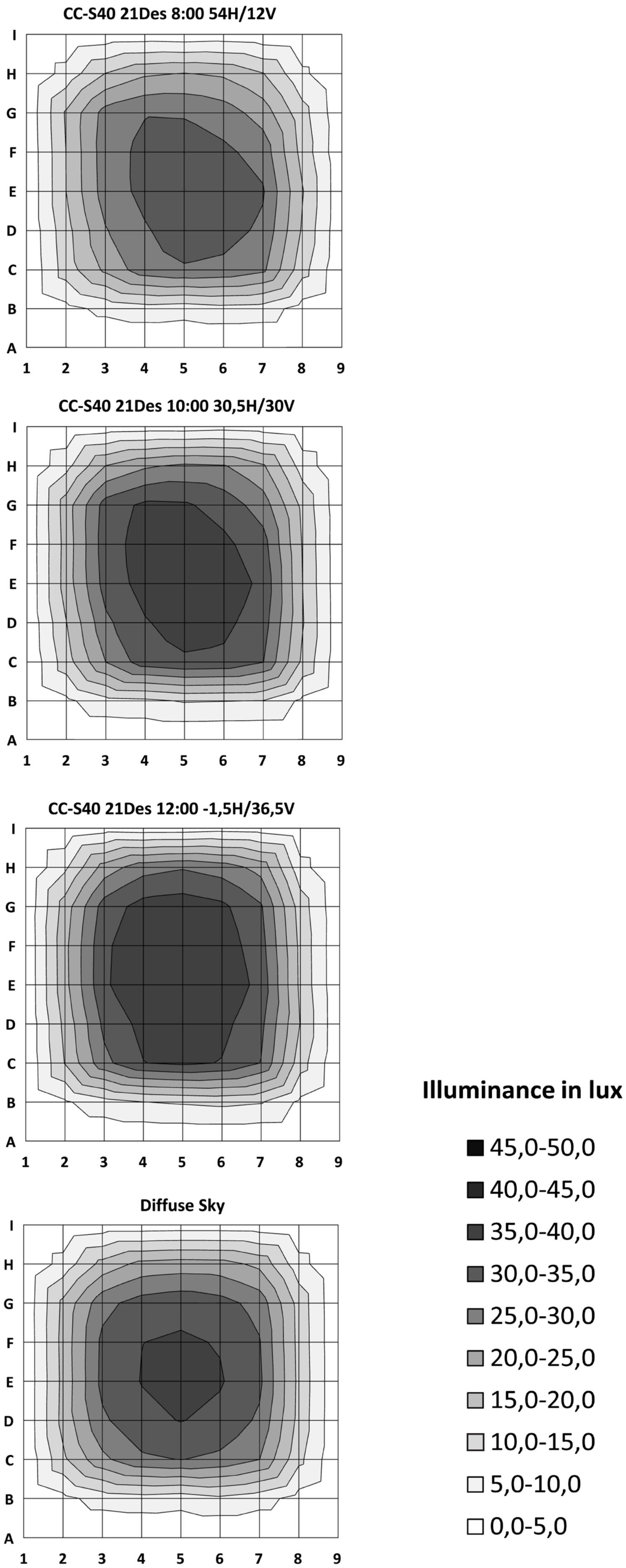


Figure 5.113 *Isoline diagrams show the performance of the proposed daylight system CC-S40 at different sun position and under diffuse light. The diagrams illuminance values are normalised to arrive at values equal to that when 10 klx is incident on the system.*

The luminous flux Φ_m is calculated from every component as:

$$\Phi_m = \Phi_s \cdot \eta_t$$

Where: Φ_m is the luminous flux incident on the measurement area, Φ_s is the luminous flux received by the system from sun, diffuse sky, or reflected diffuse light, and η_t is the system daylight transfer efficiency for a specific sun position, diffuse sky, or reflected diffuse light.[(1)]

And then, we calculated the average illuminance on the measurement area $\overline{E}_m$ from the calculated luminance flux Φ_m.

$$\overline{E}_m = \Phi_m / A_m$$

Where: $\overline{E}_m$ is average illuminance on the measurement area, Φ_m is the luminous flux incident on the measurement area, A_m measurement area.

When comparing the illuminance values through horizontal single glass panel and through 40° tilted single glass panel in (Figure 5.96 and Figure 5.98), we realize that the variance between illuminance values of the months are reduced and changed in order. This is because tilting the glass to face the winter sun path has reduced slightly the value for summer months and increased the values for winter months that fall on the glass. Further, the calculation of the average illuminance $\overline{E}_m$ on the measurement area (Figure 5.115), shows that the variance between illuminance values of the months are relatively further reduced and changed in order; this can be recognized from the value on 21 Sep.

The daylight transfer efficiency η_t and average illuminance $\overline{E}_m$ values can be used to utilize the system in real applications. (Figure 5.114 and Figure 5.115) However, we realised from the measurements that the illuminance fades steeply in a short distance before it reach the end of the 9 x 9 raster, and the illuminance is more confined in an area of 65,625 x 65,625 cm, which covers 7 x 7 points of the raster and fit in ~39° beam angle. (Figure 5.107 to Figure 5.110) This means, in practice calculation the illuminance outside this area can be neglected and the average illuminance $\overline{E}_m$ for this area will be more reliable. Therefore, we repeated the calculation according to the new area and excluded the insignificant values at the end of the raster.

The results show that, the values of the average illuminance $\overline{E}_m$ in the confined area of 7 x 7 raster are higher than that in measurement area 9 x 9 raster as expected; and the $\overline{E}_m$ variance between the months become larger. Actually, the variance between monthly value and its order is in accordance with the value of the illuminance through horizontal 40° tilted single glass panel. (Figure 5.98). Perhaps excluding the small value at the end of the raster helps to refine the results or it may effects some calculation more than others. In any case using this value in practice will be more reliable.

Additionally, taking account of the isoline diagrams (figure 5.113) in the lighting design process will help to estimate the illuminance value that can be focused on the middle of the space.

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1. The system daylight transfer efficiency for diffuse sky is the same for reflected diffuse light.

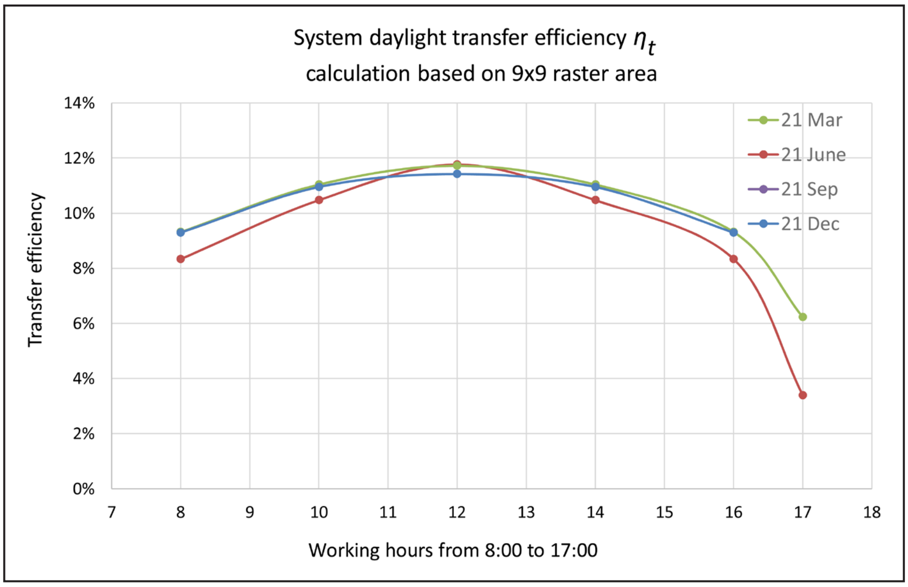


Figure 5.114 *The CC-S40 system daylight transfer efficiency ηt at different sun position. The ηt is the ratio between the luminous flux received by the system Φs and the luminous flux incident on the measurement area Φm. Note: The ηt at 21 Mar and 21 Sep have the same values.*

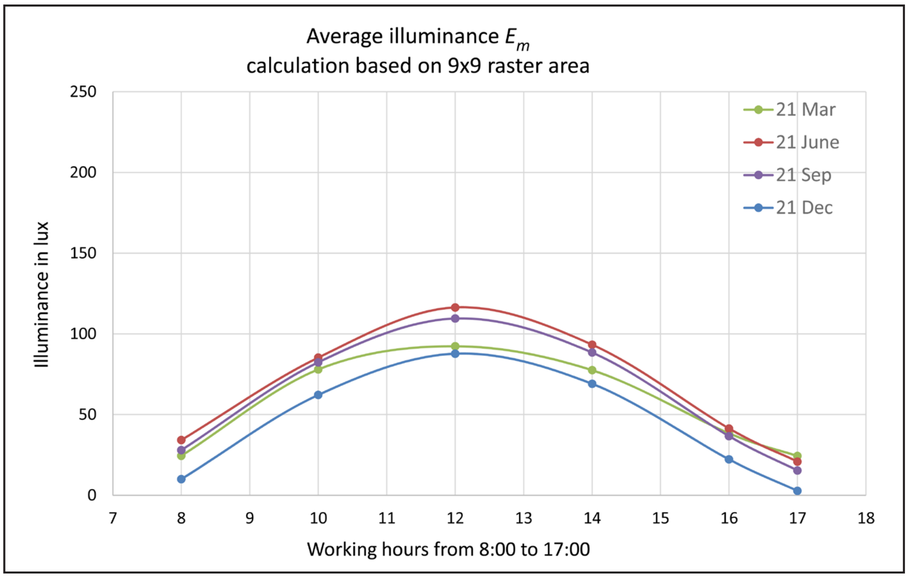


Figure 5.115 *The average illuminance $\overline{E}_m$ according to Cairo weather data. The calculations are based on 9x9 raster of the entire measurement area.*

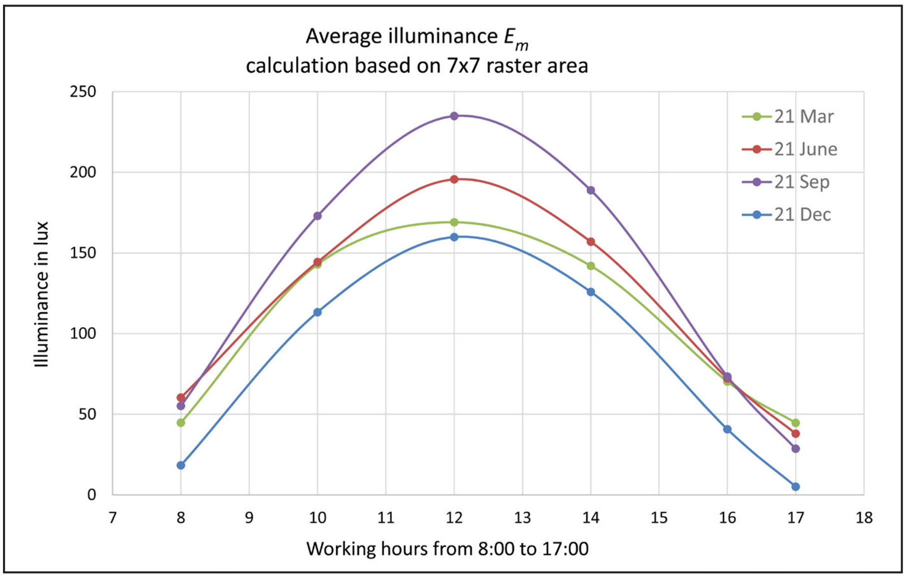


Figure 5.116 *The average illuminance $\overline{E}_m$ according to Cairo weather data. The calculations are based on the area of 7 x 7 raster, where illuminance is more confined.*

5.3.1.2.5 Testing chamber-system in museum model

5.3.1.2.5.1 Testing illuminance levels

The height of the Large Side Hall in the museum model is 84,2 cm, which is close to the 83 cm height of the measurement box, thus it will be applicable to use the daylight system model in the museum model and to adapt the previous measurements. The model of the CPC has a bottom opening of 9,8 x 9,8 cm, which is in the museum model scale 1:20 equal to 1,96 x 1,96 = 3,8416 m^2. In the schematic design the proposed system is 5 CPCs with 1 m^2 bottom opening, which form a 5 m^2 opening in the ceiling of the museum hall. Thus, the measurements values need to be multiplied with ratio of 1,30 to be adapt to the schematic design. Despite that the shape of the CPCs opening in the design is different than that of the system model, it is adequate for the evaluation. According to the design, we need to focus the light on the platform, where the illuminance target is 200 lx for galleries with low-responsive-to-light exhibits and 550-800 lx for galleries with irresponsive-to-light exhibits. (Figure 5.73 and Figure 5.81) The platform dimension is 3,8 x 7,4 m and according to the measurement raster this area is covered with 3 x 3 points of the raster and stretches little bit outside. Thus, we calculated the average illuminance $\overline{E}_m$ on 3 x 3 points area and we scaled it to fit with the proposed system size.

The results show that the average illuminance $\overline{E}_m$ on the platform will achieve the target of 200 lx for a long period during the year, and it will only fall in the early hours of the day. To maintain a stable value, the values higher than 200 lx can be controlled with the roller-screen, and the value less than 200 lx can be boosted with artificial light. On the other hand, the results show that the central area will not reach 550-800 lx. The number of the CPCs need to be increased to reach this high target. As for the area around the platform, it will have illuminance value less then 200 lx, which is suitable to be a room lighting and a surrounding for showcases that is mostly displayed in this area and illuminated with artificial light. (Figure 5.117)

5.3.1.2.5.2 Testing the lighting effect

According to the design, the light beam's brim is incident on upper floor and as it turns out, it creates a high spot of light on the floor, that will disturb the dim atmosphere of the upper floor and create a veiling reflection on the showcases' glass. (Figure 5.119 - b)

The edge of the void casts shadow on the ground floor's walls, that will disturb the appearance of the exhibits on the walls. As well, the edge receives a lot of light and it is so bright. The brightness can be reduced by changing the edge colour. (Figure 5.119 - a)

As intended, the illuminance distribution has to create a gradual brightness from the centre of the space toward the walls. Unfortunately, the illuminance distribution does not create this visual effect and it appears uniform to the eye. (Figure 5.118 - a)

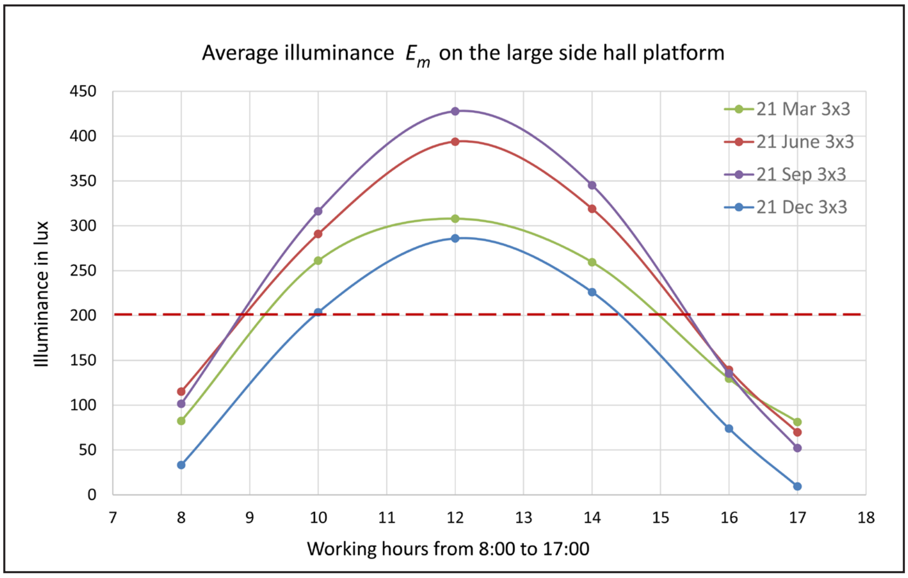
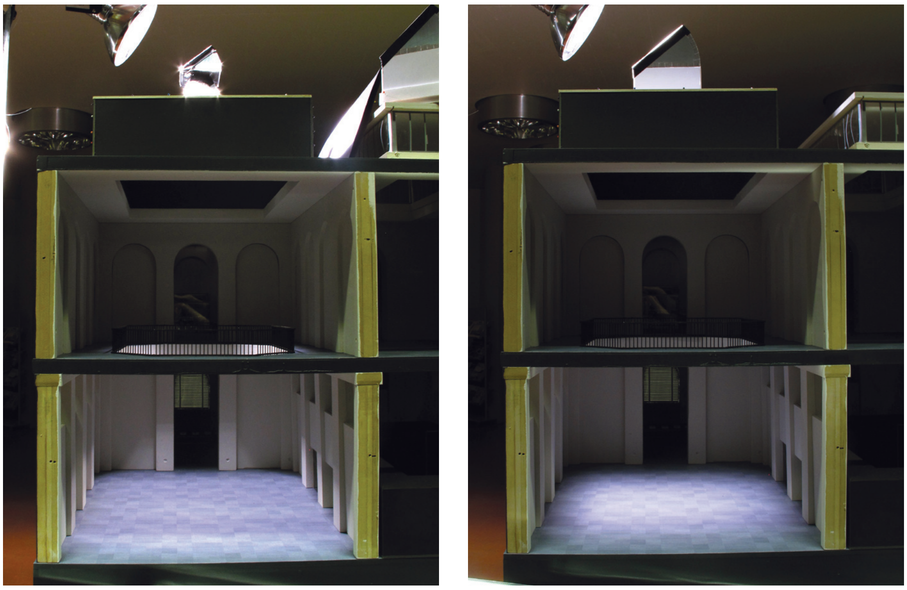
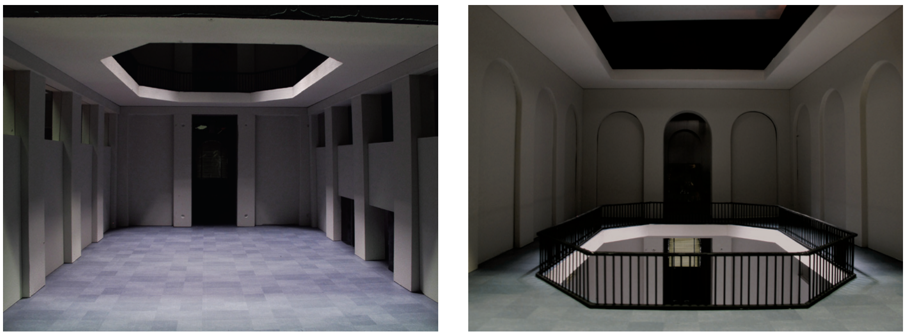


Figure 5.117 *The average illuminance $\overline{E}_m$ on the Large Side Hall platform according to Cairo weather data.*



(a) (b)

Figure 5.118 *The light effect created by the daylight system on the ground floor (a) with CPCs 44.5° beam angle (b) with CPCs 30° beam angle, after modifying the system.*



(a) (b)

Figure 5.119 *The light effect of a 44,5° beam angle CPC on the model (a) The edge of the void casts shadow on the ground floor walls and it is so bright. As well, the illuminance on the ground floor appears uniform and did not highlight the centre. (b) The incident light on the border of the void creates a spot of light, that will disturb the dim atmosphere of the upper floor.*

We tried to reflect a part of the light beam on the walls to highlight the exhibits, as suggested in the schematic design; however the light at the end of the beam is weak to highlight the wall and the reflectors creates a dark shadow on the floor. The idea is not applicable in our case.

5.3.1.2.6 The chamber-system final design

A final step in the development of the daylight chamber system is to fit the system to design goals and to approve its performance.

5.3.1.2.6.1 Adjusting the system to design goals

To raise the illuminance levels on the platform and to solve the visual problems; the CPC numbers have to be increased, and their light beam angle have to be narrowed. According to the geometry of the gallery, a 10 m^2 ceiling opening installed with a 30° beam angles CPCs can increase the illuminance, cover the entire floor, and focus the light more on the centre, and avoid all visual problems. (Figure 5.136 and Figure 5.137) In the real building, the ceiling opening will encompass a 40 units of 30°- CPC that are attached to a one large daylight collecting chamber. For the difficulty of modelling the system, the same ceiling area in the model will be covered with 10 units of 30°- CPC. Changing the CPCs size that cover the same area technically do not change the system performance. (Figure 5.120) The new daylight system is constructed from the same material as the previous one. The construction of the model is explained in (Figure 5.121).

5.3.1.2.6.2 Approving the final design performance

Changing the geometry of the chamber and the beam angle of the CPCs may affect how the system performs. Therefore, we conducted a few measurements for the final system to confirm its performance.

The measurements are conducted in the museum model. The walls and floor of the Large Side Hall GF in the model were covered with black paper. The floor paper contains a 48 x 64 cm raster with 7x9 points. The calculation area is 56 x 72 cm and it has the same size of the gallery floor area. The height between the system and the measurement surface (the lux meter cell) is 85,55 cm. The measurement was conducted in the artificial sky of Bartenbach Light Laboratory. Note that: since the system beam angle cover the entire floor, we had to lay the measurements raster within this area and not exactly at the end of the beam angle, this may decrease the luminous flux valve slightly. (Figure 5.122)

We conducted the measurements at sun positions: on 21 Mar at 8:00, 10:00, 12:00; on 21 Dec at 12:00; and on 21 June at 12:00. As well, under diffuse sky. The six measurements are adequate to evaluate the system new form performance and compare it to the previous form. We followed the same procedures and measured the same values as we done previously. (5.8.1.2.4.3 Measuring systems performance).

The results in (Table 5.6) show that, the system daylight transfer efficiency η_t have a stable values, which means the new system form balance the amount of light entering the system between different sun positions as previous one. Additionally, the luminous flux Φ_m and the average illuminance $\overline{E}_m$ incident on the measurement area are higher, which means the new system form bring more daylight to the museum interior as we expected.

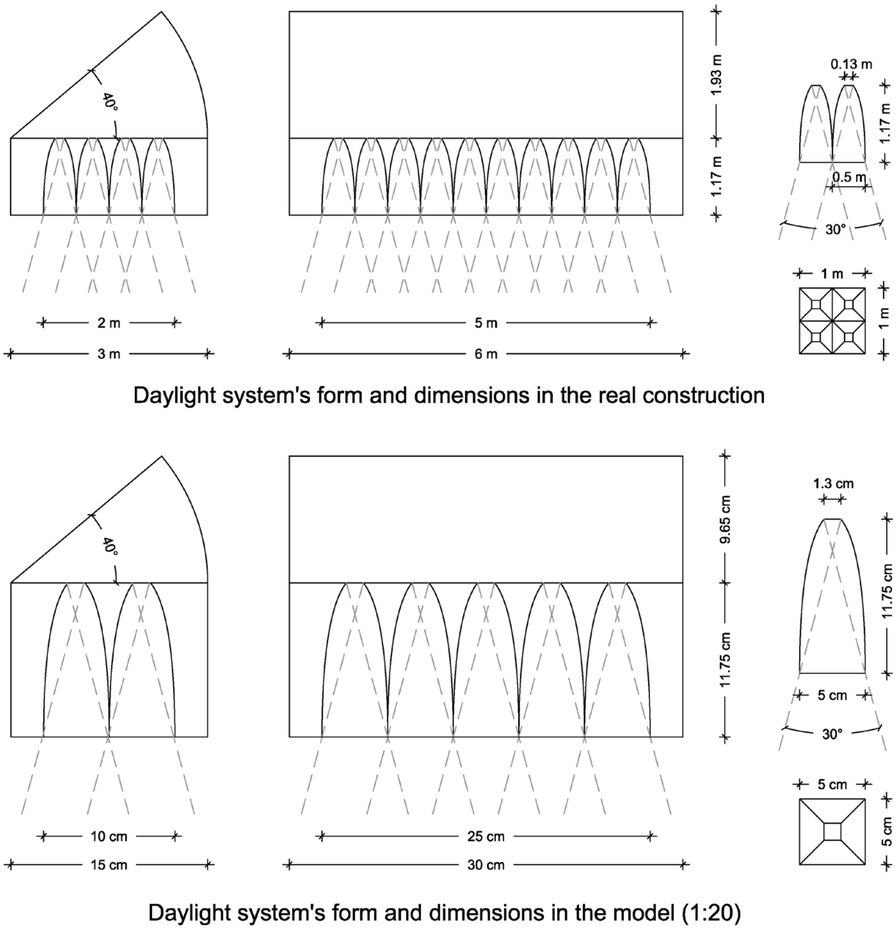


Figure 5.120 *The Daylight system's form and Dimensions in the real construction and in the model (1:20). Changing the CPCs size that cover the same area technically do not change the system performance.*

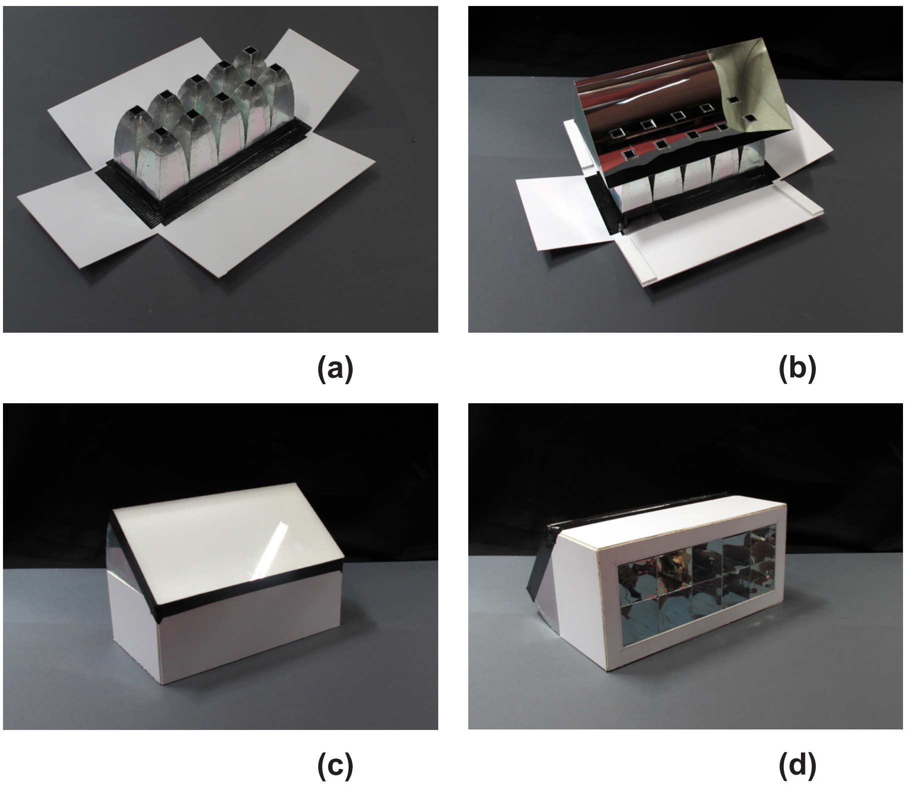


Figure 5.121 *Constructing the new 30°- CPCs model. (a) Building a 10 units of the 30°- CPCs and assembling them in a box made of a carton paper. (b) Connecting the daylight collecting chamber to the CPCs. (c) Covering the chamber with two panels of diffuse and clear plexiglass, and assembling the box. (d) A bottom view for the system.*

To compare the illuminance values and its distribution between the new form and the previous one, we normalised the 63 measured lux value to arrive at values equal to that when 10 klx is incident on the system, and from the normalizations we constructed an isoline diagrams. The results show that, average illuminance $\overline{E}_m$ at 10 klx for the new form is about two times the results of the previous form. (Table 5.6) The isoline diagrams show that, the light distribution of new form are less shifted with the change of sun position than the previous one. On the other hand, the illuminance value of the new form drop faster between the centre and end of the measurement area. This is due to the narrow beam angle of the CPCs. Generally, differences between the old and new form are minor. (Figure 5.125 and Figure 5.113).

To compare the performance of the two systems we assume that, dividing the CPC to a smaller units that share a one large daylight chamber do not alter the amount of luminous flux enter the CPCs. So it is valid that, the ratio between the luminous flux enters the 10 units 30°- CPC and that enters the 44.5°- CPC, is equal to the ratio between the top opening area of the 10 units 30°- CPC and the top opening area of the 44.5°- CPC. By calculating this ratio, a factor of 1,1675113 can be use to estimate luminance flux Φ_{m30} for the new system from the previous luminance flux $\Phi_{m44,5}$ as follow:

$$\Phi_{m30} = \Phi_{m44,5} \cdot 1,1675113$$

Further, since the new system cover a smaller area, the average illuminance $\overline{E}_{m30}$ will be higher and the illuminance distribution will be different. Nevertheless, the average illuminance $\overline{E}_{m30}$ can be calculated from the previous luminance flux $\Phi_{m44,5}$ as follow:

$$\overline{E}_{m30} = \Phi_{m30} / A_{m30}$$

$$\overline{E}_{m30} = (\Phi_{m44,5} \cdot 1,1675113) / 0,4032\ m^2$$

$$\overline{E}_{m30} = \Phi_{m44,5} \cdot 2,89561$$

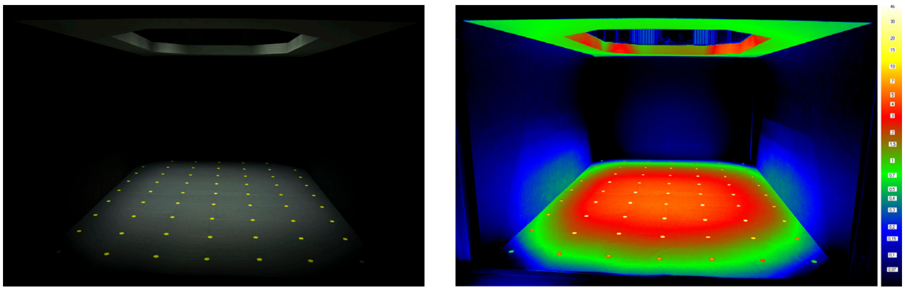
By applying these calculations to the measurements we find that, the average ratio between the luminous flux at 10 klx for both systems is 1,093, which is very close to the assumed value 1,167. Whereas, the ratio for diffuse light is 1,165, which is almost equal to assumed value. As well, the average illuminance $\overline{E}_{m30}$ that is calculated from the diffuse luminance flux $\Phi_{m44,5}$ at 10 klx (9,7 44733979 lm) is 28,21 lx, which are almost the same as our measurement 28,15 lx.

Accordingly, we can infer that, changing the collecting chamber size does not alter the amount of luminous flux enter the CPC, but rather changing the CPC top aperture area. Most probably this is because the internal reflection inside the chamber creates an even illuminance distribution on its surfaces. And most likely, the slight differences in the luminous flux between the two measurements' results occur because, in the first measurement the raster area are exactly adjusted to the beam area and in the second measurement the raster area are a bit within the beam area due to the tightness of the model, as we explained above. Further, the results of the diffuse light is more accurate because the diffuse light is distributed more evenly around the center of the beam angle.

MEAS	Date	Time	Sun Position	Φ_m	$\overline{E}$	$\overline{E}$ at 10 klx	η_t
1	**21 Mar**	**08:00**	73,8H/24,4V	21,75	53,95	22,02	**1,97%**
2	**21 Mar**	**10:00**	49,5H/47,3V	49,20	122,02	29,25	**2,62%**
3	**21 Mar**	**12:00**	2,0H/59,2V	61,36	152,17	31,09	**2,79%**
4	**21 Dec**	**12:00**	-1,5H/36,5V	60,10	149,06	30,03	**2,69%**
5	**21 June**	**12:00**	-5,1H/83,4V	51,77	128,40	30,85	**2,76%**
6	-	-	**Diffuse**	3,86	9,57	28,15	**2,52%**

Where:
Φ_m is luminous flux incident on the measurement area.
$\overline{E}$ is average illuminance on the measurement area.
$\overline{E}$ at 10 klx is value of $\overline{E}$ normalized at 10000 lx.
η_t is daylight system's transfer efficiency, as $\eta_{dl} = \Phi_m / \Phi_{system} \bullet 100$

Table 5.9 *Measurements results of studying the daylight system final design in museum model to confirm its performance.*



(a) (b)

Figure 5.122 *(a) The light distribution of final daylight system design under sun position 21 Dec 12:00 (b) A false colour image shows the luminance distribution for the first image. (Values are in cd/m2: Approx. white 46, yello 15, orange 7, red 3, green 0.7, and blue 0.15)*

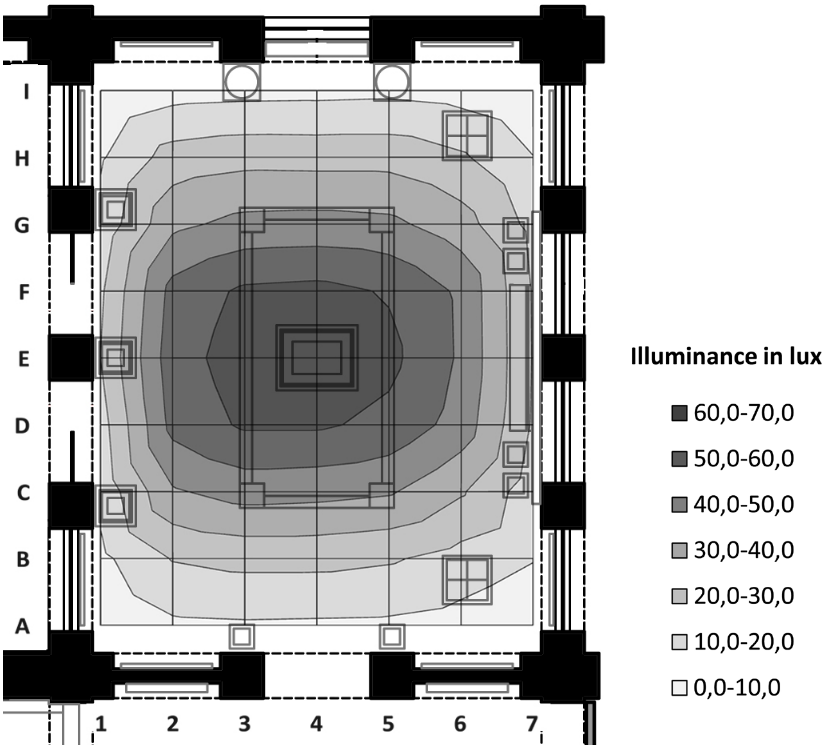


Figure 5.123 *The daylight illuminance distribution of the final daylight chamber-system in the Large Side Hall GF. The isoline values are correlated to 10 klx diffuse light on the system.*

As a conclusion, changing the size of the collecting chamber does not change its properties, thus the previous calculation can be use to estimate the new form performance; raising the amount of luminous flux delivered by the system depends on CPC top opening; and the new form brings more light to the gallery.

5.3.1.2.6.3 Approving the final design lighting effect

The visual study of the system final design shows that, the 30°- CPCs creates the intended visual effect for both the architectural space and the exhibits.

Concerning the architecture space: the centre of the room is highlighted, the illuminance distribution on the floor and walls is very acceptable, and all visual problems are solved. However, the brightness of the central area at 800 lx are little bit high and may cause uncomfortable visual situations, but this can not be confirmed before the whole model is finished. (Figure 5.118 - b and Figure 5.123)

Concerning the rendering of the objects: we set a collection of five natural gray tones statues to test, how statues with different colours will appear under the illumination of the system. The results was distinct owing to the fact that, the 30° beam light creates adequate form-shadows to render the statues form, meanwhile creates a cast-shadows with soft edge that do not disturb the form. On the other hand, the system creates a large specular highlights and smooth lit areas that help to render both bright and dark statues. (Figure 5.124) Note: the photo was taking during conducting the measurements with dark surrounding. In real museum the relatively bright surrounding will help to add a soft fill light into the shadows and dark areas to reveal more details.

Figure 5.124 *A set of five natural gray tones statues demonstrate how statues appear under the illumination of the system.*

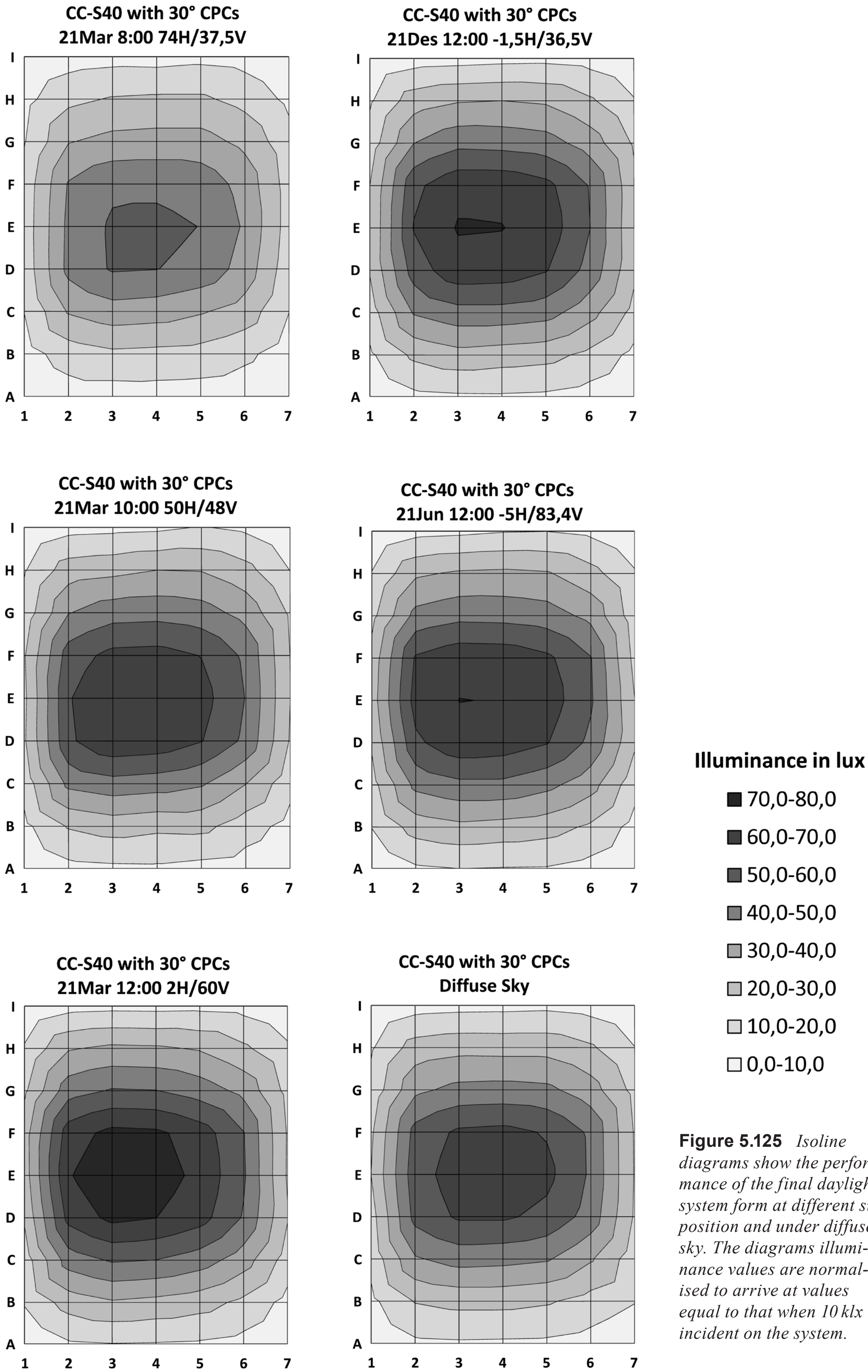


Figure 5.125 *Isoline diagrams show the performance of the final daylight system form at different sun position and under diffuse sky. The diagrams illuminance values are normalised to arrive at values equal to that when 10 klx is incident on the system.*

5.3.1.2.7 Finalizing the model construction

After developing the chamber system for the ground floor illumination (CC-S40 with 30°- CPCs), we need to finalize the model construction to conduct the final measurements and evaluations. What remains to be finish is to construct the skylights system, and to furnish the museum spaces. Note that: the Lateral Gallery GF has a different daylight topology and will be discussed after finishing the design development of areas covered with skylight.

5.3.1.2.7.1 Daylighting solution for UF illumination

The daylighting solution for UF illumination (diffuser-box system) is consists mainly of two parts a diffuser-box and a window with horizontal louvres. (See "5.3.1.1.4 Proposed solution for UF illumination.")

The diffuser-box is a white diffuse box circling the skylight and it is opened with a laminated diffuse glass from the top. (Figure 5.126) According to real construction dimension, the laminated diffuse glass has a width of one meter and a length of 45,4 m for the Large Side Hall upper floor (LSH-UF), 42,56 m for Small Side Hall in the upper floor (SSH-UF), and 34,4 m for Lateral Gallery upper floor (LG-UF). Where, the interior dimension of the diffuser-box is ~1 x 3 m and its length in every skylight is as much as the laminated diffuse glass length, that is mentioned previously. In the museum model, we utilized the selected diffused plexiglas panel with ~ 68% light transmission.

The window system consists of two parts: a clear glass to close and protect the diffuser-box from dust, and a horizontal louvres toward the interior to control the distribution of daylight. (Figure 5.126) According to real construction dimension, the windows are raised from the ground 44 cm and their height are 1,84 m. The windows area of the LSH-UF is 67,93 m^2 , the SSH-UF is 62,7 m^2 , and the LG-UF is 47,69 m^2. In the museum model, we utilized a transparent plexiglas panel with ~ 88% light transmission. As well, we constructed the louvres' horizontal slats from a 3 mm cardboard that has a white surface with ~ 85% LRV facing upward and a gray surface with ~ 25 % LRV facing downward. According to real dimension, the open area between the louvres' slats is ~ 34 m^2 in the LSH-UF, ~ 31,67 m^2 in the SSH-UF, and ~ 23,85 m^2 in the LG-UF. These areas represent the apertures where light can pass to the space. The slats cut-off-angle is ~ 8° in the short side of the skylight and ~ 22° on the long side of the skylight. In the model construction, the large cut-of-angle is realized by adjusting the distant between the slats and the narrow angle by tilting the slats. In real application, the lovers can be simply constructed from wood with adjustable slats, however we recommend an advanced system with automated metal slats in insulated glass that give more control on daylight.

A quick checkup in the museum model shows that, the system is functioning good. However, the system's performance cannot be easily estimated, thus it will be measured directly from the museum model when it is finished. (Figure 5.126 - f).

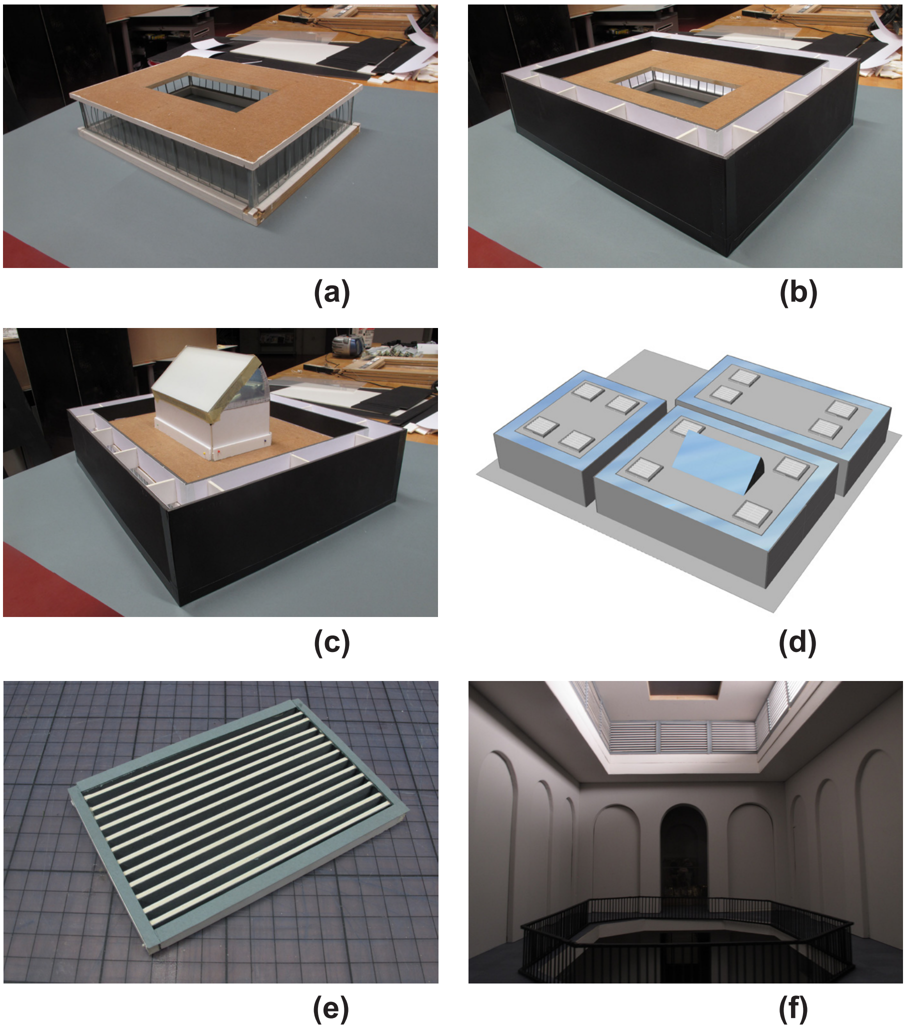


Figure 5.126 *The daylighting solution for UF illumination in museum model. (a) The original form of the skylight. (b) The diffuser-box surrounding the skylight. (c) The daylight chamber system installed in the middle of the skylight. (d) A 3D rendering for the skylights final design. (e) The louvres system. (f) The Large Side Hall UF after installing the louvres system.*

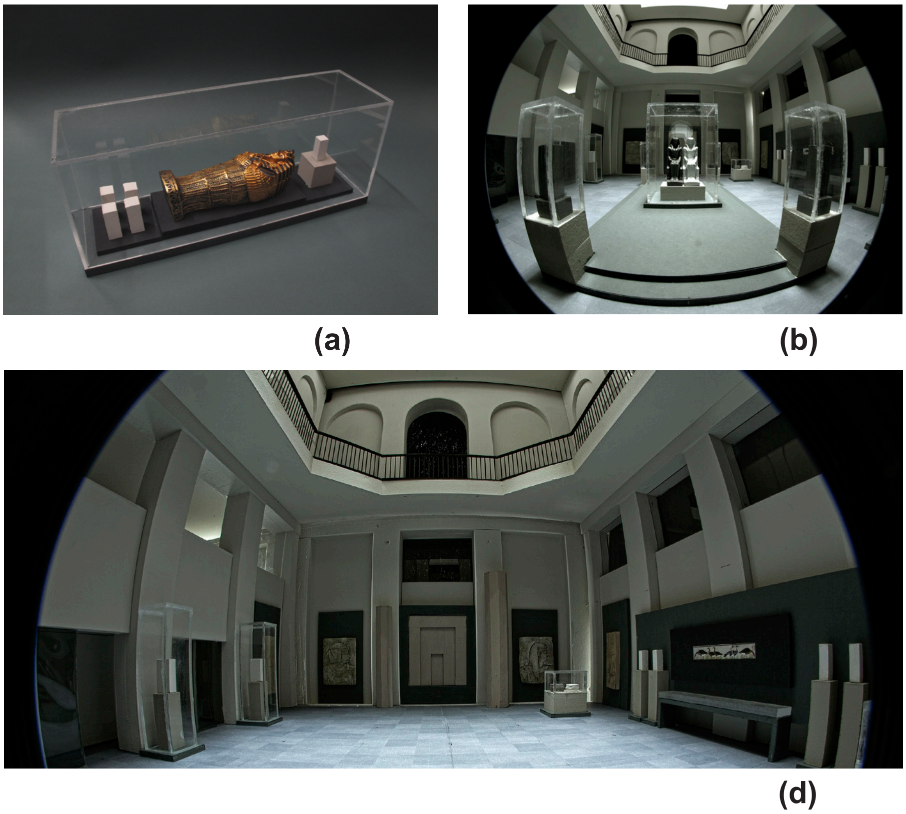


Figure 5.127 *The museum model interior. (a) A showcases model used in lateral gallery UF. (b) The dark and bright small acrylic statues on the platform in the centre of the Large Side Hall GF. (c) The walls of the Large Side Hall GF. The walls holds the reliefs and its background panels.*

5.3.1.2.7.2 Furnishing the museum model

Furnishing the museum model mainly includes the interior elements, showcases, and exhibits samples. (Figure 5.127) The interior elements as walls, floors, ceiling, and partition-walls have the same colours and LRVs determined in the interior design concept. The walls materials are architectural matte plastic painting. The floor is a printed marble texture on matte paper. The partition-walls are MDF wood covered with dark-gray-green matte papers. *(See New colour scheme, "5.2.5.1 Key elements of interior concept").*

The showcases are made of MDF wood that is painted or covered with coloured paper and 3 mm plexiglas with light transmission ~ 88 %. The showcases follow the forms and dimension determined in the interior design concept. (Figure 5.71 to Figure 5.78) and (Figure 5.127).

To give an actual impression of how the display and the lighting will be in reality, we resemble the exhibits as much as we can. We use a set of small acrylic statues that fit to the model scale and we used a pieces of MDF wood to occupy small statues places. The statues and the wood pieces are painted with dark and bright tones of gray to help seeing the lighting effect. As well, a set of small acrylic reliefs are made especially for the model. The reliefs have the common sandstone colour. The reliefs are larger than the scale they supposed to have, this is made intentionally to help seeing and judging the light when it falls on them. Additionally, for the famous fresco of "Meidum Geese" we used a copied photo on cardboard, for the architecture elements we used a simple form of wood pieces, and in the Lateral Gallery UF we used small golden acrylic coffins. (Figure 5.127)

5.3.1.2.8 Evaluating the daylighting design in spaces with skylight

As we finished the development of the daylight systems and the construction of the museum model, we need to have a final evaluation of how the daylight systems perform together under real weather condition and how the systems' illumination interacts with the architecture, display, and exhibits to render the final interior appearance.

5.3.1.2.8.1 Measuring illuminance levels

The illuminance levels were measured in all spaces with skylights: the Large Side Hall GF & UP, the Small Side Hall UF, and the Lateral Gallery UF; as well as in the Small Side Hall GF, to know the amount of light enters the space from the adjacent Large Side Hall GF.

Although the chamber system is designed to illuminate the ground floor level and the diffuser-box system is designed to illuminate the upper floor level; the illumination of every level is reflected into the other. As well, both systems act differently to the direct and diffuse components of daylight. Accordingly, the illuminance measurements were conducted for every daylight component incident on one of the systems and then the sum of the four measurements at a point gives the final illuminance level at this point. (Figure 5.128 to Figure 5.135)

Since the performance of the chamber system is more stable at the same hour between seasons and it changes more during the course of the day. The measurement on 21 Mar at 8:00, 10:00, and 12:00 were taken as an average value for the entire year. As for the diffuse component, it was measured one time under diffuse sky. The measurements were conducted in the Artificial Sky at Bartenbach GmbH.(1)

To help compare and evaluate different spaces together, all presented illuminance values in (Table 5.7) are normalised to arrive at values equal to that when 30 klx or 40 klx is measured normal to the glass surface of both daylight systems. These values are chosen because the analysis of the measurements show that 30 klx is a threshold value at which the illuminance targets in the galleries are fulfilled, and the range between 30 to 40 klx is the acceptable range for daylight fluctuation. In other words, when illuminance value falling on the systems is within 30 to 40 klx, the correlated illuminance in museum spaces maintains acceptable levels for conservation and a good visual atmosphere as we planned in the general lighting schemes (Figure 5.81).

Technically, since we measure separately the illuminance value of direct and diffuse component, both values are normalised at half the incident value 15 or 20 klx and they were added together to give the final value of 30 or 40 klx. In reality, both components will not have the same value, as will the incident angle on both daylight systems are different. Moreover, the values and the angles change constantly. However, the measurements show that both daylight systems act almost the same for direct and diffuse component, thus change of the ratio between the two components will not be recognizable and will not cause an imbalance in the systems functions. Additionally, the systems will receive much more illuminance from the sun and the sky; and a big portion of this illuminance will be reduced by control systems, so in this case neither the change in the values nor in the angles of incident light on the systems will disturb the illuminance levels in the space.

The value represent an area in (Table 5.7) is the average illuminance value for the points of interest in this area. The points of interest can be seen in (Figure 5.128 to Figure 5.135), where green dots are for horizontal illuminance and purple dots are for vertical illuminance, and both are measured at 150 cm from floor level. These figures represent the measurements at 10:00 on 21 Mar, when 35 klx is incident on the daylight systems; which can be considered as an average value during the hall year. Additionally, the sections in Figure 5.136 and Figure 5.137) show the position of the daylight systems on the spaces and the distribution of light in the cross and longitudinal sections. Further, the distribution of light in the spaces can be identify from the isoline diagrams in (Figure 5.123 and Figure 5.125).

1. Bartenbach GmbH, Innsbruck, Austria, with permission.

5.3.1.2.8.2 Controlling illuminance levels

Since the daylight level constantly change and fluctuate during the day, we chose the range between 30 - 40 klx external illuminance on the system as a correlated value to the acceptable range of illuminance levels inside the museum. When the external illuminance reach 40 klx on the system the control system has to reduce the illuminance to 30 klx. The range of 10 klx allow small change of the illuminance levels inside the museum. This strategy is a appropriate for the roller-screen as a control system. However, this range can be further narrowed, if a Switchable Glass/Smart Glass (as the Electronically Tintable Dynamic Glass) used with a sensor as a controller. It will give a precise control over the amount of light passing through the system. Generally, the control strategy can be changed from gallery to other and it can be adjusted according to the type of exhibits and the intended degree of visual attraction in display. On the other hand, the location of the building, the placement of the system on the building, and the level of dust in the air and its maintenance, all alter the range of external illuminance needed to balance the light in the museum.

5.3.1.2.8.3 Evaluating illuminance levels

The range of illuminance described in the evaluation represents the highest - lowest average illuminance in every area when the external illuminance range between 30 - 40 klx on 21 Mar between 8:00 to 12:00. (Table 5.7) Keeping in mind that, these values to some extent increase between Mar - Oct and decrease between Nov - Feb due to the change of sun path and weather condition during the year.

- **The Large Side Hall GF:** The horizontal illuminance levels on the platform central area range between 233 - 332 lx, and on the platform corners range between 133 - 210 klx. This is due to the distribution shape of the light beam. (Figure 5.123) Accordingly, the central area will be always higher than the 200 lx and the corner area will reach 200 lx when the external illuminance is 40 klx. If the light is needed to be precisely controlled for conservation aspects, an optical filter can be installed on the top of the showcase to reduce the light. As well, if the statues on the platform corners need more light the arrangement of the platform can be change to make the statue closer to the light centre, or to use a rectangular CPC with 30°/45° beam angle in the system to spread the light more in the long direction.

  The horizontal illuminance levels on the circulation area range between 88 - 141 klx, which is a suitable for this area as a circulation and transition zone between the platform and the walls.

  The vertical illuminance levels on the walls range between 15 - 24 klx, and at the centre of the east-west walls it range between 27 - 42 klx. We expected to have an average of ~ 50 lx; nevertheless, the existing values is sufficient to be a background for the relief with 200 lx artificial light, and to create a general dim surrounding around the centre of the space.

- **The Large Side Hall UF:** The vertical illuminance levels on the showcases range between 20 - 33 klx, and the upper wall reaches a higher levels. The illuminance levels are appropriate as a room lighting for showcases with 200 lx artificial light.
- **The Small Side Hall GF:** The seeped light from one side of large windows bring 4 - 6 lx on the floor area. Thus, both sides will make the illuminance levels 8 - 12 lx. Which is suitable as a room lighting for showcases with 50 lx artificial light.
- **The Small Side Hall UF:** The horizontal illuminance levels on the floor area range between 54 - 82 lx; the vertical illuminance levels on the showcases range between 23 - 35 klx, and the upper wall reaches a higher levels. The illuminance levels are appropriate as a room lighting for showcases with 200 lx artificial light.
- **The Lateral Gallery UF:** The horizontal illuminance levels on the floor area range between 36 - 69 lx; the vertical illuminance levels on the showcases range between 14 - 27 klx, and the upper wall reaches a higher levels. The illuminance needs to be slightly increased and that can be easily achieved by adjusting the lovers. In real museum building, the area adjacent to the skylight gets light from two adjacent skylights, therefore it will have 16 - 30 lx horizontally on floor area and 8 - 18 klx vertically on the showcases. This area will be illuminated with artificial light.

Galleries with skylight		Position (1)	Incident Illuminance 30 klx (2)			Incident Illuminance 40 klx (2)		
Space	**Area**		08:00	**10:00**	12:00	08:00	**10:00**	12:00
LSH-GF	Platform central area	E_h	233	**230**	249	311	**307**	332
	Platform corners	E_h	133	**145**	157	177	**194**	210
	Circulation Area	E_h	88	**96**	106	117	**128**	141
	Wall central area	E_v	27	**30**	32	36	**40**	42
	Walls	E_v	15	**17**	18	20	**23**	24
LSH-UF	Showcases	E_v	20	**27**	25	27	**35**	33
SSH-GF	Floor area (adjacent)(3)	E_h	4	**4**	4	6	**5**	5
SSH-UF	Floor area	E_h	54	**58**	61	72	**78**	82
	Showcases	E_v	23	**25**	26	30	**34**	35
LG-UF	Floor area	E_h	36	**48**	52	47	**64**	69
	Showcases	E_v	14	**19**	20	19	**25**	27
	Floor area (adjacent)(3)	E_h	8	**11**	11	11	**14**	15
	Showcases (adjacent)(3)	E_v	4	**6**	5	5	**9**	7

(1) Horizontal and vertical illuminance values were measured at 150 cm from floor level.
(2) Incident illuminance is the value measured to the normal of both systems' glass surface.
(3) Area defined as (adjacent) is area connected to area with skylight.

Table 5.10 *The model measurements results for spaces with skylight. The values represent the average illuminance for the points of interest in the model when 30 to 40 klx is falling on the glass surface of both systems. The points of interest can be seen in (Figure 5.128 to Figure 5.135).*

Illuminance of direct daylight component
in Large Side Hall GF and the Small Side Hall GF

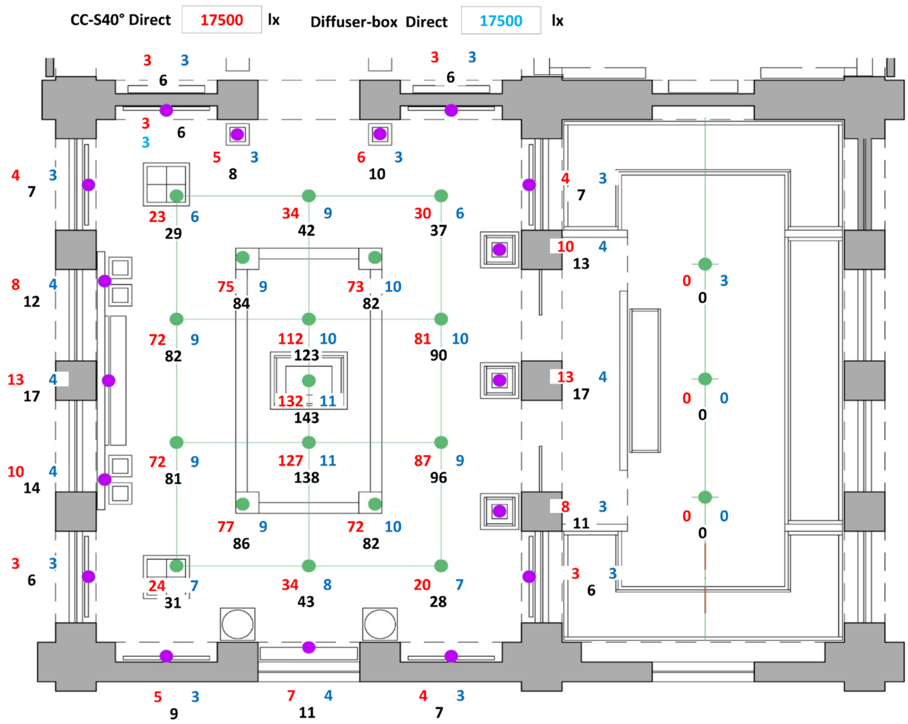


Figure 5.128 *The illuminance of direct daylight component in the Large Side Hall GF and the Small Side Hall GF. The illuminance value in black are correlated to 17,5 klx external solar daylight component incident on both daylight systems at 10:00 on 21 Mar. The values are the sum of the red and blue values which are respectively illuminance delivered from the chamber system and the diffuser-box system.*

Illuminance of diffuse daylight component
in Large Side Hall GF and the Small Side Hall GF

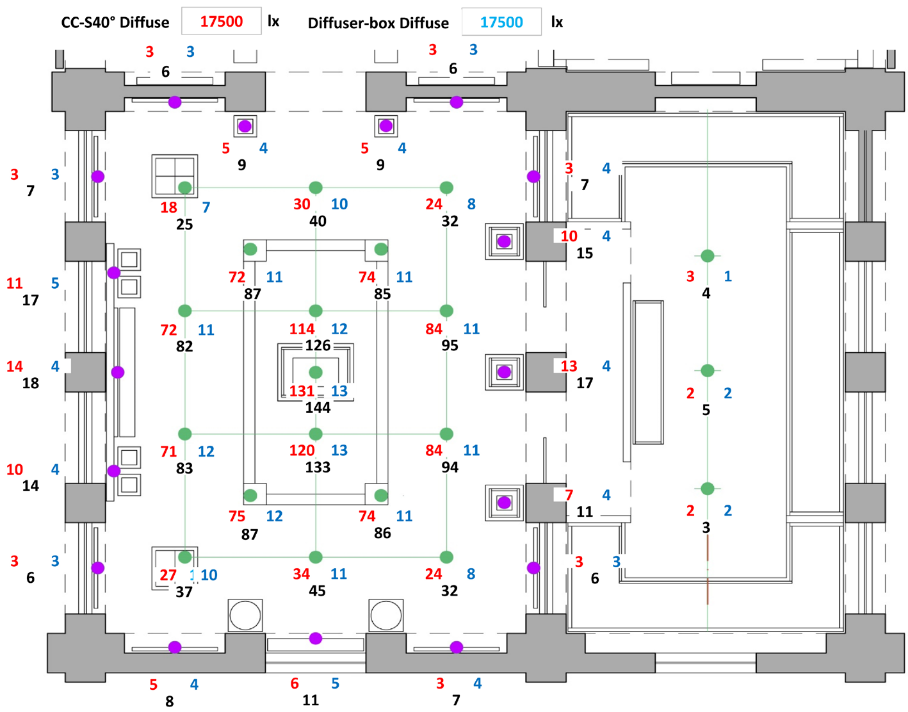


Figure 5.129 *The illuminance of diffuse daylight component in Large Side Hall GF and the Small Side Hall GF. The illuminance value in black are correlated to 17,5 klx external sky daylight component incident on both daylight systems at 10:00 on 21 Mar. The values are the sum of the red and blue values which are respectively illuminance delivered from the chamber system and the diffuser-box system.*

Illuminance of direct daylight
in Large Side Hall UF

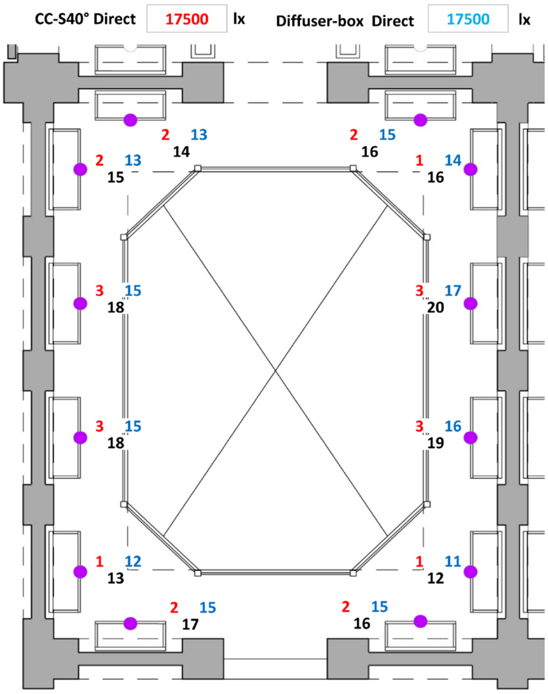


Figure 5.130 *The illuminance of direct daylight component in Large Side Hall UF. The illuminance value in black are correlated to 17,5 klx external solar daylight component incident on both daylight systems at 10:00 on 21 Mar. The values are the sum of the red and blue values which are respectively illuminance delivered from the chamber system and the diffuser-box system.*

Illuminance of diffuse daylight
in Large Side Hall UF

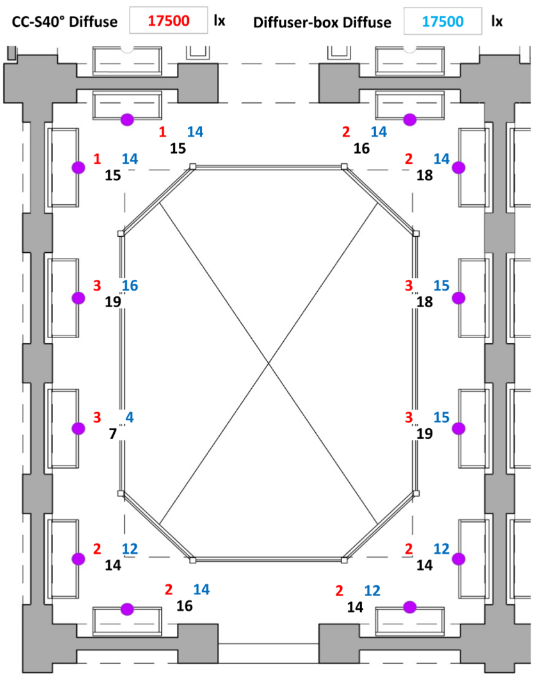


Figure 5.131 *The illuminance of diffuse daylight component in Large Side Hall UF. The illuminance value in black are correlated to 17,5 klx external sky daylight component incident on both daylight systems at 10:00 on 21 Mar. The values are the sum of the red and blue values which are respectively illuminance delivered from the chamber system and the diffuser-box system.*

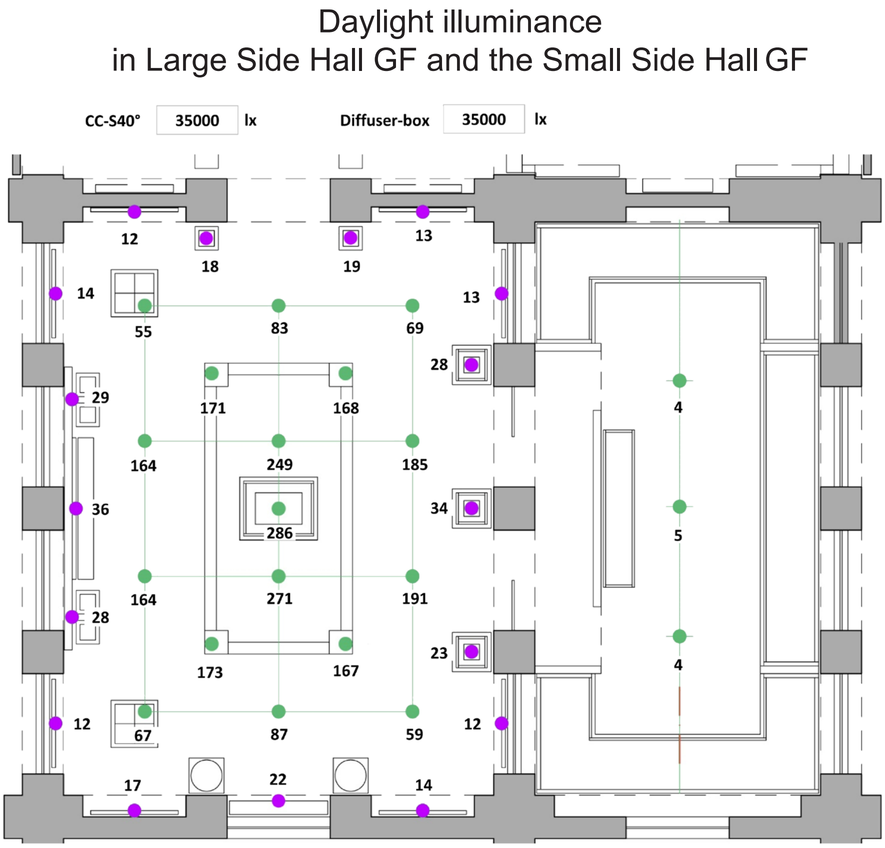


Figure 5.132 *The daylight illuminance values in the Large Side Hall GF and the Small Side Hall GF. The illuminance values are correlated to 35 klx external daylight illuminance incident on both daylight systems at 10:00 on 21 Mar. (The illuminance values presented here are the sum of the direct and diffuse daylight components values in Figure 5.128 and Figure 5.129).*

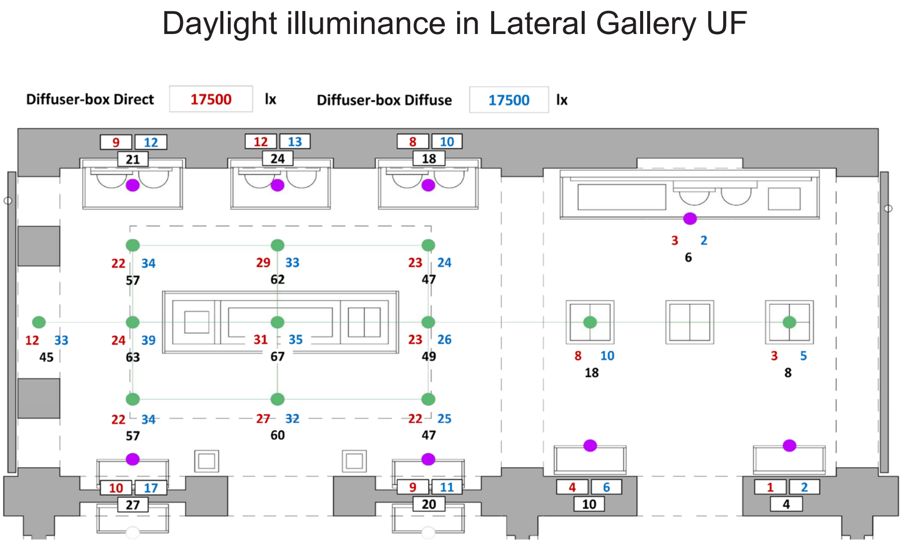


Figure 5.133 *The daylight illuminance values correlated to 35 klx external daylight illuminance at 10:00 on 21 Mar in the Lateral Gallery UF. The values in red are correlated with 17,5 klx solar illuminance incident on the diffuser-box system; the blue colour values correlated to 17,5 klx sky illuminance incident on the diffuser-box system; and the black values represent the total illuminance at this point.*

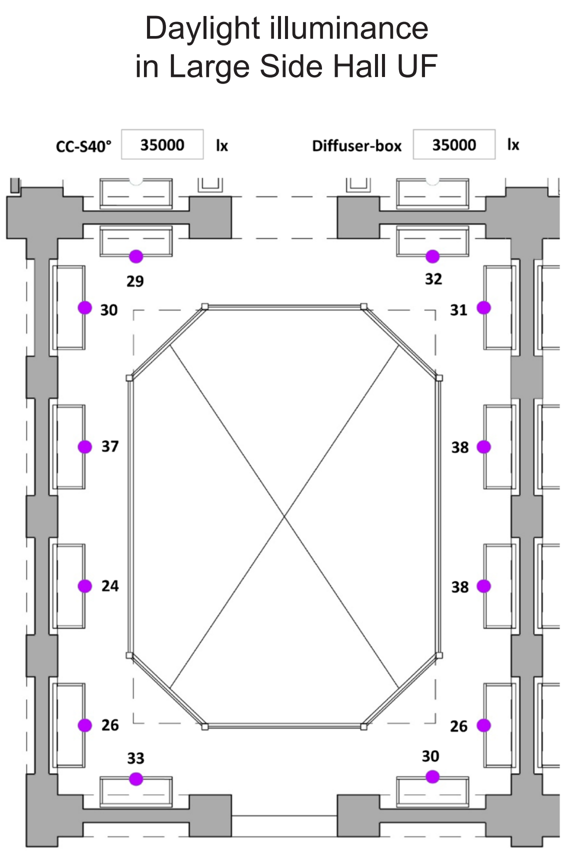


Figure 5.134 *The daylight illuminance values in the Large Side Hall UF. The illuminance values are correlated to 35 klx external daylight illuminance incident on both daylight systems at 10:00 on 21 Mar. (The illuminance values presented here are the sum of the direct and diffuse daylight components values in Figure 5.130 and Figure 5.131).*

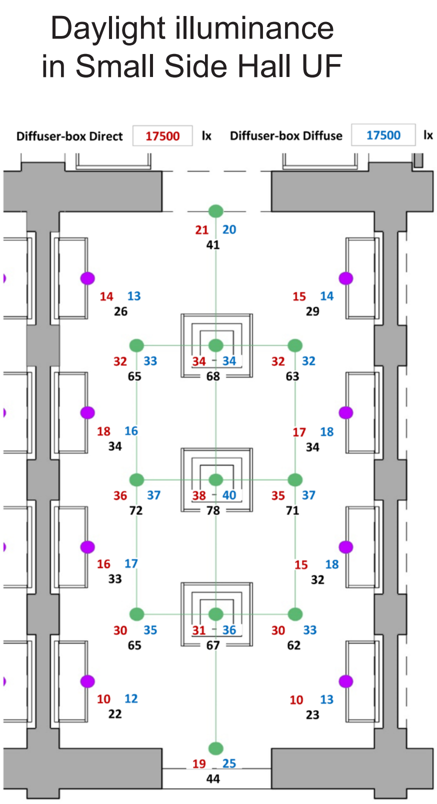


Figure 5.135 *The daylight illuminance values correlated to 35 klx external daylight illuminance at 10:00 on 21 Mar in the Small Side Hall UF. The values in red are correlated with 20 klx solar illuminance incident on the diffuser-box system; The values in blue are correlated to 20 klx sky illuminance incident on the diffuser-box system; and the black values represent the total illuminance at this point.*

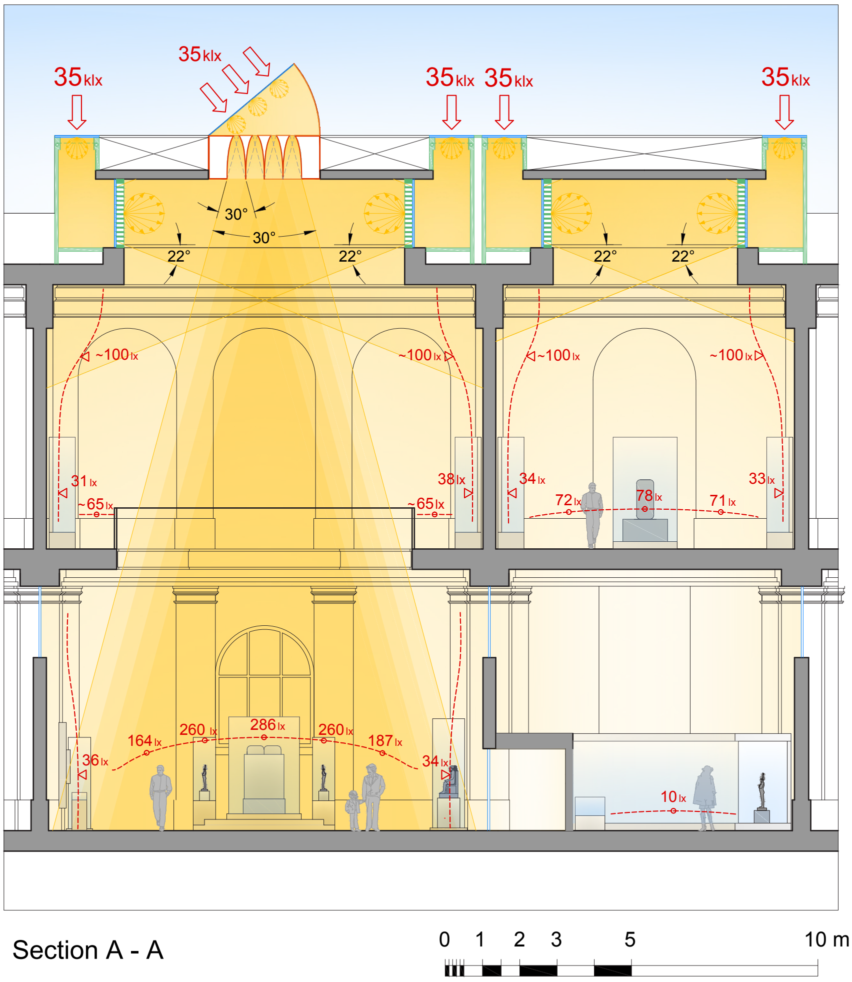


Figure 5.136 *Cross section A-A shows the design of the daylight systems in spaces covered with skylight, and the illuminance levels when the external illuminance is 35 klx. (Reference plan Figure 5.81)*

In addition to the previous evaluation it is important to add the following explanations:

In the plans and sections in (Figure 5.128 to Figure 5.137), the external illuminance incident on both daylight systems is 35 klx and the sun takes its position at 10:00 on 21 Mar. This settings are chosen because this external value is an average of the acceptable range of daylight between 30 - 40 klx, and the sun has an average position at this time and month of the year. In point of fact, according to daylight simulations based on weather data and the geometry of the building, the incident daylight value on the chamber system is 73729 lx (consist of direct 51338 lx, and diffuse 22391 lx); and on the diffuser-box system is 71582 lx (consist of direct 49340 lx, and diffuse 22242 lx). There is a plenty amount of daylight on the system at this time of the year. The excessive amount of daylight will be reduced with the control system. Only in the low sun position at early morning and late afternoon especially in winter times the day light levels will recede and the level of illuminance inside the spaces will need to be boost with artificial light. For instance, the level of illuminance at 17:00 well need to be complemented with artificial light at most of year time, and this is the reason why we exclude the measurements and analysis of illuminance levels at 17:00. A precise estimation of how the system works will come in the system performance evaluation.

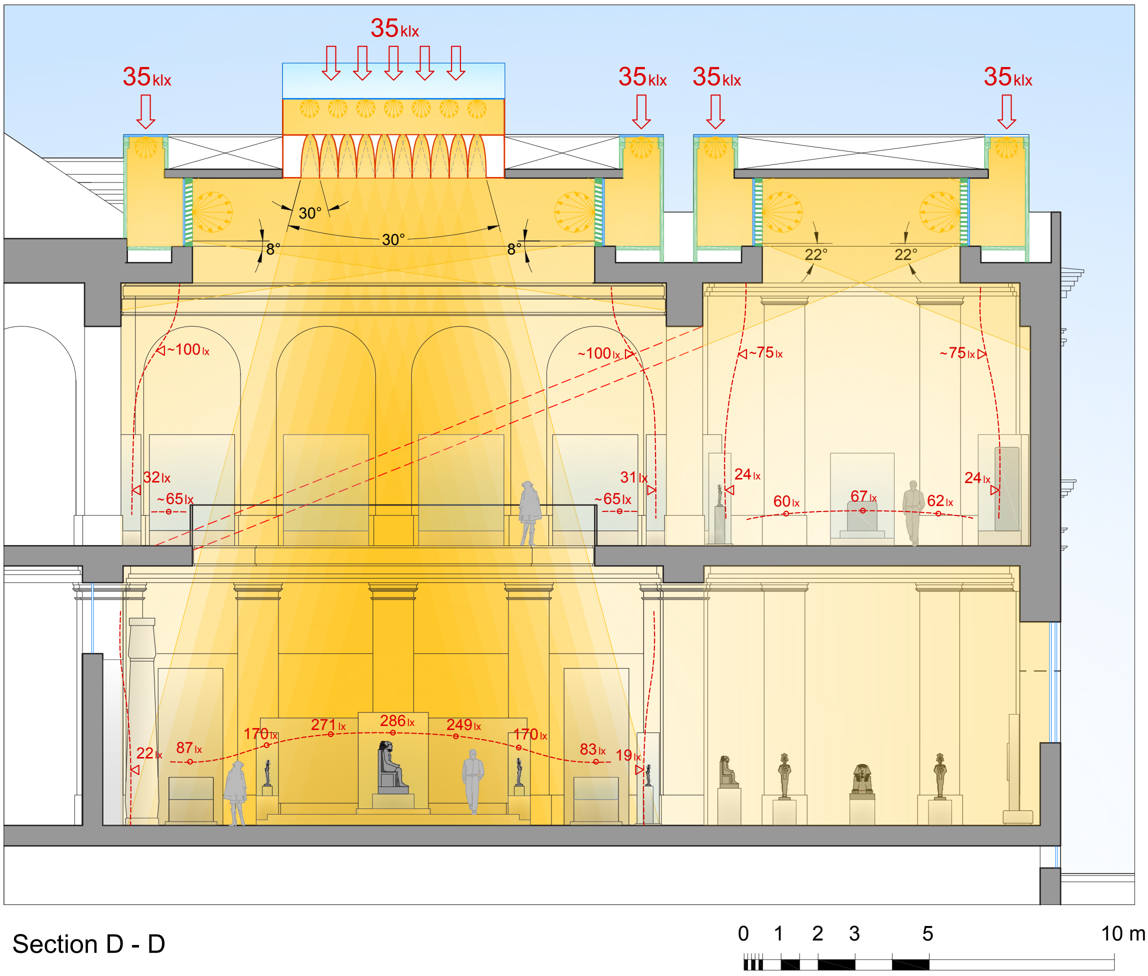


Figure 5.137 *Longitudinal section D-D shows the design of the daylight systems in spaces covered with skylight, and the illuminance levels when the external illuminance is 35 klx. (Reference plan Figure 5.81)*

We find that it is important for conservation aspects to measure the illuminance precisely at the artifacts placements. Therefor, the illuminance measurements in the Large Side Hall GF and UF took into account the reflected diffuse light from every level into the other. According to our calculations, when the external illuminance is 35 klx, the reflected diffuse light into the ground floor from upper floor is about 22 lx which is about 10 % of light falling on the platform. This means that enhancing the performance of the diffuser-box or raising the illuminance in the upper floor will affect the illuminance of the exhibits in the ground floor. (Figure 5.128 and Figure 5.129) On the other hand, the reflected diffuse light into the upper floor from ground floor is about 5 lx which is about 15 % of light falling on the showcases. However, raising the illuminance in the ground floor well not affect the illuminance in the upper floor because the ratio of the reflected light is very small to the incident light on the ground floor, and this light mainly work as background of the showcases. (Figure 5.130 and Figure 5.131) In general, the procedure of measuring and adjusting the illumination of the space has to take place in the real gallery after finishing the installation work of the artificial light and focusing the light on the exhibits.

5.3.1.2.8.4 Evaluating the visual environment

- **Large Side Hall UF & GF:** The chamber system directs the light to the ground floor and the light beam covers the whole floor area. It creates a smooth light distribution from the centre of the floor to the walls, which highlight the platform and the masterpiece. The reflected light from the floor illuminate the walls and the ceiling with a dim, soft light that is sufficient to be a background for the displayed reliefs on the walls, which will be illuminated with artificial light. The dim surrounding emphasize the highlighted platform in the centre of the space. (Figure 5.138)

  The louvres of the diffuser-box system direct the light onto the upper parts of the walls and the ceiling. The light distribution is equally on the four walls, it has a smooth gradient from the upper parts of the wall till the floor. The white ceiling and the upper parts of the walls reflect the light back into the space to illuminate the upper-floor flooring and small amount contributes into the ground-floor illumination. The light on the upper-floor is soft and diffuse, which support the artificial light of showcases. The systems is glare free and do not create veiling reflection on the showcases. (Figure 5.139)

  The light in the entire hall is gradually distributed from the top downwards, it start from the white ceiling, and moves to the walls in the upper-floor, and then to the walls in the ground-floor. This creates a soft surrounding that envelope the strongly lit masterpiece in the centre of the ground floor. As well, it strengthens the position of the skylight as source of light in the top of the space, and emphasize centre of the space where the masterpiece, the platform, the void, and the skylight are aligned on vertical axis. Which contributes to the architect of the hall and reveal its beauty. (Figure 5.140 and Figure 5.141)

  The light from both daylight systems contribute in lighting the exhibits. The light from the chamber system creates an adequate clear form shadows with soft edges, smooth lit areas, and specular highlights that helps to render dark objects. On the other hand, the reflected light from the surrounding and the light from the diffuser-box system attenuate the shadows and dark areas, which helps to see details in these areas. This is because the chamber system emits the light from relatively large area in a steep incident angle and the light is stronger than the light from the diffuser-box system and the reflected light in the space. Taking into consideration that the artificial light especially for the reliefs on the wall, will add for some extent more light to the space. (Figure 5.142)

  The masterpiece statues need to be placed little bit out of the platform centre, so the faces of the states will have more light and avoid the long form shadows that cover the features of the face. As well, the statues at the corners need to be facing inwards, to the direction of light, to get more light on its front sides. If the display retains in this position, the states faces need to be highlighted with narrow beam spotlights. In general, using a narrow beam spotlights with the daylight will insure to keep the artifacts' shadows and highlight sharp specially when the daylight recedes.

When we raise the illuminance of the platform to > 850 lx(1), the light creates a strong, large lit area in the middle of the space and the walls start to look darker. In the real hall, this will create uncomfortable visual situation and difficulties in seeing the exhibits. We recommend that the platform illuminance do not exceed ~ 500 lx, and raising the illuminance of all irresponsive-to-light exhibits in the hall will be locally with artificial light. In case there is a Large Side Hall contains only irresponsive-to-light exhibits, as uncoloured statues and architectural elements, the light in the centre of the gallery can be raised; but that entails rising the illuminations of the walls to balance the light in the centre of the space. Generally, the system creates a good museum quality of light and it is totally glare free from both the ground and the upper floor.

- **The Small Side Hall UF:** The light distribution is similar to the Large Side Hall UF. The light is distributed equally on the four walls, it has a smooth gradient from the upper parts of the wall till the floor. The floor has high uniform light distribution. The soft diffuse light support the artificial light of the showcases and create a quite room atmosphere. The system is glare free and do not create veiling reflection on the showcases. (Figure 5.143 and Figure 5.144)
- **The Lateral Gallery UF:** The area under the skylight has the same lighting quality as the Large Side Hall UF and the Small Side Hall UF. (Figure 5.145)

  Concerning the area adjacent to the skylight area, the light gradually fades from the skylight to this area and creates a smooth transition between the light and dark areas of the gallery. In real museum building, this area gets light from two adjacent skylights, therefore it will be slightly brighter than the model. The lit areas will guide the visitors inside the dime surrounding and connects them with the outside world. The dark areas will be illuminated with artificial light. The entire atmosphere is appropriate to display funeral exhibits. (Figure 5.146)

Although the lighting design still need to be finished by adding the artificial light, we can compare the model photos with the real photos presented in ("5.2.1.2 Visual and photometric evaluation"). Notes that the false colour images represent the luminance distribution, and they do not describe the level of illuminance. The illuminance levels inside the model is related to the external illuminance. Anyhow, at any illuminance level the ratio between the luminance value stay the same.

1. It is worth to mention that, without controlling the light at 12:00 on 21 Mar the platform central area can reach > 867 and the corners > 545 when the external illuminance reaches 100 klx. This value to some extent is higher between Mar - Oct and it represent 10% of the time annually..

Figure 5.138 *The light atmosphere in the Large Side Hall GF. The chamber system directs the light to the entire ground floor area. It creates a smooth light distribution from the centre of the space to the wall, that highlight the platform and the masterpiece. The reflected light from the floor illuminate the walls and the ceiling with a dim, soft light. The systems is glare free from both floors.*

Figure 5.139 *The light atmosphere in the Large Side Hall UF. The louvres of the diffuser-box system direct the light onto the upper parts of the walls and the ceiling. It creates a soft and diffuse atmosphere that will support the artificial light of showcases. The systems is glare free and do not create veiling reflection on the showcases.*

Figure 5.140 *The light atmosphere in the Large Side Hall GF & UF. The light in the entire hall is gradually distributed from the top downwards, this creates a soft surrounding that envelope the strongly lit masterpiece and emphasize its position in the centre of the space. Which contributes to the architect of the hall and reveal its beauty. Compare the result with (Figure 5.15, Figure 5.21, Figure 5.44, and Figure 5.45)*

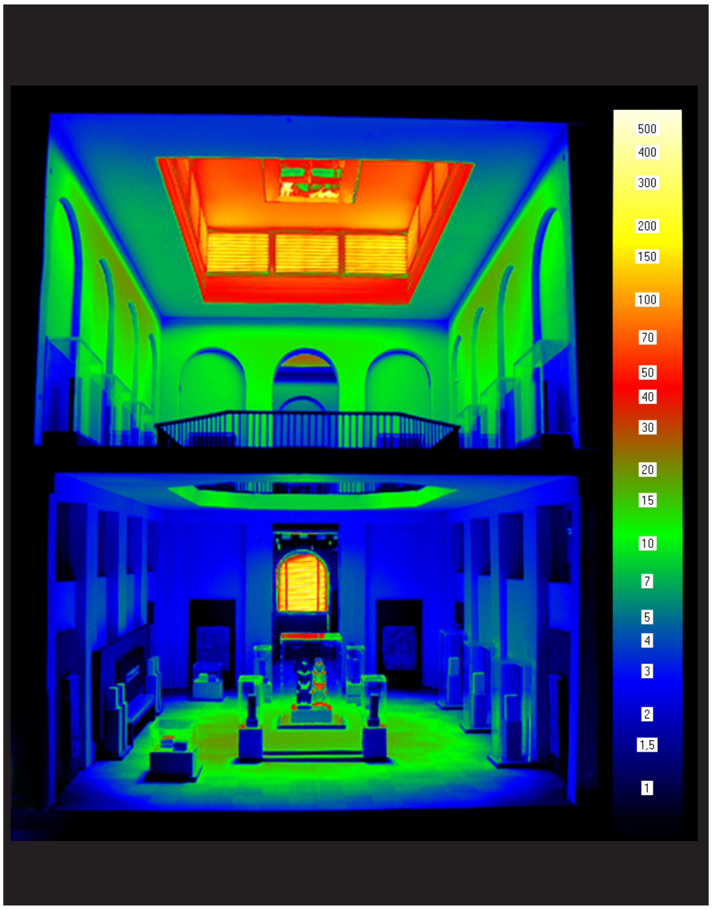


Figure 5.141 *A false colour image represents the luminance distribution for the previous photo of the Large Side Hall GF & UF. (figure 5.138). The luminance scale values are in cd/m²: Approx. white 500, yello 200, orange 100, red 40, green 10, and blue 2,5.*

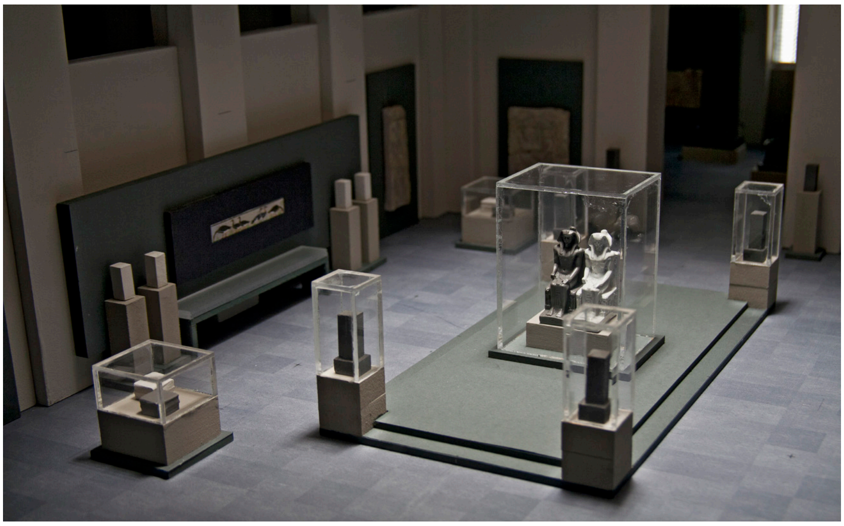
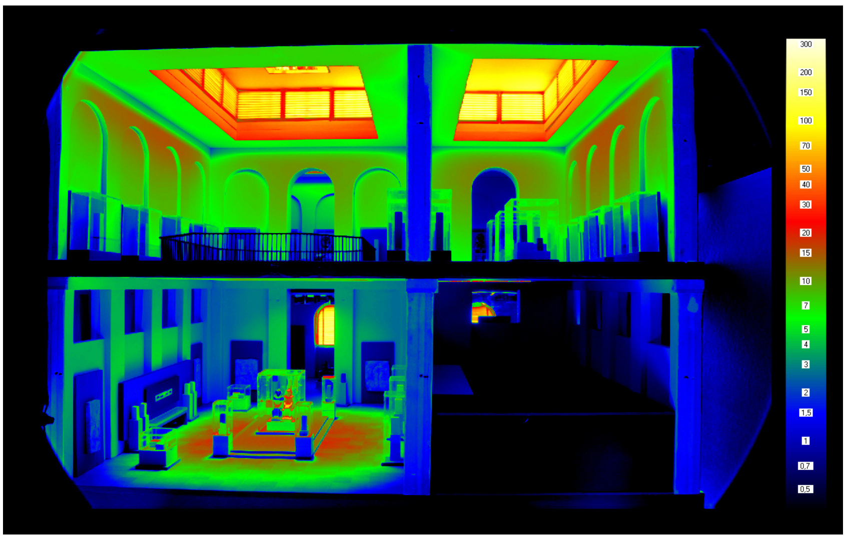


Figure 5.142 *A close photo in the model for the Large Side Hall GF. The dark and bright small acrylic statues and the small pieces of wood that occupy statues places helps to see the lighting effect of the daylight systems. Compare the result with (Figure 5.46).*

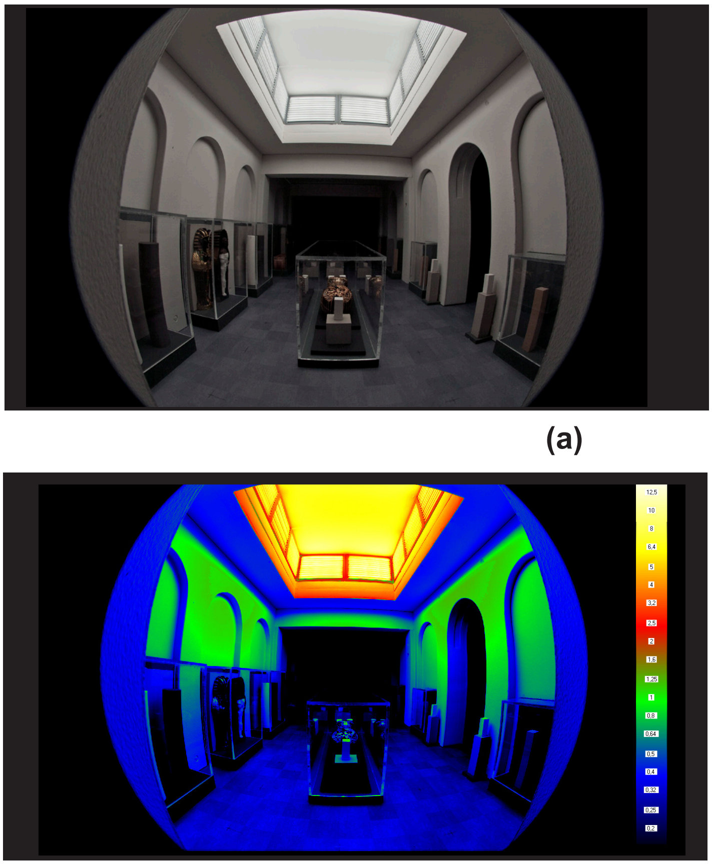
(a)



(b)

Figure 5.143 *The daylight distribution in the Large Side Hall GF & UF, the Small Side Hall GF, and Small Side Hall UF. (a) A real photo shows the daylight atmosphere. (b) A false colour image represents the luminance distribution for the previous photo. The luminance scale values are in cd/m^2: Approx. white 300, yellow 100, orange 60, red 25, green 6, and blue 1,5.*

Figure 5.144 *The light atmosphere in the Small Side Hall UF. The louvres of the diffuser-box system creates a soft and diffuse atmosphere that will support the artificial light of showcases. Compare the result with (Figure 5.16 and Figure 5.48).*



(a)

(b)

Figure 5.145 *The daylight distribution for the area under the skylight in the Lateral Gallery UF. (a) A real photo shows the daylight atmosphere. (b) A false colour image represents the luminance distribution for the previous photo. The luminance scale values are in cd/m^2: Approx. white 12,5, yellow 7, orange 4, red 2,5, green 1, and blue 0,32. Compare the result with (Figure 5.13 and Figure 5.42).*

Figure 5.146 *The daylight atmosphere for the area adjacent to the skylight in the Lateral Gallery UF. In real museum building, this area gets light from two adjacent skylights, therefore it will be slightly brighter than the model.*

5.3.1.2.8.5 Evaluating system performance in real condition

According to illuminance measurements and analysis, we found that when the external illuminance is 30 klx the illuminance targets in the galleries are fulfilled, and when it range between 30 to 40 klx the change in illuminance levels inside the galleries are acceptable. The question is: How long during the year the external illuminance on the system will exceed 30 klx? To answer that we need to conduct an annual daylight analysis.

The natural light incident on a daylight system is affected with the weather condition and geographic location of the building; the size and form of the system; and the geometry of the building and surroundings. This makes daylight calculation a complex task, and to easy mange this calculation a daylight simulation tools based on weather data need to be used. For that purpose, a 3d-model for the museum and surroundings was built in SketchUp program, then it was imported in Rhinoceros 3D program[1] to be use with Grasshopper's environmental design analysis plug-ins Ladybug and Honeybee[2] to conduct a daylight simulations.

The 3d-model contains the geometry of the museum and the main buildings in the surroundings that can block daylight or cast shadow on the museum. Since the proposed design will be applied to other similar spaces in the museum, especially the west and East Wing. We replicated the new skylights design over other spaces that have the similar skylights in the West Wing, so we can conduct the analysis for the entire West Wing. (Figure 5.147, Figure 5.67 and Figure 5.1)

All buildings in the 3d-model are assigned the light reflectance value (LRV) according to its materials' colour as follow:

The Egyptian Museum: 45 %

The Nile Hilton hotel: 70 %

The museum coffee-shop: 15 %

Tiles around the museum: 25 %

The raised roadway: 20 %

Default Material LRV: 20 %

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1. Both SketchUp and Rhinoceros are computer 3D modelling software.
2. Ladybug and Honeybee are environmental design analysis plug-ins. Ladybug: is a plug-in that connects the digital geometry in Rhino (Rhinoceros 3D modeling software) and Grasshopper's parametric visual scripting (a graphical algorithm editor for Rhino) with standard EnergyPlus Weather files (a specific type of weather data that are exist for many locations across the globe), and allows conducting weather data analysis, producing interactive graphics that are helpful in early design phases, and testing initial design options' implications. Honeybee: is a plug-in that connects Rhino and Grasshopper with advanced building energy and daylighting simulation engines; such as EnergyPlus, Radiance, Daysim and OpenStudio; and makes many of its features available in a parametric way and allows for almost instantaneous feedback on design modifications. Ladybug and Honeybee are free and open sources; user can customize them based on his needs and contributes to the source code. Reference: Grasshopper, Ladybug Analysis Tools, <http://www.grasshopper3d.com/group/ladybug>, (8.1.2017)

The important settings used for Radiance simulations:

Weather data file: EGY_Cairo.623660_IWEC.epw (1)

Time steps: in hour.

Time period: between 8:00 to 17:00 during whole year

Test grid: all glass surfaces of daylight systems and windows have a test grid size 0.4 m and test points are offset 0.05 m from the surfaces.

Quality of rendering: Medium

Ambient bounces: 4

Ambient divisions: 2048

Ambient super-samples: 128

Ambient resolution: 300

Ambient accuracy: 0,1

(see"5.2.1.4.3 Digital model analysis")

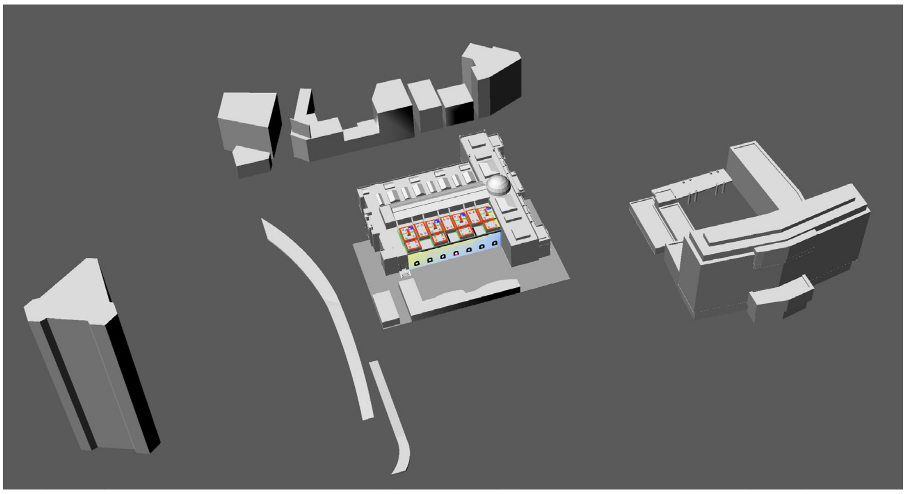


Figure 5.147 *General view for the 3D model in Rhinoceros 3D software view port.*

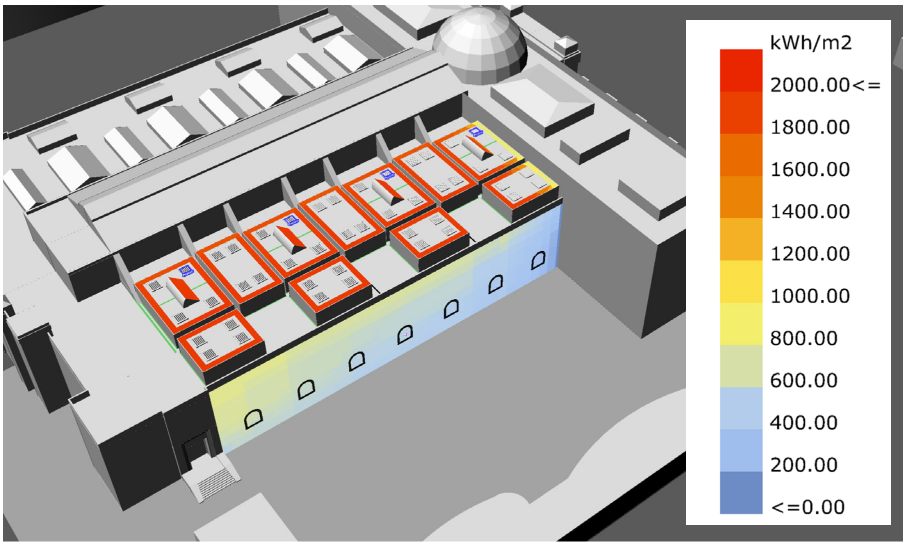


Figure 5.148 *The annual irradiance exposure (direct and diffuse solar radiation) received by the systems and windows during the working hours from 8:00 to 17:00 over the entire year. (100 kWh/m² = 2740 lx of annual average illuminance)*

1. Source of the data: <https://energyplus.net/weather-location/africa_wmo_region_1/EGY//EGY_Cairo.623660_IWEC>, (17.06.2016).

The software gives various results that reveal many aspects of the design from general overview to a precise evaluation at a point.

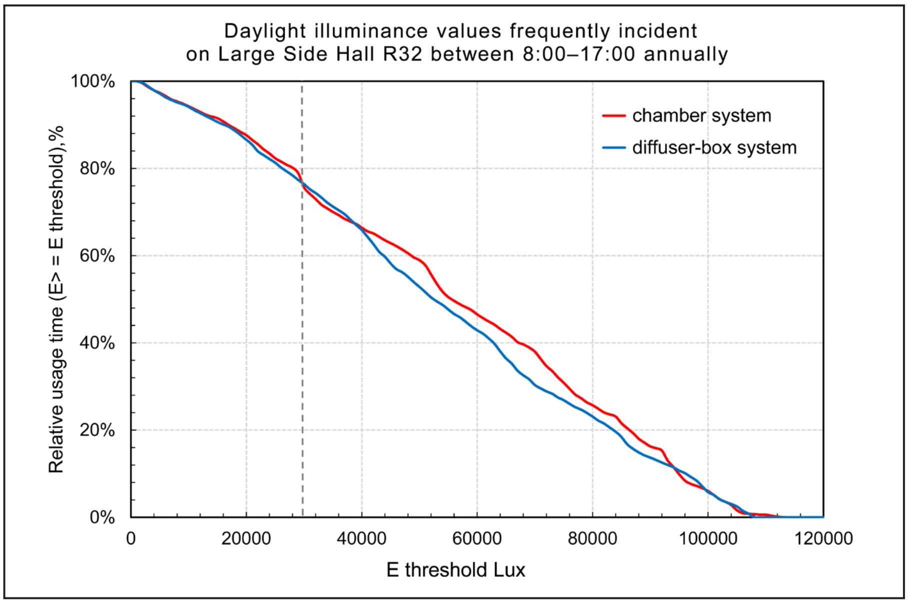
A general overview about the annual illuminance exposure can be obtained from the annual irradiance exposure (direct and diffuse solar radiation) received by the systems and windows during the working hours (8:00 to 17:00) over the course of the year. (Figure 5.148) Originally this measurement is important to identify areas in which solar energy may potentially be utilised, as well as where some means of protection may be required to limit solar exposure. However, we use it here to identify the areas that lack to be exposed to daylight and are the differences between areas exposed to daylight acceptable or not? As well, the irradiance [W/m^2] can be converted to illuminance [lx] with a very rough factor of 100 lm/W.(1) Accordingly, we find that the roof is much more exposed to daylight than the west facade and receives a higher levels of illuminance. This is mainly because the facade receive direct sun light only in the afternoon. The skylights is almost exposed to the same amount of daylight during the year except parts of the first two skylights in the West Wing (The skylight over the Large Side Hall R42 and the skylight in the Lateral Galley upper floor R41). This is because these areas receive shadows from the South Wing roof and they view less area from the sky. This has to be considered when designing the control system and the artificial light. In general, the skylights receive annual average illuminance about 52054 lx.(2) This indicates that the 30 klx external illuminance is received by systems most of the year between 8:00 to 17:00. *(see "5.2.1.4.3.1 Shadows study").*

For a precise performance evaluation, we calculated the annual daylight availability(3) for the 30 klx external illuminance incident on the chamber system and the diffuser-box system of the Large Side Hall R32 (the third skylight from the south) at every hour between 8:00 to 17:00 over the course of the year. The result shows that the external daylight illuminance values incident on both systems exceed 30 klx for 76,5 % of the working hours annually. (Figure 5.149) Which means the daylight illuminance target in the spaces will be achieved by daylight alone for 76,5 % of the working hours annually and it need to be boosted with artificial light for 23,5 % of the time.

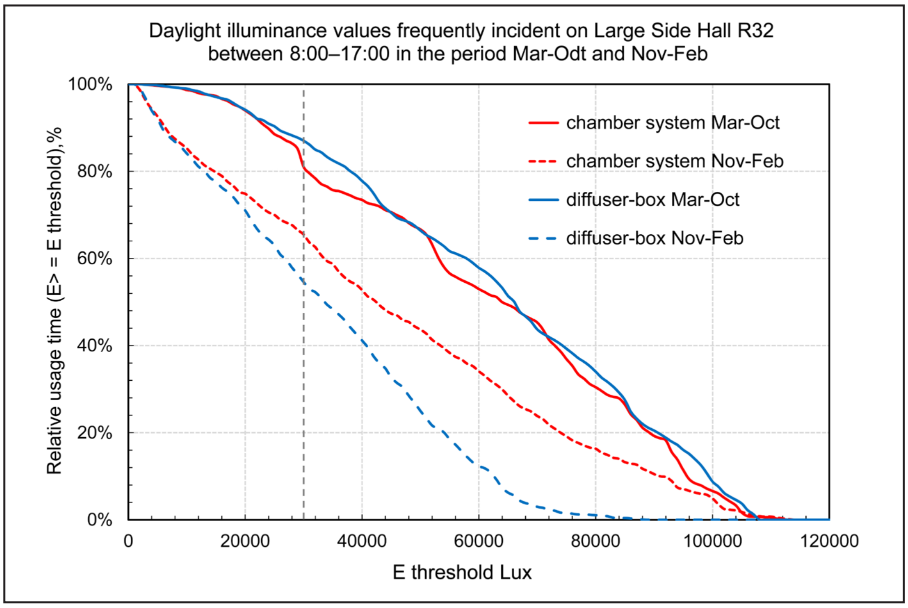
---

1. According to the DIN 5034 the direct sunlight: 18 lm/W – 102 lm/W (depending on the height of the sun), clear sky: 125.4 lm/W , and the overcast sky: 115 lm/W. So 100 lm/W can be considered an average value to convert [W/m^2] to [lx]. However, it is not possible to convert [lx] to [W/m^2] because the illuminance depends on the spectrum composition and the luminosity function. Reference: Data Bank, Research and Development department, Bartenbach GmbH, Innsbruck, Austria, with permission.
2. The calculation: 1900 kWh/m^2 x 100 lm/W = 190000 klx h
   1 year = 365 x 10 h (daylight 8:00 - 17:00)
   E_{av} = 190000 klx h / (3650 h) = 52.054 klx = 52054 lx.
3. The annual daylight availability is the same as the daylight autonomy, which is the percentage of occupied hours per year, when the minimum illuminance level can be maintained by daylight alone at a certain point in a building. (Reference: Christoph F. Reinhart, Tutorial on the Use of Daysim Simulations for Sustainable Design, Institute for Research in Construction , Ottawa, Canada, 2006, p10).

Investigating the data further show that, the 76,5 % daylight availability increases between Mar - Oct and decreases between Nov - Feb, as well it differ between the two daylight systems. (Figure 5.149) For the chamber system the value is 81 % between Mar-Oct, and 65 % between Nov - Feb, and for diffuser-box system the value is 87 % between Mar - Oct , and 54,6 % between Nov - Feb. Which means most of the complemental artificial light will be needed between Nov - Feb and it will be more for the diffuser-box system than the chamber system. However, there is a possibility to raise this value by enhancing diffuser-box system.

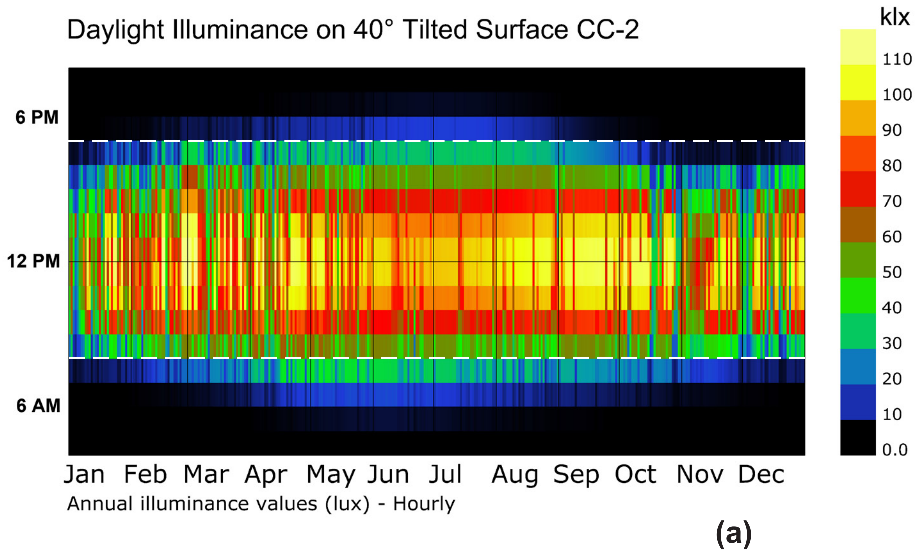


(a)



(b)

Figure 5.149 *Daylight illuminance values frequently incident on the chamber system and the diffuser-box system in the Large Side Hall R32 (a) between 8:00–17:00 annually (b) between 8:00–17:00 in the period Mar-Oct and Nov-Feb.*



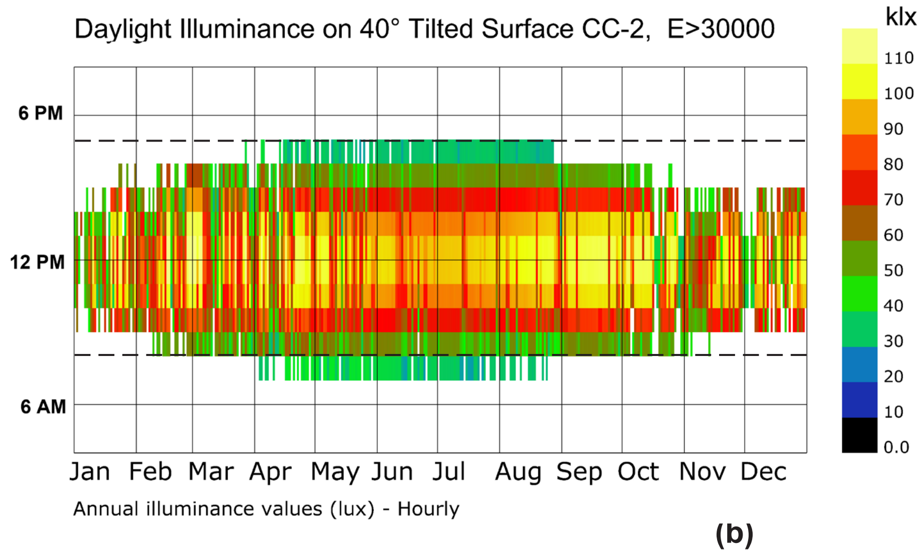


Figure 5.150 *A temporal maps for the daylight illuminance values incident on the chamber system of the Large Side Hall R32. (a) The presentation of the entire values. (b) The presentation of values E > 30 klx.*

The temporal maps in (Figure 5.150 and Figure 5.151) show more details about the daylight availability on the systems. The drop of the daylight values than 30 klx is mainly in early and late hours of the day and on cloudy days in winter season, therefore the value is strongly decrease between Nov-Feb. *(See hourly recorded sky cover in Figure 5.58)*

In general, a 76,5 % annual daylight availability for a daylight systems that depend mainly on the direct sun in a location with 79,8 % sunshine probability is a very good value. *(See"5.2.1.4.1.3 Sunshine probability").*

5.3.1.2.8.6 Notes on system performance

All skylights on the West Wing will have the same daylight availability value and will perform the same except for the first two skylights. These two skylights has to have their own daylight simulation.

The evaluation of the systems performance is not absolute, it is based on the illuminance targets of the design, the placement of the system on the building, and the maintenance services on the long run.

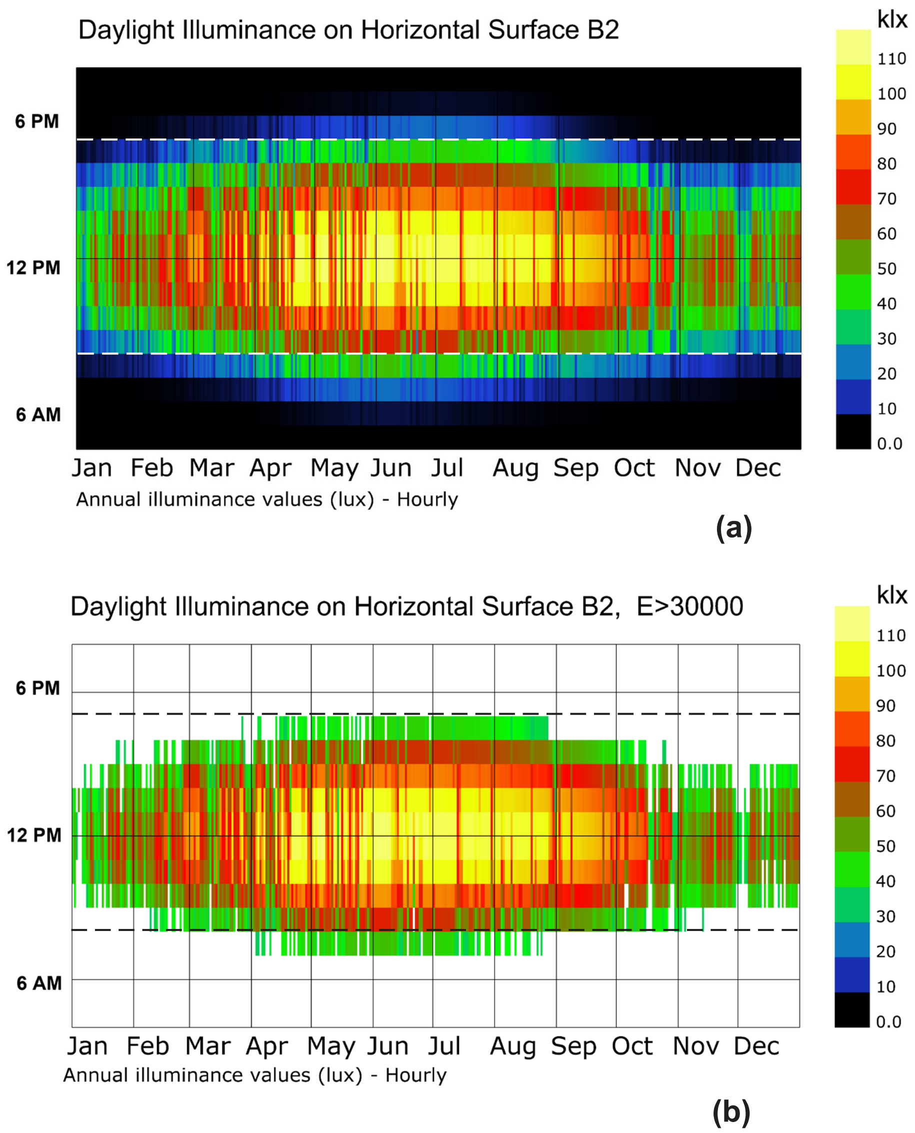


Figure 5.151 *A temporal maps for the daylight illuminance values incident on the diffuser-box system of the Large Side Hall R32. (a) The presentation of the entire values. (b) The presentation of values E > 30 klx.*

In most of the museum spaces the lighting design depends on using the daylight as a room lighting, so in such spaces the fluctuation of daylight will not significantly affect the artificial light of the exhibit and showcases.

Although the diffuser-box system is simply constructed in the model, it has reached its design goals. The diffuser-box system has a potential to increase its performance by using high specular surfaces to raise its light transfer capacity and by using a high-quality louvre system to have more control on light distribution.

The design of the daylight systems are flexible and they can be applied to different parts of the museum and this entail revaluation of the systems performance according to the new condition.

5.3.2 Daylighting design for the Lateral Gallery GF

5.3.2.1 Schematic Design (SD)

5.3.2.1.1 Analysis of the problem

The Lateral Gallery in the West Wing GF R41-to-R11 is a daylit space with seven large windows. From the previous analysis, *(See "5.2.1.2.1 The Lateral Gallery GF R41-to-R11" and "5.2.1.4.3 Digital model analysis"),* we can summarize the main technical illumination problems in the space to:

- The windows have no means of controlling daylight and glare.
- The direct sun penetrates the space in the afternoon.
- The movement of the sun in accordance to west facade creates a big difference between the illuminance levels before noon and afternoon, unstable levels of illumination, and constant change in light distribution.
- Although there is enough daylight, its distribution and unstable condition do not match with the norms of museum lighting.
- The area in front of the windows and the wall opposite to the windows get the highest level of illuminance in the space, while the windows' wall has the least level of illuminance. Accordingly, the exhibits facing the windows have sufficient illuminance, while all the exhibits on the windows' wall have insufficient illuminance and they look dark due to the contrast with the high level of windows luminance. (Figure 5.39 to Figure 5.41)
- Generally, there are no aspects of modern museum lighting for both the daylight and the artificial light.

5.3.2.1.2 Fundamental concept

According to the new interior design arrangement, the Lateral Gallery GF is divided with partition-walls to several zones that help to organize its long space and to add more vertical surfaces for the display. Every window is centred in one of these zones, and the lighting concept mainly aims to use the light of every window to illuminate its surrounding zone.

The concept will be achieved by integrating a daylight system in every window to control the daylight and redirect it to a reflective-ceilings. The reflective-ceilings are centred in every zone and they will distribute the light evenly on the partition-walls and highlight the exhibit. (Figure 5.152)

(See Interior configurations, "5.2.5.2.6 The Lateral Gallery GF" and Figure 5.71, Figure 5.79 and Figure 5.80)

(See "5.2.6.3 Illuminance distribution" and Figure 5.81)

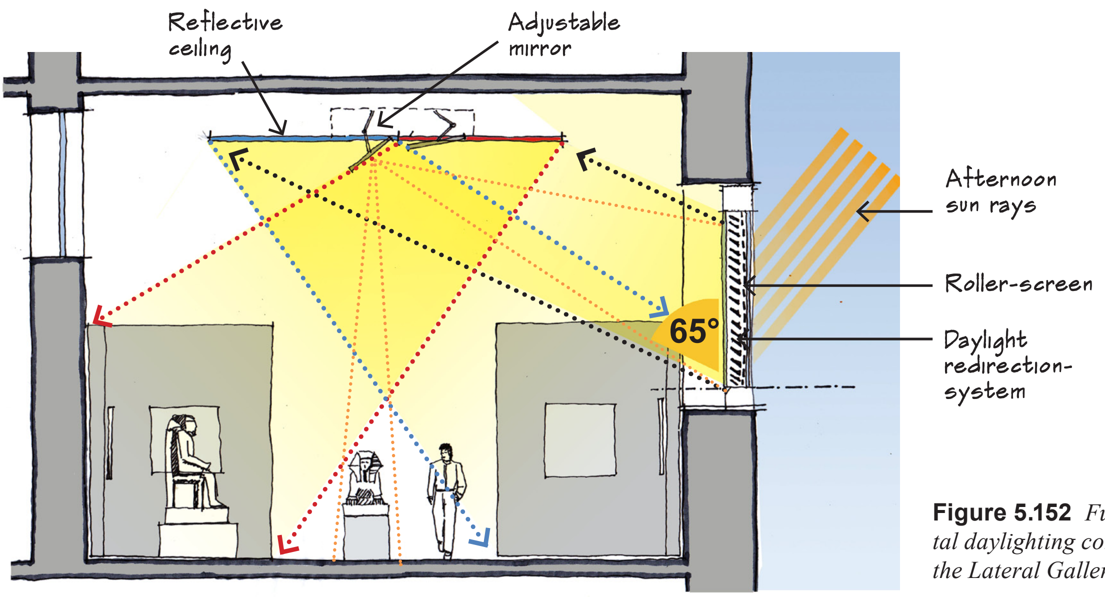


Figure 5.152 *Fundamental daylighting concept for the Lateral Gallery GF.*

5.3.2.1.3 Proposed solutions for the windows

- **The systems objectives:** are to control glare, control the amount of daylight during the day, utilize the sun of the afternoon by diffusing it, and redirect the light falling on the window to the reflective-ceiling.
- **The system main concept:** Before noon the windows on the west facade receive only diffuse light from the sky. In this case the amount of light on the windows are almost equal and the change of the daylight level is slowly and gradually increase till the noon time. During this period a redirection-system needed to redirect the diffuse daylight to the reflective-ceiling and to prevent glare. In the afternoon the direct sun rays start to reach the windows, and the level of daylight increases dramatically till about 15:00, then it decreases till it completely recede. In this period a roller-screen is needed to be utilized with the redirection-system to diffuse the direct sunlight and control the changing in its levels.
- **Technical Description:** The required system is a custom-made system that is able to redirect the external daylight that fall on the window exactly in 65° angle to cover the reflective-ceiling in middle of every zone in the Lateral Gallery GF. (Figure 5.152) The system need to be constructed according to the architectural dimension of the gallery and to be tested. Anyhow, for the purpose of the study we will use the "Fish" system, which is a an existed system that will fit with our needs, however it will redirect the daylight not only on the ceiling but also on the upper part of the room. This is because the "Fish" system redirect the external light confined in 90° into a cut-off-angle of 90° in the interior. We have to consider this differences in our evaluations.

Technically, the system "Fish" consists of fixed horizontal louvres with a triangular section that has been precisely aligned by special connections to the louvre itself.(1) The louvre triangular section is described by a parabola which has its focus exactly at the apex of the next element. The ray paths from various angles of incidence are reflected into the room above the horizon.(2) (Figure 5.153 and Figure 5.154)

The system redirect diffuse light that fall from 90° of the sky and transmits 0 % of the light reflected from the ground. If the system is constructed with aluminium 85 % LRV (externally high reflective and internally matt) it transmits 60 % of sky light; and if it is further installed in insulated glass with a transmission of 80 %, it transmits 50 % of sky light. If the window luminance is 3000 cd/ m^2 without the system, it will be 200 cd/m^2 with the system. Additionally, if the system is constructed with aluminium 98 % LRV (externally mirror and internally matt), it transmits 90 % of sky light; and if it is further installed in insulated glass with a transmission of 80 %, it transmits 75 % of sky light. If the window luminance is 3000 cd/m^2 without the system it will be 300 cd/m^2 with the system.(3) (Figure 5.155)

In addition to the Fish-system a roller-screen is installed between the external glass panel and the louvres. The roller-screen consists of diffuse screens with different light transmission connected in sequence to diffuse and control the sun of the afternoon or to block it completely if the system need to be closed. There is also a possibility to install the roller-screen externally out of the insulated glass of the Fish-system, with or without third glass layers. The roller-screen is connected to a sensor and it is managed automatically.

A Switchable Glass/Smart Glass (as the Electronically Tintable Dynamic Glass) with a sensor can replace the roller-screen to give a precise control on the amount of daylight, however, the technology is new and had to be tested.

How it works:

- Before noon the roller-screen will be elevated and the Fish-system will reflect the diffuse light of the sky onto the reflective-ceiling.

- In the afternoon the roller-screen will be closed to diffuse the direct sun light, and as the level of illuminance increases to a certain level the roller-screen rolls over to place less light transmission screen in front of the Fish-system.

1. Nancy Ruck and others, Daylight in buildings, A source book on daylighting systems and components, A report of IEA SHC Task 21/ ECBCS Annex 29, July 2000. p4-24.
2. Wilfried Pohl, Christian Knoflach, & David Geisler-Moroder, Principles of Daylight Guiding Design, International Light Simulation Symposium (ILSS) 2012.
3. Data Bank, Research and Development department, Bartenbach GmbH, Innsbruck, Austria, with permission.

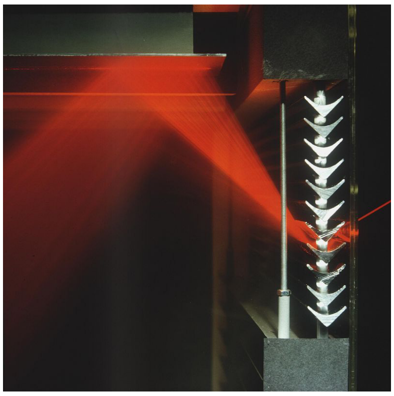


Figure 5.153 *(left) A section in the Fish-system showing its construction and its distribution for a laser beam. (Bartenbach GmbH, with permission.*

Figure 5.154 *(right) An office used a Fish-system with a reflective panel to distribute the light deeper in the room. (Bartenbach GmbH, with permission).*

Directed transmission as a function of angle of incidence beam light

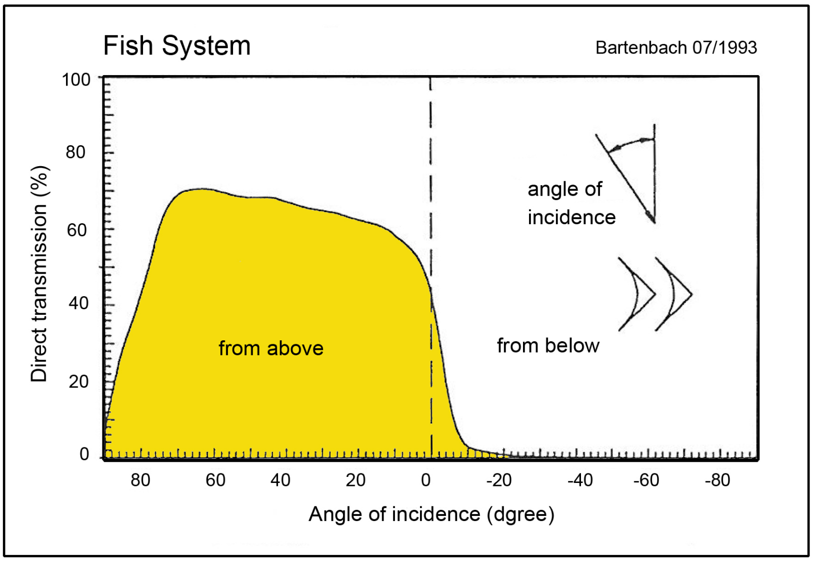
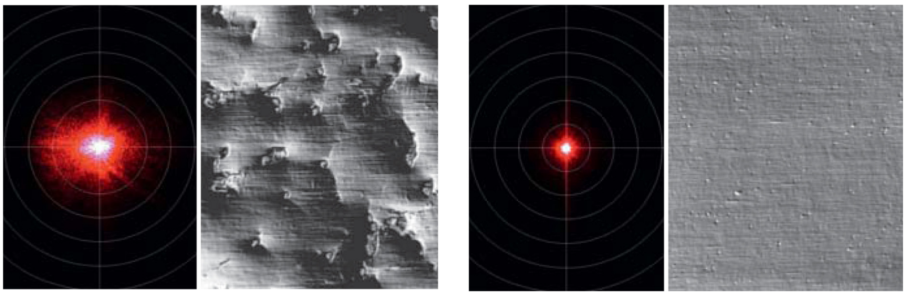


Figure 5.155 *Directed transmission as a function of angle of incidence beam light in Fish-system. (Bartenbach GmbH, with permission).*



(a) (b)

Figure 5.156 *The scattering and the topographic images of surfaces under the microscope for: (a) MIRO-SILVER 8 / 5100 AG (b) MIRO-SILVER 27/4270 AG. (www.alanod.com)*

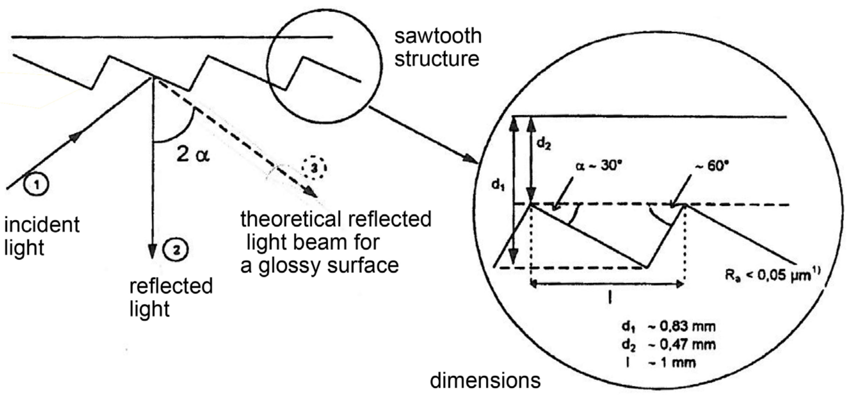


Figure 5.157 *The structure and dimension of SKY-BRIGHT 713GS aluminium sheets from company Alanod.*

5.3.2.1.4 Proposed solutions for reflective-ceiling

- **The systems objective:** is to distribute the daylight redirected to it from the window's redirection-system over the walls and over the main exhibits in the space to highlight them.
- **The system main concept:** Normally, the light reflected on a plane reflective surface from a window will be directed deep in the space. The concept is to divide the ceiling to three parts: the first part is a plane surface to redirect the light on the walls opposite to the window, the second part is zigzag surface to redirect the light on the windows' walls , the third part is adjustable mirror surface to highlight the important exhibits in every zone. (Figure 5.158)
- **Technical Description:**

  - The first part of the ceiling is a plane reflective panels constructed from aluminium sheets MIRO-SILVER 8 / 5100 AG from the company Alanod. The material is a top grade aluminium sheets with lumenal mat surface, with a diffuse reflection value about 68 - 75 %, no preferential direction and it has a high brightness. (Figure 5.156)

  - The second parte of the ceiling is constructed from aluminium sheets SKYBRIGHT 713GS from the company Alanod. The material is a fine structured aluminium surface with a clear sawtooth profile at angles of 30°and 60°. The structured surface of the panel can be utilized to confine or disperse incident light, depending on the setting of the panel. The product has a total reflection of 80 - 84 %. (Figure 5.157)

  - The third part of the ceiling is a small adjustable mirror constructed from aluminium sheets MIRO-SILVER 27/4270 AG from the company Alanod. The material is a top grade aluminium sheets with high reflective coating layers. The material has a total reflectivity of ≥ 98 %, low diffuseness < 6 %, very low preferential direction, and optical mirror effect. (Figure 5.156)
- **How it works:** The light from the first and second parts are directed on the walls in the two sides to create an even light distribution on the walls and the reliefs. The third part, the adjustable mirror, will be adjusted according to the important exhibits in the display, and it will be used mainly for highlight statues in the middle. Although the system is designed to be used with daylight, it will be used as well with artificial light to boost daylight when it decrease and at night time to create a soft room lighting. Light fixtures can be mounted and concealed over the partition-walls. (Figure 5.158)

It is important to point out that, the new arrangement of the display in the Lateral Gallery GF has excluded the showcase from the display and this suits the new daylight lighting concept. On the other hand, by using this concept there is no view to the outside. Therefor the areas before and after the Lateral Gallery GF have to insure the exist of a transparent windows that allow a visual contact to the outside.

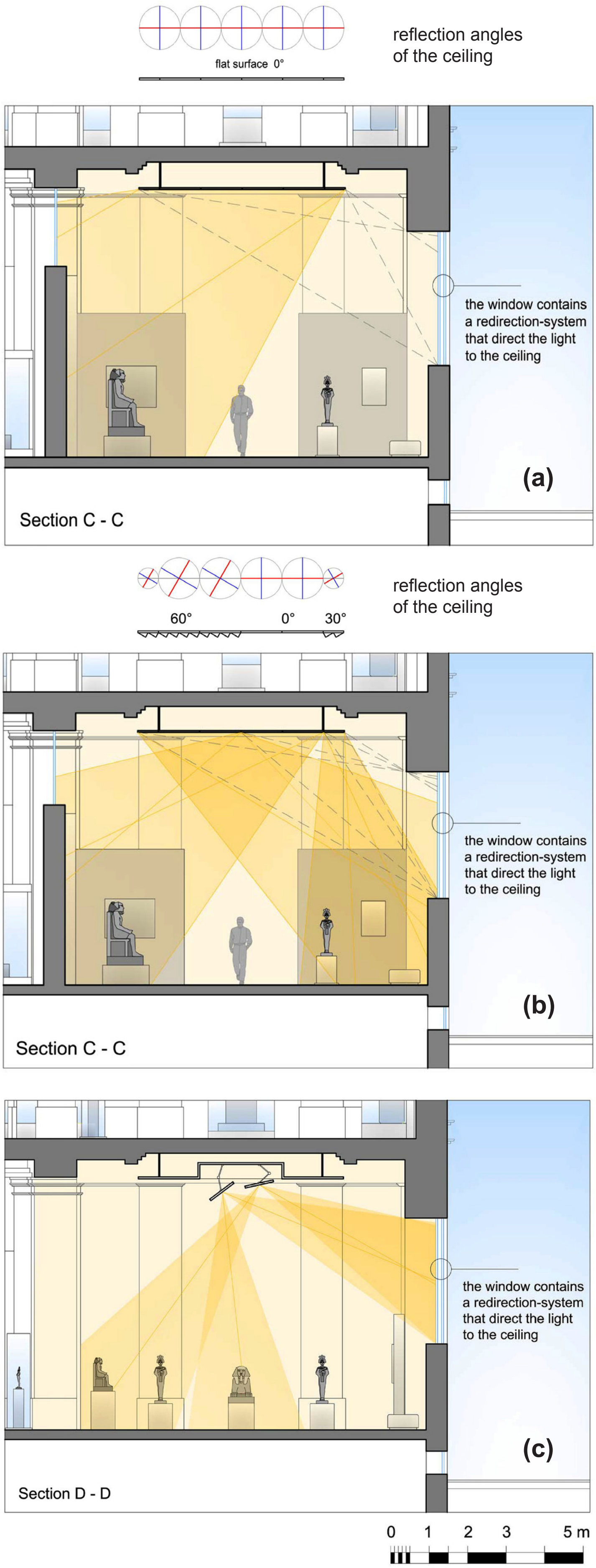


Figure 5.158 *The concept of the reflective ceiling (a) A normal flat ceiling reflects the light deep in the room (b) The proposed ceiling with different reflection angles will distribute the light on both walls (c) The adjustable mirrors in the middle are to highlight the important exhibits.*

5.3.2.1.5 Finalizing the conceptual design

For a computer simulation there is no digital data available for the Fish-system and aluminium sheets that is used in the reflective-ceiling to quickly check the reliability of the system and its expected visual appearance. Therefore our calculation and visual evaluation will be conducted in the physical model during the development phase.

Nevertheless, in an optimum condition, when the windows' redirection-system is custom-made to redirect the light only on the reflective-ceiling and the reflective-ceiling distributes the light evenly on the partition-walls, and the following gauges exist:

- the required redirection-system has the same light transmission of the Fish-system between 50 - 75 %,
- the system area in the window is 6,25 m^2,
- the reflective-ceiling has average LRV of 75 %,
- all reflected light is only directed and distributed evenly on the partition-walls and the floor which is ~240 m^2 in zone A and ~190 m^2 in zone B,
- the external daylight illuminance on the window is 10 klx;

then the average illuminance on the partition-walls and floor will be between 97 - 146 lx in zone A and 123 - 185 lx in zone B.

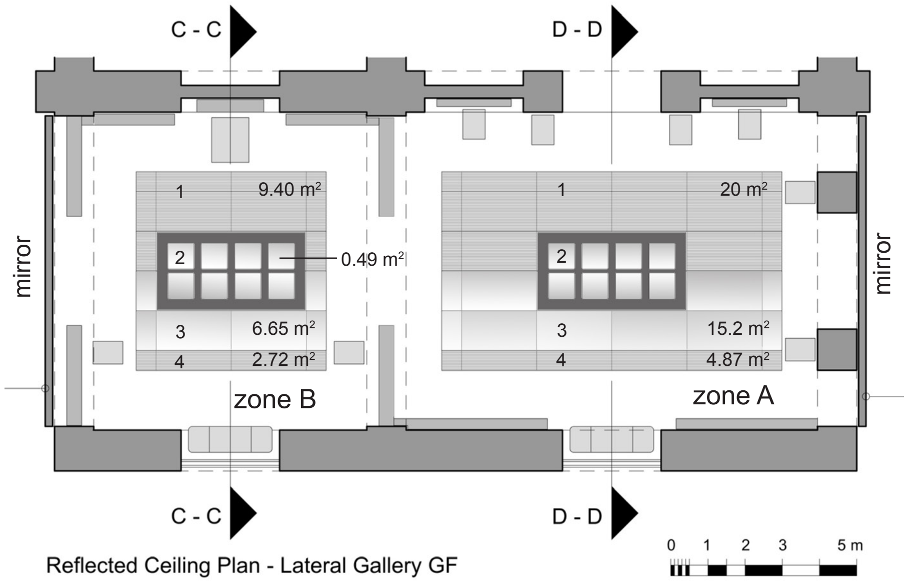
Keeping in mind that the illuminance on the west facade will increased in the afternoon and reach its maximum ~80 klx in summer time, we find that the concept of the design is reliable and can yield a good results.

5.3.2.2 Design Development (DD)

5.3.2.2.1 Constructing the systems in the model

The redirection-system was constructed from a Fish-system sample with 12 mm width and 60 % light transmission from the 90° angle between the normal and the system. (Figure 5.160) The sample was integrated between two transparent plexiglas panel with about ~88% light transmission each. The sample and the transparent plexiglas resemble a complete Fish-system in insulated glass, and we expect that the system model will have about ~50 % light transmission. The system takes the window arched form with a complete area of 7.8 m^2 and glass area without frame of 6.8 m^2. Externally we used a diffused plexiglas panel with ~68% light transmission to resemble the effect of the roller-screen.

The ceiling is constructed according to the technical material described previously *(See "5.3.2.1.4 Proposed solutions for reflective-ceiling")*. We constructed a hanging ceiling that cover the entire Lateral Gallery GF in the model and contains the reflective areas in the centre of every zone according to the design in (Figure 5.159). The adjustable mirror was fixed on a Z-shape holder to help moving and adjusting its direction. In the centre of every zone there are 10 mirrors and each mirror has a size of 70 x 70 cm. In real application the mirror size can be reduced to be more concealed in the ceiling. (Figure 5.161)



1. High reflective zigzag surface (SKYBRIGHT), angle of reflection 60° toward the window.
2. High reflective adjustable mirror, (MIRO-SILVER 27/4270 AG) .
3. High reflective matt flat surface , (MIRO-SILVER 8 / 5100 AG).
4. High reflective zigzag surface (SKYBRIGHT), angle of reflection 30° toward the window.

Figure 5.159 *Reflected ceiling plan for the Lateral Gallery GF, The drawing is for the area of study in the model.*

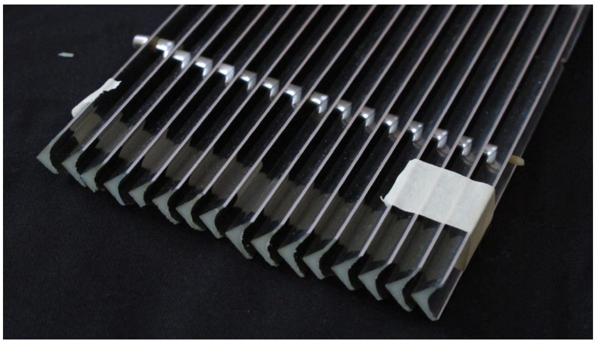


Figure 5.160 *A Fish-system sample with 60 % light transmission from the 90° angle between the normal and the system.*

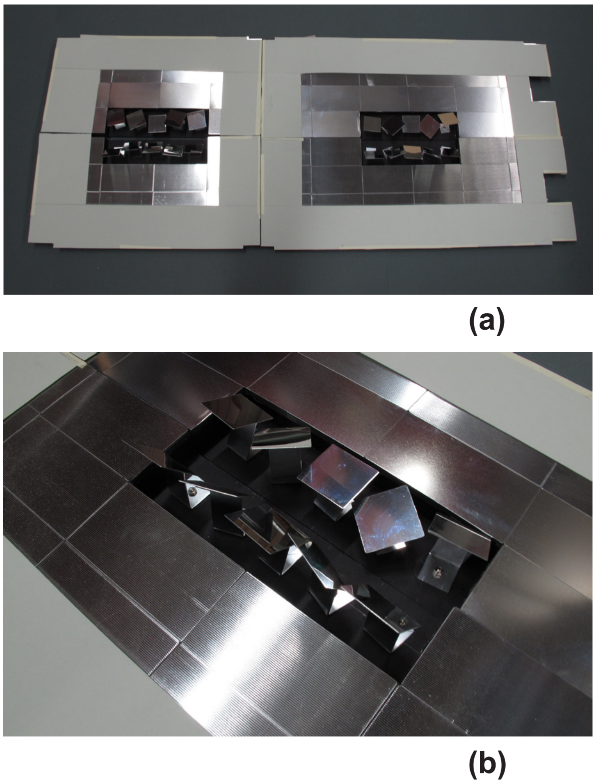


Figure 5.161 *The construction of the reflective-ceiling in the model (a) The ceiling is made to cover the entire Lateral Gallery GF space in the model and the reflective areas to centre every zone. (b) The adjustable mirror in the centre of the reflective-ceiling.*

5.3.2.2.2 Limitations in model construction

In our concept the redirection-system reflects the light in 65° angle, that cover only the reflective-ceiling. Because the required redirection-system is a custom-made; we used instead of it a Fish-system, that we can obtain. The Fish-system directs the light in 90° angle, which is wider than required. It covers not only the reflective-ceiling, but also the ceiling around it and the upper parts of the walls that face the windows. This makes these areas brighter than expected; while in the original concept the light has to be focused only on the partition-walls and statues, while other areas stay in less light. (Figure 5.152) This difference alter the atmosphere we need. During the measurements, as compromise to handle this change, we covered the ceiling area between the windows and the reflective-ceiling with a small piece of black cloth to eliminate its high luminance that drags eye attentions, also this will reduce the light in the space. In contrast, we left the upper parts of the walls that face the windows without any treatment, because covering all areas will alter the measurement values dramatically. (Figure 5.170)

These differences have to be considered in the photometric and visual evaluation, and to keep in mind that:

- A redirection-system with 65° angle directs the light only on the ceiling will increase the illuminance.
- Using a Mirror Fish-system(~75 % LRV in insulated glass) instead of the Fish-system we used in the model (~ 50 % LRV in insulated glass), will increase the illuminance ~ 66,7%.

Another limitation that is related more to how the reflective-ceiling will appear, is the size of adjustable mirror. In real application, every mirror can be replaced with few smaller mirror to be more concealed in the ceiling and direct the light more precisely on the exhibits. As well, if the position of the exhibits are fixed, a secondary reflector comprised of individual facets can replaces the mirror and be fully integrated in the ceiling. (Figure 5.162)

Although, these differences exist, conducting the evaluation with the available systems and materials will give a good indication about how the original concept will function photometrically and visually.

(a) (b)

Figure 5.162 *An example of a secondary reflector comprised of individual facets used with artificial light. The facets reduces the glare and distributes the light as required. (a) A secondary reflector in the ceiling of station of Metro Kastrup Copenhagen, Denmark. (b) a close up photo. (Bartenbach GmbH, with permission)*

5.3.2.2.3 Evaluating the daylighting design in Lateral Gallery GF

5.3.2.2.3.1 Measuring illuminance levels

Although every Fish-system and reflective-ceiling mainly illuminates the zone surrounding them, the light spread out directly and indirectly from every zone to other zones. Therefore, we measured the illuminance levels in both zones together when the light falls on both windows.

In the model there are two parallel mirrors one in the beginning and the other in the end of the sector of Lateral Gallery GF. The purpose of the mirrors are to compensate visually the loss of length and physically the loss of illuminance that would come from other windows that were not built in the model. During the measurements the mirror in the side we are measuring is opened to facilitate conducting the measurements, therefor its effect physically did not count and the illuminance level in reality is expected to be slightly higher.

The daylight condition changes dramatically during the day. Before noon the sky diffuse light falls directly on the Fish-system. In the afternoon the sun start to fall on the system and the roller-screen is closed. Thus the measurements were conducted for five following conditions:

- The Fish-system under diffuse sky to measure the before noon illuminance. (Figure 5.163)
- The Fish-system with roller-screen under diffuse sky to measure the illuminance from the daylight diffuse component in the after noon.
- The Fish-system with roller-screen under direct sun on 21 Mar at 13:00, 15:00 and 17:00 to measure the illuminance from the daylight direct component in the after noon.

For the evaluation of the afternoon time both daylight component are added together to give the illuminance of the afternoon hours. See (Figure 5.164 to Figure 5.166), where the red value is the direct solar component, the blue value is the diffuse sky component, and the black value is the sum of both of them.

The sun position on 21 Mar at 13:00, 15:00; and 17:00 represent the other sun position during the course of the year, this is because the angel of the sun on the west facade do not change a lot at the same hour between the months. The sun angles on 21 Mar at the selected hours are:

- At 13:00 v 74,6°, h 248°, which is 14.3° to the surface of the system.
- At 15:00 v 49,0°, h 272°, which is 41,0° to the surface of the system.
- At 17:00 v 23,3°, h 284°, which is 62.7° to the surface of the system.

(See stereographic sun path diagrams in Figure 5.55 and Figure 5.69)

In addition to the previous measurements we measured the illuminance at three other model configurations to help evaluating the system:

- The original window and white ceiling under diffuse sky to measure the before noon illuminance. (Figure 5.169)

- The Fish-system and white ceiling under diffuse sky to measure the before noon illuminance. (Figure 5.167)
- The Fish-system with roller-screen and white ceiling under diffuse sky to measure the illuminance from the daylight diffuse component in the after noon.
- The Fish-system with roller-screen and white ceiling under direct sun on 21 Mar at 15:00 to measure the illuminance from the daylight direct component in the after noon.

For the afternoon time both daylight components are added together to give the illuminance of the afternoon hours. See (Figure 5.168) where the red value is the direct solar component, the blue value is the diffuse sky component, and the black value is the sum of both of them.

To help compare and evaluate different measurement conditions together, all presented illuminance values for before noon conditions are normalised to arrive at values equal to that when 10 klx is measured normal to the glass surface of the windows, and all presented illuminance values for afternoon conditions are normalised to arrive at values equal to that when 20 to 30 klx is measured normal to the glass surface of the windows. (Table 5.8 and Table 5.9)

These values are chosen because the analysis of the measurements show that, the illuminance values in the galleries are acceptable at 10 klx external illuminance before noon, and between 20 to 30 klx external illuminance in the afternoon. As well, the range between 20 to 30 klx is an acceptable range for daylight fluctuation.

Technically, for the afternoon conditions we measured separately the illuminance value of direct and diffuse component. The diffuse value is normalised at 10 klx and the direct component at 10 or 20 klx, then they were added together to give the final value of 20 or 30 klx. In reality, the west facade is facing half the sky and the change in the diffuse component is not large, where the change in the direct component depend on the position of the sun which is changing constantly and significantly. In the real practice the facade will receive much more illuminance from the sun and the sky in the afternoon; and a big portion of this illuminance will be reduced by control systems, so in this case neither the change in the values nor in the angles of incident light on the systems will disturb the illuminance levels in the space. (Figure 5.154)

The values presented (Table 5.8 and Table 5.9) are the average illuminance value for the points of interest in every area in zone A and B. Where A is the area in front of the Large Side Hall GF, and B is the area in front of the Small Side Hall GF. In every area the horizontal illuminance values were measured at the position where the statues stand (gray spots in figure Figure 5.163 to Figure 5.169) and the floor; and the vertical illuminance values were measured at the external, the internal and the middle/partition-walls. The points of interest can be seen in (Figure 5.163 to Figure 5.169), where green dots are for horizontal illuminance and purple dots are for vertical illuminance, and both are measured at 150 cm from floor level. These figures represent the measurements before noon when 10 klx is measured to the normal of the windows, and afternoon when 25 klx is measured to the normal of the windows; which is an average value between 20 to 30 klx.

5.3.2.2.3.2 Evaluating illuminance levels

The range of illuminance described in this evaluation represents the highest - lowest average illuminance in every area when the external illuminance is 10 klx befoor noon and when it range between 20 - 30 klx on 21 Mar at 13:00, 15:00, and 17:00 in the afternoon. (Table 5.8 and Table 5.9) Keeping in mind that, these values to some extent increase between Mar - Oct and decrease between Nov - Feb due to the change in climate condition.

The illuminance values for the proposed design (Fish-system and reflective-ceiling) in the model of the Lateral Gallery GF, in (Table 5.8) and in (Figure 5.163 to Figure 5.166), show that:

- Before noon condition (the Fish-system and the reflective-ceiling): In zone A, the average illuminance value on the floor and the walls are very close to each other and can be described as uniform. The average illuminance value on the statues are high and it is almost twice that of the surrounding. In particular, the walls illuminance values have a close value between the external walls and partition-walls, while they are relatively higher on the internal walls this because they face the windows and the Fish-system has a wide angle of distribution. The light distribution in zone B are similar to that in zone A, however the illuminance levels are slightly higher because zone B has a smaller area and have the same window; however, the differences in values are insignificant.
- In the afternoon condition (the Fish-system with the diffuse screen and the reflective-ceiling): Generally, the illuminance distribution and the relationship between the values stay the same as before noon. When 30 klx falls externally on the window at 13:00 the illuminance values are the same as before noon. As the sun position change from 13:00 to 17:00 the illuminance values increase, because the sun become more perpendicular on the window, thus the light transmission increases. As a result, the difference between the illuminance at 30 klx and 40 klx increase. In the model we used one diffused plexiglas panel with ~68% light transmission to resemble the effect of the roller-screen. In the reality different screens must be defined and tested according to the annual external illuminance on the window to regulate the differences and keep the illuminance inside the space stable, or perhaps using a Switchable Glass with a sensor can be an easier and more effective solution.

Testing the Fish-system with a white ceiling in the model shows how effective is the reflective-ceiling. The results in (Table 5.9) and in (Figure 5.167 and Figure 5.168) shows that:

- Before noon condition (the Fish-system and the white ceiling): The average illuminance value is the same on the floor area, and it is reduced for about ~ 40% in zone A and ~ 50% in zone B on both the walls and the statues.
- In the afternoon condition (the Fish-system with a diffuse screen and the white ceiling): The illuminance distribution and the relationship between the values stay the same as before noon. And of course, as the sun position change from 13:00 to 17:00, the illuminance values increase.
- The results show how effective is the reflective-ceiling in directing the light to the walls and the statues and increasing the illuminance levels about 40-50%. This effectiveness will increase, if the light is only directed on the reflective-ceiling and there is less undirected diffuse light in the space.

The illuminance values for the original configuration (a glass window with grids and white ceiling) shows how the hall concept is effective. The results in (Table 5.9) and in (Figure 5.168) shows that:

Results with reflective-ceiling			**Fish-system + reflective ceiling**	**Fish-system + Screen + reflective ceiling**		
Lateral Gallery GF with Windows		Position (1)	Before Noon (2) 10 klx	Afternoon(2) 20-30 Klx		
Zone	**Area**		**8:00-12:00**	13:00	**15:00**	17:00
A	Floor (3)	E_v	**50**	37-47	**51-76**	62-98
	Statues (4)	E_v	**97**	79-104	**115-174**	138-221
	External walls	E_h	30	24-31	34-51	41-64
	Internal walls	E_h	58	45-58	65-98	78-124
	Partition walls	E_h	37	28-37	42-64	48-76
	Wall average	E_h	**42**	32-42	**47-71**	56-88
B	Floor (5)	E_v	**64**	52-67	**81-123**	102-165
	Statues (4)	E_v	**80**	64-81	**96-146**	128-209
	External walls	E_h	38	28-35	43-66	56-91
	Internal walls	E_h	73	55-70	88-136	112-185
	Partition walls	E_h	48	39-51	62-97	74-122
	Wall average	E_h	**53**	40-52	**64-100**	81-133

(1) Horizontal and vertical illuminance values were measured at 150 cm from floor level.
(2) Incident illuminance is measured to the normal of the windows.
(3) Floor in zone A : the six points on the middle of the floor and not occupied with statues.
(4) Statues: areas marked with a light gray circle.
(5) Floor in zone B : all nine points on the middle of the floor.

Table 5.11 *Theilluminance values for the proposed design (Fish-system and reflective ceiling) in the model of the Lateral Gallery GF. The values represent the average illuminance for the points of interest in the model when 10 klx is falling on the windows before noon and when 20 to 30 klx is falling on the windows in the afternoon. The points of interest can be seen in (Figure 5.163 to Figure 5.166).*

- Before noon condition: there is enough light in the space the illuminance distribution is very bad. This is evident in the differences between the illuminance value on the internal and external walls, and on the area close and far from the window.
- In the after noon: We did not measured this condition because it is totally unstable. As we explained previously, in the after noon the sun rays will penetrate the space and will constantly alter the appearance and the illuminance distribution in the space.

As a general conclusion, the illuminance measurements show that the daylighting concept for the Lateral Gallery GF is effective in distributing the daylight evenly on the partition-walls and floor, and highlighting the free standing statues in the middle of the space; as well, maintaining a stable illuminance distribution between the before noon and the after noon periods of the day. However, due to the limitation of model construction the system did not reach the illuminance target in all the working hours. Nonetheless, the illuminance target; which is 100 lx on the walls and floor, and illuminating the exhibits as much as possible with daylight; can be achieved if all model limitation are solved and the proposed concept is precisely built. *(See "5.3.2.2.2 Limitations in model construction")*

Results with white ceiling			**Fish-system + white ceiling**	**Fish-system + Screen + white ceiling**	**Original configuration**
Lateral Gallery GF with Windows		Position (1)	Before Noon (2) 10 klx	Afternoon(2) 20-30 Klx	Before Noon (2) 10 klx
Zone	**Area**		**8:00-12:00**	**15:00**	**8:00-12:00**
A	Floor (3)	E_v	**57**	**71-103**	**241**
	Statues (4)	E_v	**60**	**73-106**	**216**
	External walls	E_h	17	21-32	26
	Internal walls	E_h	31	37-55	262
	Partition walls	E_h	23	29-42	72
	Wall average	E_h	**24**	**29-43**	**120**
B	Floor (5)	E_v	**57**	**65-95**	**280**
	Statues (4)	E_v	**48**	**57-83**	**155**
	External walls	E_h	16	19-28	33
	Internal walls	E_h	31	35-51	302
	Partition walls	E_h	30	34-46	99
	Wall average	E_h	**25**	**30-42**	**145**

(1) Horizontal and vertical illuminance values were measured at 150 cm from floor level.
(2) Incident illuminance is measured to the normal of the windows.
(3) Floor in zone A : the six points on the middle of the floor and not occupied with statues.
(4) Statues: areas marked with a light gray circle.
(5) Floor in zone B : all nine points on the middle of the floor.

Table 5.12 *Theilluminance values for Fish-system with a white ceiling and for the original configurations in the model of the Lateral Gallery GF. The values represent the average illuminance for the points of interest in the model when 10 klx is falling on the windows before noon and when 20 to 30 klx is falling on the windows in the afternoon. The points of interest can be seen in (Figure 5.166 to Figure 5.169).*

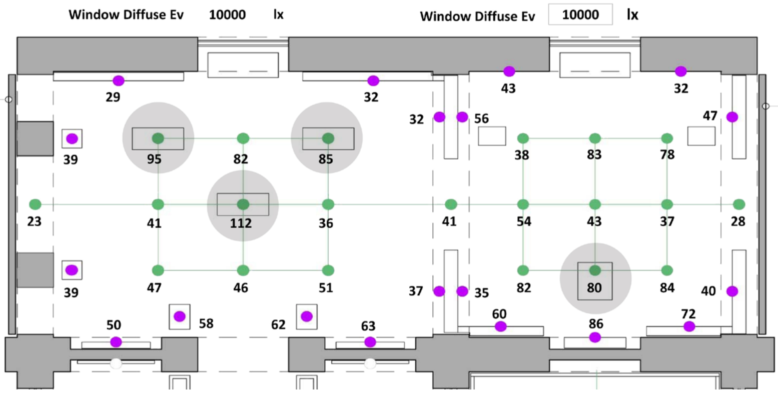


Figure 5.163 *The daylight illuminance values in the Lateral Gallery GF before noon when 10 klx external daylight illuminance is measured to the normal of the windows. A fish system is installed in the windows and a reflective ceiling in every zone.*

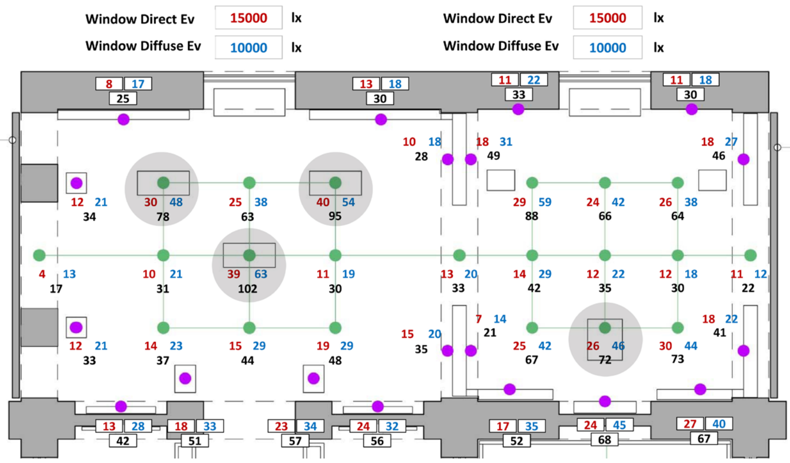


Figure 5.164 *The daylight illuminance values in the Lateral Gallery GF in the afternoon on 21 Mar at 13:00 when 25 klx external daylight illuminance is measured to the normal of the windows. A fish system with a roller-screen is installed in the windows and a reflective ceiling in every zone.*

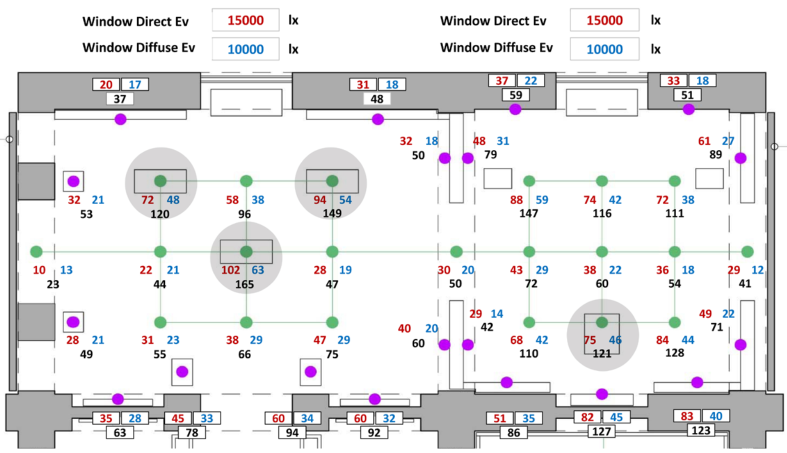


Figure 5.165 *The daylight illuminance values in the Lateral Gallery GF in the afternoon on 21 Mar at 15:00 when 25 klx external daylight illuminance is measured to the normal of the windows. A fish system with a roller-screen is installed in the windows and a reflective ceiling in every zone.*

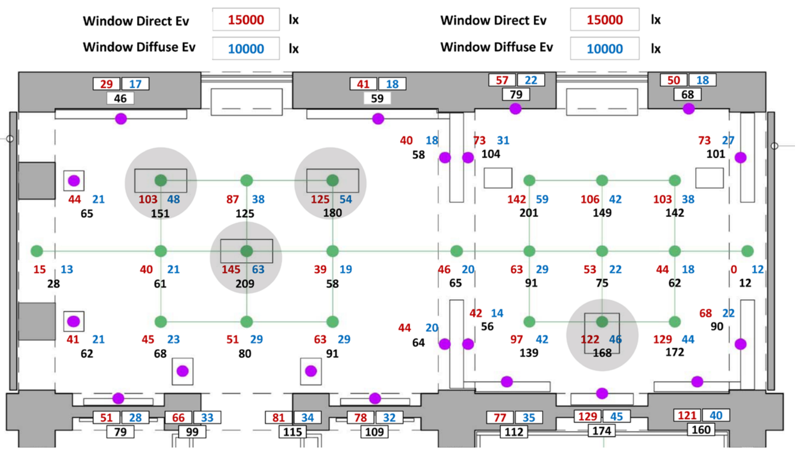


Figure 5.166 *The daylight illuminance values in the Lateral Gallery GF in the afternoon on 21 Mar at 17:00 when 25 klx external daylight illuminance is measured to the normal of the windows. A fish system with a roller-screen is installed in the windows and a reflective ceiling in every zone.*

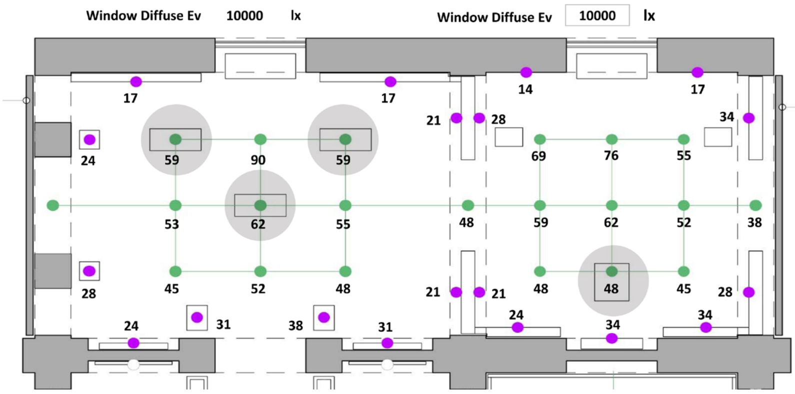


Figure 5.167 *The daylight illuminance values in the Lateral Gallery GF before noon when 10 klx external daylight illuminance is measured to the normal of the windows. A fish system is installed in the windows and the ceiling is the original white ceiling.*

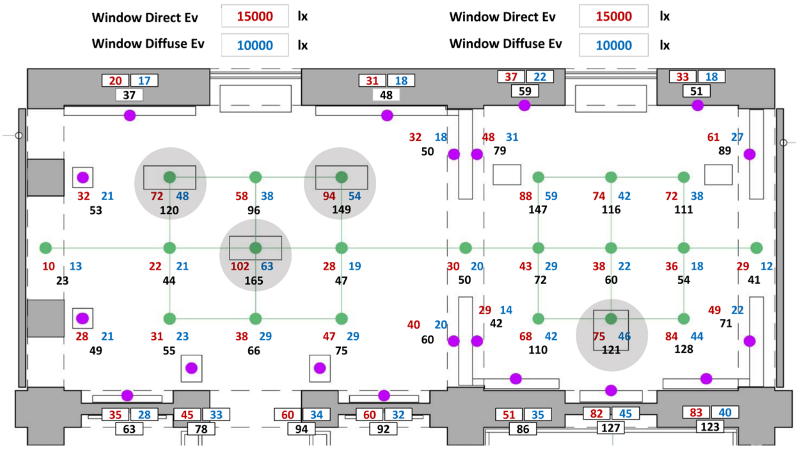


Figure 5.168 *The daylight illuminance values in the Lateral Gallery GF in the afternoon on 21 Mar at 15:00 when 25 klx external daylight illuminance is measured to the normal of the windows. A fish system with a roller-screen is installed in the windows and the ceiling is the original white ceiling.*

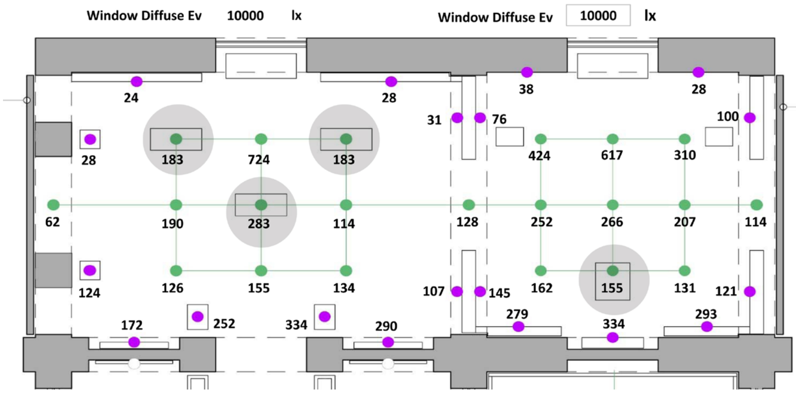


Figure 5.169 *The daylight illuminance values in the Lateral Gallery GF before noon when 10 klx external daylight illuminance is measured to the normal of the windows. The widows and the ceiling are in their original condition.*

5.3.2.2.3.3 Evaluating the visual environment

- **The Lateral Gallery GF, zone A:** The Fish-system redirect the light (in 90° angle) on the upper half of the space. The light falling on the reflected-ceiling is redirected evenly on the partition-walls and the exhibits, while the light falling on the rest of the ceiling and on the upper part of the internal-walls is diffused back in the room. The diffuse light attenuate the shadows, so it soften the effect of the direct light. (Figure 5.170)

  The internal wall has a smooth gradient from the upper parts of the wall till the floor, and it is brighter than the external wall. The black part in the ceiling, that we used as a compromise to adjust the light distribution in the model, makes the upper parts of external wall darker than it should be. The light is evenly distributed on the partition-walls and the lower area of the walls. The adjustable mirror highlight the exhibits and this is clearly evident from the highlights of the free standing dark statues, and from the strong cast shadows of the reliefs and statues near the wall. The exhibits have a good visual quality.

  The visual analysis shows that it is good that the space has some diffuse light that fill in shadows and reveal details in dark areas. Accordingly, it will be bitter if the direction-system direct the light on the entire ceiling, so the reflective part creates a strong direct light and the matt parts creates a diffuse soft light. As well the luminance of the upper part of the internal wall will be reduced and the wall luminance will be balanced with the external wall.

  The analysis of the luminance photos at eye level in the model show that, the correlation between the external illuminance on the Fish-system with diffuse screen and the average internal luminance of the Fish-louvres is: 97 cd/m^2 at 10 klx, 195 cd/m^2 at 20 klx, 310 cd/m^2 at 30 klx, and 460 cd/m^2 at 40 klx. According to the control system, the 30 klx maximum permitted illuminance yields 310 cd/m^2 internal illuminance and it do not poses any glare hazard. However, if the Fish-louvres have a mirrored finish from inside, it will further reduce the louvres luminance value. Concerning, the reflective-ceiling, it is totally free from high luminance values. (Figure 5.170)

  Generally, the space is well illuminated, the light is focused more on the exhibits, the visual effect is moderate, and the space is free from glare. Although the system is visually acceptable, it has potential to be further enhanced.

- **The Lateral Gallery GF, zone B:** Zone B has the same visual quality as zone A, however the space is relatively brighter because it is smaller, has less number of exhibits, and the external wall is not covered with the dark partition-walls. The distribution of the light on the external wall can be clearly observed. (Figure 5.171)

- **Fish-system with a white ceiling in zone A:** This analysis was made to show how effective is the reflective-ceiling. In this situation the Fish-system redirect the light on the upper half of the space. The white ceiling and the upper part of the walls diffuse and reflect the light back into the space. The upper par of the space is brighter than the lower part, and all exhibits are immersed in diffuse light which makes them lose their visual quality. The white ceiling is the brightest element in the space and it drag eye attention. By comparing this situation with the proposed design, it can be concluded that the reflective-ceiling is erective in directing the light more on the exhibits and revealing its visual quality. (Figure 5.170 and Figure 5.172)
- **The original configurations in zone A:** This analysis was made to show how effective is the entire system. In this situation the window has a transparent glass with grids, the ceiling is white and the sky is diffuse. The diffuse light flows from the window and makes the floor near the window and the walls facing the window the brightest part of the space; and in the contrary, the external wall the darkest parts of the room. The exhibits facing the windows have a good lighting, while the exhibits on the external walls and far from the windows have insufficient light. The windows creates glare and grabs eye attention. It is obvious that the Fish-system reduces glare and the reflective ceiling distribute the light better in the space. (Figure 5.170 and Figure 5.173).

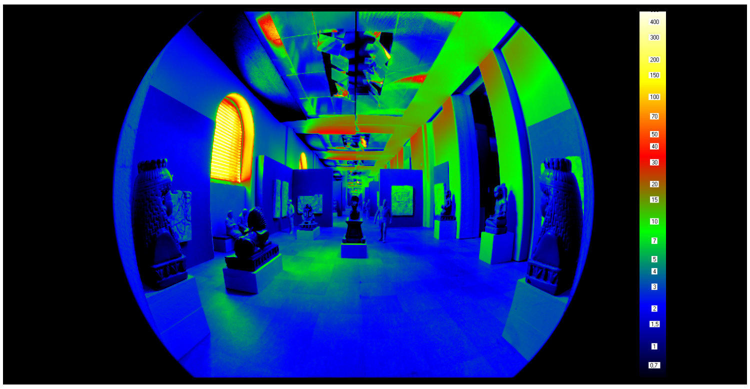
Note that: photos in (Figure 5.170 to Figure 5.173) were taken at different external illuminance and the scales of the false colour images are not the same. The photos and the images give an impression about the light atmosphere and its distribution in the space, and they can not to be used for one-to-one comparison between different situations. For comparing the illuminance levels see (Table 5.8 and Table 5.9) and (Figure 5.163 to Figure 5.169)

5.3.2.2.3.4 Evaluating system performance in real condition

According to model measurements and analysis, the illuminance values in the Lateral Gallery GF are acceptable when the external illuminance is 10 klx before noon, and ranges between 20 to 30 klx in the afternoon. How long annually the external illuminance on the system will exceed 10 klx before noon and 20 klx in the after noon? This question can be answered based on the daylight simulation we previously conducted for the museum building (in 5.3.1.2.8.5).

A general overview about the average annual illuminance exposure can be obtained from the average annual irradiance exposure received by the windows during the working hours (8:00 to 17:00) over the course of the year. Accordingly, we found that the windows are annually exposed to different levels of daylight and the average annual illuminance ranging gradually from 10960 lx at the first window south to 27400 lx at the last window north. (Figure 5.148)

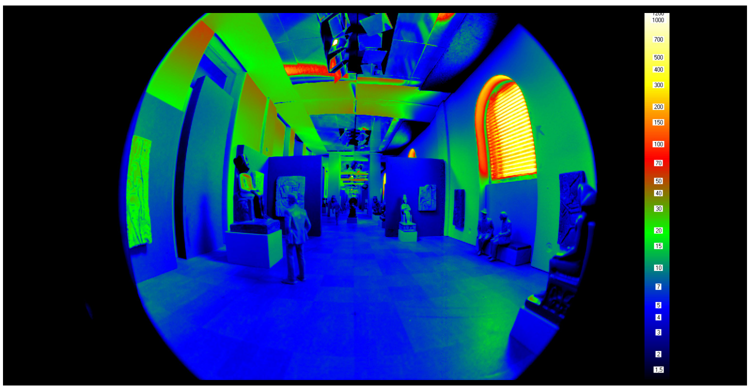
(a)



(b)

Figure 5.170 *The light atmosphere in the Lateral Gallery GF zone A. (a) The space is well illuminated, the light is focused more on the exhibits, the visual effect is moderate, and the space is free from glare. (b) A false colour image represents the luminance distribution for the previous photo. The luminance scale values are in cd/m²: Approx. white 530, yellow 175, orange 85, red 35, green 8, and blue 2. (External illuminance on the windows 20 klx)*

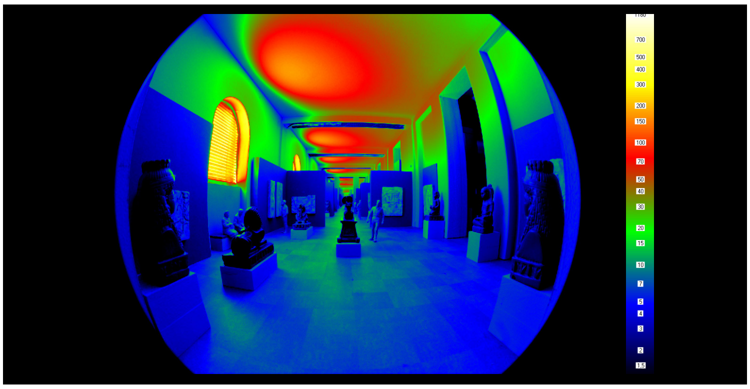
(a)



(b)

Figure 5.171 *The light atmosphere in the Lateral Gallery GF zone B. (a) Zone B has the same illuminance distribution as zone A, however the space is relatively brighter because it is smaller, has less number of exhibits, and the external wall is not covered with the dark partition-walls. (b) A false colour image represents the luminance distribution for the previous photo. The luminance scale values are in cd/m²: Approx. white 1200, yellow 350, orange 200, red 85, green 20, and blue 4. (External illuminance on the windows 37,7 klx)*

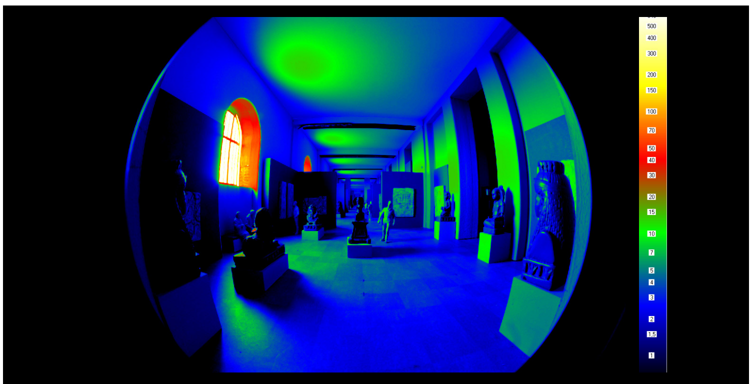
(a)



(b)

Figure 5.172 *The light atmosphere for Fish-system with a white ceiling in zone A, in the Lateral Gallery GF. (a) The upper par of the space is brighter than the lower part, and all exhibits are immersed in diffuse light which makes the exhibits lose their visual quality. (b) A false colour image represents the luminance distribution for the previous photo. The luminance scale values are in cd/m²: Approx. white 1180, yellow 350, orange 175, red 85, green 20, and blue 3. (External illuminance on the windows 25 klx)*

(a)



(b)

Figure 5.173 *The light atmosphere for the original configurations in zone A, in the Lateral Gallery GF. (a) The internal wall and the exhibits facing the windows have good lighting, and the external wall and exhibits far from the windows have insufficient light. The windows creates glare and grabs eye attention. (b) A false colour image represents the luminance distribution for the previous photo. The luminance scale values are in cd/m2: Approx. white 646, yellow 200, orange 100, red 45, green 10, and blue 2. (External illuminance on the windows 2,9 klx)*

The big differences between windows illuminance occurred because the South Wing casts shadow on the West Wing and blocks out a big part of the sky, this affect mainly the first three windows. *(See "5.2.1.4.3 Digital model analysis")*

For a precise performance evaluation, we calculated the annual daylight availability (daylight autonomy) for 10 klx external illuminance before noon at every hour between 8:00 to 12:00; and 20 klx in the after noon at every hour between 12:00 to 17:00 according to annual daylight incident on the fourth window (middle of the west-facade).

The result shows that the external illuminance values incident on Window 4 annually exceed 10 klx for 48,7 % of the time between 8:00 to 12:00 and exceed 20 klx for 71 % of the time between 12:00 to 17:00. Unfortunately, the result is lower than expected, since the annual global illuminance on west facade show that the values are 88% between 8:00 to 12:00 and 85% between 12:00 to 17:00.(1) (Figure 5.147 and Figure 5.54) Nevertheless, the data show that the external illuminance exceeds 7,5 klx for 80 % between 8:00 to 12:00, which indicate that enhancing the performance of the system will extend the time of utilizing the daylight for about 31%; as well, a big part of the illuminance in the space will be dependent on daylight before noon. Generally, these values for some extent increase for northern windows and decrease for southern windows, as well increase between Mar - Oct and decrease between Nov - Feb. The temporal maps in (Figure 175) show more details about the daylight availability on the window 4.

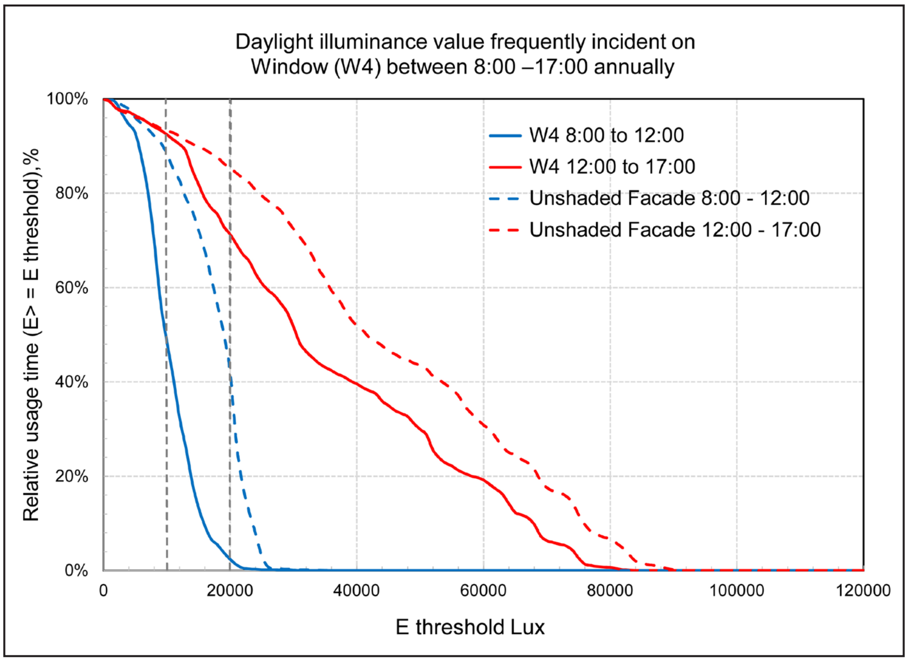


Figure 5.174 *Daylight illuminance values frequently incident on the west facade at Window 4 (continuous line) and Unshaded Facade (dashed line).*

1. Notes that: Window 4 is not located in the shadow of the South Wing and this differences are far too high to be caused only by blocking part of the sky from the window. We checked the simulation parameters of the two programs several times and most probably the differences lies in the mathematics of modelling the sky. We have to adopt the lowest value to be sure there will be no complications in applying the design in reality. Anyhow, conducting as well, a check up measurements in the location is needed to finally approve the design.

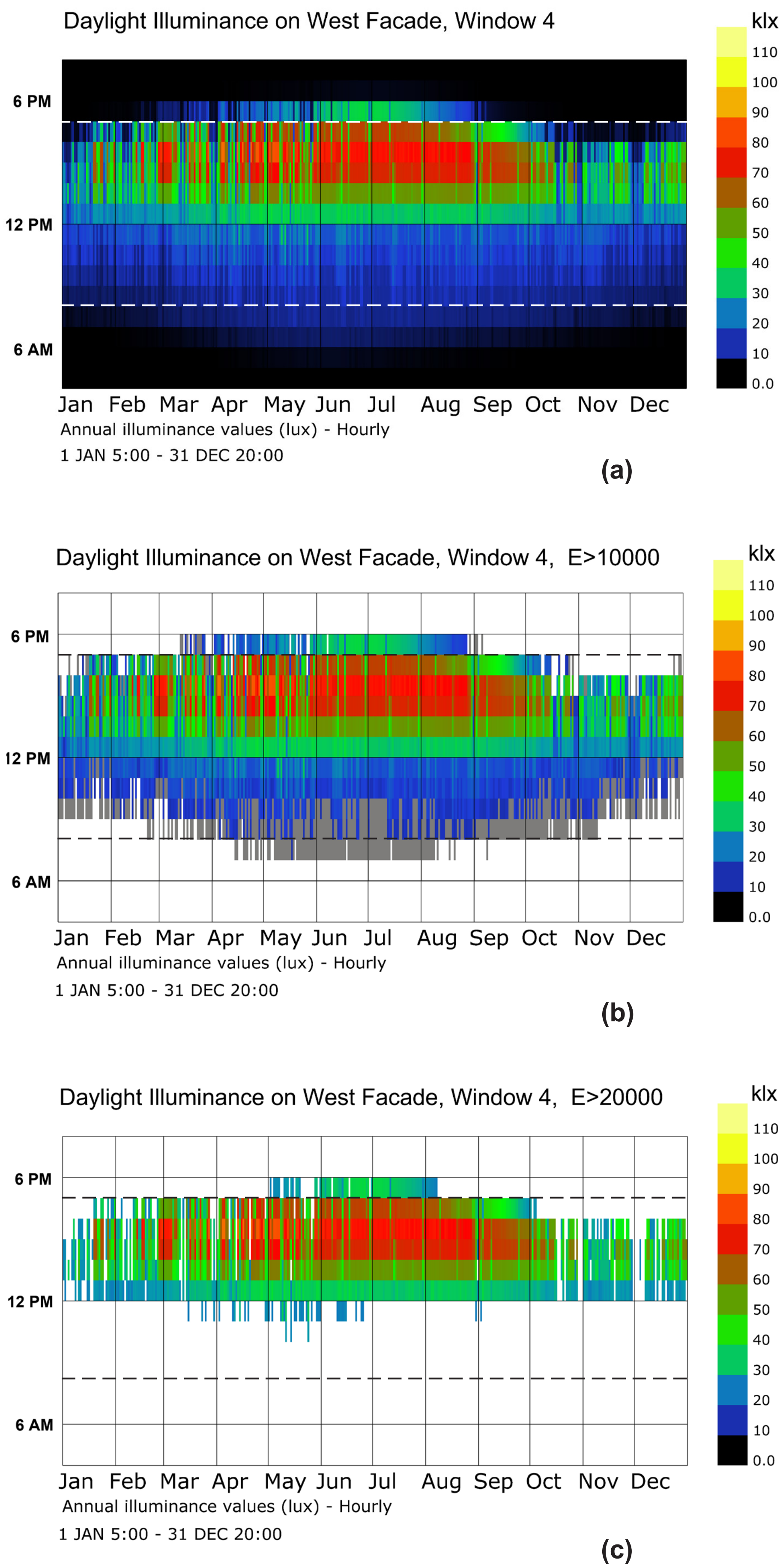


Figure 5.175 *A temporal maps for the daylight illuminance values incident on the Window 4 in the Lateral Gallery GF. (In the middle of the west facade) (a) The presentation of the entire values. (b) The presentation of values $E > 10$ klx. Notes: the gray colour represents the expansion of the data when $E > 7{,}7$ klx. (c) The presentation of values $E > 20$ klx.*

Although the proposed solution achieves a good visual quality for the space and exhibits, it do not reach the expected illuminance value for a long period of time due to the limitations of constructing it in the model. As well, the annual daylight simulation shows that in real conditio there will be a shortage of daylight before noon. Accordingly there is a two possibility to utilize this concept in real condition:

- First, if the design is fully applied without limitations, the daylight can be used as the main source for illuminating the space and the exhibits. In this case the daylight will be boost with artificial light when it recedes. This will require boosting the daylight ~ 40 % of the time at different levels. In addition, the free standing statues will be illuminated with spotlights to reach 550 to 800 lx. The result is a bright daylight atmosphere and high visual quality.
- Second, if the design is applied with the limitations, the daylight can be used as general illumination at stable low level and all exhibits will be illuminated with artificial light. A stable low level of general illumination can be achieved when external illuminance is 7,5 klx between 8:00 to 12:00 to exceed 80% of the time before noon and 15 klx between 12:00 to 17:00 to exceed 82% of the time in the after noon. (Figure 5.174) In this case, the adjustable mirrors (or the secondary reflectors) can be cancelled and instead of them there will be more flat reflectors to direct more light evenly on the walls. Thus, the reflective-ceiling will be easy to construct and it will have a simple form that fits more with the style of the old museum building, however the space will have a dim daylight atmosphere.

5.3.2.2.3.5 Notes on system performance

For further developing the system, a daylight simulation has to be conducted for every window accompanied with a temporal maps for the daylight illuminance values incident on that window.

As well, before finalizing the design and preparing constructions drawings a mock-up has to be built and a check up measurements in the location is needed to be taken.

5.3.3 Artificial lighting design for the Large Side Hall GF & UF

In our case the artificial lighting design is directly focused on how to fulfil the main lighting concept and to be fully blended with daylight. In general, the artificial lighting will be divided to room lighting (general illumination) and exhibit lighting.

5.3.3.1 The room lighting

In the Large Side Hall, the room lighting is not only concerned with the appearance and feeling of the space, but also with the appearance of the exhibits. Beside that the daylight illuminates the space; it works as exhibit lighting for the exhibits on the platform in the ground floor, and as a background lighting that supports the illumination of the relief in the ground floor and the showcases in upper floor. Accordingly, the artificial room lighting has to follow the daylighting concept and strategy.

See "1.2 Lighting strategies in museum" and "1.2.1.6 Daylight and artificial light integration"

5.3.3.1.1 General requirements

The general requirements of the artificial room lighting are:

- To have the same direction of daylight. This can be achieved be integrating the artificial light sources in the daylighting system or to mount them near the daylight system.
- To have the same distribution of daylight: In the ground floor the artificial lighting has to cover the entire platform in the middle of the space with 200 lx and to create a gradual distribution from the platform toward the walls. In the upper floor it has to have an even and soft light distribution on the four walls with average illuminance of 50 lx.

  See "5.2.6 General Lighting schemes", "5.2.6.3 Illuminance distribution", and (Figure 5.81).
- To have the same CCT of the daylight or not to show a big difference with it, all artificial light used in the design are 4000 k natural-white.

  See "1.1.7 Correlated Colour Temperature CCT"
- To boost and replace the daylight. Therefore all luminaires have to be dimmable and digitally managed. A digital light management system (e.g. DALI or DMX) connects the luminaires together with a sensor and automatically controls the level of illuminance in the space.
- To insure high rendering quality for the exhibits. Therefore all lamps will have a CRI values of 80 or greater.

  See "1.1.8 Colour Rendering"

- To insure the safety of the Exhibits. Therefore all luminaires will be with LED light sources and all SPD will be checked up for its potential of damage and be filtered between 400-700 nm.

  Generally, All safety precautions has to be taken to insure that artificial light will not harm the exhibits. See Chapter 3. Exhibits Conservation Aspects in Museum Lighting.

5.3.3.1.2 Proposed solutions for GF illumination

- **The main concept:** is to integrate a small LED luminaires with narrow beam angles and high intensity in the daylight system.
- **Technical Description:** After different digital calculations[1], we find that the best solution to reach the same daylight direction and distribution is to integrate a small LED luminaires with a narrow beam angle of ~20° between the CPCs of the daylight system.[2] Technically, expanding the gaps between the CPCs to ~ 10 cm will not alter the daylight distribution. Actually, this gabs will be filled with a U-profile steel channel, which will help to support the construction of the daylight system, as will carry the artificial lighting system. According to the daylight design we have 40 CPCs, and if we fixed one luminaire at every corner we will have 55 luminaires in the ceiling. For our design we used 45 luminaires. Generally, the luminaires can be positioned anywhere in the U-profile. (Figure 5.176, Figure 5.177 and Figure 5.183)

  The maximum luminous flux for every luminaire is 1000 lm. We used the 45 luminaire with luminous flux of 500 lm each, which gives total luminous flux of 22500 lm.

5.3.3.1.3 Proposed solution for UF illumination

- **The main concept:** is to mount linear LED Wall-Washers near the skylight's windows and illuminate the ceiling with the same intensity and distribution of the daylight controlled by the louvres. The reflected light from the ceiling will create the room lighting for the UF level and will add some light to the GF level. (Figure 5.183)
- **Technical Description:** Every linear LED Wall-Washer is one meter tall and ~4 x 8 cm in the cross section. They are surface mounted, as well they can be semi-recessed. The Wall-Washer beam angle is ~75°. (Figure 5.178)

  The maximum luminous flux for every luminaire is 7200 lm. We used the 32 luminaire with luminous flux of 2500 lm each, which gives total luminous flux of 80000 lm.

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1. All calculations made for the artificial lighting is made by Relux 2016. Relux is a high-performance, intuitively operated application for simulating artificial light and daylight. The program is free online.
2. All used Luminaires in the calculations are real products in the market. We intentionally did not show the name of the luminaires or their images to keep your scientific work away from advertising.

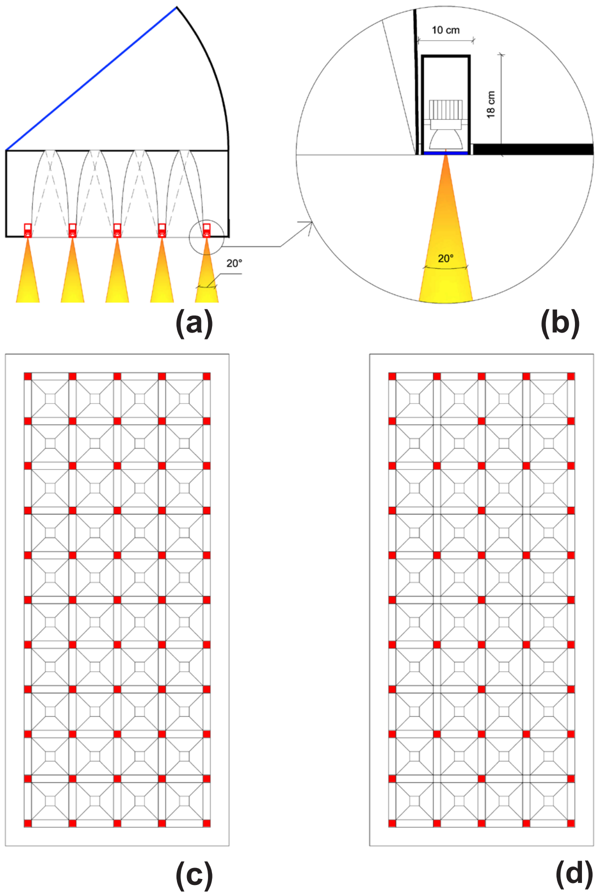
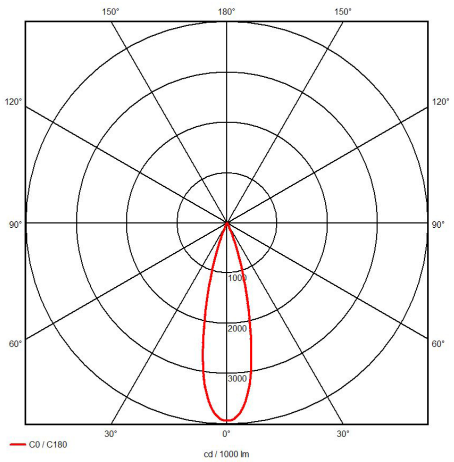
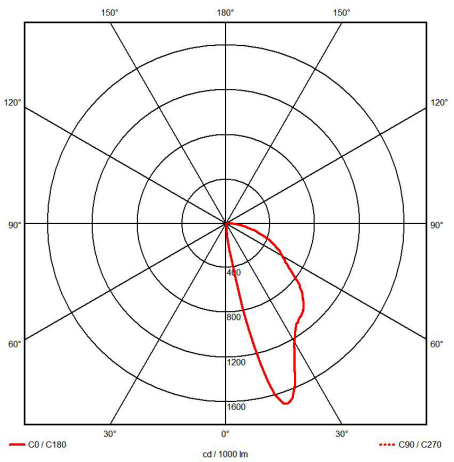


Figure 5.176 *Integrating LED luminaires in the daylight system for GF room lighting. (a) A cross section in the daylight system shows the position of the LED luminaires between the CPCs. (b) Detail shows the U-profile steel channel that supports the construction of the daylight system and carries the artificial lighting system. (c) The 55 luminaires positions. (d) The 45 used luminaires positions for the design.*



	C0	C90	C180
0°	3926	3926	3926
5°	3689	3689	3689
10°	2794	2794	2794
15°	1543	1543	1543
20°	655	655	655
25°	197	197	197
30°	74	74	74
35°	45	45	45
40°	28	28	28
45°	16	16	16
50°	8	8	8
55°	2	2	2
60°	0	0	0
65°	0	0	0
70°	0	0	0
75°	0	0	0
80°	0	0	0
85°	0	0	0
90°	0	0	0
	cd / 1000 lm		

Figure 5.177 *The Light Distribution Curve (LDC) generated by the Eulumdat of the 20° spot light used to generate the GF room lighting.*



	C0	C90	C180
0°	1	1	1
5°	40	1	0
10°	470	1	0
15°	1468	0	0
20°	1694	0	0
25°	1466	0	0
30°	1227	0	0
35°	1104	0	0
40°	1059	0	0
45°	982	0	0
50°	859	0	0
55°	693	0	0
60°	581	0	0
65°	492	0	0
70°	389	0	0
75°	280	0	0
80°	181	0	0
85°	87	0	0
90°	33	0	0
	cd / 1000 lm		

Figure 5.178 *The Light Distribution Curve (LDC) generated by the Eulumdat of the Wall-Washer used to generate the UF room lighting.*

5.3.3.1.4 Calculations and results

The distribution and values of light in the space show a high similarity with that of the daylight systems. As well, the luminaires have the capacity to increase or decrease the light output thus boosting the daylight at any level, or replacing it completely.

At height of 150 cm from ground floor level the average illuminance is E_{av} 133 lx; where the platform is covered with 200 - 250 lx and the illuminance is graded to 50 - 75 lux at the walls. In the upper floor, the walls have E_{av} 46 lux with a very good uniformity of E_{min}/E_{av} 1 : 2,73 and E_{min}/E_{max} 1 : 3,97; and the floor in front of the showcases has E_{av} 75 lx. (Figure 5.179 and Figure 5.180)

The false colour image for the luminance distribution show a high level of similarity with the daylight distribution. In general, the artificial room lighting achieved the same light atmosphere that is created with the daylight systems. See (Figure 5.181 and Figure 5.182).

(Compare with Figure 5.140 and Figure 5.41)

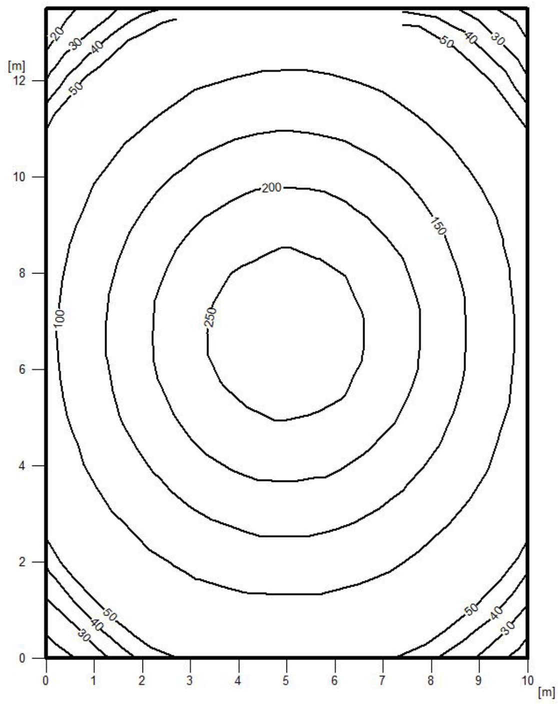


Figure 5.179 *Isoline diagram shows the illuminance distribution of the room lighting in the Large Side Hall GF. The measurement surface is horizontal at 150 cm from floor level. E_{av} : 133 lx, E_{max} : 274 lx E_{min} : 13 lux (Compare with Figure 5.23 and Figure 5.132)*

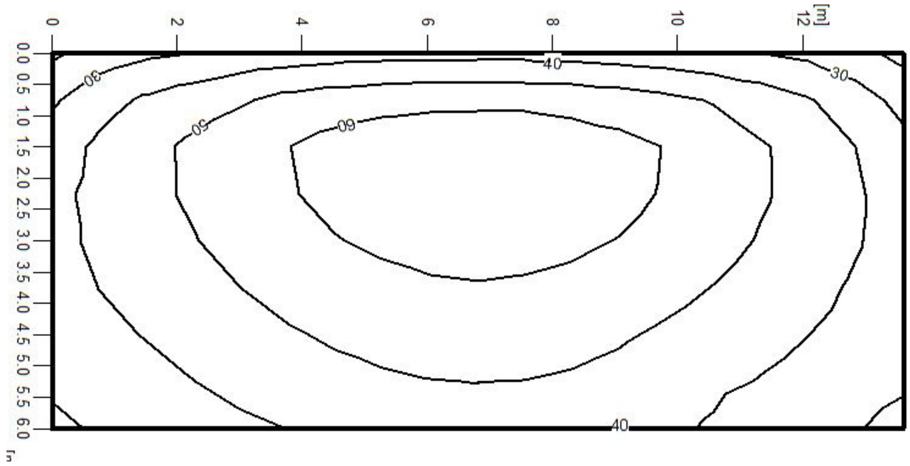


Figure 5.180 *Isoline diagram shows the illuminance distribution of the room lighting on the south-wall of the Large Side Hall UF. E_{av} : 46 lx, E_{max} : 67 lx E_{min} : 17 lux*

Figure 5.181 *A ray tracing rendering shows the room lighting distribution created with the artificial light in the Large Side Hall GF & UF. The ray tracing rendering are generated by Relux software. (Compare with Figure 5.140)*

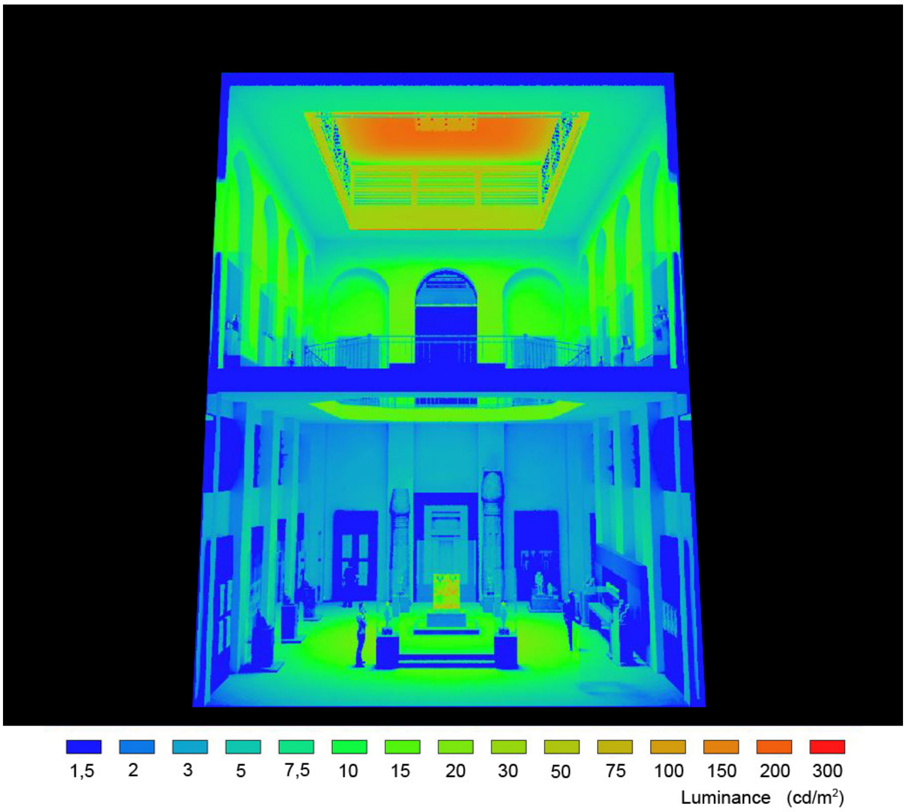


Figure 5.182 *A false colour image represents the luminance distribution for the previous rendering of the Large Side Hall GF & UF. The false colour image is generated by Relux software. (Compare with Figure 5.41)*

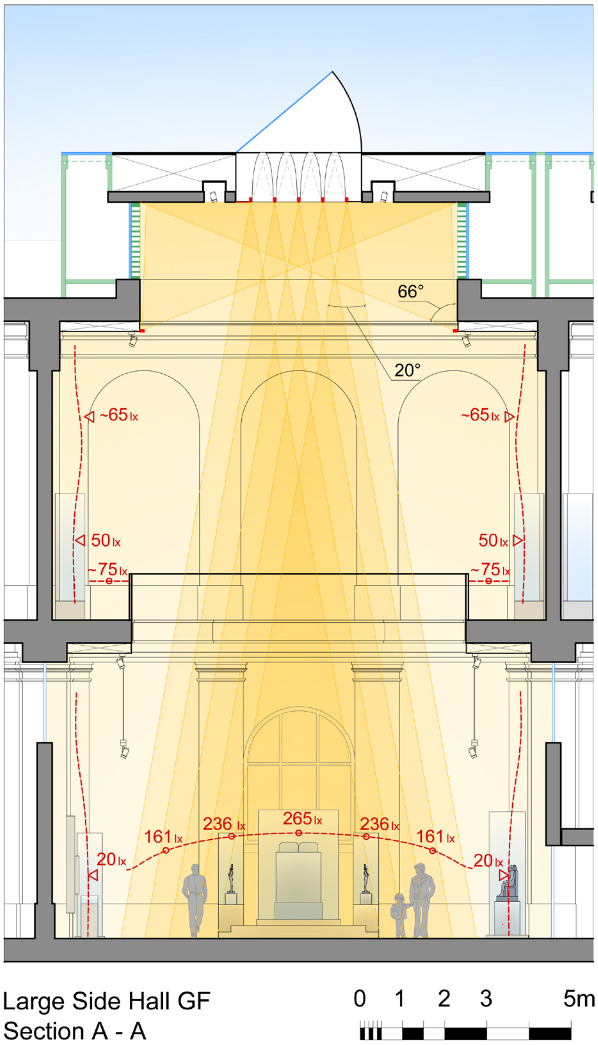


Figure 5.183 *Section A-A shows the artificial room lighting in the Large Side Gallery GF & UF.*

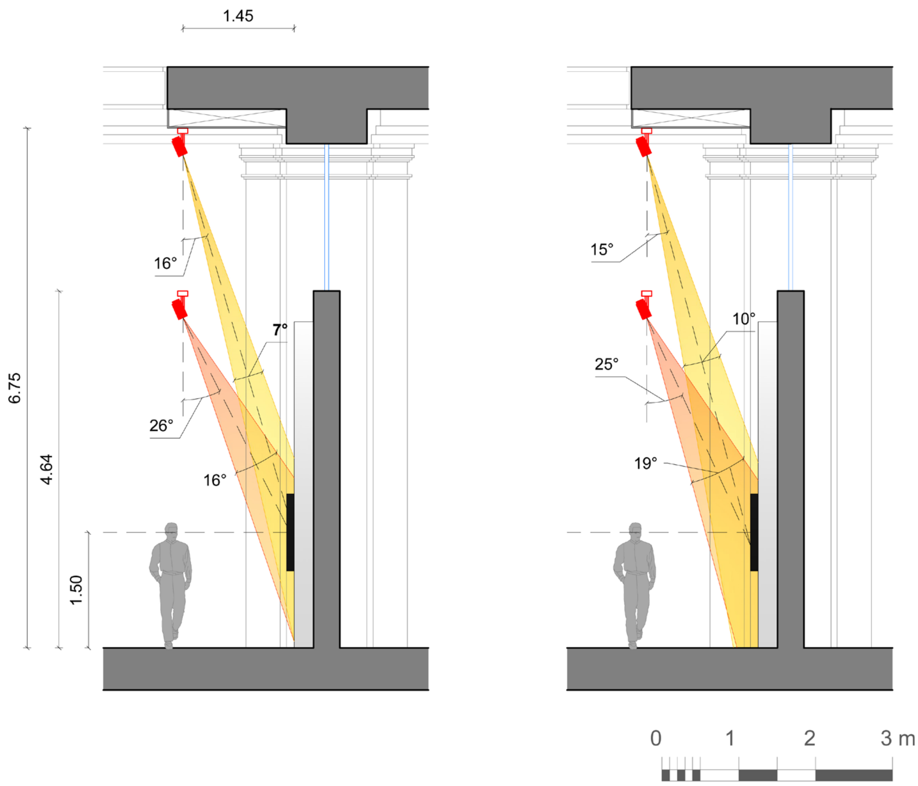


Figure 5.184 *Artificial lighting for the reliefs. The drawing shows the positions and angles of spotlights needed to light 1 m² vertical flat object on the walls of the Large Side Gallery GF.*

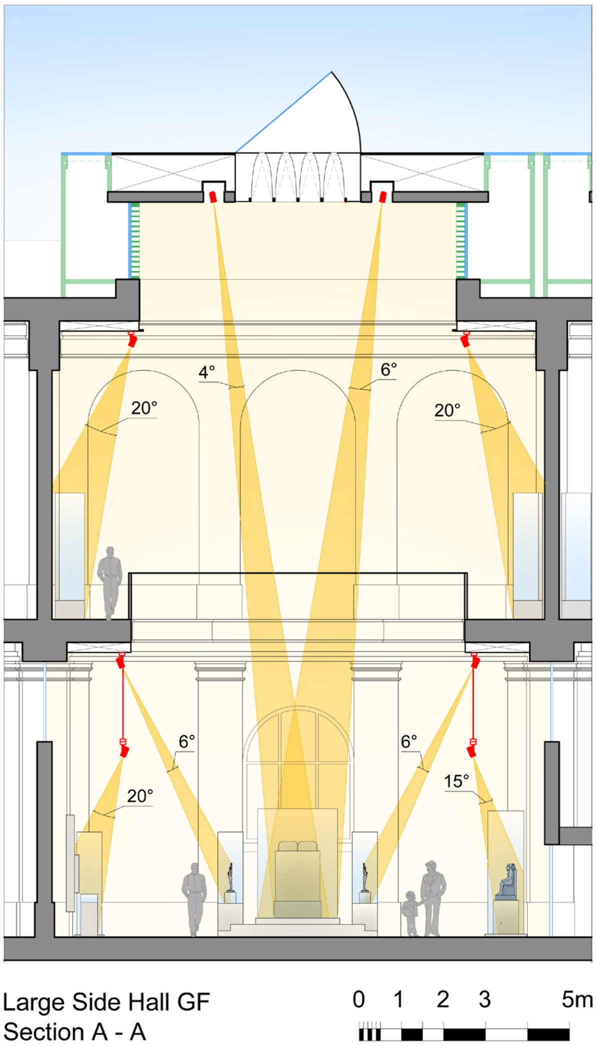


Figure 5.185 *Section A-A shows the artificial exhibit lighting in the Large Side Gallery GF & UF.*

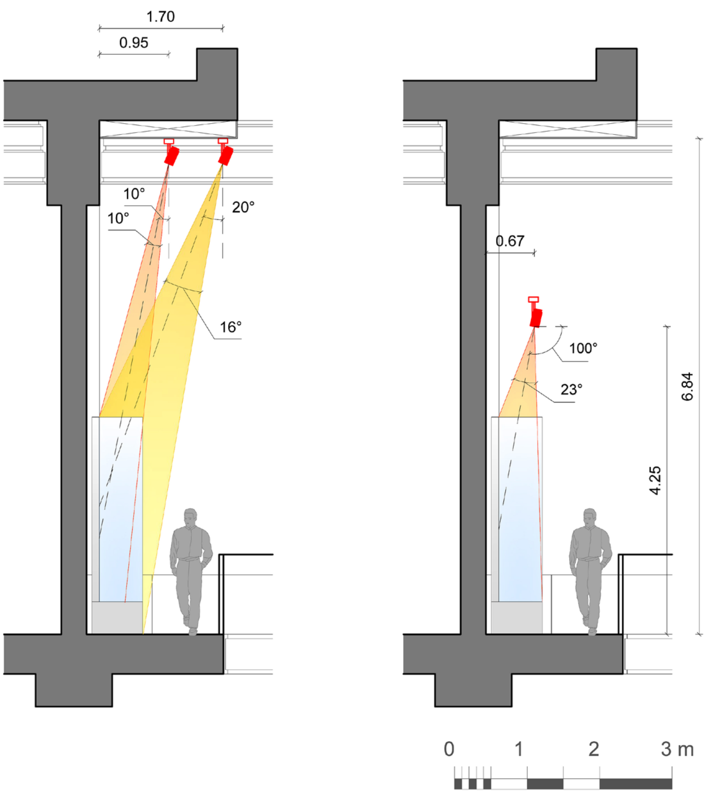


Figure 5.186 *Artificial lighting for the showcases. The drawing shows the positions and angles of spotlights needed to light the entire showcases in the Large Side Gallery UF.*

5.3.3.2 The exhibit lighting

There are different strategies to illuminate exhibits according to their types, materials, colours, methods of display, etc. We here are only proposing the general configuration of the luminaries that can be used in lighting the exhibits in the Lateral Side Hall GF & UF.

For more details see "1.2.2 Artificial lighting strategies" and "1.3 Exhibits lighting quality and techniques"

5.3.3.2.1 General requirements

The general requirements of the artificial exhibit lighting are:

- All luminaires will be with LED light source and all SPD will be filtered between 400-700 nm and checked up for its potential of damage to insure the safety of the exhibits.
- All spotlights will have CCT of 4000 k natural-white to be mixed with daylight without showing any colour disharmony.
- All lamps will have a CRI ≥ 80 to insure high rendering quality.
- All luminaires have to be dimmable and digitally managed to be easy adjusted to its task and to help creates different atmosphere.
- All luminaires, especially spotlights, have to be provided with a large number of accessories to ensure total control on the beam angle, the SPD, and intensity.
- The luminaire system has to be very flexible to suit different displays.

5.3.3.2.2 Proposed solutions

The proposed system is simply a power-track systems with LED spotlights for both the ground floor and upper floor. The power-tracks are mainly mounted on the ceiling and it can be suspended if spotlights needed to be close to the exhibits. The spotlights have to be very simple in style so they do not interfere with the appearance of the artefacts and the interior. As well, a small suspended ceiling (depth ~ 20-30 cm) has to be built to conceal the speakers, emergency lights, cleaning lights, security cameras, etc. This configuration is flexible and easy to be used in other galleries and to fit with different displays. Further, to illuminate the exhibits in the middle of the space there are spotlights mounted on the man gallery ceiling around the daylight system. The spotlights are mounted in a recessed channel to be concealed and do not disturb the appearance of the ceiling. (Figure 5.185)

From a quick study to know the required beam angles, we found that:

- In the ground floor, the beam angle of the spotlights needed to cover a 1 m^2 flat object on the walls range between 7° to 15° for spotlights mounted on the ceiling and between 16° to 19° for spotlights on low suspended tracks. (Figure 5.184) *See "1.3.3.1 Flat displays"*
- In the upper floor, the beam angle of the spotlights needed to cove the entire showcase range between 10° to 16° for spotlights mounted on the ceiling and about 35° for spotlights on low suspended tracks. (Figure 5.186)
  See "1.3.3.3 Showcase" and "5.2.5.2.2 The Large Side Hall UF"

- In general, a narrow beam spotlight will strongly highlight the exhibits; while a wide beam spotlight with soft edges will light the exhibits with a big part of the walls around it and it will create a smooth, homogeneous appearance that can easily blend with room lighting.
- In all cases, accessories for spotlight are required to shape of the beam and block out the light from areas where it is not wanted.

5.3.3.3 Lighting atmosphere

As we finished the design of both the room lighting and exhibit lighting, a light simulation in a form of a ray tracing rendering images will be helpful to show how the space will look like; however, such graphics has its limitation and can not be considered the real image of the space. In later steps of developing the design the luminaires have to be tested in a mock-up or/and in the real location to approve their lighting effects.

We conducted a ray tracing rendering with Relux software for the following cases:

5.3.3.3.1 Moderate atmosphere

The moderate atmosphere is the original settings we planned, where the room lighting can be achieved with either the daylight or the artificial light independently, or with a mix of both of them. In the lighting simulation here, the room lighting is achieved only with artificial light.

- **Illuminance levels:**

  The room lighting is adjusted to have the same value and distribution of daylight systems. *(See "5.3.3.1.1 General requirements")*

  In the ground floor the exhibits are illuminated as follow:

  - The reliefs on the walls are illuminated with 10° spotlights to reach E_{av} ~ 200 lx. (Figure 5.197)
  - The masterpiece in the centre is illuminated with room lighting that is integrated in the chamber system and two spotlights mounted on the skylight ceiling. The purpose of the extra two spotlights is to rase the vertical illuminance of the statue. Eventually the masterpiece reach E_{av} ~ 250 lx. (Figure 5.179)
  - The free standing small statues are illuminated with 6° spotlights to reach E_{av} ~ 600 lx.
  - Painted fresco are illuminated with asymmetric 15°/60° spotlight to reach E_{av} ~ 100 lx.
  - Architectural elements are illuminated with 30° spotlights to be bright at the top and soft illuminated at the bottom.

  In the upper floor, the artifacts in the showcases are illuminated with 15° spotlights to reach E_{av} ~ 200 lx. (Figure 5.198)

In general, both the room lighting and the reflected light from the exhibits are mixed together in the space and raise the level of illuminations. Accordingly, at height of 150 cm from ground floor level the average illuminance is 221 lx; and in the upper floor the average illuminance on the floor in front of the showcases is 122 lx.

- **General Notes:**

Every exhibit is illuminated with one spotlight mounted on the ceiling. One spot is enough in case the statues is small and room lighting is bright, however, in real museum a lot of artifacts and the showcases will need more than one spotlight.

The illuminance value of the exhibits are the product of the room lighting and exhibit lighting together.

The mentioned values E_{av} are the average illuminance on the coverage area. (Figure 5.197 and Figure 5.198)

The uniformity of the illuminance can be higher if the beam angle is large, pointed at the bottom of the object, and the unwanted light is shaped of with accessory such as barn-doors.

Illuminance uniformity on flat object is easy to be achieved, while it is difficult, or perhaps cannot, be achieved on three dimensional objects; because the more the surface is facing the light, the more illuminance he receives.

In our rendering all reliefs and showcases are illuminated with 200 lx; however, according to the results of the visual perception experiments in Chapter 4, to perceptually optimized the artifacts' appearance in real museum luminance values for every artifact have be adjusted according to its luminance and colour relationship with the background. (Table 4.2 to Table 4.4) Of course these value is a result of a lab experiment and have to be tested in real museum before it be put in practice, however it serves as a reliable approximations.

- **Results:**

In general, the room lighting is moderate and the exhibits appear brighter than the surrounding. The exhibit lighting highlights the exhibits, and the room lighting fill in the form-shadows and attenuate the cast-shadows of the exhibits. (Figure 5.187)

The exhibit lighting fit with the artifacts, nevertheless some of the reliefs lighting need to be shaped of to be limited only to the relief and its near surrounding. Unluckily this can not be done in a computer simulation. (Figure 5.191)

The lighting effect that is generated in the middle of the ground floor to imitate the effect of the daylight system, is tempered and no longer noticeable because of the reflected light from the exhibits. Thus to maintain this effect level of illuminance has to be higher in the centre or the distribution has to be more centralized. Compare (Figure 5.140 with Figure 5.187) and (Figure 5.141 with Figure 5.188).

The room lighting in the upper floor is moderate, soft, and even on the walls. The showcase lighting blend in with the room lighting and there is no strong border between them. (Figure 5.194)

5.3.3.3.2 Dramatic atmosphere

The dramatic atmosphere depends only on the exhibit lighting where the room lighting is totally absent. (Figure 5.189, Figure 5.192, and Figure 5.195)

- **Illuminance levels:** is the same as in the previous moderate atmosphere without the exist of the room lighting.
  - All exhibit and showcases have the same exhibit lighting, except for the masterpiece in the centre. The masterpiece has four spotlights two from the front and two from the back. Its illuminance E_{av} ~250 lx. (Exactly it has 330 lx at height of 150 cm and 200 lx at height of 75 cm from ground floor level).
  - At height of 150 cm from ground floor level the average room lighting is E_{av} 88 lx; and in the upper floor the average room lighting on the floor in front of the showcases is 47 lx.
  - The upper parts of the walls in both the ground and the upper floor have average luminance of 3 cd/m^2, equal to average illuminance of 14 lx, which is considered very dark.
- **Results:**

In general, the exhibits are strongly highlighted, and the reflected light from the exhibit is enough to show the visitors their way in the gallery. However, the absence of room lighting will make visitors not able to perceive the room dimension and stay longer in the room. As well, the exhibits shadows will be very dark and it will obscure a lot of exhibits' details.

5.3.3.3.3 Focal atmosphere

The focal atmosphere depends on low room lighting levels and focusing more light on the platform to drag the attention to the centre of the space. (Figure 5.190, Figure 5.193, and Figure 5.196)

To focus more light on the platform and the masterpiece only 21 of the integrated spotlights in the centre of the chamber system is turned on, so the light will not spread outside of the platform. This can be created as well with the daylight system, if only the 20 CPCs in the middle are controlled to bring more light and the light of the CPCs at both sides are dimmed or closed.

- **Illuminance levels:**
  - All exhibits and showcases have the same exhibit lighting that we used previously in the moderate atmosphere, except for the masterpiece in the centre. After focusing the 21 spotlights on the centre (without any extra spotlights) the masterpiece has E_{av} 750 lx and the platform has E_{av} 500 lx.

Figure 5.187 *The moderate atmosphere in the Large Side Hall. The room lighting is moderate and the exhibits appear brighter than the surrounding.*

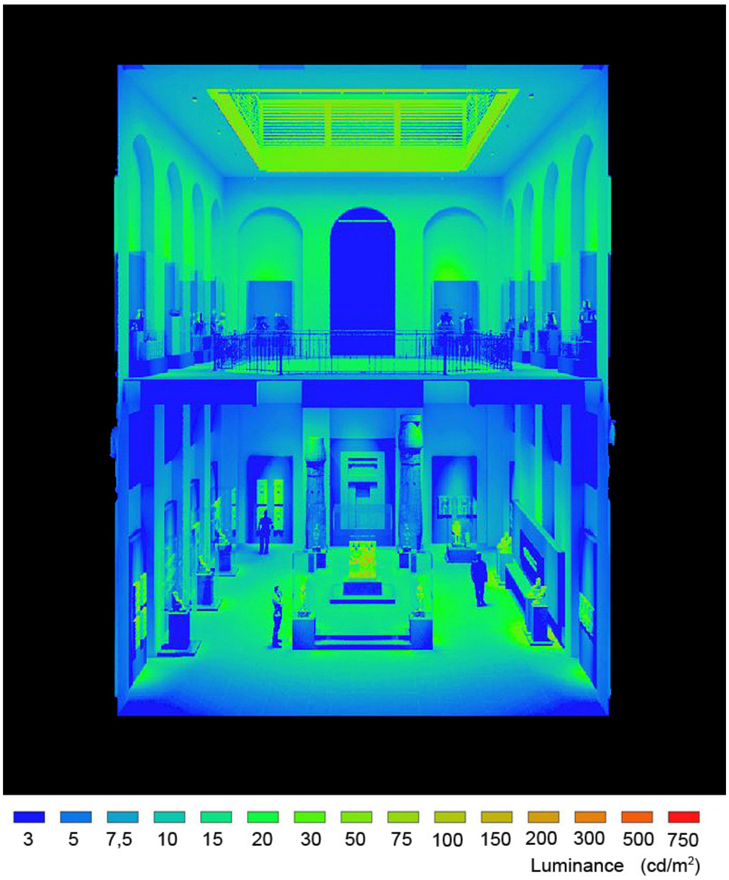


Figure 5.188 *A false colour image represents the luminance distribution for the previous rendering of the Large Side Hall GF & UF.*

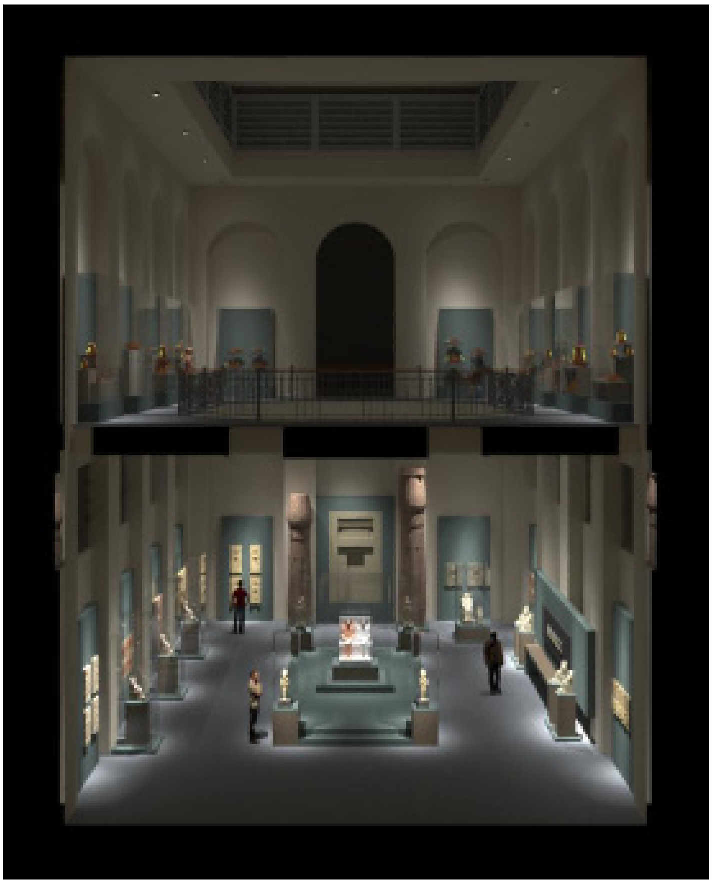


Figure 5.189 *The dramatic atmosphere in the Large Side Hall. The atmosphere depends only on the exhibit lighting where the room lighting is totally absent.*

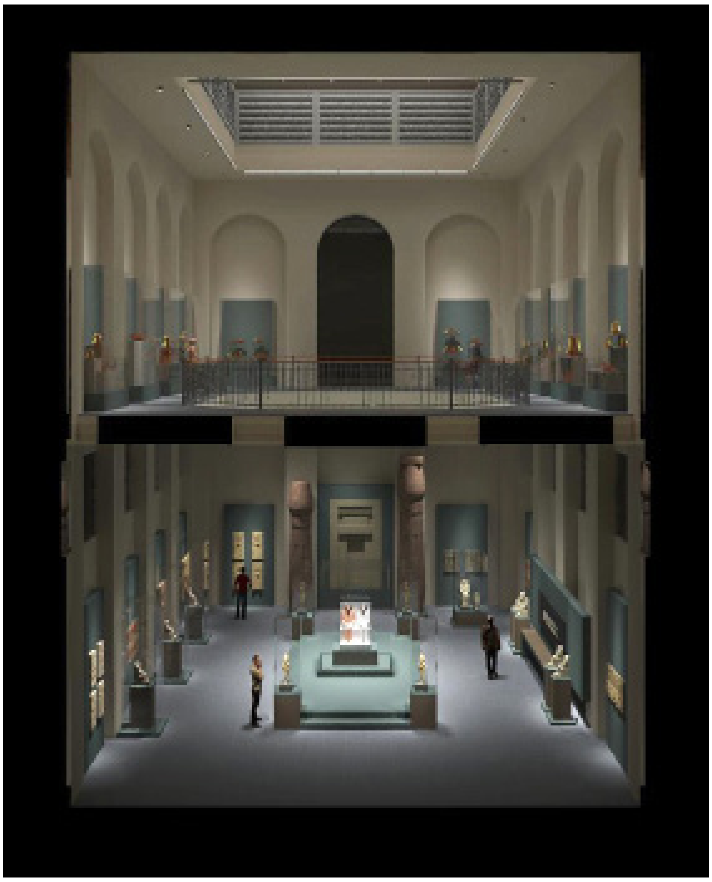


Figure 5.190 *The focal atmosphere in the Large Side Hall. The atmosphere depends on low room lighting and focusing more light on the platform.*

Figure 5.191 *The moderate atmosphere in the Large Side Hall GF. The exhibit lighting highlights the artifacts and makes them brighter than the surrounding.*

Figure 5.192 *The dramatic atmosphere in the Large Side Hall GF. The reflected light from the exhibit is enough to show the visitors their way in the gallery. However, the walls are dark.*

Figure 5.193 *The focal atmosphere in the Large Side Hall GF. The high brightness of the masterpiece and the platform creates a focal point in the centre of the space, that drags visitors attentions and gives the masterpiece a superior appearance among the exhibits.*

Figure 5.194 *The moderate atmosphere in the Large Side Hall UF. The light is soft and even on the walls and the showcase lighting highlight the exhibits and blend with the room lighting.*

Figure 5.195 *The dramatic atmosphere in the Large Side Hall GF. There is enough lights in front of the showcases, however the walls and the ceiling is dark and visitors can not see the architecture of the gallery.*

Figure 5.196 *The focal atmosphere in the Large Side Hall UF. The room lighting is reduced so it will not affect the appearance of the masterpiece and the platform in the ground floor. (Compare with Figure 5.194)*

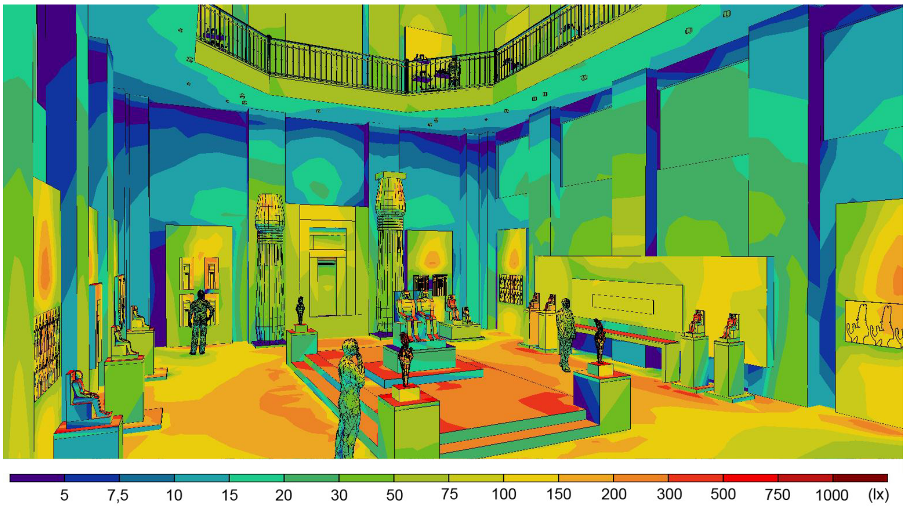


Figure 5.197 *The illuminance distribution for the moderate atmosphere in the Large Side Hall GF.*

- At height of 150 cm from ground floor level the average illuminance is 350 lx; where the platform is covered with 500 - 750 lx and the light is graded to 20 - 75 lux at the walls.
- In the upper floor, the upper parts of the walls have E_{av} 20 lx, and the average illuminance of the floor in front of the show-cases has E_{av} 70 lx.

- **Results:**

In general, the room lighting is dim and the centre of the space is more brightness than the surrounding. The exhibits are well illuminated and the masterpiece are strongly highlighted.

The high brightness of the masterpiece and the platform creates a focal point in the centre of the space, that drags visitors attentions and gives the masterpiece a superior appearance among the exhibits. This sittings adds majesty to the master pice and the space, and makes the display more attractive.

Of course, illuminance level of 750 lx for a coloured statue exceeds the conservation illuminance limits; however, this setting can be adopted to other galleries where the masterpiece is irresponsive to light. (e.g. the funerary statue of the Pharaoh Khafre that centre the gallery 42 in the west wing).

Reducing the room lighting in the upper floor makes the whole space dim and that promote the appearance of the masterpiece and the platform in the ground floor.

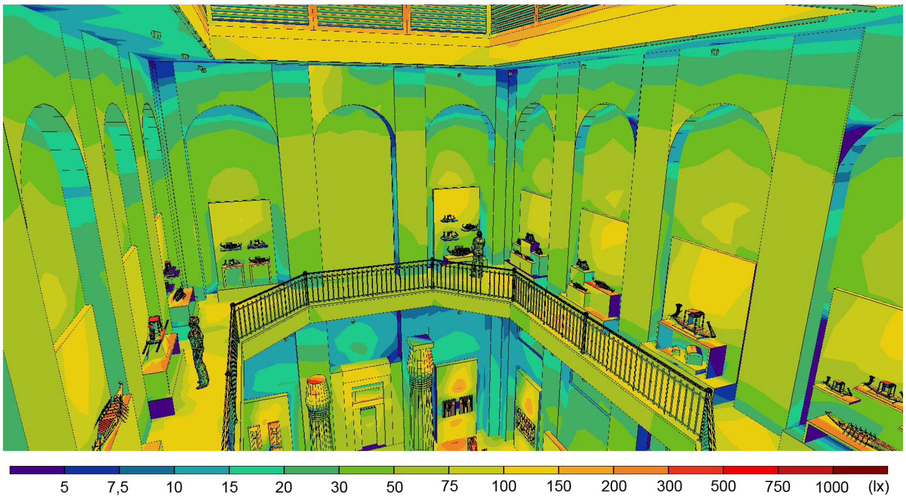


Figure 5.198 *The illuminance distribution for the moderate atmosphere in the Large Side Hall UF.*

5.3.3.4 Notes on the artificial lighting design

All 3D exhibits used in the rendering are a simple models that only occupied and represent the artifacts in the gallery, and they cannot show the real effect of lights on the artifacts. The actual choice of the luminaries has to be done after testing the their lighting effects on artifacts replicas or on the real artifacts in the museum.

In general, rendering images give a good indication about how the space will appear, but they cannot be considered a full representation of the final lighting product.

The concept of the room lighting in the upper floor can be adopted in other spaces with skylights. Perhaps in small galleries it is more practical to have two sets of wall-washer on illuminate the ceiling and the other illuminate the upper parts of the walls. This will give more control on the light levels and the appearance of the space, however, it will required more luminaires.

Unfortunately, the space of the research can not fully cover all spaces in the museum, however the concepts of daylight and artificial light we presented cover a large part of the museum.

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Conclusions

Museum lighting design has a different aspects that have to be optimized and harmonized together to create a good lighting quality. The aspects mainly concern the level of illumination that insure a good visual performance, the strategy of lighting (daylight and artificial light) in the space, and the artifacts' lighting quality and conservation aspects. These study addressed these aspects as an attempt to promote the knowledge in this field and formulate a set of guiding principles for the concept of lighting in Egyptian’s museums spaces.

The study shows that, a lighting design concept for the Egyptian museum spaces can be achieved by understanding the Egyptian artifacts' aesthetics and cultural background. This study leads to three main items for the lighting design concept:

- creating a pattern and quality of daylight for the artifacts.
- creating a majesty and sacredness lighting atmosphere in the space.
- maintaining a visual identity of lighting for the artifacts.

Of course, these items have to be achieved while taking into account the museum standards for lighting and conservation aspects.

In Egypt, where the sunshine probability is 80%, daylight can be a very powerful tool in lighting a museum. Most of daylight systems depend on blocking the direct sunlight and benefit from the skylight. The study shows that with the newly available technology of controlling daylight a new system can be developed to utilize the powerful direct sunlight. This was confirmed with the daylighting system we developed for our case study. The newly developed systems have a high control on daylight, utilize both direct sunlight and diffuse skylight, achieve a good illumination, and create majesty and sacredness lighting atmosphere in the space.

The lighting design concept for research case study, the West Wing in the Egyptian Museum in Cairo, is a real practical study based on the existing building condition and real weather data of Cairo. The study leads to an efficient daylight- and artificial-lighting solutions, and a new modern interior design concept that can be a good base for a real renovation project to enhance the Egyptian museum.

Deep in the practice of museum lighting, the study of the conservation aspects shows that: In general, LEDs induce less damage to sensitive-to-light artifact than halogen and fluorescent lamps. In precise, it is recommended to conduct a spectrum analysis for the lighting sources to know its potential of damage before using it in lighting sensitive-to-light artifacts.

As part of our study, we analysed and compared the damage potential of 27 frequently used museum light sources. The results of this analysis can be used as a reference in the selection of light sources for sensitive-to-light material in museum applications.

The micro-fading test is a very important tool to assess the colour-fading state of a material and its sensitivity to light. By knowing the results of a micro-fading test and the potential of damage from a light source a museum can accurately plan its display policy for lighting and displaying sensitive-to-light artifacts.

To experience and test the lighting levels in museum practice, we conduct a series of visual perception experiment in a physical model and a mock-up. The experiments show that standard and norms values are general guidelines that cannot cover all lighting situations. The results' data of our experience can be used as a guideline for museum lighting levels in practice and help understanding the brightness relation between an object and its background.

General Recommendations

We conducted a series of visual perception experiments to study exhibits' illuminations level and the brightness relation between an object and its background. These experiments are a pilot laboratory studies conducted with a limited number of observers (three persons), thus they need to be repeated in real museum for several times to verify its findings.

The luminance environment effects the vision quality of the visitors, the duration of staying in the museum, the degree of enjoying the display, the feeling of the space, and the appearance of the artifacts. Such aspects cannot be fully experimented and judged in the laboratory, thus museum authority has to be aware of the important of studying these aspects and be involved in conducting experiments in these fields.

Preserving the artifacts from photochemical damage is a very important aspect in museum lighting. The study shows that, to select the right luminaire, we have to determining the damage potential of its light source and how it will affects the museum material. These are a very complicated processes. Several procedures can help facilitated these processes:

- Extending the range of data that describe the sensitivity of museum's materials to light. (The material relative spectral responsivity function).
- Obligate the museum-lighting manufacturers to issue the important conservation data for every product like: the UV measurements, Spectrum Power Distribution for light source, etc.
- Every museum authorities have to conduct a Microfading Tests for sensitive-to-light artifacts in the museums and to build its own data base.

There are a lot of museums that display the Egyptian artifacts around the world. It will be useful if these museums cooperate together to build a conservation database for the Egyptian artifacts, to create a common standards, and maintain a visual identity for lighting the Egyptian artifacts.

The development of the museum's daylight systems by utilizing the direct sunlight shows a high performance. This indicates a good potential of using this systems in other applications and further developing this concepts to enhance the building condition in Egypt or any other sunny countries.

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Appendix

Appendix 1. Additional information on chapter 3

1.1 UV Data from indicated published sources[1]

Relative UV Portion of the Total UV and Visible Radiation (product measurements).

Data are from the indicated published sources, UV is the flat-weighted emission between 300 and 400 nm wavelength. UV percent is the ratio of UV (300-400 nm) to the flat -weighted emission between 300 and 700 nm (UV plus visible). Brackets indicate interpolated data.

#	Light Source	UV (µW/lm)	UV (percent)
	Incandescent and halogen		
1	CIE Source A inc. (2850 K)	75	1.7
2	500-W incandescent (2950 K)	78	1.8
3	Q1000T3/CL + glass	80	1.8
4	Q1000T3/CL (3000 K)	100	2.3
5	5Q500T2.5/2CL (photocopy)	130	3.1
6	100-W Halogen + glass (3360 K) [a]	130	3.4
7	100-W, 12-V Halogen (3360 K) [a]	185	4.6
	Fluorescent		
8	3500 K (unspecified phosphor)	53	1.7
9	soft white	63	1.7
10	4500 K (unspecified phosphor)	72	1.7
11	daylight	93	1.7
12	Philips 37	60	2.2
13	white 3000 K (unspecified phosphor)	107	3.8
14	cool white (high output)	125	4.0
15	coolwhite (F40MM)	125	4.0
16	coolwhite (F40)	170	5.0
	MetalHalide		
17	MV400	330	9.0
18	250W Osram HQUL	420	11.2
19	MV250	630	16.0
20	MH175 (Metalarc)	800	20.0
	Daylight		
21	daylight + glass	275	6.7
22	daylight (5500 K)	350	8.3
23	overcast sky + glass	410	9.5
24	overcast sky (6500 K)	540	12
25	summer sun/sky + glass	720	17

Footnotes: (a) This high colour temperature short-life lamp for photographic or stage-studio use is not typical of halogen-incandescent sources used for display lighting.

Table 6.1 *Relative UV portion to the UV plus visible radiation and UV percentage in SPD of light sources (data from indicated published sources). (Museum and art gallery lighting a recommended practice, IESNA,p19)*

1. Frank A. Florentine Chair, Museum and art gallery lighting a recommended practice, IESNA, RP-30-96, 1996, New York, USA, p19.

1.2 UV Data from product measurements[1]

Relative UV Portion of the Total UV and Visible Radiation (product measurements).			
Data are measured for several current products that may be used for display lighting. UV is the flat-weighted emission between 300 and 400 nm wavelength. UV percent is the ratio of UV (300-400 nm) to the flat -weighted emission between 300 and 700 nm (UV plus visible).			
#	**Light Source**	**UV (μW/lm)**	**UV (percent)**
	Incandescent and halogen		
A	50-W halogen MR16 (dichroic) (with glass cover)	36	0.9
B	50-W halogen MR16 (dichroic) (without glass cover)	38	0.9
C	50-W halogen MR16 (aluminized) (with glass cover)	95	1.9
D	50-W halogen MR16 (aluminized) (without glass cover)	108	2.1
E	90-W halogen PAR38	67	1.4
	Fluorescent		
F	2700 K compact (F26DBX/T4/SPX27)	80	2.0
G	cool white (F40/CW) (a)	140	3.6
H	3000 K HI CRI (F40/SP30) (b)	130	3.9
I	3000 K HI CRI (F40BX/SPX30/RS) (b)	140	4.6
J	3000 K HI CRI (F40/AX30) (c)	150	4.7
K	27OO K compact (F13BX/SPX27) (c)	280	8.3
Footnotes: (a) halophosphate single coat (b) triphosphor and halophosphate base coat (c) triphosphor single coat.			

Table 6.2 *Relative UV portion to the UV plus visible radiation and UV percentage in SPD of light sources (product measurements). (Museum and art gallery lighting a recommended practice, IESNA,p20)*

1.3 Historic Pigments and Their Lifetimes (Permanence) for Various Light Intensities[2]

Historic Pigments and Their Lifetimes (Permanence) for Various Light Intensities										
		PERMANENT	I DURABLE		I INTERMEDIATE		I	FUGITIVE		
	ISO	8	7	6	5	4	3	2	1	
carbon blacks		Cadmiums*	•		alizarin (madder) lake		•	Carmine lake		
ultramarine		•	•	full	half	tint	•	gambage***		
ochres, umbers		•	•	•	•	•	•	quercitron lake***		
iron oxides		•	Vermilion	•	•	•	•	•	•	
terre verte		•	•	•	•	•	carmine	•	•	
azurite		•	•	•	•	full	tint	•	•	
CS 98-62 Class I**		•	•	•	•	•	•	•	•	
ASTM D4303 Class I**				•	•	•	•	•	•	
		30	10	3	1	•	•	•	•	@10000 lx
		300	100	30	10	3	1	•	•	@1000 lx
		1000	300	100	30	10	3	1	•	@300 lx
		6000	2000	600	200	60	20	6	•	@50 lx
YEARS+ TO FIRST PERCEPTIBLE COLOUR CHANGE+ +										

*Cadmiums (red, yellow) may in fact be permanent, but the data so far places them at the high end of durable.
**These U.S. artists' paint standards include both permanent and durable colours in their top category.
***These yellows were also part of many greens, such as Hooker's green, sap green, and prussian green.
+3,000 hours per year (i.e. 300 days x 10 hours).
++Almost complete loss of the colour takes about 30 times longer, less for tints.

This chart assumes good UV filtration, and ignores other effects on permanence such as pollution.

Table 6.3 *Historic Pigments and Their Lifetimes (Permanence) for Various Light Intensities (Museum and art gallery lighting a recommended practice, IESNA,p15)*

1. Previous Reference, p20.
2: Previous Reference, p15.

1.4 The CIEDE2000 colour difference

The CIEDE2000 colour difference, ΔE_{00} between the two samples denoted by subscripts 0 (reference) and 1 the (test) shall be calculated as follows:[(1)]

$$\Delta E_{00} = [(\Delta L'/k_L S_L)^2 + (\Delta C'/k_C S_C)^2 + (\Delta H'/k_H S_H) + R_T (\Delta C'/k_C S_C)\ (\Delta H'/k_H S_H)]^{1/2}$$

where:

$\Delta L' = L'_1 - L'_0$ *lightness difference*

$\Delta C' = C'_1 - C'_0$ *chroma difference*

$\Delta H' = 2\,(C'_0 C'_1)^{1/2} \sin(\Delta h'/2)$ *hue-angle difference*

$\Delta h' =$ *CIEDE2000 hue-angle difference*

$\Delta h' = 0°$ if $C'_0 C'_1 = 0$

$\Delta h' = h'_1 - h'_0$ if $C'_0 C'_1 \neq 0$ and $|h'_1 - h'_0| \leq 180°$

$\Delta h' = h'_1 - h'_0 - 360°$ if $C'_0 C'_1 \neq 0$ and $(h'_1 - h'_0) > 180°$

$\Delta h' = h'_1 - h'_0 + 360°$ if $C'_0 C'_1 \neq 0$ and $(h'_1 - h'_0) < -180°$

$S_L = 1 + \{0{,}015\,(\overline{L'} - 50)^2 / [20 + (\overline{L'} - 50)^2]^{1/2}\}$ *lightness weighting function*

$S_C = 1 + 0{,}045\,\overline{C'}$ *chroma weighting function*

$S_H = 1 + 0{,}015\,\overline{C'}\,T$ *hue weighting function*

$T = 1 - 0{,}17 \cos(\overline{h'} - 30°) + 0{,}24 \cos(2\overline{h'}) + 0{,}32 \cos(3\overline{h'} + 6°) - 0{,}20 \cos(4\overline{h'} - 63°)$

T-function for hue weighting

$R_T = -\sin(2\Delta\Theta)\ R_C$ *rotation function*

$\Delta\Theta = 30° \exp\{-[(\overline{h'} - 275°)/25°]^2\}$ *hue dependence of rotation function*

$R_C = 2\,[(\overline{C'})^7 / (\overline{C'})^7 + 25^7]^{1/2}$ *chroma dependence of rotation function*

K_L, K_C, K_H *lightness- , chroma-, hue- parametric factors. Experimental observation and material variables can have parametric effects that influence the visual colour-difference results (CIE, 1993). The parametric factors may be used to correct for these effects. Under the reference conditions the parametric factors have assigned values of unity and do not affect the total colour difference. Industry groups may define parametric factors to correspond to typical experimental conditions for that industry.*

$\overline{L'}$, $\overline{C'}$ *and* $\overline{h'}$ *are the arithmetic means of the corresponding values of the colour-difference pair. A consequence of this is that the total colour difference is reversible, that is, the total colour difference between a pair is the same whether the first or second sample is used as the standard for calculation of colour-difference components.*

Users should take care in calculating the mean hue angle if the colour-difference pair has samples in different quadrants. For example, if a colour-difference pair has hue angles of 30° and 300°, the simple mean, 165°, is incorrect, the correct value being 345°. To determine the mean correctly, the following equations (sharma et al., 2005) shall be used.

$\overline{h'} = (h'_1 + h'_0)/2$ if $|h'_1 - h'_0| \leq 180°$ and $C'_0 C'_1 \neq 0$

$\overline{h'} = (h'_1 + h'_0 + 360°)/2$ if $|h'_1 - h'_0| > 180°$ and $(h'_1 + h'_0) < 360°$ and $C'_0 C'_1 \neq 0$

$\overline{h'} = (h'_1 + h'_0 - 360°)/2$ if $|h'_1 - h'_0| > 180°$ and $(h'_1 + h'_0) \geq 360°$ and $C'_0 C'_1 \neq 0$

$\overline{h'} = (h'_1 + h'_0)$ if $C'_0 C'_1 = 0$

1. Colorimetry - Part 6: CIEDE2000 Colour-Difference Formula, CIE S 014-6/E:2013;

1.5 Comparison between important values for selecting a glass for a museum application

A comparison of Visible Light Transmittance (VLT), Solar Heat Gain Coefficient (SHGC), Total Ultraviolet Transmittance (UV) and Damage Weighted Transmittance (Tdw ISO) for various high performance glazing constructions. The compared glass and glass systems are produced by PPG Industries[1] and information are adopted from glass technical document: Fading and Material Degradation of Interior Furnishings Caused by Solar Radiation Exposure, TD-148.

Product Description	(VLT)	(SHGC)	(UV)	(Tdw-ISO)
Typical Residential Insulated Vision Unit - 3/4" (19mm) unit with 1/2" (13mm) airspace and two 1/8" (3mm) lite clear				
Clear/Clear	81	0.75	59	0.74
SOLARBAN®60 (2)Solargray - Clear	48	0.30	12	0.38
SOLARBAN®70XL (2) - Clear	64	0.27	6	0.43
SOLARBAN®Z50 (2) - Clear	60	0.35	17	0.48
SOLARBAN®60 (2) - Clear	71	0.39	16	0.56
SUNGATE®500 (2) - Clear	76	0.66	49	0.66
Typical Commercial Insulated Vision Unit - 1" (25mm) unit with 1/2" (13mm) airspace and two 1/4" (6mm) lites; interior lite clear				
Clear/Clear	79	0.70	50	0.70
SOLARBAN®60 (2)Solargray - Clear	35	0.24	8	0.28
SOLARBAN®70XL (2) - Clear	64	0.27	5	0.43
SOLARBAN®60 (2) - Clear	70	0.38	19	0.54
SOLARBAN®60 (2) Azuria™-Clear	54	0.28	13	0.44
SOLARBAN®Z50 (2) - Clear	51	0.31	14	0.42
SOLARBAN®80 (2) - Clear	48	0.24	13	0.37
Typical Monolithic Laminates - 5/8" (14mm) overall thickness with 0.090" (2.3mm) thick clear PVB and two 1/4" (6mm) lites: interior lite clear				
Clear/Clear	86	0.70	0.0	0.57
SOLARBAN®60 (2)Solargray* - Clear	35	0.40	0.0	0.24
SOLARBAN®70XL (2)* - Clear	60	0.31	0.0	0.38
SOLARBAN®60 (2)* - Clear	72	0.45	0.0	0.46
SOLARBAN®60 (2) Azuria™*-Clear	55	0.44	0.0	0.38
SOLARBAN®Z50 (2)* - Clear	52	0.42	0.0	0.36
SUNGATE®500 (2) - Clear	81	0.64	0.0	0.52
Typical Commercial Insulated Vision Unit with Laminated Inboard Lite - 15/16" (32mm) overall thickness with ¼” (6mm) outboard lite, ½” (12mm) airspace and two 1/4" (6mm) clear inboard lites laminated with 0.090" (2.3mm) thick clear PVB:				
Clear + Clear/Clear	76	0.65	0.0	0.50
SOLARBAN®60 (2)Solargray* + Clear/Clear	34	0.24	0.0	0.22
SOLARBAN®70XL (2)* + Clear/Clear	62	0.27	0.0	0.38
SOLARBAN®60 (2)* + Clear/Clear	68	0.37	0.0	0.44
SOLARBAN®60 (2) Azuria™*+ Clear/Clear	52	0.27	0.0	0.36
SOLARBAN®Z50 (2)* + Clear/Clear	49	0.31	0.0	0.34
SUNGATE®500 (2) + Clear/Clear	71	0.59	0.0	0.46

Table 6.4 *Comparison between important values for selecting a glass for a museum application:. (Reducing Fading and Material Degradation of Interior Furnishing Caused by solar Radiation Exposure, PPG, Glass Technical Document TD-148, p4-5).*

1. PPG Industries is an American global supplier of paints, coatings, optical products, speciality materials, chemicals, glass, and fiber-glass. http://www.ppg.com/en/Pages/home.aspx

1.6 Comparison of various light sources damage potential.

Nr	SPD Groups	CCT	CRI	CRI Std Div	Input Φv	Φe A (380-780 nm)	Φe B (400-700 nm)
	2700K						
1	**TH GE EYC 71W MR16**	2708	99	0,68	100	0,670	0,407
2	**TH Philips 50W MR16**	2729	98	1,77	100	0,597	0,398
3	**LED LSI LumeLEX 2040-C2M2-6S**	2710	97	1,78	100	0,396	0,362
4	**FL 827 LUMILUX Warm white**	2707	70	24,11	100	0,291	0,271
	3000K						
5	**TH Sylvania Concord 2627632 MK41**	2934	99	0,95	100	0,611	0,394
6	**TH Osram 12V Diachroic**	2963	99	0,76	100	0,540	0,388
7	**LED LSI LumeLEX 2040 C3M2-6S**	2965	95	2,55	100	0,395	0,362
8	**LED Sylvania Concord 2048794**	3008	97	2,84	100	0,383	0,353
9	**LED CRS SP12 WW MR16**	3048	94	6,32	100	0,370	0,343
10	**FL 930 LUMILUX DE LUXE WW HH31**	2953	89	7,33	100	0,350	0,338
	4000K (3700-4300K)						
11	**TH Erco Eclipse Blue Lens**	4056	94	5,80	100	0,842	0,439
12	**LED Osram Oslon**	3763	92	4,38	100	0,379	0,356
13	**LED Oslon ColorChamp 70lm**	4001	89	5,08	100	0,356	0,338
14	**LED LSI LumeLEX 2040 C4M2 6S**	4113	97	3,77	100	0,378	0,355
15	**FL 940 LUMILUX DE LUXE Cool White HH31**	3769	96	3,91	100	0,347	0,339
16	**FL Philips TLD 36W**	4304	96	24,27	100	0,375	0,335
	5000K (4400-5300K)						
17	**TH Solux 12V Diachroic**	4483	97	1,39	100	0,474	0,383
18	**LED FEM**	5054	91	6,83	100	0,366	0,348
19	**FL Osram Photon Beard Dulux L 954**	5311	87	10,53	100	0,317	0,302
	6000K (5600-6900K)						
20	**LED Z5 hCRI cold white 80 lm**	6899	89	9,30	100	0,373	0,359
21	**FL GE F40W AD**	5669	91	4,37	100	0,401	0,369
22	**FL 965er**	6496	91	6,99	100	0,343	0,336
	Special filtered SPD						
23	**TH GCI Filter Mark2 on MR16**	2862	95	6,65	100	0,330	0,322
	Standard Electrical Illuminant						
24	**CIE A**	2856	100	0,00	100	0,649	0,404
25	**CIE F8**	4997	95	2,94	100	0,395	0,365
	Standard DL Illuminant						
26	**DL Nature Studio-2 Filtered Daylight**	5594	97	2,60	100	0,463	0,380
27	**CIE C Average daylight**	6776	96	3,04	100	0,497	0,415

Table 6.5 *Test data (Note: the table is divided on two pages). A comparison of various museum light sources according to its damage potential to museum object. The comparison are made according to the damage function in Berlin model for: water colour on rag paper and low grade paper.*

We classified the tested 27 SPD to five groups according to its correlated colour temperature (CCT) and we added another three groups contain especial and standards SPD that are important in museum lighting.

We ensured that every group contain three different types of spectrum: tungsten halogen (TH), light emitting diodes (LED), and fluorescent lamp (FL).

For more details and diagrams see Visible light SPD and potential of damage in chapter two:Exhibits' Conservation Aspects in Museum Lighting.

B/A %	Luminous efficacy of radiation (K) lm/W for Φe A	Damage Potential for Water Colour on rag paper SPD (A)	Damage Potential for Water Colour on rag paper SPD (B)	Damage Potential for Water Colour on rag paper SPD B/A %	Damage Potential for low grade paper SPD (A)	Damage Potential for low grade paper SPD (B)	Damage Potential for low grade paper SPD B/A %
61%	149,28	0,02	0,02	89%	0,0002301	0,0001638	71%
67%	167,46	0,02	0,02	90%	0,000195	0,0001554	80%
91%	252,30	0,02	0,02	98%	0,0001034	0,0001033	100%
93%	343,16	0,02	0,02	98%	0,0001974	0,000185	94%
65%	163,76	0,02	0,02	90%	0,0003198	0,0002183	68%
72%	185,03	0,02	0,02	91%	0,0002776	0,0001992	72%
92%	253,47	0,02	0,02	99%	0,0001251	0,0001248	100%
92%	261,04	0,02	0,02	99%	0,0001073	0,0001073	100%
93%	270,61	0,02	0,02	99%	0,0001299	0,0001293	100%
96%	285,31	0,02	0,02	97%	0,0004142	0,0003672	89%
52%	118,80	0,03	0,03	89%	0,0004048	0,0003433	85%
94%	264,06	0,02	0,02	99%	0,0003325	0,0003236	97%
95%	281,09	0,02	0,02	99%	0,000298	0,000293	98%
94%	264,73	0,02	0,02	99%	0,0002281	0,0002279	100%
98%	288,57	0,02	0,02	98%	0,0004378	0,0003923	90%
90%	266,95	0,03	0,02	98%	0,0003656	0,000335	92%
81%	210,97	0,03	0,03	88%	0,0009002	0,0005405	60%
95%	272,91	0,03	0,02	99%	0,0002591	0,0002584	100%
95%	315,11	0,03	0,03	99%	0,0004226	0,0004038	96%
96%	267,76	0,03	0,03	100%	0,0003446	0,0003432	100%
92%	249,20	0,03	0,03	95%	0,0007681	0,0006154	80%
98%	291,91	0,03	0,03	99%	0,000484	0,0004712	97%
98%	303,30	0,02	0,02	100%	0,0001064	0,0001064	100%
62%	154,14	0,02	0,02	88%	0,000319	0,0002066	65%
92%	253,34	0,03	0,03	95%	0,0006339	0,0005168	82%
82%	216,20	0,03	0,03	98%	0,0004583	0,0004549	99%
84%	201,41	0,04	0,04	89%	0,0012495	0,0008229	66%

Appendix 2. Additional information on chapter 4

2.1 Tools of the research in details

The tools of the research are a physical scale-models equipped with different types of light fixtures and different exhibits types and samples.

f. The Physical model: is a wood box representing a simple museum's showcase or a space. The box is opened from the front and has an extended space from behind allows extending the box depth or having a back let wall if needed. The box interior space dimension in plan is 50x50cm, the height is 35cm, and the extended space depth is 35cm. (In the scale of 1:20 the model represents a museum space with 10x10 m floor dimension and 6m ceiling height). The box interior walls appearance can be change by inserting thin plywood boards in tracks parallel to the walls. The floor can be covered with different coloured paper. The ceiling is always black.(Figure 5.7)

g. Light fixtures: The model is equipped with three different light fixtures represent different types of illumination. (Figure 5.7)

- Fiber optics (as a general illumination): There are 36 accesses (perforation) for the fiber optics in the upper surface of the model. Thy are distributed in 6x6cm orthogonal grids, with 5 cm distance between the points and they are 12.5cm offset from the walls. Eventually, The fiber optics appear as a grid of spotlights in the model ceiling. We used a Blue filter in front of the projector lamp to make the light output colour temperature ~ 4000K. The device is controlled with a dimmer to adjust the amount of illuminance.

  The fiber optics device technical data:
  Manufacturer: Crystal Fiber Optics Swarovsky, Austria
  Without transformer: A . 9942 . NR 040 300
  With transformer type tridonic: TE 0105 S001 A.9942.NR 040 310
  Input voltage: 12V AC, 50Hz
  Bulb: Philips 13100 100w GY 6.35
  Ventilator: Papst 8412 NGL/12V
  Safety boundary: 110C, IP 20

- Fluorescent lamp with raster for wall lighting (wall-washer): Three compact fluorescent lamps are fixed with its electronic control gears on the roof of the model. The lamps are posed over a plastic rasters, which are parallel to the wall. The raster is 6cm away from the walls and its plastic silver lovers are declined with angel of 45° to direct the light over the entire walls surface. The lamps have metal reflector cover to ensure not to lose lamp output light as much as possible. The lamps colour temperature is 4000K. Every lamp is controlled individually with a dimmer.

  The lamps technical data:
  Manufacturer: Osram
  Item Name: Fluorescent
  Types: FQ Osram T5 HO Constant 24W/840 LUMILUX Cool White G5
  Lamp power: 24 watts
  Luminous flux: 1950lm

Socket: G5
Colour temperature: 4000K
Ra: 80 to 89
Lamp Shape: Tube
Diameter: 16mm
Overall length: 549mm

- LEDs points for exhibits direct illumination (spotlight): Six LEDs with optics, every point is fixed individually on a metal base on the ceiling of the model. The metal base gives the LEDs point the ability to change location or angle on the model ceiling. The LEDs colour temperature is 4000 K. They are divided into three groups. Every group consists of two LEDs points controlled together in one channel by the digital controller (dimmer).

  The LEDs point technical data:
  LED Manufacturer: Philips Lumileds
  Luminous flux: 100lm/w
  Color temperature: 4000K
  Optic Manufacturer: Luxeon Rebel
  Optic type: 10193 Narrow
  Optic tenth angle: 9.5°
  Optic coefficient of utilization: 86.1
  Controller Manufacturer: Lite-Puter
  Controller Type: DMX touch screen panel ECP-T04

h. The exhibits samples:

- Grayscale round statues, 5 pieces size 20cm, from polyester.
- Head statues replica, 5 pieces size 15cm, from limestone. The head representing King Akhenaten, new kingdom.
- Relief replica, 5 pieces size 23x23cm, from polyester. A model of a stela representing the bearer of offerings from tom kha-em-hat, thebes, new kingdom, 1370-1349 B.C. The original from limestone.[1](Figure 5.9)

2.2 Selecting Natural-gray tones for the experiment.

a. Choosing a Colour Order Systems: After a brief study for the well-known colour systems available to us, we chose the Natural Colour System (NCS) for the flowing reasons:

- The Lightness, intensity of colour and hue ordered are very easy to understand and communicate with in the NCS.
- Many different colour theories based on this dimensional model .
- The primary hues in NCS (Yellow, Red, Blue, Green, White and Black) correspond with the perception of colour in our brain and arranged according to the opponent theory of colour vision.[2]
- The spacing of the codes is determined by visual assessment by a large number of observers.

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1. The Pharaonic replica was purchased from Egyptian Antiquities Authority 3 Al-Adel Abou-Bakr Street - Zamalek - Cairo - Egypt
2. Opponent process, http://en.wikipedia.org/wiki/Opponent_process

- Additionally, it is applied widely in the building industry and in the architectural and interior design fields.

For the previous reasons the system allows us to map colour mentally in a way that is intuitive, relates to the way we see it, and to easily use it in practice.[1] (Figure 6.1)

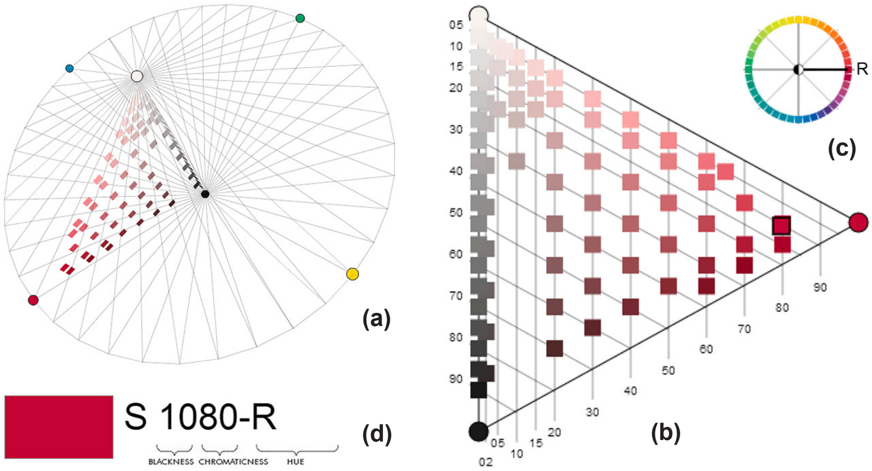


Figure 6.1 *NCS Space: (a) Location of red colour triangle R in NCS colour space (b) NCS colour triangle, a longitudinal section in the colour space, where the natural-gray tone are located in the axis of the triangle (c) NCS colour circle, a horizontal section in the colour space (c) Notation of the marked colour tone within the colour triangle R. (http://www.ncscolour.com/en/ncs/ncs-navigator/)*

b. Natural-gray tones notation in NCS: The Natural-gray tones scale have two notations in the NCS[2]:

- The luminous reflectance factor Yl [3]: is the physical value of the quantity of the light energy reflected by a surface, expressed as the percentage of light reflected under the same conditions by a perfect reflecting diffuser.
- NCS lightness number L_N : when the luminous reflectance factor scale between white W and black S is divided into equal steps, it will not represent a linear scale of visual differences in lightness. In the NCS system the perception of lightness is denoted by the lightness number L_N, which range between 0 for black and 1 for white, i.e. Black has the least visual lightness and white has the most. The natural-gray scale tones are visually equal intervals between white and black.

For pure gray colours the relation between the lightness number L_N and the blackness S is:

$L_N = 100 - S / 100$

For chromatic colour the visual lightness can be determined using the W-S scale of NCS system as a reference scale. It has been exper-

1. NCS Online Training, Introduction to colour Specification. http://www.ncscolour.co.uk/
2. NCS Lightness table Booklet, Scandinavian colour Institute, general representative office Renate Dworak, Vienna, Austria.
3. Notes that Light reflectance value (LRV) or Reflectance of a surface is ρ = Φr/Φi the ratio of the reflected flux to the incident flux. This is only valid for a perfect diffuse surfaces and modifiers had to be ad for other surfaces. (The IESNA lighting handbook, 9 Ed, 2000, P1019, 1020).

imentally established that colours of equal visual lightness also have approximately the same instrumentally measured luminous reflectance factor. If Y_l is known the L_N can be calculated by the equation:

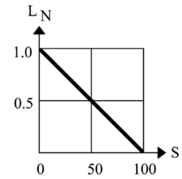
$L_N = 1.56\,(Yl / Yl + 56)$

The graph (Figure 6.2) represents the equation.

This means that, there is a constant relationship between visual lightness and light reflectance values and on the NCS atlas pages (triangl the lines that plot visual lightness and LRVs are the same; however it's an indication that lightness is not an intuitive thing.

For some users to the NCS it’s very confusing to find that the middle gray S 5000-N, visually is located half way between white and black, with a visual lightness of 0.5 on a scale of 0-to-1 but a light reflectance value of only 26 on a scale of 0-to-100.

$$L_N = \frac{100 - S}{100}$$



$$L_N = 1.56\,\frac{Y\ell}{Y\ell + 56}$$

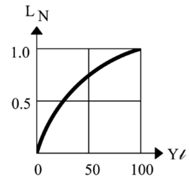


Figure 6.2 *The relationship between the lightness number L_N and both the blackness S and the The luminous reflectance factor Yl in the NCS. (NCS Lightness table Booklet)*

c. Selecting the Natural-gray tones for the experiments samples: We determined that our selection has to includes both scale ends white and black tones and odd number of gray tones in between. A five equal perceptually lightness steps of natural gray tones will be practical to use in the experiment, since they are manageable in analysing and describing the results data, sufficient to show differences and easy to identify and remember. However, there are 18 steps between white and black in the NCS neutral gray scale, that means we cannot select five tones with equal interval steps. So we have to skip one of the gray tones, which was the dark gray tone closer to black, which almost have no significant difference than black. The selected tones were purchased from a provider of the NCS paints. Its notation and LRVs from black to white are as following: S 9000-N (3.8), S 6500-N (15,7), S 4500-N (29.9), S 2500-N (51.7), S 0500-N (85.6).

The tones were applied to experiments samples. After that we measured the luminance value (L cd/m^2) for the samples in the artificial-sky in Bartenbach lighting laboratory under diffuse light and we calculated the light reflectance with the equation:

$\rho = (L . \pi / E) \times 100$

Where: ρ Reflectance %, L luminance cd/m^2, $\pi = 3.14159$, E illuminance Lux (lm/m^2).

There were shift in the values of LRV between measured samples and NCS Luminous reflection factors. Most probably, this is regard to the simple method of measurement we use or/and the samples were not perfectly diffuse. However, this is more close to the real practice and all simples are identical. The experimental five natural gray tones were denoted and organized from black-to-white with its LRVs as following:

B1 (5.2), G3 (15.9), G5 (27.4), G7 (49.3),W9 (77.0).

Comparing the LRVs for our five gray samples' tones with NCS natural-gray steps, we find that the shifting exist more in the bright tones. However, the middle gray of the five samples has a 27.4 LRV is very close to the NCS middle gray 26 LRV. (Figure 5.6)

d. For the model's wall tones (background) we chose three natural-gray tones black, gray, and white. The LRVs measurement for the panted plywood background were:

Black (4.0), Gray (26.3), White (85).

2.3 Light measuring Instruments

All measuring Instruments are belonging to Bartenbach light laboratory.Adress: Rinner Straße 14, 6071 Aldrans / Tirol, Austria.

2.3.1 Luminance Meters

Konica Minolta Luminance Meters LS-100. Hand-held and light-weight precision. (Figure 6.3)

Technical data: Output range 10^{-3} : $3{,}10^{5}$ cd/m^2 (max:min); acceptance angle 1°; size 208x79x150 (mm); weight 0,85 (kg).(1)

2.3.2 Illuminance-meter

Digital luxmeter "MINILUX". (Figure 6.4)

Technical data: Standard version with silicon-V(lambda)-cos-photocell, directly fixed with a cable of 1 meter length to the measuring instrument; Diameter of the light-sensitive surface of the photocell = 11 mmø; Measuring range: 1 mlx (solution) to 199,900 lx (six ranges); Photometric uncertainty according to DIN 5032, class B. Dimensions: 157x0,84x0,30 mm (length, breadth, height), weight: 300 g (2)

2.3.3 Luminance Camera

Luminance Camera from TechnoTeam Bildverarbeitung GmbH. Camera 350D (digital/reflex). Lense sigma 18-50mm F2.8 EX DC (Calibrated); Software LMX2000 measuring software.

Technical data: Sensor/resolution: CMOS Canon ASP-C mit 3456(H) x 2304 (V); Luminance resolution 1728(H) x 1152(V); Dynamic resolution: Single measurement: 1:4000 High-Dyn measurement: 1:32000 (1/1250 sec. =ti=8sec.). (3)

1. Konica Minolta, Luminance Meters LS-100 / LS-110, http://www.konicaminolta.eu/en/measuring-instruments/products/light-display-measurement/luminance-meters/ls-100-ls-110/features.html

2. MX-ELECTRONIC, Digital luxmeter "MINILUX", http://www.mx-electronic.com/english/price02eur.htm

3. For more information see, http://www.opteema.com/upload/pubfiles/lmkmobile_web_de_ger.pdf

Figure 6.3 *(Left) Konica Minolta Luminance Meters LS-100. (Photo from http://www.hellopro.fr/)*

Figure 6.4 *(Right) Digital luxmeter "MINILUX". (http://www.mx-electronic.com/)*

Appendix 3. IES Lighting design process phases [1]

The lighting design process is a part of the architecture planning process, which can be either progressive or conventional. A **progressive planning** refers to a planning process that engages many disciplines, including the influence of daylight in the site selection, and the influence of daylight and artificial-light on early architecture design phases. A **conventional planning** is reference to typical process of project design based on client programming requirements, where lighting comes late after the architecture design is finished. Regardless of the planning strategy employed on project, a lighting design process that parallels and complements the building design process will make the most of lighting and of the architectural resources involved.

The process outlined here in addition to good knowledge of lighting fundamentals will help lighting designers to establish lighting layouts and equipment choice based on full set of criteria. At least six phases can be identified: pre-design, schematic design (SD), design development (DD), contract documents (CDs), construction administration (CA), and post occupancy.

3.1 Pre-design

An investigative effort to collect general information about the projects before planning. Information that will help to know the project type and detriment opportunities of lighting solutions. As well, to defining scope of work[2], time schedules, involved teams and its responsibilities, and knowing the budget.

1. IESNA, The Lighting handbook, Lightin design in the building design process,10th Ed. 2011, p11.1-to-p11.14.
2. Scope: determines which phase of design work are undertaken and how much of the project is involved.

3.2 Schematic Design (SD)

Schematic design is the first phase in planning that aim to define design direction and finalize that in a preliminary design. Schematic design commonly involve the following steps.

- **Programming**: is collecting information and analysis about the intended architecture design or existing building that help to formulate a decision about which design is to be undertaken.
- **Taking inventory:** is collecting information, thoughts, and visions about the projects from the client, architect, users; as well reviewing available design documents, and requests and standard for qualifications.
- **Design goals:** Depending on the information of the two first steps designing team should establish design goals. Design goals can classified in two groups: The first is related to aesthetic aspects, as spatial and psychological factors. It is about the look and feel of space. The second is related to analytic aspects, as physiological, task, and system factors. A review of these factors should be made to establish which best help address needs of the occupants and users of the space.
- **Design Strategy:** Strategies are generally classified to daylight strategy and artificial light strategy. In this phase planning team has to select methods that involves various techniques and systems that can lead to achieve design goals. Since the selected lighting strategy effects architecture, interiors, and mechanical systems; deliberate and collaborative decisions should be made as early as possible about possible lighting strategies.
- **Lighting schemes:** is a preliminary lighting design that presents untested partial composition of strategies. Different lighting schemes can be reviewed from planning team for considerations and feedback before presenting the final lighting scheme to the client for approval. A lighting scheme mostly presented in a form of images, drawings, rendering, products cut-sheets, and samples that convey and seek feedback on tentative design approach.

The previous steps can summed up as: collecting information and analysis, client's prerequisite and sanders, aspects need to be achieved, selected strategies, and tentative/preliminary design presentation.

3.3 Design Development (DD)

Design development is a number of design steps aim to verify techniques and solutions that help to realize the schematic design.(1)

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1. Some important definitions: **Design:** complete composition of strategies. **Concept/approach:** is the idea behind a design. It's how you plan on solving the design problem in front of you. Also, in some cases, a concept can be the applied technique. **Technique:** means to address one criterion or perhaps several criteria. **Solutions:** tested design that satisfied all, most, or key criteria priorities as agreed by team and client. **Scheme:** untested partial composition of strategies.

The DD steps occur simultaneously and do not follow a fixed order, it influence each other, and it depends on designer's perspective and priorities. In Most cases, the first step in the DD is to check which lighting effects are appropriate to support the SD. Accordingly, a selection of lighting systems and luminaire will tack place. These steps influence each other. To optimise the lighting effect and the choice of lighting systems and luminaires, different steps can be taken like: exploring additional imagery, renderings, calculations, a physical model, and/or a mock-up.

The early phase DD consists of a number of exercise which end of documenting a proposed lighting design. Exercise that includes visualization, determining light sources, luminaires, controls, and details. The later leaders of DD consist of quantification and preliminary documentation. Quantification include calculation, mock-ups, and measurements. Documentation varies significantly depending on contractual obligations of the deliverables, schedule, and the degree of estimating desired.

3.4 Contract Documents (CDs):

Contract documents include the necessary documentation for the procurements, installation, and operation of the lighting systems; such as architectural CAD drawings, diagrams, luminaire and electrical equipment schedules. In some projects, a 3D Modelling types that can be used in BIM software (Building Information Modelling) can be required, or construction drawings for custom-made luminaire are needed. During early CDs some design refinement is likely to occur to finesse lamp and wattage selection; and finalize control schemes.

3.5 Construction Administration (CA)

When CDs are completed, they are released for bidding and construction. During bidding the lighting designer has to be available to answer contractors' inquiries. Throughout construction the lighting designer tasks are reviewing the shop drawings[1], and creating new details and construction drawings as a response to field condition. Near the end of the construction lighting designer may be asked to visit the site and to issue a punch list (Confirmation that what indicated in the shop drawing is installed).

3.6 Post Occupancy

Post occupancy is a set of evaluations helps to establish a baseline of performance to be checked against design predictions. Some projects scopes call for post occupancy review; As well, it can be also as a standalone project. Post occupancy can be performed by the design team or assigned to independent team of designers or researchers.

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1. A shop drawing is a drawing or set of drawings produced by the contractor, supplier, manufacturer, subcontractor, or fabricator. Shop drawings are typically required for prefabricated components. (Shop Drawings, wikibidia, <https://en.wikipedia.org/wiki/Shop_drawing>, (06.05.2016)).

Appendix 4. Components of daylight simulation in chapter 5

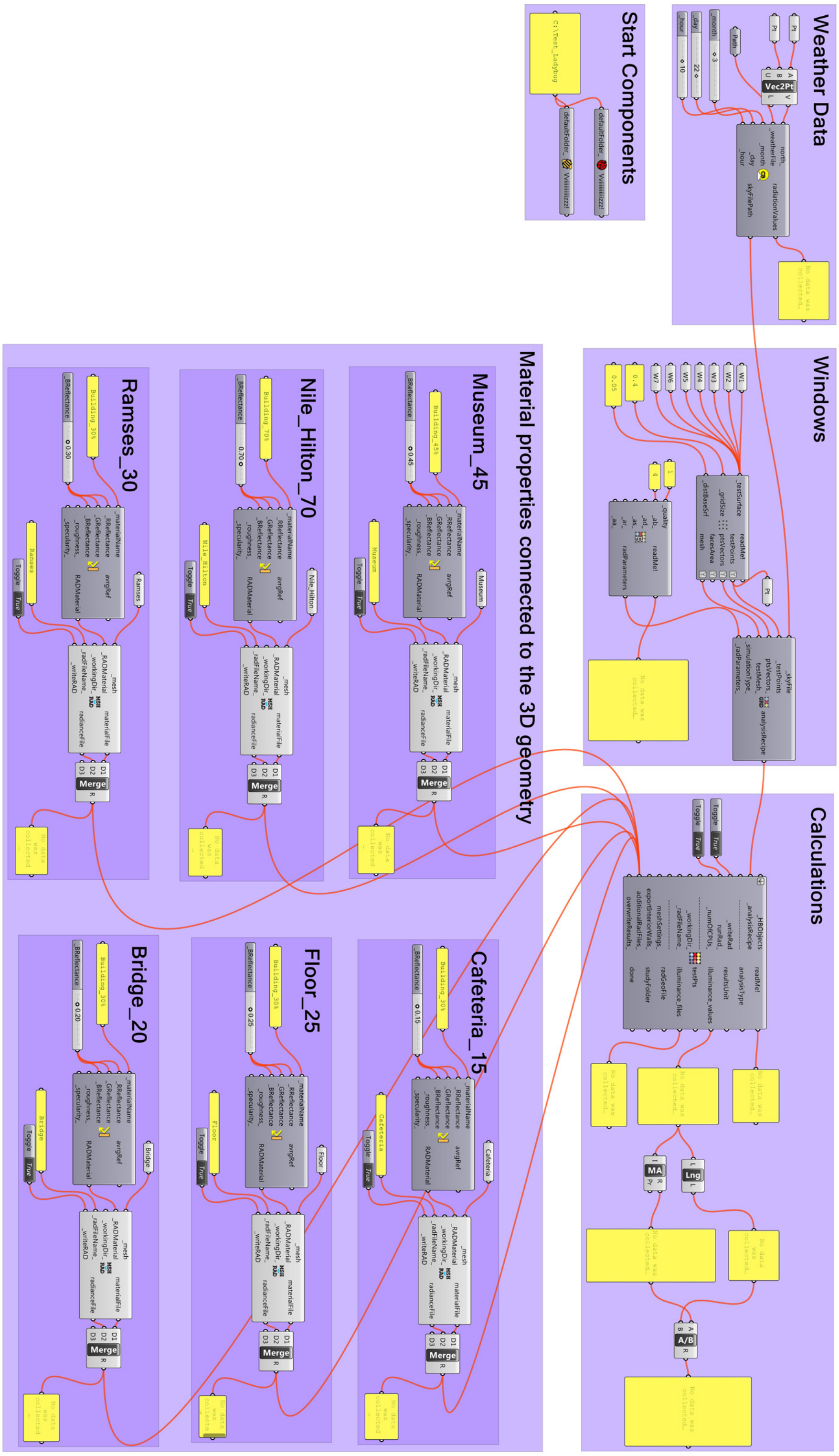

Figure 6.5 *The interface of Honeybee/Grasshopper plug-in in Rhinoceros-3D showing the components that are connected to the museum 3D model and responsible on calculating the daylight falling on the museum windows.*

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