Architectural mirrors

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Architectural mirrors (2012/2013)
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Abstract

This paper investigates the role that heliostatic mirrors can play in the transformation of vacant office buildings. There lies a huge assignment for the transformation of vacant office buildings. Amsterdam teleport has an increasing office vacancy rate that is now 22.4% (Amsterdam, 2011). This permanent vacancy problem calls for the transformation of these existing buildings. With finding a new purpose for these existing buildings, several problems come to light. The often deep building volumes have poor daylight access and are therefore highly dependent on artificial lighting. Besides these outdated buildings do not meet today's energy requirements which is primarily caused by an extensive heating demand of 500 MJ/m². Second comes lighting which is responsible for an energy consumption of 260 MJ/m² (Meijer Energie & milieu-management B.V., 2008). Together heating and lighting are responsible for respectively 40% and 22% of the energy consumption in existing office buildings.

Heliostatic mirrors are computer controlled mirrors that can focus sunlight onto a predetermined target. The possibility to bring daylight deeper into a building contributes to better daylight access, minimizing electrical lighting, and reducing the demand for heating. And because daylight can be brought deeper into existing office buildings new spatial organisations become possible, these transformed buildings can operate differently. The main research question therefore is; "How can heliostatic mirrors play a role in the transformation of deep vacant office buildings, contribute to daylighting, heating and minimize the electrical lighting of dark spots?" The research found in this document is structured around a linear process that starts with understanding the concepts involved due to literature study. Because of the absence of a manual or quantifications on my topic of research, the next step will be to build a quantification method. Then the research will put (generic) models to the test, so that guidelines and conclusions for the eventual design will derive.

The research will show that the application of heliostatic mirrors has implications for the internal organisation. On the basis of references and design study several variations will be explained. On the topic of energy this research shows that the contribution of heliostatic mirrors to heating does not live up to the expectations. The energy contribution seemed to be rather limited. In terms of daylight contribution results are pending and the topic of minimizing electrical lighting promising literature showed there is a significant decline in the demand for artificial lighting. Last a literature study on how to light effects the functioning of a space provides a range of criteria and concepts that will influence the eventual design.

Keywords – Heliostatic mirrors, Heliostats, daylight optimisation, Smart lighting, office transformation
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1. How do heliostatic mirrors work?
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   7.6.4 Impressions of privacy or intimacy

7.7 Functions
   7.7.1 Residential lighting
   7.7.2 Office and studio lighting
   7.7.3 (Public) exhibition lighting
The following chapter will give insight in the structure of the research found in this paper and how the research will be implemented in the integral design. It must be stipulated that my research until the p2 is, on its most important topics, characterized by a linear process.

In order to base a design on a technical subject two main things are important. First it is important to have good insight in the operation of the system that is being researched and secondly a (general) quantification of that system. This is the reason my research has followed a rather intensive process. A quantification of the impact of heliostatic mirrors on architectural design is not something that can be found in literature. For that I have to build a method or structure that can quantify (generic) models so that the conclusions deriving from that quantification can be implemented in the final integral design. In other words no shortcut can be found in literature.

The question; “How does, in the transformation of a deep office building, the application of heliostatic mirrors influence the spatial organisation?” will be answered by design research. Conceptual schemes and reference projects are used to explain the directions my eventual design can take.

The other research questions like; “What do heliostatic mirrors contribute to heating?”, “What do heliostatic mirrors contribute to daylight access?”, “How can heliostatic mirrors minimize electrical lighting?”, are answered by a tree step process that starts with giving a general explanation of the concept. Once the concept is explained a way to quantify models will be found so that finally by quantifying generic and designed models an answer to the question will be given.

The last part of the research, and the last research question; “What is the influence of the use if heliostatic mirrors to the light experience and functioning of that space?” will be answered by a two-step process. Because in literature criteria and quantification can be found on these questions the study will start with literature research. And finally study on design models.
Research questions

Main question

How can heliostatic mirrors play a role in the transformation of deep vacant office buildings, contribute to day lighting, heating and minimize the electrical lighting of dark spots?

Introductory

1. How do heliostatic mirrors work?
   A. What is the concept of the heliostatic mirror?
   B. How are heliostatic mirrors constructed?
   C. What are the current applications of heliostatic mirrors?

Architecture

2. How does, in the transformation of a deep office building, the application of heliostatic mirrors influence the spatial organisation?
   A. How does the application of heliostats on the roof of a building affect the spatial organisation?
   B. How does the application of heliostats on the facade of a building affect the spatial organisation?
   C. How to position heliostatic mirrors to gain the maximum amount of light?

Heating

3. What do heliostatic mirrors contribute to heating?
   A. How do heliostatic mirrors contribute to heating?
   B. How to quantify the contribution of heliostatic mirrors to heating?
   C. What do heliostatic mirrors contribute to the heating of the (generic) models?

Day lighting

4. What do heliostatic mirrors contribute to daylight access?
   A. How do heliostatic mirrors contribute to daylight access?
   B. How to quantify the contribution of heliostatic mirrors to daylight access?
   C. What do heliostatic mirrors contribute to daylight access of the (generic) models?

Electrical lighting

5. How can heliostatic mirrors minimize electrical lighting?
   A. How do heliostatic mirrors minimize electrical lighting?
   B. How to quantify the contribution of heliostatic mirrors to minimizing electrical lighting?
   C. What do heliostatic mirrors contribute to minimizing the electrical lighting of the (generic) models?

Perception

6. What is the influence of the use if heliostatic mirrors to the light experience and functioning of that space?
   A. How is light perceived by humans?
   B. What are the demands and desires for residential spaces?
   C. What are the demands and desires for studios and office spaces?
   D. What are the demands and desires for public exhibition space lighting
   E. How do the demands and desires in terms of lighting relate to the (generic) models?
Models

My research will use models in order to quantify and generalize the implications of different design choices. The first models will be simple and generic whereas the last model will be my final design. In early versions of this research document only generic cases that are not representative for the integrated design will be included.

Model 01

This model can be referred to as the most simple model used for study. It is a 100m² box I have used as a test model to generate my computations. This model is not part of the design research, but is very useful for understanding the basic principles of what my research is about. Specially for gaining awareness of what my research implies on a spatial level.

The specifications of model 1 can be found in figure 0.3

<table>
<thead>
<tr>
<th>Building specifications</th>
<th>Surface</th>
<th>Facades</th>
<th>Surface</th>
<th>Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>260 m²</td>
<td>North</td>
<td>26 m²</td>
<td>50%</td>
</tr>
<tr>
<td>Total floor surface</td>
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<td>East</td>
<td>26 m²</td>
<td>50%</td>
</tr>
<tr>
<td>Floor 1</td>
<td>100 m²</td>
<td>South</td>
<td>26 m²</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>West</td>
<td>26 m²</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roof (V5+V7)</td>
<td>100</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Floor</td>
<td>2120</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>RC [m²K/W]</td>
<td>Blind facade</td>
<td>5,7</td>
<td>0,176</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RC [m²K/W]</td>
<td>1,8</td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>Inhabitants</td>
<td>2 Persons</td>
<td>2</td>
<td>Persons</td>
</tr>
<tr>
<td></td>
<td>Lighting</td>
<td>10 watt/m²</td>
<td>1</td>
<td>watt/m²</td>
</tr>
<tr>
<td></td>
<td>Computers/items</td>
<td>50 watt/item</td>
<td>5</td>
<td>watt/item</td>
</tr>
</tbody>
</table>

Fig 0.2 A cad plan and front view of the south façade with dimensions of the existing office building (source: image by the owner)

Fig 0.3 Specifications model 2 (source: image by the owner)
Model 02

This model represents the existing building that is going to undergo a transformation. This model will be used for testing design choices, but also for analysing its current state. The seven story high office building is currently used by ING. The deep floors in this 70’s/80’s office building most likely have poor daylight penetration and will therefore serve as an excellent object of study.

![Model 2 existing situation](source: images from google maps)
Fig 0.5 A cad plan and front view of the south façade with dimensions of the existing office building (source: image by the owner)

The specifications of model 2 can be found in figure 0.6.
### Building specifications

<table>
<thead>
<tr>
<th>Volume</th>
<th>32760 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total floor surface</td>
<td>12600 m²</td>
</tr>
<tr>
<td>Floor 1-5</td>
<td>2120 m²</td>
</tr>
<tr>
<td>Floor 6-7</td>
<td>1000 m²</td>
</tr>
</tbody>
</table>

### Facades

<table>
<thead>
<tr>
<th>Surface</th>
<th>Transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>1148 m² 50%</td>
</tr>
<tr>
<td>East</td>
<td>1197,5 m² 50%</td>
</tr>
<tr>
<td>South</td>
<td>1148 m² 50%</td>
</tr>
<tr>
<td>West</td>
<td>1197,5 m² 50%</td>
</tr>
<tr>
<td>Roof (V5+V7)</td>
<td>2120 20%</td>
</tr>
<tr>
<td>Floor</td>
<td>2120</td>
</tr>
</tbody>
</table>

### Construction

<table>
<thead>
<tr>
<th>RC [m²K/W]</th>
<th>U [W/m²K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparent facade</td>
<td>1,8</td>
</tr>
<tr>
<td>Blind facade</td>
<td>5,7 0,176</td>
</tr>
</tbody>
</table>

### Production

| Inhabitants       | 252 Persons |
| Lighting          | 10 watt/m²  |
| Computers/items   | 50 watt/item |
How do **heliostatic mirrors** work?
1. How do heliostatic mirrors work?

In this chapter an introduction to heliostatic mirrors will be given. Explaining the concept of the mirrors, how they

1.1. The concept of heliostatic mirrors

Heliostat is a combination of the Greece word “helios” and “stat” that stand for respectively Sun and stationary (http://en.wikipedia.org/wiki/Heliostat). These devices determine the position of the sun by its elevation- and azimuth angle (fig 1.1). A pv-panel equipped on a heliostat will receive constant sunlight perpendicular to its surface.

![Fig 1.1 Explanations of the concept elevation angle and azimuth angle (Source: image by the author)](http://www.solaripedia.com/images/large/3287.jpg)

In the case of a heliostatic mirror however, the mirror will reflect the sunlight in a constant beam onto a predetermined target. This target can be a water tank, a window, an atrium or a spot on a ceiling. Since the heliostatic mirror does not point directly at the sun but focusses in-between the sun and the target, it must be distinguished from solar-trackers. The fixed target is, like the position of the sun, defined by its elevation- and azimuth angle relative to the mirror. By simply focusing the mirror in between those angles the light will be reflected onto the target (fig 1.2).

![Fig 1.2 The movement of the heliostatic mirror. T=target, F=focus, S=sun (Source: image by the author)](http://www.solaripedia.com/images/large/3287.jpg)

The next section will explain how the concept of the heliostatic mirrors translates to the components that construct it and the types of heliostatic mirrors that can be distinguished.
1.2. Construction and types of the heliostatic mirror

In the very earliest heliostats, which were used for daylighting in ancient Egypt, servants or slaves kept the mirrors aligned manually, without using any kind of mechanism. There are places in Egypt where this is done today, for the benefit of tourists.

1.2.1 Major components

The major components shown in figure 1.3 are briefly described below. Endless variations to the heliostatic mirror described are possible.

![Heliostatic mirror components](image)

**Support structure**

The support structure positions the mirrors accurately and carries the weight of the structure and wind loads through the drives to ground.

**Pedestal**

By far the most common type of ground support for solar concentrators is the poured-in-place tubular pedestal.

**Tracking controls**

Tracking controls are the electronic algorithms that are used to provide the signals to the drive motors for maintaining the position of the concentrator relative to the sun. Heliostats must always track a point in the sky that is located midway between the target and the sun in order to reflect their image onto the target.

**Mirror surfaces**

Thin silvered glass, which may or may not have a low iron content for enhanced reflection. Aluminium and silver polymer films have been under development for solar applications for some time, but these materials have not yet demonstrated the ability to survive the 20 to 25 years required for power plant applications.
The concentrator drive causes the heliostat to track across the sky in two axes, azimuth and elevation, to maintain the sun’s image at a predetermined location. In case of the drive not only provide the tracking but it also must carry the weight of the concentrator and any wind loads to ground through the pedestal and foundation.

1.3. What are the current applications of heliostatic mirrors?

1.3.1 Solar-thermal power plant

In a solar thermal plant 30-50% of the initial capital investment goes to the heliostatic mirrors (http://en.wikipedia.org/wiki/Heliostat). The solar energy is collected at the receiver and delivered to a storage system or used directly to generate steam and power a conventional turbine generator (Mancini et al., 2000). Studies have shown that a 100 MW power tower would require nearly one million square meters of glass heliostats, corresponding to approximately 10,000, 100-m² heliostats (Mancini et al., 2000, vi). Examples of Solar-thermal plants are; “The solar project” and “PS10 plant in Spain” (fig 1.5).

![Fig 1.5 The 11MW PS10 near Seville in Spain. When this picture was taken, dust in the air made the converging light visible. (source: http://en.wikipedia.org/wiki/File:PS10_solar_power_tower_2.jpg)](http://en.wikipedia.org/wiki/File:PS10_solar_power_tower_2.jpg)

1.3.2 Architecture

The Genzyme Centre, corporate headquarters of Genzyme Corp. in Cambridge, Massachusetts, uses heliostats on the roof to direct sunlight into its 12-story atrium. The design by Behnisch architects will be further explained in chapter 2.1.1 Roof applications

![Fig 1.6 Heliostats on the roof of the Genzyme centre and a view of the atrium (source: http://www.solaripedia.com)](http://www.solaripedia.com)
Chapter 2

How does, in the transformation of a deep office building, the application of heliostatic mirrors influence the spatial organisation?
2. How does, in the transformation of a deep office building, the application of heliostatic mirrors influence the spatial organisation?

The new means that arise from the use of heliostatic mirrors affect the way buildings can be organized. Daylight can penetrate deeper into building volumes making new spatial organisations possible. Because new, deviating spatial organizations are possible, in this chapter I will explore the variety of these new organisations to be able to include their implications in the rest of the research. Eventually conclusions deriving from the studies of the deeper layers will interact with the organisation schemes and vice versa. The quantity of these integration capabilities consist of design studies by the author, mixed with existing solutions extracted from reference project(s). For the concepts that are covered by design study counts that along the way of the graduation they may or may not prove themselves.

2.1. How does the application of heliostats on the roof of a building affect the spatial organisation?

2.1.1 Roof applications

Applications of heliostatic mirrors on the roof of a building consist of three elements. First heliostatic mirrors that catch the light and send it off to a fixed predetermined target. This fixed target in the case of roof applications is a fixed mirror. This fixed mirror than redirects the light to penetrate the building via a roof opening.

![Image of roof applications](source:image by the author + image from http://behnisch.com/projects/104)

The concept of these roof solutions is to let more light penetrate through smaller roof openings. As a side effect sunlight is directed into a predetermined direction so that lighting becomes a more planned component in the design. A reference using heliostats on the roof of a building is the Genzyme centre, by Behnisch architects (fig 2.1).

2.1.2 Internal implications for roof applications

With the applications of heliostatic mirrors on the roof of a building a whole new design language emerges that has implications for the internal organization of a building. In the case of the Genzyme centre the light that penetrates the building via the roof is led to the office floors via a central atrium (fig 2.2). This atrium is not only designed to function as a circulation space but also to be a distributor for light. From the perspective of the atrium all surfaces are reflective or transparent to let as much of the light penetrate the surrounding floors. There is even a circuit of mirrors whirling in the open space to diffuse the light even more (fig 2.2).
The same principle, but with a different building organisation could be applied in case of a multifunctional building. Here different functions or residences require a subdivision within the large volume of the building. One could think of making units within the building. Because of the freedom the heliostatic mirrors entail in terms of daylight these units not necessarily need to be organized across the facades of the building volume. Assuming a free organization of small units within a large building volume it is evident to make the external layers of the units completely reflective or transparent (fig 2.3).

In the organisation of the Genzyme building, diffuse light spreads through a circulation space to finally seep into individual units. Where the Genzyme building has an atrium figure 2.3 has an intermediate space. In the case of figure 2.4 this intermediate space becomes less important. Because the units are directly planned around a lighting beam the intermediate space loses its function as a reflective light conductor.
In this organisation the intermediate space could also be outdoor space, meaning there is less volume to be heated. And because of the loss of its function as light conductor the internal design of the unit itself becomes more important. First of all these units receive direct sunlight which means comfort issues like glare have to be taken into account. Secondly the materials with their specifications become increasingly important and last the form of the unit and the electrical lighting plan.

The last alternative using heliostats on the roof is one using large open floors spreading all across the building volume. The lighting beams coming from the roof all get their own target floor. Than holes in the floors lying above make sure the light reaches its destination. Grids with trusses parallel to the lighting beam cover the hole but make sure the light can pass.
2.2. How does the application of heliostats on the facade of a building affect the spatial organisation?

2.2.1 Movable lightshelves

Where the application of heliostatic mirrors on a roof can increase the density of light penetrating a transparent surface, the application of heliostatic mirrors on the façade does no more than redirect the light (fig 2.6). These systems are designed to increase the daylight contribution deeper in a room, control and redirect sunlight, and realise a more uniform lighting distribution throughout the room.

![Fig 2.6 How Façade applications of (heliostatic) mirrors only redirect lighting and not increase the density of light (source: image by the author)](image)

The mirrors in façade applications not necessarily need to be heliostatic. Two directional control of the mirror will make the light appear onto the exact same spot on the ceiling. If the mirror would only be controlled in one direction, however, the spot would appear on the same distance relative to the façade but would be able to move in the parallel direction (fig 2.7).

![Fig 2.7 Movable light shelf. By courtesy of SBI, Denmark (Source: (Velds, 2000, 167))](image)

2.2.2 Anadolic system

As research has shown only light shelves that are tilted up to the sky slightly increase the luminance levels at the back of the room (Velds, 2000, 168). Therefore anadolic systems have been developed. These systems are comparable to lightshelves, but are optimised in form with the aim to increase the illumination levels at the back of the room.
The experiment shown in figure 2.8 showed that under overcast sky conditions, higher visual comfort is reached.

2.3. How does the application of heliostats externally affect the spatial organisation?

External applications of heliostatic mirrors are very much the same as their application in solar towers. Like in a field of heliostatic mirrors heating a watertank on a solar powerplant, there is no integration between the target and the heliostatic mirror itself. A huge disadvantage of this application is that the target, which is a building instead of a slender solar tower, lies inbetween the sun and the mirror increasing the risk of shading the mirrors.

External heliostatic mirrors do move on two axes. DIY have also discovered the heliostatic mirrors, making endless domestic variations on heliostatic mirrors. Many of these homemade heliostats are simply placed in the south garden and reflect light into the home via the window (fig 2.10).
2.4. Positioning the mirror

2.4.1 Angle of incidence and light reflection

To be able to design with heliostatic mirrors it is important to know where to position the mirror to maximize its efficiency. The concept of this efficiency is rather simple. When the sun and the target lie close together the angle of insolation is small and therefore a lot of sunlight will be reflected by the mirror (Fig. 2.11). However when the sun and the target are far apart the angle of insolation is large and therefore fewer sunlight will be reflected (Fig 2.11).

![Image](source: image by the author)

To show the implications of different positions of the target I have experimented with different azimuth angles of the target and different elevation angles of the target. The calculations made for this research are based on astronomical equations made by the NOAA. Further explanation about the calculation of the position of the sun can be found in 3.2.1 Solar position.

2.4.2 The implications of different target orientations

Three different targets with different azimuth angles (orientations) are put to the test. The blue mirror has a target orientated on the south east (azimuth 135°), the black mirror on the south (azimuth 180°), and the red mirror on the south west (azimuth 225°). The 90% line represents the theoretical maximum of what the mirror can reflect since mirrors absorb 10% of the radiation they receive.

![Image](source: image by the author)
As seen in figure 2.12 the blue mirror that has its target orientated on the south east is more efficient in reflecting the morning sun and the red mirror is more efficient in reflecting evening sun. However when the same calculation is done for October this extra efficiency in is not that significant anymore. Therefore a target orientated on the south (azimuth 180°) should be designated as most efficient.

2.4.3 The implications of different target elevations

In this research three different targets with different elevation angles are put to the test. The blue mirror has a target elevated 60°, the black mirror 30° and the red mirror 0°. The 90% line represents the theoretical maximum of what the mirror can reflect since mirrors absorb 10% of the radiation they receive.

As expected the blue mirror is more efficient during summer months when the sun is high, whereas the red mirror is slightly more efficient during winter months. The black does not excel on specific months but overall can be called most efficient.
Chapter 3

What do heliostatic mirrors contribute to heating?
3. What do heliostatic mirrors contribute to heating?

This chapter covers the contribution of heliostatic mirrors to heating, and possibly overheating a building. To gain insight in the heating contribution, the concept of heating with heliostatic mirrors is traversed from sunlight penetrating the atmosphere to the mirrors light reflection. The quantification of the actual light reflection makes is possible to study heating gain on the models mentioned in the introduction.

3.1. How do heliostatic mirrors contribute to heating?

3.1.1 Position of the sun

The position of the sun, represented by the azimuth- and elevation angle (See also: 1.1. The concept of heliostatic mirrors), determines the angle at which sunlight enters the atmosphere. The angle at which the sun penetrates the atmosphere influences the light that reaches the earth’s surface because it affects the amount of air mass the light has to penetrate (fig 3.1).

![Fig 3.1 Solar angle and the quantity of penetrated air mass (source: Image by the author)](image)

By calculating the penetrated air mass at a given solar angle and altitude an approximation of the solar intensity in kw/m² can be calculated. This approximation, however, does not incorporate factors like weather conditions and the atmospheric composition.

3.1.2 Weather conditions

Heliostatic mirrors only function under directional sunlight. Diffuse light would, instead of reaching the target, scatter around in space. Clouds cause sunlight to scatter and form diffuse light. Global radiation is a summation of directional sunlight and diffuse light circulating in the environment. In case of a clear sky global lighting levels are about 1,1 times the directional light. When directional sunlight penetrates a cloudy sky the light circulating in the environment is reflected back by the clouds causing even higher general light levels.

3.1.3 Angle of incidence

As the solar position, atmosphere and weather conditions are being covered the only thing left to affect the light reflected by the heliostatic mirror is the angle of incidence. The angle of incidence highly affects the actual light reflected by the heliostatic mirror as explained and researched in 2.4. Positioning the mirror.

3.2. How to quantify the contribution of heliostatic mirrors to heating?

3.2.1 Solar position
The position of the sun is represented by the azimuth- and elevation angle (See also: 1.1. The concept of heliostatic mirrors). There is a whole range of different astronomical calculations that each has its own accuracy. NOAA, national oceanic and atmospheric administration, provided a visual basic calculation that can be integrated in excel (NOAA, 2012) (See also: appendix X).

3.2.2 Weather data

There is a variety of sources from which to gain solar intensity data. As mentioned above an approximation can be made by calculations. These calculation, however, do not represent realistic days since changes in weather over a daytime period are not incorporated. What’s left are KNMI long-term average data and KNMI realistic data. Long-term average data uses average solar hours, meaning that there will be no completely clouded or clear days. This made me choose for realistic weather data where extremes in weather are not filtered out to see what the effects on the distribution of heath are.

Weather data is downloaded from (KNMI, 2012) and imported in excel (See also: appendix X). For the energy balance, hourly data of temperature, minutes of sunshine, and the solar radiation in J/cm² can be retrieved from the KNMI database.

3.2.3 Mirror reflection computation

The solar angle of incidence of a rectangular mirror is widthEfficiency* heightEfficiency

widthEfficiency = \cos(90-(90-(azimuthS - azimuthF)) \cdot mirrorWidth
heightEfficiency= \cos (90 - (90 - (elevationS - elevationF)) \cdot mirrorHeight

3.2.4 Computation of energy balance

To see to what extend heliostatic mirrors can compensate in the demand for heating. The heating gain by heliostatic mirrors will be plotted against other heat flows like heat transmission, heat production, ventilation gains and losses and sunlight penetration. To see how the energy balance is calculated every 10 minutes on a given realistic day where the KNMI database provides weather conditions.

Heat transmission

The heat resistance for every construction differs for the individual models and constructions. The heat resistance is determined by the formula Heathtransmission = $U^* (T_e-T_i)^*\text{façade surface}$

Heat production
The heat production by people is 58 watt per person. For a computer I’ve used a heating gain of 50 watts and 10 watt/m² for electrical lighting

Ventilation

For ventilation gains and losses are, like all the other aspects affecting the energy in and outflows, calculated every 10 minutes. The KNMI data provides hourly temperatures for the formulas used below.

\[ Q_{\text{vent}} = \frac{1}{3} \frac{W}{K \text{ per m}^3/\text{h}} \]
\[ T_{\text{inflow}} = T_e + (T_i - T_e) \times \text{recoveryRate} \]
\[ \Delta T = T_i - T_{\text{inflow}} \]
\[ Q_{\text{vent}} = (\Delta T/3) \times \text{Airflow} \]

Sunlight penetration

For computing the solar gain via windows and openings the same KNMI data, that is used for the computation of the heat gain by heliostatic mirrors. Unlike the computations of heliostatic mirrors sunlight penetration uses the global radiation instead of direction lighting.

Notifications

In the energy balance as computed in Apendix X, the X-axis or 0-watt line represents a stationary condition where the outgoing and ingoing energy flows are in balance. In this balance the desired climate conditions are achieved. The graph going into the positive area means energy is added to the building climate, causing increased temperature. The graph going into the negative area represents energy is flowing out of the building climate. The energy balance graph does, however, not translate into the to the indoor temperature. Because of the presence of building mass energy will be stored in the building construction. The energy balance therefore is an indicator of temperature changes that will take place in a delayed and more levelled manor. Any indication of the savings of the heliostatic mirror system that is based on the energy balance is no more than an indication of the accrual contribution to heating.
3.3. What do heliostatic mirrors contribute to the heating of the (generic) models?

3.3.2 Model 2

Regarding the existing building I want to use for my design, it is highly relevant to study the heat gain by a heliostatic mirror plan. For the following calculations the roof plan will be filled with 96 heliostatic mirrors with dimensions $2.3m \times 2.3m = 5.29m^2$. That is a total of $507.84 \, m^2$ mirror.

![Model 2 Plan - Heliostatic mirrors on the roof](image)

![Model 2 Section - Heliostatic mirrors on the roof](image)

Fig 3.3 Cad drawings containing a roofplan filled with a mirror plan and a section (source: image by the author)

The heliostats are arranged in groups of 24 mirrors that point at the same fixed mirror. This implies that the lighting beams leaving the fixed mirror will be spread in various directions. Alternatively more fixed mirrors can be installed so that this effect can be minimized. For the sake of this calculation, however, the scheme as presented in figure 3.3 will be used.

To achieve a realistic energy balance more conditions of the building have to be determined. The calculations (appendix 2) for this model have been made under the conditions as displayed in figure 3.4.
As the arrangement of the heliostatic mirrors and other conditions of the building have been determined it is possible to compute the energy balance of each individual day. To make concluding remarks the realistic weather conditions of 2012 (KNMI) have been used (see also 3.2.2 Weather data). To give an example, the energy flows on 26-6-2012 for model 2 have been computed and put into graphs (fig 3.5). Together with the temperature and solar radiation from KNMI (blue graph) and the energy balance (red graph) an overview of the flows on any particular day can be given.

![Graphs showing temperature, solar radiation, and energy balance](image)

By calculating the energy balance of each individual day in 2012 an annual overview of the energy distribution can be made. The energy gain by heliostatic mirrors is displayed in kwh for each day (fig 3.6).
arises what part of that heating was beneficial and what part caused overheating, and can be the role of a water tank connected to a medium for seasonal heat storage. In that case the mirrors would not heat. On 26-05-2012 it would be better to reflect the light to another target outside the building. That target.

3040 kWh. On 26-05-2012 the energy gains peek at 4237 kWh. A large part of that overheating is caused by the heliostatic mirrors take 631 kWh for their account so that the heating load drops from 3670 to 02-2012 the energy outflow goes down to about -43000 kWh and the positive flow peeks at around 1250 kWh, which means the mirrors reflected 507,84 kWh/m² over the year 2012. The question, however, is how this energy gain relates to the other flows of energy in the building.

As shown in figure 3.6 the gain by heliostatic mirrors in 2012 goes up to approximately 2200 kWh for an individual day. According to the calculations the total energy gain by heliostatic mirrors in 2012 is 255.395 kWh, which means the mirrors reflected 507,84 kWh/m² over the year 2012. The question, however, is how this energy gain relates to the other flows of energy in the building.

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As shown in figure 3.7 the energy flow of heliostatic mirrors (black graph) is quite significant in relation to the other energy flows. Two extreme days will be briefly discussed. 06-02-2012 and 26-05-2012. On 06-02-2012 the energy outflow goes down to about -43000 kWh and the positive flow peeks at around 1250 kWh. The heliostatic mirrors take 631 kWh for their account so that the heating load drops from 3670 to 3040 kWh. On 26-05-2012 the energy gains peek at 4237 kWh. A large part of that overheating is caused by the heliostatic mirrors. The mirrors reflected 2193 kWh into the building, which is 51% of the excessive heat. On 26-05-2012 it would be better to reflect the light to another target outside the building. That target could be a water tank connected to a medium for seasonal heat storage. In that case the mirrors would not only contribute to a heat storage system, but also actively provide shade for the roof. As seen in figure 3.6 and 3.7 the heliostatic mirrors produce most heat on days where the fewest heat was needed. The question arises what part of that heating was beneficial and what part caused overheating, and can be the role of seasonal storage?
Figure 3.8 shows the same graph as figure 3.6 but with beneficial heating separated from the energy that is causing the building to overheat. Here can be seen that a large part of the heat gain by the mirrors led to overheating. Of the 255.395 kWh of heat produced by the heliostatic mirrors 52.623 kWh was beneficial heat and 202.773 kWh led to overheating which is respectively 20% and 80%. The calculation shows that with the 94 mirrors caused overheating during 194 days. Looking at it more positively, a building volume per square meter heliostatic mirror ratio of 65 covered the heating load during 194 days in 2012. In 171 days a heat load still remained and that load seems to be 230.301 kWh total for 2012. If the 202.773 kWh that led to overheating could be accumulated and stored for a season the conclusion must be that model 2a with a building volume per square meter heliostatic mirror ratio of 65 can almost completely compensate in demand for heating (Note: This does not take into account possible storage losses).
Chapter 4

What do heliostatic mirrors contribute to daylight access?

Bram van Hemmen 4079515 graduation project 2012-2013
4. What do heliostatic mirrors contribute to daylight access?

This chapter researches the contribution of heliostatic mirrors to daylight access.

4.1. How do heliostatic mirrors contribute to daylight access?

4.1.1 Light and health

Only a small portion of the sun’s radiation that reaches the earth is visible to the human eye (fig x). This radiation is classified by wavelength into radio, microwave, infrared, the visible region that we perceive as light, ultraviolet, X-rays and gamma rays (fig 4.1).

![Different spectra of solar radiation](http://en.wikipedia.org/wiki/File:EM_spectrum.svg)

The region of visible radiation (light) is not evenly perceived by the human eye. Fig x shows how the human eye is most sensitive to yellow-green light that stand for 555 lumen per watt.

![Sensitivity of the eye to the light spectrum](http://en.wikipedia.org/wiki/File:EM_spectrum.svg)

Because of differences in the quantity of visible light that is transmitted by different light sources each light source has its own lumen per watt ratio. A candle for instance emits 0,3 lm/watt. The intensity of radiation emitted by the sun is shown in figure 4.3.

![Radiation intensity of sunlight in (w/m²)](http://upload.wikimedia.org/wikipedia/commons/c/cd/Sonne_StrahlungsintensitaetNL.svg)
As a light source sunlight has a lumen per watt ration of 93. With the ratio between light and heat the puzzle of the light reflected by heliostatic mirrors is not solved. To determine the light reflected by heliostatic mirrors more complex factors like the position of the sun, angle of incidence and weather conditions play part.

4.1.2 A substitute for electrical lighting

Heliostatic mirrors only reflect directional light from the sun (see also: 3.1.2 Weather conditions) and since sunlight causes sunlight to scatter heliostats do not reflect light towards their targets during cloudy periods of the day.

Figure 4.4 displays the reflection of light by heliostatic mirrors for model 2a. On the 1st of January 2012 can be seen that sunlight is only reflected for several minutes over the day forming these peeks in reflected light. As a light source heliostatic mirrors are too unreliable. Therefore heliostatic mirrors may not be seen as a substitute for electrical lighting but as an addition to day lighting.

4.2. How to quantify the contribution of heliostatic mirrors to daylight access?

To simulate light in a model for designing purposes I aim to generate realistic renderings. In these renderings the relative brightness is displayed so that contrasts and relative dark areas can be found. To quantify lighting levels, however, renderings with false colours can provide a solution (fig 4.5).

To build a 3d cad model on which daylight analyses can be performed I use Rhinoceros for making cad models and DIVA for providing daylight analyses. To simulate heliostatic mirrors DIVA daylight analyses are made via Grasshopper. The DIVA plugin for Grasshopper includes a vector that represents the solar angle. Geometry linked to that vector and a vector that aims at the target mirror form the basis for the heliostat component.
Heliostatic mirror geometry component

The heliostatic mirror component is a subdivided circle that is defined by a diameter and a vector. The vector represents the focus of the mirror and lies in-between the sun vector and the vector towards the target (fig 4.6).
4.3. What do heliostatic mirrors contribute to daylight access of the (generic) models?

4.3.2 Model 2

Daylight analysis

Model represents the existing office that will be transformed in the design. To see how daylight penetrates the design in its current appearance the 5th floor has undergone a daylight analysis. The conditions under which they are performed are shown in figure 4.7.

<table>
<thead>
<tr>
<th>Radiance Material</th>
<th>Reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor</td>
<td>0.20</td>
</tr>
<tr>
<td>Ceiling</td>
<td>0.80</td>
</tr>
<tr>
<td>Walls</td>
<td>0.50</td>
</tr>
<tr>
<td>Exterior Ground</td>
<td>0.20</td>
</tr>
<tr>
<td>Glazing</td>
<td>0.76 Transmittance</td>
</tr>
</tbody>
</table>

Fig 4.7 conditions under which analysis in fig x are made (source: image by the owner)

As figure 4.8 shows a large part of the models floor remains unexposed to daylight.

The addition of heliostatic mirrors

Here a daylight analysis was planned for the same floor but with the addition of heliostatic mirrors. The model I have built in rhino, grasshopper and diva was supposed to show this analysis. However my model has shown a misalignment within the diva plugin and the diva analysis component. My model has been sent to the organisation for analysis.
How can heliostatic mirrors minimize electrical lighting?
5. How can heliostatic mirrors minimize electrical lighting?

Artificial lighting is one of the major electricity consuming items in many building, constituting about 20-30% of the total energy load (Li and Tsang, 2005). This unfinished chapter tries to figure out to what extend heliostatic mirrors can compensate in the need for electrical lighting.

5.1 How do heliostatic mirrors minimize electrical lighting?

5.1.1 Daylight aware electrical lighting systems

Daylight aware electrical lighting systems are artificial lighting systems that turn off when sufficient daylight is available. Photo sensors measuring daylight levels send signals to automatically control artificial lighting levels (fig 5.1).

![Fig 5.1 Scheme of daylight levels turning off the artificial lighting (Source: image by the author)](image)

5.2. How to quantify the contribution of heliostatic mirrors to minimizing electrical lighting?

My initial goal for his chapter was to quantify the energy savings heliostatic mirrors cause in minimizing daylight. This is, however, a complex procedure. It includes at least a simulation of daylight, an electrical lighting design, a script that simulates the operation of the daylight aware lighting system and an analysis of the savings. Instead of making a complex simulation to quantify this system I will engage in learning from a study done by (Li and Tsang, 2005).

5.2.1 Study in the savings

An empirical study of how daylight optimisation and smart lighting can minimise artificial lighting consumption is done by (Li and Tsang, 2005). A corridor (fig 5.2) functioned as their object of study.

![Fig 5.2 Interior view of the study corridor with a CAD plan (Source: (Li and Tsang, 2005, 974))](image)
Two photo sensors were used to regulate and record the light intensity. The first sensor with measuring range from 0 to 2000 lx was mounted onto the ceiling located at the mid-way of the corridor. It detected both daylight and reflected light from corridor surfaces to provide a 'close loop' control dimming system. Since it is a narrow plan walkway (18.3m long and 2.85m wide), a single-zone control is considered adequate. The lighting level received was sent to a dimming controller, which varied the light output of the fluorescent lamps accordingly via dimmable electronic ballasts.

The second sensor with measuring illuminance level up to 16,000 lx was mounted next to the windows to record the amount of transmitted daylight. This sensor was installed just to give an indication of the available daylight and did not form any part of the dimming control system.

The results

Figure 5.3 shows how in the case of these experiments the electrical lighting load decreased as the photo sensor measured the amounts of daylight. The lighting savings varied from 5.9 kWh in February to 8.31 kWh in June.
5.3. What do heliostatic mirrors contribute to minimizing the electrical lighting of the (generic) models?

In this section of the research future models will be accessed. However, it is disputable to what extent I should investigate models on their electrical lighting savings. As daylight optimisation by heliostatic mirrors (chapter 4) plays the most important role in minimizing artificial lighting by the lighting systems mentioned above, it is probably wiser to focus more in quantifying the daylight gains by heliostatic mirrors.
What is the influence of the use of heliostatic mirrors to the light experience and functioning of that space?
6. What is the influence of the use if heliostatic mirrors to the light experience and functioning of that space?

The following demands and desires for the functions in the project concentrate mostly on electrical lighting (luminaries). My goal is, however, to use heliostatic mirrors to create equivalent lighting designs that can provide in the same needs. The knowledge presented in the following chapter can be used as tools for the design as well as criteria to which the design must comply.

6.1. How is light perceived by humans?

We experience space by the walls – the boundaries of the space – and the distribution of light (Santen and Hansen, 1985, 9). What we perceive is the difference in brightness, the colour of the surroundings and the colour of the light. An artist who plays with light and how we perceive space is James Turrell.

![Fig 6.2. 'Bridget's Bardo', Model, 2009, by James Turrell (source: photo by Florian Holzherr)](image)

His installations (fig X) are designed to filter away all that makes us perceive space as we normally do. By manipulating the horizon, illuminance differences, contrast and colour he creates the illusion of infinite space.

### 6.1.1 Vision

Light falling on the retina causes electrical signals to flow to the brain, which then interprets these signals for meaning.
As figure 6.2 explains the human vision exists of three zones. The first and most sharp region of our vision lies around the centre of vision is the foveal vision. The centre of vision points about 15° downwards.

The second and larger region in our vision is the “foveal surround” that lays 15° above and under the centre of vision and then comes the peripheral vision that is limited by the upper limit of vision that lies about 45° above the horizon and 85° under the horizon.

Commonly experienced brightness levels

Within the range of pour- to blinding brightness levels are a lot of intermediate steps. Fig x quantifies these steps in cd/m² and links them to existing situations. The relationship between cd/m² and the commonly used lux is 1 cd/m² = 4π lumen/m² = 4π lux
6.1.2 Contrast perception

*Lateral inhibition*

It is commonly known that observation and reality are not the same. When white and black are adjacent to each other the contrast gets enhanced: white becomes whiter and black becomes blacker. On the edges of the square (fig. X) you see that the white becomes whiter. And because the effect does not occur on the corners the mind perceives grey spots. In neurobiology, when a neuron is stimulated it reduces the activity of its neighbours. This phenomena called lateral inhibition (Santen and Hansen, 1985, 11) sharpens the

![Contrast perception example](image)

 perception of a spatial profile.

6.1.3 Brightness perception

*Brightness relativity*

The absolute value of brightness as measured by a photometer is called luminance. The brain, however, judges the brightness of an object relative to the brightness of the immediate surroundings.

<table>
<thead>
<tr>
<th>Brightness (cd/m²)</th>
<th>Qualification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidewalk on a dark night</td>
<td>0.0033</td>
</tr>
<tr>
<td>Sidewalk in moonlight</td>
<td>0.033</td>
</tr>
<tr>
<td>Sidewalk under dim streetlight</td>
<td>0.33</td>
</tr>
<tr>
<td>Book illuminated under a candle</td>
<td>3.3</td>
</tr>
<tr>
<td>Wall in an office</td>
<td>33</td>
</tr>
<tr>
<td>Well-illuminated drafting table</td>
<td>330</td>
</tr>
<tr>
<td>Sidewalk on a cloudy day</td>
<td>3.300</td>
</tr>
<tr>
<td>Fresh snow on a sunny day</td>
<td>33.000</td>
</tr>
<tr>
<td>500w incandescent lamp</td>
<td>330.000</td>
</tr>
</tbody>
</table>

Fig. 6.4 Commonly experienced brightness levels (source: (Lechner, 2001, 335))
This phenomena called brightness relativity (Lechner, 2001, 337) has been used by the painters of the renaissance to create the illusion of bright sunshine (fig 6.6).

**Brightness constancy**

Another adjustment the brain makes to what the eyes see, is a phenomena called brightness constancy (Lechner, 2001, 337). When a room has windows on one end a photometer would clearly show greater luminance on the part of the ceiling near the window. The brain, however, knows that the reflectance factor of the ceiling is constant and makes you perceive the ceiling as if it has a constant brightness.

(Correlation study) The acceptability of different illuminance levels in offices and other areas has been examined to try to determine the effect of illuminance on observer preference (Illuminating Engineering Society of North America, 1994, 97).

**Preferred brightness**

The percentages of observers rating the luminance of their desk as too dark, good or too bright can be

![Graph showing percentages of observers rating luminance](image)

*Fig. 6.7 The percentages of observers rating the luminance of their desk as too dark, good or too bright (source: Illuminating Engineering Society of North America, 1994, 97)*
6.1.4 Colour Perception

Colour constancy

The sun projects different colours during the times of the day. The setting sun projects red where the rising sun projects blue light. To perceive colours in a constant way during the day, the brain adjusts the perception of colours due to differences in illumination. This phenomena called colour constancy (Lechner, 2001, 338), has very important survival implications because without it we would never recognize our own home if we returned at a different time of the day. Colour constancy is not possible, however, if more than one type of light source is used simultaneously. An object illuminated by north light (bluish) from one side and by an incandescent lamp (reddish light) from the other side will give one reddish and one bluish shadow. This effect can be avoided by not mixing light sources and by, for instance, not placing clear glass adjacent to tinted glass.

Warm and Cool colours

Another phenomenon is that the brain seems to favour warm colours. Red, orange and yellow appear to advance toward the eye, while cool colours, like blue, green and dark grey appear to recede (Lechner, 2001, 338). This is why the choice of wall colours can make a space seem larger or smaller than it actually is.

The afterimage effect

The afterimage effect (Lechner, 2001, 338) appears when you have prolonged exposure to a concentration of any colour. When a surgeon works on a bright red organ he will see a cyan organ as after effect when he looks elsewhere. The afterimage always has the complementary colour of the initial image. This is why hospitals use green sheets and wall surfaces in operating rooms (Lechner, 2001). A cyan afterimage is much less noticeable when imposed on a green sheet than when it is imposed on a white sheet.

Colour and psychology

Studies have been done on the impact of light and colour on psychological mood (Küller et al., 2006). This showed a correlation between colour in work environments and the long term effects on the subject’s mood.

![Fig. 6.8 The mood was better throughout the year for those who had the most colourfull work environment (source: (Küller et al., 2006))](image)

(fig 6.8).
The subjects that had some colour in their work environment graded their mood significantly higher than those who had colourless work environments.

Colour temperature
There is often confusion between chromaticity and colour rendering of light sources. Chromaticity refers to the colour appearance of a light source, or its colour temperature. Colour rendering refers to the ability of a light source, with its particular chromaticity to render colours of an object (Illuminating Engineering Society of North America., 1994, 98).

Experiments have shown that the preferred colour temperature of lightsources at various illuminance levels (the unshaded area). The illuminance – colour temperature combinations I the blue area can produce cold, drap environments, while those in the red area produce overly colourful and unnatural appearances.

**Colour rendering**

Variation in lamp colour rendering seems to have clear psychological effects. Lower illuminances are required from lamps with good colour rendering to achieve judgements of equivalent brightness, visual clarity and visual satisfaction than from lights with poorer rendering properties (Illuminating Engineering Society of North America., 1994, 98).

6.1.5 Spatial distribution of light

That changing the spatial distribution of light affects vision has been known since the mid nineteenth century (Illuminating Engineering Society of North America., 1994, 98) A large number of correlation studies have identified the effects of special distributions of light on visual performance and preference.

Subjects were asked to perform a task on several desks with different reflectance. They were asked to indicate at which desk they preferred to perform the task under different illuminances. The illuminances tested were 50, 100, 500, 1000 lx. As the illuminances increased the subjects preferred lower reflectance desktops. For higher illuminances (500 lx)

6.1.6 Light structure models

Much of the studies cited above can be termed “correlation studies” in that a relationship can be found between subjective responses and lighting factors such as illuminance and colour temperature. Other psychological techniques have been used in lighting research, such as semantic differential rating scales, multidimensional scaling and factor analysis. These techniques have been used to develop light structure models.
The concept of light structure is based on the notion that the experience of room lighting is, in part, an experience of recognizing and assimilating complex light patterns.

### 6.1.7 Behavioural studies

**Spatial orientation and way finding**

Light clearly affects orientation and way finding. When navigating around a barrier, people will tend to follow the direction of greater luminance (Illuminating Engineering Society of North America., 1994, 100).

**Activity and attention**

Lighting also can affect activities not directly related to seeing and vision (Illuminating Engineering Society of North America., 1994, 100). A significant reduction in sound level in a school was found when the luminance was low. The effectiveness of supplementary classroom lighting in improving attentiveness in primary school children has also been studied. Lists of words used in spelling tests were displayed at the front of classrooms. Supplementary lighting was used to high lighten the word lists in one condition. Significantly more inattentive behaviours were coded in the control condition then when the word lists were highlighted.

<table>
<thead>
<tr>
<th>Subjective impression</th>
<th>Reinforcing lighting models</th>
</tr>
</thead>
</table>
| Impression of visual clarity| - Bright, uniform lighting mode  
- Some peripheral emphasis, such as with high reflectance walls or wall lighting                                                                 |
| Impression of spaciousness   | - Uniform, peripheral (wall) lighting  
- Brightness is a reinforcing factor, but not a decisive one                                                                                               |
| Impression of relaxation     | - non-uniform lighting mode  
- peripheral (wall emphasis, rather than overhead lighting)                                                                                               |
| Impressions of privacy or intimacy | - Non-uniform lighting mode  
- Tendency toward low light intensities in the immediate locale of the user, with higher brightness remote from the user  
- peripheral (wall emphasis is a reinforcing factor, but not a decisive one)                                                                 |
| Impressions of pleasantness and preference | - Non-uniform lighting mode  
- peripheral (wall) emphasis                                                                                                                                   |

Fig. 6.10 Lighting reinforcement of subjective effects (source: (Illuminating Engineering Society of North America., 1994, 99))
6.2. What are the demands and desires for residential spaces?

6.2.1 Factors affecting the interior lighting plan

Human factors

The character and definition of a space is greatly dependent on the distribution and pattern of light and shadow. Lighting design does not start with the selection of luminaires, but with an evaluation of the occupants needs, their visual capabilities and their lifestyles.

6.2.2 Lighting criteria for interior spaces

Quality of light

Lighting bright be broadly described as diffuse or directional. Diffuse light minimizes shadows and provides a more relaxing and less visually compelling atmosphere. The artful use of directional light can provide highlights and shadows that emphasize texture and form. In many residential spaces, it is desirable to create more than one mood or be able to vary the atmosphere (See also: 6.1.8 Light structure models).

Seeing zones

A person’s visual field consists of three major zones (fig 6.11)
For visual comfort the luminance of the immediate surroundings (zone 2) should range between 1/3 of the task luminance and 3 times the task luminance (fig 6.12). The luminances of areas in the general surround (zone 3) should range between 1/10 of the task and 10 times the task (fig 6.12).

Typical task luminance range is 40 to 120 candelas per square meter. Task luminance seldom exceeds 200 candelas per square meter.
Reflectance

Reflectance is the ration between the amounts of light leaving a surface to the amount of light incident on it. To assist the designer in obtaining recommended surface reflectance’s, values are listed in figure 6.13.

Veiling reflections

Reflected glare

When the reflections of glossy glass-top tables or mirror-like surfaces in or near the visual task, the condition is known as reflected glare (Illuminating Engineering Society of North America., 1994, 608). If these reflections are excessively bright, they will cause visual discomfort.

Quantity of light

Tasks in living spaces range from simple to extremely difficult. Where sewing requires higher luminance because it’s an activity with small details and low contrast, simply orientating in an entry foyer can be done under lower luminance. Therefore adaptable lighting is recommended in rooms that facilitate tasks that require different luminance levels.

6.2.3 lighting methods

Areas for visual activities

Many visual tasks can be, and are, performed in almost any part of the home. Therefore residential lighting is planned on the basis of activities and not on the basis of rooms. After the designer determined what activities are performed in what room, the individual task areas are tied together by means of a general lighting system. The general lighting system should also help to avoid excessive luminance differences between adjacent rooms.
The equipment most commonly used to light room surfaces and create a satisfactory background for visual work includes general diffuse ceiling luminaires, wall luminaires, indirect portable luminaires and coves. In case of specific tasks such as, the use of a mirror or reading, portable or supplementary task lighting way be needed in addition to a system which provides general illumination.

Areas for relaxation

For periods of relaxation, when prolonged and exacting visual task performance is at a minimum, a low level of general illumination creates a pleasant atmosphere for conversation, watching television or listening to music. Moderate variations in illumination create a more attractive pattern of light.

Halls and stairways

The level in the hall or stair should be no less than one-fifth that of the adjacent area. Wall luminaires are crucial in creating a sensation of lightness and reducing shadows on the stairs. Therefore, luminaires should direct light to the walls, and wall and floor finishes should have high reflectance values. On stairs, it is critical that tread edges be emphasized, and that the top and bottom steps be well lighted for safety. Under no circumstances should a person descending the stairway look directly at the light source.

6.3. What are the demands and desires for studios and office spaces?

The visual effect of an office space depends in perceived luminance and colour. These may be achieved by varying surface reflectance, colour or luminance. Shadow as a design element is just as important as light.

6.3.1 Colour

Surface colours

Colour adds visual interest to a space, making it more inviting and pleasant place to work. (See also 6.1.4 Colour perception, colour and psychology). Touches of accent colour will give vitality and dramatic interest to any office area. Contrasting colours, or light and dark values of the same colour may be used at some points in the room like pictures, tapestry’s, furniture and wall covering.


Small offices can be made to appear larger and less crowded if woodwork and furniture placed against the walls have the same hue or a similar reflectance (Illuminating Engineering Society of North America., 1994, 517) Colours selected for large surface areas should have reflectance's as recommended in figure 6.14.
Light source colours

As explained in section 6.1.4 Colour perception there are two distinct application considerations with respect to colour and light sources namely, the chromaticity and colour rendering properties of the light source. In case of heliostatic mirrors there is no possibility for altering the colour specifications of the light except for using filtering glass.

6.3.2 Illuminance differences

Transient adaptation and disability glare

Luminance differences are necessary for vision. Print may be seen and interpreted because of the differences in illuminance between the white page and black print. Similarly, an interior space will be seen and interpreted because of illuminance differences of the surfaces.

![Image](source: image by the author/(Illuminating Engineering Society of North America., 1994, 518))

Within the area where visual tasks are performed large luminance differences can be problematic. If luminance-ratio limits (fig 6.15) are exceeded the chance of excessive transient adaptation, expansion and contraction of the pupil, is more likely to occur, because of continuous adaptation to the changing luminance levels. Secondly glare sources within the field of view may cause stray limes within the ocular media of the eye.

Reflectance’s and finishes

The brightness of objects depend upon illuminance as well as surface reflectance. For example, reading 80%-reflectance white paper on an evenly illuminated desk top will require that the desk top have reflectance of at least 27% (one third of 80%).

6.3.3 Visual comfort

Fenestration

Windows and skylights have variable luminance. It is therefore advisable to have exterior shading or some exterior shading or some interior device to variably control the luminance of each window.

Electric lighting and daylight

One way of integrating daylight with electric lighting is to circuit perimeter luminaries on a separate switch which may be manually or photo electrically switched or dimmed. Horizontal blinds or refractors can control brightness or, to some extent, redirect light in useful directions. (See also: 5.1 How do heliostatic mirrors
6.3.4 Visual tasks

Illuminance selection

Illuminance should be determined based on visual performance research as well as on design experience. The procedure is task specific and knowledge of the task is important. Illuminance is measured on the plane of the task. If there is more than one task in the space, and each requires a different illuminance, the designer must choose among them. If one designs for the highest level and provides diming capabilities, the user may adjust the lighting level in various areas to suit particular tasks. Multilevel lighting systems may also be appropriate.

6.3.5 Quality of lighting

Veiling reflections

As discussed earlier, the contrast of the visual task affects visibility. The contrast will depend in part upon the glossiness of the task surface and upon the geometric relationship between light sources, the task and the eyes. If the visual task produces a mirror angle between the eye and the luminaire or another bright object, contrast can be reduced. This effect is called veiling reflections, because the luminance’s of the task details and their backgrounds become more alike due to reflections of the object in the task area (fig 6.16). The area of the ceiling where the problem luminaire is located is termed offending zone (fig 6.16).

Considering multiple working spaces in one space, one luminarie placed outside the offending zone of one worker may be in the offending zone of another. Luminaire light output should therefore be limited at angles greater than 55° from vertical, to prevent veiling reflections and to reduce discomfort glare (Illuminating Engineering Society of North America., 1994, 522).

Reflected glare

Reflected glare is usually caused by a mirror image of the light source in the offending zone reflected from highly polished wood or glass covered desktops to the workers eyes. It can be reduced by the use of matter surfaces.
Shadows

Shadows on the visual task reduce the luminance of the task, and may impair effective seeing. In addition, when shadows are sharply defined at or near a task, they may be annoying and cause high luminance ratios. Shadows can be softened by light coming from different directions. High reflectance matte finishes on room surfaces become effective secondary light sources and materially reduce shadows by reflecting a significant amount of diffuse light into the space.

6.3.6 The psychological effect of lighting in offices

Although office spaces are primarily task orientated, more subtle effects of lighting on user’s satisfaction and wellbeing must be considered during the lighting design process. Light structure models (See also: 6.1.8 Light structure models) form a good foundation for designing an office that provides in a variation of different subjective moods.

6.3.7 Lighting methods

There are two methods for lighting office tasks. One is to design the general lighting so that required illuminances are provided at the various tasks (appropriate for private offices). The other is to supply most of the task illuminance with local lighting from task lighting luminaries, and provide a lower level of general illumination (mostly used in open-plan arrangements).

![Fig 6.17 Different lighting methods explained in schemes of luminaries A=Direct lighting, B= indirect lighting, C=Direct-indirect lighting (source: Image by the author)](image)

Indirect lighting

Indirect lighting illuminates the ceiling, which in turn reflects light downward. To avoid excessive luminance, the illumination on the ceiling should be evenly distributed. Two criteria should be established in evaluating an indirect lighting approach. First the maximum allowable ceiling luminance should be determined by the task. And the uniformity ratio, the ratio between the brightest and darkest area on the ceiling, should not exceed 8:1, however 4:1 is more desirable (Illuminating Engineering Society of North America., 1994, 526).

Direct lighting

Direct (downward) lighting deemphasizes the ceiling surface and the luminaries themselves, and emphasizes horizontal planes, such as work surfaces and the floor. Floor colours are reflected and may actually tint the ceiling. There are several types of controls available for direct lighting systems; Diffusers scatter the light emitted by the lamps before it leaves the luminaries. Lenses incorporate a series of small prisms which reduce the apparent brightness of the luminaire to the near- horizontal viewing angles of 45˚ to 90˚ form vertical. Polarizers reduce light veiling reflections and reflected glare under special conditions. Luminaires with a grid of parabolic louvers can control brightness precisely. The louver is an array of open cells, the walls of which form parabolic reflectors.
Direct/indirect lighting

A combination of direct and indirect approaches can produce excellent results. This combination can be provided by using two different luminaire types within the same area, one providing uplight, the other providing downlight. The other approach is to provide both upward and downward light from the same luminaire.

6.4. What are the demands and desires for (public) exhibition space lighting?

Exhibit displays can be categorised in many groups. For my research I will focus on The type of art that will be exhibited in my eventual design;

- Three dimensional objects
- Flat displays of vertical surfaces

6.4.1 Three dimensional objects

Irrespective of size a three-dimensional object must have some variation of illumination from different directions in order to provide the essential highlights and shadows which reveal the objects shape of texture. This can be accomplished by using different lamps, colour filters or beam patterns from different angles. When the object is low and small, the luminaires may be angled steeply from above, and because the viewer is not looking upward, glare is not a problem. When the object is high, some of the light might go past the display and cause glare for the viewer located on the other side of the display looking upward. Some solutions to this problem are;

1. Angle the luminaires sharply downward and relieve shadows with a high reflectance pedestal.
2. Keep the light beams entirely within the mass of the display.
3. Illuminate objects from below if that will not distort their appearance.
4. Combine ambient, diffuse lighting (fill light) in the space with narrow beam lighting (key light) on important parts of the object.

Fig 6.18 Sculpture lighting: Alan Houser's Apache warrior. Los angeles museum of natural history, 1982. (a) Key, fill and back light. (b) Key light only (c) Fill light only. (d) Back light only. (source: (Illuminating Engineering Society of North America., 1994, 581))
The sculpture in *figure 6.18* is displayed in 4 different situations. In situation (d) the sculpture is lightened by backlight which makes the object appear flat only showing its silhouette. In situation (c) only a fill light illuminates the sculpture leaving crucial parts of the sculpture as in the shadows. Situation (c) illuminates the most important parts of the sculpture with a key light, but other parts appear dark and flat. Situation (a) combines all the lights which shows the sculpture in all its dimensions and highlights the most important part.

Exhibition lighting.01

![Fig 6.19 Plan and front elevation (1:200) of situation a (fig X) with dimensions (image: by the author, knowledge: (Illuminating Engineering Society of North America., 1994, 582))](image)

In *figure 6.19* you can see the placing of the back-, key- and fill light as displayed in the Los Angeles museum of natural history. This is the same as in situation (a) *figure 6.18*.

### 6.4.2 Flat displays on vertical surfaces

Illuminating large vertical displays uniformly is often desired, but is one of the more difficult lighting problems. Paintings, prints, documents and explanatory labels are objects in this important category. Occasionally one feature of the object may need to be high lightened. This can be done with spots. A good method for providing vertical illumination is to employ wall washer luminaries. Such luminaries mounted far from the surface will mute the texture; mounted close to it, they will accentuate the texture (*fig 6.20*).
Murals

In case of murals, especially tall murals where spotlights or floodlights would cause unwanted highlights, wall washers can be used with many different lamps.

Small and medium sized pictures

For small and medium-size pictures or label panels mounted on a wall, spotlights or floodlights are usually selected. The mounting position can be determined according to the formula in figure 6.21.

\[
X = (\text{Ceilin height} - \text{Eye level}) \times 0.577
\]

Fig 6.21 Section with guidelines for luminaire mounting position. (Source: image by the author, knowledge: (Illuminating Engineering Society of North America., 1994, 584))
The formula in figure 6.21 should be used as a guide. Increase or decrease “x” as required to avoid shadows from oversize frames on paintings. Compute angle of incidence/ reflection to avoid glare to viewer. It is also possible to use optical projectors which can delineate the object in a “frame”. This so called framing can cause the object to appear self-luminous or translucent. Such effects are rarely desired, and it will be necessary to provide additional diffuse lighting.

6.4.3 Galleries for changing exhibits

Galleries for special exhibitions usually have flexible lighting systems. Flexible lighting systems may include:

1. Lighting track throughout the space
2. Ample electrical power supply in both ceiling and floor
3. Installation of lighting equipment only where needed
4. Modular ceiling panels, which facilitate substitution of different luminaires
5. Exhibit furniture that provides both display and ambient lighting or only display lighting
6. General lighting for the space

Track lighting is the most common form of flexible directional lighting. The luminaire positioning is determined by the surface to be illuminated, the object being illuminated and the lamp intensity distribution. For illuminating vertical surfaces, the angle of incidence at eye level should be between 50˚ and 60˚. Reducing the angle of incidence to 30˚ will minimize the apparent texture of vertical surfaces but may cause reflected glare. Increasing the angle of incidence to 70˚ will accentuate texture (fig 6.20). Luminaires in a track should be positioned parallel to the display surfaces. Concentric tracks located in the centre of the room can be used to illuminate displays which are not located at permanent walls.

6.4.3 Light damage

All artefacts will experience some degradation when exposed to light, even in small amounts. This, however, does not mean artefacts must be only exposed to small amounts of light. To justify light exposure the artefact must be displayed with sufficient luminance.

6.5. How do the demands and desires in terms of lighting relate to the (generic) models?

For synthesis and conclusions move to chapter 7
7 Coherent synthesis and conclusions

Based on the research that has been done, this chapter will provide a collage of coherent synthesises. The process of working towards these synthesises will be discussed and induce conclusions. Deeper and more conclusions can be obtained from making a new synthesis taking into account the lessons induced from the synthesises that are here presented. In other words this chapter is a first step in the design research.

Note

The lighting designs in this chapter are based on all the research that has been done. A final evaluation in terms of brightness levels is still absent because of some complications in chapter four. After this evaluation it could be that; (a) more artificial light should be added, (b) artificial light should be subtracted (c) the artificial lighting levels should simply change, or (d) more of the light coming from the heliostatic mirror should be absorbed and used as heat energy. In other words it would have no major impact.

7.1 Organisation 1, reflective circulation

As the title of this alternative to building organisation suggests the main element of this building is a reflective circulation space. The heliostats are directed at that space so that the directional light will bounce around and finally penetrate the adjacent floors or rooms. This principle is superficially explained in 2.1.2 internal implications for roof applications.

Freedom

This design principle induces a lot of freedom. As long as the cavity is highly reflective it can take many forms and manoeuvre thru the buildings section. If the cavity takes a lot of turns in the building, however, it is better to make the openings at the end of the cavity relatively bigger to make sure that the openings at the top of the shaft don’t let in disproportionate amounts of the light send into the shaft. The shafts opening,
most likely located in the roof, does not necessarily need to be big. Multiple lighting beams sent to a fixed mirror close to the shaft opening can direct many beams into the building via the small (roof) opening. A smaller (roof) opening however does imply that the shaft receives less diffuse light from the surroundings so that the system becomes more dependent on directional light sent in by the mirrors. A desirable shaft opening can be designed by studying the brightness levels according to the research in chapter 4.

**Overheating**

At times where heliostats cause the building to overheat, all the heliostats or a part of them can be directed towards a second target. The second target can be a water tank connected to a place where the heat can be stored. The heliostats being directed to another target provide shade for the roof so that they not only adapt to the heat demand, but even play an active role in preventing the building to overheat.

A huge advantage of this design is that directing the heliostat mirrors gradually or completely at another target only lowers the lighting levels inside the shaft and subsequently the entire building. If, however, each heliostatic mirror would send its light directly towards a particular room it wouldn’t be possible to redirect some of the mirrors without letting some of the rooms unexposed to the light, so that the system gets disturbed. In other words this design offers the possibility to send only the right amount of light into the shaft to warm the building so that subsequently the shaft will distribute the light evenly over the rooms/floors.

**Spatial level**

Because in this principle light penetrates the room as diffuse light the implications on a spatial level will be described in chapter 7.4 (Diffuse lighting from heliostatic mirrors)

**7.2 Organisation 2, direct penetration**

In the direct light penetration alternative floors or rooms receive directional light from heliostats.
Planning

The lighting beams become very dominant in determining the spatial organisation. Each room in the building requires the right amount of light beams to enter per room volume and each beam needs its own uninterrupted shaft to be able to penetrate the room as directional light. The freedom of bending sunlight, in the case of this principle, entails a whole new set of limitations. The synthesis in figure x was an attempt to plan an entire building like this and I can tell that it has failed. The concept sounds appealing but planning an entire building like this is very hard. Especially when other aspects, like the reuse of an existing building, are determining factors as well. In terms of planning can be said that the concepts of planning rooms/units around lighting beams is interesting, however, in planning an entire building according to this concept entails a lot of limitations.

Autonomy

In this concept each room or unit that is connected to one or more lighting beams can be regarded as an autonomous unit. Tuned to the amount of light penetrating the façade and the heat resistance of the shell of the unit a specific plan can be made in terms of heating and lighting. When a unit overheats the heliostatic mirror on the room that is connected to that room can reflect the light to another target. A specific heliostatic mirror that stops reflecting light inside the building does however mean that the lighting system on that specific place stops working as well. There is no gradual adaptation, like in organisation 1 (7.1 Organisation 1, reflective circulation)

Diffuse light

Where in organisation 1 diffuse light can still penetrate the reflective shaft so that the system still somewhat functions under cloudy weather, no light will reach a unit under cloudy weather in this organisation principle. Again this pleas for using this principle not so much on the scale of a building, but more on specific places where directional light may be desirable.
Spatial level

Because in this principle light penetrates the room as direct light the implications on a spatial level will be described in chapter 7.5 (Directional light from heliostatic mirrors)

7.3 Organisation 3, open floors

Open floors. The main concept of the open floors alternative is to create voids in the building floors for each individual lighting beam. Each beam has its own “target floor”, where the light will be utilised. Once a beam has reached this floor the void will stop so that the light can sing around.

Fig 7.4 Section organisation 3 (source: image by the author)
In figure 7.4 you see how two times four lighting beams are distributed over seven floors. When the first beam enters the top floor half of the beam will be passed on to the next floor, then the next beam does the same with the next two floors, and so on. The result was clear. Together the holes that have to be made for each beam were the size of a new atrium or huge vide. To cover that space up meshes should be used to still let the lighting beams pass thru. Therefore I can conclude that this concept on the scale of an entire building organisation did not become reality. This does not mean however that a part of the building can function according to the concept.

**Spatial level**

Because light from heliostatic mirrors is send to these floors in the form of directional lighting the implications on the level of a room or floor can be found in 7.5 direct lighting.

**7.4 Diffuse lighting from heliostatic mirrors**

This section introduces using diffuse light coming from heliostatic mirrors on a spatial level

**7.4.1 General principles**

**Particularity**

When a room or floor is fed by indirect light the impact on that room or floor is not that particular. The directional light from the heliostatic mirrors has become diffuse because it has bounced around in the circulation shaft and subsequently penetrates a room. This situation is similar to light penetrating from a window.
situated at the north. This section (7.4) will provide synthesis and conclusions on rooms fed by diffuse light and therefore applies on diffuse light from heliostatic mirrors as well as rooms that receive light from a façade window.

**Amount of light per room**

The size of the window that lets in the diffuse light is not necessarily fixed. What is fixed, however, is the size of the window relative to the volume of the room and the volume of the other rooms. To prevent rooms from receiving disproportionate amounts of light and heat the ratio room volume per square meter window should be about similar in all the rooms in the building.

![Fig 7.6 Diffuse light penetrating a room with a “room volume per square meter diffuse light” ratio of 18 m³/m²](image)

A low ratio would mean the rooms are very open to the light conducting shafts (circulation space) so that the light is less diffuse and hasn’t scattered around that much before reaching the room. On the contrary a high ratio would mean the light would have hit the shafts (circulation shaft) walls multiple times already before entering the space. Light hitting the shafts walls multiple times would cause more of the light to be partially absorbed so that less would eventually flow over to the rooms.

**7.4.2 Lighting methods**

According to the organisation the window that lets the diffuse light in can be in a wall, in the ceiling or even the bottom of a floor. As explained above the dimensions of these windows can vary.

**7.5 directional lighting from heliostatic mirrors**

This section introduces using directional light from heliostatic mirrors on a spatial level.

**7.5.1 General principles**

**Amount of light per room**

The synthesis on spatial level will be done in the same building volume per square meter heliostats ratio as on the level of the building as a whole. If not, the sub conclusions presented in chapter 3 (heating) do not apply.
To draw upon the same conclusions induced from the heating chapter the following synthesis will be performed with the same building volume per square meter light ratio of 130 m³/m² (fig 7.7).

7.5.2 Lighting methods

When directional light from heliostatic mirrors is planned to enter a room there are different methods to edit the experience of that beam. The first and most simple method is to let light that penetrates the shell of the room enter as directional light. And form an illuminated spot on the floor. This emphasizes that spot on the floor and creates sharp shadow lines.

Secondly light can be directed at a reflective cavity in one of the walls or ceiling. Eventually the light will enter the room via holes in the inner layer. This method will be referred to as an alternative to the anadolic lighting system that uses a similar reflective cavity.

A third method is to let the light enter the room as direct light to subsequently hit a mirror that is applied in the floor or is elevated, so that the beam gets redirected at the ceiling. This beam now diffuses via the ceiling material. This method is similar to the in 6.3.7 Lighting methods described lighting method that uses
The last method, which is an alternative to figure 7.10, is the use of a reflective chandelier that scatters and diffuses the light into the room. Depending on the design of the chandelier spots can be created on the ceiling, walls or on the floor and the material of the chandelier determines the degree of diffusing.
7.6 Moods (subjective impressions)

Light structure models (6.1.6 Light structure models) are light structures that can provide in subjective moods. In the following section I will provide lighting designs according to the light structure models and see how heliostatic mirrors can contribute to these lighting designs. It’s a free exploration of how to design certain lighting impressions with heliostatic mirrors. For all light structure models a synthesis of a generic rectangular room (fig 12-28) has been made by (Banks, 2011). These designs will form the basis of 2 syntheses I will present in this section. The first synthesis will present a similar mood/lighting design but with the contribution of diffuse light from heliostats and the second with the contribution of directional light coming from heliostats.

7.6.1 Impression of visual clarity

Design by (Banks, 2011)

As for all the other moods (Banks, 2011) made a visualisation. The impression of visual clarity, according to the light structure models, can be achieved by Bright, uniform lighting mode and some peripheral emphasis, such as with high reflectance walls or wall lighting.

![Fig 7.12 impression of visual clarity (source: (Banks, 2011))](image)

Diffuse lighting

![Fig 7.13 A resemblance of the impression of visual clarity with the use of diffuse light from heliostatic mirrors (source: image by the author)](image)

The impression of visual clarity was hard to produce. Not so much for the peripheral emphasis but for the uniform lighting. With the use of artificial lighting a chain of lightsources can produce a uniform radiation. In the case of light from heliostatic mirrors, however, this is much harder to reproduce. A skylight covered by a filter that spreads the light over the room (fig 7.13) could be a solution.
Directional lighting

As mentioned above it is hard to resemble uniform lighting with the use of heliostatic mirrors. In this scheme I tried to twin this situation by covering the lighting beam up when it penetrates the room to subsequently let it distribute gradually over the room via slits that become wider as the light moves into the room.

7.6.2 Impression of spaciousness

*Design by (Banks, 2011)*

The subjective impression of spaciousness is in very similar to that of visual clarity. A uniform, peripheral (wall) lighting with brightness as a reinforcing factor, but not a decisive one.
Diffuse lighting

![Fig 7.17 A resemblance of the impression of spaciousness with the use of diffuse light from heliostatic mirrors (source: image by the author)](image)

With the use of diffuse light I completely opened up one of the walls to gain a uniform amount of diffuse light. The other walls are highly reflective giving emphasis to the periphery of the room.

Directional lighting

![Fig 7.18 A resemblance of the impression of spaciousness with the use of directional light from heliostatic mirrors (source: image by the author)](image)

Light is sent into a reflective cavity that radiates the light in a uniform manner and emphasizes the periphery with openings directed at the walls. The walls are highly reflective giving an extra emphasis to the walls.

7.6.3 Impression of relaxation

*Design by (Banks, 2011)*

The third impression is that of relaxation. The light structure model of relaxation advises a non-uniform lighting mode with peripheral (wall) emphasis, rather than overhead lighting.

![Fig 7.19 impression of relaxation (source:(Banks, 2011))](image)
Diffuse lighting

With the impression of relaxation I tried to let light penetrate from the walls in an un-uniform pattern.

Directional lighting

With directional light I tried to emphasise the walls in a un-uniform pattern with a similar anadolic cavity as used with the impression of visual clarity.

7.6.4 Impressions of privacy or intimacy

Design by (Banks, 2011)

For privacy the light structure models aim for a non-uniform lighting mode with a tendency toward low light intensities in the immediate locale of the user and with higher brightness remote from the user. And secondly peripheral (wall) emphasis, which is a reinforcing factor, but not a decisive one.
Diffuse lighting

The diffuse solution for privacy is very simple. A window that radiates light to the surroundings of the privacy location and subsequently radiates lower levels of light to the immediate privacy location.

Directional lighting
With a directional light beam I chose to reflect the light into a cavity in the ceiling that has the size of the privacy location and radiates diffuse light to its surroundings.

7.6.5 Impressions of pleasantness and preference

*Design by (Banks, 2011)*

Another subjective impression mentioned by the light structure models is the impression of pleasantness. It can be achieved by using a non-uniform lighting mode and peripheral (wall) emphasis. The design by Banks in figure 7.27, however, does not completely meet that last criteria. Besides the description very much resembles the description of relaxation, which made me decide to skip the lighting design of this subjective impression.
7.7 Functions

7.7.1 Residential lighting

Lighting design

According to (6.2.2 lighting criteria for interior spaces) it is desirable to have more than one mood in interior spaces. Because in residential spaces lighting is planned around activities rather than rooms a suitable impression and mood should be chosen according to the planned activities (see also: 7.6 Moods (subjective impressions)). A need for differentiation of different moods even within the same space means there is not one generic design that can be made. Rather than attempting to design one residential lighting plan the plan should be a mix of different moods, lighting techniques and preferences serving the user and its activities.

7.7.2 Office and studio lighting

In the case of office space it is however possible to make a synthesis and come with abstract solutions.

Limitations

Because Heliostatic mirrors only function with directional light from the sun heliostatic mirrors are not suitable for directional task lighting. If heliostatic mirrors would be used for task lighting the workspace would not function in cloudy weather, before sunrise and after sunset. As a supplement to general lighting, however, heliostatic mirrors can really increase lighting levels and minimize the use of artificial lighting during great periods of the day.

Light design

Whether it is via directional or diffuse lighting the light can be conducted via the principles explained above. To avoid great brightness differences the principles that diffuse the light are preferred. Sharp shadows create vibrant and appealing experiences that can be preferred in an artistic studio but for normal office functions a softer diffuse lighting is desired.

Moods

Although office spaces are primarily task orientated, more subtle effects of lighting on user’s satisfaction and wellbeing must be considered during the lighting design process (6.3.6 The psychological effect of lighting in offices). For synthesis and conclusions about providing in several moods, move to 7.6 Moods (subjective impressions). Besides lighting structures that can influence the impression effective use of colour also contributes to a pleasant workspace.

7.7.3 (Public) exhibition lighting

The role of heliostatic mirrors

As (6.4.3 Light damage) explains excessive exposure to light damages the artefacts. Any exposure to light should be justified by excellent display to the public. Since light from heliostatic mirrors is very unpredictable it is not advisable to use it of the display of art. Within exposition space the mirrors should contribute to a desired atmosphere by using one of the techniques I've experimented with in 7.6 Moods (subjective impressions).
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Appendix list

Appendix 1. Model 1 energy calculations.XLSX

Appendix 2. Model 2 energy calculations.XLSX
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