The Light Cone in the Norwegian Office Building: Statoil at Stjørdal

Barbara MATUSIAK
Professor, Norwegian University of Science and Technology, NTNU, Faculty of Architecture and Fine Art, Trondheim, Norway
E-mail: barbara.matusiak@ntnu.no

Toshiki AOKI
Master student, Norwegian University of Science and Technology, NTNU, Faculty of Architecture and Fine Art, Trondheim, Norway
E-mail: tohiki.aoki@ntnu.no

Randi PEDERSEN, Nina KIELLAND, Marit ENDRESEN
Per Knudsen Arkitektkontor AS, Trondheim, Norway
E-mail: nina.kielland@pka.no

ABSTRACT
The sunlight at high latitudes is characterized by a very low mean solar angle during the year (30° at noon, Oslo) and the “around the horizon” solar route. The solar glare is a challenge.

The idea behind the Light Cone is to change the direction of sunbeams from near-horizontal to near-vertical. This is done with the help of a set of especially designed and scientifically tested mirrors, creating a nice 3-dimensional shape situated at the roof. The Light Cone is protected against the weather by a glass canopy. The sunbeams are reflected from the mirrors down to the ground floor through a cone-like space created with the help of circular floor openings with increasing diameters and a metallic web suspended around them. The Light Cone is also a form of artistic decoration, especially at the entrance hall. Visitors can admire a beautiful play of light at the surface of the web and a gradation of sunlight at the stone floor.

Keywords: Daylight, Sunlight, Sky light, Reflector, Mirror, Light redirection, Architecture Design,

1. INTRODUCTION
The sunlight at high latitudes is characterized by very low mean solar altitude during the year (30° at noon at the equinox in Oslo) and the “around the horizon” rather then “up and down” solar route. The solar glare is a serious challenge.

How to utilize sunlight in buildings situated at high latitudes?

The most typical method is transmission through windows and/or skylights equipped with different forms of solar shading devices. The most common sun shading systems for windows in office buildings situated at high latitudes are traditional internal venetian blinds. In apartment buildings different types of roller blinds and curtains are used. All those traditional systems transmit only a little part of solar radiation, the most part is reflected back to the atmosphere. To increase the usage of solar radiation in buildings many ideas of new daylighting systems have been developed in the last 20 years. Köster [5] developed a series of effective solar shading systems for windows having retro-reflective
facets, Scartezzini [8] worked with anidolic light concentrating systems for windows and skylights, Whitehead [9] at el. developed a core sunlighting system with a series of sun tracking mirrors fixed on facades and a transport system enabling delivery of sunlight deeply into the building. A wide spectrum of new systems was tested and described in connection with the CIE Task 21 Ruck [7] and a very good overview of those systems was published by Kischkoweit-Lopin [4]. Daylighting systems and components were also classified, described and experimentally analyzed within the framework of the European Concerted Action Program on Daylighting, Baker [2, 3]. Some of the ideas and systems were studied for application at high latitudes in windows, Arnesen [1], or in atrium buildings, Matusiak [6]. Why have only a very few of those new ideas been implemented? The typical challenges connected to sunlight utilization are unpredictability and continuously movement of the sun.

To deal with unpredictability of the sun in a building where constant lighting is needed a supplementary electrical light system that can be used in tact with sunlight presence/absence is necessary. To deal with the movement of the sun, two strategies may be used. The daylighting system has to have movable elements tracking the sun. Alternatively, it has to be composed of a series of non-moveable elements placed and oriented such that each of them enables reflection of sunlight coming from a small part of the sky. Any tracking element is expensive and needs much maintenance; fixed reflectors are not efficient since they operate in a short period of time.

2. THE IDEA OF THE LIGHT CONE

The idea of the Light Cone appeared at the architectural office Per Knutsen Architects (PKA) during the design of a large office building of the Statoil Company in Stjørdal and was developed further in cooperation with other authors. The objective was to deliver daylight, both sunlight and sky light, inside an office building with the help of an especially designed reflector placed at the roof. The reflector was supposed to change the direction of sunbeams from near-horizontal to near-vertical.

The very first illustration of the Light Cone idea is shown in figures 1 and 2. The Light
Cone was supposed to be clearly visible from the outside as a light sculpture and become a landmark at the countryside landscape surrounding the building. In the entrance hall the Light Cone was supposed to create a light space that would attract people, indicate the way to the main entrance gates and make a visual connection with circulation areas at upper floors. The placing of the Light Cone is also shown at the plan of the first floor in figure 4.

3. THE SHAPE OF THE REFLECTOR

As may be observed in figure 1, the first idea of the Light Cone assumed one non-moveable reflector having flat specular surface with facets placed about 3m above the roof and protected by a glazed canopy. This reflector shape enables reflection of rather low sunlight down to the building for a very short period of time. Most of the time the sunlight reflected from it will fall outside the roof opening. To increase the operation time, the reflector has to be placed closer to the roof and has to be composed of a series of mirror surfaces with different orientation, and with sloping optimized for altitude angles in the range 0-50º. The highest altitude angle of the sun during the year in Stjørdal is about 50º. A specular shape that reflects sunlight from any azimuth angle and any solar altitude < 50º down to the building may be composed of three rings, the lowest and largest ring may reflect very low sunlight 3° - 26° a middle ring placed over the first ring may reflect sunlight from altitudes 26°-36°, and the smallest ring may be optimized for altitudes between 37° and 50°. Such reflector shape will secure the reflection of the sunlight down to the building for any position of the sun at the hemisphere, but will limit the penetration of the diffuse light from the sky. How can the reflector shape be optimized for both, the direct sunlight and the diffuse light from the overcast sky?

The sun appears at the northern part of the hemisphere before 8:00 in the morning and after 18:00 in the evening, i.e.
time periods outside the typical operation time of the office building. If the light cone is oriented exactly north-south, the reflection of the sunlight from the northern hemisphere may be disregarded and the circular rings may be reduced to half-rings.

The following reflectors were proposed for evaluation, see figure 3:
- Reflectors 0 made of concentrically arranged sloped rings,
- Reflectors 1 made of concentrically arranged sloped half-rings composed in a single 3-dim. shape,
- Reflectors 2 made of separate sloped half-rings,
- Reflectors 3 made of concentrically arranged separate sloped half-rings

Reflectors 1-3 were also tested without the top half-ring i.e. with two half-rings (2 layers), the number of layers is given in brackets, see figure 3.

4. EVALUATION METHODS
4.1 physical model studies
A physical model of a small part of the office building including the entrance hall with the Light Cone was made in the scale 1:20.

To test the penetration of the sky light from the overcast sky, the daylight factor was measured at the physical model placed in the artificial sky of the mirror box type in the daylighting laboratory at the Faculty of architecture, NTNU. The measurements were taken along the N-S and the E-W lines crossing the circular projection of the Light Cone at the ground floor, see measurement points in figure 4 and the results in figures 5. To test the visual impression and the solar glare danger inside the building, sunlight studies were done in the same daylighting laboratory, this time the model was
placed beneath the artificial SUN. The sunlight studies resulted with a series of photos, see table 2.

3.2 computer simulations

Computer simulations were done with the help of the advanced lighting simulation software, Radiance. The numeric sky model “clear sky with sun” was used. To test the effect of the Light Cone alone, only the opening in the roof with the respective reflectors was simulated, windows were not.

Table 1 shows some of the results of the Radiance simulations. Pictures were “taken” from the center point of the hole at the 2nd floor.

5. RESULTS AND DISCUSSION

5.1 Overcast sky conditions, DF measurements

All reflectors made of mirrors placed over an opening in the roof reduced the penetration of diffuse light from the sky. In comparison with “No reflector”, Reflector 0 caused the strongest reduction (40%). The reduction caused by Reflector 1 (3 layers) and by Reflector 2 (3 layers) was respectively 25% and 26%.

The obstruction of the sky light is a little smaller for reflectors having only 2 layers of mirrors, see two alternative design of Reflector 2 (3 layers contra 2 layers).

---

Fig. 6. Low sunlight at Reflector 1. Sunlight from the south direction to the left and from the west direction to the right.

Tab. 1. Radiance simulations, illuminance in and around the Light Cone.

Tab. 2
The impact of the net on the daylight distribution, summer at 12:00.

Fig. 7. Two types of metallic net.
Among Reflectors 1, 2 and 3, (all with 2 layers), Reflector 3 causes the smallest reduction, about 22%. Regarding the sky light obstruction, the difference between reflectors 2 and 3 is very small.

5.2 Clear sky with sun, Radiance calculations
The Radiance Simulations show that all reflectors reduce the illuminance at the ground floor in summer solstice (12:00 altitude=50º), the highest illuminance occurring when the roof opening is without reflectors “no reflector”, Reflector 3 (2 layers) and Reflector 2 (3 layers) perform best i.e. give the highest illuminances.
Simulations for spring equinox (12:00, altitude=27º) show that all reflectors increase the illuminance at the ground floor and create some sun paths on all floors. Reflectors with 2 layers create fewer sun paths than Reflectors with 3 layers. Reflector 2 (3 layers) seems to be the best one and Reflector 3 (2 layers) the second best, as both cause much higher illuminances than “no reflector”.
Reflector 1 gives the lowest illuminance of all reflectors in both situations. Simulations for winter solstice (12:00, altitude 4º), not shown graphically here, testify about high potential of Reflector 1 for redirecting sunlight from low altitudes, but this is limited to the actual south direction. The low sunlight from other directions will only partly fall at the inside of the reflector 1, as may be observed in figure 13.
Of all reflector types, Reflector 2 has the highest potential for obtaining the most efficient redirection of the sunlight. The difference between 2 and 3 layers in Reflector 2 is not significant. The 3rd layer creates more sun patches.

5.3 Sunlight, model studies in the artificial sun
The impact of the net was studied in the physical model with Reflector 2 (2 layers).
The photos in table 2 show the penetration of sunlight to the respective floors. Since Reflector 2 does not cover the whole roof opening, the sunlight penetrates to the 2nd floor, making a large sun spot on the floor and creating a risk for glare in the neighborhood of the Light Cone. When a metallic net was added to the model, it appeared clearly that the net partly reflects sunlight down to the ground floor, partly to the ceiling on the 2nd floor. The daylight level on the 1st and 2nd floor was reduced a little, but the illuminance measured at the light spot at the ground floor was strengthened significantly (>15%). The play of light at the net was described by observers as a beautiful sun shine.
Full-scale samples of two metallic net types were taken outside and were examined in true daylight in June 2010. It became clear that both types are very transparent, thus the visual contact through the net is maintained. The bright, glaring patterns may occur at the net in the case of very strong solar radiation. Net 2 appears more glaring than net 1 which has a strong directivity. The experience of glare is strongest if the sunlight and the observer are at the same side of the net.

6. CONCLUSIONS
Since the probability of sunlight in Norway is highest in Spring and Summer, it is important to choose a reflector that is most effective for middle high and high altitudes.
Reflector 1 is the easiest one to construct, probably the cheapest one also. It has a very nice shape. It obstructs diffuse skylight more than Reflectors 2 and 3. It is very effective as a reflector of low sunlight down to the ground floor,
but only for a narrow range of azimuth angles. It could be used as a movable reflector (around the circular opening) in another project/building.

Reflector 2 has the highest potential for redirection of sunlight, especially Reflector 2 with 3 layers. Since it obstructs the diffuse sky light only a little more than Reflector 3, it was recommended for construction.

Reflector 3 obstructs the diffuse light from overcast sky the least. Its potential for redirecting sunlight is high but lower than that of Reflector 2.

Since the illuminance at the ground floor will be reduced by the glazed canopy that was not included in this study, much care should be taken to do not obstruct the Light Cone space with any additional elements, such as lighting fixtures, ventilation ducts etc.

The Light Cone will become a form of artistic decoration, especially at the entrance hall. Visitors will be guided by light toward the entrance to the main department inside the building. They will also admire a beautiful play of light at the surface of the web and a play of sunlight at the ground floor covered by the Norwegian shale stone. At darkness the artificial light will create a weaker and softer environment, visible also from the outside. The Light Cone will become a landmark.

REFERENCES