Controlling Daylight to Optimize Light Quality

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Introduction

Natural daylight is the key ingredient in allowing occupants to perceive their surroundings spatially as well as enhancing their optical comfort level. Daylight provides an essential element for experiencing architecture. Without daylight space would be void of any character and depth. Light also provides visual interest and character, which help shape our mental perceptions spatially. It is of the utmost importance that designers integrate daylight for occupant well being and quality of experience. This paper will examine basic concepts of how humans perceive light and strategies on how to achieve comfortable lighting levels. Two case studies will be analyzed in order to convey experiential daylight qualities of each building.
Human Visual Perception

The image that the retina perceives and the way the brain interprets that image are critical in creating a conscious perception of our world. Light enters the eye through the pupil which is controlled by the iris. The iris is the mechanism that controls the amount of light entering the eye. This lens focuses the image on the retina which relays a visual message to the brain via electrical impulses. The retina is able to perceive light through two types of light sensitive cells; rods and cones. The cones allow the eye and brain to discern detail and also gives us our sense of color. The cones allow humans to detect luminances in the range of 3 to 1,000,000 cd/m² (MEEB, p481). The rods are extremely light sensitive cells that can detect luminances from 1/1000 cd/m² to 120 cd/m² (MEEB, p481).

Our field of vision is also important in creating a three dimensional image of our environment. Our central (foveal) vision is where acute perception of detail occurs. Surrounding the foveal area is the binocular cone of vision where most of the rough visual information is gathered. Beyond the binocular vision cone is the farfield monocular area of vision which is essentially our peripheral vision. The peripheral vision gives us our subjective context. (Figure 01-03)

Sensation of Vision

The sensation of vision is caused by light entering the eye. The light can be thought of as a group of convergent rays emanating from different points in space thus carrying different levels of visual information. The composite of these rays comprises the entire visual image that the eye sees and the brain comprehends. These rays of light determine and describe the perceived brightness of an object or space. Basic visual tasks involve the use of the central foveal vision which includes focusing and concentrating on small details. There are three important factors when considering the perception of simple visual tasks:

- low contrast
- fine detail
- brightness gradient

A good lighting environment consists of low glare, acceptable luminance ratios, white light, and an observer with unfatigued eyes.

Transmittance

Lighting design is possible because light has inherent predictable properties and obeys certain laws of physics. The luminous transmittance of a material such as a luminaire lens or diffuser is a measure of its capacity to transmit incident light. The measurement of transmitted incident light is known as three various terms

- Transmittance
- Transmission factor
- Coefficient of transmission

These terms define the ratio of the total transmitted light to the
total incident light. In general, transmission factors should be used only when referring to materials displaying nonselective absorption. The following is a list of various types of glazing and transmittance percentages. (MEEB, 469)

- Clear glass: 80% - 90%
- Frosted glass: 70% - 85%
- Solid opaque glass: 15% - 40%

**Reflectance**

Reflectance is a measurement of total light reflected. The light reflected may be specular or diffuse, or a combination of both. Diffuse transmission takes place through any translucent material such as frosted glass, white glass, and translucent Plexiglas. This diffusing principle is widely employed to spread light throughout a space generated by a light source. Reflectance is the ratio of reflected light to incident light and is known as three various terms:

- Reflectance
- Reflectance factor
- Reflectance coefficient

The amount of absorption and reflection depends on the type of material and the angle of light incidence, because light impacts a surface at various angles it tends to be reflected rather than absorbed or transmitted.

Recommended Reflectance:
- Ceiling: 60-90%
- Walls: 30-80%
- Working Surfaces: 20-60%
- Floors: 10-50%

**Diffused and Directed Light**

Diffused light is emitted from large luminous surfaces. Diffusion creates an even soft light that illuminates a space evenly without creating hard shadows or causing reflections. Directed light is emitted from a single light source and creates shadows on objects and rough surfaces and reflects off of reflective surfaces. Brilliance effects are caused by reflection or refraction of directed light and they depend on the luminance of the light source. The optimum level of light is the balanced ratio of diffused and directed light. Daylight from a clear sky has a "ratio of directed to diffused light of between 5 to 1 and 10 to 1." (Climatedesign p.21)
Research has found daylight to be an important factor influencing human behavior, health, and productivity. Windows admitting daylight provide occupants with a view and a connection with the outdoor environment. The function of a window has an inherent task to provide daylight and a view to the outdoors. The most preferred views from a window include the sky, the horizon, and the ground. The connection to the temporal qualities of daylight improves our psychological well-being and productivity. In studies of classrooms, researchers found that students with more daylighting in their classrooms progressed faster on math and reading tests than students with less daylighting. Also, glare negatively impacts a student’s comprehension abilities, and allowing the teacher or student to control the amount of sun penetration can greatly increase a student’s ability to learn. In offices, people enjoy having windows in their work space because they feel connected to the outdoors. Windows also provide functional advantage where people can look into the distance to reduce eye fatigue after doing close desk tasks. Depending upon the type of building, the designer should be aware of the special circumstances that the occupants will be confronted with while inhabiting a building.

**Quality of Light and Glare**

Quality of light is a term used to describe all the factors in a lighting scheme. Quality of light describes the overall scene which takes into consideration the luminance, diffusion, uniformity and chromaticity of the lighting. One factor that detracts from a comfortably lit space is glare. Glare is produced by bright surfaces within the field of vision and can be experienced as discomfort glare or disabling glare. The difference between these two types of glare are:

- **Discomfort glare**: which is only bothersome when viewing an object in space.
- **Disabling glare**: reduces the capacity of the eye to perceive an environment optically.

Glare is created when excessive luminance or luminance ratios are perceived within the field of vision. There are two main types of glare: direct and reflected. Direct glare is caused by too high of luminance in the viewing field. Discomfort of direct glare stems from two conditions.

1. The eye adapts rapidly to the average brightness of the overall visual scene
2. The eye is attracted to the highest luminance within the field of vision.

Reflective glare is caused by too high a luminance contrast in the field of vision. Reflective glare depends on the reflectance and the position of the reflecting surface in relation to the glare light source by the observed object or surrounding environment. Glare decreases rapidly as the brightness source is moved away from the direct field of vision. Thus the glare produced depends on the source’s location relative to the field of view. The amount of the discomfort glare produced is inversely proportional to the adaptation level of the eye.

Glare is a difficult problem to overcome when balancing daylight and view. Any window can produce problematic glare if the window is within the field of view. High contrast ratios between a window and adjacent surfaces can occur unless the window is designed to reduce luminance ratios through the use of sunshading devices, lightshelves, or high-reflectance interior surfaces. There are certain strategies that help control daylight and reduce glare in interior spaces such as:

- Exterior fixed shades that exclude sunlight for all sun positions.
- Use systems that diffuse the incident sunlight sufficiently to eliminate glare potential.
- Occupant-controlled adjustable shades.

**Daylight and the Design Process**

Designing for the use of daylight is an integrated approach that spans all phases of the design process. While priority of overall design goals change throughout the design process, maintaining a consist thread for the treatment of daylight will provide a satisfactory result during
building occupancy. Daylighting design begins with the initial siting of a building which directly affects the subsequent phases of design.

During the Schematic Design phase, establishing orientation, building form, floor plan, and fenestration are key elements to drive the design into the next phases. Design Development consists of specifying materials and finishes that would compliment the decisions made during schematic design. Also integrating building systems such as electrical and mechanical equipment to optimize building performance should be established in accordance with occupancy schedules. During the Construction Document phase it is critical that the detail drawings clearly explain how the tectonics of the building are assembled in order to for the general contractor to bid the correct materials and ensure that they are installed correctly. Once the building is occupied, it is important to track the buildings performance in order to understand how to maintain and fine tune the building systems. Finally the last important phase of the building and design process is to provide a post-occupancy evaluation (POE). The POE is critical in determining overall occupant satisfaction, visual comfort, and daylighting performance. It allows the designers to gain a better understanding of how their decisions actually perform in reality and what changes need to be made in future projects.

Energy Savings with Daylighting

Designing with daylight can improve energy efficiency by minimizing the use of electricity for lighting as well as reducing associated heating and cooling loads. Daylighting is a critical design factor to those concerned about global warming, carbon emissions, and sustainable design. Now that we have entered what Thomas Friedman calls the “Energy Climate Era” designers must confront the rising cost of energy and rapid depletion of natural resources. To obtain lighting energy savings the Illuminating Engineering Society of North America (IESNA) have provided six essential recommendations for daylighting design. (MEEB, p.588)

1. Plan interior space for access to daylight.
2. Minimize sunlight in the vicinity of critical visual tasks.
3. Design spaces to minimize glare.
4. Zone electric lighting for daylight-responsive control.
5. Provide for daylight-responsive control of electric lighting.
6. Provide for commissioning and maintenance of any automatic controls.

Aperture Strategies: Sidelighting

Sidelighting systems provide light from apertures in window walls where daylight penetrates the space from one or more sides. The distance to which usable daylight illuminates a space and is reflected onto a work surface is the challenge for designers. Sidelighting is best for desk tasks because there are no veiling reflections. There are various sidelighting strategies that provide greater illuminance farther into a space and improve visual comfort. Below is a list of strategies when developing a sidelighting system

- Bilateral lighting: When a space is lit from two walls and distributes daylight evenly
- Place windows high on a wall. Daylight will penetrate farther into a space and have a uniform distribution.
- Use the ceiling as a reflecting surface by placing window
heads as close as possible to the ceiling.

- Use adjacent interior walls as reflectors, which reduces the contrasting edge around the window.
- Provide daylight filters such as trees, vines, and trellises to diffuse daylight.
- Provide summer shading with exterior louvers, overhangs, and lightshelves that can block direct sunlight, and reflect diffused sunlight into a space.
- Provide light-colored materials or finishes on shading elements that will reduce contrast and reflect light deeper into a space.

Toplighting

Skylights, heliostats, and clerestories are suitable apertures for allowing daylight to penetrate the roof plane of a building and allowing light to enter interior spaces. These strategies are helpful when perimeter windows cannot allow daylight into deep interior areas. To prevent veiling reflections or direct glare situations with toplighting apertures, and interior reflectors should be used to diffuse and control daylight. The following are a few toplighting strategies that will enhance overhead daylight.

- Splaying the sides of a skylight washes light along a larger surface area and reflects diffuse light into the space. It also reduces glare.
- Place toplights high in a space, this allows for more surface area for light to diffuse upon.
- Use interior devices to block, or diffuse light that can be redirected by a reflector below a roof aperture.

Innovative Daylight Strategies

There are a number of innovative daylighting systems that allow natural light to penetrate interior spaces and enhance the quality of light. These systems include prismatic panels, solar tubes, heliostats, and fiber optics. Some advanced systems use reflectors and lens to concentrate light into a conductor device that can disperse light more effectively and evenly. Though these systems can be quite costly due to the materials used and the time to develop such products, their viability is proven through the reduction of artificial lighting needed during daytime hours. These specialized lighting systems reduce overall energy consumption while increasing the mental well being of building occupants.

Light harvesting blinds redirect daylight into interior spaces while reducing glare. When sunlight hits the blind, the specular upper side of the slat turns toward the exterior and provides perfect sun shading due to the reflection of the sunrays.

Light pipes operate through channeling light from a heliostat into a highly reflective tube made of prismatic glass, aluminum film, or mirrors. Light pipes can transport light 65 ft. from a single light source and is able to diffuse the direct sunlight at the end of the pipe resulting in an even distribution of light.
Daylight Pipes are light shafts that have highly reflective surfaces and are capped by a clear skylight. The amount of light transmitted into the interior depends on the diameter of the shaft. This system is convenient and economical for supplemental illumination. Tubular skylights are able to diffuse direct sunlight through a stratified layer of reflective material, which softens and evenly distributes daylight.

Advantages of daylight pipes:
- Savings on artificial lighting due to sufficient daylighting
- No solar protection necessary
- A lower proportion of openings in the roof due to utilization of the sun
- A positive effect on the people due to daylight
Case Studies

Within this section of the paper I will transition from a technical approach to a perceptual approach of analyzing daylight within buildings I have visited during my time in Europe. I hope to convey an experiential qualities through the treatment of daylight.

Kunsthaus
Architect: Peter Zumthor
Location: Bregenz, Austria.

The facade consists of frosted glass panels that serve multiple functions. They give the building an inherent lightness with the translucency of the panels and insulates the concrete core of the building against varying weather conditions. The panels essential role is diffusing the incoming daylight for the overall interior lighting scheme. The frosted glass envelope was designed as a self-supporting structure independent from the concrete core of the building. It completely encases the core of the building with glass on the interior as well as the exterior. Between the two layers of glass is a three foot wide gap that allows daylight to enter the first subterranean level and also houses the light installation which illuminates the Kunsthaus at night.

Three vertical concrete slabs support the floors and ceilings of the interior core of the building. These slabs and walls delineate the interior space and divide the vertical arrangement of the building. The service functions for the building have been placed outside the main structure, in order to allow for three large span gallery spaces The Kunsthaus offers 1500 sf of exhibition space per floor, and about 2,000 sf on the ground floor.

This museum has an frosted glass exterior skin that diffuses direct sunlight and allows it to penetrate along the edges of the interior spaces. This treatment of daylight allows the occupant to be connected with the exterior without having any visual access to the outdoor environment. The bright edges in the museum are extremely apparent and the architect uses this edge condition to create a soft gradient of light throughout the gallery spaces The diffused light that floods the gallery spaces is optimal for displaying and viewing art. Zumthor employs a frosted glass suspended ceiling on the inside of gallery spaces which are backlit with artificial light that mimic a natural daylighting effect. He uses this type of glazing to conceal the artificial lighting above and to trick the user into thinking that the gallery is completely lit by daylight. The stairwells are completely lit with diffused daylight through a frosted glass ceiling. The glazing encourages the user to walk up the stairs towards the next gallery space as if the gallery space is emitting the light for the stairwell.

All the gallery spaces have the same floor plan and detailing but the artwork in each gallery has the ability to affect the overall ambiance of the space. Another interesting aspect are the reflections created within the polished concrete floor. The soft diffused light creates timid reflections that give the floor the quality of walking on ice.

Through the treatment of daylight and the uniterupted gallery space, the elements of art and architecture begin a dialogue with each other so
they are seen not as isolated objects but as one subject matter coexisting in a single space.

Case Study II

The Oskar von Miller Forum
Architect: Thomas Herzog + Partners
Location: Munich, Germany

The Oskar von Miller Forum is a prime example of German engineering and design in terms of daylight. The major component for manipulating daylight is its double skin facade which acts as the mediator between indoor and outdoor conditions. Its ability to diffuse daylight while maintaining a connection with the changing outdoor environment increases the quality space and well being of its inhabitants. This building has integrated many different approaches in how to manipulate daylight.

The ground level has large expanses of glass that open towards the public realm of the street and conveys a sense of openness to the community. The large glazing panels allow daylight to penetrate deep into the lecture hall. The large movable panels inside the lecture hall control and diffuse daylight through the application of the micro-perforated fabric. This allows the lecture to create a controlled environment in terms of light quantity and quality. The lecture hall has a dual nature where it can be opened and closed depending on the type of event taking place.

The sawtooth double skin facade is located on the prominent south facade of the building, which integrates several strategies in controlling daylight. The southwest glazing of the sawtooth is transparent and allows direct daylight to penetrate the first layer of the facade which is then diffused by the wooden louvers in the second layer of the double skin. The southeast glazing is translucent and immediately diffuses the daylight upon entering the southeastern direction of the facade. The transparent panels allow for views towards the southwest which would not be possible if the entire facade consisted only of translucent panels. This creates a connection between the occupant and the outdoor environment which is important for mental well-being.

Fig. 20 OvMF Forum Exterior

Fig. 24 OvMF Sawtooth double skin facade

Fig. 21 OvMF Lecture Hall

Fig. 25 OvMF Sawtooth double skin facade daylight diagram
The wooden louvers within the second layer of the double skin facade allow occupants to manipulate its position according to their specific daylight needs. This factor is important because it allows the occupant to become an active participant within the overall building system. It allows them to control their environment instead of the building automation system dictating what the indoor environmental quality should be.

The metal perforated panels on the east facade were designed to control light levels in the stairwell which would prevent overheating. These panels supposedly are opened and closed according to the building automation system. These panels could be more successful if the occupants had the ability to change their configuration similar to the wooden louver panels on the south facade. If the occupants could control the exterior metal panels the stairwell would have varying levels of light instead of having a monotone light level. This would increase the character of the space visually as well as experientially. The occupant driven configurations would give the facade a sense of vitality and would produce various aesthetic qualities on the interior as well as the exterior.

The glazing on the east facade of the building has embedded micro-louvers that reflect direct sunlight towards the exterior, which reduces glare and decreases the light level in the hallway adjacent to the professor’s apartments. The translucent glass panels that separate the apartment from the hallway allows diffused light to enter the apartment thus creating a bilateral lighting effect which reduces glare and visual contrast.

The Oskar von Miller Forum employs different daylight strategies that directly reflects the specific use of certain spaces. The careful attention to detail allows the interior spaces to become visually comfortable as well as aesthetically pleasing. The integration of building automation and occupant driven manipulation produces indoor environments that are continually changing thus adding to the overall dynamism of the interior space.

**Conclusion**

Daylight has numerous strategies which designers can employ to affect the overall quality of architectural space. In order for daylight to be a critical element of a building it must be fully integrated throughout the design process and the building systems. It cannot be treated as a trivial aspect of nature because of its abundance. Rather it is the one resource that architects can rely on to help shape their buildings. By allowing daylight to enter interior space it creates numerous benefits that are both psychological and experiential.
Figures

Figures 1-9: Mechanical and Electrical Equipment of Buildings

Figure 10-12: Created by Alberto Rodriguez

Figure 13, 15-20: Photos taken by Alberto Rodriguez

Figure 14: http://cache.wists.com/thumbnails

Figure 21-29: Oskar von Miller
Forum Presentation by Roland Schneider

References

