Daylight in Building Design 2.

For centuries, daylight was the only efficient source of light available. Architecture was dominated by the goal of spanning wide spaces and creating openings large enough to distribute daylight to building interiors. Efficient artificial light sources and fully glazed facades have liberated designers from these constraints of the past. Advanced daylighting systems and control strategies are another step forward in providing daylit, user-friendly, energy-efficient building environments. These systems need to be integrated into a building's overall architectural strategy and incorporated into the design process from its earliest stages. This chapter outlines the design considerations associated with enhancing a building's daylight utilization while achieving maximum energy efficiency and user acceptance.

Planning for Daylight at the Conceptual Design Phase 2.1.

building	**room**	**window**	**daylighting systems**
daylight availability	relation to adjacent spaces	design of facades and windows	function of system(s)
latitude	autonomous		multiple functions
sun shine probability	borrowing light	single design	glare, shading, redirection
temperature	giving light	multiple design	
...	interchanging light	division within windows	glare, solar shading
obstruction	fenestration		glare, redirection
building design scheme	unilateral, sidelight	division between windows	shading, redirection
beam shaped	unilateral, top-light		single function
courtyard/atria	multilateral, sidelight		protection from glare
block	multilateral, sidelight and top-light		solar shading
nucleus			redirection
...	proportion		other function
	height to depth, ratio		

TABLE 2-1: THE PROCESS OF DESIGNING FOR DAYLIGHT IN BUILDINGS

Daylighting strategies and architectural design strategies are inseparable. Daylight not only replaces artificial lighting, reducing lighting energy use, but also influences both heating and cooling loads. Planning for daylight therefore involves integrating the perspectives and requirements of various specialities and professionals. Daylighting design starts with the selection of a building site and continues as long as the building is occupied.

Daylighting planning has different objectives at each stage of building design:

- **Conceptual Design:** As the building scheme is being created, daylighting design influences and/or is influenced by basic decisions about the building's shape, proportions, and apertures, as well as about the integration and the role of building systems.
- **Design Phase:** As the building design evolves, daylighting strategies must be developed for different parts of the building. The design of facades and interior finishing, and the selection and integration of systems and services (including artificial lighting), are all related to the building's daylighting plan.
- **Final/Construction Planning:** The selection of materials and products is affected by the building's daylighting strategy; final details of the daylighting scheme must be worked out when construction plans are created.
- **Commissioning and Post-Occupancy:** Once the building is constructed, lighting controls must be calibrated, and ongoing operation and maintenance of the system begins.

2.1.1. Daylight Availability

All daylighting strategies make use of the luminance distribution from the sun, sky, buildings, and ground. Daylight strategies depend on the availability of natural light, which is determined by the latitude of the building site and the conditions immediately surrounding the building, e.g., the presence of obstructions. Daylighting strategies are also affected by climate; thus, the identification of seasonal, prevailing climate conditions, particularly ambient temperatures and sunshine probability, is a basic step in daylight design. Studying both climate and daylight availability at a construction site is key to understanding the operating conditions of the building's facade. The daylighting design solution for the building should address all of these operating conditions.

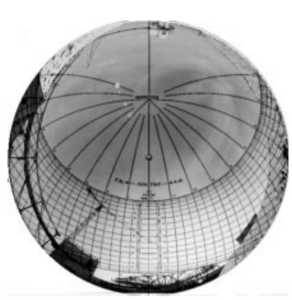

Figure 2-1: Sunpath diagram projected on a fisheye photograph of the site

There are several sources of information on daylight availability [Dumortier 1995]. For example, daylight availability data has been monitored every minute at more than 50 stations worldwide since 1991 (http://idmp.entpe.fr) and has also been monitored in the Meteosat satellite every half hour from 1996–1997 (under beta testing).

High latitudes have distinct summer and winter conditions; the seasonal variation of daylight levels is less apparent at low latitudes. At high latitudes where winter daylight levels are low, designers usually aim to maximize daylight penetration in a building; redirection of daylight into buildings from the brightest regions of the sky is an appropriate strategy at these latitudes. By contrast, in the tropics where daylight levels are high throughout the year, the design emphasis is usually on preventing overheating by restricting the amount of daylight entering the building. The obstruction of large parts of the sky, especially of areas near the zenith, and the admission of daylight only from lower parts of the sky or of indirect light reflected from the ground are useful strategies in tropical regions.

Daylight availability strongly depends not only on the latitude but also on a building's orientation; each orientation will require a different design emphasis. Study of vernacular architecture and past successful daylighting designs is a good way to understand the relationship between climate and building design.

2.1.2. The Building Site and Obstructions

At a construction site, the sky is usually obstructed to some extent by surrounding buildings and vegetation.

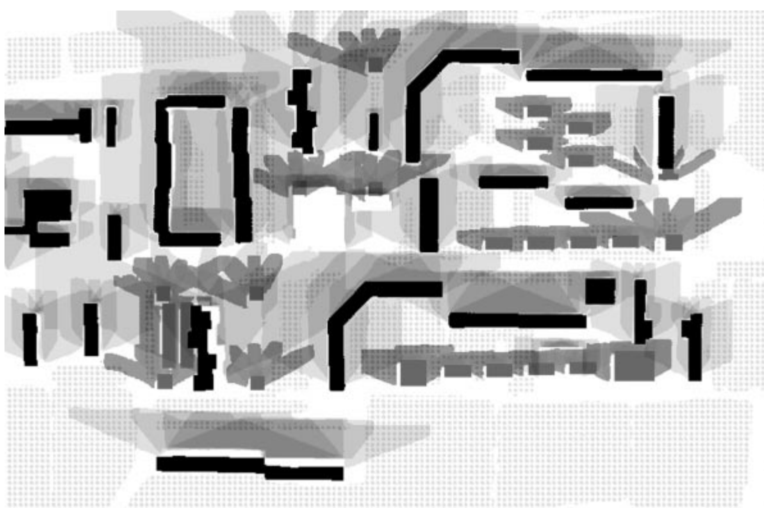

Figure 2-2: Shading study in a large-scale urban housing area in Berlin. Existing building blocks are shown in black, proposed new buildings in grey. The study was carried out with a physical model in an artificial sky. The picture shows the superposition of shadows for 08:00, 10:00, 12:00, 14:00, and 16:00 on March/September 21.

Studying the obstructions at a construction site tells a designer about the daylight potential of the building's facades and allows him or her to shape the building and to allocate floor areas with respect to daylight availability. In many cases, buildings are self-obstructing, so building design and obstruction studies become interconnected.

Local zoning regulations limit a building's design (e.g., building size, height, etc.) and the impact a new building can have on surrounding, existing buildings. The latter restrictions have their origins in fire protection, imposing minimum distances between neighbouring buildings to prevent fire from spreading. These regulations evolved into legislation to protect the right to daylight, originally drafted (as early as 1792) when powerful sources of artificial light were unknown or unavailable to the majority of the population, and the availability of daylight was essential in building interiors. In selecting daylighting strategies, a designer must take into account the degree to which the new building will create an obstruction for existing buildings, reducing their access to daylight, and/or will reflect sunlight that might cause glare at the street level or increase thermal loads in neighbouring buildings.

Zoning regulations and floor area indexes that regulate the extent of urban density also affect daylighting design. The aim of maximizing floor area in order to get the best economic return from a new building may conflict with the design goal of providing interior daylight.

Several methods and tools are available to analyse obstructions. The basic approaches are:

- plotting the "no-sky line" on the work plane of a selected space; the no-sky line divides points on the work plane that can and cannot "see" the sky [Littlefair 1991];
- examining obstructions from one specific view point by projecting the sun's course or a daylight availability chart on a representation of the building site (Figure 2-1);
- computing the amount of incident daylight and radiation for specific locations and orientations on the site; or
- projecting shadows that will fall on the facade or ground when the sun is in specific positions; this approach gives an overview of the availability of sunlight at the site (see Figure 2-2).

For heavily obstructed facades, daylight-redirecting systems can improve the distribution of light to interior spaces. Glass prisms have been used for this purpose for more than a hundred years; today a range of systems can be used, including holographic elements, laser-cut panels, and anidolic elements.

2.1.3. Building Schemes and Building Types

Commonly encountered constraints on different building types over the years have resulted in typical building shapes and design schemes for standard types of building uses. These schemes generally incorporate daylighting strategies from which designers can learn.

Daylight design and building design can merge to different degrees. In some buildings, such as churches (see Figure 2-3), the daylighting strategy and the building design scheme are almost identical; in buildings where the organization of floor areas is complex, daylight is treated as one design issue among a host of others. The more that daylight is the generating factor for a design, the more the daylighting strategy is an architectural strategy.

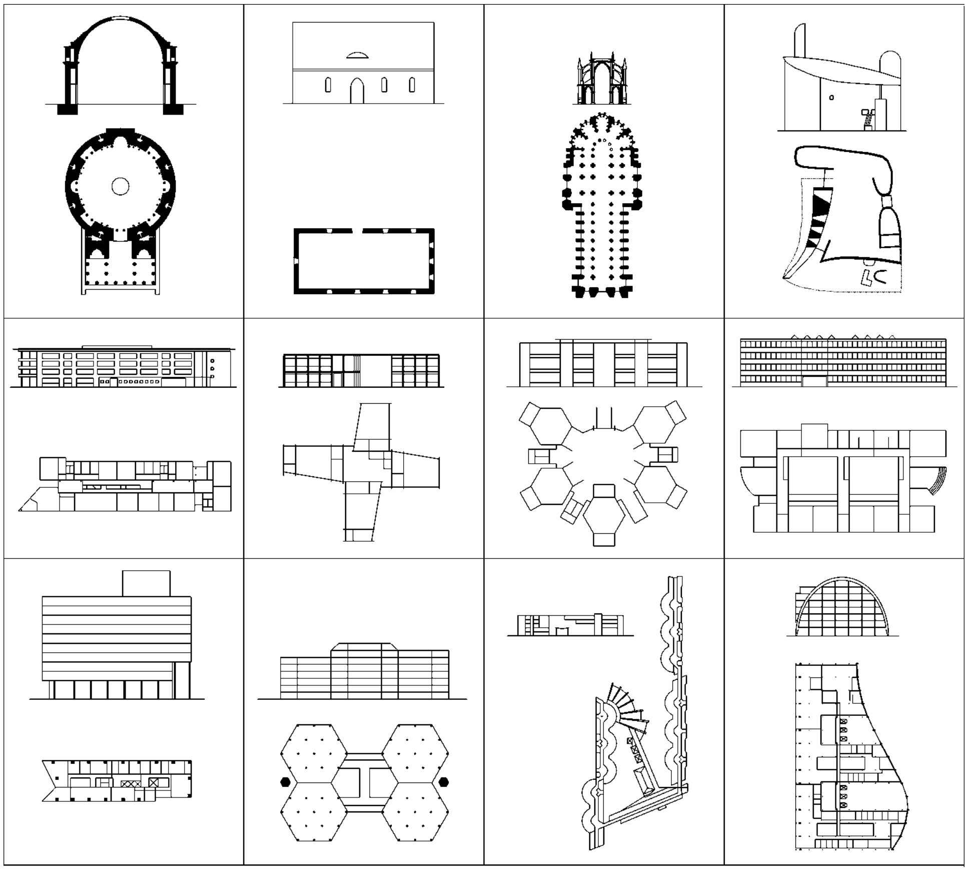

Figure 2-3: Daylighting design strategies for different building types. Churches (top row): Pantheon, Roman hall church, gothic basilica, modern. Schools (middle row): linear atrium, cross of Hamburg, nucleus, courtyards. Office buildings (bottom row): cellular, open plan, group offices, combination offices

Different organisations of building floor space develop in response to different needs. The bottom row of Figure 2-3 shows various ways of organizing space in office buildings. It is easy to see that a cellular design and an open plan design, for example, will demand different daylighting strategies. A conventional window may be adequate to distribute daylight to a shallow office room, but bringing daylight into deep spaces requires more complex design strategies.

Figure 2-4: Light and shadow in the Ronchamp chapel designed by Le Corbusier

One of the first steps in planning for daylight is to list all of a project's floor spaces and determine the lighting requirements of these areas. The required daylight level and degree of control over the visual environment are among the most important criteria (see Chapter 3).

Performance parameters are usually objective design criteria; however, the attractiveness of spaces cannot be expressed in purely quantitative terms. The work of architects such as Alvar Aalto, Le Corbusier, and Louis Kahn show how to use architectural design features to create impressive spaces with daylight (Figure 2-4).

The building's overall design scheme determines daylighting strategies and daylight potential in all building zones; therefore, performance parameters should be checked during the initial design phase. Incorrect assumptions about the distribution of daylight within the space will result in poor daylighting performance.

During the initial design phase, the daylighting designer's goal is to make sure that the specified performance can be achieved within the framework of the design. The proportion of spaces in relation to apertures should be checked. If the performance of the daylight strategy depends on the performance of particular daylighting systems, these systems have to be included in the prediction method. Rules of thumb, graphical methods, and simulation of daylight with physical or computer models are applicable at this stage of the design process (see Chapter 6). Most of these methods do not adequately account for a design's thermal behaviour even though the thermal strategy and the daylighting strategy are inseparably linked; a daylighting design should therefore include thermal calculations.

Figure 2-5: Typical building of the late 20th century that does not comply to today's daylighting standards

2.1.4. Retrofitting/Refurbishment

In most industrialised countries, the proportion of retrofit activities in the construction sector has increased steadily during the past two decades. Today, a large number of buildings are refurbished because of:

- a poor indoor environment (air quality, visual environment, etc.),
- high energy consumption,
- a poor state of repair, or
- the need for a new floor layout.

Figure 2-6: Power Gen, UK. The daylight strategy and the building design strategy are inseparably linked to each other.

Daylight design is an important component of a retrofit when building components that affect the building's daylighting performance are replaced. Common retrofit measures include replacement of windows or of the whole facade; old windows are often leaky and thus a source of heat loss. Refurbishment is a chance not only to replace old building components with new ones, but also to redefine the functional concept of a building in order to meet today's requirements.

Selection of the right glazing is of major importance for a building's daylighting strategy. The combined application of new glass and new daylighting systems, particularly those that provide solar shading, glare control, and the redirection of light, can increase daylight and decrease cooling loads. Daylighting measures are only efficient when the performance of artificial lighting systems is also addressed, i.e., new efficient lamps and luminaries and an advanced control system are installed. Combining daylighting and artificial lighting systems through, for example, a combined control strategy or the integration of lamps in an interior light shelf, is a design option in retrofits as well as new construction.

The increasing tendency to replace heating, ventilation, and air conditioning (HVAC) plants with hybrid HVAC-thermal-lighting systems and hybrid or natural ventilation strategies will affect the building envelope design. HVAC plant sizing and redesign should be integrated with envelope design because significant load reductions can occur as a result of new window and daylighting technologies.

Daylighting Strategies for Rooms 2.2.

The aims of room daylighting are to adequately illuminate visual tasks, to create an attractive visual environment, and to save electrical energy. Both the building design scheme and the application of systems play roles in meeting these goals.

The performance of a daylighting strategy for rooms depends on:

- daylight availability on the building envelope which determines the potential to daylight a space;
- physical and geometrical properties of window(s), and how windows are used to exploit and respond to available daylight;
- physical and geometrical properties of the space.

Figure 2-7:
Window, clear view

Figure 2-8:
Window with exterior louver blinds, where the view is partially obstructed

Figure 2-9:
Window with interior vertical lamellas, where the view is completely obstructed

2.2.1. Function of Windows

The old definition of a window as an aperture in an opaque envelope is no longer strictly applicable. Innovations such as fully glazed skeleton structures and double-skin facades defy the scope of this definition. Nevertheless, we will use the term "window" to analyse daylighting strategies. Windows have several functions, which vary depending on the individual design case.

One key function of a window is to provide a view to the outside. View plays an important role in an occupant's appraisal of the interior environment even if the exterior environment is not especially attractive. The size and position of windows, window frames, and other elements of the facade need to be considered carefully in relation to the eye level of building occupants. Daylighting systems can affect the view to the outside. If an outdoor view is a priority in a daylighting design, visual contact with the exterior has to be maintained under all facade operating conditions. Advanced daylight strategies therefore often allocate different functions to different areas of the facade or to different facades. View windows then can be preserved without being compromised by other functions.

Daylighting is one of the main functions of windows. The window design determines the distribution of daylight to a space. Windows chosen solely for their architectural design features may perform satisfactorily in many cases. For dwellings and other buildings that have relatively minimal visual requirements, application of advanced daylighting systems is not usually appropriate.

Advanced daylighting systems can be useful in cases where:

- difficult tasks are performed, and a high degree of control over the visual environment is required;
- the building's geometry is complex, e.g., there are heavily obstructed facades or deep rooms;
- control of thermal loads is required (adjustable solar shading can be an effective strategy in this case).

Daylighting is inseparably linked to solar gain. In some design cases, added solar gains from daylighting may be welcome; in other cases, heat gain must be controlled. If solar gains are desirable, windows are a good way to provide them. In general, the goal of building design is to reduce cooling loads. There are a number of ways to control solar gains from windows and facades; the simplest method is the direct gain approach, where a shading system simultaneously controls the visual and thermal environments. More advanced techniques, such as collector windows and double-skin facades, allow some degree of separate control over the thermal and visual environments. In passive solar architectural concepts, solar gains are controlled by the orientation and the application of shading systems as a function of the sun's position.

The operability of windows needs to be considered when daylighting systems are selected. Shading systems located in the window pane do not work properly when the window is open; if daylight-redirecting systems are attached to the window, the window's operation will have an impact on the systems' performance. Operable windows also often serve as fire escapes. The impact of fire balconies on daylight performance needs to be considered.

Glazed areas are an interface between exterior and interior; therefore, windows involve a number of design considerations. Aside from the above-mentioned primary functions, the following issues are especially important for glazed areas:

- glare,
- privacy/screening of view,
- protection from burglary.

2.2.2. Design Strategies for Windows

Figure 2-10: Large rooflights without shading system in cloudy England

A window system must address the range of a building's exterior conditions to fulfil the range of interior requirements. The placement and sizing of windows are among the most powerful features of architectural design for daylight. Because the design of windows has a decisive effect on the potential daylight and thermal performance of adjacent spaces, it needs to be checked very carefully [O'Connor et al. 1997]. The LT (Light-Thermal) method, which was developed for typical climates in the European Union, allows the estimation of energy consumption for heating, lighting, and cooling as a function of glazing ratio [Baker and Steemers 2000]. Simple design tools (see Chapter 6) allow a quick evaluation of window design and room geometry.

Windows are almost always exposed to the sky; daylighting systems can adapt windows to changing sky conditions and transmit or reflect daylight as a function of incident angle. Daylighting systems are primarily used for solar shading, protection from glare, and redirection of daylight. Whether or not daylighting systems are required to support the performance of window systems, and which system or systems is appropriate, are key decisions in the design process. See Chapter 4 for a detailed description and evaluation of innovative daylighting systems.

The adjustment of daylighting strategies to specific sources of skylight is an important characteristic of daylighting strategies.

Strategies for Skylight

Strategies for diffuse skylight can be designed for either clear or cloudy skies; however, the most significant characteristic of these strategies is how they deal with direct sunlight.

Solar shading always is an issue for daylighting except on north-oriented facades (in the northern hemisphere). If solar shading is only of minor importance as a result of orientation and obstructions, a system to protect from glare can be used for solar shading as well.

Solar shading and glare protection are different functions that require individual design consideration. Solar shading is a thermal function that primarily protects from direct sunlight, and glare protection is a visual function that moderates high luminances in the visual field. Systems to protect from glare address not only direct sunlight but skylight and reflected sunlight as well.

Strategies for Cloudy Skies

Daylighting strategies designed for diffuse skylight in predominantly cloudy conditions aim to distribute skylight to interior spaces when the direct sun is not present. In this case, windows and roof lights are designed to bring daylight into rooms under cloudy sky conditions, so windows will be relatively large and located high on the walls. Under sunny conditions, these large openings are a weak point, causing overheating and glare. Therefore, systems that provide sun shading and glare protection are an indispensable part of this strategy. Depending on the design strategy, various shading systems that transmit either diffuse skylight or direct sunlight may be applicable in this case. To avoid decreasing daylight levels under overcast sky conditions, moveable systems are usually applied.

Some innovative daylighting systems are designed to enhance daylight penetration under cloudy sky conditions (see the classification of systems in Chapter 4). Some of these systems, such as anidolic systems or light shelves, can control sunlight to some extent. The application of simple architectural measures, such as reflective sills, is another opportunity to enhance daylight penetration, but the design of the window itself is the main influence on the performance of this type of strategy under cloudy conditions.

Strategies for Clear Skies

In contrast to daylighting strategies for cloudy skies, strategies that diffuse skylight in climates where clear skies predominate must address direct sunlight at all times. Shading of direct sunlight is therefore part of the continuous operating mode of this strategy. Openings for clear sky strategies do not need to be sized for the low daylight levels of overcast skies. Shading systems that allow the window to depend primarily on diffuse skylight are applicable in this case (see Chapter 4).

Direct Sunlight

Strategies for sunlight and diffuse skylight are quite different. Direct sunlight is so bright that the amount of incident sunlight falling on a small aperture is sufficient to provide adequate daylight levels in large interior spaces. Beam daylighting strategies are applicable if sunshine probability is high. Since sunlight is a parallel source, direct sunlight can be easily guided and piped. Optical systems for direct light guiding and systems for light transport are applicable in this case (see Chapter 4). Apertures designed for beam daylighting do not usually provide a view to the outside and should therefore be combined with other view openings (→ Palm Springs Chamber of Commerce[1]). Because beam daylighting requires only small apertures, it can be applied as an added strategy in an approach that otherwise focuses on cloudy skies.

Figure 2-11: Homogeneous window design

2.2.3. Functional Division of a Window

If a designer can allocate one predominant function to a window, he or she can design it for optimum performance that will not be compromised by contradictory requirements. The designer must then make sure that all windows together fulfil the full range of requirements in a room.

Figure 2-12: Heterogeneous window design

When a window has to satisfy several functions in any operation mode, the range of applicable daylighting systems is constrained because the system selected must take account of all of the window's functions. The design approach for this type of opening therefore usually consists of applying moveable systems that can be recessed when not needed. The designer should consider controlling systems using a building energy management system because they might not otherwise be operated appropriately.

The heterogeneous design of a window allots specific functions to specific areas of a window. Different daylighting systems can be applied to different parts of the window, or similar systems may be operated separately for different areas of the window. The interaction of daylighting systems in this case needs detailed design consideration.

2.2.4. Strategies for Fenestration

Whether to use sidelighting or toplighting, unilateral or multilateral daylighting strategies should be decided during a building's conceptual design stage.

Although unilateral sidelighting is the standard daylighting case, its implementation requires care. It aims to distribute daylight into the depth of a space, to provide enough light to perform a task in the room while avoiding glare and allowing a view to the outside. Because these ambitions may conflict, the division of a facade into openings with specific functions is a promising way to apply sidelighting (→ Willy Brandt Building).

[1]→This notation is given for case study buildings documented in the Survey of Architectural Solutions, which is included on the CD-ROM.

Facades generally have a limited ability to distribute daylight into the depth of a space. Several rules of thumb apply to potential daylighting zones for diffuse skylight and appropriate window design. During the conceptual design phase, the daylighting zone may be considered to be a depth of about two times the window head height [Robbins 1986].

Unilateral toplighting can only be used on the top floor of a building. Spaces on lower floors can only be connected to rooflights by core daylighting systems or atria. Rooflights receive light from the brightest regions of the sky, so they are powerful sources of daylight. They do not, however, provide users with a view to the outside, so daylighting strategies that depend exclusively on rooflights are limited to spaces where a view is not necessary.

Because toplighting is exposed to high incident sunlight, solar shading is usually essential to prevent overheating. The size of rooflights needs to be carefully balanced to meet lighting, thermal performance, and shading requirements. Various rooflighting shading strategies and systems exist. Rooflights are often glazed with light-diffusing glass to protect the interior from direct sun rays. Light-diffusing glass does not provide solar shading, however, and becomes very bright when hit by direct sunlight, which may cause glare. The use of light shafts to baffle and disperse sunlight is a classical architectural rooflight concept (→ Gentofte Public Library). The use of awnings is another traditional technique to shade large rooflights (→ Trapholt Art Museum).

Traditionally, toplighting concepts have been used at high latitudes with predominantly cloudy skies, but advanced daylight-redirecting shading systems, such as laser-cut panels, holographic optical elements, and optically treated light shelves, can "cool" rooflights in sunny, hot climates (→ Center for Desert Architecture, Palm Springs Chamber of Commerce, Park Ridge Primary School).

Because the ability of facades to distribute daylight to deep spaces is limited, especially under cloudy skies, bilateral and multilateral lighting is an option for rooms that cannot be lit adequately by only one facade. The design of the building's fabric determines the availability of daylight on room facades. Atria and courtyards are often used to provide bilateral daylighting (→ Bertolt Brecht School).

Bilateral daylighting with a functional division between facades is a powerful daylighting strategy that can be applied in different ways. One way is to allocate the function of view to the outside to one facade using daylighting systems such as overhangs that shade sunlight but do not obstruct the view. The other facade can be used to distribute daylight to the space (→ Protestant School). The most common design solution for bilateral daylighting is to combine a window that fulfils the full scope of functions for a large portion of floor space with a clerestory to increase the illuminance level in the depth of the space (→ OSZ Wirtschaft).

Bilateral sidelighting can provide occupants with a view to the surrounding landscape. This strategy allows effective solar shading by moveable systems on a sunny facade while the second facade, which is not hit by direct sunlight, distributes daylight to the space (→ Gropius School).

Figure 2-13: Unilateral sidelighting in a laboratory

A bilateral combination of sidelighting and toplighting can distribute daylight to deep interior spaces (→ Gentofte Library). The primary function of the rooflights is usually to distribute daylight while windows provide occupants with a view to the outside (→ Park Ridge Primary School). Another application of this strategy is to create areas with their own specific apertures that provide individual lighting environments.

Figure 2-14: Unilateral rooflighting in an art gallery

Figure 2-15: Bilateral lighting, sidelight and rooflight

Core daylighting systems are optical systems in which the daylight-receiving aperture and the light-emitting opening are far apart. These systems can distribute daylight to windowless spaces. Occupants may not notice the difference between piped daylight and light generated by artificial light sources. A strategy to make these systems more cost-effective is to use them as distribution systems for artificial light as well. Core daylighting systems are usually designed to pipe direct sunlight. There are various types of core daylighting systems — sun-tracking as well as fixed systems that use optical fibres or light ducts.

Figure 2-16: Sun tracking daylighting system with fresnell collector and liquid light pipe

2.2.5. Relation to Adjacent Spaces

Clerestories in corridor walls of offices can distribute daylight to these otherwise windowless spaces; for shallow offices, this is a suitable strategy (→ DIN-Building). Daylight-redirecting systems can contribute to the distribution of daylight to these spaces in the core of a building; daylight-redirecting systems should be applied simultaneously to control glare. Windows facing an atrium have less daylight potential than windows facing an open courtyard because the glazed roof reduces the luminous flux. High reflectances within an atrium space can increase the depth of light penetration (→ Dragvoll University Center).

Even if borrowed light from interior windows does not significantly increase daylight levels to an interior space, the presence of these windows may improve light distribution and make a visual link between a space located in the core of a building and other zones of the building. The view to a daylit environment or even to an interior building landscape can increase the attractiveness of otherwise windowless spaces.

2.2.6. Finishing, Furnishing, and Using a Space

Interior finishing has to be part of the daylighting strategy. Daylight-redirecting strategies usually direct daylight to the ceiling of a room. The reflectance characteristics of the ceiling therefore influence the way daylight will be distributed. Specular in-plane ceiling surfaces reflect redirected light deep into the space but may be a source of glare. Specular out-of-plane ceiling surfaces can be shaped to deflect redirected daylight to specific areas in the room (→ Geyssel Office Building). These surfaces can act as reflectors for artificial light as well. A diffuse ceiling of high reflectance can also distribute light from daylight-redirecting systems, which may be more comfortable for occupants than a highly reflecting environment. The reflectance of walls, floor, and furniture also have a large influence on the impression created by a space. The floor reflectance should not be too low (>0.3).

Designers often assume that lighting requirements are homogeneous throughout a space and thus aim to provide uniform lighting levels, but surveys in occupied rooms show that there are patterns in how spaces are used. For example, in a cellular office occupied by one person, the desk is usually placed in the window area.

The furnishing of a space represents a frozen image of activities in the space. It affects where occupants do certain tasks. Thus, furnishing acts as a specification of lighting requirements. If the real use of a space can be determined, designs should be based on this information rather than on the assumption that a uniform luminous environment is required.

2.3. Design Strategies for Daylighting Systems

As outlined above, the application of daylighting systems is only one constituent of a daylighting strategy. Although a poor selection of systems can spoil the performance of a building with good daylight potential, a sound selection cannot compensate for errors and omissions in previous design stages.

To select a system, the designer must understand:

- the function of the window or other opening(s),
- the function of the system, and
- the interplay of the system with other systems.

A reasonable selection of systems should reduce the negative effects of windows and enhance daylight performance without interfering with other desirable effects of windows for all design cases (all seasons and sky conditions).

Daylighting systems can be categorised by many characteristics. When selecting a system, the designer must be aware of all of its properties. Function and performance parameters have the most pronounced effect on performance, but costs and details related to the skin of the building are also important. As for many decision within the design process there exists no definite procedure how to select a daylighting system. The ultimate criterion is the performance of the overall design solution.

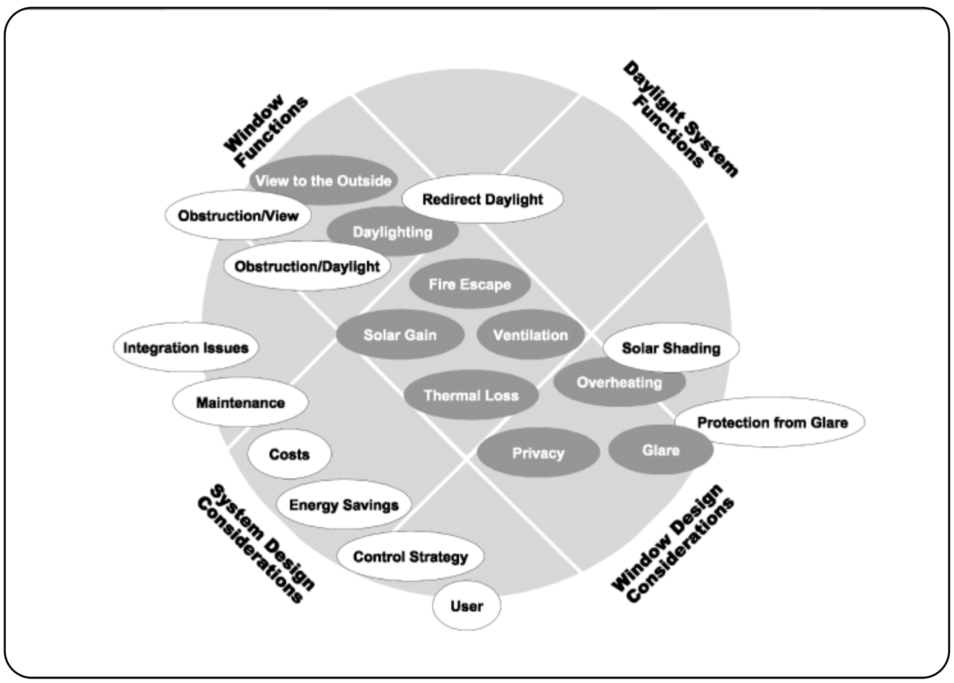

FIGURE 2-17: FUNCTIONS AND DESIGN CONSIDERATIONS OF WINDOWS AND DAYLIGHTING SYSTEMS

Windows and rooflights have different roles in a daylighting strategy. The ambience of spaces receiving skylight is completely different from that of spaces receiving sidelight. For example, the design of Le Corbusier's "Le couvent de la Tourette" emphasises the different nature of skylight and sidelight. In this design, skylight is used only in spaces that play a significant role in religious life; all secular spaces receive sidelight.

Rooflights are usually not designed for a view to the outside; therefore, obstructing elements such as deep light shafts or non-transparent daylight systems can be applied in rooflight design. The control of glare with such systems is much easier than with sidelighting designs, which must provide occupants with a view to the outside. Solar shading is a crucial issue with rooflighting. One design strategy for rooflighting in sunny hot climates is to use a very small aperture and to apply innovative daylighting systems to distribute the light homogeneously in the space (→ Waterford School, International Centre for Desert Architecture). In classrooms of the Park Ridge Primary School in the sunny but temperate climate of Melbourne in southern Australia, tunnel lights are used to exclude direct sunlight and to distribute skylight to the space (→ Park Ridge Primary School).

Shading systems for rooflights, such as sun-protecting mirror elements, prismatic panels (Chapter 4.5), and directional selective shading systems using holographic optical elements (Chapter 4.11) can be applied to large glazed roof areas in higher latitudes. When situated in the window pane, these systems are protected from dust and require little maintenance. These systems need to be adjusted to the individual application.

2.3.1. Function of Systems

multiple functions

protection from glare, solar shading, redirection
- exterior slatted blinds, awning

protection from glare, solar shading
- trees, fins, directional selective shading systems

protection from glare, redirection
- deep window reveal, mirrored prismatic panels

solar shading, redirection
- lightshelf, anidolic ceiling, lightguide

single function

protection from glare
- screen, blinds, curtain...

solar shading
- overhang, sunshade, fixed lamellas, reflective glass...

redirection
- reflectors, laser cut panels, scattering glass...

light transport
- heliostat, light-pipe, solar-tube, fibres, solux...

enhancement of daylight level
- high lintel, glass with high light transmission

aesthetic function
- glass block brick, coloured glass, printed glass

thermal
- double skin, pivoting window

The system matrix for the division and description of daylighting systems that is included in Chapter 4.2 of this book makes a distinction between two major categories of daylighting systems: those with and those without shading. This division is useful for building designers. Daylight-redirecting systems that do not shade usually need to be complemented by other window systems; shading systems might be applied as stand-alone systems for windows or window areas.

Daylighting systems have three major functions:

- solar shading,
- protection from glare,
- redirection of daylight.

Windows need protection from glare and solar shading in order to create acceptable interior conditions. The redirection of daylight can save energy but is not an indispensable function. The view to the outside is not a function of a daylighting system but a primary function of the window itself; the impact of daylighting systems on the view to the outside needs to be considered carefully.

Some systems, such as exterior louvered blinds (Chapter 4.4), are designed to satisfy all functions of a standard window as a stand-alone system. But, as outlined above, such a "one size fits all" system, which usually covers the whole window area, will, in most cases, have a poor performance. A good selection of systems means a good mixture of systems.

Figure 2-18: Exterior glazed lamellas for solar shading

Reflecting profiles in the cavity of the glass are designed for solar shading, redirection of daylight, and glare control, but create considerable obstructions to view. When this technology is applied to a facade, low incident daylight is redirected to the ceiling, and high incident daylight is rejected. This strategy performs well under sunny skies in high latitudes when oriented to the south (in the northern hemisphere), but it has poor daylighting performance under overcast conditions. It is primarily a selective shading strategy that can be applied to control the thermal performance of large areas of glazing.

Figure 2-19: Light guiding shade for solar shading and redirection of day-light

Architectural design features often to some extent fulfil or support the functions of daylighting systems, but they cannot address the full range of exterior conditions, so additional daylighting systems are generally needed. An overhang, for example, acts as a solar shading system but only for high sun positions. It does not protect from glare or redirect light into the space. Fins act to some extent as solar shading devices, attenuating and redirecting sunlight and partially controlling glare, but they are not a stand-alone daylighting system. These architectural design features selectively attenuate daylight so that simple daylighting systems can be added to supply missing functions. Other examples of architectural features that shape daylight are arcades, atria, balconies, and deep window reveals. The performance of these elements can only be evaluated within the context of a specific design solution, so surveys and case studies are useful assessment resources. In addition to the survey of architectural solutions included in

Figure 2-20: Interior fabric to protect from glare

this source book, some very useful compilations of case studies have been published in recent years [Fontoynont 1999, LUMEN 1995, *IEA SHC Task 21 Daylight in buildings: 15 Case Studies from Around the World*].

In high latitudes with predominantly cloudy skies where the exterior illuminance on winter days at noon is often even less than 5,000 lux, measures to increase daylight during winter are appropriate. A high window with a sloping lintel has proven to be more efficient in this case than most daylight-redirecting systems. The application of glass with high light transmission is also very useful. Because a large window designed for low levels of daylight on overcast days is vulnerable to overheating and glare on bright days, effective shading systems are needed to make this daylighting strategy work.

A light shelf (Chapter 4.3) combines solar shading and sunlight redirection, improving the distribution of daylight and allowing a view through the lower part of the window. Light shelves are applicable in sunny climates in mid-latitudes for south orientations (in the northern hemisphere). Light shelves are a classical device in the daylighting toolbox.

Other systems are designed for only one function; zenithal light-guiding glass (Chapter 4.10), for example, redirects sunlight but does not provide solar shading or glare protection. Interior roller blinds primarily protect against glare, but they only have a limited effect on solar shading and usually do not redirect daylight. A pivoting window adapts to summer and winter light availability conditions but has no effect on daylight distribution.

2.3.2. Location

location

1. exterior
   - deciduous trees, overhang, balcony, arcade, sun-shade, fins, louvers
2. window pane
   - holographic elements, laser cut panels, glazing with reflecting/redirecting elements, switchable glazing, light guiding glass...
3. interior
   - curtain, blinds, interior lamellas, reflective sill, prisms and venetian blinds
4. combined systems
   - light guiding shade, anidolic ceiling, light transport systems

The location of a daylighting system can be described in relation to the window pane as exterior, interior, or within the pane. Some complex systems such as the anidolic ceiling (Chapter 4.12) combine exterior and interior elements. The location of a daylighting system can affect the thermal performance of the building.

Exterior systems are most suitable for solar shading; interior systems allow for solar gains. Systems located in the cavity of the glass or within a double facade can be applied as part of an advanced ventilation strategy to serve as exhausts in summer and solar collectors in winter.

Exterior devices are costly because they have to be constructed to resist all weather conditions. Moveable exterior systems require a lot of maintenance and often collect dust. Interior systems are much less expensive, but they have only a limited solar shading effect.

The designer should therefore aim to find the right size and position of windows and use fixed elements in the window design if applicable, so the need for moveable exterior systems can be reduced. Innovative systems are often located in the window pane. They control daylight as a function of incidence angle but affect the view to the outside.

2.3.3. Ability to Change

ability to change

1. fixed, no change
- overhang, lightshelf, anidolic ceiling, angular selective skylight, solar tube, sun protecting mirror elements

2. fixed, with change
- switchable glass, photo-chromatic glass, thermo-chromatic glass, deciduous tree

3. adjustable, can not be recessed
- turnable lamellas

4. adjustable can be recessed
- venetian blinds, roller blinds, awnings

5. sun tracking
- heliostat, solux, fibres

Because one of the main functions of daylighting systems is to adapt the building to changing sky conditions, the ability to change is an important characteristic of these systems. A system itself does not necessarily need to change. A design using fixed systems that reflect the trajectory of the sun can be sensitive to sky conditions, for example. Orientations to the south (in the northern hemisphere) are especially appropriate for such a design. Although fixed systems, such as overhangs, sun shades, horizontal lamellas, and fins, are useful for solar shading, they do not control glare; therefore, another system that controls glare needs to be added to make these design solutions work. Because the glare protection device is not used for solar shading in this case, an interior system can be applied (→ OSZ Wirtschaft).

Many buildings in hot climates have in recent years been designed for solar shading rather than for daylighting. Reducing cooling loads was the driving force in these designs. Sun-shading glass has been used to exclude solar radiation, and window function has been limited to providing occupants with a view to the outside. Today, advanced daylighting systems in combination with advanced controls can bring daylight deep into a space and reduce cooling loads relative to those experienced with artificial lighting. If thermal loads are a major concern, tracking systems can be used to regulate daylight levels.

2.3.4. Transparency

Because a primary function of windows is to provide occupants with a view to the outside, the transparency of daylighting systems is a major issue. The construction material of a daylighting system need not necessarily be transparent itself in order to provide a view out; the subjective impression of visual contact to the outside is most important. The function of a system to protect from glare inevitably affects the view to the outside. Sun shading and the redirection of daylight affect the view as well.

Some advanced systems, such as holographic optical elements, laser-cut panels, and light shelves, aim to shade or redirect daylight from some incidence angles while not interfering to any great extent with the view to the outside (see Chapter 4). These systems do not control glare. Fixed daylighting systems that do control glare, such as sun-protecting mirror elements in the cavity of the glass, anidolic ceilings, and light-guiding shades, do not provide occupants with a view to the outside.

Louvers and blinds and other moveable systems that can be recessed are designed to shade and protect from glare when needed, but they do not interfere with view when they are recessed. The transparency of these systems depends on the operating conditions.

Electrochromic glass can adjust the transmission of radiation over a wide range without changing the distribution of daylight. Glass with light transmission that varies depending on the amount of incident daylight or the temperature is a promising technology that has been developed in laboratories.