Daylight Performance in Mid/Large Buildings

Basics, Strategies, Technologies

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Fig. 01 Diagram of the daylighting concept of the Arup Campus buildings

Design Goals

Indirect sky light, such as light received from the North side of a building, can be used as the primary source for ambient lighting within a space. If direct light is to be used, the building should shade task areas from harsh direct rays. This can be done with a wide range of systems and technologies designed to allow only diffuse light into a space. The control of direct sunlight is important to regulate levels of glare and contrast and prevent direct rays from falling within visual field. In large buildings, internally generated heat loads most often constitute the majority of the buildings energy consumption. The use of daylight reduces the use of electrical lighting systems within the building and lowers the internal heat loads. Daylight can be used as a source of ambient light with electric systems being used for specific task lighting.

Spaces within a building with different programmatic functions require different lighting levels. It is important to analyze these different programs at an early stage of design to organize the building to give daylighting priorities to certain spaces. Vertical circulation, bathrooms, and storage gain little benefit from daylighting and can be placed in areas that have less access to daylight or could be placed on the east and west sides of the building to shade the other spaces.

Required illumination levels for a space are directly related to the programmatic function within the space.

Listed from lower required light levels to higher required light levels:

General Space:
A: Public spaces – nighttime corridors and lobbies, waiting rooms, bedrooms
B: Simple orientation – dance halls, dining halls, transportation terminal concourses, residential living spaces

C: Occasional visual tasks – daytime corridors and lobbies, reception areas, auditoriums, banks, worship areas

Task:

D: Visual tasks of high contrast or large size – conference rooms, office work with high-contrast tasks, factory simple assembly, residential kitchens

E: Visual tasks of medium contrast or small size – drafting of high-contrast work, classrooms, offices, clerical tasks, factory work of low contrast or moderately difficult assembly

F: Visual tasks of low contrast or very small size – drafting of low-contrast work, laboratories, factory work with difficult assembly

Daylighting Basics

Daylight Factor
“The proportion of interior horizontal illuminance (usually taken on a work plane) to exterior horizontal illuminance under an unobstructed sky.” Expressed as a percentage.

Quality of Light
Quality of light is a holistic term which includes a number of factors. It consists of brightness, color temperature, color rendering, type (direct, indirect, diffuse, etc), light distribution, sparkle, variability, and flicker. Studies have shown that light quality has an effect on mood, energy levels, and sleep patterns.

Brightness

Perceived brightness depends on not only the amount of light leaving a lamp, but also on the amount of light falling on and reflecting from the various surfaces of a space. Too little or too much brightness will make performing various tasks difficult or impossible, as well as creating undesirable physical side effects, such as eye strain and headaches. Uncontrolled brightness can produce levels of glare: direct glare, which comes from the light source itself; reflected glare, which appears on a surface on which a task is being undertaken, such as on a computer screen; discomfort glare, which does not prevent seeing but can cause eye strain and headaches; and disability glare, which prevents vision entirely.

Color Temperature
Color temperature describes how “warm” or “cool” the light appears (warm light has a more yellow appearance, cool light appears more blue). In order to more accurately compare light sources to one another, their Correlated Color Temperatures (CCT) are used. Color temperatures are listed in the Kelvin temperature scale. Warm sources have a lower CCT, typically somewhere in the range of 2650K and 3200K, neutral sources range from 3200 to 4000K, and cool sources have a CCT above 4000K.

Color Rendering
An element separate from color temperature is color rendering, or how accurately a light source reproduces colors. Using the Color Rendering Index (CRI) scale, a value between 1 and 100 is assigned to a source, depending on how a particular source reproduces colors when compared to ideal (natural) light.

Daylight vs. Artificial Light
The Swedish Energy Agency’s Department for Sustainable Energy Management describes the differences between 300 lux of daylight and 300 lux of artificial light:

Distribution of Light
Daylight in diffused form tends to illuminate surfaces more evenly in all directions. Electric lighting typically illuminates in a certain direction e.g. horizontal or vertical plane. In other words surfaces are more brightly lit either in the horizontal or the vertical plane. Daylight tends to illuminate both horizontal and vertical surfaces more evenly, thus, the roof, the walls and the floor look more evenly lit. Therefore, daylight in diffused form offers better sense of space.

Discriminating Color
Colors look more natural in daylight than under electrical lighting, as electric light sources are stronger
in some areas of the light spectrum and weaker in others. The human eye’s ability to discriminate colors is dependent on the spectral content of light, and daylight contains light of almost all visible wavelengths, whereas most electric lamps emit most of their light over a limited wavelength range. Daylight thus has a continuous spectrum and therefore provides better color rendition. Colors tend to look more vivid in daylight. It may be added that under daylight human eye can differentiate between 500,000 different shades.

Flicker
Daylight does not flicker; fluorescent lights can have a noticeable flicker. People blame this for a multitude of problems like headache, eye strain

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<th>fc (Lux)</th>
<th>10°–20°</th>
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Fig. 03: Recommended daylight factors for various spaces
and attention deficit problems. Fluorescent lights than run on electronic ballasts have considerably reduced flicker problems. Daylight and other electric sources, such as halogen lamps guarantee a total absence of flicker.

**Sparkle**
Sparkle or highlighting three dimensional objects is enhanced by daylight. This makes objects more attractive and easier and quicker to understand three dimensionally.

**Variability**
The inherent variability of daylight as clouds move through the sky, successively obscuring and revealing the sun. Some studies have shown that this variability of daylight has relaxing effect on the eyes.

**Motivation**
Since daylight is almost universally preferred to electric lighting, it is likely that increased use of daylight will support workplace productivity. In a study, it was found that workers in windowless offices spend a small but statistically significantly greater amount of time talking to others, either directly or by telephone; and a small but statistically significantly lesser amount of time working on their computer, relative to the workers in the windowed offices. It was hypothesized that the people in the windowless offices would not receive sufficient light to entrain their circadian systems and so would seek to entrain them either by seeking out exposure to daylight and consequently spending less time in their offices, or by seeking more social interactions, a factor that can also be used to entrain the circadian system. An alternative explanation for these findings would be that the workers in the windowless offices were seeking additional short-term stimulation, something that was provided by the view out in the windowed offices, and the differences in behavior had nothing to do with the circadian system. Regardless of which explanation is correct, the presence of a window would seem to provide a benefit in terms of desirable behavior at work.

**Preference for Daylight**
There is no doubt that people find daylight more pleasant than electric lighting as their primary source of light. Surveys taken as far back as 1967 and as recently as 1993 have all shown that high percentages of survey respondents prefer to work by daylight. Similarly, people prefer to sit at desks that are beside windows rather than further back in the room, especially when those windows have access to direct sunlight.

**Mood and Satisfaction**
A small but statistically significant reduction in negative mood has been for people who worked for about 20 minutes in a private office with a large window during daytime; but no reduction in negative mood for the same people in the same office at night. It was also found that occupants of small offices disliked the absence of windows. Some studies have suggested that people have an innate desire to be in contact with nature; windows provide a means for establishing visual contact with nature while at work.

**Circadian Photobiology**
Lighting can be used to strengthen the human circadian rhythm, which determines various physiological functions such as sleep, digestion, alertness, depression, and probably general health. Daylight is much more effective than electric lighting at ‘entraining’ the circadian system; this is because the circadian system responds only to high levels of blue light, such as those found in daylight. Rea et al. calculate ‘circadian
Strategies

Siting/Orientation
Siting considerations:
- Surrounding buildings/landscape features
- Available daylight
- Horizontal obstructions
- Adjacent building materials that may contribute to glare

Orientation considerations:
- Movement of the sun
- Solar position during peak usage
- Quality of daylight available

Glazing on the east and west facades should be limited due to the lower angles of solar radiation and more difficulty in shading. Glazing should be maximized on the north and south facades where shading and therefore glare are easier to control.

Form

There are three commonly used building forms:

Linear Forms
These forms are narrow width and long length and offer good sidelighting opportunities.

Centric Forms
Centric forms have an internal core around which other spaces are organized. There is a fairly equal length-to-width ratio which provides opportunities of atria, lightwells and courtyards. Where the above can’t be used, careful building zoning is used.

Clustered Forms
These forms consist of a series of smaller masses in a variety of configurations which offers extensive surface area for toplighting, sidelighting.

Plan/Section

Strategies in plan and section can maximize the amount of daylit areas throughout a building. Atriums, courtyards and lightwells allow daylight to penetrate into what would otherwise be interior spaces. In plan, careful consideration must be made to the location of certain areas.

Zoning
Group spaces with similar lighting requirements into daylighting zones based on these characteristics:

1. Function
Identify the activities that will take place within a space and specify the lighting requirements.

2. Usage schedule
Identify which spaces will have the most usage and when this will occur.
3. Location and orientation
Identify the location of the space in relation to the daylight source.

Zoning spaces within a building would contribute to energy efficiency, building organization, optimized daylighting design. However, what might make sense from a daylighting point of view may not make sense from a functional point of view.

Case Studies

Arup Campus
Arup
Solihull, England
- Passive structure
- Oriented northwest to southeast to maximize daylight
- Projecting roof pods over main circulation spaces
- Light-well strategy
- Program is separated into two buildings – maximize daylit areas
- Open floor plan (good in plan and section)

Gotz Headquarters
Webler and Geisler
Wurzburg, Germany
- Grid plan organized around a central courtyard
- Open floor plates
- Minimize columns and other obstructions
- Maximize access to daylight and/or views

Apertures

Toplighting
Toplighting is a system that delivers daylight onto a horizontal task plane generally from above. It includes skylights, sawtooth roof glazing arrangements and clerestories. These apertures allow daylight to penetrate deeper into the space.

Pros: reduced consumption of electricity, improved occupant satisfaction, potential for reduced cooling loads

Cons: can only be used in single story buildings or on the top floor of a multistory building, potential leaks without proper detailing, direct solar radiation and heat gain if not properly shaded, limits the visual connection to the outdoors

Sidelighting
Sidelighting is a strategy where apertures are located in the wall planes and admit ambient daylight. This system delivers daylight onto a horizontal task plane generally from the side. This can include windows, glass block, low clerestories, and vertical openings into courtyards or atria.

Pros: visual connection to the outside creating improved occupant satisfaction

Cons: direct solar radiation can lead to heat gain and glare problems

Height and Depth Relationships
The 2.5H rule of thumb says that the daylight penetration into a space will be 2.5 times the head height of the window.

The 15/30 rule of thumb says that a 15 foot wide zone from a
window wall can be sufficiently lit through daylight. The next 15 feet need can be partially daylight and supplemented with electrical light. Zones further than 30 feet receive little daylight and rely heavily on artificial light.

**Additional strategies**
- Splay the walls of an aperture to reduce contrast and glare.
- Use adjacent walls as reflectors.
- Exterior vegetation will provide daylight filters.

**Case Study**

World’s End School
Architects’ Co-Partnership

- E-shaped plan to allow for bilateral lighting
- Daylight requirement studies were used to determine room depth and height
- Room depths at 7 meters
- Room heights at 2.985 meters

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>REFLECTANCE</th>
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<td>Aluminum</td>
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<tr>
<td>Asphalt</td>
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<tr>
<td>Brick</td>
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<tr>
<td>Concrete</td>
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<tr>
<td>Gravel</td>
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<td>Plaster, white</td>
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<tr>
<td>Water</td>
<td>30–70%</td>
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<tr>
<td>Vegetation</td>
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**Internal Reflectances**

Depends on color and texture. Color determines the quantity of light reflected – dark colors absorb while light colors reflect. Texture determines the quality of light reflected. Rough/matte textures create diffuse Light, smooth or glossy create reflected light (and potentially create glare problems).

**Pros:**
- Visual comfort, potential for optimized lighting effectiveness

**Cons:**
- glare, surfaces need to be maintained to prevent the accumulation of dust and dirt which can create light loss.

**Light Shelves**

Light shelves are used to more evenly distribute daylight entering a building through sidelighting apertures. Light bounces off of the reflective surface of a shelf, onto the ceiling which bounces it into the room. Form, material and position of the light shelf determine its efficiency. Light shelves can be located on the interior or exterior.

Glazing above a light shelf is used solely for daylight while glazing below the light shelf is for daylight as well as views.

Light shelves should be located above eye level to reduce glare.

**Pros:**
- More even lighting, deeper daylight penetration, potential glare reduction, reduce contrast around apertures, an exterior light shelf could double as a shading element

**Cons:**
- If shelves aren’t placed high enough glare is a problem, maintenance is important because dust and debris reduce reflectivity

**Technologies**

**Louvers**

Louvers are often used as a supplemental tool to other daylighting systems. They can be
the building in such a way as to create diffuse light.

**Case Study**

Administration Building  
Herzog + Partner  
Wiesbaden, Germany

- South side: combination of two shading elements pivoted about the horizontal axis
- Upper element: light-redirecting louvers
- Lower element: awning-like to allow views
- Diffuse daylight capture on overcast days
- North side: stationary light redirecting elements to capture overhead daylight

**Glass**

There are many different technologies that can be applied to glass to make it as transparent or as opaque as desired. These technologies allow the glass to create a diffuse light that blocks out harsh direct sun and permits an ambient light enter the space. In addition, different hues or patterns can be applied.

*Printed or colored films*
- Located between glass panes
- Redirect incoming light similar through prisms and lenses

*Electrochromic glass*
- Liquid crystals between glass panes
- State can be altered with an electric current
- Off: liquid crystal layers scatter incoming light
- On: liquid crystals become

![Fig. 09 Detail of the louvers on the Administration Building](image)
Daylight Performance in Mid/Large Buildings

transparent and light transmission rises from 40% to 70%

*Laminated glass with photovoltaic modules*
- Solar cells fixed between panes of glass
- Possible to create transparent, translucent or opaque modules depending on the type of cells used and the arrangement of them

*Holographic Optical Elements (HOE)*
- Guide incoming light through diffraction that depends on the wavelength of radiation
- Applied on a photographic film with high resolution and placed between two panes of glass
- Used with skylight elements or façade elements
- Greater efficiency when tilted at 45 ° because more light can be captured

*Prismatic lens (plate or film)*
- Reflect direct solar radiation
- Create diffuse light in the interior
- To maintain optimal effect, modules need to be able to track the sun
- Can lead to color variation

**Roof Structures**

Roof structures can provide regulated toplighting that may block or permit light to pass in desired areas. Some structures may focus on shading all direct sun and only allowing diffuse reflected light into a space. Other structures can focus creating shade patterns in a space.

Light pipes collect light through a heliostat and channel the light through a reflective tube of prismatic glass, plastic film, or mirrors. At the
end of the pipe diffuse light enters the space.

**Case Studies**

The Nasher Gallery
Renzo Piano
Dallas, Tx

- Simulated sun’s movement in design of roof forms
- Block direct sunlight that is south of the east/west axis
- Matrix of aluminum shells
- Thin skin of curved glass panels
- No direct radiation
- Lots of north light (no hard shadows)

Central United Methodist Church
William Wenzler and Associates
Milwaukee, Wisconsin

- Submerged into a hill
- Tower with south facing windows and a blank wall to the north
- Electrically operated thermal shutter tracks the sun redirects low angle winter sunlight but rejects high angle summer sunlight (as well as heat)
- System of mirrors within the tower redirects light into the church

**Translucent Materials**

Translucent materials can be used in place of glass to allow diffuse light into a space with no direct sun. Some translucent materials include fiberglass, plastics, Kalwall, and frosted glass.

**Case Study**

Chelsea Club
Fletcher Priest
London, England

- Client wanted privacy (no views) as well as a naturally lit space
- Vandal-resistant, light-diffusing fiberglass panels called ‘Kalwall’
- Diffuse light
- Exterior appearance seems to be solid white by day

Daylighting in a building should be designed to reflect the use of space within. Different functions and activities merit different levels and forms of daylighting and different strategies and technologies provide different daylighting conditions. It is
important to analyze these variables in order to choose the best form of daylighting and shading for each building.

Notes

References


