Basic principles of light and daylight. Energy efficient light design of buildings. Daylight design of buildings.

Introduction

Daylighting is the controlled admission of natural light, direct sunlight, and diffused-skylight into a building to reduce electric lighting and saving energy. By providing a direct link to the dynamic and perpetually evolving patterns of outdoor illumination, daylighting helps create a visually stimulating and productive environment for building occupants, while reducing as much as one-third of total building energy costs. A daylighting system is comprised not just of daylight apertures, such as skylights and windows, but is coupled with a daylight-responsive lighting control system. When there is adequate ambient lighting provided from daylight alone, this system has the capability to reduce electric lighting power. Further, the fenestration, or location of windows in a building, must be designed in such a way as to avoid the admittance of direct sun on task surfaces or into occupants' eyes. Alternatively, suitable glare remediation devices such as blinds or shades must be made available. Implementing daylighting on a project goes beyond simply listing the components to be gathered and installed. Daylighting requires an integrated design approach to be successful, because it can involve decisions about the building form, siting, climate, building components (such as windows and skylights), lighting controls, and lighting design criteria.

This overview is intended to provide specific details for Federal agencies considering daylighting technologies as part of a new construction project or major renovation.

Description

The science of daylighting design is not just how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects. Beyond adding windows or skylights to a space, it involves carefully balancing heat gain and loss, glare control, and variations in daylight availability. For example, successful daylighting designs will carefully consider the use of shading devices to reduce glare and excess contrast in the workspace. Additionally, window size and spacing, glass selection, the reflectance of interior finishes, and the location of any interior partitions must all be evaluated. A daylighting system consists of systems, technologies, and architecture. While not all of these components are required for every daylighting system or design, one or more of the following are typically present:

- Daylight-optimized building footprint
- Climate-responsive window-to-wall area ratio
- High-performance glazing
- Daylighting-optimized fenestration design
- Skylights (passive or active)
- Tubular daylight devices
- Daylight redirection devices
- Solar shading devices

- Daylight-responsive electric lighting controls
- Daylight-optimized interior design (such as furniture design, space planning, and room surface finishes).

Since daylighting components are normally integrated with the original building design, it may not be possible to consider them for a retrofit project. If possible, the building footprint should be optimized for daylighting. This is only possible for new construction projects and does not apply to retrofits. If the project allows, consider a building footprint that maximizes south and north exposures, and minimizes east and west exposures. A floor depth of no more than 60 ft., 0 in. from south to north has been shown to be viable for daylighting. A maximum facade facing due south is the optimal orientation. Deviation from due south should not exceed 15° in either direction for best solar access and ease of control. With the building sited properly, the next consideration is to develop a climate-responsive window-to-wall area ratio. As even high-performance glazings do not have insulation ratings close to those of wall constructions, the window area needs to be a careful balance between admission of daylight and thermal issues such as wintertime heat loss and summertime heat gain. A high-performance glazing system will generally admit more light and less heat than a typical window, allowing for daylighting without negatively impacting the building cooling load in the summer. This is typically achieved through spectrally-selective films. These glazings are typically configured as a double pane insulated glazing unit, with two 0.25 in. (6 mm) thick panes of glass that are separated by a 0.50 in. (12 mm) air gap. This construction gives the insulated glazing unit a relatively high insulation rating, or R-value, as compared to single pane glass. A low-emissivity coating is also often part of these high-performance glazing units, which further improves the R-value of the unit.

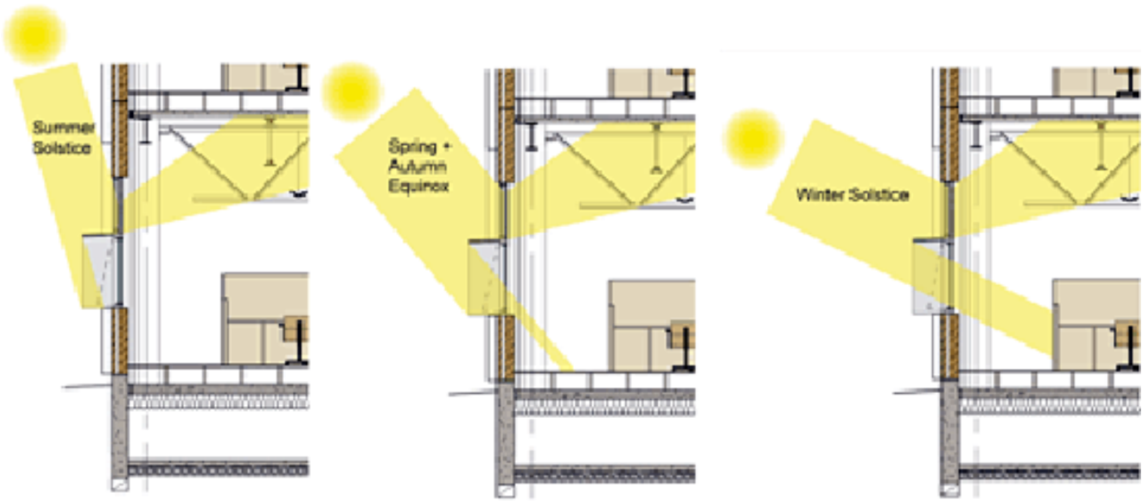
In addition to the considerations above regarding windows, a daylighting-optimized fenestration design will increase system performance. The window has two essential functions in a daylit building:

(1) daylight delivery or admittance, and

(2) provision of view to the occupants.

The former dictates a glazing with a very high visible light transmittance (commonly abbreviated as VLT, or Tvis), the latter merely needs to be clear, and, in fact, should have a relatively low Tvis to prevent glare. As a general rule, the higher the window head height, the deeper into the space the daylight can penetrate. Therefore, good daylighting fenestration practice dictates that the window should ideally be composed of two discrete components: a daylight window and a view window. The daylight window should start at 7 ft., 6 in. above the finished floor at a minimum and have a high Tvis (50% to 75%); the view window should be placed lower and have a Tvis of less than 40% in most climates. Many daylighting designs will employ skylights for toplighting, or admitting daylight from above. While skylights can be either passive or active, the majority of skylights are passive because they have a clear or diffusing medium (usually acrylic) that simply allows daylight to penetrate an opening in the roof. They are often comprised of a double layer of material, for increased insulation. Active skylights, by contrast, have a mirror system within the skylight that tracks the sun and are designed to increase the performance of the skylight by channelling the sunlight down into the skylight well. Some of these systems also attempt to reduce the daylight ingress in the summer months, balancing daylighting with cooling loads. Tubular daylight devices are another type of top lighting device. These devices employ a highly reflective film on the interior of a tube to channel light from a lens at the roof, to a lens at the ceiling plane. Tubular daylight devices tend to be much smaller than a typical skylight, yet still deliver sufficient daylight for the purpose of dimming the electric lighting. Daylight redirection devices take incoming direct beam sunlight and redirect it, generally onto the ceiling of a space. These devices serve two functions: glare control, where direct sun is redirected away from the eyes of occupants, and daylight penetration, where sunlight is distributed deeper into a space that would not be allowed otherwise. Daylight redirection devices generally take one of two forms: a large horizontal element, or louvered systems. Horizontal daylight redirection devices are often called light shelves. As mentioned previously, the windows must be carefully designed to control the solar gains and potential glare stemming from a daylighting design. To this end, solar shading devices are often employed-particularly on the view windows-to minimize the amount of direct sun that enters the space. These are typically called overhangs.

Daylight-responsive electric lighting controls are absolutely essential to any daylighting system. No daylighting design will save any energy unless the electric lights are dimmed or turned off when there is sufficient illumination from daylight. Indeed, if daylighting features such as windows and skylights are not paired with daylighting functionality such as daylight-responsive dimming controls, then the daylighting-enhanced building will more than likely use more energy, not less, than a comparable building without any daylighting features. Daylight-responsive lighting controls consist of continuous dimming- or stepped-ballasts in the light fixtures, and one or more photocells to sense the available light and dim or turn off the electric lighting in response. An often-overlooked element in a successful daylighting design is the interior design. A daylight-optimized interior design considers furniture design, placement, and room surface finishes with respect to daylight performance. For example, office cubicle partition heights will be limited, particularly those running parallel to the south facade, enclosed offices will be kept to a minimum, and walls and ceilings will be as highly reflective as possible, to help "bounce" and distribute the redirected daylight more fully. By positioning work surfaces at a distance from the south facade, solar control is easier with smaller solar shading devices than if a desk or office is placed directly against the south facade. This concept is illustrated in the following figure, and shows how a relatively small overhang provides full direct seasonal solar protection to the workspace. The area immediately adjacent to the south facade is circulation space.

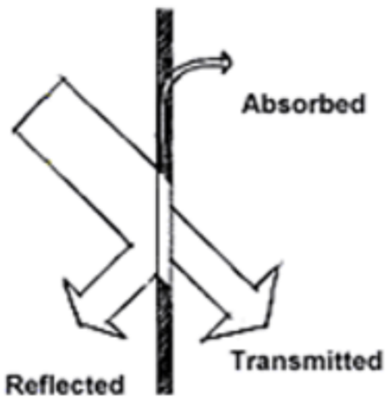


Light entering the building and bouncing around in different seasons. (Summer), (Spring, autumn), (winter)

Types of Technology

Daylighting is an energy-efficient strategy that incorporates many technologies and design philosophies. It is not a simple line item, and can vary tremendously in scope and cost. Many elements of a daylighting implementation will likely already be part of a building design or retrofit (e.g., windows and light fixtures), but a successful daylighting system will make use of the following technology types and construction methods:

- **Exterior shading and control devices.** In hot climates, exterior shading devices often work well to both reduce head gain and diffuse natural light before entering the work space. Examples of such devices include light shelves, overhangs, horizontal louvers, vertical louvers, and dynamic tracking of reflecting systems.



- **Glazing materials.** The simplest method to maximize daylight within a space is to increase the glazing area. However, three glass characteristics need to be understood in order to optimize a fenestration system:
    - U-value: represents the rate of heat transfer due to temperature difference through a particular glazing material.

- Shading coefficient: a ratio of solar heat gain of a given glazing assembly compared to double-strength, single glazing. (A related term, solar heat gain coefficient, is beginning to replace the term shading coefficient.)
- Visible transmittance: a measure of how much visible light is transmitted through a given glazing material.

Glazings can be easily and inexpensively altered to increase both thermal and optical performance. Glazing manufacturers have a wide variety of tints, metallic and low-emissivity coatings, and fritting available. Multi-paned lites of glass are also readily available with inert-gas fills, such as argon or krypton, which improve U-values. For daylighting in large buildings in most climates, consider the use of glass with a moderate-to-low shading coefficient and relatively high visible transmittance.

- **Aperture location.** Simple side lighting strategies allow daylight to enter a space and can also serve to facilitate views and ventilation. Typically, the depth of daylight penetration is about two and one-half times the distance between the top of a window and the sill.
- **Reflectance of room surfaces.** Reflectance values from room surfaces will significantly impact daylight performance and should be kept as high as possible. It is desirable to keep ceiling reflectance over 80%, walls over 50%, and floors around 20%. Of the various room surfaces, floor reflectance has the least impact on daylighting penetration.
- **Integration with electric lighting controls.** A successful daylighting design not only optimizes architectural features, but is also integrated with the electric lighting system. With advanced lighting controls, it is now possible to adjust the level of electric light when sufficient daylight is available. Three types of controls are commercially available:
  - Switching controls: on-and-off controls that simply turn the electric lights off when there is ample daylight.
  - Stepped controls: control individual lamps within a luminary to provide intermediate levels of electric lighting.
  - Dimming controls: continuously adjust electric lighting by modulating the power input to lamps to complement the illumination level provided by daylight.

Any of these control strategies can, and should, be integrated with a building management system to take advantage of the system's built-in control capacity. To take full advantage of available daylight and avoid dark zones, it is critical that the lighting designer plan lighting circuits and switching schemes in relation to fenestration. The following figure shows control scheme types.

- **Other lighting control schemes.** In addition to daylight controls, other electric lighting control strategies should be incorporated where they are cost effective, including the use of:

- Occupancy controls: using infrared, ultrasonic, or micro-wave technology, occupancy sensors respond to movement or object surface temperature and automatically turn off or dim down luminaries when rooms are left unoccupied. Typical savings have been reported to be in the 10% to 50% range depending on the application.
- Timers: these devices are simply time clocks that are scheduled to turn lamps or lighting off on a set schedule. If spaces are known to be unoccupied during certain periods of time, timers are extremely cost-effective devices.

Application

Daylighting can be a viable, energy-efficient strategy in almost any climate. The technology can work in all building types as well, including commercial office buildings, most spaces within a school (i.e., classrooms, gymnasiums, media centres, cafeterias, and offices), retail stores, hospitals, libraries, warehouses, and maintenance facilities. A viable option for most building types and locations, it is important to consider that the architectural response to daylighting differs by building type, climate, and glare tolerability.

Economics

Daylighting has the potential to provide significant cost savings. For many institutional and commercial buildings, total energy costs can be reduced by as much as one-third through the optimal integration of daylighting strategies. In addition, the benefits of a daylit building extend beyond simple energy savings. For example, by reducing the need for electric consumption for lighting and cooling, the use of daylight reduces greenhouse gases and slows fossil fuel depletion. Numerous studies also indicate that daylighting can help increase worker productivity and decrease absenteeism in daylit commercial office buildings, boost test scores in daylit classrooms, and accelerate recovery and shorten stays in daylit hospital patient rooms. As with all energy-efficient design strategies, there are some costs associated with the use of daylighting. Designers must be sure to avoid glare and overheating when placing windows. More windows do not automatically result in more daylighting. That is, natural light has to be controlled and distributed properly throughout the workspace. Also, for cost savings to be realized, controls have to be in proper functioning order. Poor installation, commissioning, or operation and maintenance (O&M) practices can all lead to less-than-favourable performance.

Additionally, it is important for the daylighting design process to involve the integration of many disciplines including mechanical, electrical, and lighting. Design team members need to be brought into the process early to ensure that daylighting concepts and ideas are carried throughout the project.

1. Awareness of basic visual acuity and performance issues is essential to an effective daylighting design, including:

    - **Veiling reflections.** Veiling reflections of high brightness light sources off specular, or shiny, surfaces obscure details by reducing contrast. They should be avoided; particularly where critical visual tasks occur.
    - **Distribution.** Introduce as much controlled daylight as deep as possible into a building interior. The human eye can adjust to high levels of luminance as long as it is evenly distributed. In general, light which reaches a task indirectly (such as having bounced from a white wall) will provide better lighting quality than light which arrives directly from a natural or artificial source.
    - **Glare.** The aim of an efficient daylighting design is not only to provide illuminance levels that are sufficient for good performance, but also to maintain a comfortable and pleasing atmosphere. Glare, or excessive brightness contrast within the field of view, is an aspect of lighting that can cause discomfort to occupants. The human eye can function quite well if extreme levels of brightness are present in the same field of view.
    - **Variety.** Some contrast in brightness levels may be desirable in a space for visual effectiveness. Dull uniformity in lighting can lead to tiredness and lack of attention-neither of which is compatible with a productive environment. Often, a good daylighting solution will integrate a "blast" of beam daylight in a circulation area for visual interest and to help lead occupants through a building. The human eye is naturally attracted to this bright area and can be useful in guiding people down an otherwise dull corridor.
2. Good daylighting requires attention to both qualitative and quantitative aspects of design. Make sure the combination of natural and artificial sources provides adequate light levels for the required task.
    - The Illuminating Engineering Society (IES) publishes an industry standard method for determining recommended illuminance levels (expressed in units of footcandles) for various tasks.
    - For office spaces, it is recommended a minimum of 50 footcandles on an imaginary desk-height horizontal "work surface." Nevertheless, when used in conjunction with an indirect ambient lighting system and direct task lighting, a high-quality daylighting design can be achieved with ambient lighting levels of 30 footcandles or less.
3. To be effective, daylighting must be integrated with electric lighting design. In particular, daylighting must be coupled with efficient electric lighting controls if net energy savings are to be realized. As part of a daylighting design, consider the use of continuously dimming fixtures controlled by luminous sensors.

Design Recommendations

During the design process, the following design strategies should be understood and explored:

- Increase perimeter daylight zones-extend the perimeter footprint to maximize the usable daylighting area.

- Allow daylight penetration high in a space. Windows located high in a wall or in roof monitors and clerestories will result in deeper light penetration and reduce the likelihood of excessive brightness.
- Reflect daylight within a space to increase room brightness. A light shelf, if properly designed, has the potential to increase room brightness and decrease window brightness.
- Slope ceilings to direct more light into a space. Sloping the ceiling away from the fenestration area will help increase the surface brightness of the ceiling further into a space.
- Avoid direct beam daylight on critical visual tasks. Poor visibility and discomfort will result if excessive brightness differences occur in the vicinity of critical visual tasks.
- Filter daylight. The harshness of direct light can be filtered with vegetation, curtains, louvers, or the like, and will help distribute light.
- Understand that different building orientations will benefit from different daylighting strategies; for example, light shelves-which are effective on south facades-are often ineffective on east or west elevations of buildings.

Energy Efficient Lighting

Introduction

Besides affecting the physical and emotional well-being of the building occupants, a building's interior lighting system is both a dominant consumer of electrical energy and a major source of internal heat. In commercial buildings it normally accounts for more than 30% of the total electrical energy consumed. Yet much of this expense can be avoided.

Specifying a high-quality energy efficient lighting system that utilizes both natural and electric sources as well as lighting controls can provide a comfortable yet visually interesting environment for the occupants of a space. Recently developed energy efficient lighting equipment such as compact fluorescent lamps and "soft-start" electronic ballasts can be used to help cut lighting operational costs 30% to 60% while enhancing lighting quality, reducing environmental impacts, and promoting health and work productivity.

Description

To achieve a quality lighting environment, carefully choose the equipment to satisfy both performance and aesthetics needs. Lighting equipment selection should be based on a balance between the requirements of the design and an effort to limit the number of fixture types and lamp types in order to have reasonable maintenance inventories. Lamp selection is based on efficacy (lumens per watt), colour temperature, colour rendering index, life and lumen maintenance, availability, switching, dimming capability, and cost.

A. Energy Efficient Lamps Commonly Used Today

Energy efficient, fluorescent lamps

Fluorescent Lamps

Fluorescent Lamps are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer. To gain the most efficiency, use current and proven equipment technology and install fluorescent luminaires in places where they can be integrated with the architecture, available daylight, and switching or dimming controls

High-Intensity Discharge Lamps (HID)

High-intensity discharge lamps (HID) are still one of the best performing and most efficient lamps for lighting large areas or great distances. Metal halide (white light) lamps are replacing high pressure sodium lamps in many outdoor applications because white light sources can be 2 to 30 times more effective in peripheral visual detection than yellow-orange sources like high pressure sodium. Pulse initiated, or "pulse-start" metal halide lamps provide better colour stability and longer life than previous technologies. PAR metal halide lamps with ceramic arc-tube enclosures are commonly used for accent lighting and highlighting in large spaces, and are now commonly used in retail applications. The small size of the metal halide arc-tube allows for excellent optical control. However, the extreme brightness of the metal halide lamp requires careful shielding and design.

Incandescent Lamps

Incandescent lamps are still used for accent and specialty lighting, where the warm colour, controlled brightness, instant-on, and dimming capabilities of these sources is needed. Incandescent lamps can provide a "sparkle" that is not characteristic of more diffuse fluorescent sources. PAR and low-voltage lamps can provide good beam control, and if dimmed, can also provide a reasonable lamp life. 130V-rated incandescent lamps are also available which will last longer than their 120V counterparts when operated at 120V (with only slightly reduced light output for the same wattage rating). However, because of their lower energy efficiency and shorter lamp life, incandescent lamps should be used carefully for lighting of specific features. Some of the most effective lighting designs balance a small quantity of incandescent accent lighting with a fluorescent ambient (general) lighting system.

LED Lamps

LED lamps are the newest addition to the list of energy efficient light sources. While LED lamps emit visible light in a very narrow spectral band, they can produce "white light". This is accomplished with either a red-blue-green array or a phosphor-coated blue LED lamp. LED lamps last 40,000 to 100,000 hours depending on colour. The current challenges of the LED source are a poor Colour Rendering Index (CRI) of 65 or lower and poor efficacy, often less than 30 lumens per watt. LED lamps have made their way into numerous lighting applications including exit signs, traffic signals, under-cabinet lights, and various decorative applications. Though still in their infancy, LED lamp technologies are rapidly progressing and show promise for the future.

B. Energy-Efficient Ballasts

Fluorescent Ballasts

- Rapid start ballasts are the most common type of fluorescent ballast. These ballasts offer a long lamp life at a reasonable cost. They have been used for years with lighting controls to provide energy savings.
- Instant start ballasts are usually the least expensive ballasts on the market. The efficiency of instant start ballasts is higher than rapid start ballasts, but lamp life is shorter, especially when the frequency of starts is increased due to the use of controls. They are often used where energy savings is the primary goal and lights are on continuously for very long periods of time. One advantage of the instant start ballast is that the lamps are wired in parallel, so that when one lamp on a multi-lamp ballast burns out, the others remain illuminated.
- Program rapid start ballasts are some of the best to use for energy efficiency and long lamp life. These ballasts are slightly more expensive than standard rapid start ballasts, but use a "gentler" starting method so that frequent starting lessens the reduction in rated lamp life. These ballasts are recommended for smaller diameter fluorescent lamps and compact fluorescent lamps. With the right lighting controls scheme, program start ballasts can provide significant energy savings.
- Dimming electronic ballasts for linear fluorescent lamps usually fall into two categories. The first type has a dimming range of 5% or 10% up to 100% light output and is generally the least expensive. This ballast is commonly used when the lowest light levels are not needed, or to achieve energy savings by dimming the lights when there is plentiful daylight. The second type of ballast, often referred to as an "architectural dimming ballast," is more expensive and has a dimming range of 1% to 100% light output. This ballast is used in situations where lower light levels are desired.

Electronic High-Intensity Discharge Ballasts

Electronic high-intensity discharge ballasts (HID) for metal halide lamps are now available for most lamps up to 150 watts. These ballasts should improve lamp performance and offer a limited range of dimming to achieve some energy savings.

C. Luminaires

A luminaire, or light fixture, is a unit consisting of one or more of the following components:

- lamp(s) and lamp socket(s)
- ballast(s)
- reflective material
- lenses, refractors, louvers, blades, or other shielding.

An efficient luminaire optimizes the system performance of each of its components. There are a few types of luminaires that offer opportunities for energy conservation in a lighting system design. Many of these provide indirect light to brighten the ceiling or are designed to brighten walls or task surfaces. Most of them are fluorescent and are easily controlled for further energy savings.

Application

Energy efficient lighting can be installed in new construction, modernization, and repair and alternation projects. It is applicable to all building types and space types, particularly educational facilities, office buildings, health facilities, research facilities, warehouses, libraries, and courthouses.

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