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design brief

DAYLIGHTING

Using fundamental components of the Daylighting Designer's Toolkit, designers can improve the visual environment, create a higher-quality space, and lower energy costs for buildings.

Summary

Daylighting provides the opportunity for both energy savings and improved visual comfort. Daylight may be introduced into a building using a variety of design concepts, including side-lighting and/or toplighting strategies.The level of integration of daylighting into the design can have a profound influence on the architectural form of the building.

When developing a daylighting design,consider the fundamental components of the Daylighting Designer's Toolkit, which includes these six design principles:

- Treat the building as a luminaire.
- Separate the vision and daylight glazings.
- Position the daylighting apertures to create mood and visual focus.
- Address the requirements of the visual task.
- Integrate the daylighting system with the architecture.
- Integrate the daylighting system with the other building systems.

Care must be taken when developing a daylighting design to minimize direct solar penetration through careful placement of daylighting apertures and the incorporation of shading elements and/or light shelves.Glazing selection is a key consideration in the overall design. Integration with electric lighting, interior design, and mechanical systems also plays an important role in

CONTENTS

the overall success of the design.

The application of these basic tools in the design of a daylighting system can provide a building with a unique architectural expression, lower energy costs, improved visual environment, higher-quality space,and improved occupant satisfaction.

Introduction

Numerous books,reports,and magazine articles have been written about daylighting design. Some have presented the merits of daylighting, while others have discussed various daylighting design strategies. However, it is often difficult to extract from these publications the underlying principles used to create a good daylighting design solution. This Design Brief will not reiterate the merits of daylight or provide an in-depth technical discussion of any particular issue.Instead,it will focus on a few basic principles and strategies used to effectively integrate daylight into a building design.We will introduce the concept of a "Daylighting Designer's Toolkit." The Toolkit addresses the basic building blocks of good daylighting design,and consists of the following "tools":

- Six underlying daylighting design principles
- Two basic types of daylighting strategies
- Three levels of daylighting design integration

In any daylighting solution, the designer can use these tools to help create a successful daylighting design.The level of integration is influenced by both the project budget and the point in the design process when daylighting is incorporated.Generally, the earlier in the design process that daylighting is considered, the *greater* the potential for success.

Six Important, but Often Overlooked, Daylighting Principles

The building design should be oriented to take full advantage of daylight availability while providing the occupants with a strong

Figure 1: Denver International Airport

The tensile fabric membrane roof of the main terminal building at Denver International Airport is a daylighting system with a profound impact on the building form.

Source: City of Denver

psychological connection to the outdoors. The glazing and fenestration systems should also consider and adapt to the orientation and configuration of each building elevation. Regardless of the ultimate daylighting solution, six important principles should always be in the back of the designer's mind. These six principles form an important part of the "Daylighting Designer's Toolkit."

- Treat the building as a luminaire.
- Separate the vision and daylight glazings.
- Position the daylighting apertures to create mood and visual focus.
- Address the requirements of the visual task.
- Integrate the daylighting system with the architecture.
- Integrate the daylighting system with other building systems.

Treat the Building as a Luminaire

A key goal of any daylighting design is to provide even and consistent interior illuminances and luminance ratios. To accomplish this, the designer should think of the building as a lighting fixture. As with any lighting fixture (or luminaire), internal and external geometries and finishes play an important role in how light is distributed within the space.

In daylighting design, the architectural form does more than dictate how daylight enters a building. The architecture can also help to redirect daylight deeply into a space, place light where it is needed, and reduce glare associated with high contrast ratios within the visual field of the building occupants. Just as in the case of a good luminaire, the architectural form and interior design can be used to prevent high contrast ratios and effectively redirect and place light where it is required.

Using reflected daylight (daylight that is bounced off of interior planes and surfaces), the system can provide even coverage while minimizing glare and contrast ratios. Light-colored

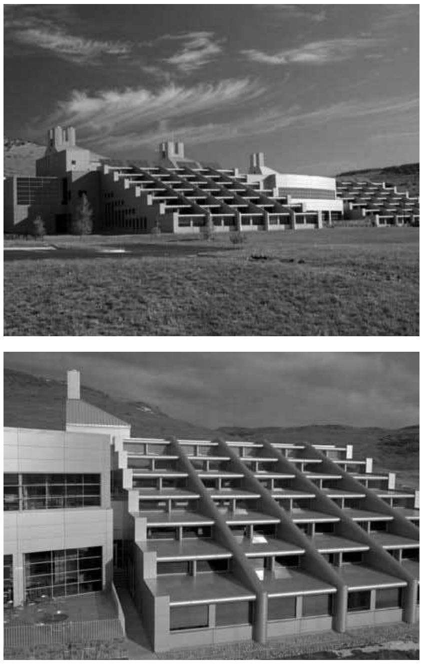
Figure 2: Interior view of the National Renewable Energy Laboratory's Solar Energy Research Facility

The interior surfaces of the Solar Energy Research Facility are used to provide reflected, indirect daylighting to the interior spaces.

Source: National Renewable Energy Laboratory

Figure 3: Exterior views of the Solar Energy Research Facility

The exterior of the Solar Energy Research Facility relies on an articulated southern façade to control direct solar penetration into the interior of the building.



Source: National Renewable Energy Laboratory

exterior and interior surfaces will effectively reflect daylight into the space and minimize contrast ratios within the visual field. Although light-colored surfaces are important design elements, care must be taken to ensure that interior or exterior surfaces within the normal visual field are not too bright. Specular surfaces should be used sparingly since they can become an especially strong source of glare. The daylighting designer should also avoid using dark surfaces or architectural elements adjacent to glazing elements and apertures (i.e., window frames/mullions, blinds, and adjacent walls/opaque surfaces), and should avoid creating interior geometries that cause sharp delineation between daylight-illuminated planes and surfaces and surrounding planes and surfaces.

It is best to use the skydome as a daylighting resource rather than the sun.The luminous intensity of the solar disk is far too variable to use reliably and comfortably. Due to the very nature of the sun's intense brightness and its daily and seasonal movement, a high-quality daylighting system should generally avoid allowing direct solar penetration into the occupied spaces.As a result,the daylighting solution often requires significant surface articulation or careful orientation of daylight apertures to exclude direct beam sunlight during normal occupied hours. Statistically, the skydome (excluding the portion containing the solar disk at any given time) provides a stable daylighting resource with more consistent luminance intensities throughout the day and year. Thus, a high-quality daylighting solution generally relies heavily on apertures that utilize daylight from the skydome.

A system that relies on the skydome rather than the sun will often provide adequate illumination under both clear and overcast skies.Light from the northern portion of the skydome may be used to provide relatively consistent illumination without having any of the heat gain and glare problems inherent with south-facing apertures. East and west apertures are especially problematic, since it is difficult to control direct solar illuminance on these orientations resulting from the low solar angles occurring during the early-morning and late-afternoon hours.

Lighting from more than one direction (i.e.,providing daylighting to a space using apertures with different orientations) will increase the potential for balanced daylight coverage and provide a higher-quality visual environment.

Separate the Vision and Daylight Glazings

When most people think of daylight utilization, they think of the standard curtain walls and/or punched windows present in almost all buildings.Because those windows admit light,people think that they provide both vision and daylight harvesting potential.While these windows do have the potential for providing daylight to their adjacent surroundings, the designer must realize that glazing serves two different purposes: providing a view out and allowing daylight in. Since glazings have two distinct purposes, the design should ensure that the building uses each glazing type to its fullest potential."Vision glass" is just that — it provides a visual connection to the outdoors. "Daylighting glass"is used to light the space. Since the two systems perform very different functions, the glazing characteristics will tend to be quite different.

Vision glazings typically use lower visible transmittances to provide comfortable views to the outside without the need for vision control elements such as mini-blinds.The final specification of vision glazing optical properties depends on a combination of factors, including glazing orientation, presence of external shading elements, reflectance of the outdoor surfaces (such as parking lots, sidewalks, and so on), internal space geometries, and internal illuminance levels and contrast ratios required by the visual task.

Daylight glazings are used primarily to provide interior illumination.In general,these glazings have a much higher visible transmittance than vision glazings.The final specification of daylight glazing optical properties depends on the placement of the aperture within the space, aperture orientation, and climatic conditions. Generally, daylight glazings are located above the occupants' heads. Fenestration control (either internal or

Figure 4: Victor Valley Community College

The daylighting design for the Victor Valley Community College Learning Resource Center separates the vision and daylight glazings and provides specialized fenestration control for each.

external light shelves or shading elements) is required to prevent direct view of daylighting apertures located within the normal visual field of the occupants.

The various glazings used in a project are selected based on façade/surface orientation, glazing purpose (view vs. daylight),

Table 1: Typical Glazing Selections for Daylighting and Vision Glass

Typical optical and thermal properties for high-performance glazing options are listed below. In order to control glare,vision glass typically has very low visible light transmittance,while daylight glazing,which is generally not in the occupant's direct field of view, has much higher visible light transmittance. All options have reduced solar heat gain coefficients to minimize cooling loads.

Color	Purpose	τ_{vis}	τ_{solar}	Winter U	Summer U	SHGC
Clear	Vision	36%	20%	.31	.32	.27
	Daylight	76%	46%	.31	.31	.53
	Daylight (enhanced)	70%	32%	.29	.28	.37
Gray	Vision	25%	16%	.32	.34	.24
	Daylight	76%	46%	.31	.31	.53
	Daylight (enhanced)	70%	32%	.29	.28	.37
Green	Vision	32%	14%	.31	.33	.21
	Daylight	65%	31%	.31	.32	.38
	Daylight (enhanced)	60%	24%	.29	.30	.30
Blue	Vision	29%	16%	.31	.33	.24
	Daylight	48%	28%	.31	.32	.35
	Daylight (enhanced)	44%	20%	.29	.30	.27
Blue/Green	Vision	31%	15%	.31	.33	.22
	Daylight	64%	32%	.31	.32	.39
	Daylight (enhanced)	60%	25%	.29	.30	.31

Notes:

1. τ_{vis} is the visible light transmittance.
2. τ_{solar} is the total solar transmittance.
3. Winter U-value is the center-of-glass thermal conductance under standard winter conditions in Btu/hr-ft^2-°F.
4. Summer U-value is the center-of-glass thermal conductance under standard summer conditions in Btu/hr-ft^2-°F.
5. Solar heat gain coefficient (SHGC) is the fraction of the incident solar radiation that becomes a cooling load.

Source: Architectural Energy Corporation exterior articulation,and interior design.However, a good starting point is to select a vision glass with a visible transmittance ranging between 20 and 30 percent, and a daylighting glass with a visible transmittance of 50 to 60 percent. In California, it is usually preferable for the glazings to have as low a solar heat gain coefficient as possible. **Table 1** lists glazing possibilities grouped by color. For each color, three specific glazing options are listed.The first two are typical low-e glazings while the third provides an enhanced high-performance low-e option.

Create Mood and Visual Focus

Just as with electric lighting design, luminance ratios can be used in daylighting design to create visual focus.Careful attention to aperture location and detailing can greatly influence the directionality and placement of daylight, thus influencing the occupants' mood. Providing a daylighting system that places additional light on or near a specific area within a building will allow the user to draw the occupants' attention to that area of the building,thus reinforcing the activities or resources that reside in that area.

Address the Requirements of the Visual Task

As with any other lighting system, the daylighting design must address the requirements of the visual tasks that take place in a space.The quantity and directionality of light provided by the daylighting system should be appropriate for the visual task, and the daylighting aperture placement and location should be used to tune the amount of daylight provided.The detailed electric lighting quantity and quality standards established by the Illuminating Engineering Society of North America (IESNA) are also applicable to daylighting solutions. For more information refer to the IESNA Handbook.[1]

Integrate the Daylighting System with the Architecture

The daylighting system should augment and enhance the architecture and not become a competing design element.

Figure 5: Skylighting at a retail store

The grouping of skylights over certain sales areas provides visual focus to store patrons.

Figure 6: Multi-Agency Library at the College of the Desert

The design of the Multi-Agency Library at the College of the Desert in Palm Desert,CA,fully integrates daylighting apertures and design into the building's unique architectural expression.

Electric lighting integration issues include matching color temperature and specifying compatible controls and light sources.

Daylighting systems can be wonderful form-givers to a building design and can be used to provide a unifying theme for creative aesthetic expression. The use of daylight, requiring the thoughtful placement and differentiation of the vision and daylighting apertures, can provide the foundation for a unique building design with "street-side" visual interest. Daylighting as a form-giver can provide justification for surface articulations that create a sense of human scale in the building façade.

Integrate the Daylighting System with the Other Building Systems

The presence of daylight should influence the design of the electric lighting and control systems. The electric lighting designer should remember that the color temperature of daylight is quite different from the average incandescent or fluorescent light source, which typically falls in the range of 2,700°K to 3,500°K. In contrast, the color temperature of daylight will vary between 4,000°K and 10,000°K depending on the time of day, sky condition (clear vs. overcast), and location of the sun.[2] Whenever possible, the daylighting and electric lighting designers should work together to specify lamp technologies and color temperatures that blend with the daylight resource.

In the daylit zones, controls are required to ensure that energy savings from the daylighting system are realized. The electric lighting system may be either dimmed or switched off when the desired levels of illumination are achieved. It is generally best to use controls that are simple to install, operate, and maintain. Complex controls increase the chances of incorrect installation and/or operation.[3] Faulty controls are responsible for the failure of many designs to achieve their full energy savings potential. Control simplicity is a compelling reason for designing a daylighting system that provides adequate daylight under both clear and overcast sky conditions, thus allowing the use of simple "on/off" controls triggered by a time clock or outdoor photocell sensor.

When daylight controls are specified, it is important that the lamp technologies be compatible with the control strategies used. With stepped control, frequent lamp cycling may occur. As a result, compact fluorescent lamps, which experience significantly shorter lamp life with rapid or frequent on/off cycling, may not be appropriate for spaces that experience frequent variations in daylight intensity. HID light sources with long restrike times may also not be appropriate.

When developing the electric lighting design, the design team should consider creating different daytime and nighttime looks within the daylit areas.One of the greatest advantages of using daylight is the psychological connection to the outdoors that is provided by the subtle lighting color and intensity changes that occur throughout the day.These changes are critical to providing the occupants with a sense of the passage of time. As a result, the design team may not want the electric lighting system to re-create the daytime appearance of the space, but rather to reinforce the notion of passage of time by providing a distinctively different luminous environment during the evening. A more subtle lighting scheme with reduced light levels is more in tune with occupant expectations, and saves additional energy. See the Energy Design Resources Lighting Design Brief for more information on electric lighting system design.

Besides influencing the electric lighting system design,daylighting systems can also influence other building design considerations, such as structural system type, sizing, and placement; floor-to-floor height; mechanical system type and ductwork space allocation;interior finishes;and selection of furniture systems. See the Energy Design Resources Integrated Design Brief for more detailed information on building system integration issues.

Types of Daylighting Strategies

While a daylighting solution can use a combination of different strategies, the basic daylighting building blocks generally fall into two broad categories: sidelighting and toplighting strategies.The

Control systems, while essential for energy savings, are also a common source of daylighting system failure. Designers must strive to keep controls simple, and anticipate the level of control required during the development of the daylighting design.

Figure 7: Top and sidelighting strategies

This schematic shows a mixture of top and sidelighting strategies in a multi-story building. Quality daylighting designs generally provide daylight from a variety of sources and directions.

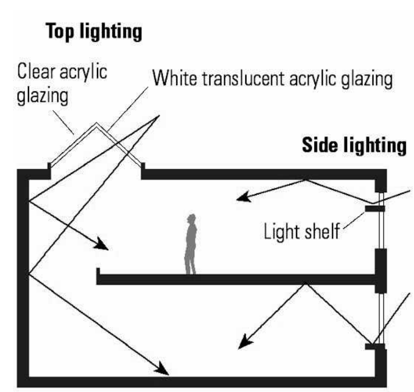
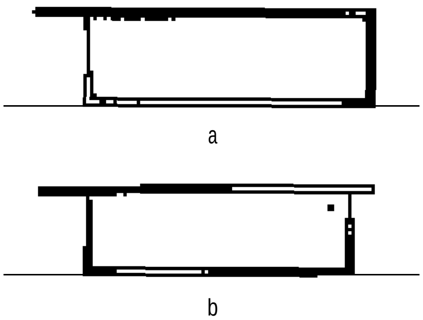


Figure 8: Sidelighting concepts

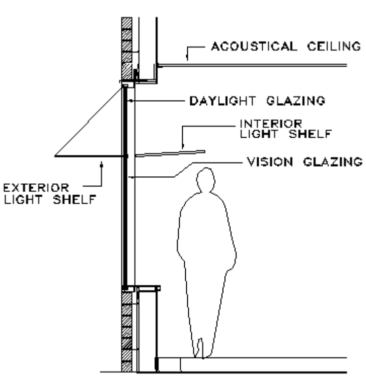
This figure contains two simplified building sections, illustrating unilateral and bilateral sidelighting concepts.



Source: Illuminating Engineering Society

Figure 9: Standard sidelighting concept

This figure illustrates a standard side-lighting design concept with vision and daylight glazings separated by an interior light shelf.



Source: Architectural Energy Corporation

appropriateness of the daylighting system will depend on the layout of the building (i.e., low-rise vs. high-rise), the siting (i.e., topography, views,and orientation), and the surroundings (i.e., presence of vegetation, rural vs. urban, height and reflectance/transmittance of adjacent shading elements).The key difference is that sidelighting strategies admit light from the perimeter walls of the building while toplighting strategies admit light through the top of the building.

Sidelighting

Due to its very nature,sidelighting is a technique that provides daylight through apertures located in the perimeter walls of a building. For buildings with long,shallow floor geometries,it is feasible to daylight up to 70 percent of the footprint with a sidelighting system.The space may be either unilaterally lit (daylit from one side) or bilaterally lit (daylit from two sides).Both unilateral and bilateral sidelightings lend themselves to curtain wall or other continuous fenestration systems. The depth of the daylit zone is typically limited to twice the window head height above the interior work plane.For this reason,the daylight glazings are placed as close to the ceiling as possible.Bilateral daylighting allows the designer to balance the admission of daylight by lighting from two sides of a space. Bilateral daylighting works well with relatively shallow floor plates using an open office interior configuration.

Sidelighting is applicable to nearly any building type,but is one of the only daylighting techniques that can be used for the average high-rise building without an internal light shaft or atrium. A sidelighting strategy usually performs best if daylight-compatible spaces are placed at the perimeter of the floor plate while spaces not conducive to daylighting are moved to the interior. Since sidelighting strategies rely on apertures located in the building's perimeter walls, access to daylight is highly dependent on façade orientation,and thus the apertures and shading articulation must be responsive to the prevailing solar conditions. Building orientation should be used to maximize the daylight harvesting potential while also minimizing glare potential and solar heat gain.

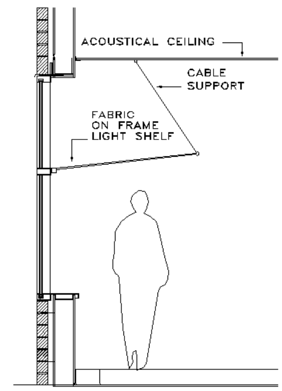
Orienting the long axis of the building in the east/west direction will maximize the amount of northern and southern orientations/façades. For northern exposures, fenestrations with high glazing transmittances can be used to provide cool, pleasant, stable daylight while also maximizing views to the outdoors. For south, east, and west orientations, the wall fenestrations should be separated into vision and daylighting systems. In this type of system, the vision glazings run from the sill height to a height of approximately seven feet above the floor, and the daylighting glazings run from the top of the vision glazings to the ceiling plane (typically a height of nine to ten feet). A light shelf is generally used to direct light from the daylighting glazings onto the ceiling and to shield occupants from direct solar glare.

To provide effective daylight coverage using simple sidelighting techniques, a nine-foot ceiling is the absolute minimum acceptable ceiling height. A ten-foot ceiling or higher is recommended. While the vision glazings provide the occupants with views to the outside, internal daylight control elements are needed to reflect and redirect light from the daylight glazings onto the ceiling plane. The daylighting system should be designed to carefully and artfully control the daylight resource, and strive to maximize daylight coverage and usability while minimizing interior luminance ratios.

Figures 10 and 12 illustrate two simple and relatively inexpensive interior light shelf concepts. **Figure 10** represents the light shelf system used in the Sacramento Municipal Utility District's (SMUD) Headquarters in Sacramento, California. **Figure 11** shows the SMUD system in use. In this system, a monolithic light shelf element is constructed using a metal frame covered with translucent, woven fabric. The frame is anchored on one side at the window frame while the interior edge is supported using cables with a fusible link. The fusible link serves to release the cable in case of fire, allowing the fabric shelf to pivot down

Figure 10: Sidelighting concept designed for SMUD headquarters

A simple sidelighting concept with a fabric light shelf was designed for the Sacramento Municipal Utility District (SMUD) headquarters building.



Source: Architectural Energy Corporation

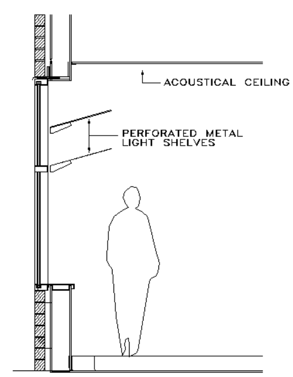
Figure 11: Completed SMUD perimeter office

This photo shows the fabric light shelf, vision glazing, and indirect lighting fixtures in a typical SMUD perimeter office.

Source: Architectural Energy Corporation

Figure 12: Sidelighting concept using stacked light shelves

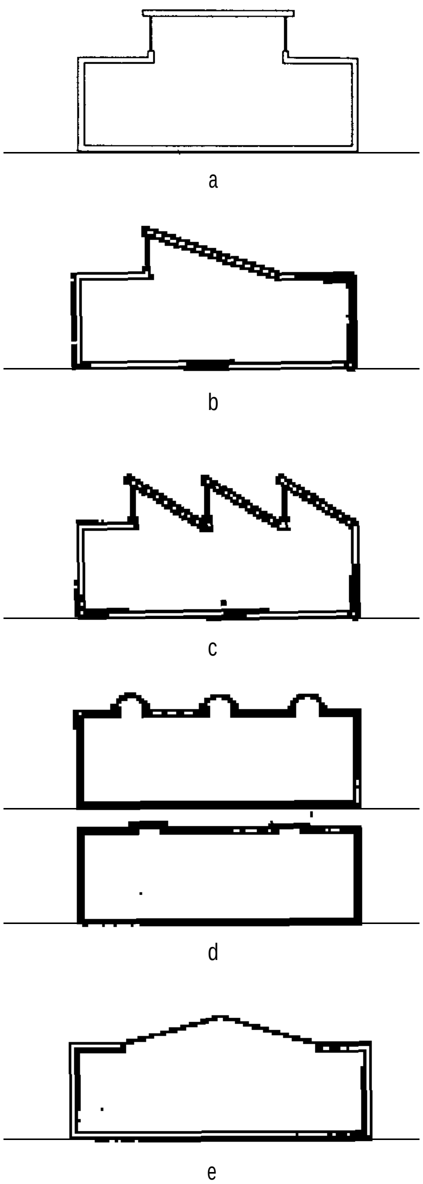
The double light shelf concept is used to provide direct beam daylight control while minimizing light shelf depth.



Source: Architectural Energy Corporation

Figure 13: Simple toplighting concepts

The five basic toplighting concepts are illustrated in these simplified building actions: a) roof monitor b) clerestory c) sawtooth d) skylight e) atrium



Source: Illuminating Engineering Society

and out of the way of the overhead sprinkler system. This cable and fusible link system allowed the light shelf to meet California fire codes.

The second light shelf scheme, shown in **Figure 12**, illustrates a system that employs multiple, smaller light shelf elements. This scheme uses white painted perforated metal panels supported at the window frame by mounting brackets. (A cable support system could also be used.) The use of either translucent fabric or perforated metal panels allows the light shelf element to be somewhat luminous, thereby reducing contrast ratios at the window wall. In either case, the light shelf/fenestration control at the daylight glazing should provide shade control for any direct beam daylight at an angle greater than 15 degrees above horizontal for most commercial applications. Detailed solar angle analyses should be performed for all daylighting solutions to verify that direct solar penetration is prevented.

For interior spaces, sidelight and transom glazings can be used in intermediate partitions to provide borrowed daylight from the perimeter daylit zones of the building. Though not necessarily supplying sufficient daylight to offset the need for electric lighting, interior glazings can provide an important psychological connection to the outdoors for the occupants of interior spaces.

Toplighting

Toplighting strategies provide daylight access through rooftop apertures, allowing for optimal separation of vision and daylight glazings. Toplighting strategies can daylight the entire top floor of a building using rooftop apertures distributed across the roof area. As a result, toplighting strategies can provide uniform interior illuminance regardless of floor plate size and geometry. While toplighting strategies must be responsive to a building's structural layout, their orientation is not dependent on the orientation of the building façade. As a result, the designer can tune the aperture orientation to take full advantage of the available daylight resource without being limited by the building orientation. Toplighting strategies can daylight only the top floor of a building, and thus are effective for daylighting single-story or low-rise buildings.

Toplighting strategies generally fall into the broad categories of roof monitors, clerestories, sawtooth elements, skylights, and atria. **Figure 13** provides illustrations of these five basic top-lighting strategies. Roof monitors occur when a central raised bay is flanked by two lower areas, allowing at least two sides of the raised bay to be glazed. Clerestories utilize rooftop glazings that run parallel to vision glazings located in the perimeter walls, and allow the designer to overcome the daylighting penetration limitations associated with a unilateral sidelighting technique. Sawtooth elements employ a series of either vertical or sloped glazed elements, which are separated by sloped roof elements. Sawtooth elements can be used to uniformly daylight a large floor area while minimizing impacts on the building's overall height. Skylights can have many forms, including dome, pitched, and flat panels that are placed in the plane of the building's roof. The designer should use skylights carefully since integral louver systems may be needed to control glare and solar heat gain. See the Energy Design Resources Skylighting Design Guide for more detailed information on skylighting design. Atria typically consist of large-area roof apertures that can use hipped, domed, shed, and/or pyramid forms. Atria can be used to provide daylight to multiple floors through the use of an interior light court. Atria are generally suitable for lighting a space that is two to four stories high.

Three Levels of Design Integration in the Daylighting Designer's Toolkit

A daylighting design can encompass varying levels of design integration or design complexity. The important concepts and daylighting strategies in the Daylighting Designer's Toolkit can be combined to generate three broad categories of daylighting design integration: component-level solutions, enhanced component-level solutions, and architecturally integrated solutions. The appropriate level of daylighting design integration will

Figure 14: Victor Valley Community College Learning Resource Center

Exterior view of the Victor Valley Community College Learning Resource Center in Victorville, CA, showing toplighting apertures.

Figure 15: Interior of Victor Valley Community College Learning Resource Center

Interior view of the Victor Valley Community College Learning Resource Center in Victorville, CA, showing toplighting apertures.

Figure 16: Supermarket interior with skylights and strip fluorescent fixtures

This supermarket uses off-the-shelf skylights and standard strip fluorescent fixtures in a simple yet effective skylighting application.

Figure 17: Standard skylighting systems

Light-colored trusses (top) serve to minimize contrast between skylights and the building structure.The dark trusses (bottom) accentuate the contrast between the skylights and the surroundings, and create a more "cluttered" appearance.

depend on the project scope,project budget,and the point during the architectural design process that daylighting is considered.

Component-Level Solutions

Component-level solutions are generally the least demanding of the daylighting solutions in the designer's toolkit; therefore, these systems typically have the lowest impact on the building form and require the least amount of time and attention during the design process.They are most suitable for projects that will not allow the building form to be highly adapted or responsive to the use of daylight, and therefore typically do not enhance the architectural form or expression.Component-level solutions are often associated with repetitive construction schemes where a prototypical design is applied in numerous locations without alteration.

The daylighting components consist of off-the-shelf units (i.e., skylights, glazing systems, or interior/exterior shading elements) that are merely applied to the building envelope.In the component-level solution, these off-the-shelf systems are used exactly as intended without modification or additional installation detailing. As a result, component-level solutions are a viable option for projects having a meager daylighting design budget. Component-level solutions are appropriate for projects where daylighting systems are applied late in the design process.They have relatively little impact on building envelope;ceiling/interior systems; and structural, mechanical, and/or electrical systems. The use of off-the-shelf components typically means that the daylight elements may not be fully integrated with the electric lighting system design.

However, significant energy savings are still possible with a component-level solution.The building must still function as a daylighting luminaire,and thus attention to detail is required to ensure that the daylighting apertures and interior surface geometries and characteristics will not create high contrast ratios, glare, or unwanted solar heat gains.The building design should be adapted to help balance the interior luminance ratios and provide more even illuminance distribution.

Fortunately for the daylighting designer, daylighting components are continuously improving and new options are being developed and introduced into the marketplace. Manufacturers have improved the performance of even the simplest skylights through the use of new prismatic and light re-directing materials, solar tracking systems, and selectively transmissive low-e coatings.Curtain wall and architectural product manufacturers have also introduced prefabricated external and internal light shelves and shading screens that can be easily integrated into typical commercial window wall and glazing systems. Paint and ceiling system manufacturers have developed high-reflectance paints and lay-in ceiling tile systems that are intended to increase both daylighting and electric lighting performance. Glazing manufacturers continue to improve the visual and thermal performance of glazing systems, and low-e coatings have become common elements of manufacturers'product lines.

Enhanced Component-Level Solutions

Enhanced component-level solutions provide the next level of daylighting integration in the designer's toolkit.These solutions use the building design and architecture to enhance the performance of off-the-shelf daylighting components, and may include a combination of customized daylighting components and/or building architecture that is more responsive to the daylighting elements. Examples include window wall designs that thoughtfully incorporate either exterior or interior sunshades and light shelves to boost daylight performance and visual comfort,window walls with distinct separation and tuning of vision and daylight glazings,and improved skylights with architectural enhancements (i.e., skylights with splayed ceilings).

Enhanced component-level systems can still be incorporated with minimal impact on architectural expression. For the most part,the systems are easily integrated into the building, though

Figure 18: Skylights using advanced optical technologies

Interior and rooftop views of the CSSA building in Antioch,CA,utilizing advanced triple-glazed prismatic skylights with motorized louvers and splayed ceiling.

Source: Sunoptics Corporation

Figure 19: Integration of daylighting and mechanical systems

Vision and daylighting glazings work with an HVAC duct/light shelf to provide daylight for an office building at the Port Hueneme, CA,Naval Base.

Figure 20: Newport Coast Elementary School site plan

Site plan accounts for solar resources and other site-related conditions in an architecturally integrated solution at Newport Coast Elementary School in Newport Beach,CA.

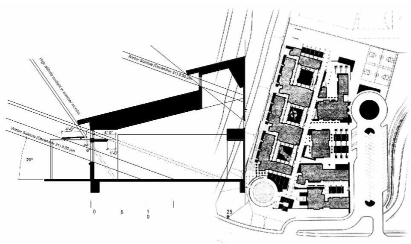


Figure 21: South exterior of the Multi-Agency Library at the College of the Desert

Daylighting is an important form-giver for the Multi-Agency Library at the College of the Desert.

they may require tuning of the glazing transmittances and additional architectural detailing beyond that provided by the product vendor. Daylighting performance can be greatly improved relative to component-level solutions,and when designed properly, enhanced component-level solutions allow the project to achieve both greater energy savings and an improved visual environment. However, since these solutions generally require greater architectural and building system integration, they will typically result in slightly higher design and construction costs.

Architecturally Integrated Solutions

Architecturally integrated solutions are the most rigorous daylighting solutions in the designer's toolkit, and allow the daylighting system to be fully integrated into the building design. In an architecturally integrated design, the design team uses the daylighting systems to define and enhance the architectural character of the building.

Achieving successful integration requires that daylighting be considered early in the design process. In an architecturally integrated solution, the building envelope and other building systems are optimized for daylight utilization and system integration. In pre-design and conceptual design, the use of daylight influences building siting and orientation to take full advantage of available views and access to the daylight resource.As the design progresses, space layout within the building form is driven by daylighting design considerations. Spaces that benefit from daylight are moved to the building's exterior/perimeter, and spaces that do not require daylight are moved to the building's interior. Spaces that need the perception of daylight (as opposed to being fully daylit) are placed adjacent to the fully daylit areas so that borrowed daylight can be provided.

While off-the-shelf components may be used, the daylighting solution combines these elements in a unique manner and may rely on systems custom-designed and fabricated for a specific building. Interior surfaces and materials are designed and oriented to maximize daylight coverage and provide a high-quality luminous environment responsive to the occupant's visual tasks. The building's form responds to daylight integration, and the daylighting elements are fully integrated with the other building systems.

Architecturally integrated solutions have the highest potential for energy savings, since the building's surface articulation can be developed to minimize solar gains while maximizing daylight performance. In these designs, the entire project team must work together to ensure that the daylighting systems are fully integrated with the building systems aesthetically, mechanically, and electrically.

Figure 22: Multi-Agency Library at the College of the Desert clerestory sunshade

The detail of the clerestory sunshade shows a high level of integration between the building form and direct beam daylight control.

For More Information

Daylighting design is a complicated endeavor, and a successful design requires the mastering of many design and psychological principles. The following resources will provide a starting point for developing and nurturing the reader's daylighting design understanding and interests.

Illuminating Engineering Society of North America (iesna)
120 Wall Street, 17th Floor
New York, NY 10005
Phone: (212) 248-5000
Fax: (212) 248-5017/18
http://www.iesna.org/
IESNA is the technical society for the lighting industry. The society publishes recommended practices for office lighting, outdoor lighting, and dozens of other applications, and also produces the Lighting Handbook, a comprehensive manual of lighting design. The IESNA also offers training programs that cover basic and advanced lighting technologies. The following IESNA publications are applicable to daylighting system design:

- IESNA Lighting Handbook, 8th edition
- CP32-1988, Choosing Light Sources for General Lighting
- DG-2, Design Guide for Warehouse Lighting
- RP-1-1993, Office Lighting
- RP-2-1985, Lighting Merchandise Areas
- RP-3-1988, Educational Facilities
- RP-5-1979, Daylighting
- RP-7-1991, Industrial Lighting
- RP-21-1984, Calculation of Daylight Availability
- RP-23-1989, Lumen Method for Daylight Calculations

Daylighting Textbooks
The following textbooks are recommended for obtaining basic information on daylighting design and analysis:

- Sunlighting as a Formgiver for Architecture. William M. C. Lam. Van Nostrand Reinhold Company, 1986. ISBN 0-442-25941-7
- Daylighting Design and Analysis. Claude L. Robbins. Van Nostrand Reinhold Company, 1986. ISBN 0-442-27949-3
- Concepts and Practice of Architectural Daylighting. Fuller Moore. Van Nostrand Reinhold, 1991. ISBN 0-442-0679-9

Energy Design Resources Skylighting Guidelines
The Skylighting Guidelines are a collection of documents intended to help architects and engineers use skylights to maximum advantage in commercial and industrial buildings. These guidelines describe opportunities for energy savings and good lighting design, explain how to integrate skylights with other building

elements, show how to estimate energy and dollar savings, and help designers avoid costly mistakes.
Energy Design Resources
http://www.energydesignresources.com/

LBNL Tips for Daylighting with Windows — the Integrated Approach
These guidelines provide an integrated approach to the cost-effective design of perimeter zones in new commercial buildings. They function as a quick reference for designers through a set of easy steps and rules of thumb, emphasizing "how-to" practical details. References to more detailed sources of information are given, should the reader wish to go further. Report Number LBNL-39945
Building Technologies Program
Ernest Orlando Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-3111
Berkeley, CA 94720
Phone: (510) 486-5605
Fax: (510) 486-4089
http://www.lbl.gov

CEC Advanced Lighting Guidelines
The CEC Advanced Lighting Guidelines are a set of twelve documents covering many issues associated with electric lighting and daylighting design. The full set of guidelines contains documents on the following topics: lighting design practice, computer-aided lighting design, luminaires and lighting systems, energy-efficient fluorescent ballasts, full-size fluorescent lamps, compact fluorescent lamps, tungsten-halogen lamps, metal halide and HPS lamps, daylighting and lumen maintenance, occupant sensors, time scheduling systems, and retrofit control technologies. Report Number P400-93-014.
California Energy Commission
Publication Office
1516 Ninth Street
Sacramento, CA 95814-2950
Phone: (916) 654-5200
http://www.energy.ca.gov/water/publication/pub0133.html

E Source Lighting Technology Atlas
The E Source Lighting Technology Atlas is a comprehensive guide to energy-efficient lighting, covering both design and technology fundamentals. It presents a "systems approach" to lighting design, and characterizes the existing stock of lighting technology with descriptions of available and emerging energy-efficient alternatives. Technologies covered include incandescent, fluorescent, and HID lighting systems, along with daylighting, controls, reflectors, and specialty products, with extensive product lists. Market trends and the energy impact of lighting are detailed, as well as implementation issues such as economics, maintenance, and the environmental impacts of lamp and ballast recycling. The atlas also offers practical tips for lighting installers and facility personnel, as

well as a resource section that includes a sample specification, guide to available software, and a glossary.
E SOURCE, Inc.
4755 Walnut Street
Boulder, Co 80301-2537
Phone: (303) 440-8500
Fax: (303) 440-8502
http://www.esource.com/

Daylighting and Productivity Studies by the Heschong-Mahone Group

The Heschong-Mahone Group studied the correlation between daylight availability and human productivity. The study was done in two parts. One part looked at elementary student test scores in three school districts, and found that significant improvement in test scores (20+percent) was strongly correlated with daylight in classrooms. The second part looked at retail sales in a chain of 100+ similar stores, and found that retail sales were as much as 40 percent higher in stores with skylighting.
Daylighting in Schools — An Investigation into the Relationship Between Daylighting and Human Performance
Skylighting and Retail Sales — An Investigation into the Relationship Between Daylighting and Human Performance
Heschong-Mahone Group
11626 Fair Oaks Blvd. #302
Fair Oaks, CA 95628
Phone: (916) 962-7001
Fax: (916) 962-0101
http://www.h-m-g.com/

The Pacific Energy Center
851 Howard Street
San Francisco, CA 94103
Phone: (415) 973-7268
Fax: (415) 896-1290
http://www.pge.com/pec/daylight/valid4.htmL

SkyCalc

SkyCalc is a simple computer tool that helps building designers determine the optimum skylighting strategy that will achieve maximum lighting and HVAC energy savings for a building. This program is a Microsoft Excel™ spreadsheet application that runs on a personal computer. SkyCalc uses simple data inputs (either common defaults or user-supplied data) to describe a building and analyze possible skylighting strategies. It calculates the lighting and whole-building energy impacts of each design, and produces graphs and charts that describe annual energy-use patterns.
Energy Design Resources
http://www.energydesignresources.com/

Lumen Micro

Lumen Micro is an MS Windows-based program that offers a range of detail in lighting calculations, from simple zonal cavity calculations through complex renderings that incorporate interreflections and obstructions. Daylighting analyses are based on latitude, longitude, time of day, and date; users may adjust the transmittance and reflectance of windows and skylights. Radiative transfer renderings include daylighting contributions.

Lighting Technologies
5171 Eldorado Springs Drive
Boulder, CO 80303
Phone: (303) 499-1822
Fax: (303) 499-1832
http://www.lighting-technologies.com

LightScape

The LightScape Visualization System offers calculation and rendering of indoor lighting applications using proprietary full-color radiative-transfer algorithms, along with a ray-tracing engine to add specular highlights and reflections. LightScape's progressive refinement algorithms produce a useful image quickly; the quality of the image improves as calculations continue. At this point, the user can take a real-time walk-through simulation. A final sweep by a ray-tracer adds view-specific highlights, creating a photo-realistic image.

Discreet Logic
10 Duke Street
Montreal, Quebec, Canada H3C 2L7
Phone: (800) 859-9643
Fax: (800) 859-9623
http://www.lightscape.com

RADIANCE

RADIANCE is a suite of programs for the analysis and visualization of lighting in design. Input files specify the scene geometry, materials, luminaires, time, date, and sky conditions (for daylight calculations). Calculated values include spectral radiance (ie., luminance + color), irradiance (ie., illuminance + color) and glare indices. Simulation results may be displayed as color images, numerical values, and contour plots. RADIANCE is UNIX freeware for lighting design and rendering, developed by the Lawrence Berkeley Laboratory and the Swiss federal government.

Building Technologies Program
Ernest Orlando Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-3111
Berkeley, CA 94720
Phone: (510) 486-5605
Fax: (510) 486-4089
http://radsite.lbl.gov/radiance/framew.html

SUPERLITE

SUPERLITE 2.0 is a powerful lighting analysis program designed to accurately predict interior illuminance in complex building spaces due to daylight and electric lighting systems. SUPERLITE enables a user to model interior daylight levels for any sun and sky condition in spaces having windows, skylights, or other standard fenestration systems. SUPERLITE 2.0 is a DOS-based program that runs on IBM-compatible personal computers under the MS-DOS operating system.

Building Technologies Program
Ernest Orlando Lawrence Berkeley National Laboratory
http://eetd.lbl.gov/btp/superlite20.html

Notes

1 *Lighting Handbook*, 8th edition (New York: Illuminating Engineering Society of North America), 1993.

2 *IESNA RP-5*—Recommended Practice of Daylighting (New York: Illuminating Engineering Society of North America), 1979.

3 Peterson, George, and John Proctor, "Statewide Measure Performance Study #2, An Assessment of Relative Technical Degration Rates," Submitted to the CADMAC Persistence Subcommittee, Proctor Engineering Group, 818 Fifth Avenue, San Rafael, CA, 1998.

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Energy Design Resources is a program developed by Southern California Edison to provide information and design tools to architects, engineers, lighting designers, and building owners and developers. Our goal is to make it easier for designers to create energy-efficient new commercial buildings in Southern California. To learn more about Energy Design Resources, please see our Web site at www.energydesignresources.com.