Performance Parameters 3.

Introduction 3.1.

Performance parameters characterise a daylighting system within the context of a specific building application and can be used to determine whether a system should be used to achieve the design objectives. Parameters include visual performance and comfort, building energy use, economy, and systems integration. The primary energy-related design objectives of a daylighting system are to provide usable daylight for a particular climate or building type for a significant part of the year, which allows electric lighting to be offset by natural daylight and cooling and heating loads to be reduced. Conventional window and skylight solutions meet some of these needs; this guide focuses on new technologies and solutions that extend performance beyond that of conventional solutions. The functions of these new design solutions can be summarised as follows:

- provide usable daylight at greater depths from the window wall than is possible with conventional designs,
- increase usable daylight for climates with predominantly overcast skies,
- increase usable daylight for very sunny climates where control of direct sun is required,
- increase usable daylight for windows that are blocked by exterior obstructions and therefore have a restricted view of the sky, and
- transport usable daylight to windowless spaces.

The term “usable daylight” encompasses objective and subjective measures for visibility and comfort:

- higher illuminance levels, often at greater depths from the daylight opening, than provided by conventional solutions under both cloudy and clear sky conditions,
- greater uniformity of light distribution,

- reduction of glare and cooling loads by controlling direct sun without compromising daylight admission.

An objective evaluation of an innovative system requires definition of performance parameters. In addition, the evaluation depends on defining baseline conditions against which the performance should be compared. The performance parameters are summarised in the table below. In the following sections, these terms are defined within the context of the general field of lighting and their respective ranges of acceptable or target values are given, if available. A discussion follows concerning how these terms apply to the unique, light-redirecting daylighting systems covered in this book. Many existing performance parameters are not directly translatable to advanced daylighting either because the parameters were developed for static electric lighting sources, or because research has been insufficient to develop adequate, robust performance models. These issues are also briefly discussed.

Table 3-1: Performance parameters

Parameters	Independent Variables	Baseline
Visual Comfort and Performance	Climate	Clear, unobstructed glass
Illuminance	Daylight availability	Glazing with shading system
Distribution	Temperature	
Glare	Site	
Direction	Latitude	
Visual Amenity	Local daylight availability	
Outside view	Atmospheric conditions	
Appearance	Exterior obstructions	
Apparent brightness	Ground reflectance	
Colour	Room	
Privacy	Geometry	
Social behaviour	Surface reflectances	
Thermal Comfort	Window	
Device Characteristics	Size	
Building Energy Use	Placement	
Lighting Energy	Orientation	
Space conditioning energy	Daylighting system	
Shading system	Shading system	
Peak demand	Lighting System	
Economy	Ambient and task system	
Codes and Standards	Control system	
Construction & Systems Integration	Task	
Product data	Reading, writing	
Systems integration	Computer or self-illuminating equipment	
User considerations		
	Occupancy schedule	

Systematic evaluations of daylighting systems involve performance assessments for several critical independent variables such as weather, site building conditions as well as room and task condition. Useful formats for data presentation and analysis will depend on the decision-making criteria. For example, visibility performance data can be summarised by various statistical measures: instantaneous data (time of day), average data (yearly, seasonal), or binned data (distribution or percentage of time above a given constant).

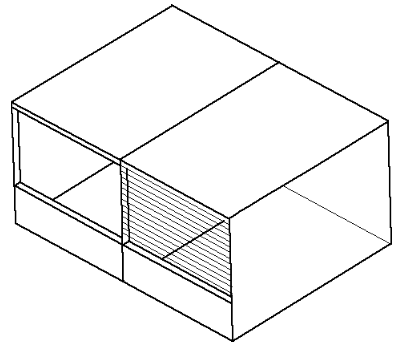

Figure 3-1: Unobstructed window versus conventional window with shading device

Definition of the base case condition will affect the results of the evaluation. Two base case categories are used by IEA SHC Task 21 laboratory and field test facilities: 1) a conventional window with glazing and shading systems, and 2) clear, unobstructed glass. The first conventional base case includes clear, tinted, or coated glass and an interior or exterior shading device, such as venetian blinds or roller shades, to control direct sun and glare, as found in typical commercial buildings. Clear glass is used for many European climates (e.g., in Scandinavia), and tinted or coated glass is often used for sunnier, warmer climates. The unobstructed, clear glass base case (2) can easily be characterized by thermal and daylighting simulation tools and duplicated among test facilities. This case was used by most of the field tests documented in Chapter 4. and as defined by the monitoring protocol (Appendix 8.5).

It is important to note how the choice of base case category will lead to certain expected results. For example, the unobstructed, clear glass base case will almost always result in higher illuminance and intolerable glare levels during the year than a daylighting system occupying the same aperture, simply because it admits direct sun and poses fewer obstructions to incoming daylight. On the other hand, more realistic window base cases may obstruct too much daylight, so the test case will yield consistently higher illuminance levels and show more favourable and perhaps misleading results.

The importance given to one performance metric over others differs with climate and building type. A method to rate the overall performance of a daylighting strategy is not provided here because of the complexity of the decision-making process. For example, for an office building located in a mild climate, designers may place more value on illuminance levels and lighting energy use; for the same building in a hot location, designers may be very concerned with thermal performance. It is important to note that a strategy should be evaluated on the basis of all its attributes, not a single parameter. Total performance ratings will differ among applications, so the reader is advised to be aware of the concepts that underlie each performance parameter, and to prioritise parameters based on the building application. Finally, as with all performance evaluations, computation analysis can often obscure the complexity of underlying concepts (e.g., physiological processes of the eye, human adaptation, etc.), so strict adherence to numerical rating systems for decision making is ill-advised. To obtain data applicable to a particular building design, see Chapter 6, Design Tools. Researchers developing and evaluating new innovative systems should see the monitoring protocol in Appendix 8.5.

3.2. Visual Comfort and Performance

Visual function parameters are used to determine whether a given lighting condition permits sight or visibility and are directly related to the physiology of the eye [IES 1993a]. Generally, good visibility is defined by an adequate quantity of light for the expected visual task, uniform distribution of illuminance and luminance, sufficient directionality to model three-dimensional objects and surfaces (direction of incident light from the side or from above), the absence of glare, and sufficient spectral content to render colours accurately when required.

3.2.1. Illuminance

Guidelines for electric lighting have defined ranges of "design" illuminance levels based on task, viewer's age, speed and accuracy requirements, and task background reflectance [IES 1993a, CIE-29.2 1986]. For daylighting, the total energy balance between lighting and thermal loads (i.e., from solar heat gains) is an added consideration. For paper-based tasks such as reading and writing, satisfactory task illuminance levels can exceed recommended electric lighting levels by factors of two or more if there is no glare and if the associated heat gains have a minimal mechanical system energy impact (especially in cooling-dominated climates). For computer-based or other self-illuminating tasks characterized by low luminance values (<85 cd/m^2), however, these guidelines may represent the maximum range of illumination, because exceeding these guidelines can often result in reduced visibility.

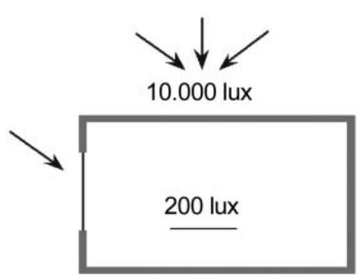

Figure 3-2: If the indoor illuminance is 200 lux when the outdoor global illuminance is 10,000 lux, the daylight factor is 2%

For some countries, an absolute illuminance level is used in a systematic evaluation. For other countries, particularly those that are dominated by cloudy sky conditions, the *daylight factor*, or the ratio between the illuminance measured indoors at a reference point (e.g. work plane) and the outdoor global illuminance on an unobstructed, horizontal surface, is used as a measure of light quantity (Figure 3-2). Because of the variability of daylight available from the sun and sky, daylighting systems are evaluated based on the quantity of illumination provided at a task *over time*. For office work that involves both paper-based and computer-based tasks, the larger the number of hours per year that a system is able to meet but not grossly exceed the design illuminance level, the more successful the design. This concept is also connected to the electric lighting energy savings potential, as discussed in Section 3.6.1 below.

For systems designed to redirect light to greater depths than is possible with conventional technologies, "good" systems are those that can meet the design illuminance level at greater depths and for a greater percentage of the year than conventional window systems. As a rule of thumb, conventional windows can daylight a room to a depth of 1.5 to two times the height of the window above the floor. Some daylighting systems are designed to achieve light redirection to depths of two or more times the window height for a greater percentage of the year than is possible with conventional designs. Task locations are often ambiguous or change frequently, so an evaluation is usually conducted at representative locations within a space.

3.2.2. Distribution

The distribution of illuminance and luminance is a measure of how lighting varies from point to point across a plane or surface. For good visibility, some degree of uniformity across the task plane is desirable. Poor visibility and visual discomfort may result if the eye is forced to adapt too quickly to a wide range of light levels. Illuminance and luminance ratios such as maximum-to-average or average-to-minimum are used to quantify lighting uniformity and are typically measured across a horizontal work plane at a height of 0.8 m above the floor for paper or reading tasks. For office lighting, for example, the ANSI/IESNA RP-1 guidelines set maximum contrast ratios among all task, background, and remote surfaces within the occupant's field of view [IES 1993b]:

- variation in luminance across the immediate task (within one's central or ergorama vision) should be kept to a maximum of 2.5:1 to 3:1;
- variation in luminance between the task and background (central or ergorama vision; e.g., black letters on a white background) is permitted, typically 3:1;
- greater variation is permitted between the task and remote surfaces (panorama view; e.g., walls, ceiling, and floor), typically 10:1, but the design must meet additional guidelines for glare (e.g., 20:1 to 40:1).

A systematic evaluation of daylighting systems is complicated by a number of factors, however:

- the sun is a variable-position light source, so the sheer number of conditions one must evaluate is large;
- the task location is often ambiguous, requiring one to either consider all views within the space or to select several representative task locations;
- if direct sun is not excluded or is redirected, continuous surface luminance maps may be the only method to determine the location, size, and intensity of bright areas of sunlight;

- the luminance of exterior obstructions (e.g., opposing semi-reflective buildings) or the ground (e.g., snow) varies with task location and solar conditions;
- occupants may accept much greater luminance variations when spaces are lit by daylight than when they are artificially lit, which further complicates comparisons.

At minimum, the illuminance profile throughout the space can be measured or simulated, and contrast ratios can be computed. This profile typically illustrates how daylighting systems achieve more uniformity throughout the space than conventional windows.

3.2.3. Glare

Disability Glare

Disability glare is caused when intraocular light scatter occurs within the eye, the contrast in the retinal image is reduced (typically at low light levels), and vision is partly or totally impeded (e.g., when the eye is confronted by headlights from oncoming automobiles). With windows and daylighting systems, which are large-area light sources, disability glare can at times be significant. Experts agree that this apparent reduction in contrast is affected by the total intensity of the glare source — not just by the brightness or area alone [Hopkinson 1972, Hopkinson 1963]. However, there are no known satisfactory models to predict and evaluate this condition.

FIGURE 3-3: GLARE IN A TYPICAL OFFICE

A daylighting design should be evaluated to determine whether there are strategies or features that enable occupants to control situations where the eye is forced to adapt to different brightness regions within the field of view.

Discomfort Glare

Discomfort glare is a sensation of annoyance caused by high or non-uniform distributions of brightness in the field of view (Figure 3-3). The physiological mechanisms of discomfort glare are not well understood; an assessment of discomfort glare is based on size, luminance, and number of glare sources, source-task-eye geometry (or glare source locations within the field of view), and background luminance. The Daylighting Glare Index (DGI) is used to indicate the subjective response to a large-area glare source and can be calculated for a person facing the window or the side wall at various distances from the window wall [Hopkinson 1972 and Appendix 8.5]. However, the DGI can only be used for large areas with a nearly homogeneous luminance distribution, e.g., a view to a uniform sky luminance through a window. When the luminance distribution from daylighting systems varies substantially, the DGI cannot be used.

To simplify analysis, several rules of thumb can be applied to evaluate daylighting systems. The values given below come from the ANSI/IES RP-1 guidelines [IES 1993b] for office tasks using computer visual display terminals (VDTs). Other applicable standards include CIE-117 [1995] for discomfort glare (which introduces the Unified Glare Rating, UGR).

Luminance. For tasks involving a computer screen with an average luminance of 85 cd/m^2, the maximum luminance level of surfaces within the field of view is 300 cd/m^2 for tasks within the immediate background and 850 cd/m^2 for tasks within the general background.

Size. The average luminance of any 0.6 by 0.6 m area within the field of view should be kept below 850 cd/m^2.

Luminance Ratios. See Section 3.2.2.

Geometry. Glare sources must be kept out of the line of sight. For a horizontal view angle, sources within 50-90° above the horizontal can cause high-angle or overhead glare.

Veiling Reflections

Visual discomfort or glare results from bright reflections off shiny surfaces. These veiling reflections reduce contrast and impair visibility. Daylighting systems can reduce or eliminate veiling reflections by controlling direct sun and luminance levels within the offending zone or the area viewed by the task surface.

3.2.4. Direction

For some tasks, sufficient directionality is required to model and evaluate three-dimensional objects and surfaces. The greater the amount of diffuse light, the less shadowing occurs, reducing an occupant's ability to evaluate the depth, shape, and texture of a surface. A balance between diffuse and directional light enables an occupant to evaluate the smoothness, nap, grain, iridescence, specularity, and other properties of a surface. For horizontal tasks, sidelighting from daylighting systems can enable better visibility than lighting from an overhead electric lighting installation.

There are no standard performance parameters to evaluate the direction and diffusion of light. Direct sunlight is typically directional with sufficient diffuse light from the sky to balance out the contrast of a three-dimensional object. Daylighting systems that rely on sky light will typically produce diffuse omni-directional light. Some daylighting systems using non-imaging optics (e.g., anidolic systems) can redirect diffuse daylight in the same way a light projector does, so some directional effects appear even in diffuse daylight.

3.3. Visual Amenity

Visual amenity encompasses the human responses to a lit environment that go beyond pure visibility criteria, including psychological elements. Light affects people's behaviour and their impressions of an environment. Little research has been conducted to enable quantification of the visual amenity provided by advanced daylighting systems. Cognitive factors such as attention, expectation, and habituation will affect an occupant's ability to recognize objects and discern details.

3.3.1. Outside View

Windows are highly valued for their views of the natural environment and for their connection to the outdoors (Figure 3-4). Movement and changes in light levels throughout the day can be mentally restful or stimulating. Views of landmarks or scenes can give a sense of place. Time of day, weather conditions, and personal safety conditions can be determined by a glance out the window. Interiors without sufficiently large side windows and without clear or lightly tinted glass can cause claustrophobia. Tolerance for moderate levels of glare may increase in proportion to the quality of view.

If view is desired, daylighting strategies and systems can be ranked from best to worst by: a) complete unmitigated, undistorted view, b) partial view (e.g., upper daylighting aperture with lower view window), c) occasional view (user can operate the system to obtain an unobstructed clear view), and d) no view. View will depend on the location of the occupant. In open plan offices, for example, direct view is often obscured within less than ~2 m from the window wall by partitions, particularly if occupants near the window deploy full-height shades to control direct sun and glare.

Figure 3-4: View of the outdoors with prismatic blinds

3.3.2. Appearance

Patterns of daylight can affect an occupant's aesthetic judgement of the environment's coherence, legibility, mystery, and spatial complexity. Architects have used direct sun to great artistic effect — to punctuate space or create spiritual effects. Daylighting rarely creates random patterns, which can often be found in electric lighting solutions. However, patterns of light and shadow can cause confusion and contrast in the visual field. Daylighting systems that create areas of excessively striated or noticeable patterns must be used judiciously.

3.3.3. Apparent Brightness

The brightness impression of an interior is an important psychological aspect of daylighting; i.e., whether the interior *appears* to be dark or bright can be independent of the physical value of illuminance or luminance. Consider two rooms with identical task illumination. If the view from a window in one room is obstructed by a building, that room may give a lower brightness impression. The other room, with no obstructions to the view, will seem brighter. The same effect occurs with different window sizes. Two rooms with the same illumination levels but different size windows will give different brightness impressions. The room with larger windows will give an impression of greater brightness.

Gradients of luminance may affect perception of brightness. For example, a non-uniformly artificially lit room appears brighter than a uniformly lit room, perhaps because the non-uniformly lit room has greater luminance contrast [Tiller and Veitch 1995]. Most office workers in Tiller and Veitch's study preferred high-brightness surfaces with some uniformity; dimly lit spaces were perceived as gloomy.

Conventional sidelighting concepts typically result in a cave-like luminance distribution (dark ceiling, bright lower side walls and floor). Light-redirecting daylighting systems that illuminate the ceiling may improve the apparent brightness of a room while providing the same task illuminance as a conventional system.

3.3.4. Colour

True colour rendition is important for tasks that involve colour matching, quality control, and accurate colour perception. Generally, the less a daylighting system changes colours from their true state, the better the system or strategy. For museums, retail, health care and other similar uses, accurate colour rendition can affect judgement and perception. The spectral distribution of the light source after it enters the building determines colour rendering. Outdoor "natural" daylight defines full-spectrum lighting, i.e., true colour rendition.

Some daylighting systems can be combined with tinted or coated window glazing that can cause shifts in both interior and exterior view colour perception. Low-transmission glazing can give a gloomy or muddy appearance to exterior views. Some holographic diffractive glazings and prisms can cause chromatic dispersion, resulting in a rainbow lighting effect and, possibly, reduced interior colour rendition.

3.3.5. Privacy

The degree of privacy afforded by a daylighting system may be difficult to quantify. Privacy depends on the relative brightness of the interior compared to the exterior and the perception of privacy by the occupant. Reflective glass, for example, will yield complete privacy during the daytime with completely unobscured views. At night, when the relative brightness is reversed, the glazing from the interior is completely reflective yet affords no privacy.

Designers should consider the level of privacy desired for the building application and provide opaque, operable shades where privacy is critical.

3.3.6. Social Behaviour

Social psychologists have conducted studies to determine the effects of illumination levels, spectral distribution, window size, window location, and other lighting factors on mood, intellectual task performance, and styles of conflict resolution (e.g., [Baron et al. 1992]). The essential argument is that a daylit environment can evoke an emotional response that affects the mood and social behaviour of an occupant. Direct sun can be stimulating through its non-uniform luminance distributions, directionality, movement, and luminous variability.

These perceptions can be altered if essential properties of the light source are modified. For example, real daylight from a skylighting tube with an opal diffuser may appear to be an artificial lighting system, and some colour-corrected, hidden electric lighting systems may appear to be sources of daylight.

3.3.7. Health

Daylight can have health effects on skin, eyes, hormone secretions, and mood. Its temporal variation may be used to combat jet lag and sick building syndrome. In some climates, daylighting systems that provide more illuminance during the winter and less during the summer (in inverse proportion to daylight availability) are considered more desirable, to counter the effects of seasonal affective disorder.

3.4. Thermal Comfort

Daylighting systems can affect thermal comfort in a variety of ways. A cold window surface can increase thermal discomfort caused by longwave radiative exchange between the window and occupant in the winter, and a hot window surface can do the same during the summer. Convective downdrafts caused by cold window surfaces and infiltration can also contribute to discomfort. In some cases, direct sun can contribute to greater thermal comfort during the winter.

Generally, the thermal comfort of daylighting systems can be evaluated using simple measures. Options to control direct sun should be available. An insulated window will increase inside window surface temperatures and improve comfort. Local standards and guidelines that govern acceptable surface temperature, direct sun control, etc. should be followed.

Device Characteristics 3.5.

Many of the fundamental properties that define the optical and thermal characteristics of advanced daylighting systems are difficult to measure and thus to compare, principally because the properties are angle- or system-dependent.

For daylighting applications, optical properties typically quantify how solar radiation and visible light are modified by a material or system by means of transmission, reflectance, absorption, scattering or diffusion, diffraction or refraction (Figure 3-5). Total solar transmittance and reflectance can be measured for planar, transparent glazings using laboratory equipment for analysis and simulation of optical performance. However, measurement protocols are still under development for typical non-homogeneous, complex, and movable systems and materials (see Appendix 8-3). Most daylighting devices fall into this category.

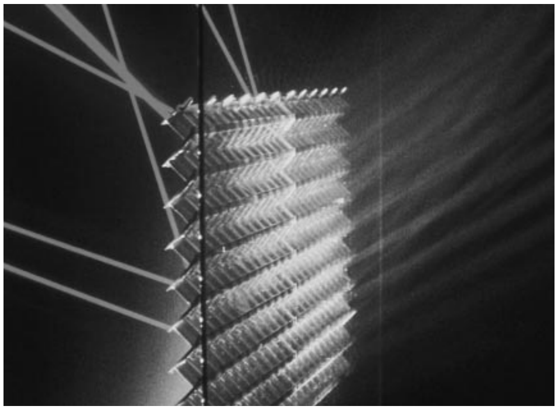

Figure 3-5: Laser visualization of light redirection, transmittance, and reflectance properties of complex Siemens louver system

Radiant and thermal properties need to be identified in order to determine window heat gains. When a daylighting system is irradiated by sunshine, the glazing materials become hotter than the air at its indoor and outdoor surfaces. Heat then flows by radiation and convection from the outer surface to the atmosphere and surrounding environment, and from the inner surface to room air and interior surfaces. Quantities defining the absorption and re-radiation or emittance of solar radiation as a function of wind speed and indoor and outdoor air temperature (known internationally as the g-coefficient, or in the U.S. as the solar heat gain coefficient (SHGC)) have not been measured for many daylighting systems and strategies.

Similarly, properties related to ultraviolet protection, durability, sound transmission, colour rendition, structural strength, flammability, weight, and resistance to condensation are not systematically available for daylighting devices. Refer to Chapter 4 for detailed information on specific systems.

3.6. Building Energy Use

3.6.1. Lighting Energy

From the energy-efficiency perspective, daylight offsets the need for electric lighting by providing adequate levels of task or ambient illuminance. At the simplest level of evaluation, task locations, solar conditions and illuminance data at given depths from the window wall can be compared to evaluate the energy-efficiency performance of daylighting systems. These data can be presented as 1) the percentage of time when the building is occupied that interior daylight illuminance levels equal or exceed the desired design illuminance level or, 2) binned absolute illuminance data over the course of a year. Use of these data will depend on the electric lighting control strategy.

For manual or automatic on/off switching, the first method of presenting data yields what is known as "daylight autonomy" or the yearly relative "time of utilization." These are terms that essentially denote the percentage of work hours when interior daylight illuminance levels meet or exceed the required illuminance levels so that the electric lighting system can be turned off. For dimming systems, the second method of presenting the data can allow a user to roughly estimate the number of hours, for each set of bin data, during which the lights can be dimmed to a particular power and light output level. "Usable light exposure," a term used in Europe, denotes the yearly percentage of added electric lighting needed to increase the daylight levels to the design illuminance setpoint [Aydinli and Seidl 1986]. If yearly data are not available, data can be given for a subset of days and hours representing typical solar conditions (e.g., equinox and solstice clear sunny days, and overcast day). Summarised weather data can then be used to obtain a rough estimate of annual lighting energy use.

For greater accuracy, hour-by-hour building energy simulation tools can be used to evaluate the energy effects of simple daylighting systems given monitored weather data, a detailed description of the interior space, and the characteristics of the electric lighting system and its controls. For more complex systems such as those described in this book, however, such simulation tools require functional modifications to adequately predict daylighting impacts. Simulation tools for homogeneous (e.g., conventional transparent glazing) and optically complex daylighting systems are described in Chapter 6.

The above methods use horizontal work plane illuminance data to estimate potential lighting energy use reductions. For more complex evaluations involving dimming systems, one may conduct field tests or build mathematical models to accommodate the response characteristics of automatic electric lighting dimming control systems.

The performance of both the daylighting system and the electric lighting system can be expected to degrade with time, as a result of accumulated dirt, oxidation of high-reflectance films, or occupant intervention. Manually deployed shading devices will decrease interior daylight levels. Poor design, faulty installation, and lack of system commissioning will degrade the performance of automated lighting control systems, as well as contribute to user dissatisfaction. User switching behaviour for manually controlled systems is known to be motivated by non-energy-efficiency considerations (e.g., transient adaptation, apparent brightness, a desire to signal that the occupant is "in").

3.6.2. Space-Conditioning Energy

If the interior space is mechanically conditioned, daylighting systems will typically affect the thermal load on the HVAC system by increasing window heat gains but decreasing electric lighting heat gains (if the lights are controlled in response to daylight).

Generally, window and lighting heat gains are beneficial for heating-load-dominated buildings and are detrimental for cooling-load-dominated buildings. In some European countries dominated by cloudy sky conditions and heating loads, building codes prohibit the use of air-conditioning systems in commercial buildings unless the need for the system can be demonstrated (e.g., for protecting the hardware in a computer centre). In this case, the cooling load criteria can drive the design and selection of the window system to ensure thermal comfort during occasional sunny periods.

Evaluation of daylighting systems' energy use typically involves an hour-by-hour calculation of the thermal loads produced by the daylighting system, followed by calculations to determine the mechanical energy used to meet these loads. Some building energy simulation programmes cannot perform calculations for optically complex daylighting systems without simplifying assumptions or modifications to the algorithms within the programme. Energy performance modeling has been done by some researchers. Available references are given for each system in Chapter 4.

3.6.3. Peak Demand

Peak demand is the maximum power used by a building during the entire year. For commercial buildings, this peak occurs typically during the hottest period in the summer when the cooling system is running at maximum capacity, and the building is fully occupied. Because the peak cooling load is used to size the mechanical cooling system, its reduction can lead to reduced first cost as a result of system downsizing.

Reduced peak demand also has environmental consequences, because the local utility company must often use expensive, non-environmental energy sources to accommodate this non-recurring load. Utility companies will often penalize building owners for exceeding a maximum load by charging significantly higher rates during peak periods.

Daylighting systems are an effective option to reduce peak demand simply because there is good daylight availability during summer peak periods. Lighting energy use can be significantly reduced if automated control systems are installed in a building. However, in some climates, solar heat gains from uncontrolled daylighting can increase the cooling load. Building energy simulations are required to determine the optimum balance between electric lighting use and cooling energy.

3.7. Economy

Daylighting system material costs are typically greater than the costs of conventional systems, principally because of low volume in an immature market. Rebates and incentives for these early market technologies are offered in some countries. Utility deregulation has contributed to a decline of these economic measures, however. Concerns regarding “free ridership” have resulted in creative methods to reduce the first cost to the consumer of new technologies (e.g., procurement programmes).

Daylighting systems can contribute to lower first costs for a building’s mechanical system by lowering peak cooling load relative to that of the same building with conventional lighting design. Mechanical system downsizing is dependent on the mechanical engineer’s confidence in the estimated load and the reliability of the daylighting system to reduce loads during peak periods. Since mechanical systems are offered in standard sizes, however, incremental differences in calculated capacity may not always result in a change in equipment size.

Operating costs for energy can be calculated using the local utility rate. It is important to model utility rates accurately (as opposed to using an average flat rate), particularly for daylighting technologies, because savings are often realised during summer peak periods when electricity costs are the highest.

Some daylighting systems should be maintained on a regular basis. Light-admitting apertures that are inclined or horizontal should be cleaned on a scheduled basis to maintain optical efficiency. Systems with operating parts or those that rely on sensors for proper operation must be tuned or recommissioned when the interior space is reconfigured or its use is redefined. If the system is static and enclosed, then maintenance costs will probably be equal to those for conventional systems. Systems that permit natural ventilation may require more maintenance because of increased exposure to weather and dirt.

Environmental costs in all phases of the building life cycle (construction, operation, refurbishment, and dismantling) should also be considered. Some daylighting reflectors require the use of high-grade aluminium coatings to maintain optical efficiency. Anodized aluminium foil represents a large amount of embodied energy (100 MJ/m^2 in the case of recycled aluminium and 360 MJ/m^2 in the case of primary aluminium) whereas aluminium deposition requires far less production energy [Courret et al. 1998].

Codes and Standards 3.8.

Energy-efficiency standards for conventional daylighting systems (i.e., windows, skylights) are widely adopted and implemented in the industry; however, there are no specific standards for the daylighting systems noted in this source book. Conventional codes will either “prescribe” minimum or maximum levels for window properties (U-factor, g-coefficient, air leakage, etc.) or allow the designer to meet “performance” goals. In many European countries where cloudy skies predominate, codes regulate the minimum window size, minimum daylight factor (for commercial and residential buildings), and window position in order to provide view to all occupants and to create a minimum interior brightness level.

The performance goal approach will likely be most appropriate for advanced technologies, such as daylighting systems. To meet performance requirements, a designer must simulate the building’s energy consumption with the advanced daylighting system, which, in turn, requires that standardised rating methods and design tools be available to reliably determine product performance. Single manufacturer tests and calculations are insufficient. Standardised industry ratings are critical to ensure code compliance and consumer protection. In addition, field verification protocols are required to ensure proper implementation by code officials. At present, this infrastructure is not routinely in place for daylighting systems in most countries, so there is no way to prove the system’s performance. Proof of performance is necessary, however, if the daylighting system is to get credit under energy codes.

Construction and Systems Integration 3.9.

3.9.1. Product Data

When assessing a daylighting system for use within a building, a designer must review architectural, structural, and construction technical data related to the system’s use. Most of these data will be available directly from the manufacturer. Other data regarding structural issues (thermal expansion), fire safety (flammability, toxic fumes, melting, breakage), or property safety (bullet-, intrusion-, shatter-resistance, etc.) may not be provided by the manufacturer and thus need to be inferred from experience and knowledge about the materials that make up a system. The architectural appearance of daylighting systems can be conveyed via photographs, line drawings (plans, sections, elevations), product samples, full-scale mock-ups, and other visualisation methods.

Durability is a measure of the degradation of material or system performance resulting from moisture, sunlight, and operating temperatures, as a function of time. This parameter quantifies how key operational, optical, and other parameters will change within the expected lifetime of the product, typically 15-20 years. For example, oxidation may affect the reflectivity of prismatic films. Ultraviolet solar radiation may break down certain plastics. Weathering or corrosion, particularly in locations near the ocean or in industrial settings, may lead to degradation of performance. Durability tests are generally conducted by an independent laboratory that uses standard test procedures.

3.9.2. Systems Integration

Daylighting systems must be designed within the context of all building systems. Interior light shelves, for example, must be considered in the context of overhead electric light because they may create shadows at night. Spray from fire sprinklers or air from mechanical system diffusers may also be blocked by horizontal obstructions such as light shelves. Integrated electric light and daylighting solutions can incorporate ambient or task lighting within the underside or below the light shelf. This may reduce commissioning and tuning costs and can improve the reliability of system performance.

Additional design features that are peripheral to the principal design objective can increase a system's usability within typical building contexts, increase the chances that users will find the system acceptable, and add functionality to a daylighting system. The definition and importance of "usable" features depend on building type. Two usable features are:

Natural Ventilation. For moderate climates and during some periods in all climates, natural ventilation and access to fresh air are amenities that can improve occupants' environmental satisfaction in low-rise commercial buildings, such as schools and small offices. For these building types, daylighting systems that enable a user to fully operate a window or that enable the designer to combine the system with operable windows meet this criterion.

Blackout Option. For some spaces (schools, conference rooms, etc.), complete blackout of daylight is desired for viewing of audiovisual presentations or other activities that require a dark interior space. It is important to provide occupants with operable shades to control daylight when necessary.

3.9.3. User Considerations

Users can react negatively or positively to the physical appearance, operation, and visual quality of daylighting systems. Daylighting effects that occur with conventional window systems are generally expected and acceptable. The degree of acceptance of unusual effects depends on the building type (e.g., occupants will have different expectations regarding the lighting effects in a church than in an office) and the mentality of the occupants.

Documentation of operating features is necessary for sustained performance. User options should be made clear. For example, if a light-redirecting system needs to be adjusted seasonally, there should be clear instructions to the building manager or individual occupants to explain this fact to the users. If there are automatic controls, these features should also be documented as well as explained to the users, especially if these features are essential for accurate or acceptable control. Maintenance, recommissioning, and fine tuning are required for sustained, acceptable performance.

Some systems that involve moving parts and motors may generate unacceptable noise. Daylighting systems that operate within the background noise threshold of the building type are generally considered successful. It should be emphasised, however, that moveable parts are usually not recommended in buildings because of higher failure risks and maintenance costs than for systems without moveable parts.