Laboratories for the 21st Century: Best Practices

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Daylight through clerestories and small, stacked windows illuminates the interior office area of a laboratory building at the National Renewable Energy Laboratory (NREL) in Colorado; the towers help to distribute heated or cooled air.

Daylighting in Laboratories

Introduction

Science can improve our lives dramatically, and even change the world as we know it. Therefore, it is important to provide scientists and other researchers with laboratories that foster innovation and enhance performance. One way to do this is by designing and building laboratories that make good use of natural light, or daylighting. Daylighting not only saves energy, it also helps to provide an interior work environment that stimulates creativity and discovery. And *discovery* is what research laboratories are all about.

Studies conducted in schools and retail centers show that daylighting helps to increase productivity and enhance performance.[1,2] An increase in productivity of even 1%—as a result of providing natural light and views to the outdoors—has been known to nearly offset an organization's annual energy costs. In addition, providing access to natural light and exterior views in offices and labs is a good way to recruit and retain top scientists, technicians, and other key research personnel.

United States Environmental Protection Agency

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Energy Efficiency and Renewable Energy
Federal Energy Management Program

This guide to daylighting is one in a series on best practices for laboratories. It was produced by *Laboratories for the 21st Century* ("Labs 21"), a joint program of the U.S. Environmental Protection Agency and the U.S. Department of Energy. Geared toward architects, engineers, and facility managers, these guides provide information about technologies and practices to use in designing, constructing, and operating safe, sustainable, high-performance laboratories.

Technology Description

Daylighting is the controlled entry of natural light into a building. The use of daylighting allows occupants to dim or turn off a building's electric lights to save energy. Daylighting is provided through windows, clerestories, roof monitors, skylights, sawtooth roofs, or special light-pipe systems. To save the most energy, the designer must integrate daylighting into the building's overall design, interior spaces, electric lighting system, and mechanical systems.

Increasing the amount of daylight in a space entails more than simply adding windows. Rather, designers must locate and size windows and other elements to ensure a relatively even amount of brightness in the building's interior, avoid excess heat and glare, and minimize the amount of bright sunlight that falls directly on work areas.

Although information about how to use daylighting in commercial buildings is widely available, designers of daylighting systems for laboratories face different issues. These differences are primarily due to the large interstitial spaces between floors, lighting requirements in labs, and the relative complexity of a laboratory's electrical and mechanical equipment and systems.

Interstitial spaces above the ceilings in laboratories are often large, so they can accommodate ductwork and mechanical and electrical equipment. If space is not needed near the windows for these items, the added floor-to-floor height provides a unique opportunity for effective daylighting. The higher that daylight can enter a space, the farther back it can reach.

Lighting and daylighting requirements in labs can vary widely. In some labs, access to views is desirable, but daylighting might not be. In other labs, scientists may require more ambient light because task lighting is a problem for them. However, sometimes it is difficult to design for daylighting in the the lab portion of a building. In that case, the designer might want to specify daylighting for offices and public areas, instead. In most labs, less energy is needed for lighting than for ventilation. But in offices and public areas, lighting typically accounts for 37% of energy consumption, and daylighting helps to reduce both the lighting load and the cooling load.

Given the complex mechanical, electrical and plumbing (MEP) systems in labs, integrating daylighting into the design of a laboratory building is more challenging than it is for other building types. For example, MEP systems may represent up to 50% of a lab's construction budget,(3) whereas these systems typically represent 20%–25% in an office building.

Some designers might be put off by daylighting's seeming complexities. However, armed with information about where to start and how to use it, they could soon make daylighting a "standard practice" for new laboratory buildings.

Daylighting within a space comes from three sources: (1) exterior light reflected into a building from the ground, pavement, adjacent buildings, and other objects; (2) direct light from the sun and sky, which is typically blocked from occupied space because of heat gain, glare, and ultraviolet (UV) degradation issues; and (3) internal light reflected off walls, ceilings, and other interior surfaces.(4) The most common daylighting approaches make use of side lighting, top lighting, and atria; other techniques can be used, as well.

Side lighting. In side lighting, light enters a space from windows below ceiling height, for views and daylight. It is a very common daylighting technique. Horizontal strip windows are often used because they provide more uniform daylight than individual windows. Also, windows located higher in a space allow daylight to penetrate the interior of the space to a greater depth. If possible, separate windows should be used for views and for daylighting, because the optimal properties of the glazings are different for each use (see box on page 7).

The building section shown in Figure 1—which includes a light shelf, a view window, and a clerestory window—illustrates a rule of thumb for daylighting the south side of a building: the distance that daylight can extend into an interior space is equal to 1.5 to 2 times the distance (d) from the floor to the top of the window.(5) Adding a light shelf distributes the illumination better and reduces glare, because light shelves help the light bounce off the ceiling. Exterior light shelves provide more shade and less glare than interior light shelves do, but both are best for year-round light distribution. Without a light shelf, the distance to which daylight can extend into the space is no more than 1.5 times d. If the light shelf has a reflective top surface, the daylit zone can be up to 2.5 times d.

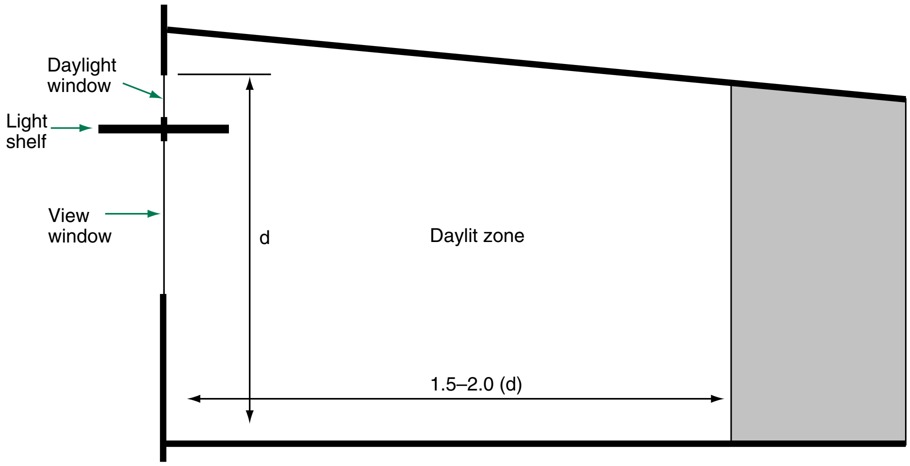


Figure 1. This section drawing illustrates a rule of thumb in designing for daylighting.

Figure 1 shows the ceiling sloping downward and away from the window. This improves the quality of light in the space because the sloped ceiling allows light to diffuse uniformly. A flat ceiling would be darker near the center. In the configuration shown, ideally the view window has a lower visible transmittance (VT) than the glass in the window above the light shelf. (See the box on page 7 for definitions of VT and other terms.)

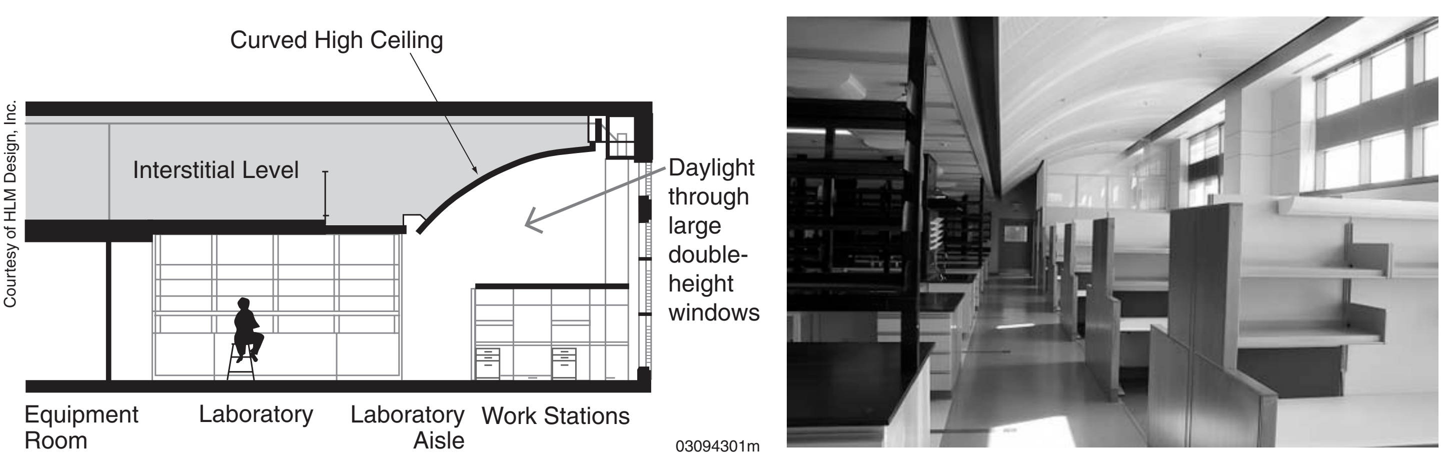
Performance issues usually depend on orientation. In the northern hemisphere, south-facing windows require horizontal overhangs, external light shelves, or internal and external light shelves to control glare and heat gain. North-facing windows do not require shading, but they experience greater thermal losses during the heating season, which can cause comfort problems. These can be minimized by using windows on the north side with a lower U-value or well insulated windows with low-emissivity (low-E) coatings. East- and west-facing windows are not recommended for daylighting because it is difficult to control glare and heat gain, especially on the west side. If these windows are used for daylighting, external vertical fins for shading or recessed windows are recommended.

Figures 2 and 3 illustrate two options for placing windows high in the space. Figure 2 shows how the designers of Building 50 at the National Institutes of Health (NIH) complex in Bethesda, Maryland, took advantage of large floor-to-floor dimensions to provide daylighting in a multistory lab building. Figure 3 (page 4) illustrates how the Georgia Public Health Laboratory (GPHL) in Decatur, Georgia, accomplished the same thing. In this example, staff can see outside through three layers of windows. Figure 4 (page 4) is a cross section of a planned laboratory designed for the National Renewable Energy Laboratory (NREL) in Golden, Colorado. It illustrates how the building provides daylighting for labs through the use of side lighting on the north and south.

Top lighting. For top lighting, daylight enters a space through vertical windows located above the ceiling line. Windows can be configured other than vertically if overheating can be avoided, such as by using specially designed horizontal skylights in deep window wells. Top lighting can be effective when windows are incompatible with the function of the perimeter walls, when interior spaces cannot easily accommodate side lighting, when the design or lighting criteria make sidelighting inappropriate, or when there are security concerns.

Daylight apertures can face north or south. Baffles under the roof monitors or deep window wells can be

Courtesy of HLM Design, Inc.



Don Prowler & Associates/PIX10304

Figure 2. This cross section and photo of laboratories and work stations in Building 50 of the NIH complex shows how daylighting is achieved through double-height windows.

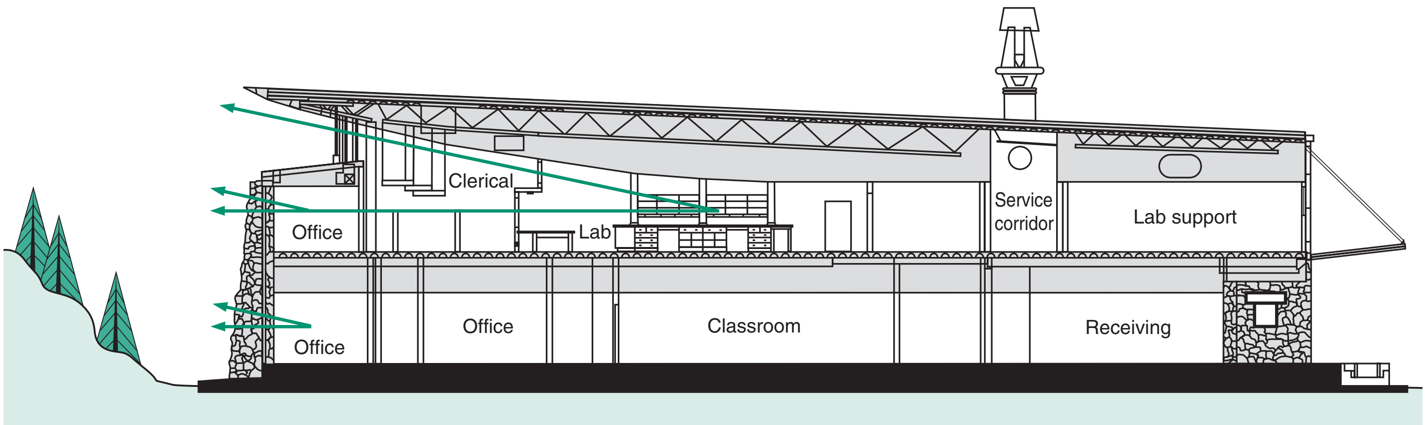


Figure 3. The arrows show views from the GPHL laboratory through either two or three sets of windows.

used to diffuse and reflect light in the space. Top lighting can also be provided with stepped clerestory windows, sawtooth or roof monitors, or horizontal window wells. Figure 5 shows top lighting in a classroom building on the Colorado School of Mines campus in Golden, Colorado. Light is diffused through a perforated metal ceiling; this prevents glare caused by direct sunlight on computer screens. A cross section of this building is shown in Figure 6.

Atria. Adding an atrium is a good way to increase the amount of space that receives natural light in a building. An atrium is often a central area one or more stories high (depending on the building's height) with side lighting or top lighting. Atria are used for daylighting in Pharmacia's Building Q, a pharmaceutical research laboratory in Skokie, Illinois.

Other techniques. Not all buildings or sites are optimal for daylighting. A square building, or one with a long axis running north and south, is not optimal. In both cases, there is more east- and west-facing glass than is best for a daylit building. Even so, some techniques can be helpful. For example, designers can orient top lighting to face north and south. Figure 7 is a floor plan of Donald Bren Hall, a classroom and lab building in Santa Barbara, California. In this building, the windows in the office are oriented at an angle from the wall to take advantage of the primarily southern light. Another technique is to use vertical or egg-crate-shaped shading devices and selective surface glazing to reduce heat gain on the east and west sides while retaining some of the view to the outside.

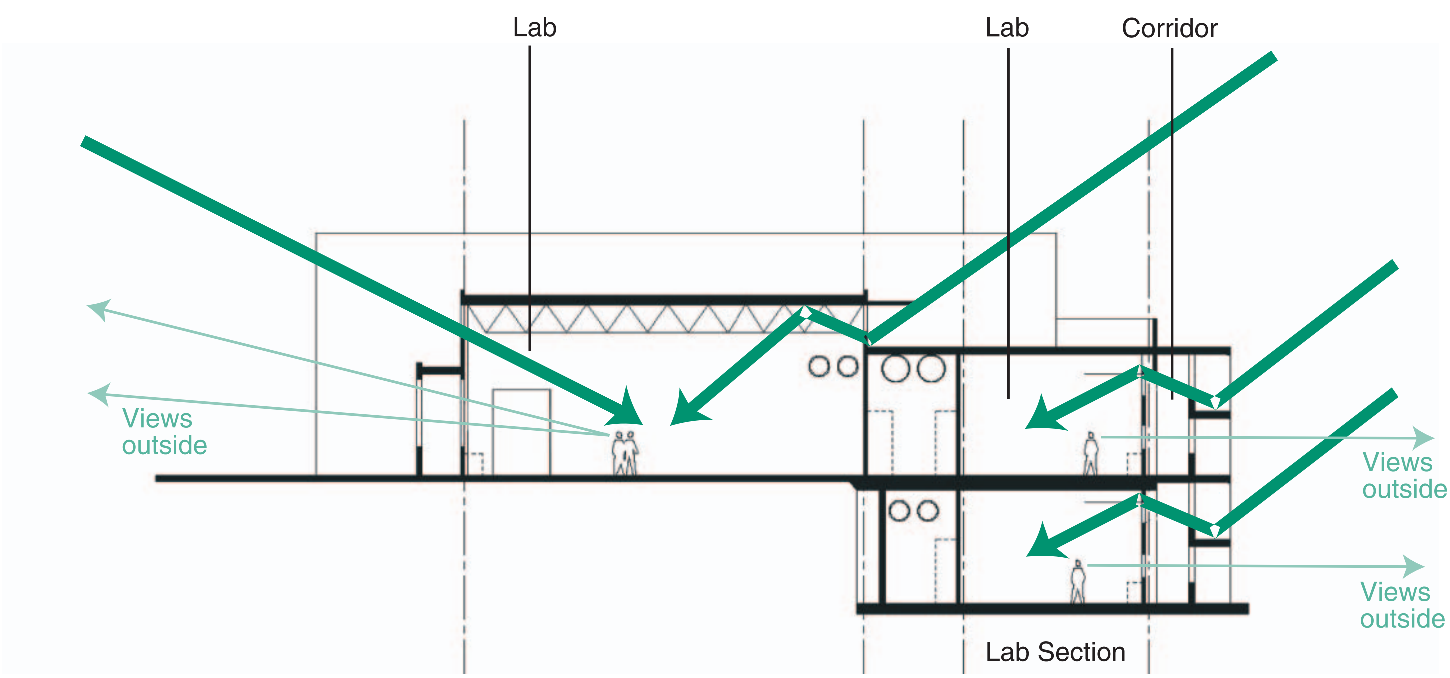


Figure 4. Daylighting will enter NREL's planned lab building primarily through clerestory windows on the north and south. Labs will also have windows for views to the outside.

Photo courtesy of Anderson, Mason, Dale Architects/PIX12815

Figure 5. Top lighting used at the Center for Technology and Learning Media (CTLM) building at the Colorado School of Mines.

Design Considerations

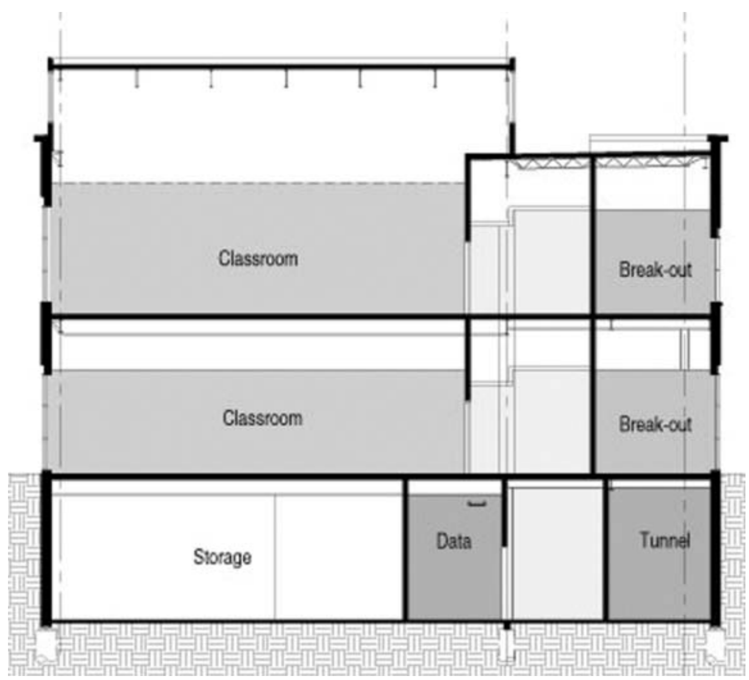
Design considerations include the building's footprint and mass, shading issues, placement of walls and windows, colors of interior spaces, and glazing properties. Integrating daylighting with electric lighting, the quantity and quality of light, and codes and standards are also important considerations.

Building footprint and mass. As much as possible, specify a long, narrow footprint along an east-west axis; it is easier to daylight the north and south sides of a building than the east and west sides. Low sun angles on the east and west make shading difficult, so glazing should be minimal, especially on the west side.

Window shading. Because a well-designed daylighting system captures indirect light from the sun or sky, be sure to shade windows on the south, east, and west facades from direct sunlight. Shading options include "self-shading" windows in deep exterior wall sections, horizontal overhangs, louvers, vertical fins, and light shelves that can be integrated into the building's structure. Horizontal shading devices work well on the south facade. Architecturally, this means that the north and south facades will look different. Vertical baffles, fins, or wing walls are recommended for east and west facades if windows are needed there.

Interior colors, ceiling height, and window height. Specify light-colored interior spaces, tall ceilings, and high windows to distribute natural light most effectively. If private offices must be along exterior walls with windows, specify a horizontal band of glass that is above eye level and adjacent to the ceiling on the walls across from the windows. This provides workers in interior spaces with natural light and access to views through the private offices. Also, provide a strip of glazing above shades, so occupants always have unobstructed windows even when they close their shades.

Glazing properties. Choose glazing that minimizes heating and cooling loads and maximizes visual comfort. See the glazing performance indicators on page 7 for more information.



Drawing courtesy of Anderson, Mason, Dale Architects

Figure 6. Section through classroom block of the CTLM building at the Colorado School of Mines, showing the top lighting.

Integration with electric lighting. Coordinate the daylighting design with the electric lighting design so they work together as one system. This includes defining zones for electric lights, selecting proper task and ambient lights, and determining the best control strategy for the lights, including photosensors and occupancy controls. Commissioning the lighting controls system to make sure it works as designed is an important consideration.

Key Questions for Daylighting Project Teams

Questions to ask your project team:

Predesign

- What is the daylighting goal for our project? Can we set a quantitative goal (such as to use 100% daylight for ambient light from 10:00 a.m. to 2:00 p.m.) for each type of space—labs, offices, public spaces, meeting rooms, and so on?
- How can we integrate daylighting into an overall design to ensure that this project saves energy and dollars?

Schematic Design

- What different kinds of glass are needed for view windows and daylighting windows at a given orientation?
- How can we ensure that light will be distributed uniformly?
- How can we simulate or model light levels to make sure our daylighting strategy works?
- What is the design lighting power density?
- What shading strategies will be compatible with the building's apperance?

Construction Documents

- Is a process for commissioning of the electric lighting controls in response to daylight clearly defined in the documents?

Design Development

- What type of overhead and task lighting fixtures will be needed?
- How will lights be controlled? How many zones are needed? Where will switches and sensors be in each zone?

Questions to ask when selecting daylighting consultants:

- Did previous daylit buildings that you designed perform as expected? Can we visit them and talk to occupants?
- What simulation tools will you use to design the daylighting system?
- How have you worked with the project design team in the past? Are your design philosophies similar?

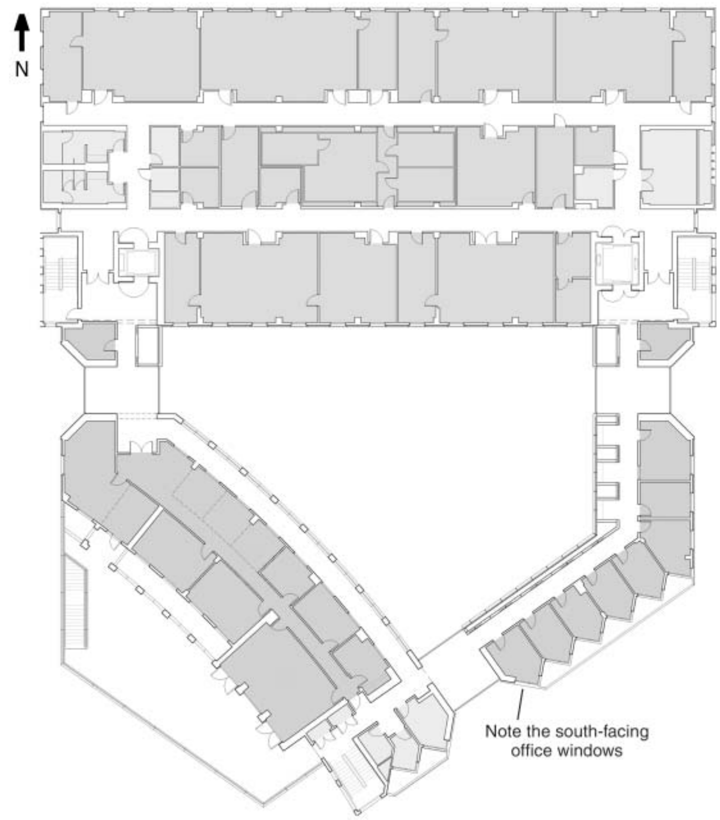


Figure 7. Windows for the offices of the Donald Bren Hall lab and classroom building were oriented to take advantage of southern light in Santa Barbara, California.

Quantity and quality of light. Good daylighting design is both an art and a science. A daylighting consultant is a "must" if your architect has never designed a daylit space. Consultants use computer modeling tools to size window openings properly, specify glazing properties, integrate daylighting with electric lights, and specify the lighting control system. These factors ensure that interior spaces have the proper quantity as well as quality of light for a given set of tasks.

Proper light quality is important. Quality issues include the uniformity of light levels and control of glare and veiling reflections. Some variation in light levels is pleasant, but too much causes eyestrain and unnecessary use of shades and electric lights. A well-daylit space has relatively even brightness, low contrast ratios (where the illuminance levels in the space vary by less than a 3:1 ratio), and windows on two sides to provide more uniform light. Glare and veiling reflections obscure people's ability to see details and cause eyestrain. (Glare is extreme brightness in the field of view; veiling reflections are caused by vertical specular surfaces, such as computer monitors, that reflect light into the eye.) A good daylighting system avoids these problems by minimizing or eliminating direct daylight on visual tasks.

Codes and Standards

The Illuminating Engineering Society of North America (IESNA) defines criteria for appropriate lighting, which depend on the nature of the tasks. IESNA recommends foot-candle levels as well as visual quality guidelines to consider in lighting design. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 90.1–1999 Table 9.3.1.2 lists lighting power densities for various building types and suggests 1.8 watts (W) per square foot as a guideline for lighting power density in buildings most like labs. And the Uniform Building Code specifies the amount of glazing that can be placed in internal walls, depending on the hazard rating for the laboratory building and the fire rating for the specific wall.

Performance Examples

The Labs 21 case studies contain examples of lighting designs with measured electric power densities of 0.7–1.0 W per gross square foot (GSF) (see page 8 for more information about the case studies). Monitoring results show that lighting loads in Pharmacia's Building Q average 1 W/GSF, and those for Sandia National Laboratories' Process and Environmental Technology Laboratory (PETL) are 0.75 W/GSF (though designed for 1 W/GSF). In both buildings, electronic controls turn off lights in unoccupied spaces.

Daylighting can be designed as a significant source of lighting in a space. If automatic lighting controls are used to integrate daylighting with a building's electric lighting system, the average measured power density will be significantly less than the designed power density, because electric lights will be used less during part of the day.

Designers can set quantitative performance specifications, such as the percentage of time that daylighting will be used rather than electric lighting. If the daylighting and electric lighting systems are well integrated, in theory the lighting load will be close to zero between 10:00 a.m. and 2 p.m. on most workdays. Computer models can help designers verify whether their design meets specifications. For example, in a new laboratory being designed for one of the Labs 21 pilot partners at NREL, designers specified this performance goal: 100% daylighting between 10:00 a.m. and 2 p.m. in office spaces and 50% daylighting during the same hours in laboratory spaces. A computer simulation verified that the goal will be met.

Conclusion

Daylighting saves energy, enhances productivity, and reduces costs assoiciated with electric lighting. Daylighting should be considered during the design phase of every new laboratory building. The best time to address it is during the goal-setting process, when defined, measurable goals can be specified. A successful daylighting strategy must be well-integrated with the building's external image, site, and form as well as its mechanical and electrical systems. Therefore, it is important to set a goal for daylighting early in an integrated design process.

Glazing Performance Indicators

It is important to clearly specify these glazing performance indicators when designing a daylighting system.

Visible transmittance (VT). The percentage of visible light that will pass through glass. Glass with a relatively high VT (such as 0.7) has a clear appearance and is ideal for daylighting. However, glare can be a problem for people who work near windows made of this material. In such cases, it is better to use view windows with well-shaded glazing or glazing with a lower visible transmittance, to control glare.

Solar heat gain coefficient (SHGC). The fraction of incident radiation that enters a building as heat gain. A value of 1.0 indicates that 100% of the solar gain enters the building. A value of 0.0 indicates that no solar gain is entering the space. To daylight a building in which heat is not wanted at any time of the year (e.g., a large laboratory), specify glazing with a low SHGC (e.g., 0.35). For a building designed to take advantage of passive solar heating in winter (e.g., a very small lab), specify a glass with a high SHGC for the south side (e.g., 0.7) and one with a lower SHGC for the west side (e.g., 0.35). You can either specify that the glass for the east and north sides be the same as the glass used on the south side, or select a medium-range SHGC value for them.

U-value. A measure of the rate of conductive heat transfer through the glazing as a result of the temperature change between inside and outside surfaces. A low U-value indicates a higher level of insulation, which is desirable for energy efficiency.

Shading coefficient (sc). The ratio of the solar gain of a particular glazing compared with the solar gain through clear, single-pane glass; SC = SHGC x 1.15.

Spectral selectivity. The ability of glazing material to admit visible light while rejecting unwanted infrared heat. Specifying glass with a relatively high VT and a low SHGC results in a spectrally selective glazing with good properties for daylighting the space in a commercial building. In general, glass with a low-E coating, either as a film applied to the glass or suspended between two double panes, has the right properties for daylighting. A low-E coating transmits visible light and reflects UV, near-infrared, and far-infrared light. Certain types of blue- and green-tinted glass offer some of the same properties that low-E coatings provide, but they also absorb rather than reflect heat, which radiates into the building.

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For More Information

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